Hydrobiologia (2011) 669:105–117
DOI 10.1007/s10750-011-0653-0

PRIMARY RESEARCH PAPER

Relationships among rotational and conventional grazing systems, stream channels, and macroinvertebrates

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Received: 18 June 2010 / Revised: 20 January 2011 / Accepted: 26 February 2011 / Published online: 9 March 2011

Abstract Cattle grazing in riparian areas can reduce water quality, alter stream channel characteristics, and alter fish and macroinvertebrate assemblage structure. The U.S. Department of Agriculture, Natural Resources Conservation Services has recommended Rotational Grazing (RG) as an alternative management method on livestock and dairy operations to protect riparian areas and water quality. We evaluated 13 stream channel characteristics, benthic macroinvertebrate larvae (BML), and chironomid pupal exuviae (CPE) from 18 sites in the Upper Midwest of the United States in relation to RG and conventional grazing (CG). A Biotic Composite Score comprised of several macroinvertebrate metrics was developed for both the BML assemblage and the CPE assemblage. Multi-Response Permutation Procedures (MRPP) indicated a significant difference in stream channel characteristics between RG and CG. Nonmetric Multidimensional Scaling indicated that RG sites were associated with more stable stream banks, higher quality aquatic habitat, lower soil compaction, and larger particles in the streambed. However, neither MRPP nor Mann–Whitney *U* tests demonstrated a difference in Biotic Composite Scores for BML or CPE along RG and CG sites. The BML and CPE metrics were significantly correlated, indicating that they were likely responding to similar variables among the study sites. Although stream channel characteristics appeared to respond to grazing management, BML and CPE may have responded to land use throughout the watershed, as well as local land use.

Keywords Bank stability · Grazing management · Chironomid pupal exuvia · Benthic macroinvertebrate

Introduction

Grazing animals can transform the landscape by removing riparian vegetation, compacting the soil, and trampling the stream bank (Trimble & Mendel, 1995). Intensive grazing pressure can influence

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Handling editor: Nicholas R. Bond

The Unit is jointly sponsored by the U.S. Geological Survey, the University of Minnesota, the Minnesota Department of Natural Resources, the Wildlife Management Institute, and the U.S. Fish and Wildlife Service.

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stream habitat and water quality by increasing erosion rates, sediment input, delivery of nutrients, bacterial and fecal material, and decreasing shade along the stream (Meehan & Platts, 1978; Kauffman et al., 1983; Trimble & Mendel, 1995; Knapp & Matthews, 1996; Owens et al., 1996; Belsky et al., 1999).

Continuous grazing systems (CG) are the most common form of livestock grazing. In CG, cattle are allowed access to a pasture for the duration of the growing season. Vegetated riparian buffers and exclusion fencing are commonly implemented as best management practices (BMPs) to mitigate the effects of CG. The effectiveness of buffer strips to improve water quality through increased infiltration and reduced cattle access to the stream has been demonstrated (Beeson & Doyle, 1995, Nerbonne & Vondracek, 2001; Tate et al., 2006). However, researchers have recognized the implementation limitations of the current practices for buffers and are evaluating alternatives (Stonehouse, 1999; Barden et al., 2003). Researchers and managers have suggested rotational grazing (RG) as an alternative management system for livestock and dairy operations (Undersander et al., 1993; Scrimgeour & Kendall, 2003; NRCS, 2005). Rotational grazing is considered a conservation strategy by the Natural Resources Conservation Service (NRCS, 2005), because RG requires a management change on the whole farm and often incorporates other BMPs, such as exclusion fencing and alternative water sources.

Rotational grazing is a multifunctional system that manages land to produce commodities, such as meat and milk, and non-commodity benefits, such as improved water quality and increased wildlife habitat (Boody et al., 2005). Rotational grazing systems manage pastures by rotating a grazing herd through a series of small paddocks, which allows the pasture a period for vegetation to regrow. The stocking density and grazing period in each paddock is often set to maintain a minimal height of vegetation. Although supplementary food may be provided during periods of drought, a RG dairy herd obtains a majority of its food from the pasture.

Rotational grazing systems differ from CG systems in that they are managed to maintain a minimal forage height, which should prevent overgrazing, and RG reduces the temporal and spatial access of cattle to the riparian area. Studies have indicated RG can be associated with improved water quality through reduced runoff, stream bank erosion, sediment inputs, turbidity, embeddedness, organic pollution, and nutrient inputs compared to CG (Olness et al., 1975; Sovell et al., 2000; Bishop et al., 2005; Zaimes et al., 2008). Haan et al. (2006) found that RG did not contribute more sediment or phosphorus than ungrazed grassland, and significantly less than CG pastures. Rotationally grazed pastures were associated with significantly less fine substrate and bank erosion than CG pastures (Lyons et al., 2000; Weigel et al., 2000). Magner et al. (2008) found riparian areas that were not grazed were associated with reduced soil compaction and greater bank stability, whereas CG sites were associated with increased soil compaction and lower bank stability; short-duration grazing sites experienced an intermediate impact.

Improved habitat quality at RG sites is expected to result in increased biotic integrity; however, studies have demonstrated inconsistent results. Weigel et al. (2000) found increased macroinvertebrate biotic integrity along RG sites. Magner et al. (2008) found that macroinvertebrate Index of Biological Integrity (IBI) scores were distributed along a gradient of riparian management; low IBI scores were associated with CG sites, high scores with nongrazed sites, whereas intermediate scores were associated with RG sites. However, Lyons et al. (2000) found no effect of RG relative to CG on fish IBI scores. The effects of RG and CG on the environment differ, but more research is needed to determine whether RG is a beneficial system of land management in regard to water quality and aquatic ecosystems.

The goal of this study was to provide a comparative field study of the physical and biological characteristics along RG managed pastures in the absence of BMPs, such as exclusion fencing and riparian buffers, on adjacent stream channels. This study had two objectives: (1) evaluate stream channels characteristics and grazing density along RG pastures compared to CG pastures, and (2) evaluate macroinvertebrate composition and biotic integrity in streams along RG compared to CG pastures using benthic macroinvertebrate communities as a surrogate measurement of water quality in agricultural landscapes. We expected differences to be observed in stream channel characteristics and macroinvertebrate assemblage between RG and CG streams. Overall, RG sites were expected to have greater bank stability, less bank erosion, larger substrate sizes, fewer fines, reduced embeddedness, and less soil compaction than stream channels along CG sites. Streams adjacent to RG pastures were expected to have greater taxa diversity, particularly within orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), and more sediment and pollution intolerant taxa than streams adjacent to CG pastures.

Materials and methods

Study sites

We identified potential dairy farms adjacent to streams from the Wisconsin Dairy Producer List in county plat books for our study. One hundred and forty-two potential dairy farms were contacted via letter followed by a telephone call. Grazing specialists in southwest Wisconsin assisted in locating RG dairy farms in Wisconsin and Iowa. Two RG dairy farms in Minnesota that had participated in a previous study by Magner et al. (2008) that compared RG and CG management were also included. Ultimately, 18 sites on 9 RG and 9 CG dairy farms in the Driftless Area Ecoregion of the United States (Omernik & Gallant, 1988) were selected for this study: 15 in southwest Wisconsin, 2 in southeast Minnesota and 1 in northeast Iowa (Fig. 1). Grazing management had been in place for ≥15 years for all study sites. All RG sites moved their cows to a fresh paddock every 12–24 h, common for RG dairies in the region. The number of paddocks per site ranged from 10 to 24, with an average return interval of 3 weeks. Study sites without fenced riparian buffers were selected; cows at all study sites had access to the riparian area and stream channel. Two CG sites (2 and 3) had sections of the stream where the bank was stabilized by rip-rap installation within the past 10 years. Each site was visited once between 24 May and 24 June 2008.

The drainage area above each site was delineated from digital elevation maps using ArcGIS. The percent land use in the drainage basins was calculated using ArcGIS. The drainage basin of CG sites ranged from 0.2 to 52.4 km^2 with mean percent land use of 25.5% pasture, 27.6% crops, 40.8% wooded, 5.8% urban, and 0.2% water. The drainage basin of RG sites ranged from 2.2 to 181.0 km^2 with mean percent land use of 17.5% pasture, 46.9% crops, 26.7% wooded, 8.9% urban, and 0.2% water. The stocking rate (where a AU = one 455 kg animal) at CG sites ranged from 0.3 to 4.8 AU/ha, and RG sites ranged from 0.2 to 4.7 AU/ha.

Channel characteristics

Channel characteristics were assessed for stream reaches located at the downstream end of the grazed area at each site. Length of the stream reach was defined by the mean stream width multiplied by 35, following the protocol of Simonson et al. (1994), with a minimum reach length of 150 m. Reach lengths ranged from 150 to 650 m.

Thirteen channel characteristics were measured for analysis (Table 1). Eight measurements were taken along 10 equally spaced transects following a modified protocol from Simonson et al. (1994). Measurements

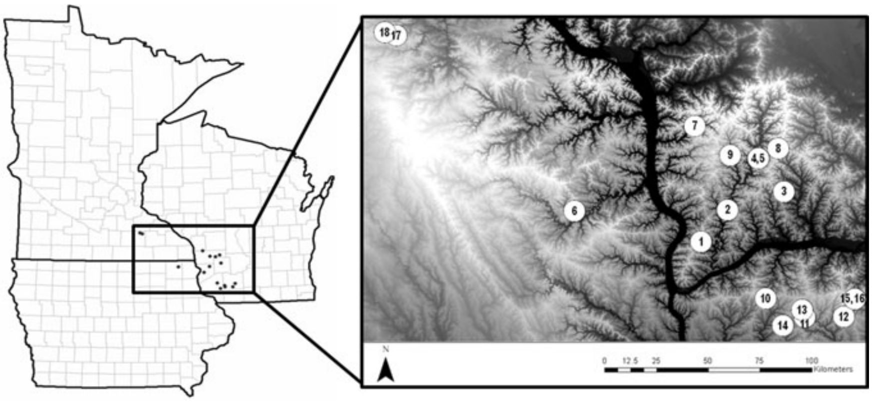

Fig. 1 Study site locations and upstream drainage basin. Sites 1–9 were continuous grazing sites, and sites 10–18 were rotational grazing sites

Table 1 Thirteen channel characteristics evaluated at rotational grazing and conventional grazing sites in Iowa, Minnesota, and Wisconsin

Site	Minnesota stream habitat assessment	Pfankuch stability index	Bank erosion (%)	Width coefficient of variation	Velocity coefficient of variation	Depth coefficient of variation	Width/Depth ratio	Embeddedness (%)	Fines (%)	Median particle size (D_{50})	84th Percentile particle size (D_{84})	Canopy cover (%)	Soil compaction (kg/cm^2)
Conventional grazing sites													
1	44	112	70	0.1	0.53	0.45	22	54	74	1	14	0	79.5
2	67	52	19	0.12	0.9	0.58	9	30	23	25	91	8	94.1
3	67	77	25	0.27	0.83	0.29	7	29	26	36	91	7	89.0
4	51	70	20	0.2	2.02	0.77	13	68	61	1	91	41	70.2
5	51	62	51	0.4	1.01	0.53	24	21	19	91	182	35	83.2
6	37	89	66	0.52	1.54	0.44	12	53	50	5	55	11	82.2
7	52	88	41	0.28	0.63	0.33	9	31	31	15	32	10	72.6
8	45	80	34	0.61	0.64	0.39	11	32	27	20	60	23	64.4
9	47	85	21	0.39	0.74	0.51	9	64	10	12	23	27	75.4
Rotational grazing sites													
10	65	86	43	0.14	1.06	0.88	24	49	44	16	91	50	82.2
11	71	61	18	0.15	1	0.4	10	35	51	4	91	48	74.0
12	66	71	46	0.17	0.57	0.53	17	59	20	55	182	30	52.2
13	49	87	29	0.18	0.42	0.32	5	63	62	1	15	31	46.7
14	72	46	22	0.33	0.64	0.35	13	0	5	39	182	65	67.2
15	60	48	11	0.2	0.64	0.35	5	32	27	17	48	0	67.9
16	67	56	12	0.2	0.74	0.35	5	18	6	43	182	0	61.0
17	45	70	27	0.2	0.61	0.28	25	32	19	48	182	4	85.3
18	62	55	31	0.42	1.21	0.52	14	25	18	50	182	25	81.2
Mean CG	51	79	38	0.32	0.99	0.48	13	42	35	23	71	18	231
Mean RG	62	64	26	0.22	0.79	0.44	13	34	28	30	128	28	198

included velocity, wetted width, depth, bank erosion, embeddedness, canopy cover, and soil compaction. Stream depth and velocity were measured at 5 points along each transect using a Marsh-McBirney Flo-Mate^{TM} flow meter and a graduated wading rod. We calculated a wetted width/depth ratio for the stream channel. The coefficient of variation (CV) was calculated for width, depth, and velocity at each study site for data analysis. Percent bank erosion was visually estimated to the nearest 10% of bare soil within ±0.5 m of the transect extending up the streambank. Percent embeddedness was visually estimated to the nearest 10% for 10 particles randomly selected along each transect. Canopy cover was estimated to the nearest 10% of each transect in shade when the sun was directly overhead. Riparian soil compaction was measured 1 m from the stream bank on either side of the stream at depths of 7.6, 15.2, 22.9, 30.5, and 38.1 cm, using a Dickey John$^{®}$ soil compaction tester at each transect. The mean values for all measurement over the 10 transects were calculated for each stream reach.

A modified Wolman pebble count was conducted at each site, following a zigzag pattern throughout the stream reach (Bevenger & King, 1995). The diameter of the intermediate axis of 200 pebbles was estimated to ±1 mm for diameters <64 mm and by size class for diameters ≥64 mm. The pebble count was used to calculate percent fines ≤6.4 mm, median particle size (D_{50}), and the particle size of the 84th percentile (D_{84}).

Two qualitative indices were conducted in each study reach to evaluate bank stability and aquatic habitat quality: the Pfankuch Stability Index (PSI) (Pfankuch, 1975) and Minnesota Pollution Control Agency's Stream Habitat Assessment (MSHA) (MPCA, 2007). The MSHA is modified from the Ohio Qualitative Habitat Evaluation Index (Rankin, 1989).

Benthic macroinvertebrate communities

Previous studies that have evaluated macroinvertebrates in relation to grazing have only collected benthic macroinvertebrate larvae (BML). In this study, in addition to benthic macroinvertebrates, we identified chironomid pupal exuviae (CPE). The collection of CPE is a cost-effective alternative biomonitoring method because CPE are simple to collect, more easily identified than larval chironomids, and chironomids alone may be as informative for bioassessment as using a larger group of taxa (Ferrington et al., 1991). Chironomid pupal exuviae have been useful in assessing the impact of point sources of sewage and heavy metals (Coler, 1984; Ferrington & Crisp, 1989; Hayford & Ferrington, 2005). Thus, Chironomidae may also be as or more sensitive to local agricultural land use as other benthic macroinvertebrates.

Benthic invertebrates were sampled from all sites within a month to reduce seasonal effects on the benthic communities. Samples were collected using a modified Hess sampler (surface area, 0.086 m^2; mesh size 500 μm). Three samples were collected from riffles in the downstream portion of each study reach, except sites 4 and 6 where two samples were collected. The BML were only collected in riffles rather than multiple habitats, because riffles tend to be more sensitive to disturbance gradients than multiple habitat samples or other single habitat samples (Blocksom et al., 2008). Samples were preserved in 70% ethanol. Each sample was subsampled in the laboratory to 300 specimens or until all specimens in the sample had been sorted (Hilsenhoff, 1987). Thus, up to 900 specimens were identified at each site. Insect larvae, except Chironomidae, were identified to genus using Merritt & Cummins (1996). Non-insect taxa were identified to family or order.

A single qualitative CPE sample was collected at each study site. In streams <10 m wide, most pupal exuviae drift less than 100 m from their emergence site before entering an eddy (Wilson & Bright, 1973), but low numbers of exuviae can drift up to 250 m downstream from their site of emergence (Wilson & Ruse, 2005). CPE samples were collected in the downstream end of each site following the protocol of Ferrington et al. (1991) to guarantee that most of the specimens originated from the study reach. Collection was focused along stream edges and in eddies where foam, debris, and exuviae accumulate. Floating exuviae were collected for a 10 min period by dipping the edge of a pan (30 cm × 22.5 cm × 5 cm) beneath the water surface, allowing water, exuviae, and debris to flow into the pan. The contents of the pan were poured through a 125 μm sieve. This process was rapidly repeated during the collection period, starting at the farthest downstream area and continuing upstream, on average a 50 m length of the channel was sampled. Each sample was subsampled to 150 specimens. Less than 150 CPE specimens were collected from two sites likely due to high discharge prior to sampling. These two sites were excluded and analysis of CPE was performed on the remaining 16 sites. Chironomid pupal exuviae specimens were identified under the dissecting scope to genus using Wiederholm (1986). Three specimens from each genus from each sample were individually mounted in Euparal® on microscope slides to verify identification.

Biotic composite scores

Biotic composite scores (BCS) comprised of several macroinvertebrate metrics were developed for both the BML assemblage and the CPE assemblage. Biotic composite scores provided a narrative assessment of water quality to compare the two grazing types. Metrics for BML samples (Table 2) included taxa number, percent dominance of the three most abundant taxa (percent dominance-3 taxa), Hilsenhoff Biotic Index, percent Chironomidae, percent Ephemeroptera, percent Coleoptera, percent predators, and percent depositional (Hilsenhoff, 1987; Barbour et al., 1992; Kerans & Karr, 1994; DeShon, 1995; Fore et al., 1996; Barbour et al., 1999; Karr & Chu, 1999, p. 76; Zweig & Rabeni, 2001; Braccia & Voshell, 2006, 2007). Metrics for the CPE samples (Table 3) included taxa number, percent dominant-3 taxa, Hilsenhoff biotic index, percent intolerant, percent Tanytarsini, percent Orthocladiinae, and percent burrower (DeShon, 1995; Angradi, 1999; Kosinicki & Sites, 2007).

Metric values were assigned unitless scores: 5, 3, and 1 (Tables 2, 3). Division between scores was set at the 1st and 3rd quartile for each metric (Karr et al., 1986). For metrics with a negative response to increasing disturbance, a 5 was assigned to values ≥3rd quartile, indicating relatively good quality. A score of 3 was assigned to metric values between the 1st and 3rd quartile, and a score of 1 was assigned to metrics ≤1st quartile. Metrics with a positive relationship to increasing disturbance were assigned scores in reverse order. Scores of the metrics for each site were summed, to generate the BCS. The maximum BML BCS was 45 and the maximum CPE biotic index score was 35. A BCS was calculated for each BML sample, and the mean BCS was calculated for each site.

Table 2 Metrics for benthic macroinvertebrate larvae (BML), the predicted response, reference, and score for each metric

Metric	Metric driver	Response to overgrazing	Reference	Score		
				1	3	5
Taxa number	Habitat homogenity, sedimentation	Decrease	Barbour et al. (1992), Barbour et al. (1999), Karr & Chu (1999), (2001)	≤5.8	>5.8 and <11.0	≥11.0
Percent dominance-3 taxa	Disturbance	Increase	Barbour et al. (1999), Karr & Chu (1999)	≥94.6	<94.6 and >80.6	≤80.6
HBI	Disturbance	Increase	Fore et al. (1996), Karr & Chu (1999)	≥5.0	<5.0 and >4.6	≤4.6
Percent Chironomidae	Disturbance Sedimentation	Decrease	Karr & Chu (1999), Zweig & Rabeni (2001)	≥52.3	<52.3 and >12.9	≤12.9
Percent EPT	Disturbance	Decrease	Fore et al. (1996)	≤13.5	>13.5 and <52.3	≥52.3
Percent Ephemeroptera	Organic pollution, dissolved oxygen	Increase	Hilsenhoff (1987), Barbour et al. (1992), Kosinicki & Sites (2007)	≤7.9	>7.9 and <43.5	≥43.5
Percent Coleoptera	Sedimentation	Increase	Fore et al. (1996)	≤0.3	>0.3 and <11.2	≥11.2
Percent predator	Trophic relationships, disturbance	Decrease	Kerans & Karr (1994), Karr & Chu (1999)	0	>0 and <2.6	≥2.6
Percent depositional	Sedimentation	Decrease	Braccia & Voshell (2006), Braccia & Voshell (2007)	≥92.5	>64.7 and >64.7	≤64.7

Division between scores was set at the 1st and 3rd quartile for each metric

Table 3 Metrics for chironomid pupal exuvia (CPE), the predicted response, reference, and score for each metric

Metric	Metric driver	Response to overgrazing	Reference	Score		
				1	3	5
Taxa number	Habitat homogenity, sedimentation	Decrease	Barbour et al. (1992), Zweig & Rabeni (2001)	≤ 9.0	>9.0 and <13.5	≥ 13.5
Percent dominance-3 taxa	Disturbance		Barbour et al. (1999), Karr & Chu (1999)	≥ 87.3	<87.3 and >71.0	≤ 71.0
HBI	Disturbance biological oxygen demand	Increase	Barbour et al. (1999), Karr & Chu (1999)	≥ 6.9	<6.9 and >6.3	≤ 6.3
Percent Intolerant	Sediment	Decrease	Deshon (1995), Kosinicki & Sites (2007)	≤ 4.5	>4.5 and <33.5	≥ 33.5
Percent Tanytarsini	Organic pollution, dissolved oxygen	Increase	Angradi (1999)	≤ 3.6	>3.6 and <14.3	≥ 14.3
Percent Orthocladiinae	Organic pollution, dissolved oxygen	Increase	Barbour et al. (1992), Hilsenhoff (1987), Kosinicki & Sites (2007)	≥ 94.0	<94.0 and >63.7	≤ 63.7
Percent Burrower	Sedimentation	Decrease	Fore et al. (1996)	≥ 14.7	<14.7 and >3.7	≤ 3.7

Division between scores was set at the 1st and 3rd quartile for each metric

Data analysis

A Multi-Response Permutation Procedure (MRPP) with Sorenson's distance measure was used to compare watershed and channel characteristics, Biotic composite scores for BML, CPE, and combined BML, and CPE assemblage composition between grazing types using PC-ORD version 5 (McCune & Mefford, 1999). MRPP is a non-parametric procedure that does not require assumptions of normality or variance (McCune & Grace, 2002). MRPP can address similar questions as a Multivariate Analysis of Variance to compare two or more pre-existing groups of variables. For analysis of the watershed characteristics, drainage area was log$_{10}$ transformed and all land use variables were converted to proportions and arcsine square-root transformed. For analysis of the stream channel characteristics, embeddedness, bank erosion, canopy cover, and percent fines were converted to proportions and arcsine square-root transformed and width/depth ratio, D_{50}, D_{84}, MSHA, PSI, and soil compaction were log$_{10}$ transformed. Values for BML, CPE, and combined BML and CPE assemblage composition were log$_{10}$ transformed.

One-sided Mann–Whitney *U* tests using Statistica (StatSoft, Inc., 2009) were performed to compare stocking rate (AU/ha) of pasture and stocking rate per length stream (AU/ha/km); where a AU = one 455 kg animal (Holechek et al., 2001) between the grazing types and on the BCS of both assemblages to compare the water quality between the two grazing types. Mann–Whitney *U* tests were considered significant at $P \leq 0.05$. Pearson correlation analyses were performed to evaluate; (1) the relationship between the stocking rate and each channel characteristic separately, (2) the stocking rate per length of stream and each channel characteristic separately, (3) the relationship between the BML and CPE BCS, (4) the relationship between the metrics of community structure for the BML and CPE with each channel characteristic, and (5) the relationship between the metrics of community structure for the BML and CPE with stocking rate. The Pearson correlations were considered significant at $P \leq 0.05$.

Nonmetric multidimensional scaling (NMS) with PC-ORD version 5 (McCune & Mefford, 1999) with Sorenson's distance measure was used to ordinate stream channel characteristics. Nonmetric multidimensional scaling does not assume linear relationships among variables (McCune & Grace, 2002). Nonmetric multidimensional scaling calculates the stress of the ordination or the optimality of the solution. A final stress <10 indicates little risk in making inferences, whereas interpretation of an ordination with a final stress >10 may be misleading (Clarke, 1993). Real data were run 50 times and a Monte Carlo simulation (a standard option in PC-ORD version 5) was completed with 50 runs of randomized data to evaluate the

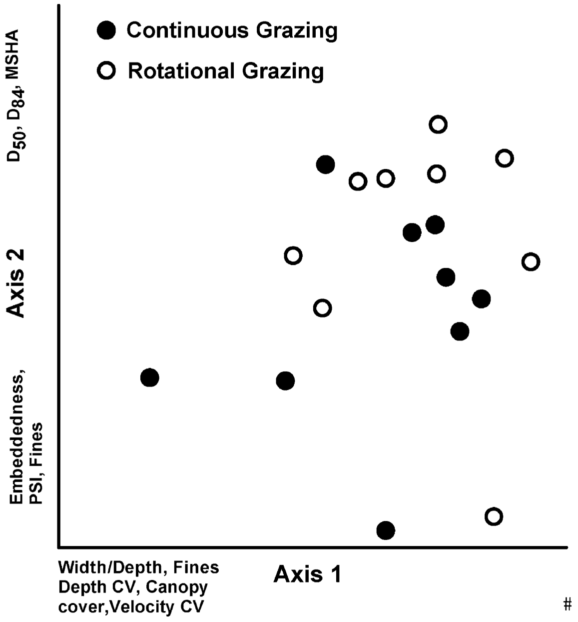

Fig. 2 Nonmetric multidimensional scaling ordination of 13 stream channel characteristics for 18 stream sites. Numbers indicate site number in Table 1. Final stress = 9.57, final instability <0.00001, and number of iterations = 54

probability that a similar final stress could be obtained by chance. A random starting configuration was used. The NMS used the 13 channel characteristics with embeddedness, bank erosion, canopy cover, and percent fines converted to proportions and arcsine square-root transformed (Table 1). Soil compaction, D_{50} D_{84}, MSHA, and PSI were $\log_{10}$ transformed. Following the ordination, channel characteristics were correlated with both axes using a Pearson correlation and Kendall's rank correlation ($P = 0.05$). Stocking rate and stocking rate per length stream were correlated with both axes of the NMS of the channel characteristics using a Pearson correlation and Kendall's rank correlation ($P = 0.05$).

Results

Drainage area and watershed land use were not significantly different across grazing types ($A = -0.005$, $T = 0.177$, $P = 0.474$, MRPP). However, stocking rates of the 18 sites ranged from 0.2 to 4.8 AU/ha or 0.1 to 7.7 AU/ha/stream length and were significantly different ($P = 0.050$ and 0.019, respectively; Mann–Whitney *U* test). Only the CV of velocity ($P = 0.013$ and 0.012, Mann–Whitney *U* test) and percent fines ($P = 0.019$ and 0.010, Mann–Whitney *U* test) in the stream channels were correlated with AU/ha and AU/ha/stream length. The relationships were positive, thus the CV of velocity and percent fines increased with higher stocking rates.

Channel characteristics were significantly different between grazing types ($A = 0.067$, $T = -1.996$, $P = 0.050$, MRPP). The 13 physical channel variables explained 15.3% of the variance along axis 1 and 78.8% along the second axis in a two-dimensional NMS after 54 iterations (Fig. 2). Final stress was 9.57 and instability was <0.00001. CV of Velocity, CV of Depth, width/depth ratio, and canopy cover were significantly and negatively correlated with the first axis of the NMS (Table 4). D_{50}, D_{84}, and MSHA were significantly and positively correlated with the second axis of the NMS, whereas percent fines and embeddedness were significantly and negatively correlated with the second axis of the NMS. Neither measure of stocking rate was correlated with the first or second axes of the NMS ($r < 0.270$).

A total of 104 taxa was collected; 68 taxa were collected from BML samples, dominated by Chironomidae, *Baetis*, and *Simulium*. The number of taxa ranged from 6 to 20 at BML sites. Thirty-six genera of CPE were collected, dominated by *Eukiefferiella*, *Cricotopus*, and *Micropsectra*. The number of taxa ranged from 4 to 18 taxa for CPE samples. We found no significant difference between grazing management for BML ($A = 0.004$, $T = -0.310$, $P = 0.329$, MRPP), CPE ($A = -0.002$, $T = 0.103$, $P = 0.480$, MRPP), or BML and CPE combined ($A = 0.002$, $T = -0.221$, $P = 0.365$, MRPP).

The range of BCS for BML samples was 19.7–35.0 and the range of BCS for CPE samples was 11–29. The mean BML BCS for CG was 26.6 and the mean score for RG was 27.4. The mean score for the CG BCS for CPE was 19.9 and the mean for RG was 22.0. The BCS for BML and CPE were not significantly different between CG and RG sites (BML = 0.875, CPE = 0.318, Mann–Whitney *U* test). There were no relationships with stocking rate (AU/ha or AU/ha/km) or Fines with metrics of community structure for riffle larvae; however, Coleoptera were correlated with PSI ($r = -0.519$, $P = 0.028$) and embeddedness ($r = -0.543$, $P = 0.020$) and percent dominant-3 taxa was correlated with bank erosion ($r = 0.503$, $P = 0.034$); channel characteristics which are affected

Table 4 Pearson and Kendall's rank correlations with the NMS ordination axes for channel characteristics

Axis	1			2		
	r	r^2	τ	r	r^2	τ
D_{50}	0.309	0.095	0.013	**0.933**	0.87	**0.766**
% Fines	**−0.457**	0.209	−0.021	**−0.852**	0.726	**−0.721**
D_{84}	−0.237	0.056	−0.157	**0.883**	0.78	**0.757**
Velocity CV	**−0.861**	0.742	**−0.529**	−0.052	0.003	0.007
Embeddedness	−0.325	0.105	−0.163	**−0.686**	0.47	**−0.621**
Depth CV	**−0.719**	0.517	**−0.464**	−0.045	0.002	−0.059
PSI	−0.147	0.022	−0.066	−0.7	0.49	**−0.525**
Width/Depth	**−0.559**	0.312	**−0.477**	0.127	0.016	0.137
MSHA	0.131	0.017	0.092	**0.556**	0.309	**0.446**
Canopy cover	**−0.471**	0.222	**−0.356**	0.133	0.018	0.013
Bank erosion	−0.33	0.109	−0.281	−0.36	0.13	−0.111
Soil compaction	−0.307	0.094	−0.294	0.197	0.039	0.033

Values in bold are significant at $P < 0.05$

by grazing. Intolerant taxa ($r = -0.655$, $P = 0.005$) and HBI ($r = 0.659$, $P = 0.006$), metrics of community structure for CPE, were correlated with soil compaction, and Tanytarsini were correlated with stocking rate (AU/ha; $r = 0.530$, $P = 0.031$) and stocking rate per stream length (AU/ha/km; $r = 0.576$, $P = 0.022$). The BML and CPE BCS were significantly correlated ($r = 0.781$, $P < 0.001$) (Fig. 3).

Discussion

We found a significant difference in the stream channel characteristics and habitat between RG and CG sites. Pastures managed by RG indicated a reduced impact of cattle at the local reach scale, which included greater streambank stability, larger substrate size in the streambed, and overall greater habitat quality. However, we found no difference in the macroinvertebrate assemblages between the two grazing types. The lack of difference in the macroinvertebrate assemblage between management types is similar to a study of stream reaches with and without livestock exclusion to the riparian area (Ranganath et al., 2009). There may be two reasons why the macroinvertebrate assemblages may not have been different between RG and CG; (1) the macroinvertebrate assemblage may have responded to land use at a scale greater than the study reach, and (2) the differences of the channel variables between the two grazing types may have been statistically different, but not ecologically different enough to effect a change in the macroinvertebrate assemblage.

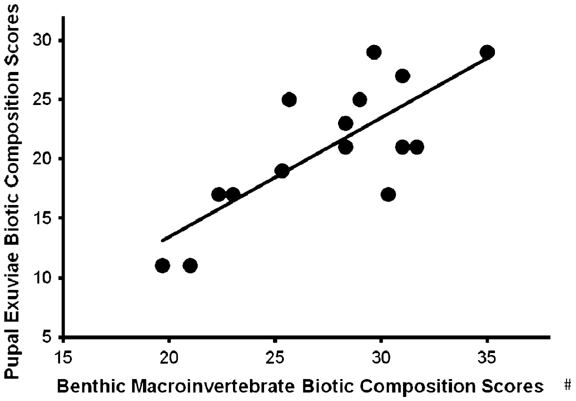

Fig. 3 Relationship of the mean benthic macroinvertebrate biotic composite scores with chironomid pupal exuviae biotic composite scores

The underlying assumption in this study was that the management of grazed pastures at the local scale would be the most influential factor affecting channel characteristics and the macroinvertebrate assemblages. We found that the stocking rate was correlated with the CV of velocity and the percent fines in the streambed. The positive relationship with percent fines is consistent with increased cattle activity on the streambanks (Trimble & Mendel, 1995), which may have decreased infiltration and increased the delivery of fine sediment into the streambed. Thus, there was an effect of grazing at the local scale.

There has been significant discussion in the literature about the scale at which benthic macroinvertebrate assemblages are influenced; land use and land cover at the local reach (Sponseller et al., 2001), land use and land cover along the riparian corridor (Rios & Bailey, 2006), or land use and geology throughout an entire watershed (Richards et al., 1996), or land use both adjacent to the stream and throughout the catchment (Vondracek et al., 2005). Although stream channel characteristics were significantly different along our study sites, these sites existed in watersheds where other land uses upstream may have affected the water quality, stream channel characteristics, and the macroinvertebrate assemblage in the study reaches.

We evaluated stream reaches on individual farms and did not evaluate the extent of grazing practices or BMPs at the watershed scale. Wang et al. (2002) found that a watershed with widespread riparian and upland BMPs had higher overall stream habitat quality, bank stability, and abundance of coldwater fishes. However, a watershed with limited riparian and upland BMPs did not have similar habitat quality or bank stability. Thus, differential implementation of RG and other BMPs in the watersheds upstream of our study sites may account, in part, for the lack of response of the macroinvertebrates.

The current condition of the watersheds must also be placed into an historical context. Agricultural activities, including grazing on steep hillsides after 1850 significantly altered stream systems; however, soil conservation practices after the 1930s and the implementation of Public Law (PL) 566 in the 1950s and 1960s reduced frequent flooding and associated erosion, and increased infiltration and base flow (Thorn et al., 1997). However, Harding et al. (1998) found that watershed land use in the 1950s was a better indicator of present invertebrate and fish diversity than land use in the 1990s. While grazing management at all study sites had been in place for $\geq$15 years, land use prior to that time may have had long-term impacts on the aquatic ecosystem.

The percent of the watershed in cropland, urban land use, and to lesser extent, pasture likely influenced the macroinvertebrate assemblage, possibly concealing a response of the macroinvertebrate assemblage to grazing management (Allan, 2004). Macroinvertebrates and fish can be affected by low levels of urbanization in a watershed. The threshold of watershed impervious cover associated with urbanization is between 7 and 14%, above which IBI scores are consistently poor (Wang et al., 2001; Wang & Kanehl, 2003; Miltner et al., 2004; Stepenuck et al., 2008). The drainage area of 12 of the 18 sites had urban land cover above 7%, which could have influenced the macroinvertebrate assemblage more than grazing type within the reach. Wang et al. (2001) found that agricultural land use in a watershed >50% resulted in low IBI scores. The drainage area of 6 of 18 sites had >50% land in row crops, which could have also influenced the macroinvertebrate assemblages, concealing a response of the macroinvertebrates to grazing type at a local scale.

The second hypothesis for the why differences in macroinvertebrate communities were not observed is that although several channel variables were statistically significant, the habitat may not have been ecologically different enough to affect the macroinvertebrate assemblages. For example, Kaller & Hartman (2004) found macroinvertebrate diversity was reduced when fines comprised >0.9% of the substrate mass in riffles. Even though substrate size in RG sites was significantly larger than CG sites, fines were likely not reduced below a threshold level. Cuffney et al. (2000) concluded that benthic macroinvertebrates had a threshold response to low levels of agricultural intensity.

We found support for the use of RG without additional BMPs as a conservation strategy on pastured land to increase bank stability and aquatic habitat quality. Rotational grazing is considered a conservation strategy by the Natural Resources Conservation Service (NRCS, 2005). The increased frequency of rotation in RG management and the implementation of other BMPs, including exclusion fencing and alternative water sources, are likely to further decrease the impact of grazing in the riparian area and on the stream channel (Wang et al., 2002). However, RG on a small stream reach may not result in significant changes in water quality. Although RG at the study sites was associated with increased streambank stability and larger particle sizes in the streambed, the overall land use in the watershed may have prevented improved biological integrity. Many studies have concluded that BMP implementation should be focused on longer reaches or whole watersheds (Brezonik et al., 1998; Wang et al., 2002; Vondracek et al., 2005; Ranganath et al., 2009). Thus, grazed lands adjacent to streams impaired for sediment or biotic integrity could be targeted for adoption of RG as part of an integrated watershed management system.

The CPE assemblage composition and BCS did not distinguish between the two grazing types. However, the BML assemblage composition and BCS, which included commonly used metrics (Hilsenhoff, 1987; Barbour et al., 1992; Kerans & Karr, 1994; DeShon, 1995; Fore et al., 1996; Barbour et al., 1999; Karr & Chu, 1999, p. 76; Zweig & Rabeni, 2001; Braccia & Voshell, 2006, 2007), also did not distinguish the grazing management types. The significant correlation between the two BCS indicated that they were likely responding to similar variables among the study sites. This study did not provide sufficient evidence to conclude that CPE could more effectively or efficiently be used to monitor degradation in agricultural watersheds; however, the use of CPE may warrant further investigation.

Conclusions

This study demonstrated a difference in overall stream channel characteristics and habitat quality between stream reaches adjacent to rotational grazing and continuous grazing management. Although there was an increase in percent fines in the streambed with increased stocking rate, rotational grazing sites had more stable streambanks, higher quality aquatic habitat, lower soil compaction, and larger particles in the streambed than conventional grazing sites. Rotational grazing is a strategy that may mitigate local bank and stream habitat degradation, and implemented over a long reach may improve the macroinvertebrate assemblage.

Acknowledgments We thank the members of the research group: Nick Jordan, Steve Manson, and Kristen Nelson for their contributions to the formation of this project. We also thank Brandon Wiarda and Sonya Ewert for their help collecting field data, Rebecca Jacobson for insect identification, Adam Berland for GIS analysis, and Leonard Ferrington Jr. for his wealth of knowledge about Chironomidae. An earlier draft of this manuscript was improved thanks to reviews by Shaun Moore, Eric Romaniszyn, and Brian Weigel. This research was funded by the National Science Foundation under the Biocomplexity in the Environment Priority Area, Award ID 0709613. Reference to trade names does not imply endorsement by authors or the U.S. Government.

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