Landscape and Urban Planning 157 (2017) 56–62

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research paper

Urban rights-of-way as extensive butterfly habitats: A case study from Winnipeg, Canada

Lionel Leston*, Nicola Koper

Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada

HIGHLIGHTS

- Butterfly species richness increased with plant species richness at study sites.
- Some species increased with resource plant cover or vegetation density.
- Resources predicted butterfly richness and numbers better than urban land.
- Resources were less abundant in frequently mowed and sprayed rights-of-way.

ARTICLE INFO

Article history:
Received 25 February 2015
Received in revised form 19 April 2016
Accepted 25 May 2016
Available online 25 June 2016

Keywords:
Urbanization
Transmission line
Butterflies
Resource plants

ABSTRACT

Urban rights-of-way (ROWs) offer large underused tracts of land that could be managed for plants and butterflies of threatened ecosystems like tall-grass prairies. However, built-up unvegetated urban lands might serve as barriers preventing butterflies and resource plants from settling along ROWs. Further, negative edge effects from surrounding urban lands or frequent mowing and spraying associated with urbanization may prevent butterflies from benefiting from urban ROWs as habitats. However, because ROWs often run for kilometres, they might facilitate movement from other, similar habitats by which they run close. To determine if surrounding built-up lands had a greater effect on butterflies than did the abundance of resource plants along ROWs, we surveyed butterflies and resource plants along transects in 48 transmission lines in or near Winnipeg, Manitoba, 2007–2009. In general, butterfly richness and abundance were better predicted by available resources than by built-up urban lands surrounding ROWs. Butterfly species richness per visit increased by 85% with increases from 10 plant species per site to 80 species of plants per site, while abundance per species per visit increased by 100% with increases from negligible forb cover to 5% forb cover, and by 112% with increases in vegetation height-density from 5 cm to 40 cm high. If appropriate resource plants are reintroduced and managed for along urban ROWs, densities of most butterfly species will increase along these lines despite surrounding built-up urban lands. Thus, urban ROWs present an opportunity for restoring habitats for prairie butterflies.

1. Introduction

Humans need to manage expanding urban landscapes so that they sustain biodiversity and minimize the loss of wildlife habitat (Cadenasso, Pickett, & Schwarz, 2008; Young, 2000). Urban grassy spaces that people rarely use (e.g. transmission line and roadside rights-of-way [ROWs]) could have high conservation value for butterflies, if those spaces serve as alternative habitats for plants that inhabit low-growing, threatened ecosystems like tall-grass prairies (Hoekstra, Boucher, Ricketts, & Roberts, 2005; Samson & Knopf, 1994). Restoring and managing for key resource plant species along ROWs may benefit threatened butterflies like the monarch (*Danaus plexippus*), which depends on milkweeds and dogbanes as larval host plants (Brower et al., 2011; Klassen, Westwood, Preston, & McKillop, 1989); the regal fritillary (*Speyeria idalia*), which depends on violets as host-plants (Klassen et al., 1989), and the Karner blue (*Lycaeides melissa samueli*), which uses lupines as host-plants (Forrester, Leopold, & Hafner, 2005). Combined with prairie restoration along roadsides (Ries, Debinski, & Wieland, 2001), such practices could increase needed habitat for many plants and butterflies.

* Corresponding author. Present address: #201-6969 Twenty-First Avenue, Burnaby, British Columbia, V5E 2Y8, Canada.
E-mail addresses: llestonraptor@live.com (L. Leston), Nicola.Koper@umanitoba.ca (N. Koper).

http://dx.doi.org/10.1016/j.landurbplan.2016.05.026
0169-2046/

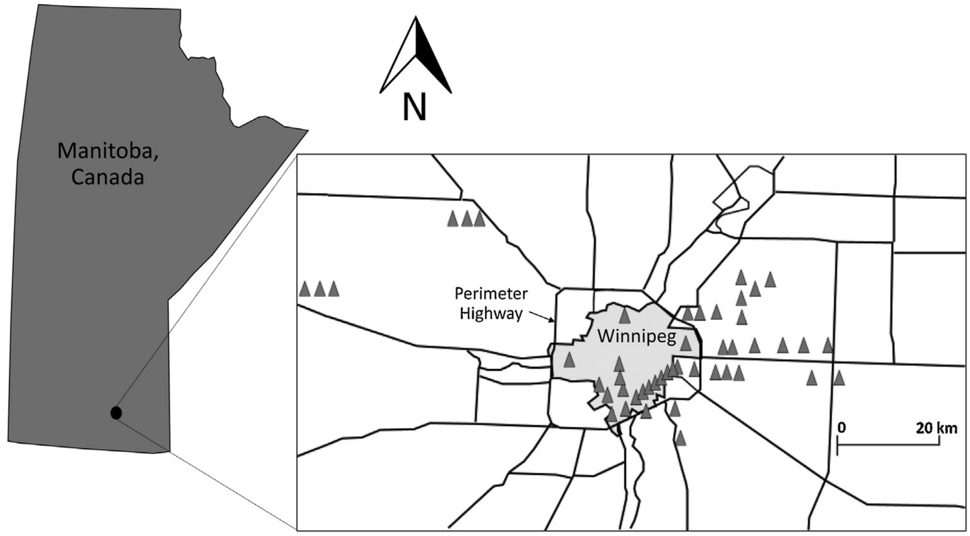

Fig. 1. Locations of butterfly survey sites along 48 transmission lines within 70 km of Winnipeg, Manitoba, 2007–2009. Triangles = study sites.

If urban ROWs are to serve as habitats for butterflies, planners must first determine if surrounding lands will prevent butterflies from reaching and benefiting from these new habitats. Frequent mowing and spraying along urban ROWs helps to control weeds and create tidy homogeneous green spaces as a symbol of order and prosperity (Byrne, 2005), but may degrade butterflies and their habitat through mortality of insects (Munguira & Thomas, 1992), removal of taller vegetation that is shelter habitat for butterflies and their caterpillars (Collinge, Prudic, & Oliver, 2003; Dover, 1996; Kruess & Tscharntke, 2002), and reduction in diversity of resource plants (Munguira & Thomas, 1992; Öckinger, Dannestam, & Smith, 2009; Parr & Way, 1988; Valtonen, Saarinen, & Jantunen, 2007). Reducing resource plant diversity may have larger adverse effects on specialist butterflies with larvae that only feed on few species of plants (Clark, Reed, & Chew, 2007; Kitahara, Sei, & Fujui, 2000). Butterflies may also decline as built-up, unvegetated land increases around sites with many resources for butterflies (Bergerot, Fontaine, Renard, Cadi, & Julliard, 2010), perhaps because habitat conversion reduces the mean size of urban wildlife areas while increasing their physical isolation by large expanses of suboptimal habitats or hostile non-habitats (McDonald, Kareiva, & Forman, 2008). High densities of urban roads may be barriers or sources of mortality for butterflies moving between habitats (Ries et al., 2001), preventing sedentary butterfly species from colonizing isolated urban habitats (Hill, Thomas, & Lewis, 1996; Polus, Vandewoestijne, Choutt, & Baguette, 2007; Sutcliffe, Thomas, & Moss, 1996), and preventing smaller urban habitats from supporting specialist butterfly species (Hill et al., 1996; Kraus, Steffan-Dewenter, & Tscharntke, 2003; Polus et al., 2007).

In this study, we explored whether built-up urban lands prevented transmission lines with large amounts of resources from serving as attractive habitats for butterflies. Unlike patchy butterfly habitats such as domestic gardens and abandoned lots (Bergerot et al., 2010), urban ROWs provide many hectares of potential habitat for butterflies and resource plants (Morgan, Collicut, & Thompson, 1995). Butterflies might also increase in urban landscapes if they are able to feed on exotic plants (Graves & Shapiro, 2003; Tooker, Reagel, & Hanks, 2002). We predicted that butterfly species richness and abundance would increase along transmission lines with greater plant species richness, dense vegetation, greater cover of nectar-plants for adult butterflies, and more larval host-plants. If surrounding urban lands prevented butterflies from using transmission lines, we predicted that butterfly species richness and abundance would decline as the amount of built-up urban lands surrounding transmission lines increased, regardless of available resource plants for butterflies along urban transmission lines.

2. Methods

2.1. Study area

We conducted surveys in a study area that was historically occupied by tall-grass prairie, which is a critically endangered ecosystem in North America (Hoekstra et al., 2005). Study sites were along 48 power transmission line sections with grassy ROWs that were at least 30 m wide and 500 m long (mean width = 50.36 m, SD = 19.35 m), in or near Winnipeg, Manitoba (49.90°N, 97.14°W) (Fig. 1). Although these lines had low levels of native prairie plant cover, native tall-grass prairie plant species naturally colonized these lines (Leston & Koper, 2016).

2.2. Butterfly surveys along transmission lines

To measure butterfly diversity, we counted individuals of all species detected within 5 m of a straight 500-m transect line at each of the 48 transmission lines. We only surveyed butterflies in conditions when butterflies were more likely to be actively flying and detected, from 10:30 to 1:30 on warm days (>13 °C) without strong wind (≥15 km/h) or precipitation (Pollard, 1977). There were 3–11 butterfly surveys per site from June to August of 2007–2009, with up to four surveys per site in a given year. There were 7 surveyors across 3 years. We spent approximately 30 min per transect. Where possible, we 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 we tentatively identified crescent butterflies on the surveys as northern pearl crescents (*Phyciodes morpheus*) based on the voucher specimens, some individual crescents during the surveys could have been similar-looking pearl crescents (*P. tharos*). We deposited voucher specimens at the J.B. Wallis/R.E. Roughley Museum of Entomology, Department of Entomology, University of Manitoba.

Study sites occurred along an urbanization gradient, as measured by the proportion of built-up lands (roads, railways, homes and gardens, other buildings) within 100 m of the transmission line's 500-m transect line for butterfly surveys. The most distant sites were ~70 km from Winnipeg's city limits, where 20 urban sites were located within Winnipeg's perimeter highway. Sites were at least 500 m apart to reduce the likelihood that we recorded the same individual butterflies at multiple sites, and to minimize spatial autocorrelation among sites.

2.3. Butterfly habitat metrics and study sites

We measured land uses that might influence butterfly numbers and richness along transmission lines by serving as sources of habitat (e.g. grasslands) or as non-habitat (built-up urban lands or roads). We focused on the proportion of land within 100 m of transmission lines that was grasslands as the primary measure of habitat for butterflies, since grassland was the predominant land use along Winnipeg's urban transmission lines that is subject to management by mowing and spraying, and because most butterfly species that we recorded were associated with grasslands (Klassen et al., 1989). We treated grassland habitats along both urban and non-urban lines as potential habitats for butterflies (Cadenasso et al., 2008). Built-up urban lands within Winnipeg's Perimeter Highway consisted of unvegetated surfaces with roads, concrete, houses, or larger buildings. Although building walls and homes with gardens provide habitat for butterflies (Bergerot et al., 2010; Ruszczyk & Silva, 1997), we treated the proportion of land within 100 m of each transect consisting of these unvegetated lands (hereafter, the variable "built-up lands") as the main non-habitat of concern, because we were interested in whether or not built-up lands prevented butterflies from using resources along transmission lines in urban landscapes (Bergerot et al., 2010). We measured habitat or non-habitat as a proportion of land use within 100 m rather than patch size, because butterflies might use different patches of the same kind of habitat within 100 m and because delineating discrete patches of habitat and non-habitat may be subjective (McIntyre & Barrett, 1992). To measure amounts of built-up land and grassland habitats within 100 m of study sites, we georeferenced transects and land cover data for southern Manitoba in 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, we 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.

We measured resources that may vary with vegetation management along urban transmission lines. Most urban transmission lines were mowed and sprayed at least twice a year (approximately mid-June and late August) with a broadleaf herbicide (2,4–D) that kills weeds like dandelion (*Taraxacum officinale*), Canada thistle (*Cirsium arvense*), and incidentally other broadleaf, non-target plants that might provide food for butterflies or their caterpillars (Klassen et al., 1989). In contrast, grassy non-urban transmission lines beyond the perimeter highway were usually mowed and sprayed once a year (approximately late August), hayed (mowed once a year, with cut vegetation baled and removed), or left unmanaged except for tree removal.

We used four vegetation metrics to assess the diversity of butterfly resource plants along transmission lines: (1) cumulative plant species richness from both plots per site as a measure of resource plant availability for butterfly species richness in general; (2) total cover of all forbs (%) from all subplots per site as an estimate of abundance of nectar plants for adult butterflies (Tooker et al., 2002; Tudor, Dennis, Greatorex-Davies, & Sparks, 2004); (3) shelter habitat for butterflies (Dover, 1996; Kruess & Tscharntke, 2002) measured as mean height-density of herbaceous vegetation (cm) from all subplots per site with a Robel pole (Robel et al., 1970); and (4) mean larval host-plant cover from all subplots per site, for each butterfly species' or species-group's caterpillars. Larval host-plants consisted of violets for fritillary butterflies (*Boloria*, *Speyeria*, *Euptoieta* spp.) as a species-group; milkweeds and dogbanes for monarchs; asters for crescent butterflies as a species-group; timothy and redtop grasses for European skippers (*Thymelicus lineola*); mustards for cabbage whites (*Pieris rapae*); and legumes for common sulfurs (*Colias philodice*) and silvery blues (*Glaucopsyche lygdanus*) (Klassen et al., 1989). Total grass cover represented larval host-plant cover for common wood-nymphs (*Cercyonis pegala*), ringlets (*Coenonympha tullia*), 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), and because the native skippers we detected on the surveys-even those that are host-plant specialists (Clark et al., 2007)-will consume abundant grasses like Kentucky bluegrass (*Poa pratensis*) (Klassen et al., 1989), which was the predominant grass species at our sites.

We recorded plant species richness and abundance of butterfly resource plants within two 1000 m^2 vegetation survey plots (mid-July to late August) at each site. There were ten 0.1 m^2 systematically spaced subplots (for 20 subplots per site) in each larger survey plot, within which we measured cover of individual plant species (Kalkhan & Stohlgren, 2000). We 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%). We 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.

We conducted butterfly and vegetation surveys at all 48 sites in either 2007 or 2008 (mid-July to mid-August). Sites with butterfly surveys in 2007, or both 2007 and 2008, had vegetation surveys in 2007, while sites with butterfly surveys that began in 2008 had vegetation surveys in 2008. We assumed that vegetation species in our plots remained similar between these years, given the short duration of our study. In 2009, we repeated butterfly and vegetation surveys at 20 of our 48 sites as part of another study, in which we compared vegetation at 12 control sites to eight sites where we arranged for the adjustment of mowing frequency for one year (Leston, 2013).

2.4. Statistical analyses

We conducted exploratory data analyses to eliminate redundant variables and determine how to assess the effects of resource plants and land use on butterfly species richness and abundance per species appropriately (Tables 1 and 2). We modeled dependent variables (butterfly species richness and abundance per species or species-group per visit) with either Poisson or negative binomial distributions, using the distribution that had the lower model deviance. We compared among the following models to determine if butterfly abundance and species richness along transmission lines were related to the amounts of built-up land (UL) and grassland habitat (GL) within 100 m of transmission lines, or to vegetation density (VD), forb cover (FC), larval host-plant cover (HPC), or plant species richness (PSR) along transmission lines. We included year (Y) and Julian day (J) as time effects in all models except the null model to account for annual and seasonal weather/temperature-related effects on vegetation, and in turn butterflies (Taylor, 1963): Julian date of butterfly surveys was strongly, positively correlated ($r > 0.60$, $p < 0.0001$) with mean and minimum weekly temperatures in Winnipeg, 2007–2009. Our models were: (1a) $M_{LOCALVEG}$: Y, J, HPC, VD, FC (full vegetation

Table 1
Summary statistics (mean, 95% confidence interval limits) for habitat and vegetation characteristics along 48 transmission line sites within 70 km of Winnipeg, Manitoba, 2007–2009, by management regime.

Predictor variable	Mowed and sprayed twice per year	Mowed (unhayed) and sprayed once per year	Hayed once per year	Unmowed and unsprayed
% built-up land	29.82 (21.73–37.91)	10.59 (4.51–16.67)	9.22 (5.63–12.81)	12.66 (8.19–17.13)
% grassland	49.22 (42.01–56.43)	33.82 (16.69–50.95)	50.19 (33.35–67.03)	49.95 (42.21–57.69)
% forb	1.94 (1.16–2.72)	1.28 (0.83–1.73)	4.61 (3.18–6.04)	1.25 (0.96–1.54)
% grass	6.32 (4.75–7.89)	10.59 (6.18–15.00)	4.98 (4.10–5.86)	8.35 (6.74–9.96)
vegetation density (cm)	16.18 (12.34–20.02)	21.67 (14.91–28.43)	18.11 (10.54–25.68)	31.09 (27.05–35.13)
plant species richness	35.32 (30.20–40.44)	59.20 (52.42–65.98)	48.57 (42.85–54.29)	45.19 (39.21–51.17)
% legume	0.57 (0.22–0.92)	0.39 (0.21–0.57)	3.38 (2.05–4.71)	0.23 (0.09–0.37)
% mustard	negligible	negligible	negligible	negligible
% aster	0.05 (0.01–0.09)	0.06 (0.00–0.12)	0.17 (0.01–0.33)	0.11 (0.03–0.19)
% redtop, timothy	0.02 (0.00–0.04)	0.14 (−0.06–0.34)	0.21 (0.03–0.39)	0.41 (0.10–0.72)
% violet	negligible	negligible	negligible	negligible
% milkweed, dogbane	0.04 (0.00–0.08)	0.01 (−0.01–0.03)	0.01 (−0.01–0.03)	negligible

Table 2
Summary statistics (mean, 95% confidence interval limits) for butterfly species richness and abundance along 48 transmission line sites within 70 km of Winnipeg, Manitoba, 2007–2009, separated by management regime along the lines.

Response variable	Mowed and sprayed twice per year	Mowed (unhayed) and sprayed once per year	Hayed once per year	Unmowed and unsprayed
Butterfly species richness	2.68 (2.39–2.97)	3.69 (3.24–4.14)	3.53 (2.94–4.12)	3.24 (2.89–3.59)
Cabbage White	0.49 (0.22–0.76)	0.81 (0.26–1.36)	0.50 (−0.11–1.11)	0.42 (0.22–0.62)
Common Sulfur	2.41 (1.16–3.66)	1.33 (0.82–1.84)	3.43 (1.94–4.92)	1.06 (0.65–1.47)
Common Wood-nymph	1.49 (0.69–2.29)	2.06 (0.90–3.22)	2.28 (0.93–3.63)	1.92 (0.94–2.90)
Crescent species	0.17 (0.03–0.31)	1.34 (0.48–2.20)	0.62 (0.25–0.99)	2.42 (1.46–3.38)
European Skipper	3.58 (1.46–5.70)	12.28 (6.15–18.41)	8.77 (2.99–14.55)	10.95 (1.74–20.16)
Fritillary species	0.08 (0.00–0.16)	0.62 (0.23–1.01)	0.25 (0.11–0.39)	0.82 (0.51–1.13)
Monarch	0.34 (0.16–0.52)	0.84 (0.39–1.29)	0.65 (0.24–1.06)	0.49 (0.29–0.69)
Native skipper species	0.15 (0.03–0.27)	0.79 (0.32–1.26)	0.12 (0.02–0.22)	0.30 (0.16–0.44)
Ringlet	2.53 (1.41–3.65)	2.06 (1.32–2.80)	1.87 (0.87–2.87)	2.23 (0.78–3.68)
Silvery Blue	0.97 (0.38–1.56)	0.24 (0.10–0.38)	2.93 (1.58–4.28)	0.54 (0.30–0.78)

model), (1b) $M_{LOCALVEG}$: Y, J, PSR, VD, FC (full vegetation model for butterfly species richness),

(2a) M_{HPC}: Y, J, HPC (larval host-plant cover), (2b) M_{PSR}: Y, J, PSR (plant species richness), (3a) M_{VD}: Y, J, VD (vegetation density), (3b) M_{VD}: Y, J, VD, VD^2 (quadratic function of vegetation density: ringlets only), (4) M_{FC}: Y, J, FC (forb cover), (5) $M_{LANDSCAPE}$: Y, J, UL, GL (landscape model), (6a) M_{GLOBAL}: Y, J, HPC, VD, FC, UL, GL (global model), (6b) M_{GLOBAL}: Y, J, VD, FC, UL, GL (global model for common sulfurs and silvery blues), (6c) M_{GLOBAL}: Y, J, PSR, VD, FC, UL, GL (global model for butterfly species richness), (7) M_{TIME}: Y, J (time effects model), and (8) M_{NULL}: null model (no time effects, resource or landscape effects).

We excluded larval host-plants of common sulfurs and silvery blues from the global models for those species, because legume cover was strongly positively correlated with total forb cover along transmission lines ($r = 0.84$, $p < 0.0001$). We used the cumulative plant species richness from both vegetation surveys per site as a predictor of butterfly species richness. We also evaluated ringlet abundance as a quadratic function of vegetation density, based on exploratory graphs.

We ran the aforementioned models as mixed models (PROC NLMIXED, SAS, 2011) to account for correlations among repeated measurements at the same sites. We then ranked models using multi-model inference (Arnold, 2010; Burnham & Anderson, 2002). In multi-model inference, a model that better predicts a dependent variable has a smaller or more negative Akaike Information Criterion (AIC) test statistic value relative to other models in the model set. A model's log-likelihood increases with the number of predictors in the model; therefore, complex models are penalized by having larger AIC values and AIC is a measure of a model's parsimony. We calculated model AIC modified for small sample size (AIC$_c$) and ΔAIC$_c$ for each model (the difference between a model's AIC$_c$ and the smallest AIC$_c$ value in the model set). We considered the model with the smallest AIC$_c$ value (ΔAIC$_c$ = 0) to be the "best" model in the model set for predicting each dependent variable, although models with ΔAIC$_c$ < 2 have similar explanatory power if they do not contain more predictors (Arnold, 2010). We calculated model AIC weights ($\omega \leq 1$) expressing the relative likelihood that a given model best predicted each dependent variable (Burnham & Anderson, 2002). For individual predictors, we calculated cumulative weights and weighted average effect sizes and 95% confidence intervals for the predictor's parameter, based on the weights of all the models in which that parameter occurred (Burnham & Anderson, 2002).

As the AIC is a measure of relative rather than absolute model fit, we also calculated the marginal R^2 values for the top models predicting each dependent variable. Marginal R^2 is similar to the R^2 coefficient associated with ordinary least-square regression, except that (1) marginal R^2 represents the proportion of variance in a dependent variable explained by the fixed effects in a mixed model, and (2) marginal R^2 does not assume that the dependent variable in a mixed model is normally distributed, e.g. our Poisson-distributed butterfly counts; Johnson (2014), Nakagawa and Schielzeth (2013).

3. Results

Herbaceous vegetation that might serve as shelter habitat for butterflies was less dense along mowed lines (urban or rural, hayed or unhayed) than unmowed rural lines (Table 1), and total forb cover that provides nectar sources for adult butterflies was lower along unhayed lines (urban or non-urban) than non-urban hayed lines. Forb cover primarily consisted of exotic species like dandelion, Canada thistle, and various legumes (*Lotus corniculatus*, *Medicago sativa*, *Melilotus alba*, *Melilotus officinale*, *Trifolium hybridum*, *T. praetense*). There were also small amounts (<1% cover) of other larval host plants for other species of butterflies (Table 1),

Table 3
Butterflies recorded along 48 transmission lines within 70 km of Winnipeg, Manitoba, 2007–2009. Number in parentheses after each name indicates number of individuals for that species that were recorded over all surveys at 48 sites.

Family	Subfamily	Species over three years
Hesperiidae	Hesperiinae	*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), *Lycaena* spp. (1)
	Melitinae	*Feniseca tarquinius* (17)
	Polyommatinae	*Everes comyntas* (7), *Glaucopsyche lygdanus* (401)
Nymphalidae	Heliconiinae	*Boloria bellona* (12), *Boloria selene* (10), *Boloria* spp. (51), *Euptoieta claudiae* (17), *Speyeria cybele* (163)
	Danainae	*Danaus plexippus* (422)
	Limenitinae	*Limenitis archippus* (43), *Limenitis arthemis* (11)
	Nymphalinae	*Chlosyne nycteis* (2), *Phyciodes morpheus/tharos* (749)
		Junonia coenia (2), *Nymphalis antiope* (39), *Nymphalis milberti* (60), *Vanessa atalanta* (32), *Vanessa cardui* (1)
	Satyrinae	*Satyrodes eurydice* (158)
		Cercyonis pegala (1117), *Coenonympha tullia* (1114), *Megisto cymela* (1), *Satyrium acadica* (9)
Papilionidae	Papilioninae	*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)

including many native forbs that are characteristic of tall-grass prairie. Plant species richness was lower along frequently mowed and sprayed transmission lines (Table 1).

We recorded a total of 46 species of butterflies in this study over all visits (Tables 2 and 3). Common butterfly species within the study area included exotic species such as the cabbage white, common sulfur, and European skipper, as well as native skippers inhabiting woodland edges, such as the long dash (*Polites mystic*) and the hobomok (*Poanes hobomok*); the monarch; great-spangled (*Speyeria cybele*), silver-bordered (*Boloria selene*), meadow (*B. bellona*), and variegated fritillaries (*Euptoieta claudiae*); northern pearl (*Phyciodes morpheus*) and pearl crescents (*Phyciodes tharos*); common wood-nymph; ringlet; and silvery blue.

Butterfly species richness per visit was lower along frequently mowed and sprayed urban lines (Tables 2 and 3). After accounting for effects of year and time of season, the best model to predict butterfly species richness included plant species richness along transmission lines (marginal $R^2 = 0.28$, $p < 0.0001$, Supplement 1 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). The best butterfly species richness model predicted respectively 30% and 85% more species of butterflies per visit along transmission lines with 40 and 80 species of plants (which varied from 10 to 85 species per site) than along lines with only 10 species of plants. Cumulative model weights and model-weighted parameter effect sizes suggested that individual butterfly species increased as one or more types of resources increased along transmission lines. Crescent butterflies increased with vegetation density, in which lines with 20 and 40 cm-tall vegetation height-density had on average respectively two and five times more crescent butterflies per visit than lines where density was 5 cm (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). The best model for ringlets predicted that their abundance was a quadratic function of vegetation height-density, reaching a predicted maximum number along transmission lines where dense vegetation was 20 cm high. Butterflies with legume-eating caterpillars increased along transmission lines with more legumes, but were best predicted by forb cover (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). The best models for common sulfurs and silvery blues 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 (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). Surprisingly, the best models predicted that both European and native skippers would decline with increasing forb cover along transmission lines, but European skippers also increased with increasing vegetation height-density and larval host-plant cover (timothy and redtop grasses) along transmission lines (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026).

Cabbage whites increased with mustard cover along transmission lines despite negligible mustard cover, as did fritillaries with violet cover along transmission lines, despite negligible violet cover along transmission lines and only moderate support for including violets in the best model (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). Monarch and crescent butterflies increased where there was greater milkweed and aster cover, respectively, although the confidence limits for these parameters included zero, and models including milkweed cover had low AIC weights and probabilities of being the best model to predict Monarch abundance (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026). The model with the lowest AIC_c value predicted that monarchs increased with vegetation density, but the model-weighted confidence limits for vegetation density included zero, and a model with only time effects ranked within 2 AIC_c units of the vegetation density model. In other words, a model without any habitat metrics explained Monarch abundance as well as a more complex model including habitat metrics as predictors, thus the model without habitat metrics was more parsimonious. These results suggest relatively small effects of vegetation density and milkweed cover within transmission lines on monarch abundance.

Built-up land and habitat amounts had few effects on most butterfly species in our study, although the amount of built-up land influenced distributions of a few species. On average, we detected 86% and 98% fewer crescents, 71% and 91% fewer fritillaries, and 35% and 57% fewer monarchs per visit at sites surrounded by 20% built-up lands and 40% built-up lands (which varied from 0 to 65% of land within 100 m) than along lines with no built-up land within 100 m (Supplement 2 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026); however, the model containing only time effects explained monarch abundance as well as or better than models including built-up land and habitat amounts, suggesting little effect of land use (Supplement 1 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026).

Fixed effects of time and plant species accounted for only 28% of the variance in butterfly species richness measured by marginal R^2; however, the high weight of this model implies that variables apart from land use and local vegetation variables may be affecting butterfly species richness. Larger marginal R^2 values for the top models predicting other butterfly species suggest that the fixed effects from those top models explained butterfly abundance well (Supplement 1 in the online version at DOI: 10.1016/j.landurbplan.2016.05.026).

4. Discussion

To increase habitat for butterflies in cities, there needs to be a paradigm shift in the way that vegetation is managed in underused green spaces like transmission lines (Byrne, 2005). Although people have managed transmission lines and other ROWs as butterfly habitats before (Forrester et al., 2005; Ries et al., 2001), our study is the first to note that if they have a sufficient abundance of "butterfly plants", urban transmission lines can also support more butterfly species and greater numbers of butterflies. We recorded larger numbers of European skippers, silvery blues, and common sulfurs occurred along transmission lines with more of their preferred host plants in our study, consistent with effects of host plant cover in other studies (Krauss et al., 2003; Leon-Cortes, Cowley, & Thomas, 2000). Negligible effects of larval host-plant cover on abundance of some butterfly species (e.g. cabbage white, monarch, fritillaries as a group) may have been due to negligible amounts of or variation in cover by those host plants along transmission lines throughout our study area. We also observed positive relationships between plant species richness and butterfly species richness at sites in our study as in previous studies (Munguira & Thomas 1992; Ries et al., 2001; Valtonen et al., 2007). Finally, sites with taller vegetation in our study supported greater numbers of European skippers and crescents, as reported for greater butterfly numbers in previous studies (Collinge et al., 2003; Kruess & Tscharntke, 2002). Also, sites with greater forb cover (primarily introduced legumes) supported common sulfurs and silvery blues in our study, also consistent with previous studies (Clark et al., 2007; Munguira & Thomas, 1992; Shepherd & Debinski, 2005). Although European and native skippers declined with increasing forb cover at sites, despite using and competing with each other for patches of forbs as nectar sources (Layberry, Hall, & Lafontaine, 1998), we suspect but were unable to test that haying of host-grasses with skipper eggs reduced the abundance of skippers that would otherwise be found along these lines (Layberry et al., 1998).

We found that built-up land amount had little effect on butterfly species richness and abundance within transmission lines along an urban gradient at the studied scale, and that resource availability for butterflies within transmission lines had stronger effects than landscape characteristics, in contrast to a previous study (Bergerot et al., 2010). Reasons for different results may include that most of the common butterfly species in our study were relatively mobile (Burke, Fitzsimmons, & Kerr, 2011; Pywell et al., 2004; Wood & Pullin, 2002), and that we surveyed long, linear grassy habitats along transmission lines, which were separated from the nearest similar habitat by no more than a single road, unlike the isolated resource plant-rich gardens studied by Bergerot et al. (2010). Smaller, relatively sedentary butterflies like silvery blues, skippers, and crescents (Pywell et al., 2004; Stasek, Bean, & Crist, 2008; Thomas, Thomas, & Warren, 1992) can disperse along roadsides if appropriate host-plants are present (Dirig & Cryan, 1991). Further, silvery blues and European skippers increased at study sites with more nearby urban land; thus, while urban sites hosted fewer crescents and fritillaries, it seems unlikely that roads or other built-up lands prevented these species from settling along urban transmission lines.

Those species that were less abundant along urban lines might have found fewer resources due to frequent mowing and spraying. As our study was observational and not experimental, we cannot entirely disentangle the effect or lack of an effect of built-up land around transmission lines from the effects of frequent mowing and spraying on butterfly abundance within urban ROWs, or establish causal relationships between vegetation management and butterfly numbers. Nevertheless, our results suggest that managing urban ROWs as butterfly habitats by reintroducing and maintaining large numbers of appropriate resource plants will require reducing the frequency and extent of mowing and spraying of urban vegetation along ROWs, but also varying the mowing and spraying regime to benefit more species of resource plants for butterflies. As in previous studies (Hovd & Skogen, 2005; Parr & Way, 1988), frequently mowed and sprayed sites had lower forb cover than infrequently mowed and hayed sites, shorter herbaceous vegetation than unmowed sites, and fewer plant species than both unmowed and infrequently mowed sites. Thus, reducing mowing and spraying frequency and extent, and creating a mixture of unmowed and infrequently mowed zones with or without haying may promote vegetation structure and species composition that supports more species of butterflies along urban ROWs.

Given that common butterflies in our study increased along transmission lines with more potential resources, despite surrounding urbanization at the studied scale, we advocate large-scale restoration of native plant communities to create habitats along urban ROWs for butterflies. Although butterflies will also use exotic plants as resources (Graves & Shapiro, 2003; Tooker et al., 2002), there are critically endangered, low-growing ecosystems like tall-grass prairie in need of large-scale restoration (Hoekstra et al., 2005). Restored prairie habitats have been documented as benefiting butterflies (Ries et al., 2001), including endangered species like the threatened Karner blue butterfly (*Lycaeides melissa samuelis*) (Forrester et al., 2005). Planting milkweeds and dogbanes along urban ROWs may aid conservation of monarch butterflies, which are declining across North America due to large-scale reductions of milkweed host-plants in agricultural landscapes (Brower et al., 2011). Funds for wildlife management and restoring ecosystems along urban ROWs may even be available in the form of savings in vegetation management costs associated with less mowing and spraying of urban ROWs (Leston & Koper, 2016). We also advocate exploring whether reintroducing and managing for different resource plant species along urban ROWs would benefit other wildlife groups (e.g. bees, hummingbirds). Urban ROWs with reintroduced nectar plants might serve as "pollinator parks" for important declining pollinators like native bees (Hopwood, 2008; Kearns, Inouye, & Waser, 1998). Other studies could explore if restoring native plant communities along urban ROWs enables those ROWs to serve as stepping stones for hummingbirds or other migratory species moving between other urban wildlife refuges, if large sections of urban ROWs are managed as wildlife habitats (Wojcik & Buchmann, 2012).

Acknowledgments

This study was made possible by grants from the Manitoba Hydro Research and Development Grant, Manitoba Conservation Sustainable Development Innovations Fund, Environment Canada's Science Horizons Fund, Manitoba Career Focus Program, and the University of Manitoba's Faculty of Graduate Studies. Academic advice for this study came primarily from Dr. Nicola Koper, and additionally from Dr. Micheline Manseau, Dr. Terry Galloway, and Dr. Douglas Johnson. Field work was conducted by Dong-jie Bao, Alley Krause-Danielsen, Praepun Khattiyakornjaroon, Kimberley Madsen, Chelsea May, Ellen Reid, and Jennifer Tran. In-kind support was provided by Dr. Robert Roughley and Technician Dave Holder (University of Manitoba Department of Entomology); Tamara Keedwell and Dalia Naguib (University of Manitoba Natural Resources Institute); and Wade Munro, Trent Hreno, Wayne Ortiz, and Spencer Heaman (Manitoba Hydro).

References

Arnold, T. W. (2010). Uninformative parameters and model selection using Akaike's Information Criterion. *Journal of Wildlife Management*, *74*, 1175–1178.

Bergerot, B., Fontaine, B., Renard, M., Cadi, A., & Julliard, R. (2010). Preferences for exotic flowers do not promote urban life in butterflies. *Landscape and Urban Planning*, *96*, 98–107.

Brower, L. P., Taylor, O. R., Williams, E. H., Slayback, D. A., Zubieta, P. R., & Isabel, M. (2011). Decline of monarch butterflies overwintering in Mexico: is the migratory phenomenon at risk? *Insect Conservation and Diversity*, http://dx.doi.org/10.1111/j.1752-4598.2011.00142x

Burke, R. J., Fitzsimmons, J. M., & Kerr, J. T. (2011). A mobility index for Canadian butterfly species based on naturalists' knowledge. *Biodiversity and Conservation*, *20*, 2273–2295.

Burnham, K. P., & Anderson, D. R. (Eds.). (2002). *Model selection and multi-model inference: a practical information-theoretic approach*. New York: Springer-Verlag.

Byrne, L. B. (2005). Of looks, laws and lawns: how human aesthetic preferences influence landscape management, public policies and urban ecosystems. In D. Laband (Ed.), *Emerging issues along urban-rural interfaces* (2nd ed., pp. 42–46). Alabama: Auburn University. Linking Science and Society Conference Proceedings

Cadenasso, M. L., Picket, S. T. A., & Schwarz, K. (2008). Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. *Frontiers in Ecology and the Environment*, *5*, 80–88.

Clark, P. J., Reed, J. M., & Chew, F. S. (2007). Effects of urbanization on butterfly species richness, guild structure and rarity. *Urban Ecosystems*, *10*, 321–337.

Collinge, S. K., Prudic, K. L., & Oliver, J. C. (2003). Effects of local habitat characteristics and landscape context on grassland butterfly diversity. *Conservation Biology*, *17*, 178–187.

Daubenmire, R. (1959). A canopy-coverage method of vegetational analysis. *Northwest Science*, *33*, 43–64.

Dirig, R., & Cryan, J. F. (1991). The status of silvery blue subspecies (*Glaucopsyche lygdanus*) in New York. *Journal of the Lepidopterists' Society*, *45*, 272–290.

Dover, J. W. (1996). Factors affecting the distribution of satyrid butterflies on arable farmland. *Journal of Applied Ecology*, *33*, 723–734.

ESRI (Environmental Systems Research Institute). (2002). *ArcGIS. release 8.3*. Redlands, California, USA: ESRI.

Forrester, J. A., Leopold, D. J., & Hafner, S. D. (2005). Maintaining critical habitat in a heavily managed landscape: effects of power line corridor management on Karner Blue butterfly (*Lycaeides melissa samuelis*) habitat. *Restoration Ecology*, *13*, 488–498.

Graves, S. D., & Shapiro, A. M. (2003). Exotics as host plants of the California butterfly fauna. *Biological Conservation*, *110*, 413–433.

Hill, J. K., Thomas, C. D., & Lewis, O. T. (1996). Effects of habitat patch size and isolation on dispersal by *Hesperia comma* butterflies: implications for metapopulation structure. *Journal of Animal Ecology*, *65*, 725–735.

Hoekstra, J. M., Boucher, T. M., Ricketts, T. H., & Roberts, C. (2005). Confronting a biome crisis: global disparities of habitat loss and protection. *Ecological Letters*, *8*, 23–29.

Hopwood, J. L. (2008). The contribution of roadside grassland restorations to native bee conservation. *Biological Conservation*, *141*, 2632–2640.

Johnson, P. C. D. (2014). Extension of Nakagawa & Schielzeth's R2GLMM to random slopes models. *Methods in Ecology and Evolution*, *5*, 944–946.

Kalkhan, M. A., & Stohlgren, T. J. (2000). Using multi-scale sampling and spatial cross-correlation to investigate patterns of plant species richness. *Environmental Monitoring and Assessment*, *64*, 591–605.

Kearns, C. A., Inouye, D. W., & Waser, N. M. (1998). Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual Review of Ecology and Systematics*, *29*, 83–112.

Kitahara, M., Sei, K., & Fujui, K. (2000). Patterns in the structure of grassland butterfly communities along a gradient of human disturbance: further analysis based on the generalist/specialist concept. *Population Ecology*, *42*, 135–144.

Klassen, P., Westwood, A. R., Preston, W. B., & McKillop, W. B. (1989). *The Butterflies of Manitoba*. Winnipeg: Manitoba Museum of Man and Nature.

Krauss, J., Steffan-Dewenter, I., & Tscharntke, T. (2003). How does landscape context contribute to effects of habitat fragmentation on diversity and population density of butterflies? *Journal of Biogeography*, *30*, 889–900.

Kruess, A., & Tscharntke, T. (2002). Contrasting responses of plant and insect diversity to variation in grazing intensity. *Biological Conservation*, *106*, 293–302.

Layberry, R. A., Hall, P. W., & Lafontaine, J. D. (1998). *The butterflies of Canada*. Toronto: University of Toronto Press.

Leon-Cortes, J. L., Cowley, M. J. R., & Thomas, C. D. (2000). The distribution and decline of a widespread butterfly *Lycaena phlaeas* in a pastoral landscape. *Ecological Entomology*, *25*, 285–294.

Leston, L., & Koper, N. (2016). Urban rights-of-way as reservoirs for tall-grass prairie plants and butterflies. *Environmental Management*, *57*, 543–557.

Leston, L. (2013). *Chapter 2. Experimentally disentangling the effects of urbanization from mowing on prairie wildlife along urban transmission lines. PhD Dissertation*. Winnipeg, Manitoba, Canada: Natural Resources Institute, University of Manitoba.

Manitoba Conservation Data Centre. Retrieved September 30, 2006 from http://web2.gov.mb.ca/conservation/cdc.

McDonald, R. I., Kareiva, P., & Forman, R. T. T. (2008). The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation*, *141*, 1695–1703.

McIntyre, S., & Barrett, G. W. (1992). Habitat variegation: an alternative to fragmentation. *Conservation Biology*, *6*, 146–147.

Morgan, J. P., Collicut, D. R., & Thompson, J. D. (1995). *Restoring Canada's native prairies: a practical manual*. Manitoba: Prairie Habitats Incorporated.

Munguira, M. L., & Thomas, J. A. (1992). Use of road verges by butterfly and burnet populations and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology*, *29*, 316–329.

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R^2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution*, *4*, 133–142.

Öckinger, E., Dannestam, A., & Smith, H. G. (2009). The importance of fragmentation and habitat quality of urban grasslands for butterfly diversity. *Landscape and Urban Planning*, *93*, 31–37.

Parr, T. W., & Way, J. M. (1988). Management of roadside vegetation: the long-term effects of cutting. *Journal of Applied Ecology*, *25*, 1073–1087.

Pollard, E. (1977). A method for assessing changes in the abundance of butterflies. *Biological Conservation*, *12*, 115–134.

Polus, E., Vandewoestijne, S., Choutt, J., & Baguette, M. (2007). Tracking the effects of one century of habitat loss and fragmentation on calcareous grassland butterfly communities. *Biodiversity Conservation*, *16*, 3423–3436.

Pywell, R. F., Warman, E. A., Sparks, T. H., Greatorex-Davies, J. N., Walker, K. J., Meek, W. R., et al. (2004). Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation*, *118*, 313–325.

Ries, L., Debinski, D. M., & Wieland, M. L. (2001). Conservation value of roadside prairie restoration to butterfly communities. *Conservation Biology*, *15*, 401–411.

Robel, R. J., Briggs, J. M., Dayton, A. D., & Hulbert, L. C. (1970). Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management*, *23*, 295–297.

Ruszczyk, A., & Silva, C. F. (1997). Butterflies select microhabitats on building walls. *Landscape and Urban Planning*, *38*, 119–127.

SAS Institute Inc. (2011). *The SAS system for Windows version 9.3*. Cary, North Carolina: SAS Institute Inc.

Samson, F. B., & Knopf, F. L. (1994). Prairie conservation in North America. *Bioscience*, *44*, 418–421.

Shepherd, S., & Debinski, D. M. (2005). Evaluation of isolated and integrated prairie reconstructions as habitat for prairie butterflies. *Biological Conservation*, *126*, 51–61.

Stasek, D. J., Bean, C., & Crist, T. O. (2008). Butterfly abundance and movements among prairie patches: the roles of habitat quality, edge: and forest matrix permeability. *Environmental Entomology*, *37*, 897–906.

Sutcliffe, O. L., Thomas, C. D., & Moss, D. (1996). Spatial synchrony and asynchrony in butterfly population dynamics. *Journal of Animal Ecology*, *65*, 85–95.

Taylor, L. R. (1963). Analysis of the effect of temperature on insects in flight. *Journal of Animal Ecology*, *32*, 99–117.

Thomas, C. D., Thomas, J. A., & Warren, M. S. (1992). Distributions of occupied and vacant butterfly habitats in fragmented landscapes. *Oecologia*, *92*, 563–567.

Tooker, J. F., Reagel, P. F., & Hanks, L. M. (2002). Nectar sources of day-flying Lepidoptera of Central Illinois. *Annals of the Entomological Society of America*, *95*, 84–96.

Tudor, O., Dennis, R. L. H., Greatorex-Davies, J. N., & Sparks, T. H. (2004). Flower preferences of woodland butterflies in the UK: nectaring specialists are species of conservation concern. *Biological Conservation*, *119*, 397–403.

Valtonen, A., Saarinen, K., & Jantunen, J. (2007). Intersection reservations as habitats for meadow butterflies and diurnal moths: guidelines for planning and management. *Landscape and Urban Planning*, *79*, 201–209.

Wojcik, V. A., & Buchmann, S. (2012). Pollinator conservation and management on electrical transmission and roadside rights-of-way: a review. *Journal of Pollination Ecology*, *7*, 16–26.

Wood, B. C., & Pullin, A. S. (2002). Persistence of species in a fragmented urban landscape: the importance of dispersal ability and habitat availability for grassland butterflies. *Biodiversity and Conservation*, *11*, 1451–1468.

Young, T. P. (2000). Restoration ecology and conservation biology. *Biological Conservation*, *92*, 73–83.