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Linking Management Practices with Range Health in Northern Temperate Pastures

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Abstract: Little information exists on the management and range health (RH) of northern temperate pastures, where health is defined as the ability to sustain ecosystem function. We surveyed 102 pastures for RH and their associated managers during 2012-2013 across central Alberta, Canada. Pastures were generally diverse mixes of introduced grasses and contained few legumes, despite most (55%) being seeded to legumes. The majority of pastures were healthy (mean RH score = $78.8 \pm 1.3\%$), with 2.9% having scores $< 50\%$. Criteria reducing scores were noxious weeds, bare soil, and evidence of erosion. Most pastures had a reported history of cultivation (75.5%), with those previously cultivated and seeded to introduced forage having greater stocking rates [6.18 ± 0.91 animal-unit-months (AUM) ha^{-1}] compared to those lacking cultivation (2.14 ± 2.91 AUM ha^{-1}). Farms with horses or mixed livestock tended to practice year-round continuous grazing and supplemental hay feeding. Stocking rates on continuous and rotationally grazed pastures were similar regardless of grazing season (Table 3), with the highest stocking on pastures used year-round (19.54 ± 2.03 AUM ha^{-1}) or used throughout the dormant season (20.29 ± 3.10 AUM ha^{-1}). Use of management inputs were variable, with manuring and harrowing common, and fertilizing, over-seeding and aerating infrequent. Herbicide use was reported on 15.7% of pastures, despite 83.3% containing noxious weeds. Use of prescribed fire was rare, although 36.3% of pastures had evidence of fire. Industrial disturbances were reported on 48.3% of pastures. Overall, these results

indicate that these pastures experience complex management, and the limited decline in RH is due to high stocking under year-long grazing.

Keywords: cultivation history, forage seed mixes, grazing system, herbicide use, stocking rates

Introduction

The Central Parkland Natural Subregion lies at the northern extent of the North American Great Plains. This area exceeds 5 M ha in size, is historically dominated by cool-season grasses, and today is well known for being an area of diversified agriculture. Although fertile soils (e.g. Black Chernozems) have given rise to an abundance of annual cropping (Kupsch et al. 2013), the Parkland constitutes an important area of forage and livestock production in Canada (McCartney 1993). Remaining pockets of pasture are used to support small to medium sized cow/calf operations, consistent with the average Canadian cattle herd size of only 63 head (Canadian Agriculture Census 2011), a trend at least partly exacerbated by the increasing presence of hobby farmers (i.e. smaller farms managed for pleasure or supplemental income) that are geographically situated near metropolitan areas. Few native grasslands remain in the northern prairies (Gauthier and Wiken 2003), and thus, their management contributes to ongoing grassland conservation efforts, including understanding the impact of invasive species, which can include introduced forage grasses (Tannas 2011; Sinkins and Otfinowski 2012; DeKeyser et al. 2015). Alternatively, pastures are expanding on private land into the boreal forest with the increasing demand for arable land (Young et al. 2006).

Management of pastures is ultimately the result of complex sociological, economic, and ecological factors. Understanding the management regimes employed on private land are important due to their ability to impact plant community composition and productivity (Willms and Jefferson 1993), soil properties (Dormaar et al. 1997; Baron et al. 2001; Donkor et al. 2002), ecosystem functions such as nutrient cycling (Naeth et al. 1991; Baron et al. 2002), as well as range condition and health (Willms et al.

1985). While some impacts of management are likely to be acute (e.g., cultivation, fertilization, or herbicide application), chronic grazing practices can also influence pasture vegetation more subtly (e.g., type of livestock, season of grazing, grazing system), eventually leading to marked changes in soil and vegetation properties (Willms et al. 1985).

Despite the importance of management practices in regulating pasture characteristics, many previous studies have been limited to observing one or two select management treatments in controlled greenhouse or field experiments, such as mowing (Fulkerson and Michell 1987), herbicide application (Grekul and Bork 2007), fertilization (Malhi et al. 2000; Kopp et al. 2003), or stocking rate (Willms et al. 1985; Baron et al. 2001; Baron et al. 2002), occasionally in combination. While these studies are useful in linking pasture soil and vegetation responses to select management activities, they are unlikely to represent the complex array of management actions taking place on fragmented northern temperate pastures in western Canada. Few large-scale studies have been conducted examining the impact of contemporary pasture management activities, and previous surveys reporting on pasture management in western Canadian rangelands are rare (Chorney and Josephson 2000; Popp et al. 2004). As a result, further investigation is necessary to understand pasture responses in relation to the full range of pasture management actions occurring in this region.

The Alberta Rangeland Health Assessment (RHA) tool (Adams et al. 2005) was developed to help agrologists, producers, and land management specialists assess the condition of rangelands relative to various management regimes (i.e. livestock grazing, industrial disturbance, etc.). Within this assessment tool, rangeland health (RH) scores are assigned to a series of questions that reflect the maintenance of key ecosystem functions. In brief, the main criteria assessed include the presence, cover and diversity of desired plant community components (vegetative structural layers and desirable forage composition), non-desirable vegetation (abundance of noxious weeds and woody vegetation), ongoing capture and use of water (i.e., amount of litter), and the prevention of erosion (Adams et al. 2005).

In this investigation we characterize and quantify the history and management activities, as well as range health, of 102 pastures distributed across north central Alberta's Central Parkland and adjacent

boreal Mixedwood regions. The large sample size ensured pastures were representative of a wide range in pasture age and management history. We report on the history of these pastures (e.g., cultivation and other land use history, forage species seeded, fertilization, herbicide), as well as the type and number of livestock, and associated grazing systems employed. Specific objectives were to 1) identify and quantify in-person survey responses from pasture managers relative to each management regime, and 2) summarize associated rangeland health assessment data and relate this to land use and management activities.

Materials and Methods

Study sites

A total of 102 pastures were surveyed during 2012 (N=44) and 2013 (N=58) between May 24 and July 6, distributed across 4 counties (Leduc, Parkland, Strathcona, and Sturgeon County) extending 80 km from the city of Edmonton, Alberta (Fig. 1). Sampling included 50 pastures from the Central Parkland natural subregion, characterized by Black Chernozemic soils (i.e. organic matter of 4-10%) and receiving 445 mm of precipitation annually, with about 77% falling during the growing season (April through September) (Fig. 2). The remainder of pastures (n=52) were situated in the neighboring Boreal Mixedwood, where although precipitation levels were similar to the Parkland, soils were lower in organic matter, varying from Eluviated Black Chernozems to Gray Luvisols. Previously cultivated and seeded pastures within the boreal resemble parkland pastures in composition (Donkor et al. 2002).

Pastures were selected at random and separated by at least 800 m. Sampled pastures were visually identified from roadsides following a grid network. Site acquisition was further constrained by the willingness of landowners to grant permission once their land was identified as a candidate study site. Although only a small number of landowners directly refused entry at first contact (n=2), several other landowners were initially consulted to enquire about sampling and were not heard from again (approximately <10), in which case we assumed they were either too busy or unwilling to participate.

Grazing management surveys

Landowners were surveyed using an in-person interview, approved by the Research Ethics Office at the University of Alberta, and designed to identify historical and current land use practices (see Table 1 for summary). Surveys identified all key management activities that may influence plant communities and range health metrics. In brief, managers were asked about land tenure (owned vs leased pasture), how long they managed the pasture in question, and when applicable, they identified how long the land had been under their management. Operators were also asked the date of last cultivation. If land had not been cultivated, or the date of last cultivation was unknown (often the case with grazing lease holders or when the land was cultivated prior to their possession), this was noted. For those with a history of cultivation, information was collected on seeding history, including the forage species sown. Other information collected was the grazing history (typical number of animals grazed, type of herbivore, and both the timing and pattern of use such as whether animals were continuously or rotationally grazed), use of fertility amendments (inorganic fertilizer or manure), herbicide spraying, and whether the pasture had been otherwise disturbed [mowed, harrowed, aerated, burned, or if pests were present (burrowing mammals and grasshoppers), as well as subject to industrial disturbance from oil and gas, gravel removal, etc.]. Other information may have been volunteered by producers based on their familiarity with management history (i.e. organic management). A final section was allowed for 'other' comments, where unique management actions or concerns were recorded (e.g., stewardship awards, reclamation concerns, intensive rotational grazing). When participants were unclear with certain terminology or our motivation for collecting this information, these aspects were clarified.

During 2013 minor amendments were made to the survey to ask more specific questions about weed management (i.e., herbicide product, target weeds, year last treated) and determine whether livestock had been fed hay in the pasture, as well as gather information on pasture size. To determine the pasture area aerial images in conjunction with county landowner maps were used to determine the size of each pasture/grazing area and the total land area available. Holdings < 33 ha were defined as acreages and hobby farms. Other classifications included small farms (33-65 ha), medium farms were the standard

quarter-section in size and ownership of adjacent allotments was absent (65 ha), and larger farms where managers owned or rented multiple allotments (>65 ha).

Pasture health evaluation

Rangeland health assessments (RHA) were conducted on each pasture within 2 days of completing the producer survey, using the Alberta Environment and Sustainable Resource Development (now Alberta Environment and Parks) Tame Pasture Health Assessment (TPHA) form (Adams et al. 2005). Pastures within the Central Parkland are typically comprised of seeded, introduced forage species; thus, we assessed RH using the tame pasture criteria. The TPHA evaluates key properties in each pasture that directly reflect ecosystem function, including the provision of forage. The assessment uses 10 questions (Table 3) to rate the abundance of tall-statured desirable forages (including legumes) and non-desirable vegetation (weed abundance and density, together with woody encroachment), site stability and soil erosion, as well as litter abundance (a proxy for hydrologic function and nutrient cycling). The relative weighting of questions varies depending on their projected contribution to overall ecosystem function (Table 3), with changes in species composition towards weedy and undesirable plants more likely to reduce pasture health and associated utility (Adams et al. 2005). Following a thorough examination, pastures were first identified as tame (i.e. grassland dominated by introduced forage grasses) or modified-tame (i.e. more than 50% native forb and grass cover) in composition; scores were then assigned for each criterion and the total score (%) obtained. Aggregate scores over 75% were considered healthy, while those from 50-74% are healthy with problems, and those below 50% are unhealthy (Adams et al. 2005). Scoring information allows for both the diagnosis of problematic conditions, and the identification of improvements needed. During the field assessment, the top 15 cm of mineral soil was examined using soil cores to detect charcoal and therefore the presence of historical fire events.

Stocking rate determination

Information was collected during the interview to calculate stocking rates for 78.4% (n=80) of the pastures. When rotational grazing was practiced we calculated the stocking rate using the herd size and duration of grazing, either directly from information provided for the pasture size during the survey, or if not available, by assessing the total grazed area from aerial photos. Pastures rested from grazing over several years were assigned a stocking rate of 0 animal unit months (AUM) ha⁻¹. Herd sizes included the numbers of different types of livestock. As actual animal sizes were not available, we assumed animal unit equivalents (AUE) for different livestock as follows: cows and cow-calf pairs = 1.2 AUE, bulls and horses = 1.5 AUE, yearling cattle = 1 AUE, ponies = 0.6 AUE, donkeys = 0.55 AUE, sheep = 0.2 AUE, and alpaca = 0.1 AUE. Where pastures were described as grazed 'all summer', as was often the case with continuous grazing, we assumed this was equal to 5.2 months, which was the mean length of the growing season calculated based on specific dates of grazing provided by producers.

Statistical analysis

Producer management information and pasture range health data were summarized to provide a quantitative summary (i.e. frequency distribution) on the management and vegetation/soil conditions associated with all pastures. Data were pooled across years because management was not expected to change given that the surveys reflected ongoing activities of landowners. Similarly, vegetation and soil data from perennial pastures were expected to be relatively consistent during the 2 sampling years.

Information on grazing season length was obtained for pastures rotationally (n=29) and continuously (n=26) grazed during the growing season. Median grazing season length was compared using a Kruskal-Wallis test in R statistical software using the package *Agricolae* ($P < 0.05$). Stocking rate data were log transformed and tested using one-way ANOVA with type III sums of squares (SS) in R against management factors. Results are presented for least squared (LS) means and standard errors, with post-hoc Bonferroni corrected contrasts applied to the means of all significant management factors having 3 or more treatment levels.

To identify groups of producers using similar management practices, and link management information to RHA categories, we conducted a multiple correspondence analysis (MCA), which uses

Euclidean distance to partition categorical (management) data and identify patterns among management factors. This was performed in R software using the package *FactoMineR*. Management factors were plotted for the first 3 axes as they were all significant ($P = 0.01$), together with any significant management vectors ($P < 0.05$). Joint biplots are shown to visualize all possible comparisons of the three axes.

Results

Pasture management activities

For the 102 pastures surveyed, we spoke to 73 separate land managers, of which 31.5% were female. Two participants had received stewardship awards. Across all pastures surveyed, 10.8% were on crown land belonging to the county or province, with the balance (89.2%) privately owned. On privately owned land, 7.7% of pastures were rented to others. With the study area's proximity to the city of Edmonton, 7.8% of pastures were on acreages and small hobby farms (<33 ha), with an additional 2 pastures on land units less than this size but rented by larger cattle operations. More than half (53.9%) of pastures were on landholdings exceeding 65 ha.

Most pastures were identified as tame (88.2%, $n=90$), while modified-tame vegetation accounted for the remaining 11.8%. Overall, 7.8% of pastures had never been cultivated, while 75.5% had been cultivated (Fig. 3). Based on producer responses to land tenure ($n=74$), the average age of pastures since last known cultivation was 20.4 years, excluding pastures with unknown histories, as well as pastures never broken (Fig. 3). For privately owned pastures ($n=85$), participants reported that land had been in their families' possession for an average of 39.5 years.

For pastures with a known seeding history ($n= 65$ or 63.7%), managers provided detailed seed mixtures for 40.2% of pastures, and included a description of plant species with at least one species to the genus level (Fig. 4). Remaining pastures had seed mixes described as either a grass mixture (9.8%), legumes and grasses (5.9%), a grass mix specifying no legumes (2.0%), a pasture or forage mixture (5.9%), with the remainder unknown (27.5%). Additionally, 8.8% were reported as 'never seeded', and

one manager indicated ‘natural recovery’ of forage from the seed bank. Among pastures known to be seeded, 54.4% (n= 35) included legumes at seeding (Fig. 4), which increased to 66.2% (n= 43) if generic forage mixtures at seeding were assumed to contain legume. The most common grasses seeded were bromes (*Bromus* spp.; 30.7%), timothy (*Phleum pratense* L., 20.0%), and orchard grass (*Dactylis glomerata* L., 13.8%), while the most common legumes were alfalfa (*Medicago sativa* L., 27.7%) and clovers (*Trifolium* spp., 23.1%). A few producers (4.6%, n= 3 of 65) were unable to recall the individual species seeded.

Most pastures were grazed solely by cattle (67.6% by cow/calves and 5.9% by yearlings) or equids (14.8%), with only a handful abandoned (3.9%). Mixed grazing by cattle and horses occurred in 5.9% of pastures. Alternative livestock (e.g. sheep and alpacas) were rare (3.9%). In assigning pastures to different grazing systems, rotational systems were the most common (56.9%), followed by continuous grazing (39.2%). Rotational systems were diverse, and many pasture managers reported adaptive practices (i.e. allowing pastures to ‘green up’ before grazing, flexible rest periods, etc.), with systems typically described as simple-rotational systems. Pastures rotated over the growing season included an average grazing season length of 4.9 ± 0.2 months (Median=5, Mode=5; n=29). For those reporting the use of rest-rotational grazing, rest periods between grazing events averaged 4.8 weeks (Median=4; Mode=3; n=32), while other pastures were grazed once and allowed the remainder of the growing season to recover with a mean grazing period of 1.9 months (Median= 1.5; Mode= 1; n= 13). High intensity - low frequency (HILF) rotational grazing (5.5%; n= 6) and temporary cross fencing (5.5%; n= 6) were also utilized within rotational systems.

Continuous systems were defined by pasture exposure to livestock throughout the growing season; in some cases animals remained in pastures all year (20.0%; n= 8 of 40). The average duration of grazing in continuously grazed pastures over the growing season was 5.2 ± 0.2 months (Median= 5, Mode= 5; n= 26), the remainder defined their grazing period as ‘all summer’ (18.8%; n= 32). For pastures grazed continuously over the growing season, the median grazing season did not differ from pastures grazed rotationally over the same period ($X^2 = 1.26$, $P = 0.26$). The expanded survey of producers in 2013

revealed that 27.6% ($n=16$ of 58) of pastures were subject to hay feeding, and generally coincided with very high stocking rates ($P = 0.003$; Table 2).

Stocking rates did not differ between rotational and continuously grazed pastures ($P = 0.26$), however stocking densities were higher in rotated pastures (2.56 ± 0.30 AU ha⁻¹) than continuous pasture (1.11 ± 0.34 AU ha⁻¹) ($P = 0.001$). Pastures used year-round had stocking rates roughly four-fold greater than pastures grazed only during the growing season (Table 2). Stocking rates were also 188% greater on pastures with known previous cultivation ($P < 0.001$), nearly two-fold greater on areas receiving manure application ($P = 0.03$), and nearly three-fold greater in pastures where hay was fed (Table 2). Finally, stocking rates were several fold greater ($P = 0.07$) in pastures owned rather than rented.

Producers indicated that herbicide had been sprayed previously on 15.7% of pastures ($N= 16$). The product used and target weed(s) were also recorded during the 2013 survey. Products with a group 4 mode of action (synthetic auxins) were most common. Overall, 83.3% of pastures surveyed contained noxious and prohibited noxious weeds, with Canada thistle (*Cirsium arvense* L. Scop) the most common (77.5% of pastures; $n=79$), and was the primary target for herbicide use (Fig. 5). Other forms of weed control included hand-pulling and mechanical cutting, sometimes to augment chemical control. Rarely was herbicide used to target nuisance weeds like dandelion (*Taraxacum officinale* F.H. Wigg) and western snowberry (*Symphoricarpos occidentalis* Hook). In Alberta, the *Weed Control Act* (Province of Alberta 2010) is enforced by municipalities, and while not asked directly, two managers indicated that the county had sprayed their pasture for noxious weeds.

Fertilizer was applied to 8.8% of pastures ($N= 9$) in our study area, though few producers recalled the composition or application rate, and is therefore not reported further. Among those applying fertilizer, more pastures were treated in spring (55.6%) than fall (44.4%). Notably, manure spreading was more common than fertilization, affecting 24.5% of pastures, even though this information was not requested in the 2012 survey (i.e. this constituted voluntary information). Harrowing was often used for the spreading of manure, being reported in 33.3% of pastures. Mowing or swathing was reported in 8.8% of pastures, while aeration was used infrequently (3.9%). Additional information volunteered from producers

identified 2.0% of pastures as using 'organic' management. Single occurrences occurred of drilling mud application, mulch spreading, and poultry manure application.

Fire was reported to have occurred in 14.7% of pastures by respondents, with 6.9% being wild (i.e. accidental) and 7.8% prescribed. When evidence of charcoal in the top soil was combined with pastures identified in the survey as known to have been burned, 36.3% of all pastures showed evidence of fire impacts.

Burrowing mammals like pocket gophers (*Thomomys talpoides*), Richardson's ground squirrels (*Urocyon richardsonii*), Franklin's ground squirrels (*Spermophilus franklinii*), and North American badgers (*Taxidea taxus*) were perceived as pests by 58.8% of respondents. Grasshoppers were not perceived as a pest in recent years, with some producers referring to a drought in the early 2000s (presumably 2002, as per Bonsal and Regier 2007) leading to problematic grasshoppers.

During 2013, 48.3% of participants reported industrial disturbances. Access roads and railways were reported in 12.1%, while oil and gas disturbance (indicated by the presence of pipelines) were present in 39.7%, with 29.3% containing wells and 3.4% pump jacks. Gravel pits were less common (5.2%). Of the 42 respondents in the 2013 sample group, 7.1% of participants reported ongoing 'disagreements' over resource extraction and 4.8% were concerned about agricultural land being subdivided into small acreages.

Rangeland health summary

Field assessments revealed that 65.7% of pastures received a score of healthy (RHA score $\geq 75\%$), 3.9% were unhealthy (RHA score $\leq 50\%$), and the remaining 30.4% were healthy with problems (values between healthy and unhealthy), with the average RHA score being 79.8% (± 1.3 SE; $n=102$). Most pastures (64.7%) had high forage cover (i.e. relative cover $>90\%$ for tame pastures, or $>75\%$ for modified-tame pastures; Table 3), with limited cover of non-forage species like native forbs, or nuisance and noxious weeds. The cover and density of noxious weeds, worth 10% of the total RHA score, impacted scores in most pastures (83.3%). While noxious weed cover never exceeded 15%, noxious weed

density was scored as a 'heavy infestation' in 32.4% of pastures. Most pastures (71.6%) lacked sufficient woody cover (relative cover <5%) or density to affect the RHA score.

Scores for hydraulic function and litter abundance accounted for 25% of the final RHA score, with reduced scores evident in 55.9% of all pastures (Table 3). While indicators of erosion risk (i.e., hoof sheer, wallowing, flow patterns, etc.) were present in 54.9% of pastures, no evidence of macro-erosion (e.g., soil movement off-site, large water flow patterns, exposed plant roots) was found. Human-influenced bare soil exceeding 5% was found in 21.5% of pastures.

Management regimes

Multiple correspondence analysis revealed that pastures lacking grazing in recent years had similar management regimes (Fig. 6), and were negatively associated with the first axis (MCA1), explaining 14.4% of variance among pastures (Table 4). Along the second axis (MCA2), which explained 9.1% of variance, there was substantial divergence between the timing of grazing and grazing system used, as well as in the type of herbivore grazed. The third axis (MCA3), which explained 7.9% of variance, exhibited stronger divergence of secondary management inputs such as harrowing, feeding hay, manuring, or mowing, than the two previous axes (Table 4). Pastures that were mowed, grazed in winter or aerated, tended to group together (Fig. 6). County and provincial grazing reserve lands were usually rotationally grazed, and clustered next to rotationally grazed private land. Rotational grazing was also associated with larger farms (>65 ha) with cattle grazing exclusively live biomass (i.e. no supplemental feeding with hay), while continuous grazing, often by horses, was associated with small land holdings.

Documented management actions of producers were highly variable, with several distinct management regimes evident. For example, when livestock were absent, other management actions (i.e. mowing, herbicide, fertilization, etc.) were not undertaken. Small land holdings, which we defined as <33 ha, were often associated with continuous year-round use by horses, and supplemental feed was often provided. This grouping describes small hobby farmers and acreage owners housing companion animals. In contrast, larger farms (>65 ha) were associated with rotational cattle grazing during the growing

season, with the absence of supplemental feeding on pasture. Harrowing and manure spreading were closely correlated, presumably because harrowing is used to spread manure, particularly in pastures where animals were fed hay. When pastures were grazed only over the winter, there was a tendency for these pastures to be aerated and windrowed during the growing season, suggesting landowners may be using this strategy to sustain livestock throughout the year. Continuous grazing was often associated with mixed herds of livestock, horses and cattle, and could represent hobby farmers housing companion animals with their beef cattle.

Discussion

Our findings indicate these northern temperate tame pastures in central Alberta are generally in good range health, and are dominated by competitive introduced forage plants (grasses and legumes). However, issues were noted associated with increased bare soil and noxious weeds, which lowered RHA scores. The majority of pastures (64.7%) received the highest scores possible for forage cover, which exceeded 90% in tame pastures and 75% in modified-tame pasture. Reductions in range health were tied to modest reductions in forage cover, and more importantly, increases in bare soil and noxious weeds. The latter two observations could reflect excessive disturbance regimes, particularly under early spring grazing, excessive year-round stocking rates, and an insufficient recovery time between grazing events, as well as the application of manure (and its constituent weed seeds).

Previous cultivation and subsequent seeding of forages was common in these pastures. As the study area is heavily populated, being situated near a metropolitan area, it is not surprising that relatively few native grasslands remain (Williams et al. 2005), and persist primarily in the form of modified-tame pastures where they co-exist with introduced forages (Wittig et al. 2010). During homesteading settlers were mandated under the *Dominion Lands Act* (Bailey et al. 2010) to convert land into crop production to retain ownership. Land conversion into tame pasture may also represent a strategy to deal with the ongoing threat of encroachment by woody species like aspen (*Populus tremuloides* Michx), which is common in other regions of the Parkland following fire suppression (Bailey and Wroe 1974; Sheffler

1976). Together, the extensive history of cropping and concentrated settlement may have contributed to the dominance of tame pasture.

In 2003, Alberta retained the most grassland among all Canadian prairie provinces, at 43.1% (Gauthier and Wiken 2003), though only 12.0% of Alberta's Parkland remained as grassland, and this included tame pasture. We found only 11.8% of individual pastures examined had substantial representation of native vegetation, some of which had a reported history of previous cultivation. Conversion of grassland into alternative land uses continues in this region, with the Plowprint Report by the World Wildlife Fund [WWF] (2016) reporting grassland loss at 6.95, 3.08 and 3.63% during 2011-2012 (the year before the study), 2012-2013, and 2013-2014, respectively, within the "Prairie Habitat Joint Venture" region that encompasses the Canadian prairies. Newly converted acres were most commonly planted to alfalfa (19.9%), followed by wheat (19.0%) and canola (12.6%) (WWF 2016).

Our assessment suggests remaining pastures in this region exist due to an ongoing need for forage resources to support livestock on both mixed farms (which generally include cattle), or companion animals in small hobby farms (e.g. horses) within this highly settled, mostly privately-owned landscape. As a result, this suburban agricultural landscape is likely to contain at least some areas of pasture, often on poorer quality soils that are less suited for annual cropping (Samson and Knopf 1994). Alternatively, producers may rotate annual cropland with perennial forages to maintain forage supply, thereby accounting for the wide range of pasture ages encountered. In a survey by Entz et al. (1995), Canadian prairie farmers reported widespread benefits from including perennial forages in their crop rotation such as weed control and increased yield. Our pasture ages exceeded those reported by Entz et al. (1995) for forage stands (3 to 5 years) in Manitoba, and southern Saskatchewan (6-9 years), with reductions in forage yield and damage from burrowing pocket gophers being primary motives for cultivation. Periodic ploughing and reseedling can rejuvenate pastures (Levassor et al. 1990; Torell et al. 1991), particularly tame pastures and hayfields that decline in yield over time (Lardner et al. 2000).

Grazing management can vary in complexity, with certain systems requiring high inputs (i.e. infrastructure, labor, capital), such as required under rotational grazing. The majority of pasture managers

surveyed here utilized rotational grazing, with several using more sophisticated rotational practices. Considerable debate has occurred over whether, when and how continuous and rotational grazing may impact plant production and range condition (Briske et al. 2008; Teague et al. 2013). In our study, while stocking rates were similar between continuous and rotational pastures, continuous pastures were more likely to be associated with lower range health scores, including increased bare soil and weed cover, consistent with recent studies implicating frequent and intense defoliation in reducing Parkland pasture condition and production (Bork and De Bruijn 2006; De Bruijn et al. 2010). The frequency of rotational grazing found here among pastures (57%) was below that documented in a survey of cow/calf producers (78.7%) across the Canadian prairies (Chorney and Josephson 2000). This pattern may reflect the proximity of the current study area to a major urban center and the abundance of small farms. The latter may lack the expertise and urgency to implement rotational grazing, which has been reported to increase net farm income (Chorney and Josephson 2000).

Parkland grasslands are generally productive, resulting from a favorable moisture and nutrient regime (Kupsch et al. 2013). Ecologically sustainable stocking rates (ESSR) recommended for grass-dominated tame pastures (i.e., those containing Kentucky bluegrass, smooth brome or timothy) in this region are 0.74 to 1.75 AUM ha⁻¹, and 2.50 AUM ha⁻¹ for pastures that include alfalfa (Kupsch et al. 2013). In the current study, stocking levels under both continuous and rotational grazing typically exceeded the ESSR by more than two to three-fold, and in the case of year round grazing, by as much as eight-fold, necessitating supplemental feeding for much of the year. Notably, pastures that were never cultivated had the lowest stocking rates, either indicative of lower forage yields with the lack of improved forage cultivars, or these producers may have simply avoided the management practices needed to increase forage production.

In the most recent farm census (Agriculture Canada 2014) detailed information was reported on the area of land (and in some cases, the application rate) treated with manure, fertilizers, fungicides, and herbicides, although cropland and pastureland were not differentiated. The current study surprisingly revealed that manure application was a more prevalent soil amendment than fertilizer on Parkland

pastures, despite the fact that macronutrients, particularly soil nitrogen, are known to constrain plant growth in forage lands of the region (Lardner et al. 2000; Malhi et al. 2000). Chorney and Josephson (2000) found that 50% of producers fertilized their pasture, which was considerably greater than our results. Instead, the prevalence of manure application in our study may reflect the need of small operators to dispose of manure accumulated during overwinter feeding, particularly where the latter did not occur on open pasture. We also found that pastures treated with manure were grazed at high stocking rates, suggesting these managers may have had limited alternative land area to accommodate grazing, and were exploiting the adding forage production obtained from manure addition.

It was rare for farms to be certified organic (or in transition), with 2.0% of pastures, and 2.7% of land managers, so declared. These values closely resemble the 0.8% of Alberta farms and 2.0% nation-wide reporting this system of production (Statistics Canada 2011). It should be noted that our pasture managers indicated ‘organic management’ only when prompted by the questioning of herbicide use, and we did not inquire if they were certified organic operations.

Noxious weeds were present in a relatively high proportion of pastures (83.3%), with Canada thistle the most ubiquitous, yet herbicide use was only reported in 15.7% of pastures. Moore (1975) described Canada thistle as a naturalized weed of the Canadian Prairie Provinces, finding it in 40.7% of surveyed areas in Alberta and Saskatchewan. Our frequency of Canada thistle occurrence was much greater at 77.5%. None of the pastures surveyed had absolute noxious weed cover exceeding 15%, which would have resulted in the lowest possible range health score. Trace noxious weed cover (< 1%) was most common, representing 66.7% of pastures surveyed. Our frequency of herbicide use across all pastures was below that reported by Chorney and Josephson (2000), who found greater rates of chemical control for weeds and brush, at 45.1% of producers. A handful of prohibited noxious weeds were present, with single occurrences of field scabious (*Knautia arvensis* (L.) J.M. Coult), knapweed (*Centaurea* spp.), and orange hawkweed (*Hieracium aurantiacum* L.). The efficacy of the *Weed Control Act* in educating and motivating people to control problematic weeds has not been assessed formally in Alberta on a provincial or municipal level despite the important role it plays in reducing deleterious plant species. A case study in

Australia found that landowners were more likely to control a weed due to its regulated status, but compliance from neighbors and the abundance of the weed on their own property also contributed to their willingness to achieve control (Reeve et al. 2015).

Among other disturbances, not surprisingly most producers reported a prevalence of pests, particularly ground squirrels and pocket gophers, and which are often targeted for pest control through poisoning, trapping, or other means. Ground squirrels and pocket gophers are known to lead to forage losses and damage the soil surface (Entz et al. 1995; Carlson and Crist 1999). Carlson and Crist (1999) found that pocket gopher mounds could occupy 1 to 6% of pasture area, and mounds were more abundant in lightly grazed pastures. In addition, the perceived fear of livestock injury from burrows caused by larger animals like badgers (Minta and Marsh 1988) can motivate control of burrowing mammals.

Industrial infrastructure was common in Parkland pastures, and included gravel pits, energy extraction, and associated transportation corridors. These features reflect the high population density in the region, including the abundance of oil and gas, both of which contribute to the fragmentation of remaining pastures, including the ongoing loss of native grassland (Nasen et al. 2011). In central Alberta's Parkland, plains rough fescue (*Festuca hallii* (Vasey) Piper) seldom re-establishes following industrial disturbance (Desserud and Naeth 2013). Industrial activities create disturbed edges that increase bare soil (Elsinger 2009) and facilitate exotic species (Desserud and Naeth 2013; Allred et al. 2015), which collectively can reduce range health scores, including within more than a third of the current pastures examined here. Despite this, findings of the RHA in general indicated that most pastures were relatively healthy and productive as tame pastures.

Our results also revealed a significant past occurrence of fire across the study area. Historically, fire was a common disturbance among grasslands in the northern Great Plains prior to European settlement (Archibold et al. 2003), with a fire return interval of every 10-15 years (Wright and Bailey 1982). In the Parkland, fire is also a common tool to assist in land clearing. Select public lands were noted in the surveys to use prescribed fire to control woody plants and improve grazing capacity. Even when fire was reported during management surveys, assessed pastures often lacked visual indicators of fire. Pastures

that retained charred woody debris in the top 15 cm of mineral soil were likely subject to fire historically (Ponomarenko and Anderson 2001), and may reflect large-scale fire events such as that in 1895, when fire ravaged much of the area east of Edmonton and throughout the Beaver Hills (Kjorlien 1977). Given the known historical importance of fire, it is perhaps surprising that less than half of the pastures examined had evidence of fire.

We have reported on the management actions within pastures across a sizeable portion of Alberta's Parkland and Boreal Mixedwood transition. It is important to note that there are sociological and economic factors not measured that likely influence pasture management. Close proximity to the city of Edmonton influences the price of land, which could influence the size of farms, and therefore management decisions. For example, small farms, particularly hobby farms and acreages, are more likely to employ continuous grazing due to a small grazeable area. A survey by Kachergis et al. (2013) found that Wyoming ranchers gained 97% of their knowledge on grazing management from other ranchers despite a preference to acquire information through published sources. In peri-urban areas, the loss and subdivision of arable land and heritage farms to urban sprawl and development affects the persistence of agriculture, including cattle operations. This fragmentation also coincides with an increase in small livestock operations, which are more likely to have off-farm income (Rowan 1994; Sayre 2004; Cialdella et al. 2009). Notably, concerns of subdivision and annexation were raised during our surveys, and a handful of land owners volunteered that they were new to the rural lifestyle.

At the time of sampling we considered individual pastures as the experimental unit, and therefore our survey was not designed to obtain personal information from responders. Despite this, 31.5% of participants to our survey were female, which closely resembles the Statistics Canada (2011) finding that 29.0% of farm operators in Alberta are female. Statistics Canada (2011) reported that 52.0% of Alberta farm operators had off-farm businesses or income, and 32.8% of younger operators (<35 years) worked off-farm more than 40 hours a week (the highest out of all demographic groups). Being situated so close to Edmonton, it is also possible that our study pastures were more strongly influenced by landowners having multiple occupations, which in turn, could have altered management activity.

Finally, future studies linking producer management to effects on pasture communities and ecosystem function should inquire about management goals and producer motivations, so that better links can be drawn between producer actions and socio-economic variables, education, and attitude (Sayre 2004; Kachergis et al. 2013). Expanding questions to ask pasture managers about a process (i.e. how do you manage undesirable plants?), instead of directly asking if they have specifically performed an action (i.e. have you sprayed herbicide?) may yield more insight about management.

Conclusion

Pasture managers were found to practice a wide range of activities in the Parkland, which in turn, were reflected in range health scores. Producer behavior was distinguished based on factors such as management intensity, including whether they practice rotational grazing, use inputs like fertilizer or herbicides, or practice year-long grazing and conduct on-pasture supplemental feeding. The latter two factors in particular were associated with increased stocking rates. Tame pasture health scores also reflected these activities, as while most were found to be healthy, nearly one-third of pastures were classed as healthy with problems, largely reflecting increases in bare soil, a moderate reduction in the cover of productive forages, and increases in noxious weeds. This information provides clarity on the management activities taking place in northern temperate pastures, their ultimate impacts on range health, and provides insight into the actions necessary to sustain these pastures.

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List of Figure Captions

Fig. 1. Distribution of 102 pastures sampled across north-central Alberta to assess pasture health and management practices. Lower map indicates the province of Alberta's natural subregions, and sampling locations. Upper map identifies the Edmonton, Alberta, metropolitan area with cities, towns, and counties outlined. Sampled pastures (black circles) are located within the Parkland, Sturgeon, Strathcona, and Leduc Counties, with 6 pastures situated in the Blackfoot grazing reserve. Maps are adapted from the Natural Regions Committee of Alberta (2006).

Fig. 2. Monthly precipitation (mm) at the University of Alberta Edmonton Research Station in Edmonton, Alberta during 2012 and 2013 (Alberta Agriculture and Forestry, 2016).

Fig. 3. Frequency distribution of the number of years pastures had been farmed by the current family or land manager, and the number of years since the last date of known cultivation.

Fig. 4. Summary of seeding history for pastures following cultivation where producers were able to recall or estimate the seed mixture (N=65/102). ‘Grasses’, ‘legumes’, and ‘forage mixture’ were generic descriptions of species provided by managers. Totals of similar genera were also grouped together (i.e. for each of brome, clover, and fescue).

Fig. 5. Frequency of noxious weeds detected during RHAs (grey) and the proportion of pastures where specific noxious weeds were targeted for removal with herbicide (black) by the manager in the last 3 years. Note that field scabious (*Knautia arvensis*), orange hawkweed (*Hieracium aurantiacum*), and spotted knapweed (*Centaurea maculosa*) are prohibited noxious and require control measures.

Fig. 6. Multiple Correspondence Analysis (MCA) ordination joint biplots displaying categorical data representing current pasture management practices (distance=Eigen, dimensions=3). The first 3 axes describe 31.4 % of variation in management. Long-term historical management actions (i.e. fire and cultivation) were excluded, as they were non-significant responses ($P < 0.01$). Management practices are defined in Table 1. SR = livestock stocking rate; RHA = range health assessment scores.

Table 1. Summary of management practices assessed in the survey of 102 north-central Alberta pastures, during 2012 -2013.

Management Practice	Treatment Level	Description
Ownership	Owned	Pasture is deeded land
	Rented	Pasture is leased
Cultivation	Cultivated	Occupant was able to provide cultivation history
	Never Cultivated	Occupant is familiar with long-term pasture history
	Unknown	
Grazing System	Abandoned (None)	No livestock in the area for the last 3 years
	Continuous	Livestock have constant access to the pasture
	Rotational	Livestock are moved among pastures
Timing of Grazing	All Year	Livestock are present for 12 months
	Growing Season	Livestock present during summer (e.g. May-Oct.)
	Winter	Livestock are present between October and May
System x Timing	All Year (Continuous)	Grazing for 12 months of the year
	Growing Season (Continuous)	Continuous grazing in summer
	Growing Season (Rotational)	Intermittent grazing events in summer
	Winter (Rotational)	Grazing limited to periods after October
Herbicide	Herbicide	Pasture with known herbicide application
	Not Sprayed	
Fertilized	Fertilized	Pasture with known fertilizer application
	Not Fertilized	
Manure Spreading	Manured	Pasture with known manure spreading
	Not Manured	
Harrowed	Harrowed	Pasture with known harrowing
	Not Harrowed	
Aerated	Aerated	Pasture with known aeration
	Not Aerated	
Swathed or Mowed	Swath-Mow	Pasture with known mowing or swathing
	No Swath-Mow	
Fed Hay in Pasture	Hay	Pastures with known hay feeding
	No Hay	
Burrowing Mammals	Present	Reported infestation of moles or ground squirrels
	Absent	
Fire (Survey)	Present	Evidence of fire based on producer survey
	Absent	
Fire (Charcoal in Soil)	Present	Evidence of fire based on charcoal in the soil
	Absent	

Table 2. Summary of mean ($\pm$ SE) calculated stocking rates associated with various pasture management factors. All analyses were one-way ANOVA except grazing system and timing, which were assessed together due to a high potential for interactions.

Management Factor (ANOVA F and <i>P</i> - values)	Treatment Level	Stocking Rate ^a (AUM ha ⁻¹)
Ownership (<i>F</i> = 3.48; <i>P</i> = 0.07)	Owned	7.00 ($\pm$ 0.86)
	Rented	2.85 ($\pm$ 2.58)
Cultivation (<i>F</i> = 5.55; <i>P</i> = 0.006)	Previously Cultivated	6.18 ($\pm$ 0.91) a
	Never Cultivated	2.14 ($\pm$ 2.91) b
Timing of Grazing (<i>F</i> = 17.1; <i>P</i> < 0.001)	All Year	19.54 ($\pm$ 2.07) a
	Growing Season	4.98 ($\pm$ 0.67) b
	Winter	20.29 ($\pm$ 3.16) a
System x Timing (<i>F</i> = 11.3, <i>P</i> < 0.001)	All Year (Continuous)	19.54 ($\pm$ 2.09) a
	Growing Season (Continuous)	4.86 ($\pm$ 1.06) b
	Growing Season (Rotational)	5.08 ($\pm$ 0.88) b
	Winter (Rotational)	20.29 ($\pm$ 3.19) a
Herbivore Type(s) (<i>F</i> = 2.22; <i>P</i> = 0.09)	Cattle	5.67 ($\pm$ 0.90)
	Horses	13.65 ($\pm$ 2.30)
	Multiple Species	8.93 ($\pm$ 3.45)
	Other Livestock	8.41 ($\pm$ 3.45)
Manure Spreading (<i>F</i> = 5.17; <i>P</i> = 0.03)	Manured	10.05 ($\pm$ 1.59) a
	Not Manured	5.43 ($\pm$ 0.92) b
Fed Hay on Pasture (<i>F</i> = 9.57; <i>P</i> = 0.003)	With Feeding	14.75 ($\pm$ 1.90) a
	Without Feeding	5.05 ($\pm$ 1.07) b

Note: Only those factors with ANOVA main effects with *P* < 0.10 are shown.

^a Within a factor, stocking rate means from different treatments with different letters differ at *P* < 0.05.

Table 3. Summary of mean scores from the rangeland health assessments conducted on 102 pastures distributed across north-central Alberta during 2012-2013. Full details on the range health assessment used can be found in Adams et al. (2009). Also shown are the proportion of tame (n=90) and modified-tame (n=12) pastures falling in the maximum and minimum scoring categories within a criteria.

Abbreviated Range Health Question	Range of Scores (min-max)	Mean Pasture Score ($\pm$ SD)	% of Pastures with Max Score	% of Pastures with Min Score
1A. Forage cover in tame pasture	5-12	10.9 ($\pm$ 2.0)	73.3	7.7
1B. Forage cover in modified tame pasture	0-9	8.0 ($\pm$ 1.8)	75.0	0
2.1. Forage species shifts	0-14	12.6 ($\pm$ 3.2)	81.4	2.0
2.2. Weed distribution	0-14	13.3 ($\pm$ 2.1)	90.2	0
3. Hydrologic function and nutrient cycling	0-25	17.5 ($\pm$ 7.7)	44.1	3.9
4.1. Evidence of soil erosion	0-10	7.9 ($\pm$ 2.1)	45.1	0
4.2. Area of bare soil (adjusted for region)	0-5	4.4 ($\pm$ 1.3)	78.4	4.9
5.1. Noxious weed cover	0-5	3.0 ($\pm$ 1.2)	16.7	0
5.2. Noxious weed density	0-5	2.0 ($\pm$ 1.8)	16.7	32.4
6.1. Woody species regrowth	0-6	5.6 ($\pm$ 1.0)	86.3	0
6.2. Woody plant density distribution	0-4	3.0 ($\pm$ 1.6)	71.6	20.6
Max/mean score (tame pastures)	100	80.5 ($\pm$ 13.3)		
Max/mean score (modified tame pasture)	97	74.9 ($\pm$ 14.3)		

Note: Tame pastures had a known history of cultivation and seeding, while modified-tame were not seeded and therefore contained of a mix of native and naturalized tame species.

Table 4. Goodness-of-fit and associated significance of various management factors with the MCA axes depicted in Fig. 6.

Management	MCA axis 1		MCA axis 2		MCA axis 3	
	r^2	P -value	r^2	P -value	r^2	P -value
Aeration			0.08	0.005	0.33	<0.001
Burrowing Mammals			0.05	0.029		
Fertilizer						
Grazing System	0.93	<0.001	0.36	<0.001		
Harrowing	0.06	0.012			0.25	<0.001
Hay Feeding	0.07	0.022	0.16	<0.001	0.21	<0.001
Herbicide						
Herbivores	0.93	<0.001	0.52	<0.001		
Land Type	0.52	<0.001	0.36	<0.001	0.23	<0.001
Manure	0.05	0.026			0.15	<0.001
Mowing/Swathing			0.05	0.022	0.41	<0.001
Ownership						
Timing of Grazing	0.93	<0.001	0.64	<0.001	0.23	<0.001

Note: Only significant factors ($P < 0.05$) are listed.

194x135mm (300 x 300 DPI)

85x49mm (300 x 300 DPI)

86x59mm (300 x 300 DPI)

168x208mm (300 x 300 DPI)

96x83mm (300 x 300 DPI)

668x592mm (96 x 96 DPI)

750x377mm (96 x 96 DPI)