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Stream bed substrate composition adjacent to different riparian land-uses in Iowa, USA

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ABSTRACT

Extensive land-use changes in Iowa have increased erosional processes and the amount of fines deposited on stream beds. Large amounts of fines cover the other bed substrate that are essential habitat for invertebrates and fish. In Iowa and other agricultural Midwestern states, riparian conservation land-uses are being established to minimize sediment inputs to streams. This study compared stream bed substrate composition in reaches adjacent to: riparian forest buffers, grass filters, row-cropped fields, pastures with cattle fenced out of the stream and continuous, rotational and intensively grazed rotational pastures, in three regions of Iowa. The objective was to examine the impacts of the adjacent riparian land-uses on stream bed substrate composition. The percentages of fines in this study ranged from: 36 to 63% in the central region; 10 to 31% in the northeast region; and 22 to 85% in the southeast region. The high percentage of fines in most stream bed reaches indicates high embeddedness. The high embeddedness resulted in the few significant differences in substrate percentages among riparian land-uses. Decades of agricultural land-uses have heavily impacted stream beds and only significant reductions in surface and bank erosion at the watershed scale can begin to reverse this trend. There were indications that riparian forest buffers and to a lesser degree, pastures with cattle fenced out of the stream, could decrease fines resulting in a more diverse substrate composition. Overall, more targeted approaches for the establishment of conservation land-uses in combination with other restoration practices (e.g. in-stream enhancements) are required to successfully decrease fines on stream beds.

1. Introduction

Sediment input to streams is a natural process, but too much or too little sediment can be detrimental to the functioning of a stream or river (Nerbonne and Vondracek, 2001). In the last 150 years, 90% of Iowa's land has been converted from tall-grass prairies, containing many wetlands and some riparian forests (Whitney, 1994), to annual row-crops and cool-season grass pastures (Burkart et al., 1994). Bare soil between crop rows erodes easily and can be transported to streams by overland flow (Waters, 1995). Grazing in riparian areas can reduce stream bank vegetation, making banks more susceptible to erosion (Belsky et al., 1999). The USDA-NRCS (2000) estimated that from 1/3 of Iowa's land, approximately 12,000 kg/ha/year of soil are eroded with most of these materials entering streams. As a result, sediment is the most common non-point source pollutant and a major factor responsible for stream degradation in agricultural watersheds (USEPA, 1996).

Excessive sediment inputs to rivers or streams increase sedimentation in channels, reservoirs and harbours (Owens et al., 2005). Sedimentation alters the natural stream bed substrate composition by increasing primarily the fines (mud/silt and clay). Many invertebrates and fish require stream beds relatively free of fines (Minshall, 1984). In addition, stream beds with excessive amounts of fines can destabilize stream channels (Wilcock, 1997) and are more susceptible to re-suspension, a major source of stream water sediment (Evans et al., 1997) and nutrients (Owens and Walling, 2002).

In the agricultural regions of the U.S. a common ecological restoration technique to reduce sediment delivery to stream channels is the establishment of conservation land-uses, such as riparian forest buffers and grass filters. The establishment of these conservation land-uses is financially attractive to farmers in Iowa because the Conservation Reserve Program, part of the 1996 Farm

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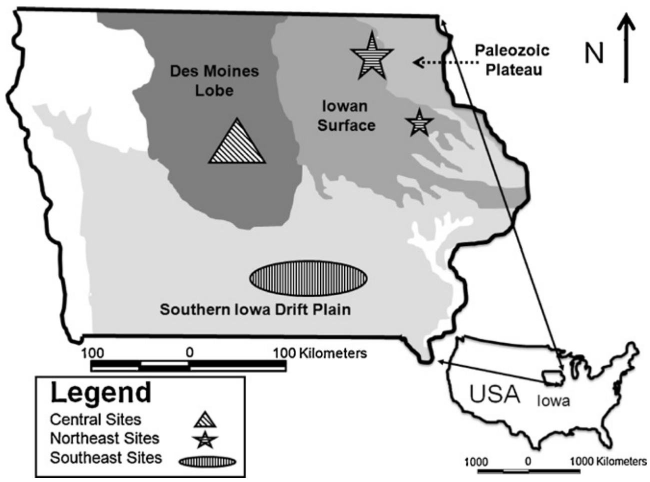

Fig. 1. The approximate location of the study reaches in central, northeast and southeast Iowa. The different gray colors indicate the landforms of each region.

Bill, subsidizes part of the lost income for planting their agricultural land to these conservation land-uses. Many studies have shown that riparian forest buffers and grass filters can significantly reduce sediment from reaching the stream bed (Mander et al., 2005) by trapping sediment from overland flow (Lee et al., 2000, 2003) and stabilizing stream banks (Zaimes et al., 2006, 2008). In addition, rotationally and intensive rotationally grazed pastures are slowly replacing continuously grazed pastures in Iowa, because these practices increase profitability (USDA-NRCS, 1997a).

Very few studies in the Midwest have examined the influence of these riparian conservation and new grazing land-uses on streams (Lyons et al., 2000). In Iowa, as with most restoration projects, few are monitored and even fewer are evaluated for their effectiveness (Shields, 2009). Since substantial amounts of money have been and are being spent for the establishment of these conservation and new grazing land-uses, it is important to investigate their impact on stream bed substrate composition.

The objective of this study was to investigate the impact of the adjacent riparian land-uses on stream bed substrate composition in low order stream reaches with similar upstream and watershed characteristics. Based on the potential intensity of the land-use on the riparian vegetation and stream bank, the hypothesis was that the percentages of fines in the stream bed substrate would increase in the following order: riparian forest buffers (RF), grass filters (GF), pastures with the cattle fenced out of the stream (FP), intensive rotational pastures (IP), rotational pastures (RP), continuous pastures (CP) and annual row-crop fields (RC). Low order streams are closely interconnected to their adjacent uplands and riparian areas that contribute a substantially larger percentage of sediment compared to high order streams (Alexander et al., 2007; Schultz et al., 2004). While upstream contributions are significant to streams (Lyons et al., 2000), in low order stream it was expected that by significantly reducing sediment contributions from overland flow and stream bank erosion with the establishment of conservation practices, stream bed substrate would also be influenced.

2. Methods

2.1. Study regions

The research was conducted in northeast, central and southeast Iowa (Fig. 1). The Iowan Surface and the Paleozoic Plateau are the major landforms in the northeast region (Prior, 1991). The Iowan Surface has gently rolling terrain created by material moved by strong weathering events under permafrost conditions during Iowa's most recent glaciations (12,000–14,000 ybp). The Paleozoic Plateau is the oldest landscape in Iowa with deeply incised narrow valleys and almost no glacial deposits. The Des Moines Lobe landform, in the central region, has a flat terrain with some broad ridges and small hills, poorly developed natural drainage and prairie wetlands that was the result of the most recent glaciation in Iowa (Prior, 1991). The Southern Iowa Drift Plain in southeast Iowa has steeply rolling hills and valleys with an extensive drainage network developed through the loess cap into the glacial material that was deposited 500,000 years before present (Prior, 1991).

2.2. Selection of the study reaches

The stream bed substrate composition was surveyed from deeply incised, 1st–3rd order wadeable stream reaches (Strahler, 1957). Each selected stream reach had the same riparian land-use on both sides of the stream for at least 300 m. In the northeast and southeast region, the watershed area above each reach was less than 52 km^2, while in the central region it was less than 78 km^2. The watershed area of all selected reaches was dominated by RC, with some pastures and homesteads and occasional small pockets of forests, mainly in the riparian corridors. The topography of the watersheds and the soil textures in the riparian areas adjacent to the study reaches were also similar within each region (Table 1). As a result, the upstream sediment contributions to the study reaches, within each region, were expected to be similar.

All of the study reaches were located on private farms to better evaluate the impacts of actual farming practices. More than 120 stream reaches were visited to find suitable study reaches. Unfortunately, it was not possible to find suitable stream reaches with all the riparian land-uses in all regions. The number of study reaches and their characteristics in each region can be seen in Table 1.

2.3. Riparian land-uses

The two main riparian conservation land-uses in Iowa are RF and GF. Study reaches with RF and GF were only selected if the conservation land-uses had been established for at least 5 years prior to the start of the study. In addition, all selected RF and GF had at least a 20 m width on both sides of the stream reach. Many RF and GF were relatively young when this project started, because these land-uses became available for cost-share in 1996 with the Conservation Reserve Program. The RF consisted of tree, shrub and warm-season grass zones (USDA-NRCS, 1997b), while the GF consisted of cool-season grasses (USDA-NRCS, 1997c). One of the stream reaches selected in the central region was part of the Bear Creek National Restoration Demonstration Watershed (Schultz et al., 2004).

Annual RC and CP are the traditional riparian land-uses in much of Iowa. *Zea mays* L. (corn) and *Glycine max* (L.) Merr. (soybean) were the crops grown in alternating years adjacent to the RC study reaches. While some stream banks of the reaches had narrow strips (<4 m) of grasses or weeds, many others were cropped up to the stream's edge.

All pastures of this study were grazed by beef cattle and dominated by cool-season grasses and forbs such as *Poa pratensis* L. (Kentucky bluegrass), *Festuca arundinacea* Schreb. (tall fescue), *Phalaris arundinacea* L. (reed canary grass), *Bromus inermis* L. (smooth bromegrass), *Dactylis glomerata* L. (orchardgrass), *Trifolium repens* L. (white clover) and *Trifolium pratense* L. (red clover). The cattle in the CP had full access to the stream throughout the grazing season. In the northeast and central regions, grazing started

Table 1
General characteristics of the stream reaches and their adjacent riparian areas in the three study regions of Iowa.

Riparian land-use	Reaches (#)	Average bank height (m)	Width/depth	Severely eroding bank length[a] (%)	Soil series[b]	Soil texture[b]	Stocking rate (cow–calf/ha)
Central							
Row-cropped fields (RC)	2	1.7	3.3	44 (6)	Spillville–Coland complex	Clay loam, loam	NA[c]
Continuous pastures (CP)	2	1.7	2.7	30 (6)	Coland, Colo, Spillville–Coland complex	Silt loam, clay loam, loam	1.5–2.0
Rotational pastures (RP)	2	1.5	3.1	25 (6)	Coland, Coland–Terrill complex	Clay loam	1.0–2.5
Grass filters (GF)	2	1.7	2.5	16 (6)	Spillville, Spillville–Coland complex	Clay loam, loam	NA[c]
Riparian forest buffers (RF)[d]	2	1.5	3.8	14 (6)	Coland, Hanlon–Spillville and Spillville–Coland complexes	Clay loam, loam	NA[c]
Northeast							
Continuous pastures (CP)	2	1.5	3.6	38 (5)	Dorchester, Radford, Otter–Ossian complex	Silt loam	1.2–2.0
Intensive rotational pastures (IP)	3	1.2	3.6	27 (5)	Dorchester, Dorchester–Chaeseburge–Viney and Dorchester–Chaeseburge complexes	Silt loam	1.0–1.7
Pastures, cattle fenced out of the stream (FP)	2	1.4	2.3	11 (6)	Radford, Spillville	Silt loam	NA[c]
Riparian forest buffers (RF)	1	1.0	2.3	10 (6)	Colo–Otter–Ossian complex, Spillville	Silt loam, loam	NA[c]
Southeast							
Continuous pastures (CP)	3	1.8	1.4	54 (5)	Nodaway, Nodaway–Cantril complex	Silt loam, loam	1.2–2.2
Rotational pastures (RP)	2	1.9	2.0	54 (6)	Nodaway	Silt loam	0.7–2.4
Intensive rotational pastures (IP)	2	2.1	1.5	32 (6)	Nodaway, Nodaway–Cantril complex	Silt loam, loam	0.7–1.2
Pastures, cattle fenced out of the stream (FP)	1	1.9	1.4	16 (6)	Nodaway	Silt loam	NA[c]
Grass filters (GF)	2	1.8	2.1	16 (6)	Amana, Nodaway	Silt loam	NA[c]

[a] From Zaimes et al. (2008); values in parenthesis are the standard errors.
[b] From SSURGO (2004).
[c] Not applicable.
[d] In this region a natural forest was used as a riparian forest buffer reach.

in early May and ended in early November. In the southeast region, one of the CP followed similar dates as the other regions, while in the other two CP cattle grazed year-round with supplemental feed provided during the winter. The reaches adjacent to the RP and IP were only selected if these land-uses had been established for at least 3 years prior to the start of the study. Older RP and IP were difficult to find when this study started, because farmers had only recently started adopting these pasture systems for beef cattle. In the RP, the pasture was divided into 2–3 paddocks, with each paddock grazed 15–30 days and rested for about 30 days. In the IP, the pasture was divided into more than 6 paddocks. Each paddock was grazed 1–7 days and rested for 30–45 days. For both the RP and IP, the grazing period started in early May and ended in early November in all regions. Each landowner started and ended grazing on slightly different dates for all pasture land-uses, which led to different numbers of total grazing days each year.

Finally, the reaches selected adjacent to the FP also had been established for at least 3 years prior to the start of the study. Previously, cattle in these reaches had full access to the stream channel. Excluding cattle from the stream is a practice that many farmers in Iowa are reluctant to adopt because the stream is the main water source for the cattle and fencing along the stream banks requires frequent maintenance due to frequent flash floods that happen in low-order streams of these regions.

2.4. *Stream bed substrate survey*

To estimate the percentages of the different stream bed substrate in each reach a survey of twenty transects, spaced two stream widths apart, was conducted. Stream width was determined as the mean of 10 stream widths measured along the entire length of the study reach prior to conducting the survey. Each transect was placed perpendicular to the stream channel (Fig. 2).

The protocol used to estimate the substrate percentages was developed specifically for the state of Iowa by Heitke (2002), based on a protocol by Simonson et al. (1994a, b). Two or four plots, 0.5 m × 0.5 m (Fig. 3), were placed along each transect. If the stream width was 5–10 m, four plots were placed equidistant from each other; if the width was 3–5 m, two plots were placed equidistant from each other. Substrate percentages were estimated visually within each plot.

Visual estimates that are also termed as "ocular assessments," are widely used by fisheries biologists but also by other scientists and are the basis of many published stream bed substrate descriptions (Gordon et al., 2004; Kondolf et al., 2003). The Instream Flow Incremental Methodology (IFIM) that was developed by the U.S. Fish and Wildlife Service Instream Flow Group, also uses stream bed visual estimates (Bovee, 1982). Although visual estimates of bed substrate are not reproducible among researchers (Kondolf

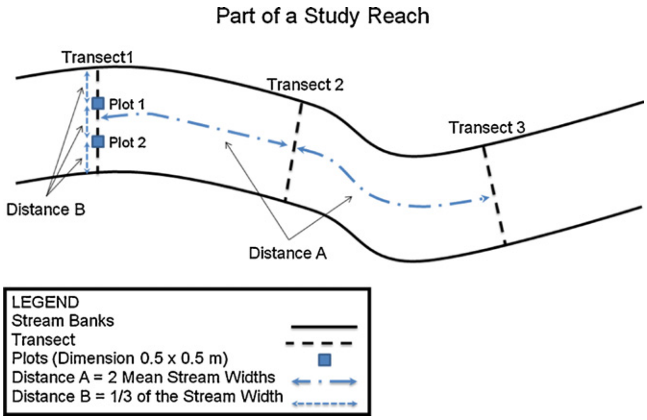

Fig. 2. Placement of transects along the study reach and the plots (dimensions 0.5 m × 0.5 m) along the transects. Twenty transects, two mean stream widths apart, were placed in each study reach. If the mean stream width was 5–10 m, four plots were placed equidistant along the transect; if the width was <5 m, two plots were placed. In each plot, the percentage of the different stream bed substrate was visually estimated.

et al., 2003), comparisons among the reaches of this study were possible because one operator conducted all the visual estimates. The categories of the stream bed substrate used in this study were: coarse particulate organic matter (CPOM), fines (<0.063 mm), sand (0.063–2 mm), gravel (2–64 mm), cobble (64–256 mm) and boulders (>256 mm). The categories are based on a modified Wentworth scale (Heitke, 2002). In this study, the clay (<0.004 mm) and mud/silt size classes (0.063–0.004 mm) were grouped into a broader size class, the fines, because of the difficulty of visually separating them in the field. The CPOM is organic matter that is not decomposed, that originates primarily from the vegetation along the stream banks and is deposited on the stream bed.

The stream bed survey was conducted once in 2002 for every stream reach. During and three days prior to all stream bed surveys no significant precipitation events occurred (NOAA, 2002–2004a, 2002–2004b) that could have increased stream flow and stream bed substrate movement. In the northeast region the survey was conducted during the middle of August, in the central region during the end of September and beginning of October and in the southeast region, during the beginning of October. In Iowa, during these months stream baseflow dominates and as result there is minimal movement of materials on the stream bed. Periods with minimal movement of material along the stream bed are the ideal time to survey stream bed substrate and compare them among different stream reaches.

2.5. Statistical analysis

Stream bed substrate percentages (dependent variables) were compared based on the regions and the riparian land-uses within a region (independent variables) using a two-way ANOVA in the SAS statistical software (SAS Institute, 1999). Because the data were expressed as percentages during the analysis they were transformed using arcsin square root to achieve normality (Sokal and Rohlf, 1995). Differences were considered significant when the p-values were <0.05.

3. Results and discussion

3.1. Stream bed substrate comparisons among regions

There were some statistically significant differences among regions in stream bed substrate composition. The percentage of CPOM of all the reaches in the northeast region had the highest percentage (7.6%, high standard error) but the reaches in the southeast region (7.4%) had a significantly higher percentage of CPOM than the reaches of the central (2.6%) ($p = 0.413$) region. The northeast region reaches had a significantly lower percentage (18%) of fines than both the central (53.9%) ($p < 0.001$) and southeast (66.8%) ($p < 0.001$) region reaches. In contrast, the reaches

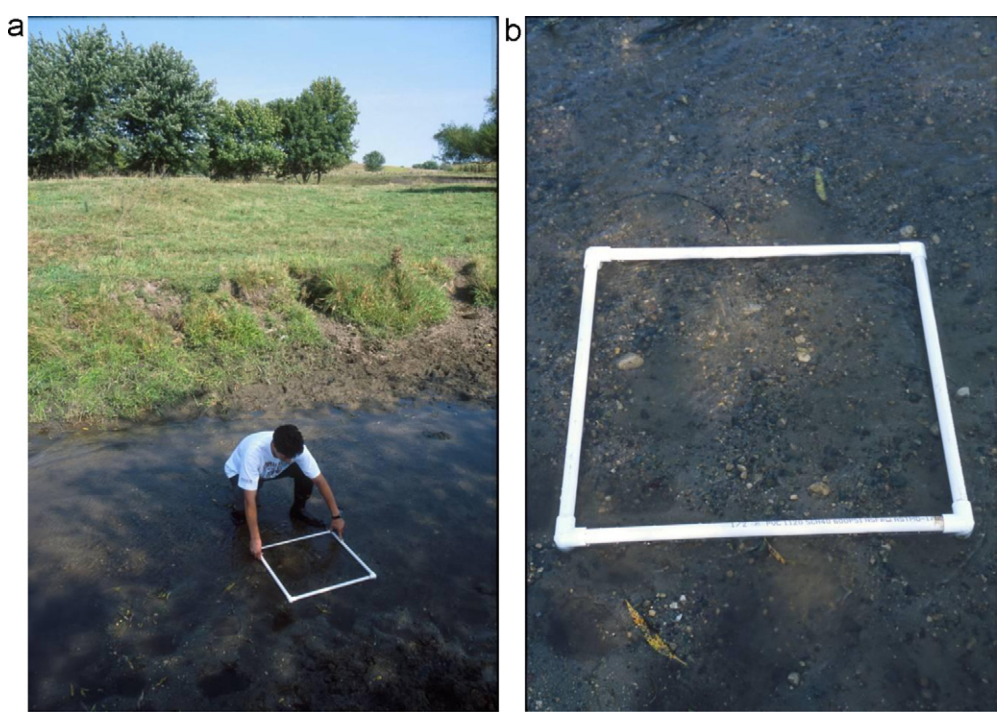

Fig. 3. Plots 0.5 m × 0.5 m were placed equidistant along the transect to visually estimate the percentage of the different substrate of the stream bed: (a) placement of the plot on the stream bed, and (b) close up of the plot; different types of substrate are visible.

in the northeast region had a significantly higher percentage of sand (31.1%) and gravel (27.7%) than the reaches of the central (sand 16.5%; gravel 9.5%) (both, $p < 0.049$) and southeast (sand 9.3%; gravel 12.9%) (both, $p < 0.007$) regions. There were no significant differences among regions regarding the percentages of cobble and boulder. The reaches of the northeast region had the highest percentage of cobble (14.4%) followed by the central reaches (12.1%), while the southeast region had the smallest percentage (9.3%). For the boulders the reaches of the central region had the highest percentage (2.1%), followed by the northeast reaches (1.0%) with reaches of the southeast having the lowest percentage (0.7%).

As expected, there were some regional stream bed substrate composition differences because of differences in the surficial geologies of each region (Leopold et al., 1964). The stream beds of the reaches in the southeast region had the highest percentage of fines, because this region is covered with a mantle of loess (Prior, 1991). The stream beds of the reaches in the northeast region had the highest percentages of sand, gravel and cobble because of the limestone bedrock. Finally, there were more boulders and high percentages of cobble and gravel in the central region reaches because the parent material is glacial till, the most recently deposited material of the three regions (Prior, 1991). More significant differences were probably not found because all the reaches were in agricultural watersheds that tend to have high percentages of fines that embedded the other substrate leading to a more uniform stream substrate composition (Nakamura and Yamada, 2005).

There were also differences in the percentages of CPOM among the regions. The central region reaches had the least CPOM because there were almost no trees along the banks of the agricultural riparian land-uses. In contrast, the banks of the agricultural riparian land-uses of the southeast reaches had the most remnant trees compared to the other two regions (authors' observations) and the highest CPOM percentages.

3.2. Stream bed substrate comparisons among riparian land-uses within a region

In the central region, the stream beds adjacent to RF reaches had a significantly higher percentage of CPOM than the RC, CP, RP and GF reaches (for all, $p < 0.016$) (Table 2). The boulders were the only other substrate with significant differences. Specifically the stream beds adjacent to the RF had significantly higher percentages than the RC and CP reaches ($p < 0.029$).

In the northeast region (Table 2), the percentage of CPOM in the RF stream beds was significantly higher than the stream beds of the CP and IP reaches (for all, $p < 0.001$). The percentage of CPOM in the FP stream beds was also significantly higher than the IP stream beds (both, $p < 0.042$). The FP reaches also had stream beds significantly sandier than the CP stream beds ($p < 0.048$).

The southeast region had the most significant differences in stream bed substrate percentages among riparian land-uses (Table 2). Some reaches with grazing land-uses in this region had high percentages of CPOM. Specifically, the IP reaches had significantly higher percentage of CPOM than the RP reaches ($p < 0.040$). For fines, the stream bed of the FP reaches had a significantly lower percentage than the CP, RP and GF reaches (for all, $p < 0.001$). In contrast, the FP reaches had a significantly higher percentage of gravel than the CP, RP, IP and GF reaches (for all, $p < 0.025$).

Many riparian land-uses had no CPOM on the stream beds because of the complete or almost complete absence of woody vegetation on their stream banks because of agricultural land-uses. It was significantly higher in stream reaches adjacent to RF than the other land-uses in both the northeast and the central regions, because of the contributions of the woody plants. In the northeast the FP reaches also had higher percentages of CPOM compared to some of the reaches adjacent to the grazing land-uses because of the large number of trees between the channel and the pasture fence (authors' observations). Similarly, in the southeast the highest quantities of CPOM were found in stream reaches adjacent to IP and FP (RF reaches were absent) again because of the many trees along the stream banks. In lotic ecosystems, the percentage of CPOM on stream beds, along with the shade provided by trees, has a positive influence on the structural and functional attributes of the aquatic community (Vannote et al., 1980) and the steam water quality (Ghermandi et al., 2009).

The percentages of fines had a wide range among riparian land-uses even within a region. In the northeast region the fines ranged from 10 to 31% among the different riparian land-uses, in the central region from 36 to 63% and in southeast region from 22 to 85% in southeast region. While the percentages of the same riparian land-use differed from region to region, overall the percentages of fines of most riparian land-uses in every region were high (Wilton, 2004; Heitke et al., 2006). Particularly in the southeast region, even though high percentages of fines were expected because of the loess origin material, the stream beds adjacent to all riparian land-uses, except the FP, had over 70% of their beds covered with fines. Fines are a main product of agricultural land-uses (Nakamura and Yamada, 2005) and the high percentages of fines indicate highly disturbed and embedded streams from excessive stream bank, gully and upland erosional processes (Wohl and Carline, 1996).

These erosional processes are accentuated in agricultural watersheds and conservation riparian land-uses are designed to and capable of reducing the amount of fines reaching the channel and getting deposited on the stream bed. The reaches of the conservation land-uses of this study did have significantly less stream bank erosion than the agricultural land-uses (Zaimes et al., 2008) (Table 1). Still only one region had significant differences in stream bed fines among the different riparian land-uses. Specifically, in the southeast region the FP reaches had significantly lower percentages than most of the other riparian land-uses of the region. In addition, some of the reaches of the conservation practices had relatively large percentages of fines for their regions (e.g. GF reaches in the southeast region and the RF in the northeast region). High percentages of fines in riparian conservation land-use reaches have also been found in other studies conducted in Iowa (Griffith et al., 1994; Wilton, 2004; Heitke et al., 2006).

The high percentages of fines indicate that the other bed substrates such as sand, cobble and gravel are probably embedded and the stream bed composition is homogenized. This led to the very few significant substrate differences as hypothesized between conservation and agricultural riparian land-uses for these larger size substrate. In the central region the RF reaches had significantly higher boulder percentages compared to the most intensive agricultural land-uses (RC and CP) of the region. The FP reaches had significantly higher percentages of gravel than the agricultural riparian land-use reaches but also the GF reaches in the southeast region of sand than the CP reaches in the northeast region.

The riparian areas of Iowa have been used for agriculture for many decades. The impacts of agriculture are still evident in certain characteristics of most Iowa streams including bed substrate composition. These lingering effects of past land-uses are common in agricultural watersheds and referred to as the historical legacy of a reach (Diebel et al., 2009). Since the conservation land-uses of this study had recently been established, more time might be required for the stream beds to recover from these historical legacies (e.g. excessive amounts of fines). Other studies have also found that streams in these regions are heavily disturbed and embedded (USEPA, 2006).

Upstream contributions to the stream bed substrate can also be very important sources of fines (Lyons et al., 2000). The length of

Table 2
The substrate percentages of stream beds adjacent to the different riparian land-uses, in the three study regions of Iowa. Standard errors are in parentheses, while significant differences among riparian land-uses within a region are shown in the SigDif columns. Different letters indicate significant difference at the 5% level. The stream bed substrate surveyed were CPOM (coarse particular organic matter), fines (<0.063 mm), sand (0.063–2 mm), gravel (2–64 mm), cobble (64–256 mm) and boulders (>256 mm).

Riparian land-use	Stream bed substrate											
	CPOM		Fines		Sand		Gravel		Cobble		Boulders	
	%	SigDif	%	SigDif	%	SigDif	%	SigDif	%	SigDif	%	SigDif
Central region												
Row-cropped fields (RC)	0.0 (3.3)	b	54.6 (11.2)	a	12.2 (9.7)	a	13.4 (6.5)	a	19.1 (8.9)	a	1.0 (1.3)	b
Continuous pastures (CP)	0.0 (3.2)	b	63.9 (11.0)	a	20.6 (9.6)	a	11.4 (6.3)	a	3.4 (8.8)	a	0.6 (1.2)	b
Rotational pastures (RP)	1.0 (3.3)	b	58.9 (11.2)	a	14.0 (9.7)	a	13.4 (6.5)	a	10.4 (8.9)	a	1.9 (1.3)	ab
Grass filters (GF)	1.1 (3.2)	b	55.9 (11.1)	a	16.0 (9.6)	a	13.7 (6.4)	a	14 (8.8)	a	1.2 (1.2)	ab
Riparian forest buffers (RF)	10.7 (3.2)	a	36.0 (11.1)	a	19.6 (9.6)	a	13.3 (6.4)	a	15.7 (8.8)	a	5.7 (1.2)	a
Northeast region												
Continuous pastures (CP)	0.0 (3.2)	bc	29.0 (11.0)	a	16.2 (7.8)	b	33.5 (6.2)	a	21.0 (8.8)	a	0.3 (1.2)	a
Intensive rotational pastures (IP)	0.0 (2.6)	c	13.0 (9.0)	a	31.0 (7.8)	ab	30.8 (5.2)	a	25.2 (7.2)	a	0.0 (1.0)	a
Pastures, cattle fenced out of the stream (FP)	7.9 (3.2)	ab	9.5 (11.1)	a	45.6 (13.7)	a	31.0 (6.4)	a	6.0 (8.8)	a	0.0 (1.2)	a
Riparian forest buffers (RF)	22.3 (4.7)	a	21.6 (15.9)	a	31.7 (13.7)	ab	15.4 (9.2)	a	5.2 (12.6)	a	3.8 (1.8)	a
Southeast region												
Continuous pastures (CP)	8.6 (2.7)	ab	82.5 (9.2)	a	12 (1.3)	a	1.3 (5.4)	b	0.0 (7.3)	a	0.0 (1.1)	a
Rotational pastures (RP)	1.2 (3.2)	b	86.0 (11.1)	a	3 (1.3)	a	1.2 (6.4)	b	8.1 (8.8)	a	0.0 (1.2)	a
Intensive rotational pastures (IP)	12.2 (3.2)	a	64.1 (11.1)	ab	6 (1.3)	a	6.3 (6.4)	b	8.1 (8.8)	a	3.0 (1.2)	a
Pastures, cattle fenced out of the stream (FP)	11.6 (4.7)	ab	21.7 (16.0)	b	19 (2.6)	a	32.1 (9.3)	a	14.4 (12.7)	a	0.6 (1.9)	a
Grass filters (GF)	3.3 (3.3)	ab	79.5 (11.2)	a	6 (1.4)	a	6.8 (6.5)	b	0.2 (8.9)	a	0.0 (1.3)	a

the conservation land-use reaches of this study ranged from 300 to 500 m, except in the central region where one of the RF reaches was more than 900 m and one of the GF reaches was more than 1200 m. One of the most important factors for the effectiveness of conservation practices is their continuity (Pinay et al., 1990). While the conservation land-uses reduced the amount of sediment eroding from the stream banks of their reaches (Table 2) compared to the agricultural land-uses (Table 2), they still received substantial amounts of sediment from the upstream reaches. The majority of the watershed area and the rest of the upstream riparian areas were in agricultural land-uses. These land-uses allow sediment to reach the stream unimpeded that afterwards can move downstream and get deposited in the study reaches. This was also evident in the stream sediment and phosphorus water concentrations of the same reaches that had few significant differences among the different riparian land-uses (Zaimes and Schultz, 2011).

Still, there were indications that establishing RF along riparian areas can be effective in reducing the percentage of fines. The substrate composition of their reaches showed some significant improvements (had high percentage of CPOM and boulders) in the two regions where they were present, compared to the agricultural riparian land-use reaches (Table 2). In contrast, the stream beds adjacent to the other conservation land-use, the GF, did not show significant improvement in stream bed substrate (had high percentage of fines). This contradicts other studies that found the percentage of fines was highest on stream beds of forested reaches and lowest on GF reaches (Lyons et al., 2000; Nerbonne and Vondracek, 2001). It must be noted that Nerbonne and Vondracek (2001) mention that the high percentage of fines and eroding stream banks found along the wooded reaches of their study was probably related to their poor quality. Other researchers have found that trees are more effective than grasses in reducing stream bank erosion, especially in incised channels, because of their deeper and greater quantity of larger diameter roots (Wynn and Mostaghimi, 2006). The stream reaches of this study were incised (Table 1). Finally, the increased effectiveness of this study's RF is also probably due to the zone of grasses and the young age of the trees. The additional zone of warm-season grasses increases the filtering of sediment from overland flow (Lee et al., 2000, 2003), while the young age of the trees can still protect the stream banks but also allow the growth of grass and/or other herbaceous cover on the stream banks because of limited shade.

Finally, comparing the four grazing practices, the FP reaches showed the greatest potential of improving stream bed substrate composition. Specifically, the FP reaches had sometimes significantly fewer fines and higher sand and gravel percentages than the other grazing land-uses. The removal of cattle from the stream banks seems to stabilize them (Table 1) and reduce this major source of fines to the stream bed (Zaimes et al., 2008).

The few significant differences indicate that other restoration measures might also be required in order to achieve quicker and more effective results to improve stream bed substrate. All our reaches were incised that are typically characterized by higher sediment concentrations and turbidity, degraded physical habitat and flashy hydrology (Shields et al., 2010). Without reducing peak discharges and channel energy slopes, even large expenditures for restoration may not adequately reduce watershed sediment yields (Shields, 2009). Richardson et al. (2011) reduced peak discharges by re-contouring and replanting along the stream, building earthen dams for reservoirs and establishing wetlands. Establishing in-stream and floodplain riparian wetlands can increase sediment and phosphorus retention (Mitsch, 1992). Huang et al. (2009) constructed a two-stage channel in an incised channel to improve drainage and ecological function. The lower stage of the two-stage channel is narrower than a conventional channel and can potentially improve sediment transport and provide greater water depth for aquatic species during baseflow conditions. Greater sediment transport capacity could lead to the removal of the fines in incised stream channels. Finally, the improvement of stream channel substrate habitat might require the construction of in-stream structures such as the placement of boulders and logs, substrate manipulation, and the construction of riffle-pool and step-pool sequences (Sear, 1994; Kashara and Hill, 2008).

4. Conclusions

Riparian conservation land-uses increase stream bank stability (Zaimes et al., 2006, 2008), filter sediment from overland runoff (Lee et al., 2000, 2003) and consequently should influence stream bed substrate composition (Lyons et al., 2000). This suggests that placing conservation land-uses primarily in the riparian zone (a small portion of the entire watershed) (Nerbonne and Vondracek, 2001) and in specific small areas of the uplands (e.g. terraces, grass waterways) can reduce stream embeddedness in agricultural watersheds. This allows land managers to maintain the majority of the watershed in agricultural production. In this study, the riparian conservation land-uses did not show in most cases the expected improvements in stream bed substrate composition. Still in some cases, the stream beds adjacent to the RF and FP reaches had a lower percentage of fines and higher percentage of large substrate and CPOM than the agricultural riparian land-uses. This was not the cases with the GF reaches that had high percentages of fines and low percentages of large substrate.

Overall, more significant differences in the stream bed substrate between the conservation (RF, GF and FP) and agricultural land-use (RC, CP, RP and IP) reaches were expected. While some parameters (e.g. stream bank erosion; see Table 1) can improve in short periods of time once the conservation land-uses are established, other parameters (e.g. stream bed substrate composition) will require more time before the conservation riparian land-uses improve them (Parkyn et al., 2005). This indicates that the past agricultural riparian land-uses are still having lingering effects on the stream bed substrate. In addition, only short reaches (typically 300–500 m) of the entire length of the streams in this study were in the riparian conservation land-use (RF, GF and FP). To reduce the amount of excess sediment from moving downstream, riparian conservation land-uses should be established beginning in the headwater reaches of a stream network (Schultz et al., 2004), while also establishing them on a large percentage of the stream length. Short, randomly placed riparian conservation land-uses can reduce local production of sediment delivery from overland flow or stream bank erosion but might have little impact on the overall sediment dynamics of the stream channel. Future research should focus on establishing the minimum lengths and locations of riparian conservation land-uses that are needed to significantly reduce excess in-stream sediment loads. This needs to be done regionally because streams have significantly different substrate composition and sediment dynamics depending on the landform they are located in. Finally, other restoration techniques might be required that can reduce peak flows or in-stream enhancements in order to effectively improve steam substrate in short periods of time.

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