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Effects of Weather and Land Management on the Western Prairie Fringed-orchid (Platanthera praeclara) at the Northern Limit of its Range in Manitoba, Canada

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Abstract.—The western prairie fringed-orchid is a rare North American orchid restricted to a few remnants of wet to mesic tallgrass prairie. It is federally listed in both Canada and the United States and both countries have developed a recovery plan for the species. Two key management objectives are to monitor population trends and identify beneficial management practices. We used 21 y of data from the Manitoba metapopulation to assess effects of weather and land management on this species. Our results suggest the metapopulation in Manitoba is relatively stable. Western prairie fringed-orchids appear to benefit most from a combination of warm temperatures in the previous growing season followed by cool snowy but short winters and wet springs. Periodic burning (*e.g.*, every 2–3 y) may benefit fringed-orchids, whereas grazing may be detrimental. This was not a controlled experiment, however, and gaps in the data may have influenced our results. Prescribed burning is a viable management tool for curtailing woody invasion and both burning and grazing reduce litter and grass cover, but careful consideration of timing, frequency, and intensity of application is required so management does not hinder fringed-orchid reproduction or reduce survival, while also recognizing management requirements may vary among years depending on weather. Long-term studies are particularly valuable for the western prairie fringed-orchid due to its erratic life cycle and fluctuating populations, which complicate studies of environmental and management effects on this species.

Introduction

The western prairie fringed-orchid (*Platanthera praeclara* Sheviak and Bowles) is a rare North American orchid restricted to a few remnants of wet to mesic tallgrass prairie in the American Midwest and southern Manitoba (Environment Canada, 2006). Populations have declined primarily because of loss and degradation of native tallgrass prairie habitat on which the species depends. Much of the North American tallgrass prairie was cultivated by early Europeans because of its high fertility, and sites unsuitable for ploughing were typically grazed by domestic livestock (Steinauer and Collins, 1996). Fire was suppressed where formerly wildfires and fires set by native tribes had burned portions of the landscape

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as regularly as every 2.6 y in some areas (Allen and Palmer, 2011), and periodic grazing by bison (*Bison bison*) was largely replaced by regular and often uniform grazing by cattle (*Bos taurus*; Knapp *et al.*, 1999). These changes have had profound effects on the tallgrass prairie ecosystem. Less than 5% remains of the 68 million ha that are estimated to have existed prior to European arrival (Samson and Knopf, 1994). Fire suppression and unmanaged grazing have resulted in extensive woody encroachment and poor diversity in many remnant tallgrass prairie patches (Howe, 1994; Briggs *et al.*, 2002; Lett and Knapp, 2005). Many species that are dependent on native tallgrass prairie, such as the western prairie fringed-orchid, are now found only in small pockets of isolated prairie or in protected areas.

The western prairie fringed-orchid is federally listed as endangered in Canada and threatened in the United States. Two key management objectives identified in federal recovery plans are to monitor population trends and identify beneficial management practices to counter continued population declines of this species. Our objectives were to assess how weather and land management affect the western prairie fringed-orchid metapopulation in Manitoba. Specifically, we were interested to know: (1) if and how population fluctuations corresponded with weather patterns, and (2) which broad-scale management practices best supported the fringed-orchid metapopulation. Understanding the effects of weather on western prairie fringed-orchid populations can improve management by enabling managers to predict population fluctuations and adjust management activities accordingly.

METHODS

STUDY AREA

The 12,728 acre (5170 ha) Tall Grass Prairie Preserve (TGPP) near Tolstoi, Stuartburn, and Gardenton, Manitoba (49°04′45″N, 96°43′53″W) protects most of the known Canadian metapopulation of western prairie fringed-orchids (Environment Canada, 2006). Most of the TGPP lands (78%) are owned by the Nature Conservancy of Canada (NCC) with the balance being owned by Nature Manitoba and Manitoba Habitat Heritage Corporation. The lands are jointly managed through a Management Committee that includes NCC, Manitoba Conservation and Water Stewardship, Environment Canada, Nature Manitoba, and the Manitoba Habitat Heritage Corporation.

Management activities at the TGPP include prescribed burning and grazing. Long-term fire management plans call for each TGPP property to be burned through prescribed fire once every 5 y, typically in spring or fall. Properties are not grazed in the year prior to prescribed fire. Actual fire frequency often departs from prescription due to occasional wildfires and seasonal weather conditions not conducive to the use of prescribed fire (*e.g.*, too wet, too dry). Since 1995 a twice-over rotational grazing system has been used with regularity (*i.e.*, at least one site grazed each year, more typically 6–8 sites) for management at the TGPP. Prior to 1995 grazing was irregular with some sites grazed using a once-over rotational grazing system, and at one site season-long grazing was permitted.

DATA COLLECTION

Tall Grass Prairie Preserve biological staff (via the Critical Wildlife Habitat Program) has conducted annual surveys for flowering western prairie-fringed orchid at the TGPP and surrounding areas since 1992 (Fig. 1). Initially, 61 sites were surveyed. Beginning in 1995 the survey area was expanded in an effort to better document the range of the metapopulation in Manitoba and included sites that were primarily agricultural fields with little chance of

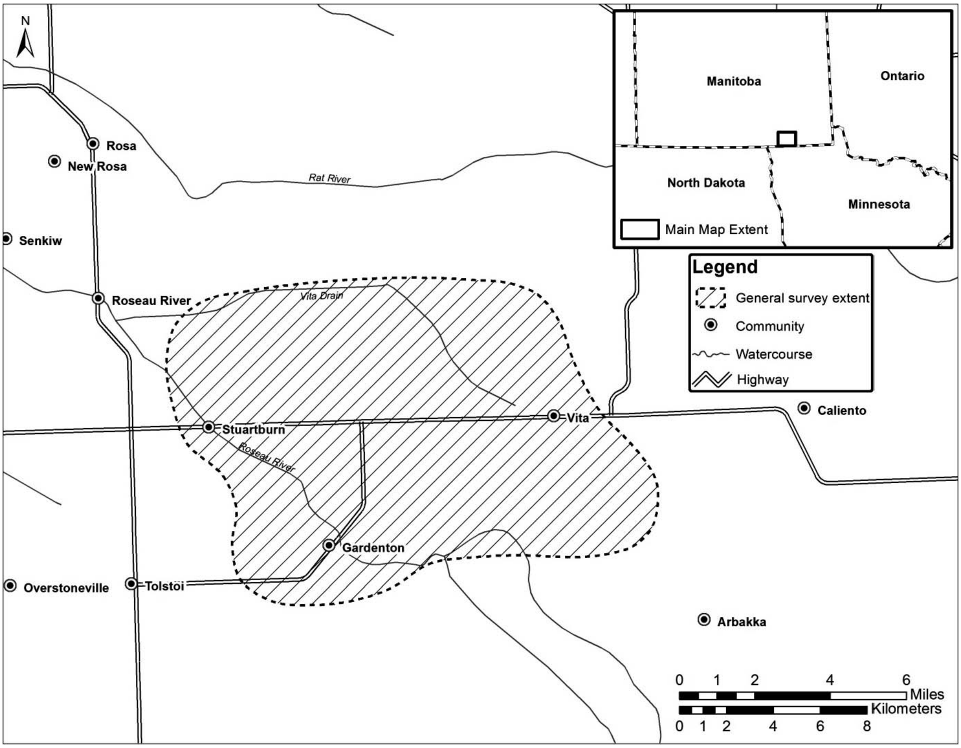

FIG. 1.—General extent of area surveyed for western prairie fringed-orchid (*Platanthera praeclara*) in Manitoba as of 2012 and containing the known range of the species in Canada

supporting fringed-orchids but which had remnant tallgrass prairie along the property edges and in adjacent road allowances. In 2012, 227 sites were surveyed.

Each survey site represented a quarter section (approximately 65 ha) of land. Sites at which a walking survey was conducted were typically visited by two surveyors. Each surveyor walked a large loop around the site to cover as much ground as possible but avoiding overlap with the other surveyor. Surveyors used binoculars to confirm some of the distant fringed-orchids. If flowering fringed-orchids were observed on privately-owned properties, they were generally surveyed from the roadside or adjacent TGPP property with binoculars because access was not requested. This allowed for the possibility of some flowering stems being missed, but for long-term monitoring, methodology was consistent in how and which portions of these sites were surveyed from year to year. Surveys were conducted when most fringed-orchids were flowering, typically 5 to 7 d after the first observed flower opened, and every effort was made to complete surveys before flowers began to wilt. The length of survey periods varied among years and was dependent on air temperature and relative humidity, which together influence the bloom period. On average the survey period was 11 d in length, within the first 3 wk of July.

Weather data were obtained from the National Climate Data and Information Archive from the Emerson station (approximately 46 km from the study area), with data from the Winnipeg station (approximately 101 km from the study area) supplementing missing data for 1 mo in each of 1996, 1997, and 2011, and 2 mo in 2009 (Environment Canada, 2013).

Emerson station was the nearest station to the study area that had weather records for all 21 y of our study. Land management information was compiled from pasture assessment, fire prescriptions, annual monitoring reports, and annual staff report records maintained by NCC and TGPP staff.

STATISTICAL ANALYSIS

We conducted all statistical analyses using SAS v. 9.3 (SAS Institute, 2010) and alpha of 0.05. We used linear regression using the REG procedure to analyze the effects of year and number of sites sampled on western prairie fringed-orchid metapopulation size (*i.e.*, total number of flowering individuals observed across all sites within a year) and on mean number of flowering individuals within occupied sites.

We used Generalized Linear Mixed Models (GLMMs) using the GLIMMIX procedure to analyze the effects of temperature, precipitation, and snow depth on presence and total number of flowering individuals. GLMMs are appropriate for these types of analyses because they accommodate nonnormal distributions typical of count data and permit clustering of data in space and time. There may be more similarity between samples taken from the same site across years than between samples taken from different sites. For each year we averaged temperature and precipitation within phenological stages delineated for this species by Wolken (1995; Table 1) and used elsewhere (*e.g.*, Willson *et al.*, 2006; Alexander *et al.*, 2010). Timing of phenological stages was adapted to reflect the Manitoba climate based on phenological information summarized in the federal recovery strategy for this species (Environment Canada, 2006). Snow depth represented the amount of snow on the ground at the end of each calendar month. We excluded October, April, and years 1998–2009 and 2012 because data were unavailable or otherwise snow depth was zero, which precluded comparisons within these periods.

We used GLMMs to analyze the effects of occurrence and frequency (within last 3, 5, and 10 y) of burning (prescribed and wildfire) and grazing on presence and total number of flowering individuals. We also analyzed the effects of time since management (burning or grazing) and season of burn (spring versus previous fall) on the presence and total number of flowering individuals. Data were limited for both management strategies, so we analyzed independent variables separately to maximize detection ability. There were insufficient data to test for interactions among independent variables.

RESULTS

Metapopulation size varied greatly from year to year within the 21 y sampling period ($P = 0.966$). Total number of flowering individuals observed across all sites ranged from 753 in 2012 to 22,486 in 2003 (Table 2). The number of sites that were sampled gradually increased over time, but this did not affect observed metapopulation size ($P = 0.959$). Mean number of flowering individuals within occupied sites ranged from 19 in 2012 to 556 in 1996 (Table 2) and was unaffected by year ($P = 0.749$) or the number of sites sampled ($P = 0.993$).

Higher temperatures in the previous mature growth and senescence/bud development stages had positive effects on the presence and total number of flowering fringed-orchids, respectively, but higher temperatures during dormancy negatively influenced total number of flowering individuals in the following growing season (Table 3). Precipitation had a strong influence on fringed-orchids within all phenological stages; however, presence of flowering individuals generally decreased as precipitation increased, whereas total number of flowering individuals increased (Table 3). Snow depth early (*i.e.*, November) and late (*i.e.*, March) in the dormant season had a negative effect on the presence of fringed-orchids

TABLE 1.—Phenological stages of the western prairie fringed-orchid (*Platanthera praeclara*) in Manitoba

Stage	Description	Time period[1]
Emergence	Emergence of shoot	April–May
Mature growth	Vegetative growth, inflorescence	June–July
Senescence/bud development	Seed production and dispersal	August
Post-senescence	Termination of above-ground growth	September
Dormancy	Dormant tuber with shoot bud	October–March

[1] Adapted from Wolken (1995) to reflect the Manitoba climate and based on phenological information observed from the Manitoba metapopulation (Environment Canada, 2006)

the following growing season, whereas snow depth mid-season (*i.e.*, January, February) had a positive effect on both the presence and number of flowering individuals the following growing season (Table 3).

The total number of flowering individuals within sites increased as the frequency of burns increased within 3 y and 5 y periods but current-year burning, season of burn, and time since burning had no effect on either presence or total number of flowering individuals within sites (Table 4). Grazing had a negative effect on fringed-orchid populations. Flowering individuals were less likely to be present and in lower abundance in currently grazed sites. Further, the presence and total number of flowering individuals within sites increased as time since grazing increased (Table 4).

TABLE 2.—Metapopulation size of the western prairie fringed-orchid (*Platanthera praeclara*) and number of sites sampled in southern Manitoba, 1992–2012

Year	No. sites sampled	No. occupied sites (%)	Total no. flowering individuals across all sites	Mean no. flowering individuals within occupied sites	Minimum and maximum no. flowering individuals within occupied sites
1992	61	22 (36)	3546	161	1–1680
1993	61	24 (39)	3613	151	1–638
1994	61	34 (56)	8509	250	3–1489
1995	74	24 (32)	1517	63	2–502
1996	94	36 (38)	20,029	556	1–4758
1997	101	43 (43)	14,784	344	1–1973
1998	101	29 (29)	3972	137	1–2142
1999	108	42 (39)	7426	177	1–787
2000	112	44 (39)	3900	89	1–321
2001	127	30 (24)	1502	50	1–400
2002	127	37 (29)	4935	133	1–643
2003	129	43 (33)	22,486	523	1–2492
2004	130	45 (35)	17,906	398	1–2094
2005	127	39 (31)	5643	145	1–1005
2006	129	44 (34)	4314	98	1–950
2007	131	51 (39)	4561	89	1–508
2008	195	59 (30)	4133	70	1–604
2009	207	51 (25)	7981	156	1–856
2010	208	61 (29)	8183	134	1–836
2011	212	64 (30)	13,620	213	1–1458
2012	227	39 (17)	753	19	1–118

TABLE 3.—Effects of weather on the presence and total number of flowering individuals of western prairie fringed-orchid (*Platanthera praeclara*) in southern Manitoba, 1992–2012

	Presence of flowering individuals			Total number of flowering individuals		
Weather variable	β	SE	P	β	SE	P
Temperature						
Previous-year mature growth	0.172	0.062	0.006	5.999	3.474	0.084
Previous-year senescence/ bud development	–0.083	0.054	0.128	10.087	3.089	0.001
Previous-year post-senescence	0.018	0.051	0.723	–4.548	2.948	0.123
Dormancy	–0.059	0.035	0.091	–11.888	2.014	<0.0001
Current-year emergence	–0.036	0.036	0.313	–2.518	2.053	0.220
Current-year mature growth	–0.052	0.050	0.297	–0.328	2.941	0.911
Precipitation						
Previous-year mature growth	–0.007	0.002	0.001	0.248	0.118	0.035
Previous-year senescence/ bud development	–0.002	0.002	0.137	0.354	0.090	<0.0001
Previous-year post-senescence	–0.004	0.002	0.038	0.267	0.118	0.024
Dormancy	–0.023	0.006	<0.0001	0.204	0.336	0.544
Current-year emergence	0.006	0.003	0.016	0.941	0.148	<0.0001
Current-year mature growth	–0.010	0.002	<0.0001	–0.215	0.124	0.084
Snow depth						
Previous November	–0.242	0.107	0.024	1.850	11.137	0.868
Previous December	–0.044	0.063	0.483	–3.794	6.784	0.576
January	0.205	0.094	0.030	–0.852	9.871	0.931
February	0.080	0.042	0.058	10.489	4.514	0.021
March	–0.064	0.022	0.005	–3.509	2.307	0.129

DISCUSSION

METAPOPULATION SIZE

Observed metapopulation size was highly erratic among years. More sites were sampled in later years; however, these included sites that did not necessarily contain fringed-orchids, whereas in earlier years, sampled sites primarily consisted of sites known to

TABLE 4.—Effects of land management on the presence and total number of flowering individuals of western prairie fringed-orchid (*Platanthera praeclara*) in southern Manitoba, 1992–2012

	Presence of flowering individuals			Total number of flowering individuals		
Land management	β	SE	P	β	SE	P
Burn	–0.57	0.57	0.322	–63.81	53.20	0.231
Season of burn	–2.03	1.26	0.115	–206.70	162.18	0.211
Last burn	0.15	0.13	0.272	8.26	9.84	0.402
Burn frequency in 3 y period	0.10	0.48	0.837	81.08	39.24	0.040
Burn frequency in 5 y period	0.48	0.48	0.321	85.98	37.90	0.024
Burn frequency in 10 y period	–0.15	0.76	0.847	24.29	45.26	0.593
Graze	–1.98	0.70	0.005	–148.93	59.54	0.013
Last graze	0.024	0.10	0.017	15.33	6.61	0.022
Graze frequency in 3 y period	–0.25	0.35	0.471	–48.95	28.69	0.089
Graze frequency in 5 y period	–0.10	0.28	0.709	–9.62	23.77	0.686
Graze frequency in 10 y period	–0.42	0.64	0.515	41.68	38.20	0.278

contain fringed-orchids. Number of sites sampled did not influence metapopulation size and mean number of flowering individuals within occupied sites remained constant, supporting this contention. Fringed-orchid populations elsewhere also demonstrate erratic fluctuations (Morrison *et al.*, 2015).

Western prairie fringed-orchids generally reproduce sexually through flower and seed production, though they are also capable of reproducing vegetatively through the division of tubers (Bowles, 1983). Individuals may not reproduce at all in some years; Sieg and King (1995) reported 32–95% of individuals remained vegetative annually in a 5 y study in North Dakota. Further, individual plants can remain dormant for several years (Sather and Anderson, 2010). These characteristics of the western prairie fringed-orchid make the species particularly challenging to tally.

Weather

Warmer temperatures in the previous growing season resulted in more flowering individuals in the current growing season, but temperatures in the current growing season did not affect fringed-orchid populations, suggesting there is a time lag in the effects of temperature on flowering. However, we acknowledge weather conditions in our study area may not have been accurately represented by weather data collected mostly from a weather station located 46 km away. We were unable to find published data on the effects of temperature on this species. Results from an unpublished study in Manitoba suggest warmer temperatures during emergence and mature growth may induce above-ground growth and flowering (Dewar, 1996); however, the effect of temperature on fringed-orchids was not explicitly evaluated. European orchid populations at their northern range limits were positively associated with temperature in both previous and current growing seasons in a Russian study (Blinova and Chmielewski, 2008). Warmer soil temperatures resulting from increased air temperature during the growing season may accelerate below-ground growth and stimulate the development of generative shoots and flower primordia (*i.e.*, the first histologically differentiated stage of development) in preparation for the following growing season (Blinova and Chmielewski, 2008). However, warm air temperatures may also intensify dry soil conditions through increased evapotranspiration (Galatowitsch *et al.*, 2009), which may be detrimental to fringed-orchids. Wolken *et al.* (2001) identified soil moisture as a strong positive determinant of fringed-orchid presence. Given the limitations of our analyses (*i.e.*, source of weather data), we conservatively conclude temperatures in the current growing season likely influence fringed-orchid growth and flowering, but temperatures in the previous growing season may be a better indicator of fringed-orchid abundance in a given year.

Fewer flowering individuals occurred in years following warm winters. Winter temperatures did not correlate well with winter precipitation ($r = -0.14$) but were negatively correlated with snow depth ($r = -0.67$). Snow insulates soil from cold ambient temperatures (Schimel *et al.*, 2004). Warmer soil temperatures permit higher rates of nutrient cycling over the winter, resulting in greater soil nutrient availability in spring (Schimel *et al.*, 2004). Nutrient cycling promotes plant growth and development (Belovsky and Slade, 2000). Therefore, greater snow depth in the previous winter may indirectly promote flowering through its positive effects on soil nutrient availability.

Increased snow depth benefited fringed-orchids in mid-winter (*i.e.*, January, February) but was detrimental in late winter (*i.e.*, March). Snow typically remains on the ground throughout the winter season in Manitoba because of consistent freezing temperatures, so snow accumulates over time and only dissipates into the soil in spring. Therefore, snow depth in mid-winter can be a good measure of the amount of moisture from winter precipitation that is available for the forthcoming growing season. Further, snow traps atmospheric nutrients that are subsequently deposited into the soil during spring melt (Clement *et al.*, 2011). In March, as the growing season approaches, accumulated snow may act as a growth inhibitor by blocking sunlight, prolonging cooler soil temperature, and restricting emergence of new shoots. Snow cover has a strong influence on plant phenology; studies from various systems have found late snow melt and prolonged ground frost in spring delay flowering and reduce flowering and seed production rates in some species (Kudo, 1991; Williams and Abberton, 2004; Lavoie and Lachance, 2006). Increased snow depth in early winter negatively affected fringed-orchid populations, possibly by slowing soil nutrient cycling prematurely and hindering below-ground growth (*i.e.*, development of the tuber, shoot bud, and flower primordia), which continues past the time of vegetative dormancy (Bowles, 1983). Further, snow retention into spring can result in rapid melting as the temperature rises and an extended period of standing water at the time when fringed-orchids are beginning to emerge, which may inhibit fringed-orchid development (Sieg and Wolken, 1999).

Precipitation within all phenological stages had a strong influence on fringed-orchids. Western prairie fringed-orchids are strongly dependent on soil moisture (Wolken *et al.*, 2001) and precipitation during some stages of development appears to stimulate flowering (Bowles, 1983; Willson *et al.*, 2006; Morrison *et al.*, 2015). We detected a positive lag effect of precipitation in the previous growing season on current year abundance of flowering individuals. Flower primordia may be initiated late in the previous growing season (Bowles, 1983), so precipitation in the previous growing season may better predict flowering than precipitation in the current growing season (Willson *et al.*, 2006). Our results support this hypothesis, as do those of Bjugstad and Fortune (1989), Bray and Wilson (1992), and Morrison *et al.* (2015); however, none of these studies directly compared primordial development with weather, and research is limited in this area of fringed-orchid development. Surprisingly, flowering individuals were less likely to be present as precipitation in most phenological stages increased, whereas the total number of flowering individuals increased as precipitation in most phenological stages increased, though spring precipitation corresponding with shoot emergence was beneficial for both population measures. One possible explanation may be that increased precipitation resulted in localized flooding, affecting only some populations, while other populations benefited from additional precipitation and produced more flowering individuals. Unfortunately, the scale at which weather data were collected did not allow us to test this hypothesis. We also acknowledge our weather data may not have accurately represented local conditions. Alternatively, the results may be spurious. The negative relationship between the presence of flowering individuals and precipitation during the dormant season appears to contradict fringed-orchid response to snow depth because most precipitation fell as snow during this period; however, this discrepancy may be a result of the averaging of precipitation across all dormant months (October to March), whereas snow depth was analyzed by month from November to March.

LAND MANAGEMENT

There were no immediate changes in presence or total number of flowering individuals following burns, nor did fringed-orchids respond to time since burning. Consistent with our findings, Pleasants (1995) and Willson *et al.* (2006) found probability and frequency of flowering were similar between burned and unburned sites. Pleasants (1995) also found vegetative growth was slower in burned sites in the year of burning but faster and more vigorous the following year. Following a second burn 2 y later, the probability of flowering in the year of burning was lower in sites that were burned twice than sites that were either unburned (for the past 6 y) or burned once, but similar between treatments the following year (Pleasants, 1995). Most notably, individuals were more likely to die out in the unburned sites (Pleasants, 1995). In our study total number of flowering individuals increased as the frequency of burns increased within 3 y and 5 y periods; however, the maximum number of burns within these periods was two and three, respectively, and only two sites experienced burns within two consecutive years. Pleasants (1995) observed delayed benefits of burning to fringed-orchids, and annual burning is presumably detrimental. Morrison *et al.* (2015) found fewer flowering individuals in burn years, but this effect disappeared when precipitation was added to the model, suggesting precipitation (which was generally low in burn years) was driving the effect.

Season of burn did not affect fringed-orchids; however, exact dates were not known for all burns, and we did not have information on which phenological stage the metapopulation was in at time of burning. Fringed-orchid phenology can differ substantially from year to year in response to weather conditions, which thereby regulate the effects of fire on fringed-orchid populations as well (Willson *et al.*, 2006; Sather and Anderson, 2010). Burning in the dormant season does not appear to negatively affect flowering the following year (Willson *et al.*, 2006). The effects of spring burning on fringed-orchids appear to depend on soil moisture; fire intensifies dry conditions by further desiccating the soil and removing moisture-retaining litter cover (Pleasants, 1995). In moist conditions spring burning may benefit fringed-orchids by reducing competition from grasses and encroaching woody vegetation, freeing nutrients trapped in dead organic matter, and increasing light penetration to the soil following litter removal (Ojima *et al.*, 1994 and references within; Pleasants, 1995); however, detailed timing of spring burns within phenological stages of fringed-orchid development likely regulates these effects. Early spring burns may benefit or have no effect on fringed-orchids (Morrison *et al.*, 2015), whereas late spring burns may irreparably damage individuals (Biederman *et al.*, 2014).

Presence and total number of flowering individuals were negatively affected by cattle grazing; however, grazing intensities were approximated and grazing history for some sites was unknown, so it is difficult to interpret our results. Limited published data exist on the effects of grazing on western prairie fringed-orchids. In a 2 y preliminary study, Sieg and King (1995) found higher numbers of fringed-orchids on seasonally grazed sites than on ungrazed sites but cautioned longer monitoring periods were required to confidently assess the effects of grazing and other land management on this species due to its erratic life cycle. Similarly, Bjugstad and Fortune (1989) found more flowering fringed-orchids on grazed sites than on control sites within a 2 y period but made no conclusions on effectiveness of grazing within this short time frame. Consistent with our results, Alexander *et al.* (2010) found grazing had a negative effect on fringed-orchid survival and seed production over a 2 y period. Bowles (1983) speculated an observed increase in flowering individuals following exclusion of grazing may indicate release from stress-induced dormancy, though this hypothesis has not been tested experimentally to include control sites. High stocking rates result in unselective heavy grazing that destroys the integrity of tallgrass prairie and increases the risk of trampling of individual plants (Howe, 1994; Alexander *et al.*, 2010). Excessive defoliation from grazing and trampling may reduce the ability of fringed-orchids to build sufficient carbohydrate reserves to survive dormancy and produce new growth the following year (Alexander *et al.*, 2010). Conversely, grazing removes grass cover and prevents heavy litter accumulation, thereby permitting the growth of forbs that would otherwise be limited by these factors (Towne *et al.*, 2005).

Grazing in our study and that of Alexander *et al.* (2010) was primarily twice-over rotational. This grazing system has been found to improve soil quality in mixed-grass prairie by stimulating ectomycorrhizal fungal activity (Manske and Caesar-TonThat, 2003). A similar association in tallgrass prairie could benefit fringed-orchids. In contrast twice-over rotational grazing supported fewer grassland obligate songbirds than light- to moderate-intensity seasonal grazing in mixed-grass prairie (Ranellucci *et al.*, 2012), which suggests this grazing regime may not be as beneficial to grassland systems as previously believed. Ideal timing, intensity, and frequency of grazing relative to fringed-orchid management will likely vary among years because timing of fringed-orchid phenological stages also varies among years as a result of environmental conditions. This makes it difficult to identify any given grazing system as beneficial or detrimental to fringed-orchids. Research on the effects of grazing systems on fringed-orchids would benefit from identifying the phenological stage of fringed-orchids at the time of grazing.

Grazing by large ungulates historically played a role in shaping tallgrass prairie and continues to maintain structural heterogeneity and biodiversity in tallgrass prairie today (Knapp *et al.*, 1999), though it is uncertain to what extent historical grazing interacted with fire and flooding to maintain integrity of tallgrass prairie at its northern limit in Canada (Henderson and Koper, 2014). Nevertheless, the western prairie fringed-orchid evolved in the presence of grazing across its historical range, suggesting grazing *per se* may not be detrimental to the species. Further research is required to determine whether altering timing, frequency, and intensity of grazing might reduce negative impacts of grazing on the western prairie fringed-orchid.

SUMMARY

Our results suggest the western prairie fringed-orchid metapopulation in Manitoba is relatively stable, with observed fluctuations in metapopulation size driven primarily by inherent population variability. Further, our results suggest fringed-orchids benefit most from a combination of warm temperatures in the previous growing season followed by cool snowy but short winters and wet springs. Periodic burning (*e.g.*, every 2–3 y) appears to benefit fringed-orchids, whereas grazing may be detrimental. Delayed effects of weather and land management practices from previous years may more strongly regulate fringed-orchid populations than current year weather and land management, and recognizing lag effects will be critical for successful management of this species.

Where suitable tallgrass prairie remains, the primary threat to the western prairie fringed-orchid is habitat degradation (Environment Canada, 2006). Exclusion by invading woody species and dominant grasses, as well as from litter accumulation, can occur in undisturbed tallgrass prairie. Prescribed burning is a viable management tool for curtailing woody invasion and both burning and grazing reduce litter and grass cover, but careful consideration of timing, frequency, and intensity of application is required so that management does not hinder fringed-orchid reproduction or reduce survival (Environment Canada, 2006), while also recognizing that management requirements may vary among years depending on weather.

This was not a controlled experiment and we recognize there were gaps in the data that may have influenced our results; however, our intent was to disclose preliminary findings from a long-term monitoring study to inform other fringed-orchid researchers and practitioners of trends observed to date in the Manitoba metapopulation. In recent years and going forward, more detailed data are being collected on the extent, timing, and ecological effects of wildfires and prescribed burns (*e.g.*, duff layer consumption, height of scorch, percent of woody species killed); and the extent, timing, and intensity (*i.e.*, stocking rate) of grazing by paddock. These data will permit more focused analyses such as detailed timing of spring burns. Long-term studies are particularly valuable for the western prairie fringed-orchid due to its erratic life cycle and fluctuating populations, which complicate studies of environmental effects on this species. Further, long-term monitoring is required to understand the effects of timing, frequency, and intensity of management on fringed-orchid populations, as well as to capture variations in weather that regulate the effects of management on this species. Long-term monitoring is also essential to identify lag effects of these variables on fringed-orchid populations, and future research on fringed-orchids should continue to explore this important concept.

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