Detecting Channel Riparian Vegetation Response to Best-Management-Practices Implementation in Ephemeral Streams With the Use of Spot High-Resolution Visible Imagery

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Abstract

Heavily grazed riparian areas are commonly subject to channel incision, a lower water table, and reduced vegetation, resulting in sediment delivery above normal regimes. Riparian and in-channel vegetation functions as a roughness element and dissipates flow energy, maintaining stable channel geometry. Ash Creek, a tributary of the Bad River in western South Dakota contains a high proportion of incised channels, remnants of historically high grazing pressure. Best management practices (BMP), including off-stream watering sources and cross fencing, were implemented throughout the Bad River watershed during an Environmental Protection Agency (EPA) 319 effort to address high sediment loads. We monitored prairie cordgrass (*Spartina pectinata* Link) establishment within stream channels for 16 yr following BMP implementation. Photos were used to group stream reaches (*n*=103) subjectively into three classes; absent (estimated < 5% cover; *n*=64), present (estimated 5–40% cover; *n*=23), and dense (estimated > 40% cover; *n*=16) based on the relative amount of prairie cordgrass during 2010 assessments of ephemeral channels. Reaches containing drainage areas of 0.54 to 692 ha were delineated with the use of 2010 National Agriculture Imagery Program (NAIP) imagery. Normalized difference vegetation index (NDVI) values were extracted from 5 to 39 sample points proportional to reach length using a series of Satellite Pour l'Observation de la Terre (SPOT) satellite imagery. Normalized NDVI (nNDVI) of 2 152 sample points were determined from pre- and post-BMP images. Mean nNDVI values for each reach ranged from 0.33 to 1.77. ANOVA revealed significant increase in nNDVI in locations classified as present prairie cordgrass cover following BMP implementation. Establishment of prairie cordgrass following BMP implementation was successfully detected remotely. Riparian vegetation such as prairie cordgrass adds channel roughness that reduces the flow energy responsible for channel degradation.

Key Words: channel morphology, Conservation Effects Assessment Project (CEAP), northern mixed-grass prairie, prairie cordgrass, remote sensing

INTRODUCTION

Cattle in rangelands spend a disproportionate amount of time in riparian zones because of the abundance of forage, water, and shade (Bailey 2005). Riparian areas are vulnerable to overuse because of the draw of cattle combined with their relatively small extent (Fleischner 1994). Eliminating direct cattle access to streams by fencing is most effective when attempting to restore riparian health and function (Elmore and Kauffman 1994). However, fencing out entire stream reaches within a pasture is not always practical or desirable to cattle producers. Best management practices (BMP) that reduce the probability of access and/or time spent in riparian zones, such

as alternative water sources, rock crossings, and specialized grazing systems, have been moderately effective at improving riparian vegetation, physical and chemical properties of streams, and abundance of aquatic life forms (Elmore and Kauffman 1994; Agouridis et al. 2005; DelCurto et al. 2005). Off-stream water sources, such as piped water into cattle drinking troughs and strategic mineral placement are attractive management alternatives for producers because they increase grazing distribution and can increase animal rate of weight gain (Porath et al. 2002). For these reasons, range improvement practices such as cross fencing, water pipelines, and off-stream water sources have often been cost shared by the USDA-NRCS (George et al. 2011) and readily adopted by producers.

The impacts of cattle on stream channel degradation are difficult to distinguish because of multiple factors contributing to the structure and function of stream channels, including gradient, geology, climate, upland and riparian plant communities, and land-use practices (Allen 1995). Fluvial processes are regulated by climate, physiography, and vegetation, and are continually adjusting to changes of these components (Montegomery and Bolton 2003). Of the factors influencing fluvial processes, vegetation is most easily influenced by land

management. Sandercock et al. (2007) identified two components of riparian vegetation that influence channel processes: 1) vegetation roughness that helps to dissipate flow energy, and 2) roots that help to stabilize bed and bank features. Manning's (1891) equation is the most widely used equation for evaluating resistance components within open channels:

$$V = 1/n \cdot R^{2/3} \cdot S^{1/2}, \quad [1]$$

where V=average flow velocity, R=hydraulic radius, S=average gradient, and Manning's roughness coefficient (n) is the sum of the components that affect the roughness of the channel. Components of roughness (n) were classified by Cowan (1956) (Eq. 2):

$$n_{\text{tot}} = (n_b + n_1 + n_2 + n_3 + n_4)m, \quad [2]$$

where n_{tot} is the total roughness, n_b is the base n for a straight uniform channel, n_1 is a correction factor for irregularities, n_2 is a value for variations in cross-section shape and size, n_3 a value for obstructions, n_4 a value for vegetation (density, flexibility, and height relative to flow depth), and m factors in channel meandering. Vegetation is an important contributor to channel roughness, as it has demonstrated to have greater influence than other roughness components (Table 1). The n_4 value will be greater when depth of flow is shallow relative to the size of roughness components. For example, when channel vegetation is sparse, flexible, and short relative to depth of flow ($<2\times$ water depth), little resistance is provided. Conversely, dense vegetation with sturdy and tall stems relative to flow depth ($>2\times$ water depth) would provide substantial resistance (Cowan 1956). Flow depths are generally shallow in ephemeral systems, increasing the weight of vegetation as a roughness component (Sandercock et al. 2007). In-channel vegetation is especially important in reducing flow energy during floods (Li and Shen 1973) when sediment transport is at its peak. Sediment transport in first-order ephemeral channels is intimately related to the stochastic nature of short-pulsed, high-amplitude flow events. Therefore, increasing the length of the pulse and decreasing the amplitude of runoff by increasing surface roughness is critical to easing sediment transport.

Prairie cordgrass (*Spartina pectinata* Link), is a native perennial warm-season grass that grows throughout much of North America. It typically is found in poorly drained soils, but is also well adapted to seasonally dry sites (Stubbendieck et al. 1992). It functions as a stream-channel stabilizer and traps sediment (Weaver 1960; Johnson and Larson 1999; Boe and Lee 2007). Once established, stands of prairie cordgrass are highly resistant to hydrological regimes, promote deposition, add riparian habitat diversity, and produce significant quantities of plant biomass (Skinner et al. 2009). Prairie cordgrass has rough leaf blade edges that result in low palatability, and therefore is avoided by cattle except when in an early vegetative growth stage. Sedgwick and Knopf (1991) reported increased prairie cordgrass biomass in response to prescribed grazing over a 3-yr period. For these reasons, prairie cordgrass is an ideal plant for revegetating incised ephemeral stream channels because of its resilience under grazing pressure and harsh hydrologic regimes.

In western South Dakota, the mixed-grass prairie upland vegetation is predominantly a mix of cool-season midgrasses and an understory of warm-season shortgrasses (Smart et al.

Table 1. Computation sheet for Manning's roughness coefficient, after Cowan (1956).

Variable	Description	n value
Basic, n_b[1]	Earth	0.020
	Rock	0.025
	Fine gravel	0.024
	Coarse gravel	0.028
Irregularity, n_1	Smooth	0.000
	Minor	0.005
	Moderate	0.010
	Severe	0.020
Cross section, n_2	Gradual	0.000
	Occasional	0.005
	Alternating	0.010–0.015
Obstructions, n_3[1]	Negligible	0.000
	Minor	0.010–0.015
	Appreciable	0.020–0.030
	Severe	0.040–0.060
Vegetation, n_4	Low	0.005–0.010
	Medium	0.010–0.020
	High	0.025–0.050
	Very high	0.050–0.100
Meandering, m	Minor	0.000
	Appreciable	0.15 n_s^2
	Severe	0.30 n_s^2

[1]No variation in these variables were found in Ash Creek.
[2]$n_s = n_b + n_1 + n_2 + n_3 + n_4$.

2007). Upland vegetation in western South Dakota, dominated by the cool-season species western wheatgrass (*Pascopyrum smithii* [Rybd.]), largely senesces by the end of June (White 1983). Distinct phenologic differences between upland and riparian species in western South Dakota provide the opportunity for remote detection of in-channel vegetation signal within narrow riparian areas in late summer with little influence from adjacent senesced cool-season–dominated upland vegetation.

Remote sensing techniques including the normalized difference vegetation index (NDVI) have demonstrated strong correlations with aboveground plant biomass (Wylie et al. 2002; Al-Bakri and Taylor 2003; Kawamura et al. 2005). However, remote sensing studies have tended to avoid riparian areas because of their inherent complexity. Diverse mixtures of vegetation types in addition to the presence of bare ground and boundary pixels often degrades the ability of the NDVI to measure actively photosynthesizing biomass (Nagler et al. 2001). The riparian remote sensing literature has given little attention to herbaceous riparian areas (Lyons et al. 2000), specifically the semiarid Great Plains.

High-resolution satellite imagery such as Satellite Pour l'Observation de la Terre (SPOT) high-resolution visible (HRV) and Landsat have been used successfully in riparian areas. Svoray (2004), for example, characterized stream channelization remotely with the use of SPOT imagery. Lattin et al. (2004) successfully assessed land cover/land use and biotic integrity of Oregon riparian areas with both aerial photography and Landsat imagery, noting that the increased spectral resolution and multiple image dates possible with satellite

imagery offer distinct advantages in accurately classifying vegetation compared to higher-resolution aerial photography.

Determining the effects of BMP implementation requires both baseline and postimplementation monitoring, allowing an appropriate time period for BMP-induced response. The value of remote sensing is amplified when necessary baseline data are not collected for the metric being used to measure improvement, a common issue when evaluating BMP effectiveness. Remote sensing provides a means to mitigate this issue, granted imagery of sufficient resolution is available from necessary periods. Though the influence of land management on vegetation production is often masked by interannual weather variations, long-term monitoring of vegetative productivity is essential in evaluating the suitability of land management and success of BMP practices (Gu and Wylie 2010).

The objective of this study was to evaluate the collective influence of BMPs (including off-stream water sources and improved grazing management) on riparian prairie cordgrass communities by utilizing SPOT HRV imagery pre- and post-BMP implementation in a western South Dakota watershed. Our results can be used to assess the ecological impacts of riparian management practices better (George et al. 2011). We hypothesized that prairie cordgrass cover increased following BMP implementation and can be monitored remotely with the use of a time series of SPOT HRV imagery.

METHODS

Ash Creek lies within the lower Bad River basin in west central South Dakota (Fig. 1). Topography is characterized by steep slopes of 16–45%, stabilized by fragile rangeland vegetation. Lack of glaciation throughout the study area has resulted in a well-defined drainage pattern that is quite apparent, as the Bad River has cut a 40–80-m-deep valley into the landscape. Gullies are often found in the breaks formation, the transition from tablelands to valley bottom of the Bad River and its tributaries. The geology of the region is dominated by Pierre shale (including Sansarc-Pierre and Sansarc-Opal), which reaches a depth of over 300 m. These cretaceous deposits are widely exposed in eroding banks and gullies, especially in the lower basin, and have a high clay content, making them relatively impermeable.

The Bad River basin has a continental climate, with daily mean temperatures ranging from 32°C in July to –14°C in January, with a yearly mean of 8°C (Smart et al. 2007). Growing season (frost-free days) averages 115–130 d. The semiarid landscape of the Bad River watershed receives 380–410 mm of precipitation annually, of which 80% occurs during the April to September growing season. Between 1971 and 2010, 80% of annual runoff occurred during a 4-mo period from March through June (USGS station 06441500). Predominant land uses within the watershed are rangeland ≈ 75% and dryland agriculture ≈ 25%.

Rangeland management within Ash Creek underwent significant changes as a result of a larger effort to reduce nonpoint source pollution within the Bad River watershed. The rangeland (3 372 ha) was grazed continuously season-long until 1997. In 1997 construction of a cross fence divided a continuous tract of 2 580 ha in two separate tracks; water
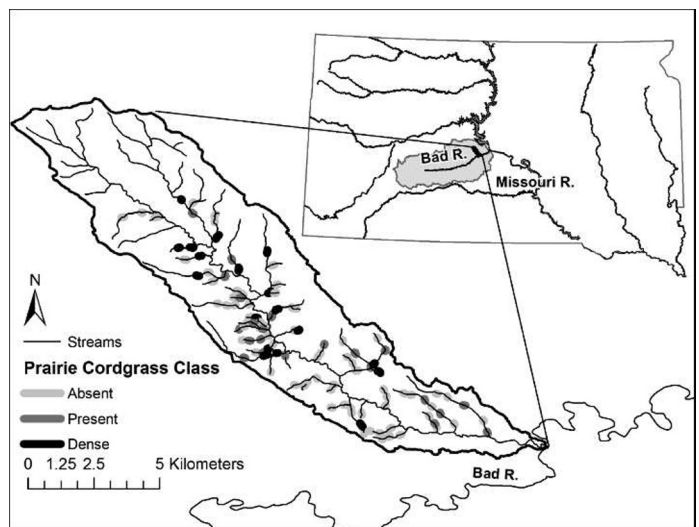
Figure 1. Ash Creek is a subwatershed within the Lower Bad River Basin located in west-central South Dakota. The 2010 ground assessment status of prairie cordgrass class is depicted in the legend.

was pumped from three water lines and several wells into 21 off-stream watering tanks, and rotational grazing was implemented. In 2002, land ownership changed and bison (*Bison bison*) replaced cattle on the majority of rangelands (2 580 ha). Cattle remained in rotational grazing systems on 703 ha and continuous grazing on 89 ha.

Ground Assessment

Channel morphology baseline assessment was conducted in 1994 within the Ash Creek watershed prior to BMP implementation. During post-BMP assessment of channel morphology in 2010, presence/absence of prairie cordgrass was recorded. Photos were later used to group sites ($n=103$) subjectively into three distinct classes; absent ($n=64$), present ($n=23$), and dense ($n=16$) based on the relative amount of prairie cordgrass present (Figs. 2a–2c). Sites classified as absent had no functional (i.e., < 5%) prairie cordgrass cover, present sites had scattered prairie cordgrass patches (estimated 5–40% cover), whereas dense sites had near full coverage of prairie cordgrass (estimated > 40% cover) with scattered patches of bare ground.
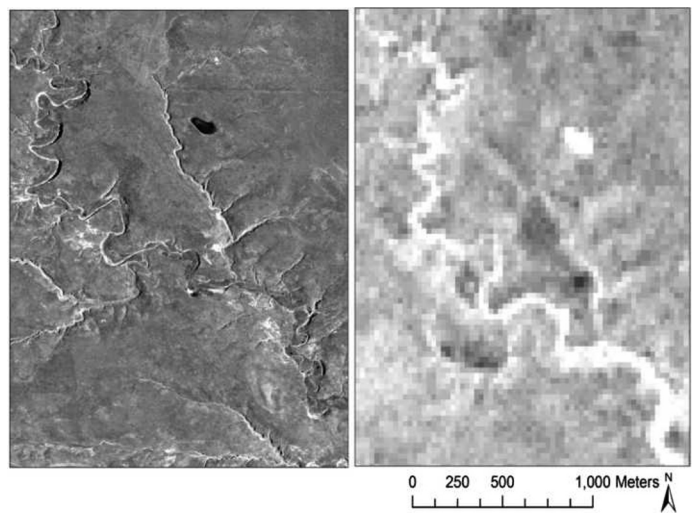
Remote Assessment

Stream reaches (1:24 000 scale, first and second order) containing a range of drainage areas (0.54–692 ha) were delineated with the use of 2010 National Agriculture Inventory Program (NAIP) imagery with the ArcMap 2010 editor. Delineation vertices ($n=5–39$ per stream reach) were sample locations subsequently used to extract NDVI values from a series of Satellite Pour l'Observation de la Terre (SPOT) high-resolution visible (HRV) satellite imagery (Fig. 3). Longer reaches contained more delineation vertices. Images from the SPOT 2, 3, 4, and 5 sensors were used. Imagery from SPOT 5 had an initial resolution of 10 m, which was resampled to 20 m with the use of the nearest-neighbor method to match the resolution of the other SPOT sensors. NDVI values were extracted from pre-BMP 1987 (30 June and 26 July), 1997 (16
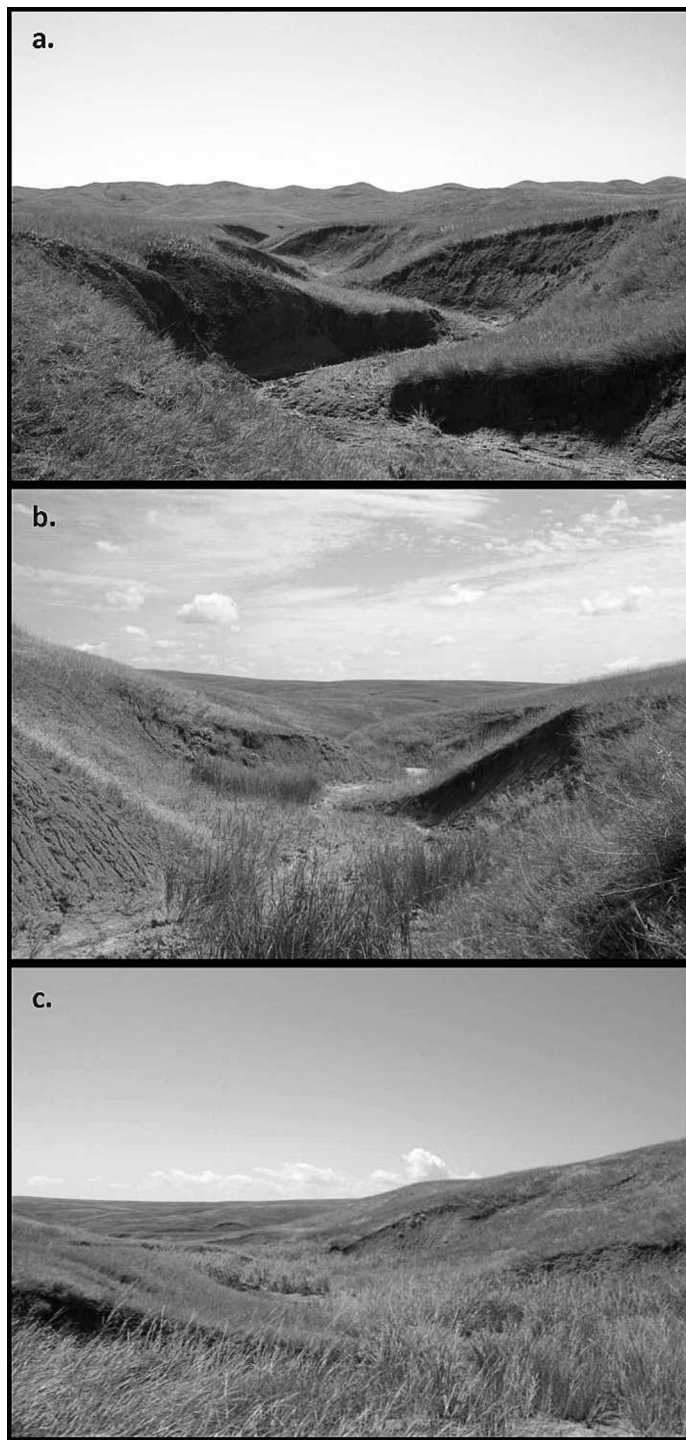
Figure 2. Variation in prairie cordgrass establishment throughout the Ash Creek watershed in western South Dakota. The range of prairie cordgrass site abundance is represented from absent (**a**), present (**b**), and dense (**c**).

Figure 3. Aerial imagery (left) with 1-m resolution and NDVI generated from Satellite Pour l'Observation de la Terre (SPOT) satellite imagery (right) with 20-m resolution for the same ephemeral stream channels seen above. White areas on the SPOT imagery refer to areas of high vegetation signal, occurring mostly in riparian areas.

July, 26 July, and 27 August), and post-BMP 2010 (26 May, 16 July, and 11 August) images (©CNES, Distribution Spot Image). The 11 August 2010 SPOT HRV scene was selected as a reference to which all other images were standardized. Standardizing was necessary because multitemporal images were acquired by different sensors under variable atmospheric conditions, solar illumination, and view angles (El Hajj et al. 2008). The standardized values of each sample location ($n = 1\,689$) were then normalized by dividing each value by the mean standardized NDVI for each respective year so that a normalized NDVI value < 1 indicates below-average NDVI, whereas a value > 1 indicates NDVI above the mean. Hereafter, normalized NDVI values will be referred to as nNDVI. Normalization of SPOT imagery has previously been used to reduce variation in nonsurface factors in order to detect actual change in surface conditions (Eckhardt et al. 1990). The influence of interannual differences in precipitation on vegetation productivity can be factored out with the use of normalization, because normalized NDVI values represent a proportion of an image mean. Deterministic and empirical approaches of normalization described by Eckhardt et al. (1990) should be considered in larger-scale projects because of 50% differences in view angle between east- and west-looking SPOT HRV acquisitions (Moran et al. 1990). Because of the small area studied in this project, a simpler method of normalization is suitable.

Statistical Analysis

Analysis of variance was used to test the hypotheses that mean nNDVI differed among riparian classes (absent/present/dense) for each individual year ($P = 0.05$). Temporal changes of nNDVI were observed both within a year (2010) to determine if and when differences in nNDVI could be expected to occur among riparian classes, and interannually to determine if patterns indicated change in riparian vegetation classes ($P = 0.05$).

RESULTS

Significant differences in nNDVI were observed through the duration of the growing season as indicated by the multitemporal 2010 imagery set (Fig. 4). As one would expect, nNDVI increased as a function of vegetation cover. The
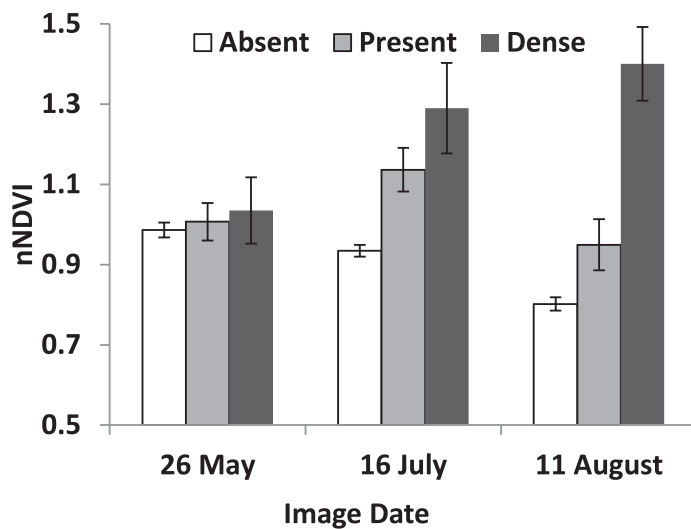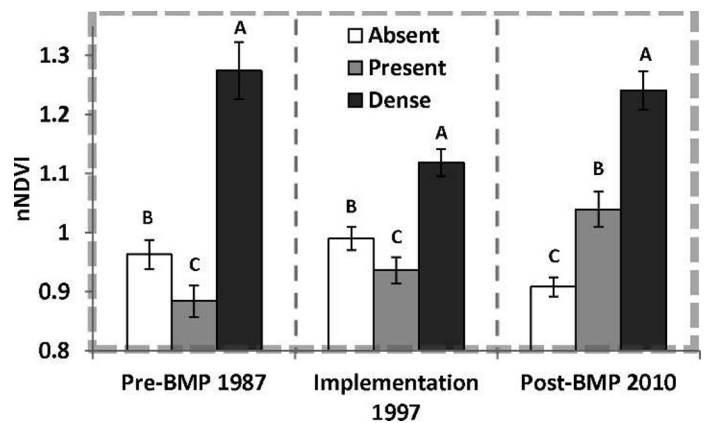
Figure 4. Mean normalized NDVI (nNDVI) and 95% confidence intervals for sites classified as absent, present, or dense cover of prairie cordgrass cover over a portion of the 2010 growing season.

Figure 5. Normalized NDVI (nNDVI) means and 95% confidence intervals of treatments by year. Letters indicate groups significant at 0.01 Tukey's. The dotted lines represent that each year was statistically analyzed independent from the others.

influence of upland species, both adjacent to and commonly within the channel itself, such as western wheatgrass and Canada wildrye (*Elymus canadensis* L.), was greatest on absent sites. Present and dense sites were influenced by moderate and heavy prairie cordgrass cover, respectively, with less influence from upland species. The nNDVI signatures of the three cover classes were relatively similar early in the growing season (May); however, as the growing season progressed, upland species senesced while riparian vegetation generally either maintained or gained photosynthesizing biomass. This phenomenon was evident later in the growing season (July and August) when distinct differences in nNDVI became apparent (Fig. 4). Contrast among classes increased in late summer because of the presence of prairie cordgrass, a C_4 species, coupled with senescence of C_3 upland vegetation. Hence, locations where upland species had proportionately large influence on nNDVI (absent sites) underwent sharp decreases in nNDVI as the growing season progressed, whereas the nNDVI increased in locations containing prairie cordgrass. This result suggested that imagery early in the growing season was unable to resolve the differences among cover classes. May images were thus excluded from further analysis.

No change in the pattern of nNDVI among the riparian classes was apparent between 1987 and 1997 (Fig. 5). During both time periods dense sites had the highest nNDVI, followed by absent and present sites ($P=0.05$). Following BMP implementation, present sample pixels ($n=389$) surpassed absent sample pixels ($n=993$) in nNDVI in 2010, and for the first time attained an nNDVI over 1 indicating prairie cordgrass likely established during this period. Samples ($n=307$) classified as dense prairie cordgrass stands in 2010 had a significantly greater mean nNDVI than absent and present sites in all years ($P=0.01$) suggesting dense prairie cordgrass stands existed pre-BMP (1987). Locations classified as present, however, were the only group that displayed a large increase in mean nNDVI (Fig. 5).

The mean nNDVI of present sites increased 19.6% following BMP implementation (Fig. 6). Dense sites maintained similar nNDVI from 1987 to 2010 with a 0.9% increase, whereas absent sites decreased by 9.6% (Fig. 6). Between 1987 and 1997 present sites and dense sites displayed contrasting changes. However, the change of present and dense sites from 1997 to 2010 was similar, suggesting establishment of prairie cordgrass in present sites occurred during the post-BMP period (1997–2010).

DISCUSSION

We determined that prairie cordgrass cover increased within the riparian areas of Ash Creek following BMP implementation, and that the 20-m spatial resolution of SPOT imagery was sufficient to assess BMP impacts, despite riparian areas generally being less than 20 m in width. The shift in pattern between absent and present sites from 1997 to 2010 provided evidence that prairie cordgrass stands established on locations classified as present (2.56 km=27.5% of total assessed channel length) following BMP implementation (Fig. 5). The increased average nNDVI in present sites from 1987 to 2010 corresponded with a 27.5% increase in prairie cordgrass extent (Fig. 6). Prairie cordgrass cover within locations classified as dense in 2010 (1.99 km) was presumably established prior to BMP implementation because of having a significantly greater mean nNDVI than absent and present sites in 1987.

Phenological differences between cool-season–dominated upland vegetation and warm-season prairie cordgrass were instrumental in successful characterization of riparian vegetation (Fig. 4). Dry years promoted greater contrast between riparian areas and surrounding upland vegetation, because prairie cordgrass tended to remain photosynthetically active in riparian areas while upland vegetation was largely senesced. Similar findings were reported by Clary and Webster (1989), who found a greater similarity in vegetation vigor between riparian and upland areas in spring than in summer. In 1987, only 75% of the 1964–2008 mean growing season (April–September) precipitation occurred, resulting in greater difference in the upland and riparian vegetation signal. Growing-season precipitation was 140% of the long-term average in
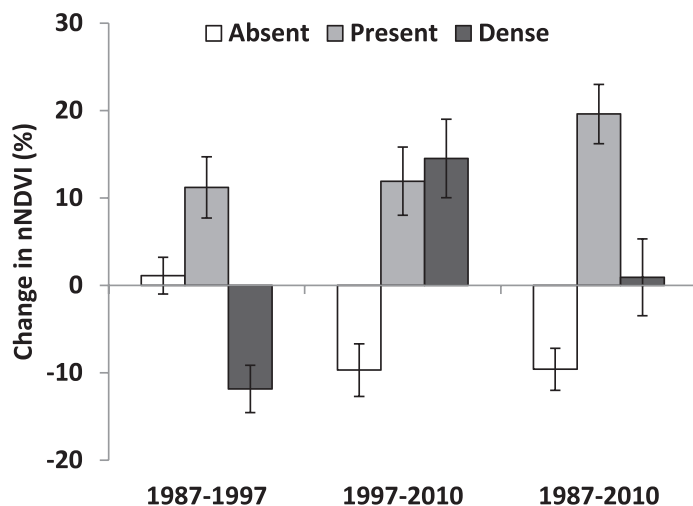
Figure 6. Average percent change in normalized NDVI (nNDVI) from 1987 to 1997 represents pre–best management practice (BMP) change and 1997 to 2010 represents post (BMP) change within prairie cordgrass cover classes. Error bars are +/− 1 standard error. $\Sigma \Delta$nNDVI$=0$.

1997, yielding more homogeneous vegetation across the landscape. In 2010, 138% of the long-term average growing season precipitation occurred. If less precipitation had occurred in 2010, greater contrasts among riparian classes than observed would be expected, as upland vegetation is more responsive to precipitation. Comparable upland vegetation growth would be expected in 1997 and 2010 because of similar growing-season precipitation. Therefore, the difference in the nNDVI of prairie cordgrass classes between these years was likely attributable to differences in prairie cordgrass cover, not precipitation.

Interannual differences in precipitation partly explained changes in nNDVI among riparian classes among years. For example, the difference in nNDVI between absent and dense sites was greater in 1987 compared to 1997. This was because of above-normal precipitation in 1997 causing the productivity of upland vegetation to be higher than normal during July and August. Had present sites contained prairie cordgrass cover in 1987, a response similar to dense would have been expected during the 1987–1997 period. The responses between these two classes were, however, exactly opposite from each other during the 1987–1997 period, indicating that prairie cordgrass had not been established in present sites. From 1997 to 2010, which were both wet years, similar direction and magnitude of change in nNDVI for dense and present was observed indicating cordgrass establishment had occurred in present locations. Over the 23-yr study period, no significant change in nNDVI occurred in dense sites; significant increases were found in present sites, whereas absent sites decreased significantly (Fig. 5). Because of the nature of nNDVI ($\Sigma \Delta$nNDVI$= 0$), the decrease in nNDVI in absent sites occurred as a result of the increased nNDVI of present sites. Presumably, the prairie cordgrass cover of dense sites was greater throughout the study period, whereas prairie cordgrass cover on present sites was established following BMP implementation.

Eliminating direct access to streams by cattle is generally the most effective method to restore riparian vegetation and thereby improve ecological health and function. We demonstrated that implementation of BMPs, including alternate water sources and cross fencing that are readily adopted by producers, were successful at increasing the extent of prairie cordgrass even as cattle were not excluded from riparian areas. Prairie cordgrass functioned as a channel roughness component that reduced flow energy, halted channel degradation, and encouraged retention of sediment (Sandercock et al. 2007). For these reasons, the channel morphology of dense sites was characteristically wide and maintained high width/depth ratios because of channel bed aggradation within historically incised channels (Vande Kamp 2012). This study suggests that prairie cordgrass may be a successful tool to address channel degradation, a pervasive issue in rangelands (Elmore and Kauffman 1994).

The switch from cattle to bison grazing in the majority of study-area rangelands confounded the influence of BMPs, as bison and cattle demonstrate different foraging behavior (Plumb and Dodd 1993; Towne et al. 2005). Signs of in-channel vegetation recovery prior to BMP implementation (1997) were absent. Prairie cordgrass expanded its extent following the implementation of off-stream watering and cross fencing in 1997 and the switch to bison grazing in 2002. Decreased grazing pressure on riparian areas would be expected as a result of both the implementation of off-stream water sources (Sheffield et al. 1997; Porath et al. 2002) and the replacement of cattle with bison (Wuerthner 1998). Though the switch to bison grazing likely aided the recovery of in-channel vegetation, the lack of appropriate replication in the study area did not permit the investigation of the influence of bison in the absence of BMPs. Despite this limitation, we report BMPs including off-stream water sources and cross fencing in combination with bison grazing increased the vigor and extent of prairie cordgrass.

We confirm prairie cordgrass as an ideal species for revegetating and stabilizing stream channels due to its tolerance of harsh hydrologic regimes, ability to dissipate flow energy, and low palatability (Weaver 1960; Johnson and Larson 1999; Boe and Lee 2007). Linking improvements in water quality (e.g., decreased sediment load) with increased NDVI could provide further insight into the capacity of in-channel vegetation to improve water quality. The approach used to evaluate riparian vegetation with SPOT or similar high-resolution sensor has potential applications in ephemeral, seasonal, and permanent streams across the Great Plains and other grassland systems.

MANAGEMENT IMPLICATIONS

Implementation of BMPs including off-stream water sources and cross fencing coupled with replacing cattle with bison in the majority of rangeland corresponded with increase prairie cordgrass extent in stream channels despite continued access to riparian areas. Remote sensing studies have tended to avoid riparian areas because of their complex mixture of upland and riparian vegetation and bare ground. However, the differences in phenology between upland and lowland vegetation combined with the high productivity of prairie cordgrass allowed the riparian vegetation signal to dominate the SPOT imagery in the mid to late growing season. Remote sensing was critical in

describing pretreatment conditions because detailed field data were absent.

We recognize that the ability of a riparian area to function properly is dependent on retaining vegetative structure and composition under the hydrologic regime of the system. Erosional features (e.g., knickpoints and gullies) in rangelands often begin to form before the carrying capacity is reached, leading to high sediment loads, a common water-quality impairment. Incised channels often are remnants from historical overgrazing and take decades, possibly centuries, to heal. Rangeland managers aim to improve grazing distribution by means of BMPs, including strategic water and mineral placement or cross fencing, allowing resource utilization to be more distributed across a landscape. Our study results suggest that implementation of a BMP suite resulted in a net improvement in riparian and channel vegetation condition. We provide a monitoring tool that can be used to detect in-channel vegetation establishment in response to improved management efforts with limited ground-truthing, a costly activity that often is neglected. Increasing awareness of the benefits these BMPs have on rangelands provides added incentive to producers and rangeland managers to increase efforts adopting improved management practices.

ACKNOWLEDGMENTS

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