Chapter 3

Adult odonates as bioindicators of cattle grazing and vegetation community at prairie wetlands

3.1 Introduction

The extensive use of wetlands as a grazing resource has persisted with little attention to the ramifications of grazing to riparian invertebrates. Agriculture dominates the Alberta prairie landscape and grazing is more common than cultivation in dry regions such as the dry mixed-grass prairie. Rotational grazing is the conventional management system and involves moving herds of cattle between a series of pastures throughout the summer. The uncommon alternative is grazing a single pasture all summer long at a lower stocking rate to ensure sufficient forage. Ungrazed (idle) wetlands are very rare in the modern prairie landscape.

Cattle in the study area (and throughout southern Alberta) have unrestricted access to wetlands occurring in pastures. On the dry mixed-grass prairie, cattle target their grazing efforts on the lush oasis of wetland vegetation and spend 5-20 times more time grazing riparian areas, lingering in the water to drink and graze submergent and emergent vegetation (Fitch & Adams 1998; Figure 3-1).

Figure 3-1: Cattle focussing grazing efforts on lush wetland vegetation.


C. Rice


C. Rice

Vegetation is integral to basic wetland functions such as filtering and slowing run-off, buffering potentially polluting nutrients, and increasing overall wetland productivity (Mitsch & Gosselink 1993). Basic ecosystem attributes affected by cattle grazing include: changed plant species composition (i.e. decreased richness, and vegetation density); disrupted ecosystem function (i.e. nutrient cycling, succession); and changed ecosystem structure (i.e. vegetation height, soil erosion) (Fleischner 1994). This study addresses the influence of cattle grazing on the composition and structure of prairie wetland vegetation and the subsequent ecological impacts on the adult odonate (Order Odonata) fauna.

Vegetation provides critical habitat for odonates during the aquatic (larval), terrestrial (adult), and emergence phases of their life cycle. Riparian vegetation provides adult odonates with perch platforms, cover from predators, habitat cues for oviposition sites, and refugia from wind, which may be particularly important in windy locations such as the prairies of Alberta (Stewart & Samways 1998, Corbet 1999). Aquatic macrophytes reduce the risk of predation to larval odonates and decrease detection by potential predators, while emergent vegetation provides a platform for odonate emergence (Corbet 1999).

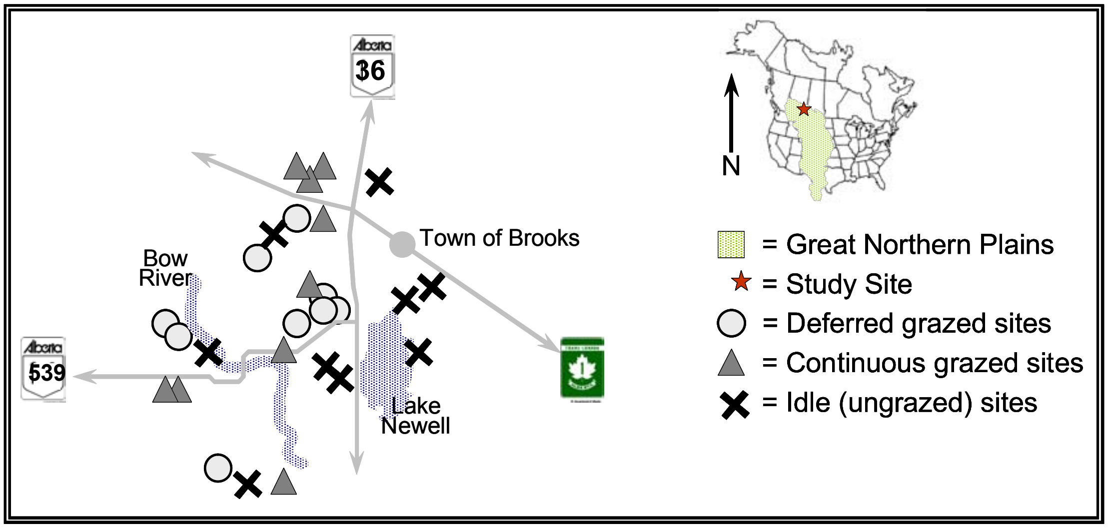
3.2 Objective

This research investigates the impact of three cattle grazing regimes on the vegetation communities of prairie wetlands, and the subsequent ecological impacts on the adult odonate (Order Odonata) fauna.

3.3 Study Area

Study sites are located within an 1800 km^2 area of the dry mixed-grass prairie of south-eastern Alberta, Canada (50º 30’ N, 111º 55’ W) (Figure 3-2). Agriculture (i.e. cropland, irrigation infrastructure, beef cattle grazing) and oil and gas extraction are the main contemporary sources of disturbance within the study area. Free-roaming bison herds and wildfires were past sources of landscape disturbance, but these have been eliminated as 94% of Alberta’s native grasslands have been converted to cropland (Environment Canada 2002). The dry mixed-grass prairie still supports substantial tracts of grazing land since precipitation is insufficient for dependable cropping regimes.

Figure 3-2: Study area location.



Moisture deficits are typical in this dry and windy eco-region, particularly at the end of summer (i.e. 250mm mean annual precipitation; 19 km/h mean annual wind speed) (Environment Canada 2002). Prairie wetlands are highly variable and many dry up by the end of summer. Inter-annual variation is great also and follows a 5-20 year drought cycle (van der Valk & Davis 1978). The wetlands in this study however are intensively managed and are not typical ephemeral potholes. Wetlands are managed to serve as irrigation basins or waterfowl/shorebird habitat by the Eastern Irrigation District (EID) and Ducks Unlimited Canada (DUC). Water levels are intensively managed and kept unnaturally high and stable (i.e. wet all season). A consequence of decreased hydrologic variation has been a change in the typical vegetation community of these sites from a Class I/II/III (i.e. ephemeral, temporary, and seasonal ponds) to Class IV/V (i.e. semi-permanent and permanent ponds), and a subsequent increase in vegetation diversity (Stewart and Kantrud 1971).

3.4 Methods

3.4.1 Experimental Design

Wetlands were selected based on five criteria: grazing regime during the previous five years, basin characteristics (i.e. size, source, and degree of isolation represented at least once in each treatment), surrounding landscape (i.e. grasslands only, no croplands), wetland class (i.e. Stewart and Kantrud (1971) Class IV or V), and access permission.

Manipulating pasture sizes and stocking rates for the sake of this project was logistically infeasible. Continuous and rotational grazing are the two predominant grazing strategies employed within the study area. Continuous grazing regimes keep cattle in one pasture all season (i.e. May to August) and consequently involve small herds of cattle on small sections of private land. More commonly, rotational grazing merges many herds to form a single ‘super herd’ managed by a local grazing association. To ensure pasture re-growth and a constant supply of forage, cattle are directed through a series of pastures beginning with early-germinating tame pastures (i.e. exotic species) and ending on native grasslands. Deferred grazing regimes are a derivation of rotational grazing systems and are promoted by DUC in an attempt to decrease waterfowl nest exposure and mortality due to foliage removal and cattle trampling. DUC negotiates contracts with grazing managers to delay cattle access to specific wetlands until after July 15th, at which time most waterfowl broods have fledged (NAWMP 1999).

The experimental unit for this study were the individual wetlands. Wetland characteristics were estimated from a continuous 250m stretch of shoreline that was selected to best represent the variation in wetland vegetation and shoreline structure. All data collection took place along these 250m segments (delineated into six 50m sections selected as random sub-samples) to standardize sampling wetlands of various sizes. The grazing regime in the pasture surrounding each wetland supported one of three treatments: deferred grazing (i.e. mid-July to mid-August), continuous grazing (i.e. approximately May to August), and idle (ungrazed) pastures (i.e. control treatment). Stratified random design was used for both adult odonate and vegetation samples (Krebs 1989); strata were delineated according to wetland vegetation zones as in Stewart and Kantrud (1971). Pseudoreplication was avoided since experimental units (i.e. wetlands) were replicated nine times in each of the three treatments, and each wetland is far enough apart (i.e.>1km) to be considered statistically independent (Hurlbert 1984). Although wetlands are connected via irrigation canals they are distinct habitats (i.e. flowing vs. standing water, sparsely vegetated banks vs. heavily vegetated shorelines), and canals are dry and unsuitable for aquatic organisms for a large portion of the year (i.e. late summer through spring); therefore wetlands were considered biologically unconnected and statistically independent. Grazing was ubiquitous throughout the study area and as a result the limitation on sample size was the number of ungrazed (idled) pastures in local protected areas. A total of twenty-seven wetlands were selected for a balanced design of nine replicates in each of the three treatments (Figure 3-2). Response variables included wetland vegetation structure and adult odonate community metrics. Water quality, larval odonates and other aquatic invertebrates are addressed in other chapters.

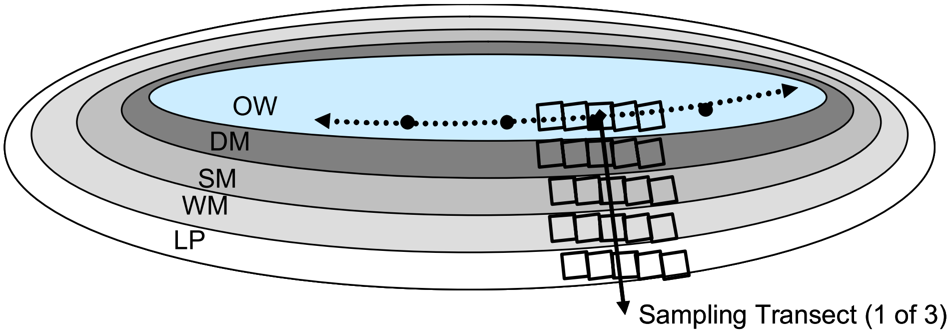
3.4.2 Measuring the Vegetation Community

Vegetation surveys were conducted once per site at the end of summer in 2000 when the majority of plants matured and were more easily identified. Grazing estimates were conservative for deferred sites because surveys occurred after grazing ceased, allowing for about two weeks of re-growth, whereas, at continuously grazed sites grazing was usually ongoing during surveys.

I measured vegetation characteristics relevant to the life histories of odonates including structure (i.e. height, abundance) and composition. Percent cover was estimated as a measure of plant abundance since it is the most common metric for estimating the percent of ground surface covered by the projection of a plant (NARSC 1996). I used a Robel pole to measure plant height since it is the simplest and most accurate method for integrating both vegetation structure and density in prairie habitats (NARSC 1996, Ganguli et al. 2000). Grazing intensity is most often measured as percent utilization of palatable forage species, but I chose percent stems grazed for each plant species as a quantitative index of grazing intensity since I was interested on the impact of cattle grazing on the entire vegetation community rather than select palatable species (Holechek et al. 2001). I used sampling frames to measure percent cover, percent grazed stems, and vegetation composition (NARSC 1996), and chose a 0.25m^2 quadrat (i.e. 0.5m by 0.5m) as compromise sized sample plots for this study since survey lines included both tall/dense and short/sparse vegetation (Daubenmire 1959). Most plants were identified to species except for willows and some non-flowering forbs (see Appendix-B for complete list).

The wetland vegetation community was composed of different zones of vegetation in concentric rings outward from the water's edge influenced by the degree of water permanency (Stewart & Kantrud 1971). Due to the inherent decrease in vegetation height, and abundance as distance from water increased (i.e. tall vigorous emergent vs. short sparse upland plants), comparisons between treatments were made within each of the five vegetation zones defined by Stewart and Kantrud (1971) including: open water, deep marsh, shallow marsh, wet meadow, and low-prairie (Figure3-3).

Figure 3-3: Vegetation survey design.
(OW=open water, DM=deep marsh, SM=shallow marsh, WM=wet meadow, LP=low-prarie)



Three of the six permanent survey points at each wetland were randomly chosen for each sampling round as starting points for vegetation transects. Rope transects were laid out perpendicular to the shoreline encompassing a span from 2m inside the open water zone outward to the beginning of the upland prairie zone, thereby traversing all wetland communities (Figure 3-3). Five sub-samples of quadrat and Robel pole measurements were taken from the middle of each vegetation zone, resulting in about 75 sub-samples per wetland.

3.4.3 Surveying Adult Odonates

Wetlands were surveyed at two-week intervals during the summer of 2000 (six sampling periods) to account for seasonal changes in odonate fauna. Odonates display diurnal movement patterns by roosting in vegetation at night and concentrating around water bodies during the day. Diurnal patterns may be predicted at an even finer scale since mature males concentrate around the water from morning to afternoon, females make shorter trips to and from the water throughout the day, and immature males generally avoid riparian habitat until late in the afternoon when the density of mature males decreases (Moore 1953). Survey biases from the diurnal movement of odonates were avoided by randomizing the time of day at which surveys were conducted at each site and each sampling period.

Standardized survey methodology for adult odonates involved direct counts made while walking through riparian habitat during suitable flight conditions (i.e. low winds, warm, sunny). I used a hand-net to catch, identify, and release odonates (Moore 1953). Disturbance by the surveyor caused a flight-response making any sedentary odonates visible and thereby facilitating identification (Moore 1953). Each wetland vegetation zone was searched once in a serpentine-transect fashion. Abundance estimates were standardized based on time spent searching (i.e. initially 1½ hours per site, reduced to 45 minutes in 2000) and catch-per-unit-effort (CPUE) was calculated as the number of individuals counted/time spent searching.

Direct counts are estimates of the number of odonates at a 250m section of wetland. Despite a tremendous reservoir of individual odonates surrounding riparian habitats, odonate density in riparian/breeding habitat has been shown to remain fairly consistent due to territorial behaviour (Moore 1953). Direct counts are considered a conservative measurement of odonate abundance (Conrad et al. 1999).

In addition to abundance and richness, a reproductive effort index was developed to assess the impact of cattle grazing on odonate breeding success. The reproductive index is based on similar indices developed for ornithology studies, where a range of observed breeding evidence/behaviours are used to weight abundance data according to certainty of reproductive success (Table 3-1).

Table 3-1: Abundance weights for odonates observed at time of vegetation surveys.

Rank	Observation
1	Mature male observed at site for 2+ consecutive rounds
2	Tandem pairs and/or females observed ovipositing
3	Very teneral individuals observed at site

4*	Exuvia collected*

*Exuvia were not collected in this study, but are included in the table to emphasize their importance in identifying breeding sites for odonates, and to promote their use in future studies.

The index is based on observations of mature male odonates, which are therefore weighted “1” to avoid artificially inflating the index (Schmiegelow et al. 1997). Only males of a certain species that were observed at a site for more than two rounds were included in the index to differentiate residents from probable drifters (Vickery et al. 1992). Ranks are not additive.

3.4.4 Relating Vegetation and Odonate Data

Vegetation characteristics significantly affected by grazing were related to odonate data to examine what influence, if any, cattle-altered vegetation has on adult odonates (i.e. linear regression where x=vegetation and y=Odonata). Only species with flight seasons corresponding to the timing of vegetation surveys were included in the analysis (i.e. *Libellula quadrimaculata, Coenagrion resolutum,* and *C. angulatum* excluded, Figure3-4). Odonates were analysed according to Order Odonata, Suborder Anisoptera, Suborder Zygoptera, and individual species, as well as by three foraging groups: ‘Flyers’ (i.e. large dragonflies that catch prey in flight; includes Aeshnidae, *Libellula sp.*), ‘Perchers’ (i.e. medium dragonflies that dart out from perches; includes Genus *Sympetrum*), and ‘Gleaners’ (i.e. glean prey off plants and includes Suborder Zygoptera) (Corbet 1999, Needham et al. 2000).

3.4.5 Statistical Analysis

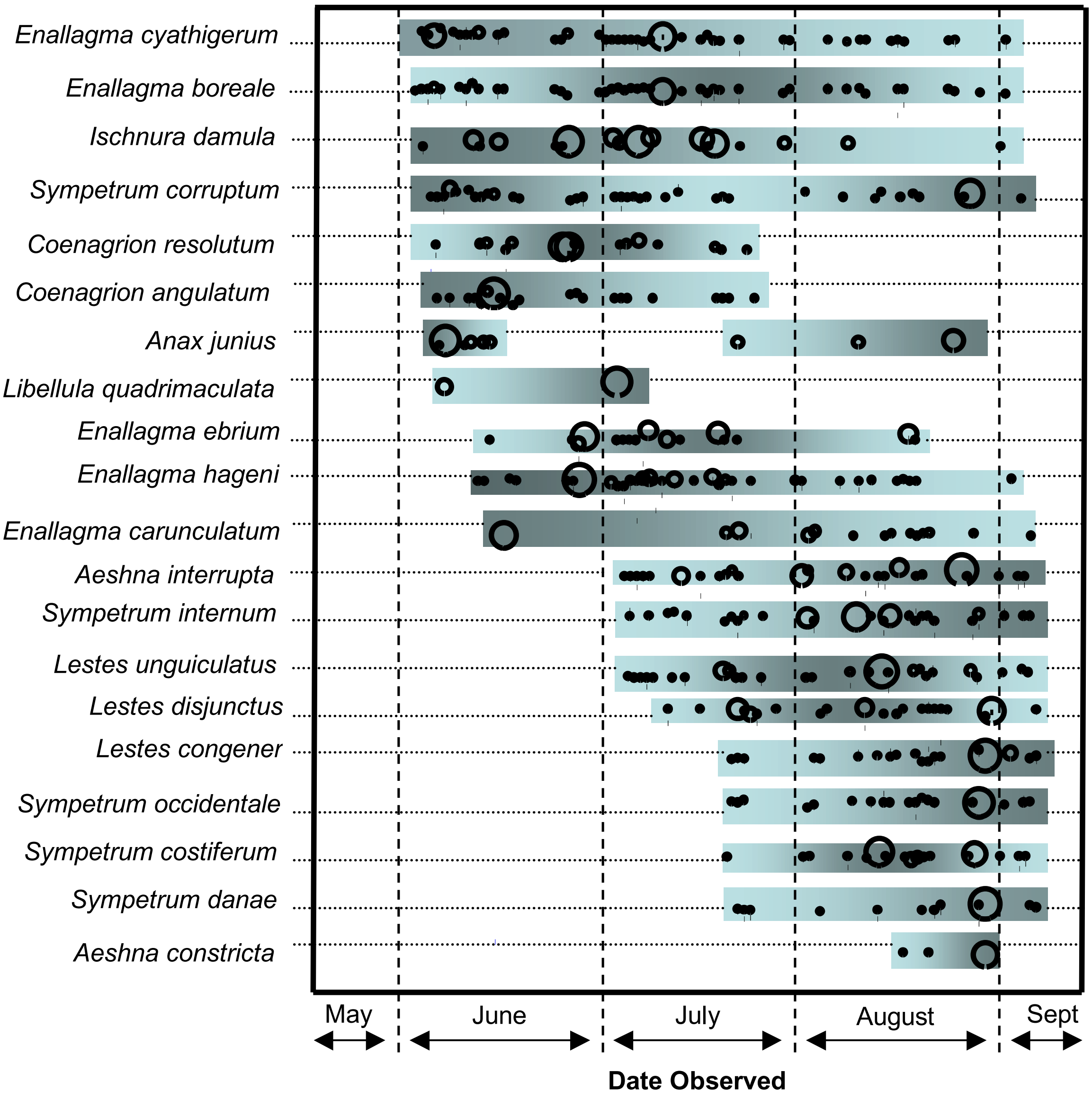
Prior to analysis normal and Poisson distributions were tested using Shapiro-Wilk and Kolmogorov-Smirnov tests, and homogeneity of variances was tested for using the Levene statistic (SPSS 1999, Zar 1999). An *a priori* alpha of 0.05 was selected for all statistical tests of significance. Where parametric assumptions could not be met, Kruskal-Wallis analyses were used to test for differences in vegetation parameters (i.e. height, %cover, %stems grazed, diversity and composition) and adult odonate parameters (i.e. abundance, richness, reproductive effort, diversity, and composition) between grazing treatments. All proportion (i.e. Morisita-Horn indices) and percent data (i.e. %cover, % stems grazed) were arcsine transformed before analysis to account for truncated distributions. Tukey's (parametric) or Nemenyi's (non-parametric) *post hoc* comparisons were performed to identify which treatments were significantly different. Friedmans's test, a nonparametric repeated measures procedure, was used to test for differences in odonate diversity and compositional differences between treatments as well as to test for time effects between sampling periods. Where significant results were identified, I used Newman-Keuls *post hoc* multiple range test to isolate which means differed. Linear regression was used to investigate vegetation parameters affected by cattle grazing with the adult odonate community (i.e. abundance, richness, reproductive effort, and diversity). Non-normal and heteroscedastic dependent variables were log (y+1) transformed. Any $r^2>0.40$ were determined *a priori* to be robust, although results with $r^2<0.40$ thought to be biologically significant/interesting are also presented for discussion.

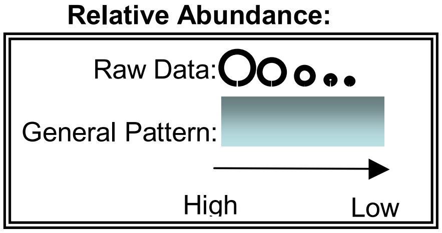
3.5 Results

3.5.1 Grazing Impacts on Wetland Vegetation and their Relevance to Adult Odonates

Fifty-five different plants (Appendix-B) and twenty adult odonate species (with seasonal changes in composition) were detected within the study area (Figure 3-4).

Figure 3-4: Seasonal changes in adult odonate composition and abundance, 2000.

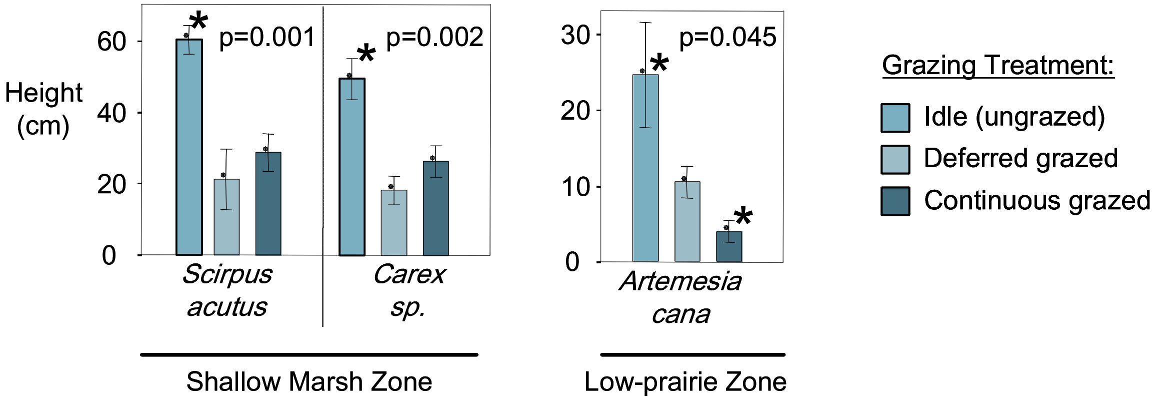




3.5.1.1 Grazing and Vegetation Height

Plant height was significantly taller at idle compared to grazed wetlands for *Scirpus acutus* (Great Bulrush; F(2, 12)=14.77, p=0.001) and *Carex* sp. (Sedge; F(2, 14)=9.47, p=0.002) in the shallow marsh zone, as well as *Artemesia cana* (Silver Sagebrush (H(2)=6.20, p=0.045), in the low-prairie zone (Figure 3-5).

Figure 3-5: Impact of cattle grazing on wetland vegetation height.
(Bars represent ± 1 SE; *= significant difference)

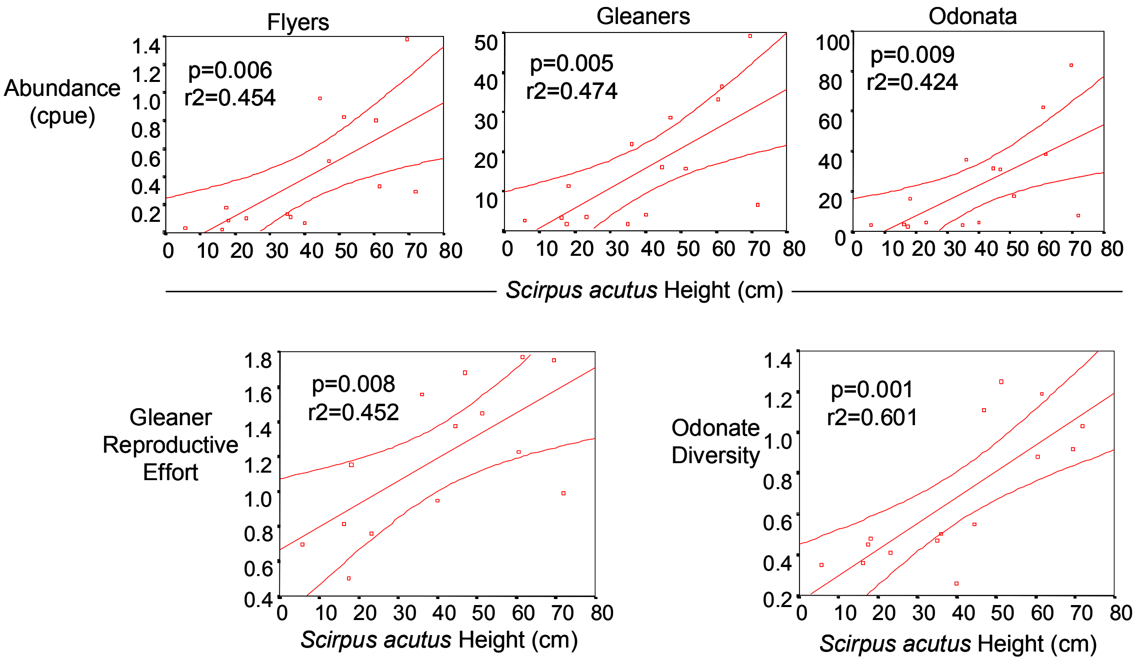


The height of dead vegetation (H(2)=7.34, p=0.025), *Agropyron smithii* (Western Wheatgrass; H(2)=10.98, p=0.004), and *Aster ericoides* (Tufted White Prairie Aster; F(2,11)= 21.98, p<0.001) in the low-prairie zone was also significantly higher at idle compared to grazed sites. No difference in height between treatments was detected for all other plants.

3.5.1.2 Vegetation Height and Odonates

The structure of *S. acutus* in the shallow marsh zone significantly impacted odonate abundance, reproductive effort, and diversity (Figure 3-6). This includes higher Flyer (r^2=0.454, F(1,13)=10.82, p=0.006), Gleaner/Zygoptera (r^2=0.474, F(1,13)=11.72, p=0.005), and overall odonate abundance where taller stems occurred (r^2=0.424, F(1,13)=9.56, p=0.009). Gleaner reproductive efforts (r^2=0.462, F(1, 12)=9.91, p=0.008) and Odonata diversity (r^2=0.601, F(1, 13)=19.61, p=0.001) declined with decreased *S. acutus* height.

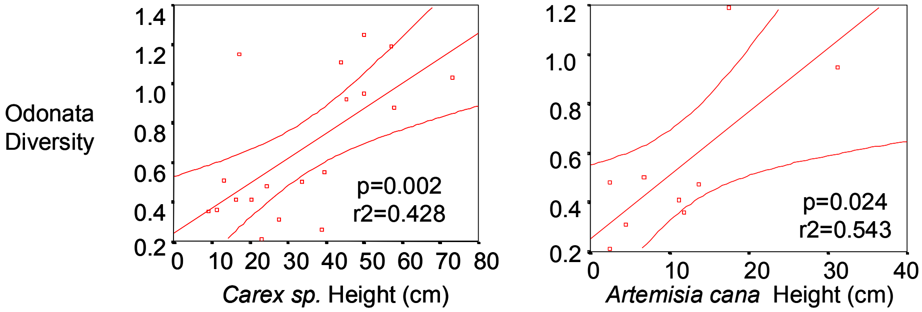
Figure 3-6: ***Scirpus acutus*** **structure and the odonate community of a wetland.**
(Bars represent 95% Confidence Intervals)



The height of *S. acutus* and *Carex* sp. in the shallow marsh, and *A. cana* in the low prairie zone directly affected four odonate species. Ae*shna interrupta* (Variable Darner) abundance declined with shorter *S. acutus* (r^2=0.455, F(1,13)=10.87, p=0.006) and *Carex* sp. (r^2=0.254, F(1,17)=5.78, p=0.028), and *Enallagma ebrium* (Marsh Bluet) abundance declined with shorter *Carex* sp. (r^2=0.436, F(1,17)=13.13, p=0.002). *Aeshna constricta* (Lance-tipped Darner) and *Enallagma carunculatum* (Tule bluet) abundance declined with shorter *A. cana* (r^2=0.673, F(1,7)=14.4, p=0.007 for both).

Vegetation structure did not affect odonate richness, however odonate diversity was positively related to *Carex* sp. (r^2=0.428, F(1,17)=12.73, p=0.002) and *A. cana* height (r^2=0.543, F(1,7)=8.32, p=0.024) (Figure 3-7).

Figure 3-7: Odonate diversity and *Carex sp.* and *Artemisia cana* height. (Round 6 Shannon Diversity Index; Bars represent 95% Confidence Intervals)

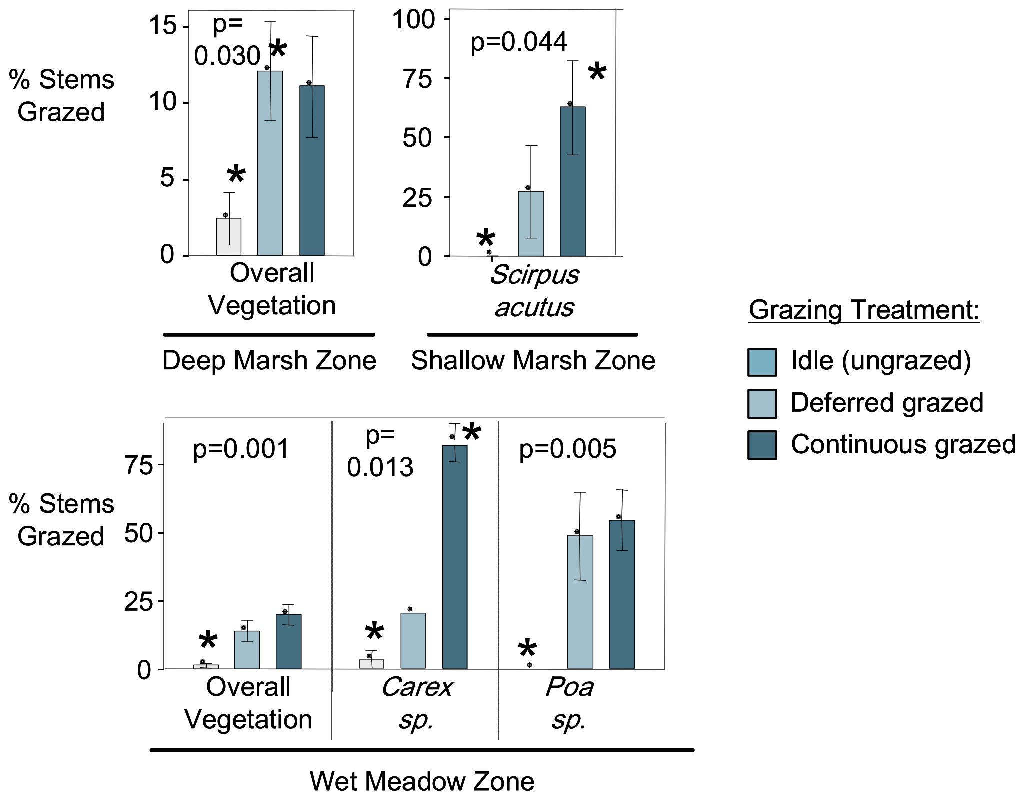


3.5.1.3 Grazing and Percent Stems Grazed of Wetland Vegetation

The percent of stems grazed was significantly lower at idle wetlands (Figure 3-8). This includes overall vegetation (H(2)=7.02, p=0.030) in the deep marsh zone, *S. acutus*

(H(2)=6.24, p=0.044) in the shallow marsh zone, overall vegetation (H(2)=15.00, p=0.001), *Carex* sp. (H(2)=8.61, p=0.013), and *Poa* sp. (Bluegrass; F(2,19)=7.15, p=0.005) in the wet meadow zone, as well as *A. smithii* (H(2)=15.13, p=0.001) and *Poa* sp. (H(2)=6.23, p=0.043) in the low-prairie zone. No difference in percent stems grazed between treatments was detected for all other species of vegetation.

Figure 3-8: Percent stems grazed of wetland vegetation between treatments. (Bars represent ± 1 SE; * =significant difference; plots of untransformed data)



3.5.1.4 Percent Stems Grazed and Odonates

No strong statistical relationship (i.e. $r^2>0.40$) existed between percent stems grazed and the abundance or reproductive effort of Odonata (with the exception of *E.*

ebrium), however trends were consistent, biologically interesting, and noteworthy. The overall trend was a decrease in odonate abundance with increased percent stems grazed, including: *A. interrupta* and Flyers with *S. acutus* (shallow marsh zone); *E. ebrium* with *Carex* sp. (wet meadow zone); and Flyers and Gleaners with overall vegetation in the wet meadow zone. There is a decline in abundance of *A. interrupta, E. ebrium,* as well as Flyers and Gleaners in general with increasing percent stems grazed of *Poa* sp. (wet meadow zone) and *A. smithii* (low-prairie zone) (see Table 3-2 for regression statistics).

Odonate diversity was negatively related to percent stems grazed of overall vegetation (r^2=0.398, F(1,25)=16.51, p<0.001,) and *Carex* sp. (r^2=0.621, F(1,9)=14.74, p=0.004) in the wet meadow zone, as well as *A. smithii* (r^2=0.535, F(1,24)=27.56, p<0.001) and *Poa* sp. (r^2=0.525, F(1,23)=25.37, p<0.001) in the low-prairie zone.

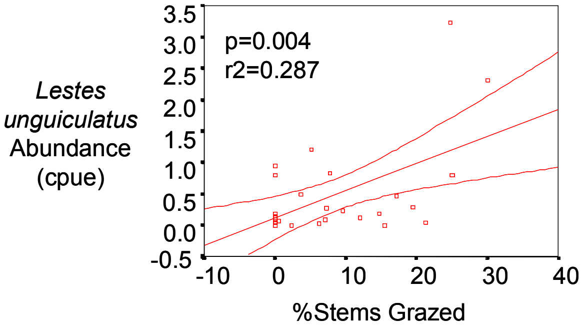
Table 3-2: Simple linear regression results comparing wetland odonate fauna to grazing intensity (i.e. percent stems grazed) at a wetland.

Vegetation Zone	**Independent variable** (%stems grazed)	**Dependent variable** (odonate abundance)	r^2	**F (df)**	**p-value**
Shallow Marsh	*Scirpus acutus*	*Aeshna interrupta*	0.345	6.84 (1,13)	0.021
		Flyers	0.344	6.81 (1,13)	0.022
Wet Meadow	*Carex* sp.	*Enallagma ebrium*	0.397	5.96 (1,9)	0.038
	Overall vegetation	Flyers	0.183	5.58 (1,12)	0.026
		Gleaners	0.165	4.94 (1,25)	0.036
	Poa sp.	Flyers	0.290	8.17 (1,20)	0.010
		Gleaners	0.217	5.55 (1,20)	0.029
		Aeshna interrupta	0.312	9.08	0.007

				(1,20)	
		Enallagma ebrium	0.301	8.60 (1,20)	0.008
Low-prairie	*Agropyrnm smithii*	Flyers	0.180	5.26 (1,24)	0.031
		Gleaners	0.312	10.90 (1,24)	0.003

Lestes unguiculatus (Lyre-tipped Spreadwing) was the only odonate that showed a positive relationship to grazing intensity, increasing in abundance (r^2=0.287, F(1,25)=10.07, p=0.004) and reproductive effort (r^2=0.261, F(1,24)=8.47, p=0.008) with higher overall percent stems grazed in the deep marsh zone (Figure 3-9).

Figure 3-9: Positive relationship between the damselfly *Lestes unguiculatus* and the percent of overall stems grazed in the deep marsh zone.
(Bars represent 95% Confidence Intervals)



3.5.1.5 Grazing and Percent Cover of Wetland Vegetation

No significant difference in percent cover between grazing treatments was detected for any species of vegetation except the exotic *Circium arvense* (Canada-thistle; wet meadow zone), which had higher percent cover at ungrazed wetlands compared to deferred grazed wetlands (H(2)=9.06, p=0.011).

3.5.1.6 Vegetation Percent Cover and Odonates

Overall odonate richness increased as the percent cover of *C. arvense* increased (i.e. highest at ungrazed compared to deferred grazed wetlands; r^2=0.423, F(1,20)=14.68, p=0.001). No other significant relationship was found between *C. arvense* percent cover and odonate abundance, reproductive effort, or diversity.

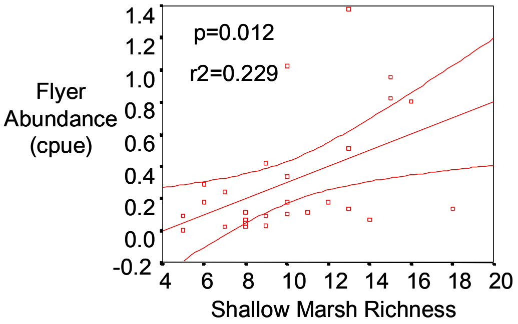
3.5.1.7 Grazing and Wetland Vegetation Richness

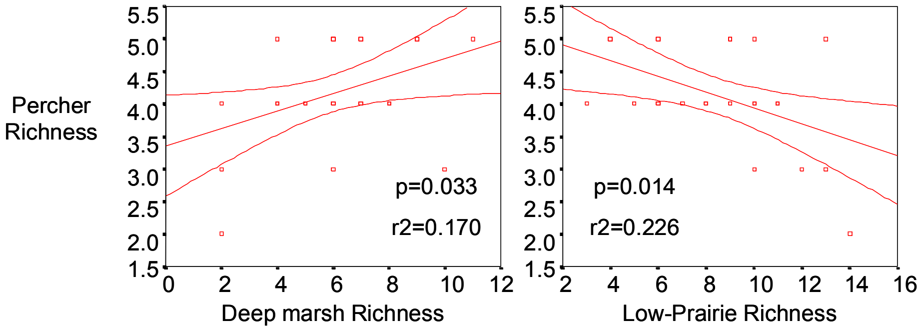
No difference in vegetation richness was detected between grazing treatments, with a total of 24 – 29 species per treatment. No difference in exotic vegetation richness was detected between treatments.

3.5.1.8 Wetland Vegetation Richness and Odonates

Vegetation richness was positively related to Flyer abundance in the shallow marsh zone (r^2=0.229, F(1,25)=7.41, p=0.012; Figure 3-10). Percher richness and vegetation richness were positively related in the deep marsh zone (r^2=0.170, F(1,25)=5.11, p=0.033) and negatively related in the low-prairie zone (r^2=0.226, F(1,24)=7.00, p=0.014; Figure 3-10).

Figure 3-10: Odonate abundance and vegetation richness at prairie wetlands.
(Bars represent 95% Confidence Intervals; plots of untransformed data)





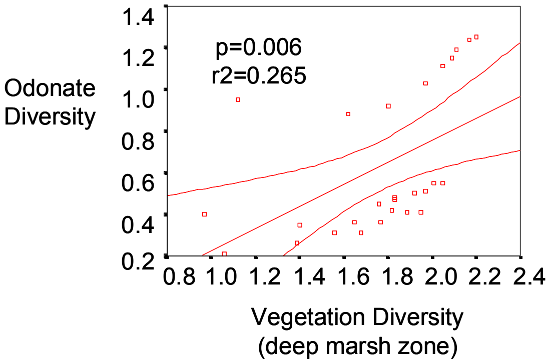
3.5.1.9 Grazing and Wetland Vegetation Diversity

Vegetation diversity within each wetland zone was compared using Shannon diversity indices, which account for both the number and evenness of species in a community. No difference was detected (α=0.05).

3.5.1.10 Wetland Vegetation Diversity and Odonates

Odonata and vegetation diversity in the deep marsh zone were positively related (r^2=0.265, F(1,25)=9.01, p=0.006; Figure 3-11).

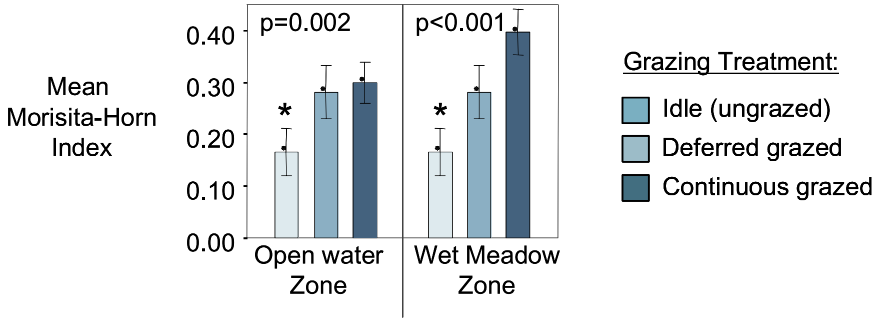
Figure 3-11: Odonate and wetland vegetation diversity within the deep marsh zone. (Diversity = Shannon Diversity Index for Round 6; Bars represent 95% Confidence Intervals)



3.5.1.11 Grazing and Wetland Vegetation Composition

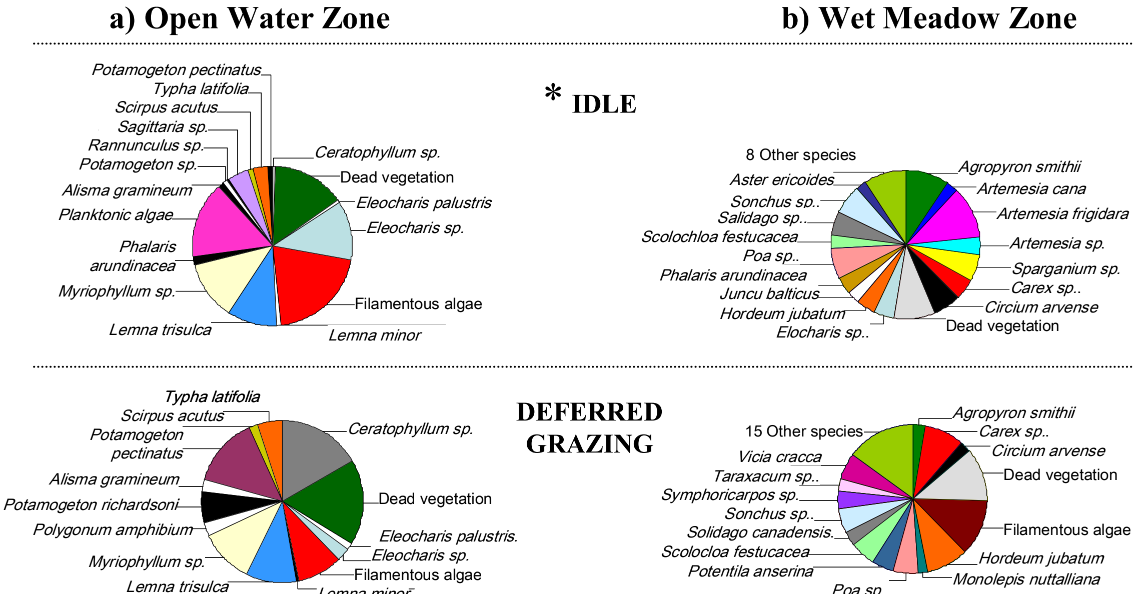
The similarity of vegetation composition between treatments was measured using the Morisita-Horn index, which is relatively independent of sample size or diversity (Wolda 1981). Significantly lower community similarity was detected at ungrazed compared to grazed sites, within both the open water and wet meadow zones, (H(2)=12.91, p=0.002 and H(2)=20.05, p<0.001 respectively; Figure 3-12).

Figure 3-12: Differences in vegetation composition between grazing regimes. (Bars represent ±1SE; *= significant difference; plots of untransformed data)



This difference in composition corresponds to a reduction in dominant species at ungrazed control wetlands compared to disturbed grazed sites (Figure 3-13).

Figure 3-13: Vegetation composition and relative abundance between treatments. (Other= sum of all species <2% relative abundance; *= significant difference α=0.05)

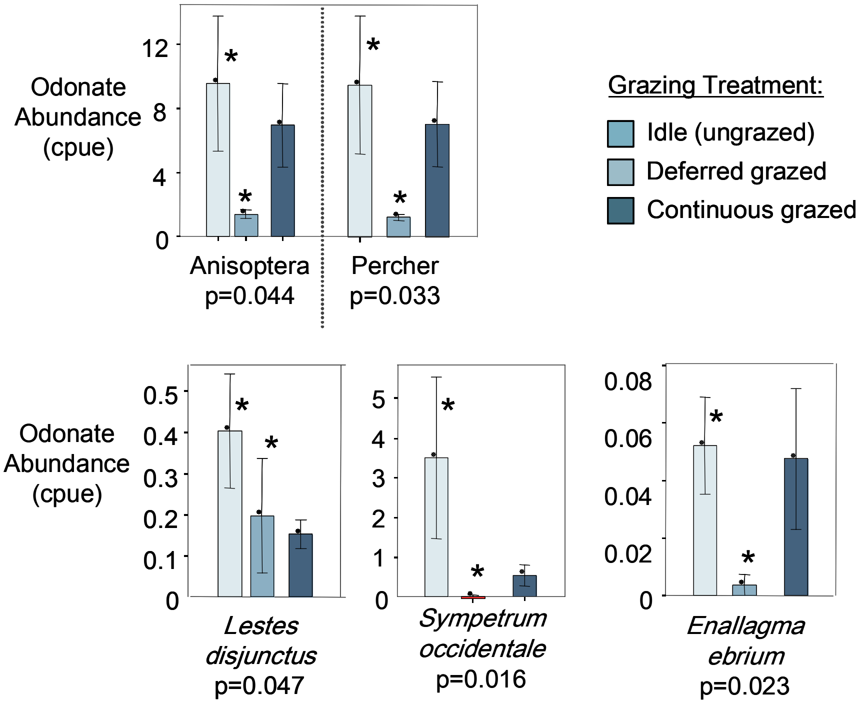


3.5.2 Grazing Treatment and Wetland Odonate Community

3.5.2.1 Grazing and Odonate Abundance

Significantly more Anisoptera (H(2)=6.23, p=0.044), Perchers (H(2)=6.84, p=0.033), *Sympetrum occidentale* (Western Meadowhawk, H(2)=8.31, p=0.016), *Lestes disjunctus* (Common Spreadwing, H(2)=6.12, p=0.047), and *E. ebrium* (H(2)=7.55, p=0.023) were detected at ungrazed compared to deferred grazed wetlands (Figure 3-14).

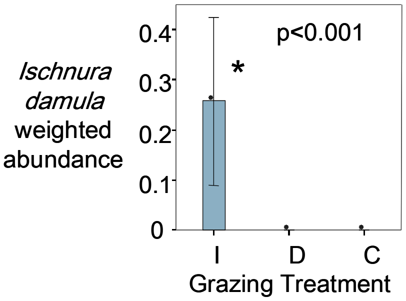
Figure 3-14: Odonate abundance between grazing treatments.
(Bars represent ±1 SE; *= significant difference)



3.5.2.2 Grazing and Odonate Reproductive Effort

The damselfly *Ischnura damula* (Plains Forktail, H(2)=6.47, p=0.039) was the only odonate that displayed significant differences in reproductive effort between grazing treatments (Figure 3-15). The differences were quite marked with no reproductive behaviours observed at grazed sites, and reflect differences in observed abundance between treatments since almost all (i.e. 97%) *I. damula* records were from idle sites.

Figure 3-15: *Ischnura damula* reproductive effort between grazing treatments. (Bars represent ±1SE; I=idle, D=deferred, C=continuous; *= significant difference)

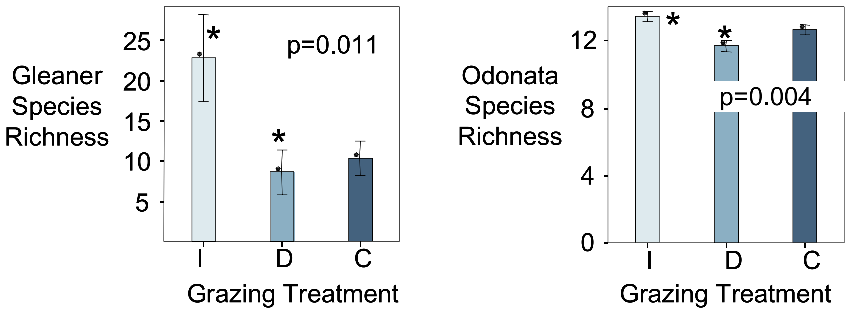


3.5.2.3 Odonate Species Richness

Species richness was significantly higher at ungrazed compared to grazed wetlands for both Gleaners and Odonata (H(2)=9.05, p=0.011 and H(2)=10.86, p=0.004 respectively, Figure 3-16.

Figure 3-16: Odonate richness between grazed and ungrazed wetlands.

(Bars represent ±1 SE; I=idle, D=deferred, C=continuous; *= significant difference)



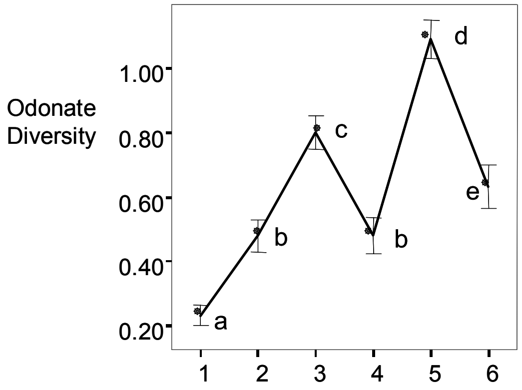
3.5.2.4 Grazing and Odonate Diversity

Odonate diversity was significantly different between sampling rounds but not significantly different between treatments when accounting for time (significant sampling period effects and interaction; no significant treatment effects; Table 3-3). Odonate diversity was significantly different for each round except Rounds 2 and 4, generally increased throughout the summer, and peaked during Rounds 3 and 5 (Figure 3-17).

Table 3-3: Results for differences in odonate diversity using Friedman's test.
(χ^2 values from Table B.1 in Zar 1999)

Source	df	H	χ^2_{crit}	p-value
Treatment	2	2.092	5.991	not significant
Round	5	78.133	11.070	<0.05
Interaction	10	15.107	51.402	<0.05

Figure 3-17: Difference in odonate diversity between grazing treatments.
(Shannon Diversity Index; Bars represent ±1 SE; α=0.05)



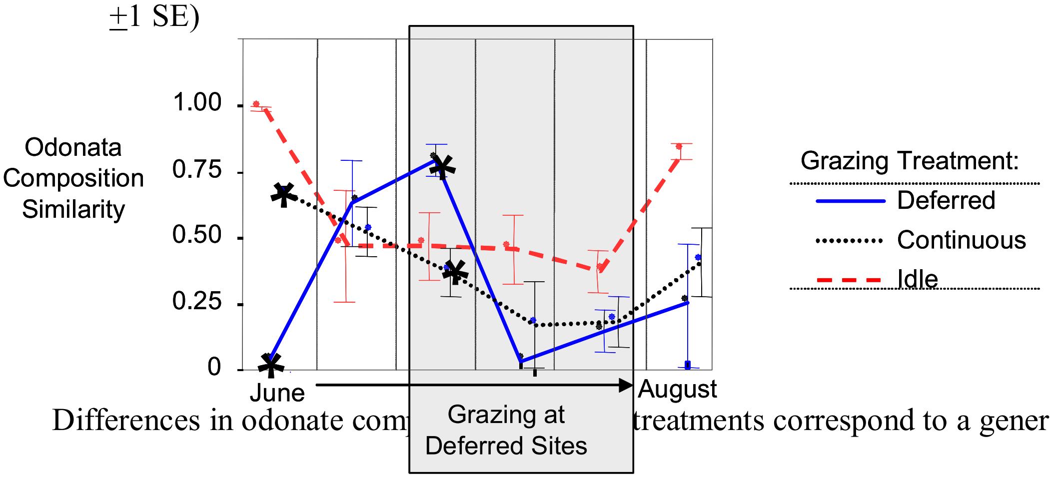
3.5.2.5 Grazing and Odonate Composition

Odonate composition was significantly different between grazing treatments when accounting for sampling period (significant treatment and sampling period effects, interaction not significant; Table 3-4). When cattle were present at grazed treatments (i.e. Rounds 1-5 for continuous sites; Rounds 3-5 for deferred sites) odonate community similarity was generally lower at grazed compared to ungrazed wetlands (Figure 3-18). Odonate community similarity was significantly higher at continuously grazed wetlands compared to deferred grazed wetlands during Round 1, however after one month of continuous grazing the reverse pattern was observed. Odonate community similarity was generally higher at ungrazed wetlands compared to grazed wetlands during the last three survey rounds.

Table 3-4: Results for differences in odonate composition using Friedman's test. (χ_r^2 values from table B.1 in Zar 1999)

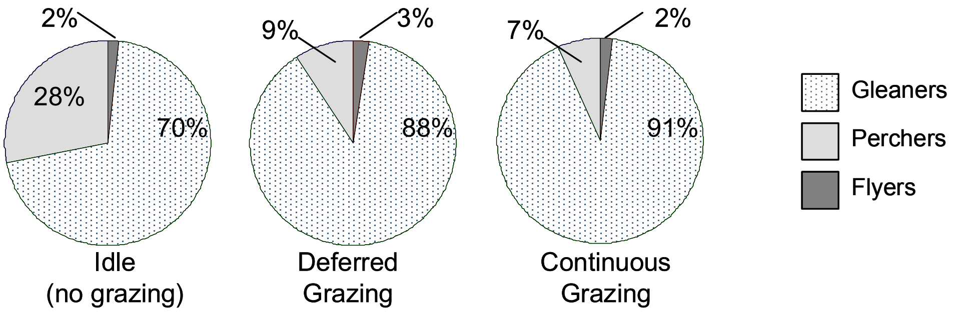
Source	df	H	χ^2_{crit}	p-value
Treatment	2	7.276	5.991	<0.05
Round	5	17.083	11.070	<0.05
Interaction	10	15.107	18.307	not significant

Figure 3-18: Differences in odonate composition between grazing treatments. (Morisita-Horn Index; *= significant difference when α=0.05; Bars represent ±1 SE)



Differences in odonate com treatments correspond to a general decrease in Perchers and increase in Gleaners at grazed wetlands compared to ungrazed wetlands (Figure 3-19).

Figure 3-19: Relative abundance of Perchers, Flyers, and Gleaners between grazing treatments.



3.6 Discussion

3.6.1 Odonate Abundance and Grazing

It is sensible that vegetation height decreases with cattle grazing, and both vegetation height (indirect grazing measurement) and percent stems grazed (direct grazing measurement) indicated the amount of grazing at these wetlands. The heights of a few key species of wetland vegetation were found to significantly affect the adult odonate community of a wetland, including *S. acutus, Carex* sp., and *A. cana* (Figures 3-5 and 3-6). Odonates were particularly negatively impacted when cattle grazed the emergent *S. acutus*. *S. acutus* grazing was associated with lower abundance for all odonates, particularly for Flyers and Gleaners. Adult odonates primarily use visual cues to assess overall breeding habitats, with limited use of tactile cues when selecting specific oviposition sites (Corbet 1999, Bernath et al. 2002). The significant change from the usually tall, lush *S. acutus* to shorter grazed stems may be perceived by adult odonates as a decrease in habitat quality, and consequently fewer adults congregated, defended territories, and oviposited at that site. Additionally, the tall ungrazed *S. acutus* provided substantial refugia from the wind at the waters edge, and may explain my observations of significantly higher numbers of those odonates that are weak flyers (i.e. Zygoptera/Gleaners) at idle sites.

Flyers and most Gleaners are endophytic species (i.e. deposit eggs within vegetation; Needham et al. 2000, Westfall & May 1996) and both *A. interrupta* and *E. ebrium* were less abundant at sites with shorter *Carex* sp. stems in the shallow marsh zone (i.e. deferred grazed and continuously grazed wetlands, Figure 3-5). Additionally, Flyer abundance decreased with lower (shallow marsh) vegetation richness (Figure 3-10). This decrease in abundance may be due to an overall decrease in visual habitat cues, or these odonates may be specifically cueing in to the conditions of emergent sedges.

The height of vegetation in the low-prairie zone also affected the abundance of adult odonates at prairie wetlands. *A. constricta* and *E. caruncculatum* were less abundant at sites with shorter *A. cana* stems (i.e. continuously grazed wetlands,

Figure 3-5). Odonates congregate around water bodies during the day; however diurnal movement patterns dictate that nocturnal roosts, in addition to emergent vegetation, are necessary components of odonate habitat, especially for darners (Moore 1953). *A. cana* tends to grow in clumps and is one of the taller plants (i.e. 30-45 cm) in the low-prairie zone, and therefore may provide important roosting habitat for adult odonate in a landscape with limited roosting structures.

Oviposition is the link between terrestrial (adult) and aquatic (larval) odonates. Desirable oviposition sites can be predicted based on the habitat requirements of aquatic larvae since there is strong selective pressure for the female to select oviposition sites at which larvae survival is high (Buskirk & Sherman 1985). Vegetation is the link between adult and larval odonates, and other research has shown a positive correlation between adult odonate abundance and aquatic macrophyte cover (Clark & Samways 1996, Stewart & Samways 1998). No significant relationship was found between odonate abundance and percent cover for any species of wetland vegetation in this study. This may reflect true conditions, or insufficient data collection since percent cover estimates were conservative for deferred grazed sites (i.e. short-term intense grazing treatment). A two-week lag occurred between cessation of deferred grazing and vegetation surveys, thereby allowing for some level of plant re-growth and cover accumulation at these sites.

Physical disturbance from cattle, in addition to removal of visual cues resulting from grazing, may decrease the abundance of odonates in wetlands. Shoreline disturbances (i.e. waves from motorboats, intermittent dam releases) are thought to interrupt odonate emergence by removing, injuring, or killing emerging and very teneral odonates and making the shoreline itself a type of 'hostile' habitat (pers. comm. J. Acorn

2002). The physical disturbance of emergent vegetation by cattle as they walk through and browse emergent vegetation may disturb fragile emerging odonates and thereby decrease the abundance of odonates successfully emerging from a wetland.

3.6.2 Odonate Reproductive Efforts and Cattle Grazing

Gleaners (i.e. Zygoptera) reproductive effort was significantly higher at idle sites; these contained taller *S. acutus* stands (Figures 3-5 and 3-6). This is likely due to the oviposition or larval habitat requirements of Zygoptera. All damselflies rely on aquatic vegetation during oviposition since they are either epi- or endo-phytic (i.e. deposit eggs on or within vegetation; Corbet 1999). Additionally, all Zygoptera larvae are 'claspers' that crawl amongst submerged/emergent vegetation to avoid detection from predators and prey, and selective pressures are strong for female odonates to identify and select oviposition sites with high larvae survival rates (Buskirk & Sherman 1985).

I. damula was the only species that showed a significant difference in reproductive efforts between grazing treatments, with no reproductive behaviours observed at grazed sites despite the presence of both adult males and females. The genus *Ischnura* is regarded to be especially weak flyers and individuals usually remain among the stems of the dense vegetation among the shoreline (Westfall and May 1996). Breeding *I. damula* may be cueing in to the shelter of the taller shoreline vegetation at ungrazed wetlands (i.e. *S. acutus* and *Carex* sp. in the shallow marsh zone, Figure 3-5).

Conversely, reproductive efforts and abundance for the damselfly *L. unguiculatus* were highest at wetlands with more intense grazing in the deep marsh zone (i.e. deferred grazed sites compared to idle sites, Figures 3-8 and 3-9). Lestes damselflies are adapted to ephemeral prairie wetlands (Westfall and May 1996) which are generally Class I-II with shorter, less dense vegetation compared to the more permanent Class IV-V wetlands in this study. *L. unguiculatus* may be cueing in to the less dense emergent vegetation at deferred grazed sites, which more closely resembles typical *L. unguiculatus* habitat (i.e. open ephemeral ponds) than the dense, tall emergent vegetation of ungrazed wetlands (Westfall and May 1996).

3.6.3 Odonate Species Richness and Grazing

Total Odonata and Gleaner species richness was significantly higher at ungrazed wetlands compared to deferred grazed wetlands (i.e. intense short-term grazing treatment; Figure 3-10). Other studies have also shown a negative correlation between adult odonate species richness and grazing intensity (as measured by percent stems grazed; Hornung & Rice 2003) or shoreline trampling from grazing (by African buffalo; Stewart & Samways 1993).

Percher richness is positively related to emergent vegetation richness in prairie wetlands (Figure 3-10). The importance of emergent vegetation to higher odonate species richness is consistent with research in other regions where adult Odonata richness and reed cover were positively correlated (Stewart & Samways 1998). Percher richness decreases as vegetation richness in the low-prairie zone increases. The significance of low-prairie species richness to Perchers may indirectly reflect grazing intensity since upland richness is known to increase with grazing intensity (Collins 1984). Additionally, *Sympetrum* sp. (i.e. Perchers) were observed spending a larger portion of the day in upland habitat compared to other odonates (i.e. congregating at water edge later in the day compared to other odonates), and may therefore be more affected by low-prairie habitat than other odonates.

C. arvense was the only plant that showed a significant difference in percent cover between grazing treatments. The positive relationship between *C. arvense* percent cover and Odonata richness may be spurious, or may be a very indirect measure of cattle grazing. *C. arvense* was more abundant (i.e. percent cover) at idle compared to deferred grazed sites within the study area. These were unexpected results since *C. arvense* is considered an unpalatable invasive forb that is expected to increase due to overgrazing (Alberta Agriculture, Food, and Rural Development 1996), and restricting grazing to allow interspecific competition is a recommended management practice for controlling C. arvense (Edwards et al. 2000).

3.6.4 Odonate Diversity and Grazing

Odonata diversity was affected by the height of two vegetation species; odonate diversity increased with taller *S. acutus* and *A. cana* stems (Figure 3-6 and 3-7). The height of both *S. acutus* and *A. cana* affected the abundance of four odonate species, including *A. interrupta*, *A. constricta*, *E. ebrium*, and *E. carunculatum* (i.e. positive relationship between stem height and odonate abundance). Lower odonate diversity at wetlands with shorter *S. acutus* and *A. cana* stems (i.e. grazed wetlands) may reflect the decline or absence of the above odonate species due to a lack of suitable habitat cues that these two vegetation species may provide, such as ovipositing substrates or wind-shelter (i.e. S. acutus), and nocturnal roosts (i.e. A. cana).

Odonata diversity declined as grazing intensity increased on overall wet meadow vegetation, *Carex* sp., *Poa* sp., and *Agropyron smithii* (i.e. percent stems grazed). Grazing is uneven within a pasture and cattle with unrestricted access to wetlands tend to focus their grazing efforts on riparian vegetation and other preferred forage species (Fitch & Adams 1998). *Carex* sp., *Poa* sp., and *A. smithii* are considered palatable good quality forage for cattle and may therefore be indicative of cattle utilization of a pasture (Alberta Agriculture, Food, and Rural Development 1996).

Adult odonate diversity is positively related to emergent vegetation diversity (i.e. deep marsh zone). Adult odonates require aquatic vegetation for emergence substrates, perch platforms, and oviposition cues, all of which are activities that occur at the water's edge (i.e. deep marsh zone). More diverse vegetation templates may offer a greater variety of vegetation habitat and therefore accommodate different odonate species with different microhabitat requirements.

Odonate diversity varies significantly (i.e. two distinct pulses) over the summer season; first as early emergent species emerge and mature and the second, for late-emerging species (Figure 3-17). Adult odonate diversity was not significantly different between grazing treatments (Table 3-4). My results do not support the Intermediate Disturbance Hypothesis (IDH) wherein maximum species diversity occurs in between the states of extreme disturbance (Connell 1978). Extreme states in my study were chronic disturbance at continuously grazed sites and greater stability (i.e. no grazing disturbance) at idle wetlands. Moderate levels of cattle grazing have been shown to increase vegetation diversity since unpalatable (ungrazed) forbs flourished because they were released from competition from dominant grasses (Hickman & Hartnett 2002). Results in support of the IDH were found for larval odonates (this study) as well as adult odonates across a gradient of disturbance in lotic habitats (Stewart & Samways 1998). Although diversity indices are similar between treatments, it is important to look at differences in odonate species composition since it is possible that overall diversity remains unchanged but a shift in composition has occurred.

3.6.5 Adult Odonate Composition and Grazing

Adult odonate composition significantly changes over the summer as the flight season for early emerging species ends and late emerging species begins (Figure 3-4, Table 3-4). Odonate composition is more similar within ungrazed sites compared to within deferred grazed or continuously grazed sites, especially during late summer (Figure 3-18). The similarity of odonate fauna within deferred grazed sites is high at the on-set of deferred grazing, but quickly drops and remains low after cattle are present. The odonate community at ungrazed wetlands consists of relatively more Perchers compared to deferred grazed or continuously grazed wetlands, which suggests a shift in odonate community composition with the presence of grazing disturbance (Figure 3-19).

3.7 Summary and Recommendations

Some of the known ‘ecological costs’ of cattle grazing are decreases in the diversity and abundance of certain taxa, changes in community organization, changes in the physical characteristics of terrestrial and aquatic ecosystems, and disruption of ecosystem function (i.e. nutrient cycling, succession) (Fleischner 1994). Although this study did not attempt to address the impact of grazing on ecological function, grazing was shown to change wetland vegetation composition and structure, which in turn decreased odonate abundance and diversity, and altered odonate composition. Cattle grazing significantly impacted emergent vegetation structure, but did not influence vegetation richness or diversity, therefore my results support the hypothesis that cattle grazing impact wetland vegetation structure (i.e. accept Hypothesis #3).

Results from this study show that adult odonates respond to changes in vegetation structure due to unrestricted cattle grazing. Cattle-altered vegetation subsequently decrease odonate abundance, thereby supporting the hypothesis that wetland vegetation impacts wetland adult odonate abundance (i.e. accept Hypothesis #4). The height and diversity of emergent vegetation, especially *S. acutus*, had the greatest impact on odonate abundance and reproductive effort, especially for Gleaners (Suborder Zygoptera) which are epiphytic, weaker flying odonates that tend to occupy the reeds of emergent vegetation. Overall odonate diversity was affected by the height of three key species of wetland vegetation (i.e. *S. acutus, Carex* sp., and *A. cana*) highlighting the importance of the structure of both emergent vegetation (i.e. breeding habitat) and upland vegetation (i.e. nocturnal roosts) to the life history of prairie odonates. Future studies should measure aquatic macrophytes in more detail since submergent vegetation provides critical habitat for both larval (i.e. cover) and adult (i.e. oviposition substrate) odonates. Future research should also incorporate exuvia collections in order to get a more accurate indication of odonate breeding success at a wetland.

Results also suggest that wetland vegetation structure is more important than vegetation composition to the life history of odonates. Odonates did not respond to changes in wetland vegetation composition due to grazing, yet odonate abundance, reproductive effort, and diversity were all significantly affected by changes in vegetation height due to cattle grazing. Vegetation diversity positively impacts odonate diversity; however vegetation diversity is more a consequence of wetland class rather than grazing treatment.

Although odonates responded to quantitative measurements of cattle-altered vegetation, few significant results were found when the wetland odonate community was directly compared to grazing treatment (i.e. qualitative variable). This counter-intuitive result is likely due to improper quantification of grazing treatments. Grazing was treated very simplistically in this study and grazing treatment was a categorical variable assigned based on the duration of cattle in a pasture (i.e. all summer, part of summer, or altogether absent). Future studies treating grazing treatment as a categorical variable should be more sensitive to the complexities of grazing regimes (i.e. number of cattle in pasture, size of pasture, number of wetland in pasture). If it is logistically impossible to control/alter existing grazing regimes to attain more precisely defined grazing treatments (as in this study), then future studies should quantify grazing treatments as a continuous variable (i.e. AUM’s, # cattle/ha pasture, or percent utilization).

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Chapter 4

Odonates as biological indicators of the aquatic macro-invertebrate community and overall habitat quality at grazed prairie wetlands

4.1 Introduction

Biological Indicator Theory has been extensively studied in the context of lotic habitats and aquatic macro-invertebrates are widely accepted and implemented as suitable habitat indicators in streams and rivers (Resh et al. 1995, Reynoldson et al. 1997, Karr & Chu 1997, US EPA 2002a & b), but little is known as to which, if any, taxa are most sensitive and suitable as biological indicators in wetlands.

Prairie wetlands are typically high-nutrient, high-productivity systems adapted to recurring natural drought cycles every 5-20 years (Van der Valk & Davis 1978). The wetlands investigated in this study are not typical ephemeral prairie wetlands since water levels are maintained for irrigation and cattle watering sites all summer. Cattle are allowed unrestricted access to wetlands and target their grazing efforts on highly palatable emergent vegetation (Fitch & Adams 1998).

Rotational grazing regimes, in which hundreds of cattle are moved through a series of pastures through out the summer season, are the most common pasture management regime in the study area; however, smaller cattle operations exist where relatively fewer cattle (i.e. <100 cattle) graze one pasture and wetland all season. Cattle grazing primarily affects vegetation (i.e. richness, abundance, composition, and structure), but may also alter soil structure or ecosystem processes such as nutrient cycling (Fleischner 1994).

4.2 Objective

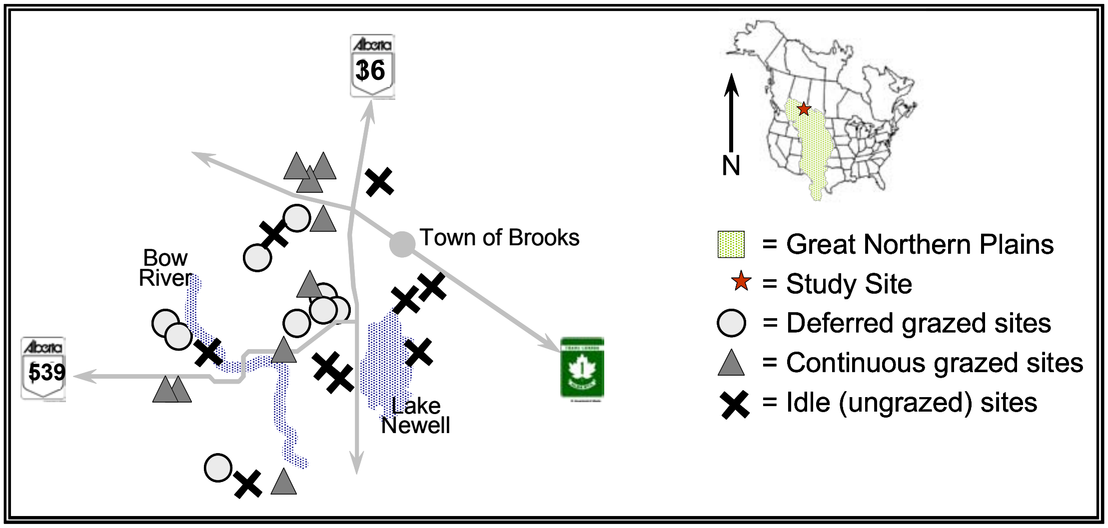
I investigate the impact of three cattle grazing regimes on the aquatic macro-invertebrate communities of prairie wetlands, and integrates biotic and abiotic data to assess the suitability of odonates (Order Odonata) as a biological indicator of grazing disturbance at prairie wetlands.

4.3 Study Area

Study sites are located within an 1800 km^2 area of the dry mixed-grass prairie of south-eastern Alberta, Canada (50º 30’ N, 111º 55’ W) (Figure 4-1). Agriculture (i.e. cropland, irrigation infrastructure, beef cattle grazing) and oil and gas extraction are the main contemporary sources of income generation and concomitant land disturbance within the study area. Free-roaming bison herds and wildfires were past sources of landscape disturbance, but these have been eliminated as 94% of Alberta’s native grasslands have been converted to cropland (Environment Canada 2002). The dry mixed-grass prairie still supports substantial tracts of grazing land because precipitation is insufficient for dependable cropping regimes.

Moisture deficits are typical in this dry and windy eco-region, particularly at the end of summer (i.e. 250mm mean annual precipitation; 19 km/h mean annual wind speed) (Environment Canada 2002). Prairie wetlands are highly variable and many are dry by the end of summer. Inter-annual variation is significant and follows a 5-20 year drought cycle (van der Valk & Davis 1978). However, the sites in this study are intensively managed and are not natural ephemeral wetlands. The Eastern Irrigation District (EID) and Ducks Unlimited Canada (DUC) intensively manage wetlands to serve as irrigation basins, sources of drinking water for beef cattle, and to a lesser degree wildlife habitat, primarily for waterfowl or shorebirds. Water levels are artificially controlled and wetlands are kept unnaturally high and stable (i.e. wet all season). Decreased hydrologic variation and deep flooding results in a subsequent increase in vegetation diversity (Stewart and Kantrud 1971), an increase in the concentration of nitrogen and phosphorus (Kadlec et al. 2000), and a shift in the typical aquatic invertebrate fauna (Murkin and Ross 2000).

Figure 4-1: Study area location.



4.4 Methods

4.4.1 Experimental Design

Wetlands were selected based on five criteria: grazing regimes during the previous five years, basin characteristics (i.e. size, source, and degree of isolation represented at least once in each treatment), surrounding landscape (i.e. grasslands only, no croplands), wetland class (i.e. Stewart and Kantrud (1971) Class IV or V), and access permission.

Manipulating pasture sizes and stocking rates for the sake of this project was logistically infeasible. Continuous and rotational grazing are the two predominant grazing strategies employed within the study area. Continuous grazing regimes keep cattle in one pasture all season (i.e. May to August) and consequently involve small herds of cattle on small sections of private land. More commonly, rotational grazing merges many herds to form a single 'super herd' managed by a local grazing association. To ensure pasture re-growth and a constant supply of forage, cattle are directed through a series of pastures beginning with early-germinating tame pastures (i.e. exotic species) and ending on native grasslands. Deferred grazing regimes are a derivation of rotational grazing systems and are promoted by DUC in an attempt to decrease waterfowl nest exposure and mortality due to foliage removal and cattle trampling. DUC negotiates contracts with grazing managers to delay cattle access to specific wetlands until after July 15th, at which time most waterfowl broods have fledged (NAWMP 1999).

The experimental unit for this study were the individual wetlands. Wetland characteristics were estimated from a continuous 250m stretch of shoreline that was selected to best represent the variation in wetland vegetation and shoreline structure. All data collection took place along these 250m segments (delineated into six 50m sections selected as random sub-samples) to standardize sampling wetlands of various sizes. The grazing regime in the pasture surrounding each wetland supported one of three treatments: deferred grazing (i.e. mid-July to mid-August), continuous grazing (i.e. approximately May to August), and idle (ungrazed) pastures (i.e. control treatment).

Stratified random design was used for all data collection (Krebs 1989): strata were delineated according to wetland vegetation zones according to Stewart and Kantrud (1971) for vegetation and adult odonate surveys, and distance from vegetation/water interface for all aquatic macro-invertebrate and water collections. Pseudoreplication was avoided since experimental units (i.e. wetlands) were replicated nine times in each of the three treatments, and each wetland was far enough apart (i.e.>1km) to be considered statistically independent (Hurlbert 1984). Grazing was ubiquitous throughout the study area and as a result, the limitation on sample size was the number of ungrazed (idled) pastures in local protected areas. A total of twenty-seven wetlands were selected for a balanced design of nine replicates in each of the three treatments (Figure 4-1). Response variables included wetland odonate (adult and larvae) and aquatic macro-invertebrate community metrics, vegetation structure, and nitrogen and phosphorus concentrations.

4.4.2 Measuring the Vegetation Community

Vegetation surveys were conducted once per site at the end of summer in 2000 when the majority of plants matured and were more easily identified. Grazing estimates were conservative for deferred sites because surveys occurred after grazing ceased, allowing for about two weeks of re-growth, whereas, at continuously grazed sites grazing was usually ongoing during surveys.

I measured vegetation characteristics relevant to the life histories of odonates including structure (i.e. height, abundance) and composition. Percent cover was estimated as a measure of plant abundance since it is the most common metric for estimating the percent of ground surface covered by the projection of a plant (NARSC

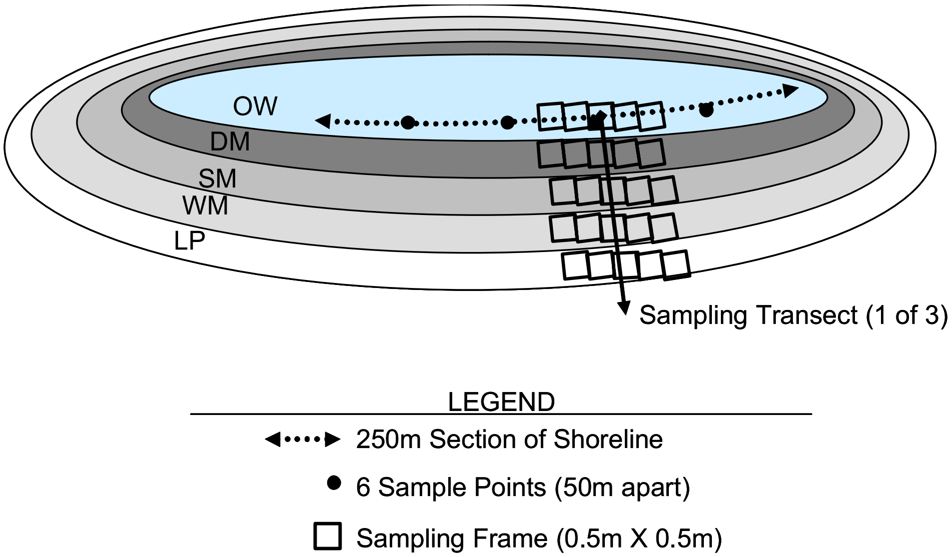
1996). I used a Robel pole to measure plant height since it is the simplest and most accurate method for integrating both vegetation structure and density in prairie habitats (NARSC 1996, Ganguli et al. 2000). Grazing intensity is most often measured as percent utilization of palatable forage species, but I chose percent stems grazed for each plant species as a quantitative index of grazing intensity since I was interested on the impact of cattle grazing on the entire vegetation community rather than select palatable species (Holechek et al. 2001). I used sampling frames to measure percent cover, percent grazed stems, and vegetation composition (NARSC 1996), and chose a 0.25m^2 quadrat (i.e. 0.5m by 0.5m) as compromise sized sample plots for this study since survey lines included both tall/dense and short/sparse vegetation (USEPA 1997, Daubenmire 1959). Most plants were identified to species except for willows and some non-flowering forbs (see Appendix-B for complete list).

The wetland vegetation community was composed of different zones of vegetation in concentric rings outward from the water's edge influenced by the degree of water permanency (Stewart & Kantrud 1971). Due to the inherent decrease in vegetation height, and abundance as distance from water increased (i.e. tall vigorous emergent vs. short sparse upland plants), comparisons between treatments were made within each of the five vegetation zones defined by Stewart and Kantrud (1971) including: open water, deep marsh, shallow marsh, wet meadow, and low-prairie (Figure 4-2).

Three of the six permanent survey points at each wetland were randomly chosen as starting points for vegetation transects. Rope transects were laid out perpendicular to the shoreline encompassing a span from 2m inside the open water zone outward to the beginning of the upland prairie zone, thereby traversing all wetland communities (Figure

4-2). Five sub-samples of quadrat and Robel pole measurements were taken from the middle of each vegetation zone, resulting in about 75 sub-samples per wetland.

Figure 4-2: Vegetation survey design.
(OW=open water, DM=deep marsh, SM=shallow marsh, WM=wet meadow, LP=low-prairie)



4.4.3 Measuring Water Quality

Budget constraints dictated that the minimum number of water samples be submitted for analysis. All samples were collected three or more days after a storm event to minimize effects from run-off. Three of the six survey points were randomly selected (Figure 4-2), and 1L of water was collected from each point at 1m into the open water zone at a depth of 30cm. The three samples were combined and one 0.5L composite sample was packed in ice and shipped that day to the Limnology Lab at the University of Alberta.

Two water samples were collected from all wetlands: 1) before deferred grazing began (i.e. mid-July 2000), herein called pre-cattle sample, and 2) during deferred grazing (i.e. late-August 2000), herein called post-cattle sample. These samples were analysed for ammonium (NH_4+), nitrates and nitrites (NO_2+NO_3), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total dissolved phosphorus (TDP), total dissolved solids (TDS), and Chlorophyll-a concentrations (i.e. algae productivity).

4.4.4 Collecting Larval Odonates and other Aquatic Macro-invertebrates

During each sampling round, odonate larvae were collected along with other aquatic macro-invertebrates using a D-frame sweep net (one of the best devices for sampling aquatic invertebrates in heavily vegetated wetlands; Turner & Trexler 1997). Three of the six survey points were randomly selected, and three distinct micro-habitats were sampled at each point including: emergent vegetation (i.e. 1m outward from open water), emergent vegetation /open water interface, and deeper open water (i.e. 1m inward from vegetation/water interface). Five 1m sweeps were collected from each microhabitat for a total of forty-five sweeps per wetland. Aquatic invertebrates that were captured were preserved in 70% ethanol solution and were identified later in the laboratory at the University of Alberta. Samples from the year 2000 were identified to Family with the exception of subclass Acari (identified to subclass only), and orders Odonata and Ephemoptera (both identified to genus), whereas 2001 invertebrates were identified to the lowest identifiable taxonomic level and used for all richness and diversity calculations (i.e. Mollusca and Annelida were identified to genus, Class Crustacea were identified to species, Class Arachnida were identified to subclass, and Class Insecta were identified to family (i.e. Orders Diptera and Hemiptera) or genus (i.e. Orders Coleoptera, Ephemoptera, and Trichoptera); see Appendix-C for complete taxa list). Primary references for identification were Clifford (1991) and Merritt and Cummins (1996).

4.4.5 Surveying Adult Odonates

Wetlands were surveyed at two-week intervals during the summer of 2000 (six sampling periods) and 2001 (three sampling rounds) to account for seasonal changes in odonate fauna. Odonates display diurnal movement patterns by roosting in vegetation at night and concentrating around water bodies during the day. Diurnal patterns may be predicted at an even finer scale since mature males concentrate around the water from morning to afternoon, females make shorter trips to and from the water throughout the day, and immature males generally avoid riparian habitat until late in the afternoon when the density of mature males decreases (Moore 1953). Survey biases from the diurnal movement of odonates were avoided by randomizing the time of day at which surveys were conducted at each site and each sampling period.

Standardized survey methodology for adult odonates involved direct counts made while walking through riparian habitat during suitable flight conditions (i.e. low winds, warm, sunny). I used a hand-net to catch, identify, and release odonates (Moore 1953). Disturbance by the surveyor caused a flight-response making any sedentary odonates visible and thereby facilitating identification (Moore 1953). Each wetland vegetation zone was searched once in a serpentine-transect fashion. Abundance estimates were standardized based on time spent searching (i.e. initially 1½ hours per site, reduced to 45 minutes in 2000) and catch-per-unit-effort (CPUE) was calculated as the number of individuals counted/time spent searching.

Direct counts are estimates of the number of odonates at a 250m section of wetland. Despite a tremendous reservoir of individual odonates surrounding riparian habitats, odonate density in riparian/breeding habitat has been shown to remain fairly consistent due to territorial behaviour (Moore 1953). Direct counts are considered a conservative measurement of odonate abundance (Conrad et al. 1999).

4.4.6 Statistical Methods

Prior to analysis, normal distributions were tested using the Shapiro-Wilk test, and homogeneity of variances were tested for using the Levene statistic (SPSS 1999, Zar 1999). An *a priori* alpha of 0.05 was selected for all statistical tests of significance. Aquatic macro-invertebrate collections were more frequent in 2000 (i.e. six rounds vs. three rounds in 2001), and more precisely identified in 2001 (i.e. lowest identifiable taxonomic level vs. family level identification in 2000); therefore all analysis regarding invertebrate abundance used 2000 data, and all analyses concerning richness or diversity measures used 2001 data. Friedman's test (nonparametric repeated measures) was used to test for differences in wetland aquatic macro-invertebrate community between grazing treatments. Where significant results were identified, I used Newman-Keuls *post hoc* multiple range test to isolate which means differed. Simple linear correlation analysis was used to investigate the relationship between larval odonates and other aquatic macro-invertebrates in preference to regression analysis because there is no clear dependent variable when considering these two communities; Spearman's rank correlation was used since data was non-normal. I used SPSS version 11.0 (SPSS 1999) for all above tests except Friedman's test, which was performed using SYSTAT Version 10 (SYSTAT 2000).

Direct ordination analysis was used to describe patterns in wetland odonate community in relation to environmental data, including water quality, vegetation structure/community, and aquatic macro-invertebrate community metrics. Adult and larval odonate data were analyzed in separate ordinations using CANOCO 4.0 (1997 version). Spearman's rank correlation analysis was used *a priori* to identify highly correlated parameters (i.e. >0.70) within both species and environmental data matrices to guard against these variables biasing the ordination results. All species and environmental data were standardized via relativization by maxima, and non-normal data were log (x+1) transformed (McCune & Grace 2002). Automatic forward selection of environmental variables was used together with a Monte Carlo permutation test (full model) to identify those parameters that significantly contribute to the ordination, to reduce the large environmental data set (i.e. only significant environmental parameters were included in the final ordination analysis), and consequently restricting these ordinations to exploratory rather than hypothesis-based analysis (McCune and Grace 2002). Redundancy Analysis (RDA) was selected since it is an extension of multiple linear regression (Makarenkov & Legendre 2002). The statistical significance for the relationship between species data and the first ordination axis, as well as species data and the set of environmental variables (i.e. sum of all eigenvalues) was computed using Monte Carlo permutation test (i.e. full model to minimize type II error and maximize statistical power).

4.5 Results

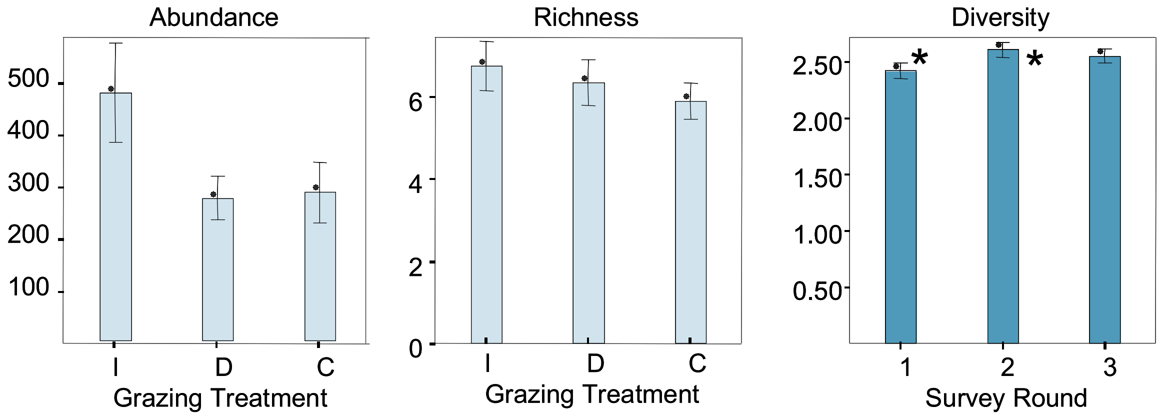
4.5.1 Grazing Treatment and Wetland Aquatic Macro-invertebrate Community

No significant difference in macro-invertebrate abundance between grazing treatments was found overall or any specific aquatic taxa, when accounting for sampling round (no significant treatment effect, sampling period effect, or interaction; Figure 4-2). No significant difference was found in overall aquatic macro-invertebrate richness or diversity between treatments when accounting for sampling round, however diversity was significantly higher in Round 2 compared to Round 1 (significant sampling period effect; no significant treatment or interaction; Table 4-1, Figure 4-2).

Table 4-1: Results for differences in aquatic macro-invertebrate diversity using Friedman's test.
(χ^2 values from Table B.1 in Zar 1999)

Source	df	H	χ^2_{crit}	p-value
Treatment	2	5.051	5.991	not significant
Round	2	7.026	5.991	<0.05
Interaction	4	<1	9.488	not significant

Figure 4-3: Differences in wetland aquatic macro-invertebrate community between grazing treatments.
(Bars represent $\pm$1 S.E.; *=significant difference, alpha 0.05; Shannon's Diversity Index)



4.5.2 Comparison of Odonates to overall Aquatic Macro-invertebrate Community

Significant positive correlations were found between overall aquatic macro-invertebrate abundance and odonates when grouped by *Enallagma* sp., Zygoptera, and overall odonate larvae abundance (Table 4-2). Gastropoda abundance was the only aquatic macro-invertebrate taxon that was significantly positively correlated to larval odonate abundance, specifically *Enallagma* sp. ($r=0.431$, $p<0.05$). Larval odonate diversity was significantly positively correlated to aquatic macro-invertebrate diversity (Table 4-2). No significant correlation was found between odonate richness and overall macro-invertebrate richness.

Table 4-2: Significant correlations between wetland odonate and aquatic macro-invertebrate communities.
(Spearman's rank correlation coefficient; $\alpha=0.05$; diversity =Shannon's Diversity Index)

		Odonata		**Zygoptera**	***Enallagma* sp.**
		Diversity	**Abundance**	**Abundance**	**Abundance**
Aquatic Macro-invertebrate	**Diversity**	+0.632			
	Abundance		+0.470	+0.482	+0.570

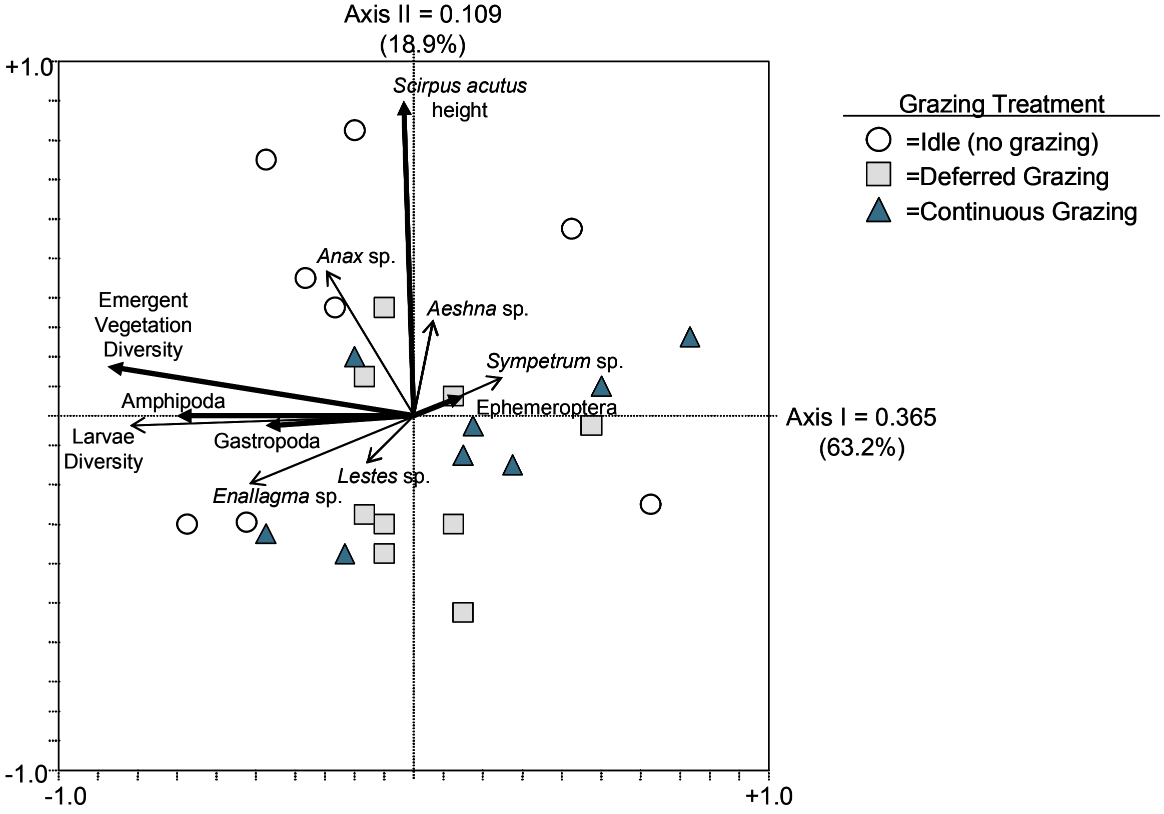
The relationship between larval odonates and their prey was analysed by comparing larval abundance, richness, and diversity to that of potential prey taxa. Potential prey taxa were identified *a priori* according to research on larval odonate diets and included the following eleven taxa: Gastropoda, Acari, Amphipoda, Coleoptera (larvae), Diptera, Ephemoptera, Corixidae, Gerridae, Trichoptera, Oligochaeta, and Hirudinea (Corbet 1999). A significant positive correlation was found for the diversity of larval odonates and their potential prey (r=0.633, p<0.01). No significant correlation was found between larval odonates and their prey with respect to abundance or taxa richness.

4.5.3 The Odonate Community in Relation to the Overall Wetland Environment

Larval and adult odonates were treated separately in direct ordination analysis since they represent two very distinct life stages. With respect to larval odonates (Figure 4-4), the first two ordination axes explained 82.1% of the total variation in both the species and the environmental parameters data set, and the first axis represented a strong environmental gradient (i.e. first eigenvalue is fairly high). Two sites were confirmed as outliers in preliminary bi-plots, and deleted from the final ordinations because they were not representative of the target population (McCune & Grace 2002); Lomond Upslope East (continuous treatment) was directly influenced by a irrigation canal due to a breach in the embankment, and Backflood South (idle treatment) experienced a severe dewatering for the majority of the summer. Removal of these outliers did not notably change the results of the ordination (eigenvalues, results of the Monte-Carlo randomization, or relative tri-plot loci), but merely expanded the ordination space of interest.

The height of the emergent plant *Scirpus acutus* (great bulrush) represented a strong environmental gradient (i.e. large vector, closely associated with the second canonical axis) that mostly influenced the abundance of the larger Anisoptera larvae (i.e. *Aeshna* sp., *Anax* sp., and *Sympetrum* sp.). Smaller Zygoptera larvae abundance was more strongly related to emergent vegetation diversity, as well as Amphipoda and Gastropoda abundance. The abundances of Zygoptera and Anisoptera larvae were divergent. Larval odonate diversity was most strongly associated with emergent vegetation diversity, as well as Amphipoda and Gastropoda abundance. Grazing treatment was only weakly associated with larval odonate diversity, especially for deferred and continuously grazed wetlands. Grazing treatments were well scattered throughout the plot, but most grazed wetlands were not at all associated with *Scirpus acutus* height.

Figure 4-4: Relationship of emergent vegetation and aquatic macro-invertebrate abundance to the larval odonate community at prairie wetlands. (RDA, inter-species focus, bi-plot scaling; $\sum$eigenvalues = 0.577 or 97.7% of variation; 1st axis and $\sum$axes p=0.0001; two outliers (1 idle, 1 continuous) omitted from ordination)

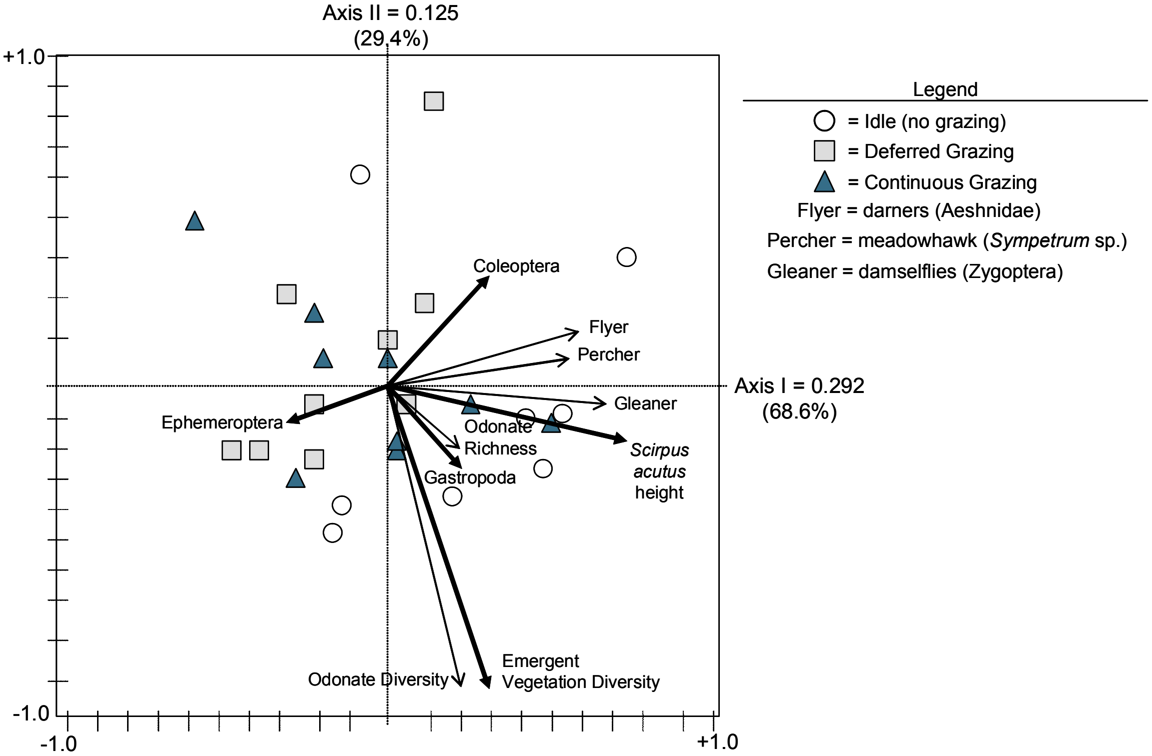


Two ordinations were performed on adult odonate data: 1) all twenty odonate species treated separately, and 2) species categorized by functional feeding groups. The twenty odonate species plot is cluttered; however it is important to show the variation within each feeding group as exhibited by individual species

The first ordination axis (Figure 4-5) was a strong gradient and the ordination axes together explained 98.0% of the total variation in both the species and the environmental parameters data set for odonates characterized as Flyers, Perchers, and Gleaners. One site was confirmed as an outlier in a preliminary ordination bi-plot and deleted from the final ordinations (McCune & Grace 2002); Backflood South (idle treatment) experienced severe de-watering for the majority of the summer. Flyer and Percher abundances were more closely related to each other than to Gleaner abundance, and the abundance of each feeding group contrasted with Ephemeroptera abundance. Odonate diversity was strongly associated with emergent vegetation diversity, and the abundance of all odonate feeding groups (especially Gleaners) was strongly associated in a positive direction with *Scirpus acutus* height.

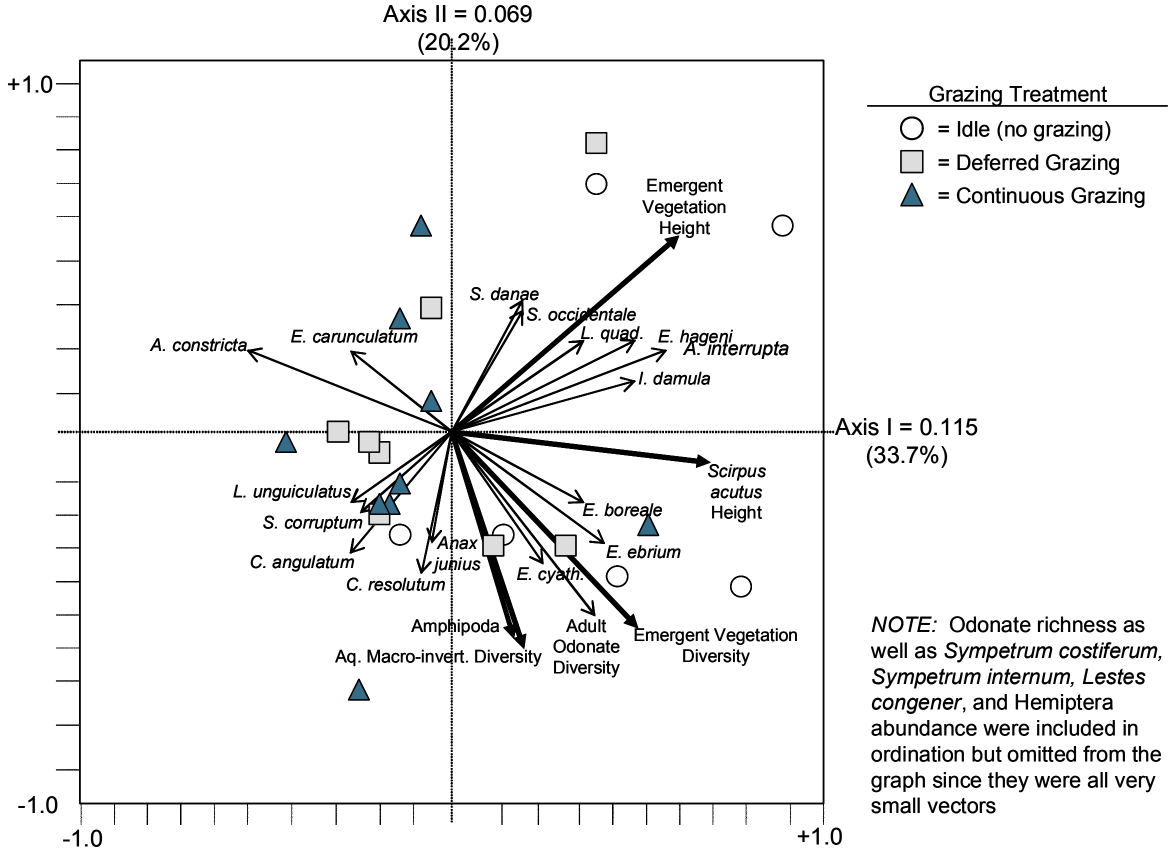
Grazing treatments were only weakly associated with emergent vegetation diversity or odonate diversity. Most grazed wetlands were not at all or only weakly associated with odonate abundance or any aquatic macro-invertebrate abundance, with the exception of Order Ephemeroptera.

Figure 4-5: Relationship of emergent vegetation and aquatic macro-invertebrate abundance to adult odonate feeding groups at prairie wetlands.
(RDA, inter-species focus, bi-plot scaling; ∑eigenvalues = 0.426 or 99.9% of variation; 1st axis p=0.0119, and ∑axes p=0.0016; one outlier (idle site) omitted from ordination)



When each of the twenty adult odonate species was treated separately, the two ordination axes only explained 53.9% of the variation in both the species and the environmental parameters data set and the strength of the gradient from the first ordination axis was diminished to 33.7% (Figure 4-6). Again, two outliers severely influenced the data and were deleted from the final ordinations; both Newell Main Dam and Backflood South (idle treatments) experienced severe draw-downs for a large portion of the summer. The abundance of every odonate species was somewhat associated with emergent vegetation height (especially the larger dragonflies) or diversity (especially the smaller damselflies), except for *Aeshna constricta* (Lance-tipped Darner) and *Enallagma carunculatum* (Tule Bluet). The abundances of Zygopterans and Anisopterans diverged. The abundances of *Enallagma boreale, E. cyathigerum,* and *E. ebrium* were most strongly related to emergent vegetation diversity. Odonate diversity was strongly associated with emergent vegetation diversity, and to a lesser degree aquatic macro-invertebrate diversity and Amphipoda abundance. No specific grazing treatment was strongly associated with emergent vegetation diversity; however grazed wetlands (i.e. deferred or continuously grazed) were not very strongly associated with taller *S. acutus*, or the overall height of emergent vegetation.

Figure 4-6: Relationship of emergent vegetation and aquatic macro-invertebrate abundance to twenty odonate species at prairie wetlands.
(RDA, inter-species focus, bi-plot scaling; ∑eigenvalues = 0.341 or 86.7% of variation; 1st axis p=0.0210, ∑axes p=0.0020; two outliers (idle sites) omitted from ordination)



NOTE: Odonate richness as well as *Sympetrum costiferum, Sympetrum internum, Lestes congener*, and Hemiptera abundance were included in ordination but omitted from the graph since they were all very small vectors

4.6 Discussion

4.6.1 Aquatic Macro-invertebrates and Cattle Grazing

The peak in aquatic macro-invertebrate diversity coincides with mid-summer (i.e. mid-July) and is consistent with peaks in diversity for wetland odonates (i.e. larval odonate diversity peaks in mid-July (Figure 2-9); adult odonate diversity peaks twice over the summer; once in early July and again in early-August (Figure 3-18).

Surrounding land use, in addition to hydroperiod and salinity, are reported to be important determinants of the aquatic invertebrate community in prairie wetlands (Zimmer et al. 2000); however grazing treatment showed no distinct impact on wetland macro-invertebrates (Figure 4-3). Grazing treatment did not affect the aquatic macro-invertebrate diversity, taxa richness, or abundance (i.e. overall or the abundance of any specific taxon).

The dissimilarity in the response of odonates and other aquatic macro-invertebrate taxa to wetland grazing regime is most likely due to the terrestrial adult life phase of odonates. Suitable odonate habitat must encompass requirements for all life stages (i.e. egg, larvae, and adult), and the terrestrial nature of adults makes odonates more closely connected to the emergent and terrestrial vegetation surrounding wetlands than other strictly aquatic macro-invertebrates (Corbet 1999). Since cattle are, at the very simplest, vegetation altering machines it makes sense that organisms, such as adult odonates, that are dependent on emergent vegetation structure would be sensitive to a reduction in vegetation by cattle herbivory, whereas organisms that are not dependent on emergent/terrestrial vegetation, such as other more truly aquatic macro-invertebrates, would not be as sensitive to vegetation altering cattle.

4.6.2 Comparing Wetland Odonate Community to other Aquatic Macro-invertebrates

A significant correlation exists for aquatic macro-invertebrates and Genus *Enallagma*, Suborder Zygoptera, and Order Odonata but the strength of this correlation decreases with each increase in taxonomic level (i.e. less precise identification). Aquatic macro-invertebrate abundance is most strongly positively correlated with *Enallagma* sp. abundance ($r={}^{+}0.570$, $p<0.05$). Aquatic vegetation is most likely the link between aquatic macro-invertebrate and *Enallagma* sp. larvae abundance, since adults of the three most common *Enallagma* sp. (i.e. *E. boreale, E. cyathigerum,* and *E. ebrium*) are positively correlated to emergent vegetation diversity (Figure 4-6), as are most aquatic macro-invertebrate taxa (Figure 4-4 to 4-6).

The positive correlation between larval odonate diversity and aquatic macro-invertebrate diversity is quite strong ($r={}^{+}0.632$, $p<0.01$). Aquatic vegetation is most likely the link to this association, and other studies show that increased structural heterogeneity in aquatic vegetation also is positively correlated with an increase in aquatic macro-invertebrate abundance (Zimmer et al. 2000, Painter 1999, Gilinsky 1984, Voigts 1976). Odonates and other aquatic macro-invertebrates share much of the same basic habitat requirements (i.e. ‘clean’ water, available prey, and substrate for concealing themselves from predators/prey) (Merritt and Cummins 1996). It follows that conditions that are favourable for increasing the number of odonate species inhabiting a wetland (i.e. more emergent vegetation substrate) will also be benefit other aquatic macro-invertebrate taxa. As well, because odonates are a top aquatic predator, their habitat should be improved by the presence of other invert prey.

The positive correlation between the diversity of larval odonates and potential prey items is almost identical to that of overall aquatic macro-invertebrates (i.e. $r=^{+}0.633$, $p<0.01$ for potential prey, and $r=^{+}0.632$, $p<0.01$ for overall macro-invertebrates). This supports the assumption that larval odonates at prairie wetlands are opportunistic feeders whose diets reflect ambient aquatic macro-invertebrate fauna (Corbet 1999). Larval odonate prey taxa were identified in this study based on results from other research rather than direct analysis of larvae gut contents or fecal pellets; therefore, the treatment of potential prey in this study is rather imprecise since I did not consider the influence of handling time or counter-adaptations by prey, and did not include Subclasses Ostrocoda or Cladocera in my invertebrate surveys, which (together with chironomids) are considered primary prey items for larval odonates (Corbet 1999). A positive correlation between the diversity of related taxa has been corroborated by other studies (Pearson & Cassola 1992, Kremen 1994, Flather et al. 1997, Pearson & Carroll 1998, Anderson & Vondracek 1999), and forms the basis of biodiversity indicator species theory. The strong correlation between larval odonate and aquatic macro-invertebrate communities suggests that the relative abundance and diversity of aquatic invertebrates, which are more time/effort consuming to sort and identify, may instead be accurately inferred from the diversity of larval odonates.

4.6.3 The Odonate Community in Relation to the Overall Wetland Environment

When interpreting an ordination graph it is important to consider the distance and angle of the vectors. I chose to preserve the relationship between species (i.e. focus on inter-species distances) rather than sites since I am most interested in the impact on environmental variables on the odonate community. With the focus on species, the species vectors in the ordination space are interpreted based on their relationship to the ordination axis, environmental vectors, and other species vectors (i.e. longer vectors and smaller angles between the species vector and axis or environmental/species vector indicate a stronger relationship), as well as to the sample sites (i.e. where the site falls at 90º to the species vector with longer distances indicating a stronger relationship).

Grazing treatment was not selected as a significant environmental parameter by selection, and the association between grazing treatment and odonate abundance or diversity is weak (Figure 4-4 to 4-6). Grazed and ungrazed sites were roughly distributed as two clusters; idle sites were more closely positively associated with tall/diverse emergent vegetation, and abundant/diverse odonates and other aquatic macro-invertebrates than grazed sites (Figures 4-4 to 4-6). It may seem incongruous that grazing treatment wanot significantly associated with odonate abundance or diversity, however *a priori* directed statistical analysis showed that grazing treatments significantly impact vegetation structure (Figure 3-6), vegetation structure is strongly positively associated with odonate abundance (Figures 3-7 and 4-4 to 4-6), and both adult and larval odonate abundance are significantly lower at deferred grazed compared to ungrazed wetlands (Figure 2-6 and 3-15). The weaker association between grazing treatment and the odonate community most likely has more to do with my simplified treatment of cattle grazing as a categorical variable rather than a continuous variable.

The reliability of an ordination is assessed by considering the consistency of a given pattern, the proportion of variance represented (30-50% considered robust *a priori*), and the statistical strength of that pattern (*a priori* α=0.05) (McCune & Grace 2002).

Interestingly, forward-selection highlighted emergent vegetation diversity and *S. acutus* height as the most important factors influencing separation along the first two axes for all ordinations (Figure 4-4 to 4-6). Emergent vegetation diversity and height were consistently roughly orthogonal on all three tri-plots, indicating that no matter how the odonate data are taxonomically delineated, vegetation structure and diversity remained the two most influential environmental parameters for the wetland odonate community. Odonate diversity in particular was always strongly associated with emergent vegetation diversity. Many of the patterns observed in the ordination tri-plots were found *a priori* in more directed and statistically robust analysis in previous chapters, further supporting my conclusions regarding these patterns (e.g. positive relationship between vegetation diversity and odonate diversity; positive relationship between vegetation height and odonate abundance; lack of significant water quality parameters).

The abundances of Anisoptera larvae and Zygoptera larvae were negatively related, especially with respect to *Sympetrum* sp. and *Enallagma* sp., which were the two genera most commonly identified in the study area (Figure 4-4). Anisoptera larvae are large voracious predators that will depredate smaller Zygoptera larvae (Corbet 1999); this predation pattern may explain an inverse relationship of abundance.

The structure and diversity of emergent vegetation is critically important to both adult and larval odonates (Figures 4-4 to 4-6). Emergent vegetation provides critical emergence structures for larval odonates and offers protection from predators and wind damage during the most vulnerable stage of their life cycle, as well as a wind-break for weaker flyers such as Zygoptera (Corbet 1999). Each genus of larval odonate identified in this study was characterized as ‘climbers’ that cling to submerged vegetation

(Needham et al. 2000, Corbet 1999). The submerged portions of emergent plants (i.e. stems and roots) added to the structural diversity of larval odonate micro-habitat and provided a substrate on which larvae clung, to avoid detection from predators/prey. Additionally, tall lush emergent vegetation may serve to shade and regulate the water temperature in the littoral zone.

The significance of emergent vegetation height (specifically *S. acutus*) to Anisoptera larvae is most likely a reflection of suitable habitat for territorial or ovipositing adults (Figure 4-4). Adult Anisopterans make up the groups Flyers (i.e. large dragonflies that catch prey in flight; includes *Aeshna* sp., *Anax* sp., and *Libellula sp.*) and Perchers (i.e. medium sized dragonflies that dart out from perches; such as *Sympetrum* sp.). Odonates from both of these groups use the tips of tall emergent vegetation, such as *S. acutus*, as perches from which they defend territories, acquire mates, or catch prey (Corbet 1999, Needham et al. 2000). Ovipositing *Aeshna* sp. and *Anax* sp. will saw into the stems of emergent plants and deposit their eggs inside plants (Corbet 1999).

Larval Zygoptera abundance was associated with emergent vegetation diversity rather than *S. acutus* height (Figure 4-4). This association most likely also reflects habitat requirements of adult Zygopterans since these weak flyers tend to select sites low amongst the emergent vegetation while searching for prey and oviposition sites (Corbet 1999). Other studies have found positive correlations between the abundance and richness of aquatic vegetation and larval odonates (Muller et al. 2002, Painter 1999, Sahlen and Ekestubbe 2001). More diverse emergent vegetation provided a more heterogeneous habitat for adult Zygopterans, and was reflected in abundance patterns for *Enallagma* sp., as well as *Ischnura* sp. and *Coenagrion* sp. (Figure 4-6). Adult

Enallagma sp. are dependent on wetland vegetation since all species are either epiphytic or endophytic ovipositors (i.e. deposit eggs either on or within vegetation; Corbet 1999), whereas adult *Ischnura* sp are well-known for hiding among emergent vegetation stems (Westfall and May 1996). The positive correlation between Zygoptera larvae abundance and Gastropoda/Amphipoda abundance is likely explained by a shared dependency on diverse aquatic vegetation, which is a source of food for Gastropoda and Amphipoda (Merritt and Cummins 1996; Figure 4-4).

The aquatic macro-invertebrate community was positively related to emergent vegetation diversity, especially for Subclass Gastropoda and Order Amphipoda (Figures 4-3 to 4-5). Diverse aquatic vegetation positively impacts aquatic invertebrate abundance in this and other studies (Zimmer et al. 2000) since aquatic vegetation provides cover from visual predators (Crowder & Cooper 1982) and increases food resources for aquatic invertebrates (Carpenter & Lodge 1986).

Gastropoda and Ephemeroptera recur as taxa that significantly contribute to patterns in the wetland odonate community (Figure 4-4 to 4-6), and both taxa are suggested in the scientific literature as being suitable biological indicators (US EPA 2002b, Merritt and Cummins 1996). The abundance of Gastropoda, implicated as an indicator of lentic habitat (US EPA 2002b), is positively correlated with Zygopteran abundance, as well as odonate diversity and richness. Conversely, Ephemoptera abundance is consistently negatively correlated with odonate abundance and diversity, as well as all other environmental parameters. This suggests that the suitability of Order Ephemeroptera as an indicator of habitat quality in lotic ecosystems does not extend to lentic ecosystems. Differences may be due to the inherent differences between lotic and lentic ecosystems, since lotic systems are typically cooler nutrient poor waters while lentic systems (especially prairie wetlands) are typically warmer nutrient-rich environments (Murkin et al. 2000). The vast majority of Ephemeroptera identified in this study were either *Caenis* sp. (50%) or *Sipholonurus* sp. (49%) that flourish in the silty sediments of hyper-eutrophic lentic habitats; these are distinctly different from sensitive clear-water specialists used in rapid assessments of lotic habitats (Merrit & Cummms 1996).

4.7 Summary and Management Recommendations

Larval odonate diversity was positively correlated with larval prey and overall aquatic macro-invertebrate diversity, and odonate larvae abundance was positively correlated with overall aquatic macro-invertebrate abundance, which supports the hypothesis that larval odonate diversity is an accurate biodiversity indicator of the aquatic macro-invertebrate diversity at prairie wetlands (i.e. accept more specific Hypothesis #5).

Cattle grazing significantly decreased wetland vegetation structure (i.e. height), but had no biologically significant effect on wetland water quality or vegetation abundance (i.e. % cover), richness, or diversity. My results support the hypothesis that odonates (larval and adult) represent accurate biological indicators of the impact of cattle grazing on vegetation structure and aquatic macro-invertebrate community at prairie wetlands (i.e. accept more specific Hypothesis #6). Surveying the larval and adult odonate community of a wetland provides information that is inherently important, as well as ecologically insightful as to the overall quality of prairie wetland habitat for odonates and other harder-to-survey aquatic invertebrates. Furthermore, aquatic macroinvertebrates are an essential part of wetland trophic webs and serve as a conduit of energy flow from aquatic systems to the terrestrial systems via birds and other vertebrates (Cox et. al. 1998).

Cattle grazing was treated very simplistically in this study; grazing treatments were defined based on the duration of cattle at a site (i.e. all summer vs. part of summer vs. control treatment), without directly addressing the absolute magnitude of this effect on flora (i.e. consider pasture size, standing crop, productivity, density of wetlands in pasture, frequency of grazing, and herd size). Odonates responded to changes in wetland vegetation, but few direct relationships between odonate community and grazing treatment, as defined by idle, continuous, or deferred, were found. Impacts of cattle grazing are typically site specific, and future studies that address cattle grazing as a more complex concept will provide a clearer picture of its ecological impacts on the odonate community. This study has demonstrated positive correlations between odonates and wetland vegetation structure and aquatic macro-invertebrate abundance and diversity, and highlighted odonates as a suitable habitat, biodiversity, and population indicator species, allowing future studies to focus on developing more specific and quantitative Indexes of Biotic Integrities (IBI's) for wetland systems, similar to those widely used in lotic systems.

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Chapter 5

Synthesis of Chapters: Are Odonates Suitable Biological Indicators?

5.1 Summary

Biological indicators are scientifically valid when selections are based on scientific criteria and when empirical studies confirm correlations between the indicator and the indicatee (McGeoch 1998). Odonates are well suited as indicator taxa (Table 1-1) and this study established correlations between the odonate community, and the vegetation and aquatic invertebrate communities of prairie wetlands (Table 5-1).

Table 5-1: Suitability of Odonates as biological indicators at prairie wetlands.

Hypothesis #	Criteria for a suitable bioindicator	Significant?	Detailed Findings	Conclusion
2	Sensitive to changes to wetland water quality due to cattle grazing	n/a	Nutrient inputs from cattle did not significantly impact wetlands water quality.	
4	Sensitive to changes to wetland habitat due to cattle grazing	Yes	Cattle grazing significantly decreased the height of emergent vegetation. Odonates were sensitive to this change with decreased abundance, diversity, and (Zygoptera) reproductive effort at wetlands with shorter emergent vegetation.	Suitable habitat indicator
5	Sensitive to changes in aquatic macro-invertebrate community of a wetland	Yes	Odonate abundance is positively correlated to overall aquatic macro-invertebrate abundance	Suitable population indicator
5	Sensitive to changes in aquatic macro-invertebrate diversity	Yes	Odonate diversity is positively correlated to aquatic macro-invertebrate diversity	Suitable biodiversity indicator
6	Consistently and sensitive to cattle impacts at prairie wetlands when environmental and species data are analysed systematically	Yes	Emergent vegetation height and diversity consistently and strongly influence larval and adult odonate abundance and diversity. Aquatic macro-invertebrate diversity is positively correlated to emergent vegetation and odonate diversity. The abundance of key aquatic macro-invertebrate taxa are positively correlated to odonate abundance and diversity.	Suitable habitat and biodiversity indicator

Wetland vegetation was the most important environmental parameter influencing odonate abundance, reproductive effort, and diversity, as well as an important ecological link explaining correlations between odonate and other aquatic macro-invertebrate communities. The direct impact of cattle grazing on wetland vegetation and the strong correlation between vegetation structure/diversity and odonate abundance/diversity begs the question: why not simply measure wetland vegetation to infer the condition of the odonate community? Surveying the wetland vegetation community gives information regarding its present condition; surveying long-lived riparian obligate taxa, such as odonates, provides additional temporal information such as the impact of past events no longer detectable in the vegetation community (i.e. intermittent events like short-term intense grazing). Maximum ecological insight is gained when bioindicators are monitored in concert with relevant environmental data (Faith & Walker 1996).

Grazing treatments significantly impacted wetland vegetation, which in turn, significantly impacted larval and adult odonates, but grazing treatments did not often directly impact wetland odonates. This apparent disconnect is most likely due to the crude measure of cattle grazing as idle, deferred, or continuous rather than a more precise quantitative metric. Treating grazing regime as a categorical value combined with the logistical constraints of being unable to alter established grazing regimes meant that factors critical to determining the utilization of a pasture/wetland by cattle were not taken into account (i.e. number of cattle per pasture, size of pasture, number of wetlands per pasture, number of days cattle present).

This study is well suited for testing the Intermediate Disturbance Hypothesis (IDH) which contends that diversity is lowest at sites with either extreme (i.e.

continuously grazed wetlands) or minor (i.e. ungrazed wetlands) disturbance (Connell 1978). Differences in odonate diversity between treatments were contradictory for adult and larval odonates; adult diversity was not significantly impacted by grazing treatment (Figure 3-18) while the patterns of larval diversity between treatments supported the IDH (Figure 2-9). Cattle significantly impacted wetland vegetation structure (Chapter 3) but had little impact on wetland water quality (Chapter 2). Results suggest that cattle impact larval odonates via the removal of predatory refugia (i.e. emergent vegetation) or by altering ovipositing habitat, and that although adult odonates are present at wetlands, they are not necessarily encountering ovipositing habitat and depositing eggs at that site. Therefore, this study supports the IDH when considering the breeding portion of a wetland odonate community (i.e. larval odonates), since diversity is consistently lower at chronically disturbed sites, and highest at wetlands immediately following a short-term acute disturbance.

I can not scientifically justify a list of specific odonate species that must be present or absent to assess the quality of prairie wetland habitat; however, this study confirms that odonates are well suited taxa for indicating the impact of grazing disturbance at these dynamic systems. The strongest relationships with wetland biota were often manifested in Suborder Zygoptera (i.e. Gleaners) yet I recommend that all odonate taxa be included in future wetland monitoring programs since the use of multi-species assemblages as bioindicator taxa guards against over-simplifying complex systems and allows for a broader scale of inference, which is more constructive in the field of conservation biology (Wilson 1988, Croonquist & Brooks 1991, Kovacs et al. 1992, Caro & O'Doherty 1999).

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