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LETTER

Evaluating establishment of conservation practices in the Conservation Reserve Program across the central and western United States

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Abstract

The U.S. Department of Agriculture's Conservation Reserve Program (CRP) is one of the largest private lands conservation programs in the United States, establishing perennial vegetation on environmentally sensitive lands formerly in agricultural production. Over its 35 year existence, the CRP has evolved to include diverse conservation practices (CPs) while concomitantly meeting its core goals of reducing soil erosion, improving water quality, and providing wildlife habitat. Ongoing threats to grasslands and decreased CRP acreage highlighted the need for a national evaluation of the effectiveness in providing the program's intended benefits. To address this need, we conducted edge-of-field surveys of erosional features, vegetation, and soil cover on 1 786 fields across 10 CPs and 14 central and western states from 2016 to 2018. We grouped practices into three types (grassland, wetland, and wildlife) and states into six regions for analysis. Across practice types, ⩾99% of fields had no evidence of rills, gullies, or pedestaling from erosion, and 91% of fields had <20% bare soil cover, with region being the strongest predictor of bare soil cover. Seventy-nine percent of fields had ⩾50% grass cover, with cover differing by practice type and region. Native grass species were present on more fields in wildlife and wetland practices compared to grassland practices. Forb cover >50% and native forb presence occurred most frequently in wildlife practices, with region being the strongest driver of differences. Federally listed noxious grass and forb species occurred on 23% and 61% of fields, respectively, but tended to constitute a small portion of cover in the field. Estimates from edge-of-field surveys and in-field validation sampling were strongly correlated, demonstrating the utility of the edge-of-field surveys. Our results provide the first national-level assessment of CRP establishment in three decades, confirming that enrolled wildlife and wetland practices often have diverse perennial vegetation cover and very few erosional features.

1. Introduction

While many conservation efforts globally focus on the role of public lands and protected areas in conserving species, habitats, and ecosystem services, private lands also play a key role in these efforts (e.g. Brasher *et al* 2019, Clancy *et al* 2020). The Conservation Reserve Program (CRP) in the United States is one of the nation's largest private lands conservation programs, providing voluntary incentives for landowners to plant perennial cover on highly erodible lands that were formerly in agricultural production. The U.S. Department of Agriculture (USDA) established the CRP in 1985 to reduce soil erosion and grain surplus while providing a farm subsidy during difficult economic times. The program quickly grew and averaged more than 13 million ha from 1989 to 2014 (USDA 2020a). Since its inception, the USDA has invested more than 53 billion U.S. dollars (nominal) implementing the CRP (USDA 2020b). The Agricultural Act of 2014 reduced conservation funding for the CRP and capped enrollment at 9 million ha (Lubben and Pease 2014), where it remains today, the smallest amount of land in 32 years.

The potential benefits of removing highly erodible crop fields from production, such as increased wildlife habitat and reduced erosion, were realized soon after the program was initiated (Ribaudo 1989, Young and Osborn 1990, Dunn *et al* 1993), and efforts began to quantify the environmental benefits provided by these newly established grasslands. In 1987, the U.S. Fish and Wildlife Service and the International Association of Fish and Wildlife Agencies initiated a national cooperative monitoring study to document trends in vegetation and habitat quality on CRP fields (Farmer *et al* 1988) that produced valuable findings and suggestions to improve the program (Hays *et al* 1989, Allen 1994). One such finding was that CRP native grass plantings provide the height and density necessary for a greater suite of wildlife than introduced grass plantings. Unfortunately, this nationwide monitoring effort ended in 1993. As a result, we still lack a comprehensive understanding of the on-the-ground status of CRP fields nationally and of how benefits provided by these fields may vary by region or conservation practice (CP).

As the CRP expanded in size in its early years, its economic and ecological significance began to expand as well (Bangsund *et al* 2004, Haufler 2005, Gascoigne *et al* 2011), with numerous studies showing direct benefits to CRP fields and indirect benefits on surrounding areas (e.g. Allen and Vandever 2012). Over time, the program evolved to include more diverse and targeted CPs that provide greater benefits by improving and protecting wildlife habitat, coldwater fish communities, water quality and groundwater recharge on wetlands, grasslands and other working lands (e.g. Marshall *et al* 2008, Hellerstein 2017). However, because of the lack of a nationwide monitoring program, many studies on the benefits and status of CRP fields were conducted at local levels or within individual states (e.g. Riley *et al* 1992, Horn and Koford 2000, Weber *et al* 2002).

Nearly 6 million ha of CRP lands have been converted to crop production over the last 12 years, and 3.4 million ha of CRP contracts are projected to expire between 2020 and 2021 (Stubbs 2007, USDA 2020a). Coupled with the ongoing irreversible losses of grasslands to development, these factors threaten to eliminate environmental gains achieved through the CRP and further fragment remaining habitat for wildlife, including for rare and declining grassland birds (Drum *et al* 2015).

As a result, there is a need to inform today's decision makers about the cost effectiveness and environmental value of the CRP as a whole. Information on the extent to which CPs have been successfully implemented, and are providing the desired vegetation cover and benefits for people and wildlife, is needed to understand the value of the CRP, but the lack of nationally consistent data regarding CRP implementation has precluded such an assessment in recent years.

Our goal was to provide a broad-scale assessment of CRP CPs across jurisdictional boundaries in the central and western United States. We quantified soil erosion characteristics and vegetation cover in 1786 fields across 10 CPs and 14 states. Our primary objectives were to quantify (a) erosion metrics and (b) the amount and composition of grass and forb cover on enrolled CRP fields across regions and three CRP CP types (grassland, wetland, and wildlife). We also sought to develop and test a rapid edge-of-field survey technique to facilitate future broad scale assessments of CRP implementation. To our knowledge, no recent systematic assessments have been performed that evaluate the extent to which desired covers are becoming established in CRP fields across the western United States (US), or how those covers may differ among different types of CPs.

We tested a suite of hypotheses about how erosional features and vegetation cover and composition metrics might differ between practice types and regions. First, we hypothesized few erosional features would be present across all practices and regions, as a fundamental purpose of the CRP is to reduce erosion on formerly cropped fields. Second, we expected that grass cover would be greater on grassland compared to wildlife and wetland practices across all regions, as the primary purpose of grassland practices is to establish perennial grass cover whereas wildlife and wetland practices focus on restoration of wetland cover and wildlife habitat by planting a diverse number of species. Likewise, we expected the number of native forb species present on a field to be greater in wildlife practices compared to grassland practices, as wildlife practices utilize seed mixes that generally include a larger number of native forbs and establish specific goals for numbers of native forb species. Related, we expected to find more native forb species on CRP fields in the Midwest (Lake States and Corn Belt regions), because the rich soils of these regions were historically tallgrass prairies with exceptional native forb diversity (Howe 1994). Finally, we hypothesized that the presence of noxious grasses and forbs would be similar and low across all practices and regions, as both federal laws and CRP guidance for on-the-ground implementation of all CPs require management measures be taken to control state-listed invasive species and noxious weeds.

Table 1. CPs in the CRP that were evaluated in this study.

Practice	Description	Practice type for analysis
CP1	Establishment of introduced grasses/legumes	Grassland
CP2	Establishment of native grasses	Grassland
CP4D	Establishment of wildlife habitat	Wildlife
CP10	Grass already established	Grassland
CP23	Wetland restoration	Wetland
CP25	Restoration of rare and declining habitat	Wildlife
CP33	Habitat buffers for upland birds	Wildlife
CP37	Duck nesting habitat	Wetland
CP38	State acres for wildlife enhancement	Wildlife
CP42	Pollinator habitat	Wildlife

2. Methods

2.1. Study area

The study area consisted of all or part of 14 central and western states: Washington, Oregon, Idaho, Montana (eastern half), North Dakota, South Dakota, Minnesota, Iowa, Missouri, Colorado (eastern half), Nebraska, Kansas, Oklahoma, and Texas (the panhandle). These states (or portions of states) were chosen because they include a significant number of fields currently enrolled in CRP in the ten CPs of interest, which we grouped into three broader CP types based on their seeded attributes and common goals (table 1). We grouped states using USDA Farm Production Regions (USDA 2000a) for analysis.

2.2. Study design

We selected sampling sites from the population of enrolled CRP fields within the study area for which spatial data were available from the USDA Natural Resources Conservation Service (NRCS) as of April 2016. We considered only those fields meeting the following criteria: (a) fields on which one of the ten CPs of interest had been implemented and was documented in the spatial data, (b) fields with an edge located within 25 m of an existing road centerline (to facilitate access by researchers), (c) fields at least 2.0 ha in size (with the exception of CP42, for which we set a minimum area of 0.8 ha to achieve an adequate sample size across multiple states), and (d) fields enrolled for > 3years (CRP contract end date of ⩽2022 in data file). Specific CPs were sampled only in those states for which at least 50 fields in that practice met criteria 2 through 4 above, to focus the evaluation on places where each practice commonly occurs. From this population of fields, we randomly selected 20 fields in each CP in each state and enforced a minimum distance of 1 km between sampled fields. In some areas, fewer or more than 20 fields per practice were sampled in a state due to logistical reasons, such as bad weather or a favorable opportunity (table A1).

2.3. Edge-of-field survey methods

Edge-of-field surveys were conducted during June–October 2016, June–November 2017, and June–October 2018. We chose this method because procuring landowner permission to enter thousands of privately-owned fields is a major obstacle that was circumvented by the edge-of-field approach. We estimated cover of all grasses and all forbs combined, and of each species of grass and forb, using percent cover categories: 0%, 1%–5%, 6%–10%, 11%–20%, 21%–30%, 31%–40%, 41%–50%, 51%–60%, 61%–70%, 71%–80%, 81%–90%, 91%–99%, and 100%. We combined these categories as follows for analysis of vegetation cover: 0%–5%, 6%–20%, 21%–50%, 51%–80%, and 81%–100%. We identified species as native, non-native, or noxious using the USDA NRCS Plants Database (USDA 2000b). However, we note that USDA designations of noxious species were not always consistent with state designations and potentially overestimate our analysis of undesired species. Although it is native, reed canarygrass (*Phalaris arundinacea*) was included as noxious because most occurrences of reed canarygrass are non-native genotypes (Lavergne and Molofsky 2007) and the species is regulated or listed in several states. Annual sunflower (*Helianthus annuus*), a native forb found throughout the continental US is considered a secondary noxious weed in Iowa, but was not considered noxious for our analyses. Cover of bare soil was categorized as <20%, 20%–60%, or >60%. The presence of rills, gullies, and pedestaling was also recorded as evidence of erosion. Multiple photos were taken of nearly all fields for reference. Edge-of-field data underwent extensive quality control checks prior to analysis.

2.4. Edge-of-field validation

Edge-of-field estimates of vegetation and bare ground cover, the presence of erosional features, and species identification are subject to uncertainty and bias from the observer and potentially difficult from a distant sightline. Evaluating the uncertainty of these estimates helps us understand such errors but is not often done (Morrison 2016). To determine if suitable accuracy could be obtained from roadside surveys, we conducted same-day roadside surveys and in-field sampling of vegetation, bare ground cover, and erosional features on a subset of fields. Fields were selected in three geographic clusters (28 in Iowa, 19 in Colorado, and 21 in Idaho) to limit drive time between fields for this component of the study. At each selected field, the surveyor first conducted an edge-of-field survey (using the same protocol as above). In-field sampling was then conducted by

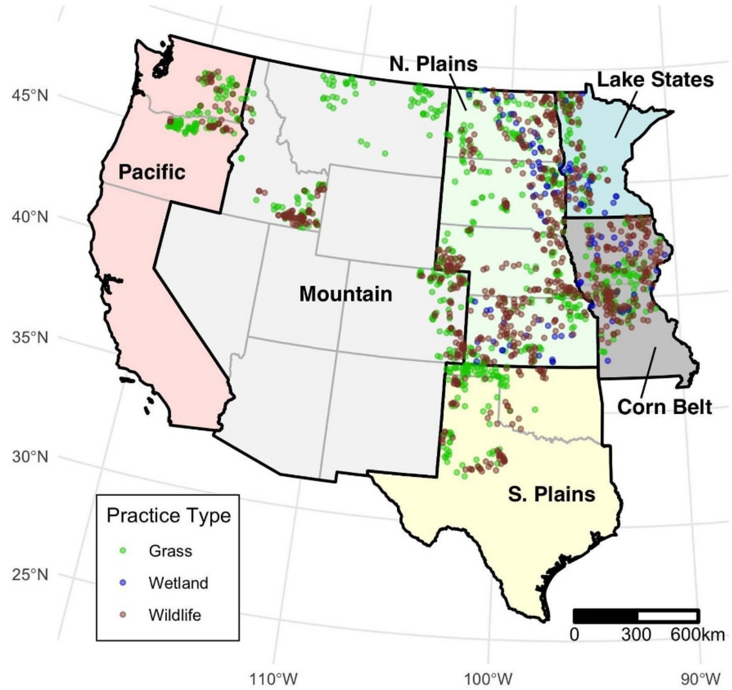

Figure 1. Locations of currently enrolled fields in the CRP that were selected for sampling, color coded by CP type (grassland, wetland, and wildlife). USDA Farm Production regions, which consist of groups of states, are labeled in black/bold.

first dividing fields into four equally sized sections to ensure measurements were well dispersed and to avoid gradients and patchiness. One 100 m transect was placed in each fourth, at least 10 m from the edge of field to avoid influence from roadside vegetation. In oddly shaped fields or where 100 m transects were not possible, efforts were made to evenly distribute the four transects at lengths that spanned the field but were outside of the 10 m buffer from the edge of the field. Each transect had four evenly distributed 1 m^2 quadrats, for a total of 16 quadrats per field. We estimated the proportion of grass, forb, and bare ground cover in each quadrat, and calculated the mean percent cover across all quadrats as our in-field vegetation measurement. We then converted the percent cover from the in-field measurements into the same categories as the roadside estimates for analysis. Evidence of erosion (rills, gullies or pedestaling of plants) was recorded as presence/absence per quadrat. We evaluated the correlation between the in-field and the edge-of-field vegetation measurements using a confusion matrix.

2.5. Analysis of edge-of-field survey data

We present vegetation and bare soil cover results as the percentage of fields by cover class, practice type, and region. We analyzed whether differences between regions, practice types, or the interaction between them explained differences in cover using analysis of variance (ANOVA), with cover class treated as an ordinal variable. While ANOVA assumes approximate normality which is not strictly met by ordinal response data, the large sample sizes involved in this study reduce the sensitivity of ANOVA to this assumption, and normality is commonly assumed for the analysis of Likert-scale data similar to ours (Mircioiu and Atkinson 2017). However, we also assessed normality of model residuals using normal quantile plots and found that residuals were approximately normally distributed in all cases except one (grass cover). For this variable, we used the Box–Cox procedure to identify an appropriate transformation (Box and Cox 1964). Square transformation resulted in approximately normally-distributed residuals. Similarly, we used ANOVA to analyze whether the number of grass or forb species varied among regions and practice types. Because the number of species is typically low, we again assessed violation of the normality assumption using normal quantile plots. In one case (number of native forb species), this plot indicated deviation from normality, which the Box–Cox procedure corrected using square-root transformation. Because all observations of bare ground fell into one of only two categories, we used logistic regression to determine whether region, CP type, or their interaction influenced bare ground cover class. All statistical analyses were performed using R version 4.0.2 (R Core Team 2020). All data used in these analyses are published and publicly available (Vandever *et al* 2021).

3. Results

We visited 1 792 CRP fields and were successful in sampling 1 786 fields across 14 states (figure 1, appendix table A1).

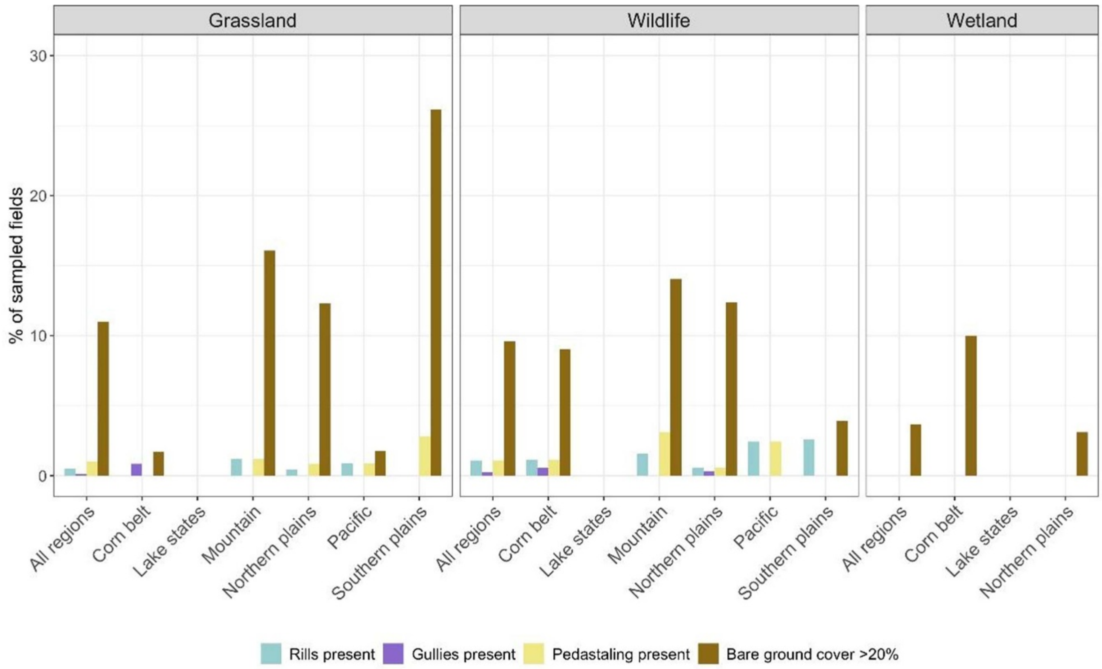

Figure 2. Prevalence of erosional features and of bare soil cover >20% on fields enrolled in the CRP by CP type and region. Note that wetland practices were only sampled in three of the six study regions.

4. Erosion characteristics of CRP fields across practice types and regions

We found that, across all practice types and regions, 99% of fields had no evidence of rills, gullies, or pedestaling (figure 2). Total bare soil cover ⩾20% was also uncommon, occurring on 11%, 10%, and 4% of fields in grassland, wildlife, and wetland practices, respectively (figure 2). Region was the most significant predictor of the prevalence of fields with ⩾20% bare soil ($p < 0.0001$, table A2, figure 2), with the highest prevalence occurring in the Southern Plains and Mountain regions. A smaller but significant overall difference was observed between practice types when averaged across all regions ($p = 0.045$, table A2), and there was also a significant interaction because grassland practices strongly reduced bare ground in the Corn Belt and Lake States, but not in the Southern Plains where wildlife practices were much more effective in reducing bare ground cover ($p < 0.0001$, figure 2). Bare soil cover ⩾20% was most common on grassland practices in the Southern Plains, occurring on 26% of sampled fields.

4.1. Vegetation cover on CRP fields across practice types and regions

4.1.1. Grass cover

Across practice types and regions, 79% of currently enrolled fields had at least 50% grass cover (figure 3), with grass cover being highest (92% of fields with >50% grass cover) on grassland practices in the Northern Plains. There were significant differences in the amount of grass cover among regions ($p < 0.0001$) and among practice types ($p = 0.0027$), and the differences between practice types varied across regions as well ($p = 0.0078$, table A3). Though highly significant, these effects explain a small proportion of the variation in the data. Region, practice type, and their interaction explain 7%, 0.6%, and 1% of the total variation, respectively. Grass cover was highest in the Northern and Southern Plains, where 89% and 88% of fields had >50% grass cover, respectively. Percent grass cover was similar for grassland and wildlife practices (79% and 78% of fields had >50% grass cover, respectively), and higher in wetland practices (87% of fields had >50% grass cover). The most commonly occurring dominant (i.e. constituting >20% cover in the field) native grass species across all CPs were big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*), while the most commonly occurring dominant non-native grass species were smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), Kentucky bluegrass (*Poa pratensis*), and intermediate wheatgrass (*Thinopyrum intermedium*).

4.1.2. Native grasses

Substantially more fields enrolled in wildlife ($p < 0.0001$) or wetland ($p = 0.069$) practices had native grass species present on the field compared to grassland practices (76% and 68% of fields, respectively, compared to 60% of grassland fields, figure 3). Native grass presence was particularly common in the Lake States, with ⩾90% of fields

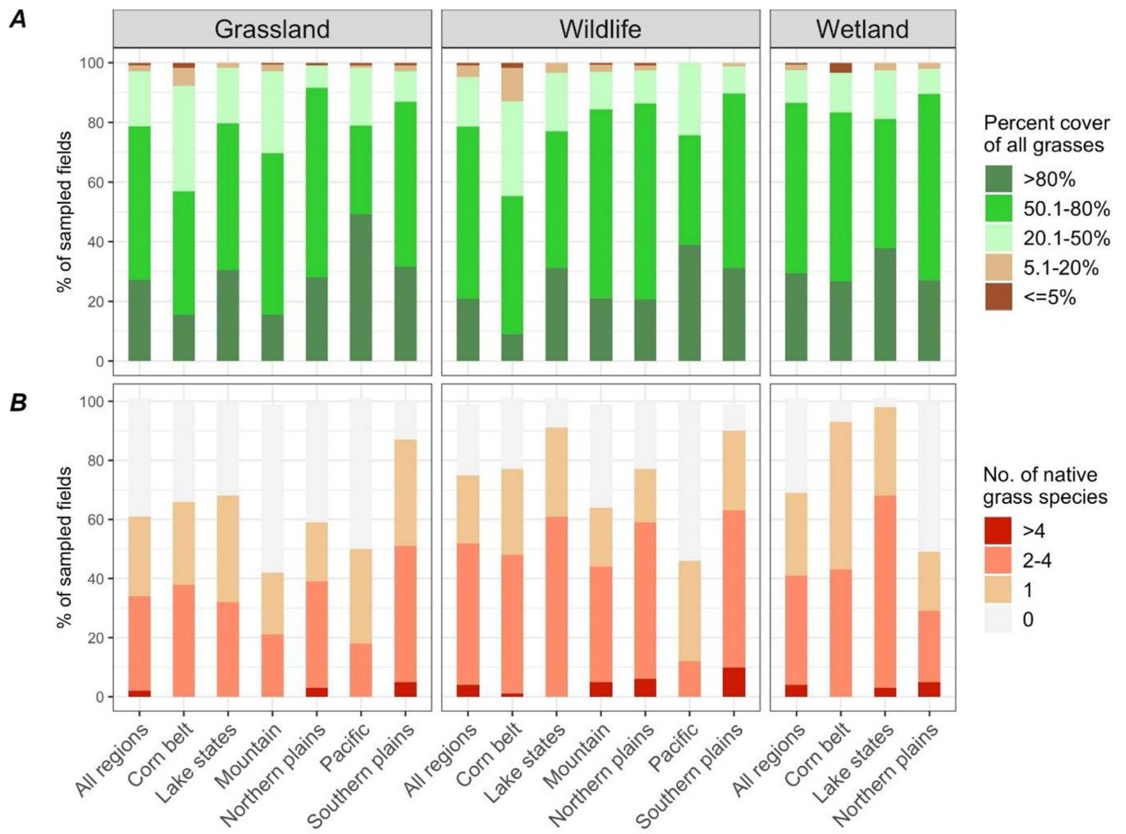

Figure 3. Percent cover of all grasses combined (A) and number of native grass species present (B) on fields enrolled in the CRP, classified by CP type and region. Note that wetland practices were only sampled in three of the six study regions.

in both wildlife and wetland practices having native grasses present, and ⩾61% of fields having at least two native grass species present. Individual occurrences of native grass species tended to constitute the greatest amount of cover on fields in the Lake States, with 41% of occurrences constituting ⩾20% of cover on the field in both grassland and wetland practices.

4.1.3. Forb cover

Similar to grass cover, the largest differences in forb cover were driven by region, with smaller yet highly significant differences among practice types (table A3, figure 4). Large regional differences explained 18% of the variation in forb cover: 80% of fields in the Corn Belt had >20% forb cover while only 16% of fields exceeded this threshold in the Pacific. The four remaining regions were intermediate, with 30%–50% of fields exceeding the 20% cover threshold. Differences between practice types were modest and only explained 0.5% of the variability in the data. Averaged across all regions, only 37% of grassland fields exceeded the 20% forb cover threshold, while 51% and 53% of wildlife and wetland fields exceeded that threshold (figure 4, $p < 0.001$). Overall, relatively few fields had abundant (>50%) forb cover: 14%, 10%, and 6% of total fields sampled in wildlife, grassland and wetland practices, respectively. The Corn Belt was a notable exception, where respectively 39% and 40% of grassland and wildlife fields had more than 50% cover of forbs.

4.1.4. Native forbs

We found that at least one native forb was present on the majority of fields sampled, with slightly more fields in wildlife and wetland practices compared to grassland practices having at least one native forb species (84%, 83%, and 73% of fields, respectively, figure 4). Substantially more fields in wildlife practices (63%) compared to grassland (49%) and wetland practices (44%) had two or more native forbs present ($p < 0.0001$).

Regional differences were again the strongest predictor of variation in the number of native forb species, explaining approximately 12% of the variation in forb species richness. Practice type explained a smaller but still highly significant portion ($R^2 = 0.03$, $p < 0.0001$), while the interaction was negligible ($R^2 = 0.002$). Tukey's post-hoc comparisons among regions indicated that the Corn Belt, Lake States, and Southern Plains had statistically similar and high forb species richness. Nearly all (⩾97%) of fields in the Corn Belt, for example, had at least one native forb regardless of which type of CP the field was enrolled in. The most commonly occurring forbs constituting ⩾5% cover on fields across all practices

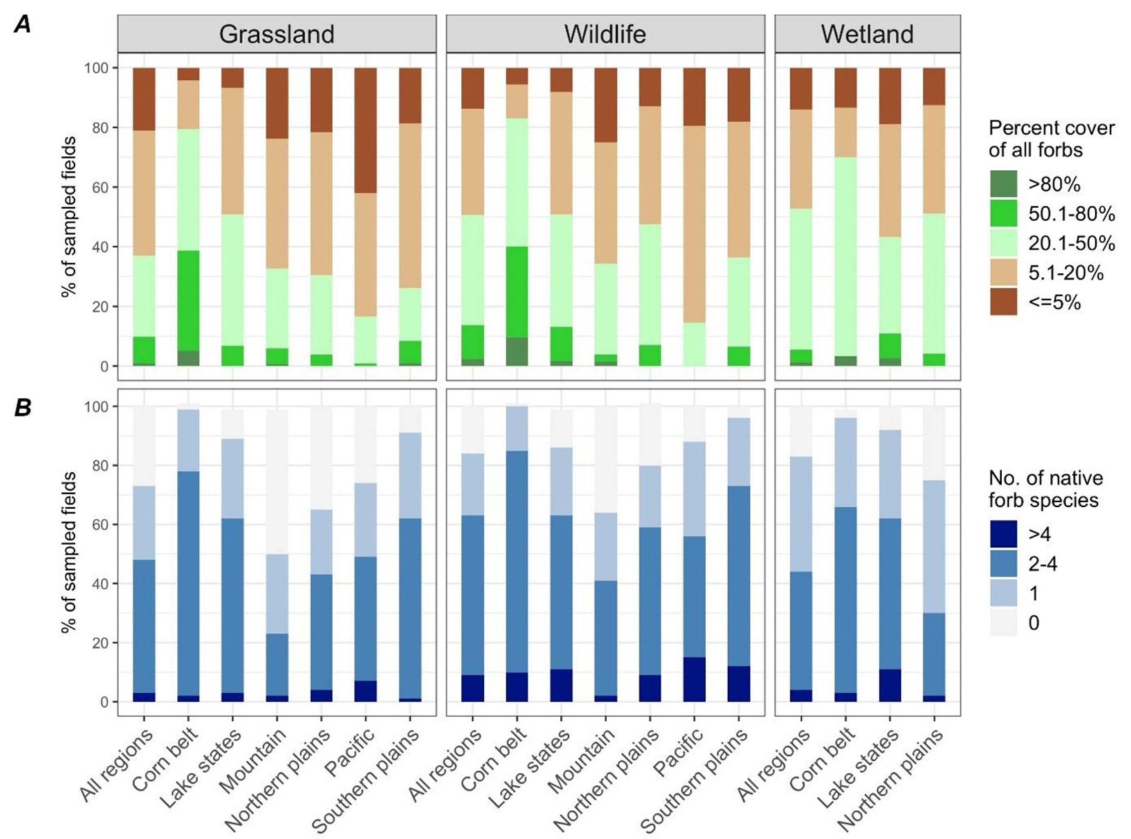

Figure 4. Percent cover of all forbs combined (A) and number of native forb species present (B) on fields enrolled in the CRP, classified by CP type and region. Note that wetland practices were only sampled in three of the six study regions.

and regions were the native species Missouri goldenrod (*Solidago missouriensis*), goldenrod species (*Solidago spp.*), and annual sunflower; and the non-native forbs sweetclover (*Melilotus officinalis*) and alfalfa (*Medicago sativa*).

When native forb species occurred on a field, those species tended to constitute slightly more of the canopy cover in the field in wildlife and wetland practices compared to grassland practices. For example, 33%, and 31% of native forb occurrences on wildlife and wetland practices, respectively, constituted ⩾5% cover of the field compared to 25% of native forb species occurrences on grassland fields. Occurrences of native forb species tended to constitute the greatest amount of cover in fields in the Corn Belt for all CP types, with 53%, 55%, and 36% of native forb occurrences constituting ⩾5% of field cover in grassland, wildlife, and wetland fields, respectively.

4.1.5. Noxious grasses

We found that noxious grasses were uncommon overall, but present significantly more often in wetland compared to wildlife practices (33% vs. 23% of fields, $p = 0.007$, figure 5), and compared to grassland practices (33% vs. 25% of fields, $p = 0.041$). The majority of occurrences of noxious grass species constituted ⩽20% cover of the field across all practice types (69%, 66%, and 65% of occurrences in grassland, wildlife, and wetland, respectively). Noxious grass species tended to constitute the largest proportion of cover in the Lake States across all practices, with 48%, 44%, and 41% of the occurrences of a noxious grass species comprising ⩾20% of the cover in the field in grassland, wildlife, and wetland practices, respectively. The highest instances of noxious grass presence occurred in grassland and wildlife practices in the Pacific (86% and 66% of fields, respectively), where cheatgrass (*Bromus tectorum)* was most common, and in wetland practices in the Corn Belt (70% of fields) and Lake States (59% of fields) where reed canarygrass was common, but in some cases allowed by USDA for wetland restoration or as existing cover.

4.1.6. Noxious forbs

Noxious forbs nearly always occurred in low abundances, but were present on the majority of sampled fields across all practice types: 58%, 63%, and 61% of fields in grassland, wildlife, and wetland practices respectively (figure 5). Noxious forbs were present on less than half of sampled fields only in grassland and wildlife practices in the Lake States (46% and 49%, respectively) and wetland practices in the Corn Belt (40% of fields). When present, noxious forb cover tended to be low: 72%, 73%, and 69% of noxious forb occurrences in grassland, wildlife, and wetland practices constituted <5% of the vegetation cover of the

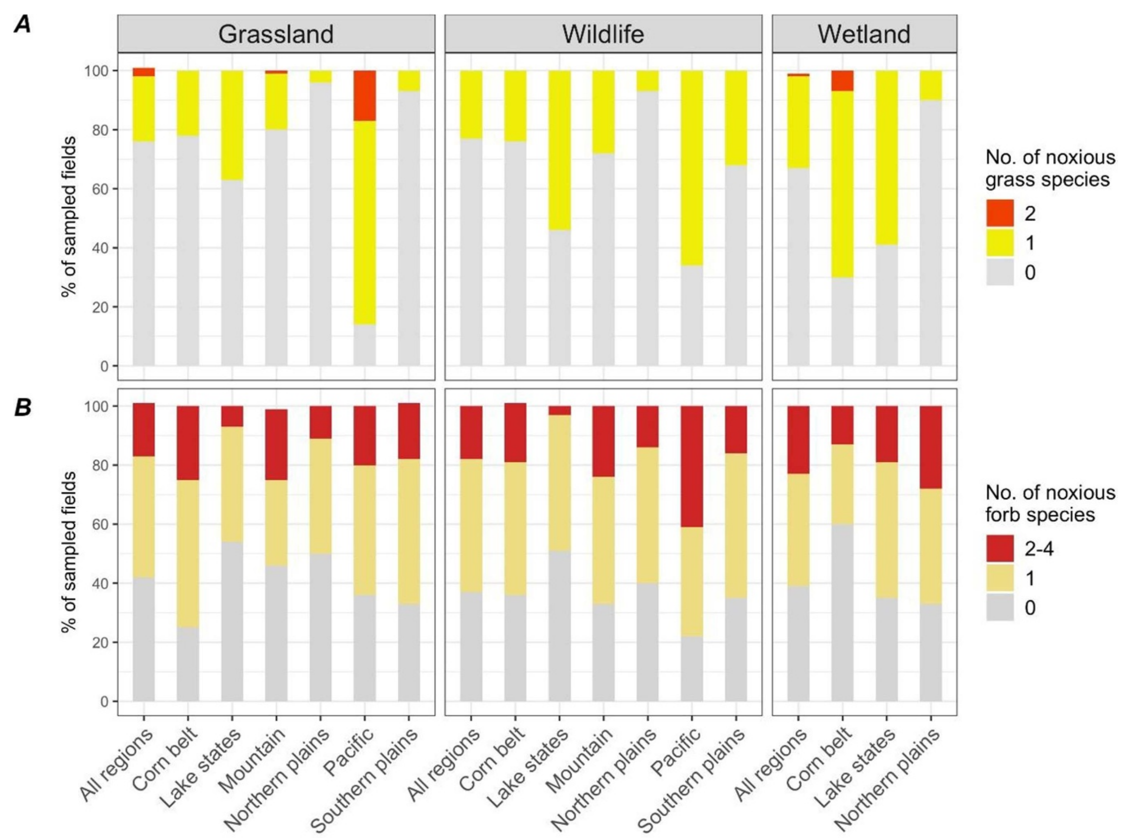

Figure 5. Number of noxious grass species (A) and noxious forb species (B) present on fields enrolled in the CRP by CP type and region. Note that wetland practices were only sampled in three of the six study regions.

field, and 94%, 94%, and 95% of noxious forb occurrences across practices constituted ⩽20% of the vegetation cover of the field. The most commonly occurring noxious forb species (constituting ⩾5% cover) across all regions and CPs combined were Queen Anne's lace (*Daucus carota*), Canada thistle (*Cirsium arvense*), and kochia (*Bassia scoparia*).

4.2. In-field validation of edge-of-field surveys

We found that edge-of-field surveys tended to overestimate grass cover in fields with medium grass cover measurements (20%–50% cover), but accurately reflected in-field measurements where grass cover was low or high (table A4). Overall, grass cover in 53% of fields was correctly classified by roadside surveys. Almost all errors (94%) were misclassifications that differed by one rank only.

Roadside estimates of forb cover demonstrated higher accuracy (60.3% correct categorization), and no misclassifications were greater than one rank category away from the in-field assessment (table A5). Roadside surveys also had a tendency to overestimate forb cover, especially in sites with low forb coverage (in-field measurements ⩽5%). Precision was lowest for sites with forb cover in the 20%–50% category (9 of 17 fields correctly classified).

Roadside estimates of bare ground cover coincided with the in-field measurement in 88.2% of the validated fields (table A6). The majority of these fields had relatively low bare ground cover (in-field measurement mean of 7.7 ± 10.2%). Erosional features were too rarely encountered to conduct meaningful formal validation. However, both survey methods confirmed that erosional features were very rare in CRP fields.

5. Discussion

The CRP is one of the largest private lands conservation programs in the United States, providing voluntary incentives for landowners to replace environmentally sensitive, annually cultivated cropland with perennial grass and forb cover. While many studies have documented the benefits of such efforts (e.g. Hansen 2007, Allen and Vandever 2012, Johnson *et al* 2016), the majority of these studies have been conducted at local or state scales. The CRP has not been assessed at the national level for nearly 30 years. Recently, substantial national pressure has been exerted to decrease funding and enrollment in the CRP to meet demands for biofuels and increased commodity prices (Fargione *et al* 2009, Hellerstein and Malcolm 2011), highlighting the importance of quantifying environmental benefits stemming from the CRP. To meet this need, we evaluated erosional characteristics and grass and forb cover on CRP fields across 14 central and western states. We found that erosional features are extremely rare across regions and practices, confirming the soil conservation benefits of the CRP. Most fields across practice types and regions had ⩾50% grass cover, with native grass species being present significantly more often in wildlife and wetland compared to grassland practices. Nearly half of the sampled fields had 21%–50% cover of forbs. Fields with >50% forb cover and abundant native forb species occurred most often in wildlife practices. Noxious grasses and noxious forbs occurred in low abundances on 25%–33% and 58%–63% of fields across practice types, respectively. Regional differences in most metrics were larger than differences among practice types, and effects of practice type often differed by region.

5.1. Erosion characteristics of CRP fields

Erosional features are present on many agricultural fields (Hively and Cox 2001), particularly those conventionally tilled, with erodibility being six times greater than on grasslands (Zheng *et al* 2004). We found that CRP fields in all CP types had very low occurrences of erosional features (<1%), and very few fields had more than 20% bare ground. This conflicts with Klute *et al*'s (1997) findings that percent bare ground cover in Kansas CRP fields averaged 76%, but generally agrees with Allen *et al*'s (2001) findings of less than 1% bare ground in Northern Great Plains CRP fields seeded to introduced grasses. We found small variations in bare ground cover by region and practice type that may provide useful information for future targeting of CRP practices. For example, in the Southern Plains, wildlife practices tend to be more effective at reducing bare ground than grassland practices. Wind erosion in this region where the Dust Bowl was most severe is a major concern (Hughes-Popp *et al* 2000, Goodwin and Smith 2003) and can be directly related to the amount of bare ground (Fryrear 1995). Indeed, we saw that pedestalling was more commonly observed on fields in the Southern Plains compared to other regions, although the overall amount was still very low.

5.2. Vegetation characteristics of CRP fields across practice types and regions

5.2.1. Grasses

Most (79%) CRP fields across practice types and regions had adequate grass cover (>50%) to provide minimal structure and cover capable of reducing sediment and improving habitat cover (Riley *et al* 1992, Fields 2004, Zheng *et al* 2004). Requirements for grass species richness differ across CPs, and we observed more wildlife fields with native grasses than grassland fields. Wildlife and wetland practices are generally required to plant more native grass species (e.g. five for CP25 in Iowa) than grassland practices (e.g. none for CP1 in Oregon), while one legacy grassland practice (CP10) does not require any new grass planting. However, even the monotypic stands of grass found in some grassland practices have brought improvement in amount of habitat for some avian species in intensively farmed settings (Vandever and Allen 2015), and from the earliest years of the CRP, most wildlife professionals have agreed that the CRP brought significant increases to the amount of idle grassland habitat for game and non-game species (Allen and Vandever 2003). Replacement of cropland to perennial grasses in all practices across regions were at some level meeting the minimum requirements for providing conservation cover in historically grassland areas (Allen and Vandever 2012).

5.2.2. Forbs

While forb cover has never been dominant in CRP plantings, newly implemented species-rich practices such as CP42 have increased forb requirements. In Kansas, Klute *et al* (1997) found greater forb cover on grazed pastures than in 6–7 year old CRP fields (6.4% cover). Over time, CRP fields can exhibit an increasing dominance of grass cover with a corresponding reduction in the proportion of forbs (Cade *et al* 2005, Dickson and Busby 2009). We observed greater forb cover in wildlife and wetland practices, with results mostly driven by regional differences in more mesic areas. This contrasts with earlier findings by Baer *et al* (2002) and McCoy *et al* (2001), who observed increased grass cover relative to forb cover in mesic sites. More recently implemented wildlife and wetland practices, along with the increased availability and lower cost of commercially available forb seeds, may contribute to higher forb cover in mesic areas than in early CRP plantings.

Forbs are the most diverse plant guild in mixed-grass and native tallgrass prairies (Dickson and Busby 2009), which can include hundreds of forb species (Howe 1994). In planted fields such as CRP, there is little resemblance in forb species richness or cover to remnant native prairies. Despite this difference, in highly engineered agricultural landscapes, planted native forb species still provide important ecosystem functions to wildlife and pollinators (Vandever and Allen 2015). Similar to Howe (1994) and Dickson and Busby (2009), we found that native forb richness was greatest in more mesic regions (Corn Belt, Lake States), but we observed much smaller numbers of native forbs per field. Low precipitation has been shown to restrict planting success of native species (Hardegree *et al* 2011, Munson and Lauenroth 2012), and, aside from the Southern Plains region, we found lower presence of native forbs in the more arid/semi-arid regions of the Pacific, Mountain and Northern Plains. Restoration of fields in areas of low water availability may require plantings with greater numbers of forb seeds to ensure forb cover (Munson and Lauenroth 2012). Overall, fields planted with more native forbs (wildlife practices) in more mesic regions exhibited greater native forb richness than those planted with fewer (grassland practices) and in more arid regions.

5.2.3. Noxious species

Weeds are a common problem across the landscape as years of altering the ground cover have introduced highly opportunistic, non-native species into the seed bank. A survey of national CRP landowners found respondents identified the CRP as a source of weeds (Allen and Vandever 2003), but some studies have shown larger seedbanks of weedy species in cultivated fields compared to CRP fields (Felix and Owen 2004) and that competition from established perennial native vegetation can outcompete annual weedy species if the CRP is properly managed (McCoy *et al* 2001, Felix and Owen 2004). We found noxious grasses and forbs in all practices across all regions, with noxious forbs occurring more often but in lower abundance than noxious grasses. Cover from individual noxious forb species, in particular, was minimal (<5%) in more than two-thirds of fields where they occurred.

A requirement of the CRP is that participants maintain fields according to their conservation plan to comply with their state noxious weed laws. Cheatgrass has successfully invaded rangeland systems across the arid western parts of North America (Ehlert 2013) for over 120 years and was observed by the U.S. Forest Service in nearly every state by 1914 (Stewart and Hull 1949). Our findings show that cheatgrass was the most commonly occurring noxious grass on CRP fields, in the more xeric Pacific and Mountain regions. Similarly, Peterson (2006) and Bradley *et al* (2018) found high percentages of predominantly cheatgrass cover in test plots across the Intermountain West at 9% and ⩾15%, respectively. Wetland practices had the greatest amount of reed canarygrass, a native grass that has widely interbred with non-native invasive genotypes and heavily invaded the more mesic regions of the Lake States and Corn Belt. This invasion is not unique to the CRP; reed canarygrass is frequently found on public lands (Cunningham 2005) and occurs on 74% of USDA Wetland Reserve Program sites (Forshay *et al* 2005). Management of these two species, like many widespread invaders, is a landscape-scale issue rather than a local-scale problem in individual CRP fields (Jakubowski *et al* 2010).

5.3. Management and policy applications

5.3.1. Roadside surveys as a potential avenue for future national scale assessments of CRP implementation and benefits

We developed, implemented, and validated a roadside field survey protocol that may provide an opportunity to cost-effectively evaluate this very large program, which has never had a plan, budget, or protocol for national-level program assessment. Roadside surveys provide logistical advantages for field studies because they allow sampling of much larger numbers of fields and do not require permission to access private lands. However, it is important to note that the roadside assessments have limitations. We found that these surveys provided acceptable accuracy for our purposes, but also that surveys tended to overestimate grass cover, particularly for fields with 20%–50% grass cover as measured in the field. Addressing inter-observer variability will require attention, particularly in studies that encompass very large extents and require relatively large numbers of observers over multiple years. Future studies could reduce this variability by repeated observations from multiple observers across space and time (Morrison 2016). Overall our validation results suggest that this method may work well with the USDA requirement to review CRP fields in years four and nine of a CRP contract and as a mechanism for national scale assessments of on-the-ground implementation of CRP practices, but that additional refinement, and/or concurrent in-field sampling of grass cover for some fields, may be necessary.

5.3.2. Evaluating the extent to which CRP fields are meeting USDA goals

Our results may also be helpful in understanding to what extent enrolled CRP fields are meeting goals established by USDA in different states and regions for individual CPs or groups of practices. USDA requirements for CRP enrollment are highly variable across states, counties, and practices, ranging, for example, from a presence of 1–3 grasses in the field (for a grassland practice planting), to planting 10% of the field with nine species of pollinator-friendly flowering plants (for a wildlife practice). In Kansas, NRCS has six pollinator mixes (for one wildlife practice) which vary depending on soil type, seed availability, and pollinator goals of the participant. But minimum requirements for CP1 (a grassland practice) only require 2 species of introduced grasses (from a list of four depending on range site). Kansas seed mixes for CP2 fields must include at least two or three native grasses (in addition to other requirements), depending on the mix. In the 20 Kansas CP2 fields that we sampled, 100% contained at least two native grass species, and 70% contained three or more native grass species. While we have summarized our data by practice type and region here, our data are collected at the level of individual fields enrolled in specific practices and include all of these cover and diversity metrics. Thus, the value of the data collected via these roadside assessments extends to field level evaluations of individual CPs in specific locations.

6. Conclusion

The USDA, wildlife community and others have long recognized the need to monitor and evaluate the impact and benefits of the CRP. In fact, a common early criticism of the CRP was the lack of monitoring and assessment of the program as a whole (Kleiman *et al* 2000, SWCS 2006, Gregory *et al* 2007). Early multi-state CRP evaluations had an immense effect, but most subsequent research was conducted in relatively small areas or targeted single species or guilds due to the time and resources required to sample fields consistently across multiple states and regions. One unintended consequence is that these challenges have been used as reasons to further limit CRP funding (Gregory *et al* 2007).

Our study was the first in decades to quantify cover on CRP fields using a consistent survey method across multiple states and CPs. As such, it represents the most comprehensive assessment of on-the-ground cover conditions of CRP fields at the national scale. Our results confirm that enrolled fields across practices and regions have very low erosion with robust and often diverse perennial vegetation cover. Further, our national level results provide important context within which results from more detailed studies conducted at local scales can be interpreted. Because all of our results correspond with specific fields enrolled in individual CPs at known locations across the landscape, they may also be useful for evaluating the extent to which CP requirements are being met in fields within those areas. Some CPs, particularly wildlife-focused practices that require planting of a large number and diversity of native forbs, can be significantly more costly for the program and landowner to implement than less diverse grassland practice plantings. Understanding the extent to which different practices and plantings are producing fields with higher or lower diversity and abundance of native grasses and forbs is one more important way in which results from this national level study may be used in the future CRP assessments.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5066/P9XCC65W.

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Appendix

Table A1. Numbers of fields sampled in the study to quantify vegetation and bare ground cover and erosional features of CRP CPs. See table 1 for a description of each CP. Blank entries indicate there were too few eligible fields enrolled in the practice in that state to meet our criteria for sampling.

		Grassland practices			Wildlife practices					Wetland practices		
Region	State	CP 1	CP 2	CP 10	CP 4D	CP 25	CP 33	CP 38	CP 42	CP 23	CP 37	Grand Total
Corn Belt	Iowa	20	20	20	20	21	20	20	19	18		178
	Missouri	17	20	19		18	20	20	19	12		145
Lake States	Minnesota	20	19	20	20	21		20		24	13	157
Mountain	Colorado	20	20	20	20			21	21			122
	Idaho	14	19	19	21			24	21			118
	Montana	17	19	20								56
Northern Plains	Kansas	21	20	20	20	21	20	20	20	20		182
	Nebraska	19	20	20	20	20	20	20	20			159
	North Dakota	20	17	20	20	22		20	21	19	20	179
	South Dakota	18	19	22	20	16		19		21	16	151
Pacific	Oregon	19	25	21	20							85
	Washington	16	17	16	21							70
Southern Plains	Oklahoma	21	20	20		20						81
	Texas	20	20	6	20		18		19			103
	Total	262	275	263	222	159	98	184	160	114	49	1786

Table A2. Analysis of deviance for the prevalence of fields with ⩾20% bare soil cover.

Source	Df	Deviance	Resid. Df	Resid. Dev	*p*
Intercept			2 147	1 312.1	
Region	5	77.876	1 777	1 044.5	2.33×10^{-15}
Practice	2	6.226	1 775	1 038.2	0.045
Region × Practice	7	33.718	1 768	1 004.5	1.95×10^{-5}

Table A3. Analysis of variance testing differences in grass and forb cover between regions, CPs, and their interaction.

		Grass cover			Forb cover		
Source	Df	MS	*F*	*p*	MS	*F*	*p*
Practice	2	185.97	5.9405	0.003	4.572	6.4845	0.002
Region	5	808.31	25.8196	<0.001	56.859	80.6455	<0.001
Practice × Region	7	85.95	2.7455	0.008	2.374	3.3677	0.001
Residuals	1771	31.31			0.705		

Table A4. Confusion matrix of grass cover comparing roadside and in-field measurements. Of the 68 sites where validation was conducted, the roadside grass cover estimation from 36 sites (52.9%) coincides with the in-field measurements (the diagonal elements).

In-field roadside	⩽5%	5%–20%	20%–50%	50%–80%	>80%
⩽5%	0	0	0	0	0
5%–20%	0	2	2	0	0
20%–50%	0	0	16	0	0
50%–80%	0	2	22	15	1
>80%	0	0	0	5	3

Table A5. Confusion matrix of forb cover comparing roadside and in-field measurements. The roadside forb cover estimation in 41 sites (60.3% of all validated sites) coincides with the in-field measurements.

In-field roadside	⩽5%	5%–20%	20%–50%	50%–80%	>80%
⩽5%	13	2	0	0	0
5%–20%	7	14	5	0	0
20%–50%	0	4	9	0	0
50%–80%	0	0	3	5	0
>80%	0	0	0	3	0

Table A6. Confusion matrix of bare ground comparing roadside and in-field measurements. The roadside bare ground cover estimation in 60 sites (88.2% of all validated sites) coincides with the in-field measurements.

In-field roadside	<20	20–60	>60
<20	59	5	0
20–60	3	1	0
>60	0	0	0

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