Detecting the Influence of Best Management Practices on Vegetation Near Ephemeral Streams With Landsat Data

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Abstract

Various best management practices (BMPs) have been implemented on rangelands with the goals of controlling nonpoint source pollution, reducing the impact of livestock in ecologically important riparian areas, and improving grazing distribution. Providing off-stream water sources to livestock in pastures, cross-fencing, and rotational grazing are common rangeland BMPs that have demonstrated success in drawing livestock grazing pressure away from streams. We evaluated the effects of rangeland BMP implementation with six commercial-scale pastures in the northern mixed-grass prairie. Four pastures received a BMP suite consisting of off-stream water, cross-fencing, and deferred-rotation grazing, and two pastures did not receive BMPs. We hypothesized that the BMPs increased the quantity of riparian vegetation cover relative to the conditions in these pastures during the pre-BMP period and to the two pastures that did not receive BMPs. We used a series of 30-m Landsat normalized difference vegetation index (NDVI) images to track the spatial and temporal changes (1984–2010, $n=24$) in vegetation cover, to which NDVI has been well correlated. Validation indicated that the remotely sensed signal from in-channel vegetation was representative of ground conditions. The BMP suite was associated with a 15% increase in the in-channel NDVI (0–30 m from stream centerline) and 18% increase in the riparian NDVI (30–180 m from stream center line). Conversely, the in-channel and riparian NDVI of non-BMP pastures declined 30% and 18% over the study period. The majority of change occurred within 2 yr of BMP implementation. The patterns of in-channel NDVI among pastures suggested that BMP implementation likely altered grazing distribution by decreasing the preferential use of riparian and in-channel areas. We demonstrated that satellite imagery time series are useful in retrospectively evaluating the efficacy of conservation practices, providing critical information to guide adaptive management and decision makers.

Key Words: best management practice (BMP), livestock grazing, northern mixed-grass prairie, off-stream water, rangeland, riparian areas

INTRODUCTION

Various best management practices (BMPs) have been implemented on rangelands with the goals of controlling nonpoint source pollution and reducing the livestock-induced degradation and overuse of riparian areas (Agouridis et al. 2005), common across the western United States (Fleischner 1994; Chambers et al. 2004). These BMPs are designed either to reduce or to eliminate the disproportionate amount of time livestock spend in riparian areas because of the abundance of forage, water, and shade (Senft et al. 1985; Fleischner 1994). Continuous season-long grazing has been widely cited as degrading to riparian areas, even in lightly stocked pastures (Ehrhart and Hansen 1997; Agouridis et al. 2005; George et al. 2011). Overuse of riparian areas compromises their ability to store water, recharge aquifers, filter chemical and organic waste, trap sediments, build banks, produce abundant biomass, and provide critical wildlife habitat (Ehrhart and Hansen 1997). Furthermore, riparian degradation reduces erosional resistance provided by vegetation, thus increasing consequent erosion (Trimble and Mendel 1995).

Although eliminating direct livestock access to streams with riparian exclosures has been advocated by some, this method removes an important source of livestock forage (Stillings et al. 2003), especially in semiarid and arid regions (Ehrhart and Hansen 1997). Moreover, doing so is often impractical, costly, and undesirable to livestock producers (Godwin and Miner 1996). In response to these shortcomings, a variety of rangeland BMPs have been implemented for riparian improvement including: off-stream water sources, alternate shade sources, controlled grazing, supplemental feeding, and herding (Agouridis et al. 2005; George et al. 2011). The Natural Resources Conservation Service (NRCS) commonly cost-shares BMP implementation programs, which have been readily accepted by livestock producers (Ehrhart and Hansen 1997). One frequently investigated BMP involves providing off-stream water sources to livestock in pastures. Researchers have often reported the effectiveness of off-stream water practices (OSWP), cross-fencing, and deferred-rotation grazing in reducing livestock use of riparian areas (Godwin and Miner 1996; Sheffield et al. 1997; Agouridis et al. 2005; George et al. 2011). Sheffield et al. (1997) reported that OSWP implemen-

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tation, for example, was associated with a significant reduction in the time livestock spent in stream channels and riparian areas, corresponding with reduced stream bank erosion, total suspended solid concentration, and stream nitrogen content.

The recovery of riparian areas that often occurs following implementation of OSWP (Sheffield et al. 1997; Agouridis et al. 2005) or BMP suites (i.e., cross-fencing and rest-rotation grazing plus OWSP; Vande Kamp et al. 2013) frequently coincides with higher quality and quantity of riparian live standing crop and vegetation cover (Elmore and Beschta 1987; Bradley and O'Sullivan 2011; George et al. 2011). Of the factors influencing stream health and stability, riparian vegetation is most responsive to land management practices and is a critical component of riparian restoration efforts and monitoring programs (Ehrhart and Hansen 1997; George et al. 2011). Establishment or increases in riparian vegetation cover following implementation is therefore an important indicator of BMP success in improving the ecological condition of riparian areas, stream bank stability, and sediment load reduction (Clary and Leininger 2000; George et al. 2011).

We evaluated the response to rangeland BMP implementation in six commercial-scale pastures in the northern mixed-grass prairie. Four pastures received BMPs consisting of off-stream water, cross-fencing, and deferred-rotation grazing, and two pastures did not receive BMPs. Prior to BMP implementation, the study area received season-long continuous grazing. We therefore hypothesized that the BMPs implemented on the four treatment pastures increased the quantity of riparian vegetation cover (as measured by remotely sensed imagery) relative to both the quantity in these pastures prior to BMP implementation and to the two pastures that did not receive BMPs.

Specifically, we tracked the changes associated with BMPs in in-channel and riparian vegetation near ephemeral streams. Of the factors influencing riparian health and fluvial process, riparian vegetation is most easily influenced by land management and therefore serves as an important indicator of BMP success (Sandercock et al. 2007; Vande Kamp et al. 2013). The results of this study can be used to fill a gap in knowledge; providing empirical data on the influence of BMPs on in-channel and riparian vegetation cover in the northern mixed grass prairie, and provide the research framework for similar analyses of riparian conservation practices in rangelands. This research is especially valuable, because few studies have examined the impacts of BMPs on riparian areas in commercial scale pastures, while even fewer have examined the impact of a combined BMP suite (Agouridis et al. 2005).

STUDY SITE DESCRIPTION

The study area (lat ~43°56′N, long 102°12′W) is located near the headwaters of the Bad River, a tributary of the Missouri River in western South Dakota (Fig. 1). Most of the study area is located within three subwatersheds of the Bad River including; Whitewater Creek South, Whitewater Creek North, and Cottonwood Creek, with small portions extending into adjacent watersheds (Fig. 1). The study area (6 601 ha) is divided into six pastures ranging from 498 to 2 080 ha in size

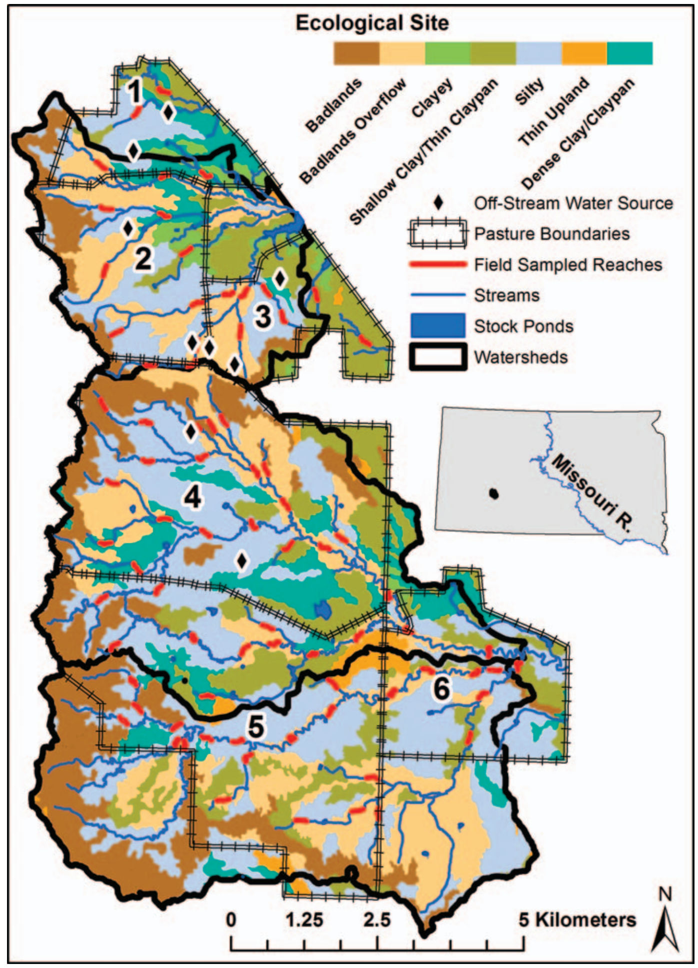

Figure 1. Boundaries of evaluated pastures (with assigned pasture numbers), watersheds, ecological sites, locations of off-stream water sources (OSWP), and stream reaches where field sampling occurred. Pastures 1–4 were defined as BMP pastures, and 5 and 6 were defined as non-BMP pastures. Inset map shows the location of the study area in western South Dakota.

and is managed by the U.S. Forest Service Buffalo Gap National Grassland.

Stream channels (total length = 124 km) were digitized in ArcGIS with the use of 2010 National Agriculture Imagery Program (NAIP) imagery. No significant changes to channel courses were observed in a comparison to 1991 aerial imagery. Streams in the study area consist of moderately sinuous ephemeral channels. Portions of some evaluated streams are poorly defined, lacking distinct bed and bank features. Channel width averages ~6 m. Most streams originate in higher-relief badlands, but the majority of their course is in clayey and/or silty flatlands (Rigge et al. 2013; Fig. 1). Streams are generally moderately sinuous and some are incised 1 to 2 m. The main stem of Whitewater North and South Creeks had zero flow 73% of the growing season (April–September), based on daily stream gauge observations from 1 November 1998 to 17 October 2001. Although pools of water likely remain, stream water is often lacking and/or unpalatable during large portions of the growing season. Soils are composed of loam, silty loam, and silty clay loam (Soil Survey Staff 2011). The Soil Survey Geographic (SSURGO) ecological site data were downloaded from the NRCS Soil Data mart, and are shown in Figure 1. For the sake of visualization the "channelized badlands overflow" and "un-channelized badlands overflow" ecological sites were combined into "badlands overflow," "dense clay," and "claypan" were combined into "dense clay/claypan." "Shallow clay/thin claypan" and "silty" were the most common ecological sites. The proportion of area occupied by each ecological site is very similar between the non-BMP and BMP pasture groupings. The biggest difference is in the "silty" ecological site, which comprised 30.5% of BMP pastures and 42% of non-BMP pastures. Additionally, the "clayey" ecological site is virtually nonexistent in non-BMP pastures, whereas it occupies 3.5% of BMP pastures. Although some areas are nearly devoid of vegetation (i.e., in badlands ecological sites), a majority are vegetated (Barker and Whitman 1988).

Climatic conditions are strongly continental, with daily mean temperatures ranging from 32°C in July to −14°C in January, and a yearly mean of 8°C (Smart et al. 2007). The growing season averages 115–130 d in length. Long-term (1909–2010) mean annual precipitation is 407 ± 25 mm (1 Stderr), for the weather station located 4 km east of Cottonwood, SD, or approximately 27 km east/northeast of the study area (South Dakota Climatology Office, http://climate.sdstate.edu/coop/monthly.asp). We are confident that the records of this station correspond closely to the conditions experienced in our study area, because there is little topographic influence on precipitation in this area. Fully 77% of annual precipitation occurs during the growing season from April to September (Smart et al. 2007; Parameter-Elevation Regressions on Independent Slopes Model [PRISM] Climate Group, Oregon State University, http://www.prismclimate.org).

Vegetation

Upland vegetation consists mostly of native cool-season (C_3) grasses. Dominant species include western wheatgrass (*Pascopyrum smithii* Rybd.), needle-and-thread (*Stipa comata* Trin.), and green needle grass (*Stipa viridula* Trin.). Buffalo grass (*Bouteloua dactyloides* Nutt.), blue grama (*Bouteloua gracilis* H.B.K.), and sideoats grama (*Bouteloua curtipendula* Michx.) are the dominant warm-season (C_4) grasses (Barker and Whitman 1988).

We defined in-channel and riparian areas as 0 to 30 m and 30 to 180 m from stream centerlines, respectively. Dominant herbaceous in-channel vegetation includes prairie sandreed (*Calamovilfa longifolia* Hook), switchgrass (*Panicum virgatum* L.), foxtail barley (*Hordeum jubatum* L.), sedges (*Carex* spp.), cocklebur (*Xanthium strumarium* L.), and American licorice (*Glycyrrhiza lepidota* Pursh). Upland species such as sideoats grama and western wheatgrass also commonly occur in riparian and in-channel zones. Woody in-channel and riparian vegetation in the study area is sparse and consists of sandbar willow (*Salix exigua* Nutt.), plains cottonwood (*Populus deltoides* Bartram ssp. *monilifera* Aiton), silver sagebrush (*Artemisia cana* Pursh), western snowberry (*Symphoricarpos occidentalis* Hook), and silver buffaloberry (*Shepherdia argentea* Hook). The majority of graminoid species richness, live standing crop, and vegetation cover in the riparian and especially in-channel zone is attributable to C_4 species.

Best Management Practices and Grazing Systems

Prior to the mid-1970s, the entire study area was managed as a single 6 601-ha pasture, with season-long (May 1–December 1) continuous grazing by yearling steers, cow/calf pairs, and horses at a stocking rate of 0.65–0.70 $AUM \cdot ha^{-1}$. Similar management continued from the mid-1970s to 1991, though the study area was split into a two-pasture system. In 1991, BMPs consisting of water pipeline with nine OWSP (with water piped from a municipal source into galvanized steel tanks [$\sim$3 m diameter]), cross-fencing, and a deferred-rotation grazing system were implemented in pastures 1, 2, 3, and 4, hereafter referred to as BMP pastures (Fig. 1). Each of the four BMP pastures had two OSWP implemented, with an additional OSWP shared between pastures 2 and 3 (Fig. 1). Several sediment control structures and riparian exclusion fencing surrounding 200 m of stream channel were also implemented. In the post-BMP period, pastures 5 and 6, hereafter non-BMP pastures, were grazed season-long from 1 May to 15 September, with the use of yearling steers at a rate of 0.58 $AUM \cdot ha^{-1}$. Pastures 1–3 were grazed from 1 July to 15 August and 16 August to 30 September, alternating periods yearly, as part of a six-pasture system (of which three pastures are not in the study area) with yearling steers at an average stocking rate of 0.74 $AUM \cdot ha^{-1}$. Pasture 4 was grazed from 15 May to 15 June and 1 August to 30 October, alternating periods yearly with yearling steers at stocking rate of 0.70 $AUM \cdot ha^{-1}$. Because cool-season species (e.g., western wheatgrass and green needlegrass) are the dominant forage species in the study area, the BMP pastures (1–4) receive a spring deferment (i.e., allowed to set seed) every other year by waiting until early–mid August to graze. Following BMP implementation, BMP pastures were 483 (pasture 1), 792 (pasture 2), 497 (pasture 3), and 1 943 (pasture 4) ha in size, whereas non-BMP pastures were 2 074 (pasture 5) and 809 (pasture 6) ha. Areas classified as the 'badlands' ecological site were excluded from analysis because livestock use of these areas is limited. It is important to note that treatments (i.e., the BMP suite) were not applied at random; however, pre-BMP differences between the riparian vegetation and biophysical conditions of BMP and non-BMP pastures was minimal (Table 1).

METHODS

Experimental Design

Each component of the BMP suite (OSWP, cross-fencing, and deferred-rotation grazing) could have influenced grazing distribution, and thus the amount of in-channel and riparian vegetation cover. The individual effects of the components of the BMP suite may have been confounded by the remaining components (e.g., the individual effect of OSWP may be confounded by cross-fencing), and the suite of BMPs were implemented simultaneously without appropriate replication (as we did not set up the treatments) to examine the individual components. Therefore, we focused on tracking temporal

Table 1. Summary of pre- and post-best management practices (BMP) mean normalized difference vegetation index (nNDVI) and associated standard error (in parentheses) in the in-channel and riparian areas of BMP and non-BMP pastures.

	Pre-BMP	Post-BMP	*P* value
In-channel			
BMP pastures	1.10 (0.027)	1.27 (0.027)	< 0.01
Non-BMP pastures	1.00 (0.032)	0.70 (0.028)	< 0.01
P value	0.06	< 0.01	
Riparian			
BMP pastures	0.97 (0.015)	1.14 (0.015)	< 0.01
Non-BMP pastures	0.96 (0.02)	0.79 (0.019)	< 0.01
P value	0.75	< 0.01	

changes of in-channel and riparian vegetation cover associated with the entire BMP suite.

Landsat Imagery

A time series of 30-m Landsat 5 and 7 Images (n=24) were downloaded from the USGS Glovis site (http://glovis.usgs.gov/) for all years between 1984 and 2010, with the exclusion of 1986, 1990, and 1993 (when no cloud-free imagery from the late summer were available). All images were cloud-free and from the late summer period, with an average acquisition date of 12 August (± 3.1 d Stderr), ranging from 10 July to 10 September. Images were re-projected to Albers Equal Area and the normalized difference vegetation index (NDVI) values were calculated with the use of ERDAS IMAGINE® (Intergraph, Madison, AL). The NDVI represents photosynthetic potential, and has been strongly correlated with aboveground live standing crop, biomass (Wylie et al. 2002; Kawamura et al. 2005), and cover (Bradley and O'Sullivan 2011) in grasslands. Late-summer imagery was used because of its ability to resolve differences between in-channel/riparian and upland vegetation (Vande Kamp et al. 2013). This pattern results from the senescence of upland vegetation, mostly comprised of C_3 species, and the maintained vigor of the in-channel vegetation, mostly comprised of C_4 species. The in-channel area may include species considered to be either riparian or upland because 1) the ephemeral nature of streams enables colonization by upland species (Senft et al. 1985), 2) all stream channels were less than 30 m in width (i.e., a 30-m Landsat pixel does not always resolve purely in-channel areas), and 3) the stream greenline often supports nonriparian species caused by channel incision (Winward 2000).

Normalization of Imagery

Normalization of imagery was required because of the variable atmospheric conditions and solar illumination at each image date (El Hajj et al. 2008), and differences in weather conditions among evaluated periods. Normalization reduces atmospheric effects and weather-related differences; focusing attention on actual changes to ground conditions (Eckhardt et al. 1990). Normalized NDVI values have been closely linked to NDVI values obtained following an atmospheric correction (El Hajj et al. 2008), and have been used successfully in previous analyses of riparian areas (Rigge et al. 2013; Vande Kamp et al. 2013). A variety of atmospheric corrections have been developed including dark-object subtraction such as the COST model (Chavez 1996) and deterministic approaches (Eckhardt et al. 1990). Because of the relatively small size of the current study area, differences in view angle are negligible, and a simpler method of normalization is suitable (Song et al. 2001).

Our normalization of imagery follows the procedure described by Rigge et al. (2013), though we did not normalize by ecological site as the former study did. Briefly, the NDVI values were normalized by subtracting each pixel value from the mean NDVI (of the pre- and post-BMP periods) and dividing by the standard deviation, so that a normalized NDVI value < 1 indicates below-average NDVI, and alternatively a value > 1 indicates an NDVI above the mean. Hereafter normalized NDVI values will be referred to as nNDVI. The sum of changes in nNDVI between periods equals zero (i.e., $\Sigma\,\Delta\text{nNDVI} = 0$) (Vande Kamp et al. 2013). The normalization procedure was only conducted in the evaluated in-channel and riparian areas, so that the pooled mean nNDVI in these areas equaled 1 in all images.

Statistical Analysis

Stream channels (total length = 124 km) were digitized in ArcGIS with the use of 2010 National Agriculture Imagery Program (NAIP) imagery. No significant changes to channel courses were observed in a comparison to 1991 aerial imagery. Twenty percent (n= 8 757) of the pixels within in-channel and riparian areas were randomly selected to calculate the average nNDVI from each Landsat image in the following areas: 1) in-channel areas in BMP pastures (n=1 397), 2) in-channel areas in non-BMP pastures (n=1 086), 3) riparian areas in BMP pastures (n= 3 664), and 4) riparian areas in non-BMP pastures (n=2 610). In each sampled pixel we generated an ordinary least-squares regression of 1984 to 2010 nNDVI values by time and calculated the associated significance. Points were mapped with the symbology reflecting the direction and significance of the regression in each point. Additionally, we determined the pre- (1984–1989 [1990 imagery was not available]) and post- (1991–2010) BMP mean nNDVI and associated standard error in each of the four areas described previously (Table 1). We used a paired two-sample, two-sided t test to determine differences between the mean nNDVI of the pre- and post-BMP period in in-channel and riparian areas in both BMP and non-BMP pastures (i.e., four tests of temporal patterns). Next, we used a two-sample, two-sided t test to determine differences between the mean in-channel and riparian nNDVI of BMP and non-BMP pastures, in both the pre-and post-BMP periods (i.e., four tests of treatment differences). Significance was assessed as ($P < 0.05$).

Ground Validation

To validate the remotely sensed data, field sampling of the evaluated stream channels was conducted from 18 to 22 July 2011. This sample consisted of approximately 10% (15 km) of the digitized stream channel length within the study area. Randomly selected sample sites (n=78) consisted of a 200-m stream reach with a 10-m buffer on both sides of the stream. Live canopy cover was observed with the use of ocular estimation at 0.5-m^2 plots (n=6) randomly located within

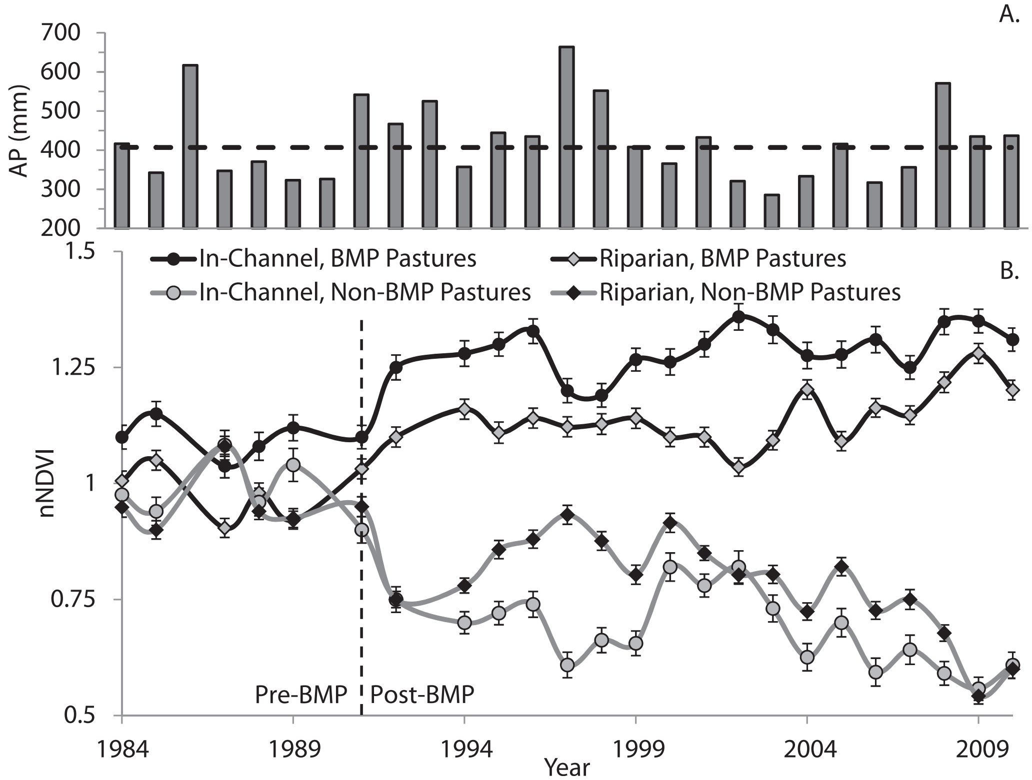

Figure 2. A, 1984–2010 annual precipitation (AP) in millimeters for the Cottonwood, SD weather station (located ~27 km east/northeast of the study area). Dashed line depicts the 1909–2010 average annual precipitation of 407 mm. **B,** Normalized NDVI (nNDVI) means and standard error of in-channel and riparian areas along western South Dakota ephemeral streams for BMP and non-BMP pastures. Yearly means were generated from a series of late-summer 30-m Landsat imagery over the 1984–2010 period. The dashed line separates the pre- and post-BMP time periods.

each site. In-channel vegetation cover at each site was classified as light: < 33% live vegetation canopy cover ($n=8$); moderate: 33–67% vegetation cover ($n=34$); or dense: > 67% vegetation cover ($n=36$). The most prevalent plot vegetation class (i.e., light, moderate, or dense) within a site was applied to the entire site (e.g., a site with four dense plots [out of six] would receive a classification as dense). Classification was performed blind; i.e., sites were classified prior to knowing their nNDVI. We downloaded an additional Landsat scene from 19 July 2011 (used only for validation) and calculated the nNDVI in a manner similar to that described previously. Subsequently, we calculated the mean nNDVI of each vegetation class. Finally, we downloaded monthly precipitation data from the South Dakota Climatology Office (http://climate.sdstate.edu/coop/monthly.asp) for 1984–2010 for the previously described site 27 km east/northeast of our study area. Data were tabulated by year (Fig. 2A) and regressed against the corresponding nNDVI values of in-channel and riparian areas in BMP and non-BMP pastures.

RESULTS

The post-BMP (2010) mean nNDVI of in-channel vegetation classes followed the anticipated pattern, as light sites had the lowest mean nNDVI and dense sites had the highest (Wylie et al. 2002). Moderate vegetation cover sites had a significantly higher mean nNDVI (0.72 ± 0.09 Stderr) than light sites (0.15 ± 0.10 Stderr), and dense sites (1.27 ± 0.05 Stderr) were significantly higher than present sites. Prior to BMP implementation (between 1984 and 1991) the difference between the mean in-channel and riparian nNDVI in BMP and non-BMP pastures was small (Table 1), with several years of insignificant differences (Fig. 2B). The nNDVI values changed dramatically following BMP implementation, with in-channel and riparian nNDVI significantly increasing in BMP pastures and significantly decreasing in non-BMP pastures. In the post-BMP period, all yearly differences between the average in-channel and riparian nNDVI in BMP and non-BMP pastures were significant. Mean in-channel and riparian nNDVI significantly increased in BMP pastures (individually and pooled) in the post-BMP period (Fig. 2B; Table 1). Conversely, the average in-channel nNDVI in one non-BMP pasture (6) significantly decreased between the pre- and post-BMP period and did not significantly change in the other (5). The net result in non-BMP pastures was a significant decrease in nNDVI between the pre- and post-BMP periods (Fig. 2B; Table 1).

In the pre-BMP period, BMP pastures had a pooled mean in-channel nNDVI of 1.10, which was not significantly different ($P=0.06$) than the pooled mean nNDVI of 1.00 for in-channel areas of non-BMP pastures (Table 1). In the post-BMP period, BMP pastures had a pooled mean in-channel nNDVI of 1.27, which was significantly higher than the pooled mean nNDVI of 0.70 for non-BMP pastures. Overall, BMP pastures demonstrated a 0.17 (15%) increase in in-channel nNDVI between the pre- and post-BMP periods, and non-BMP pastures had −0.30 (30%) decrease in nNDVI. The net result was a 0.57 (44%)

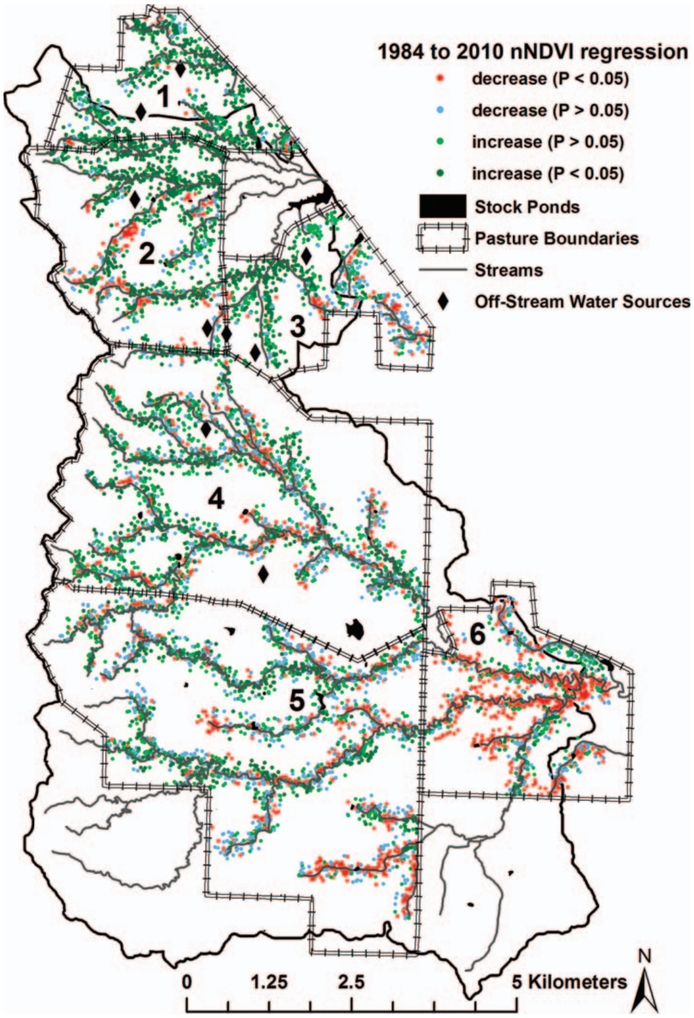

Figure 3. Linear regression of 1984–2010 ($n=24$) normalized NDVI (nNDVI) values by time at each in-channel and riparian point ($n=8\,757$). Symbology is representative of the direction (positive or negative slope) and significance of the regression at each point. See Table 2 for summary statistics.

higher mean in-channel nNDVI in BMP pastures than non-BMP pastures in the post-BMP period. Similar patterns were observed in riparian areas (Table 1) with nNDVI values significantly increasing in BMP pastures and significantly decreasing in non-BMP pastures. However, the initial (pre-BMP) difference between BMP and non-BMP pastures was much smaller ($P=0.75$) than in in-channel areas.

The distribution of temporal trend in nNDVI opposed each other between BMP and non-BMP pastures (Fig. 3; Table 2). In BMP pastures 14.19% of points demonstrated a significantly decreasing nNDVI trend between 1984 and 2010, compared to 32.95% in non-BMP pastures. Conversely, 38.58% of the points in BMP pastures underwent a significant increase, compared to only 15.67% in non-BMP pastures. Overall, the annual mean in-channel and riparian nNDVI values of BMP pastures significantly increased during the study period ($R^2=0.65$) and ($R^2=0.59$), respectively (Fig. 2B). The opposite was the case in non-BMP pastures with annual mean in-channel and riparian nNDVI values possessing a decreasing trend over the study period ($R^2=0.69$, $P<0.05$) and ($R^2=0.63$, $P<0.05$), respectively.

Table 2. Percentage of sampled points ($n=8\,757$) in best management practices (BMP) and non-BMP pastures with significant ($P<0.05$) and insignificant temporal trends (with the use of linear regression) in normalized difference vegetation index (nNDVI) between 1984 and 2010 ($n=24$). Values are pooled from in-channel and riparian areas, and correspond to the data presented in Figure 3.

1984–2010 nNDVI trend	BMP pastures	Non-BMP pastures
Decrease ($P<0.05$)	14.19	32.95
Decrease ($P>0.05$)	19.33	28.32
Increase ($P>0.05$)	27.90	23.06
Increase ($P<0.05$)	38.58	15.67

DISCUSSION

Landsat nNDVI values were representative of the extent of field-observed in-channel vegetation (i.e., light, moderate, and dense), demonstrating their capacity to monitor temporal changes. The mean nNDVI of pseudoinvariant (bare-ground) pixels in the study area did not statistically differ between the pre- and post-BMP periods ($n=100$, $P=0.78$; Rigge et al. 2013). Further, the relationships between annual precipitation and nNDVI were all weak ($R^2<0.10$) and insignificant ($P>0.05$). These findings indicated that the normalization procedure was successful at reducing differences related to atmospheric conditions and/or interannual weather variations.

No significant difference existed in the mean nNDVI of in-channel ($P=0.06$) and riparian ($P=0.75$) areas between BMP and non-BMP pastures (Fig. 2B; Table 1) when averaged across the pre-BMP (1984–1991) period. Throughout individual pre-BMP years, the differences between the in-channel and riparian nNDVI from Landsat images of the BMP and non-BMP pastures were often small, and statistically insignificant (Fig. 2B). These patterns can be attributed to the similar season-long grazing regime used in all pastures and mutual lack of BMPs. The non-BMP and BMP pastures likely had some minor underlying differences in physical templates (i.e., soil characteristics, stream size, geomorphology, ecological sites, and subsurface irrigation) as indicated by the nearly significant difference in the pre-BMP mean in-channel nNDVI between BMP and non-BMP pastures ($P=0.06$), but less so in riparian areas ($P=0.75$). The influence of these minor underlying differences is reflected in the fact the mean nNDVI of in-channel and riparian areas in BMP pastures were higher than in non-BMP pastures, in both the pre- and post-BMP periods. However, the BMP suite had a clear and positive influence on nNDVI values (Figs. 2 and 3; Tables 1 and 2).

Differences between the in-channel and riparian nNDVI of BMP and non-BMP pastures developed simultaneously with BMP implementation (Fig. 2B). The changes to the nNDVI between the BMP and non-BMP pastures occurred abruptly, following BMP implementation, with much change observed within 2 yr, indicating that vegetation responded quickly to the altered livestock distribution patterns (Sheffield et al. 1997) and reduced length of grazing period. The speed of changes (from

1991–1993) associated with BMP implementation may have been associated with the significantly wetter than average conditions in the year of BMP implementation and the subsequent 2 yr (Fig. 2A). However, the regressions between annual precipitation and nNDVI were weak and insignificant. Moreover, the data points from 1991 to 1993 were not outliers in these relationships. Therefore the abruptness of change during this period was chiefly due to the implementation of BMPs.

Spatial patterns of nNDVI trends from 1984 to 2010 were strongly associated with BMP implementation (Fig. 3), with increases predominating in the sample points of BMP pastures and decreases in non-BMP pastures (Table 2). Results from previous work in the study area by Rigge et al. (2013) indicated that some of the livestock grazing pressure and use in BMP pastures might have shifted to upland areas adjacent to OSWP and to a lesser extent in-channel areas within 200 m of OSWP, as demonstrated by a decreased nNDVI between the pre- and post-BMP nNDVI of these areas. These findings echo those of previous researchers (Godwin and Miner 1996; Sheffield et al. 1997; Agouridis et al. 2005; George et al. 2011), who reported that the implementation of implementation of BMPs such as OSWP, cross-fencing, and deferred-rotation grazing resulted in a significant reduction to the amount of time livestock spent in-channel and in riparian areas.

The contrasting temporal patterns of nNDVI by BMP and non-BMP pastures were likely a combined effect of the overuse of riparian/in-channel areas in non-BMP pastures receiving continuous, season-long grazing (Ehrhart and Hansen 1997; Agouridis et al. 2005; George et al. 2011) and the reduced in-channel grazing pressures often associated with the cross-fencing, deferred-rotation grazing, and OSWP (Godwin and Miner 1996; Sheffield et al. 1997; Agouridis et al. 2005; George et al. 2011; Vande Kamp et al. 2013) occurring in the BMP pastures. Increases to in-channel and riparian vegetation cover were likely due to a more even livestock distribution in BMP pastures (Porath et al. 2003; Stillings et al. 2003) which often results in increased upland forage consumption, weight gains, and ranch profits (Porath et al. 2002; Stillings et al. 2003), while providing ecological benefits (Fleischner 1994; Chambers et al. 2004). Because of the nature of nNDVI calculation (i.e., $\Sigma\,\Delta \text{nNDVI}=0$), the decreased values observed in non-BMP pastures do not necessarily correspond with reduced in-channel vegetation cover, but may also be due to a proportionally lower increase than in BMP pastures.

MANAGEMENT IMPLICATIONS

Our results confirmed the hypothesis that the BMP suite consisting of cross-fencing, deferred-rotation grazing, and OSWP would increase the remotely detected in-channel and riparian vegetation cover, relative to non-BMP pastures where season-long continuous grazing was used and OWSP were not implemented. These findings are significant because in-channel and riparian vegetation is critical to the health and proper function of these areas. Directly, in-channel vegetation reduces stream sediment and nutrient loads and dissipates flow energy, promoting the expansion and vigor of vegetation. Indirectly, the increased in-channel and riparian nNDVI in BMP pastures suggest reduced riparian use; that has previously been linked with reduced nutrient deposition from livestock excreta and erosion from hoof action, resulting in improved stream water quality.

Specific nNDVI values do not represent long-term management goals; rather they should be interpreted as an indicator of management impacts on riparian condition through time. The influence of rangeland BMPs on riparian health often goes unmeasured and unreported because of a lack of funding or lack of a planned experiment. The research framework outlined in this study can be applied to similar work (i.e., unplanned experiments) evaluating the influence of various conservation practices. These studies could provide empirical evidence to increase the cost-to-benefit efficiency of conservation funds, and provide resource managers with the data needed to successfully implement and monitor BMPs.

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