

Article

# Land Cover and Land Use Change in the US Prairie Pothole Region Using the USDA Cropland Data Layer

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**Abstract:** The Prairie Pothole Region (PPR) is a biotically important region of grassland, wetland, and cropland that traverses the Canada-US border. Significant amounts of grasslands and wetlands within the PPR have been converted to croplands in recent years due to increasing demand for biofuels. We characterized land dynamics across the US portion of the PPR (US-PPR) using the USDA Crop Data Layer (CDL) for 2006–2018. We also conducted a comparative analysis between two epochs (1998–2007 & 2008–2017) of the CDL data time series in the North Dakotan portion of the US-PPR. The CDL revealed the western parts of the US-PPR have been dominated by grass/pasture, to the north it was spring wheat, to the east and southern half, soybeans dominated, and to the south it was corn (maize). Nonparametric trend analysis on the major crop and land cover types revealed statistically significant net decreases in the grass/pasture class between 2006 and 2018, which accounts for more than a quarter of grass/pasture area within the US-PPR. Other crops experiencing significant decreases included sunflower (-5%), winter wheat (-3%), spring wheat (-2%), and durum wheat (-1%). The combined coverage of corn and soybeans exhibited significant net increases in 23.5% of its cover; whereas, the individual significant net increases were 5% for corn and 11% for soybeans. Hotspots of increase in corn and soybeans were distributed across North and South Dakota. Other crop/land covers with huge significant increases include other hay/non-alfalfa (15%), and alfalfa (11%), which appear to be associated with the sharp increase in larger dairy operations, mostly in Minnesota. Wetland area increased 5% in the US-PPR, due to increased precipitation as well as inundation associated with Devils Lake in North Dakota. Hotspots of decreasing grass/pasture area were evident across the study area. Comparative trend analysis of two epochs (1998–2007 vs. 2008–2017) in North Dakota revealed that grass/pasture cover showed a negligible net trend (-0.3 %) between 1998 and 2007; whereas, there was a statistically significant decrease of more than 30% between 2008 and 2017. Combined coverage of corn and soybeans experienced statistically significant net increases in both epochs: 11% greater during 1998–2007 and 17% greater during 2008–2017. Recent sharp losses of grasslands and smaller wetlands combined the expansion of corn, soybeans, and alfalfa bode ill for wildlife habitat and require a re-examination of agricultural and energy policies that have encouraged these land transitions.

**Keywords:** CDL; grassland loss; wetland loss; cropland gain; trend analysis

## 1. Introduction

The Prairie Pothole Region (PPR) is an ecologically important region of grasslands and wetlands occurring in the Northern Great Plains. The region forms the core of the formerly largest expanse of

grassland in the world—the Great Plains of North America [1,2]. The PPR stretches NW to SE across the Canada–US border. It is a major breeding area for migratory waterfowl and supports more than 70% of the continent’s duck production [1]. In addition to its unparalleled ecosystem services of the breeding of waterfowl and other wetland wildlife, the region is an important nutrient sink, stores runoff that reduces flooding, sequesters carbon, and provides other environmental and socio-economic values [2–4]. In recent years, grasslands and wetlands in the US portion of PPR (US–PPR) have been converted to croplands [5–8]. The US–PPR covers large areas of North and South Dakota, Minnesota, and Iowa, and a small portion of northeastern Montana (Figures 1 and 2). Moreover, the crops cultivated within the US–PPR have been changed, e.g., spring wheat and alfalfa have been replaced by corn (maize) and soybeans. The expansion of crops within the PPR in general, specifically the expansion of corn and soybeans can be attributed to a variety of factors, including the biofuel demand boom in the late 2000s driven by federal policies and subsidies [9], high crop prices and government subsidies in the form of crop insurance and other payments [5,10], and the development of cold tolerant varieties of soybeans and drought-tolerant corn varieties, which facilitated the expansion of corn farther west and soybeans farther north [5,11]. Furthermore, high commodity prices during this period increased the opportunity cost of participating in the Conservation Reserve Program (CRP), and program enrollment decreased [12]. The amount of CRP land has steadily declined since 2008, after reaching a peak enrollment in 2007 [13]. Between 2010 and 2013, 30% (more than 530,000 ha) of expiring CRP land parcels were returned to the production of five major crop-types (corn, soybeans, winter and spring wheat, and sorghum) in the 12-state Midwestern region of the United States that enclosed the US portion of the PPR [13]. Grasslands were the largest type of CRP land converted (360,000 ha), followed by specifically designated wildlife habitat (76,000 ha), and wetland areas (53,000 ha).

The United States Department of Agriculture (USDA) Crop Data Layer (CDL) has been used for a variety of purposes, including ecological disaster assessments, land cover/land use change analysis, and agricultural policy decision making [5,7,9,14–16]. CDL is a raster-based, georeferenced, and crop/land cover specific classification annual data layer for the conterminous USA with a spatial resolution of 56 m in earlier years and 30 m beginning in 2010 [17]. It achieved classification accuracies of 90% for major commodities like corn, cotton, rice, soybeans, and wheat [14].

Research findings using the CDL dataset showed that the western corn-belt grasslands were rapidly converted to corn and soybean cultivation, leading to a lost opportunity for realizing the benefits of a biofuel industry based on perennial bioenergy crops, rather than commodity corn ethanol and soy biodiesel [7,9]. On a national scale, corn was the crop most planted on the converted lands [9,10]. The conversion of grasslands to croplands compromise the ecosystem services provided by grasslands, such as preserving native vegetation and wildlife habitats, controlling floodwaters through storage, and maintaining water quality through sediment and nutrient retention [4,18]. Land use conversion intensifies fragmentation of remnant native grasslands, which, in turn, limits the potential for dispersal of native species [10,19]. Based on an analysis of Landsat data between 1985 and 2011, Arora and Wolter (2018) found that grassland loss rate for sites in eastern North and South Dakota was 1.5% per annum. This loss rate was much more pronounced in recent years with 5.5% per annum between 2006 and 2011 [20]. They reported a similar pattern in corn expansion rates between the two periods (1985–2011 vs. 2006–2011; [20]).

The main aim of this study was to track land cover dynamics in the US–PPR using the CDL dataset that will be vital for natural resource management, and for examining unintended consequences of federal policies on agriculture and energy. The following specific tasks were performed to achieve the aim of the study: (a) quantify and map pixel-wise crop/land cover proportions in the US–PPR for 2006–2018; (b) calculate, map, and tabulate crop/land cover proportions under different trend states (increasing vs. decreasing and significant vs. non-significant) across the US–PPR for 2006–2018 using non-parametric trend testing; and (c) compare and contrast the magnitudes of detected crop/land cover trends between earlier (1998–2007) and later (2008–2017) epochs in the CDL data for the PPR in the North Dakota, where the CDL data extend back further in time than elsewhere.

This study is distinct from previous research on documenting land cover dynamics using the CDL for six reasons. First, the focus here is on the US portion of the Prairie Pothole Region, while others focused at the regional, state, other administrative levels [9,19–21]. Second, in this study, almost every cover type (~80–90%) within the US–PPR was analyzed, while other papers have focused only on a few cover types [9,19]. Third, we examine trends across a longer period (13 years), which minimizes the influence of crop rotation on trend detection and characterization. Fourth, we visualize land cover persistency for the key crops in the study area; we derived pixel-level quantitative significant net areal increase and decrease of every crop/land cover type available in the region over a longer period [9,19–21]. Fifth, since corn and soybeans are often rotated together in the study area [22]; we analyze them together. Sixth, we have compared trends between the two longest temporal subgroups in the CDL for North Dakota, which has the longest CDL time series and covers a significant portion of the US–PPR as well. In addition to the points described above, we need to emphasize that we have incorporated all the existing CDL data in the study area, including the most recent available datasets. This step has two advantages: (a) it extends the time-span of the dataset analyzed, which helps to attenuate data errors, thereby improving the accuracy of the results; and (b) it updates the contemporary crop/land cover dynamics status in the study area.

## 2. Study Area, Data, and Methodology

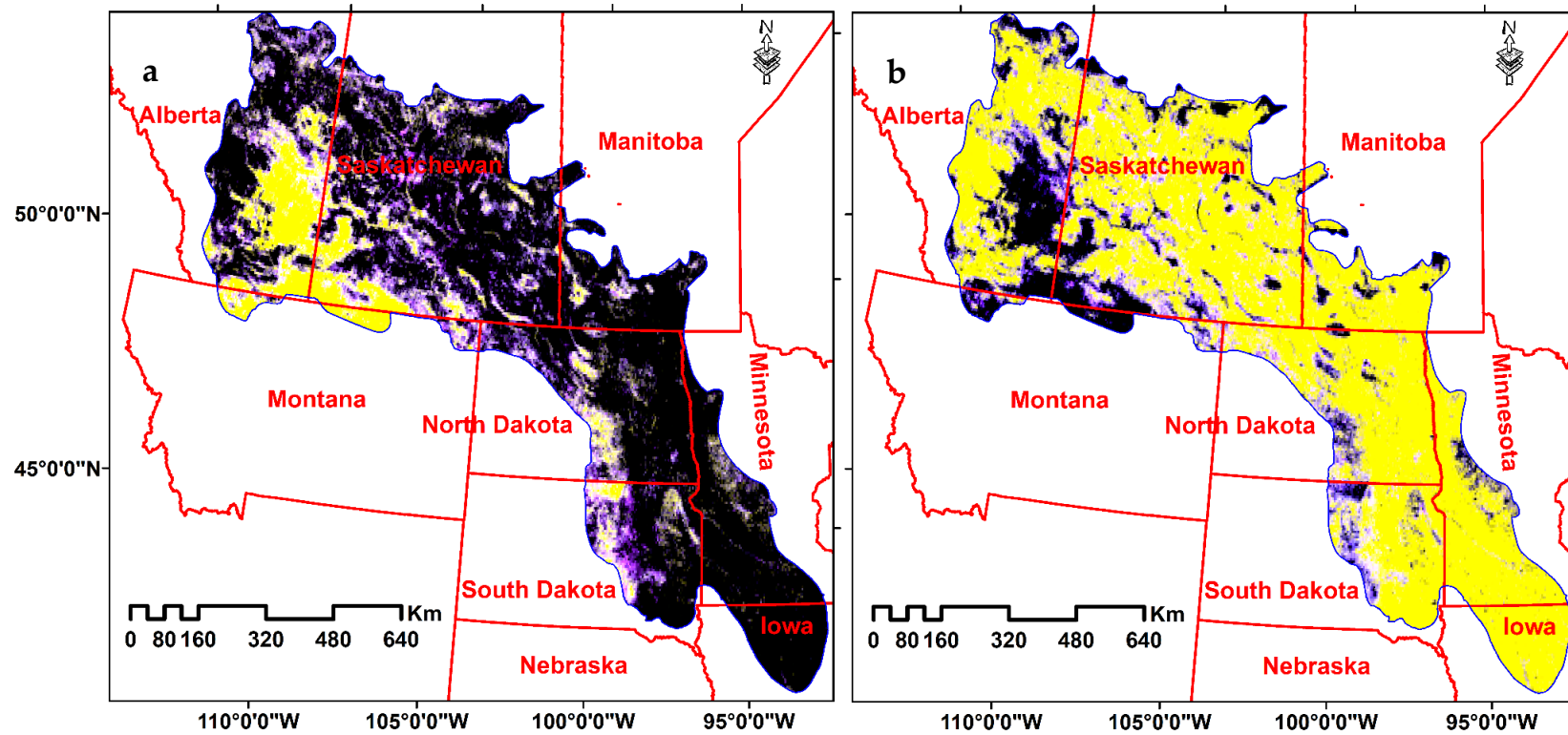
### 2.1. Study Area

Prairies are ecosystems with enormous stretches of flat temperate grasslands (midgrasses and tallgrasses) with moderate temperatures, moderate rainfall, and few trees. The prairie ecosystem that contains thousands of shallow depressions (potholes) in the interior of North America is known as the Prairie Pothole Region (PPR). The PPR stretches from north-central Iowa northwest across the US–Canada border (Figure 1). The PPR occupies parts of five US states (the northern tier of Montana, northern and eastern North Dakota, eastern South Dakota, western Minnesota, and north-central Iowa) and three Canadian provinces (southwestern Manitoba, southern Saskatchewan, and southern Alberta). PPR encompasses more than 770,000 km<sup>2</sup> area [1,23,24]. Potholes/shallow depressions were formed as a result of receding Wisconsin glaciation about 10,000 years ago [1]. Potholes are filled with water in the spring, creating wetlands with hydroperiods lasting from temporary to semi-permanent [1,23].

For this study, we focused our analyses on the US portion of the PPR, because we were using the USDA Crop Data Layer (CDL) that is produced only for the conterminous USA. The US–PPR covers an area of about 314,000 km<sup>2</sup> [24].

### 2.2. Data

The USDA National Agricultural Statistics Service (NASS) CDL is a raster-based georeferenced crop/land cover specific classification annual data layer for the conterminous USA with a spatial resolution of 30 m or 56 m [17,25,26]. From 2006 through 2009, the CDL has a spatial resolution of 56 m, and the rest of the data are at 30 m. The CDL was developed from satellite datasets and farmers' reports. The satellite datasets included Landsat TM and ETM+, Indian Remote Sensing Satellite (IRS, RESOURCESAT-1 Advanced Wide Field Sensor (AWiFS)), MODIS, and the National Land Cover Data set (NLCD) since its beginning in 1997 [17]. CDL for all states in the US–PPR is available since 2006, even though this dataset is available for North Dakota since 1998. We used 13 years (2006–2018) of CDL data for the US–PPR, and 20 years (1998–2017) for the North Dakotan portion of the US–PPR.



**Figure 1.** Land cover persistency map for (a) grasslands and (b) croplands based on MODIS 0.05° cropland and grassland percentages from the International Geosphere Biosphere Programme (IGBP) MCD12C1 time series from 2006 through 2017 [27]. The false color composite images were generated in such a way that the maximum percentage of cover type during the study period was displayed in the red panel; the mean percentage in the green panel; and the range in the blue panel [28,29]. See Table 1 for the interpretations of the map colors.

**Table 1.** Land cover persistency interpretative legend. The table shows how the color in the LC map arises from the false color composite of red, green, and blue color planes that display, respectively, the maximum percentage of LC class, the average percentage of LC class, and the range of percentages of LC class over a given study period. Modified from [28].

Color in LC Map	Red = Max% LC	Green = Mean% LC	Blue = Range% LC	Interpretation
Black	None	None	None	Land cover (LC) class absent
Blues	Low	Low	High	Unstable and ephemeral periphery; rare and erratic
Magentas	High	Low	High	Unstable and recurrent periphery; sometimes high, but usually low
Whites	High	High	High	Unstable core; sometimes low, but usually high
Yellows	High	High	Low	Stable core of LC; always high so low range

### 2.3. Methods

We extracted six main crop layers (corn, soybean, spring wheat, winter wheat, durum wheat, and sunflower) as well as grasslands, wetlands, alfalfa, and other hay/non-alfalfa from the CDL. Each extracted individual crop/land cover layer is a binary raster with pixel values of 1 for presence and 0 for the absence of the specific crop or land cover type (Figure 2).

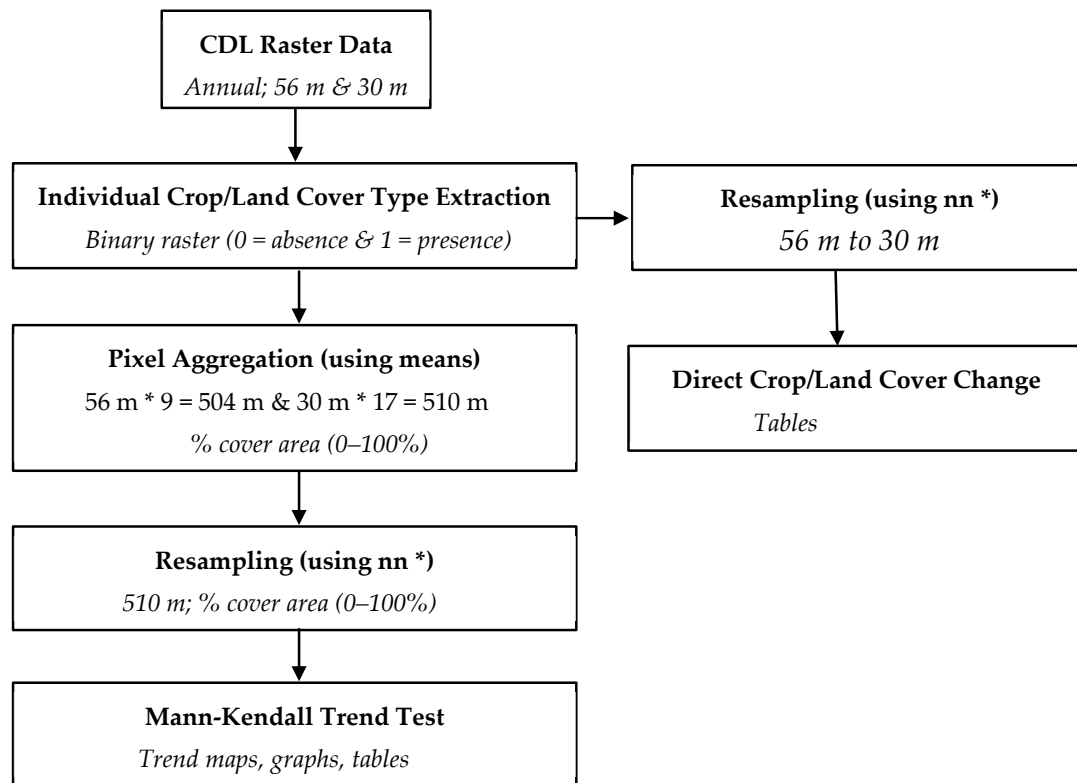
To make our analysis on fractional crop/land cover of a given area, we aggregated the binary (presence-absence) crop/land cover raster, so as to have a proportion of area covered by a given crop/land cover type. We aggregated the 30 m and 56 m spatial resolution binary CDL raster layers by a factor of 17 and 9, respectively, (using mean) resulting in a 504/510 m spatial resolution crop/land cover fraction raster layers. Pixel values range from 0.0 (no presence of the given cover type within the pixel) to 1.0 (every  $17 \times 17 = 289$  or  $9 \times 9 = 81$  pixel was covered by the same cover type). To ensure alignment of all temporal layers for subsequent analyses, all CDL layers were further resampled using the 2018 CDL layer. For this resampling, we used the nearest neighbor method to preserve original values. We then generated percentage proportions of each cover type within the 510 m raster grids. Each pixel for a given individual crop/land cover may have a percentage of that cover ranging from 0 to 100.

From these annual percentage time series, we detected trends in cover types in the PPR across the study periods using the Mann-Kendall trend test. The non-parametric Mann-Kendall trend test is robust to non-normal distributions [30] and to abrupt breaks of inhomogeneous data [31]. We grouped the trend  $p$ -values into three categories:  $p < 0.05$ ;  $0.05 < p < 1$ ; and  $p = 1$ . The pixels with  $p = 1$  pixels did not have the given crop/land cover, and their value was therefore changed to NA (not available). The Mann-Kendall tau ( $\tau$ ) statistic has three possible directions: negative indicating a decreasing trend; zero indicating no trend; and positive indicating an increasing trend. We converted all the negative values of a given  $\tau$ -raster layer into  $-1$ , positive values into  $+1$ , and left the zeros as is. Then we merged these raster layers with the corresponding classified  $p$ -value raster layers to produce maps that displayed both trend direction and category of trend significance. We calculated and tabulated proportion of pixels of given crop/land cover that fell into the three trend categories: (a) significantly increased ( $p < 0.05$ ); (b) no significant change ( $p > 0.05$ ); and (c) significantly decreased ( $p < 0.05$ ).

Furthermore, to assess the declining enrollment of land parcels into the Conservation Reserve Program (CRP) since 2008 [13], we compared cover type trends in the PPR of North Dakota during two decadal epochs: 1998–2007 and 2008–2017. We have the same series length in each temporal subgroup so that the statistical power of the trend test is equivalent.

Finally, to complement the trend results with a more familiar direct change analysis at the native pixel resolution, we calculated and tabulated the area and percentage of each cover type in terms of increased, decreased, net change, and no change at the beginning and end of the study periods: namely, for the US PPR, from 2006 to 2018 and, for the ND PPR, first from 1998 to 2007 and, second, from 2008

to 2017. We used an asymmetry ratio ( $AR = \text{area of increase}/\text{area of decrease}$ ) to evaluate which cover types were predominantly increasing ( $AR > 2.0$ ), predominantly decreasing ( $AR < 0.5$ ), or exhibited a mixture of change ( $0.5 < AR < 2.0$ ).

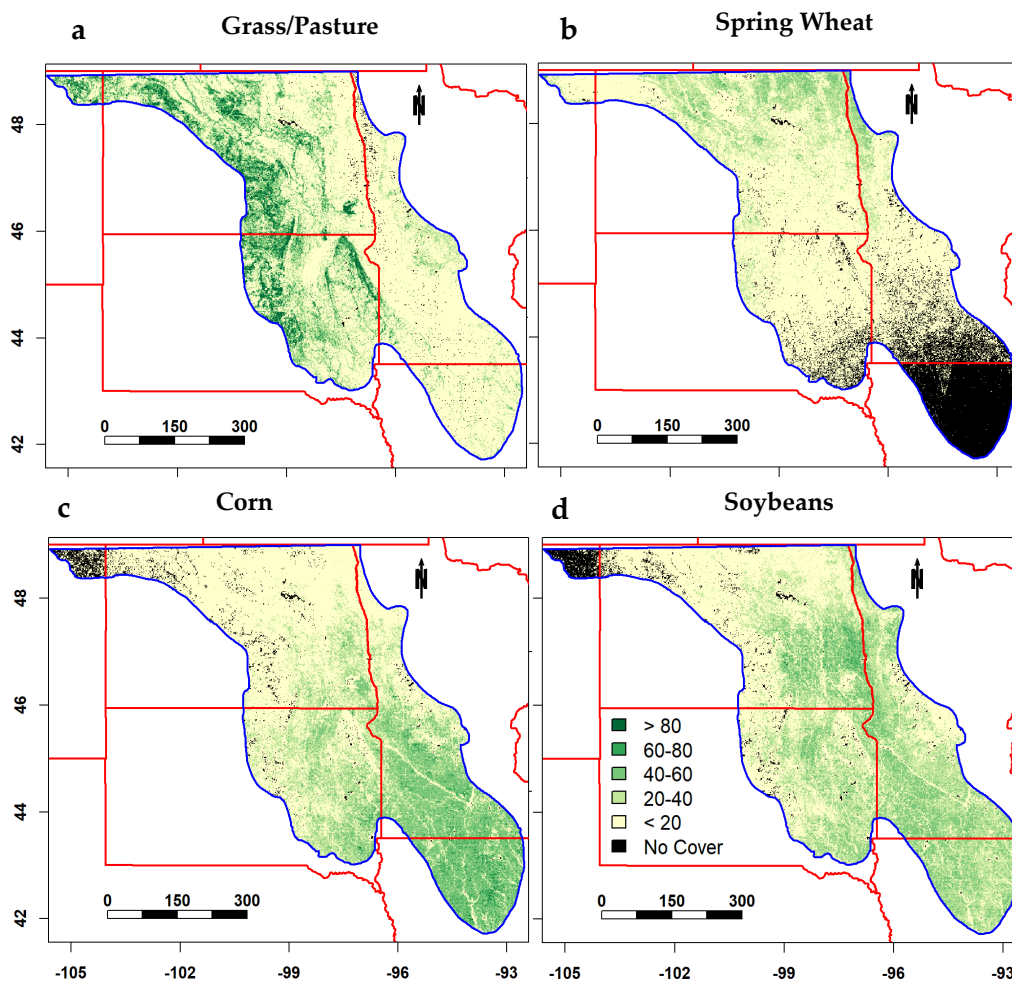


**Figure 2.** Flowchart for the trend analyses in the study. For the US–PPR, data from 2006–2018 was used, while for the ND PPR, we used two epochs (1998–2007 & 2008–2017). The CDL data have 56 m spatial resolution until 2008 and 30 m thereafter. \* nn=nearest neighbor.

### 3. Results

#### 3.1. Mean Land Cover Percentage

The mean land cover percentage from the CDL shows the western part of the US–PPR along the Missouri River in the Dakotas dominated by grass/pasture reaching up to 100% at the pixel level (Figure 3a). In contrast, cultivation of spring wheat dominated northeastern North Dakota with values up to 90% in the 510 m pixels (Figure 3b). Corn dominated the southern extents of the study region with up to 100%, mostly in Iowa (Figure 3c). Soybeans dominated the central and southern parts of the US–PPR, with up to 100% at pixel level (Figure 3d). Note that while there is a significant overlap between the extents of corn and soybeans, gradients are evident: more soybeans farther to the north (Figure 3d) and more concentrated corn to the southeast (Figure 3c; additional cover percentage maps for other crop/land covers analyzed appear in Figure S1 in the Supplementary Material).



**Figure 3.** Mean land cover percentages for the US Prairie Pothole Region from 2006 through 2018 calculated from the USDA NASS CDL at 510 m resolution. Black pixels within the blue polygon indicate nonexistence of a given cover type within the study area. US-PPR boundary appears in blue, and state borders in red. Note the scalebar unit is km.

### 3.2. Crop/Land Cover Change

The Mann–Kendall trend analysis revealed the spatial distribution of grass/pasture coverage in the US-PPR experienced significant ( $p < 0.05$ ) changes between 2006 and 2018 (Figures 4a and 5, Table S1). More than a quarter of grass/pasture cover significantly decreased during the study period, and these significant decrements were observed in areas with dominant grass/pasture coverage. Wheat crops declined, in general (Figure 5; Figure S2c–e, Table S1). Spring wheat and winter wheat showed significant net decreases of 2% and 3%, respectively. Sunflower coverage decreased significantly in more 5% of its area (Figure 5; Figure S2, Table S1). In contrast, corn and soybeans showed large significant net increases in 5% and 11%, respectively (Figure S2a,b, Table S1). The combined area of corn and soybeans crops exhibited a significant net increase in 23.5% of the combined area (Figures 4b and 5, Table S1). Alfalfa (Figure S2g, Table S1) and other hay/non-alfalfa crops (Figure 4d, Table S1) showed significant net increases of 11% and 15%, respectively. The area classified as wetlands in the US-PPR showed a significant net increase of 5%. Even though most proportion of the crop/land cover areas in the US-PPR are under the non-significant change category (gray shaded colors), vast areas of these land covers experienced increasing/decreasing trends. For example, about 87% of grass/pasture experienced a decreasing trend, while more than three-fourth of combined corn and soybeans cover showed an increasing trend.

There are some hotspots of grass/pasture loss in the region. These areas of change were predominantly converted to corn and soybeans (cf. Figure 4b, Figure S2a,b, Table S1). At the southern tip of the study area (in north-central Iowa), grass/pasture showed slight significant gains and losses in soybeans. However, there was an abrupt spatial discrepancy in grass/pasture change trend (Figure 4a, Table S1) and spring wheat absence (Figure S2c, Table S1) between north-central Iowa and southern Minnesota, which might be an artifact arising from reporting and classification disparities among the States. Such a discrepancy was also observed for durum wheat (Figure S2e, Table S1) and sunflower (Figure S2f, Table S1) between Montana and North Dakota. Hotspots of corn and soybeans combined increases were distributed all over the North and South Dakota portion of the US–PPR (Figure 4b, Table S1). There were hotspots of loss in wetlands (Figure 4c, Table S1) and spring wheat (Figure S2c, Table S1) in north-central South Dakota and northern North Dakota, respectively. Hotspots of winter wheat declines occurred, particularly in South Dakota. The wetlands, winter wheat, and grass/pasture areas in South Dakota were mainly replaced by corn, soybeans, and other hay/non-alfalfa crops.

The results of the direct change analysis of CDL cover types between the 2018 and 2006 are reported in terms of percentages in Table S2. The effect of common rotation of corn and soybeans is evident in the direct change analysis. When considering each in isolation, there was “no change” in roughly one-third of the corn or soybean cover. In contrast, combining corn and soybean covers reveals “no change” in 61.3% of the joint area as well as an increase of 27.5% against a decrease of 11.2%, for a predominant net increase of 16.3% (Table S2). Both winter wheat and sunflower exhibited comparable predominant net decreases of 51.8% and 53.5%, respectively. Smaller net decreases were also evident for the spring wheat (−15.8%) and grass/pasture (−19.0%) classes. Net increases were detected for durum wheat (+24.1%) and alfalfa (+15.2%). Wetlands showed a very small net increase of 1.3% across the region, but the magnitude of both the increases (+45.2%) and the decreases (−43.9%) were substantial using the simple difference between temporal endpoints.



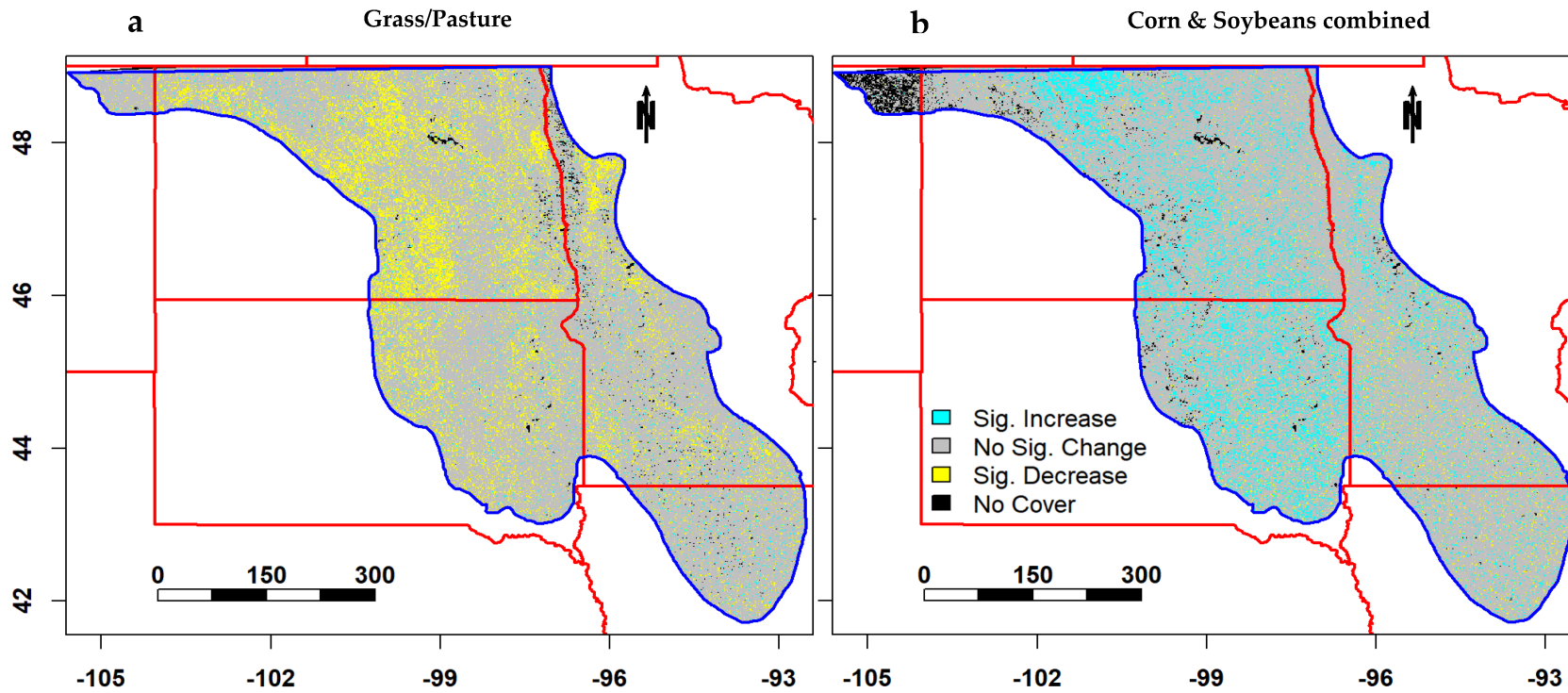
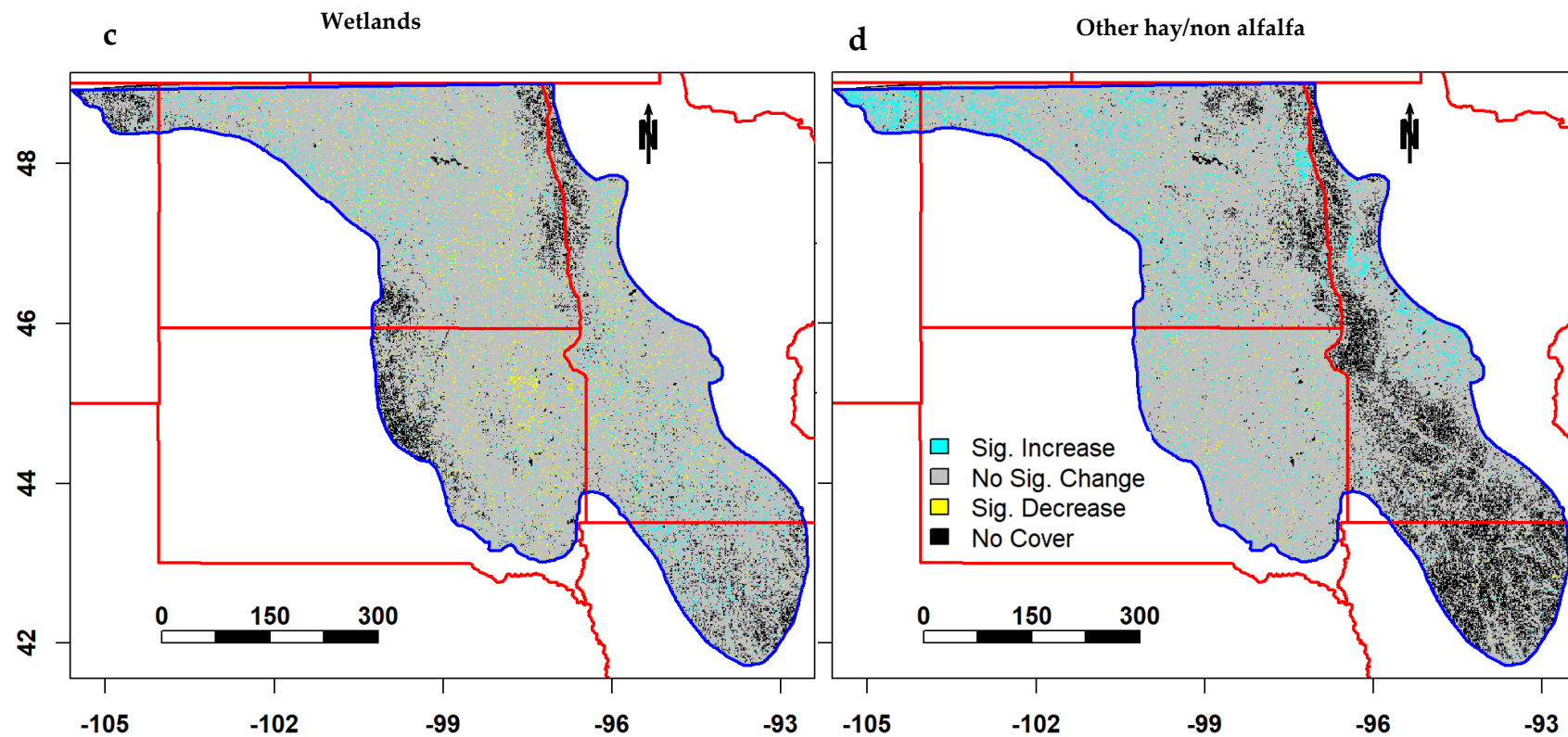
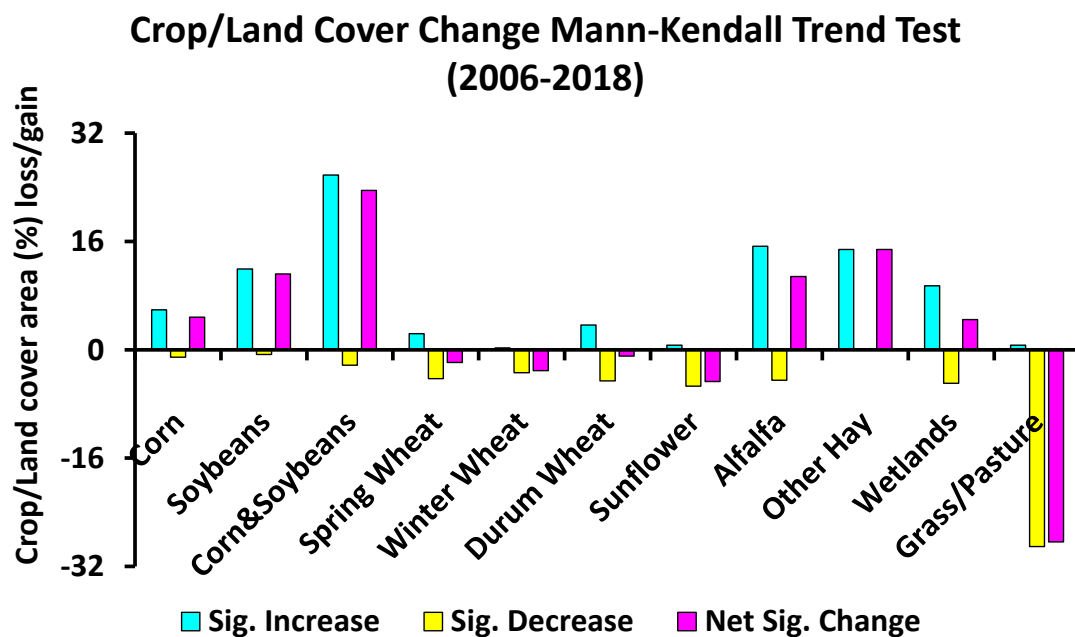


Figure 4. Cont.



**Figure 4.** (a,b). Mann-Kendall trend maps of cover classes between 2006 and 2018. Each cover class is divided into four categories: significant gains (cyan;  $p < 0.05$ ), no significant change (gray;  $p > 0.05$ ), significant losses (yellow;  $p < 0.05$ ), with cover class absence in black. Quantitative details about these trends are presented in Figure 5 and Table S1. (c,d). Mann-Kendall trend maps of cover classes between 2006 and 2018. Each cover class is divided into four categories: significant gains (cyan;  $p < 0.05$ ), no significant change (gray;  $p > 0.05$ ), significant losses (yellow;  $p < 0.05$ ), with cover class absence in black. Quantitative details about these trends are presented in Figure 5 and Table S1. Similar maps for the other crop/land covers appear in Figure S2.



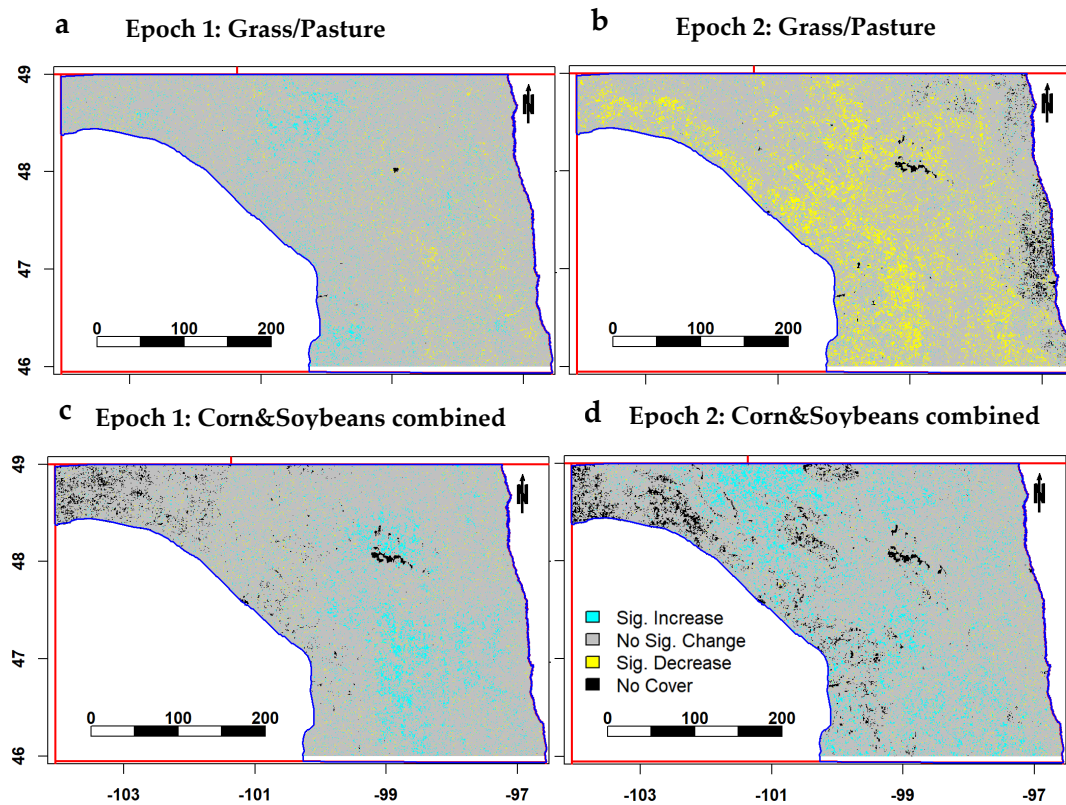
**Figure 5.** Significant changes in the US PPR: Mann–Kendall trend test crop/land cover area percentage (%) significant changes ( $p < 0.05$ ) using CDL data for 2006 through 2018. Significantly increased (gains in cyan), significantly decreased (losses in yellow), and net change (magenta) trends are presented for each crop/land cover. Note the grass/pasture and combined corn and soybeans exhibit opposite directions and larger magnitude net changes. Details are presented in Table S1.

### 3.3. Comparison of Land/Crop Cover Change between Two Epochs in North Dakota

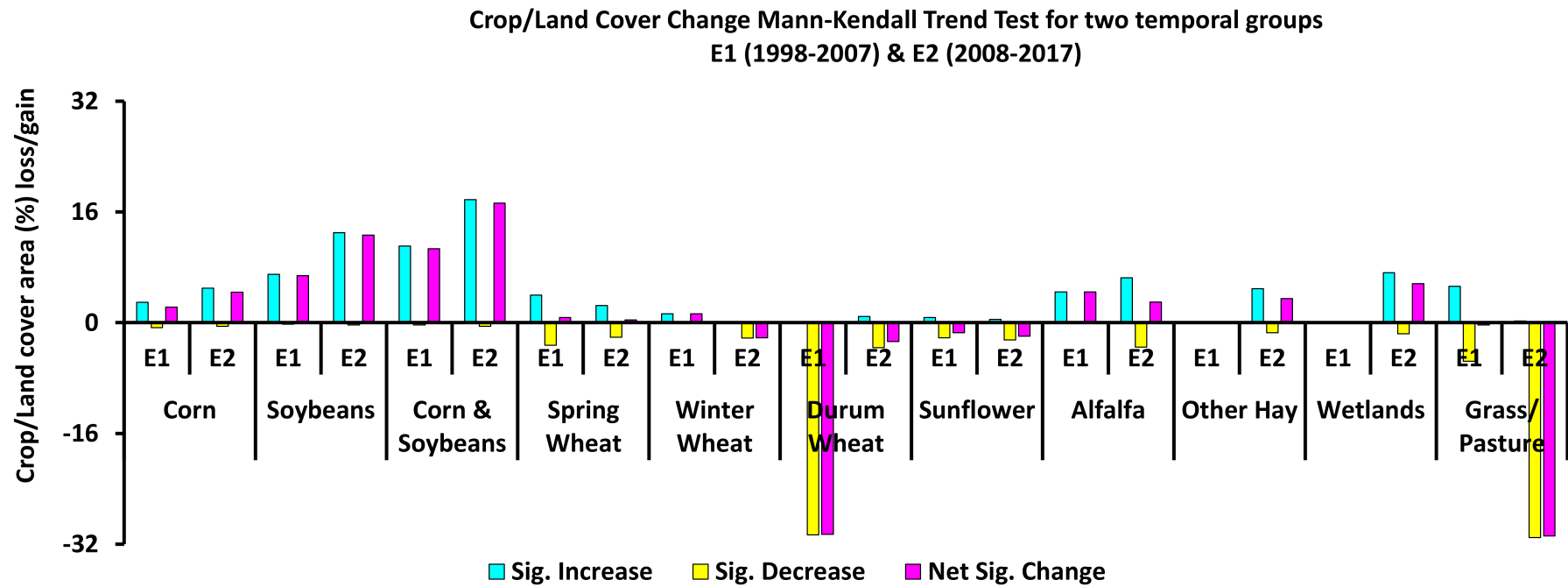
The Mann–Kendall trend tests on CDL time series of the portion of the US–PPR within North Dakota in two epochs (1998–2007 and 2008–2017) revealed significant net decreases in the grass/pasture cover class in both epochs, but the net decrease for 2008–2017 was enormous (~30% of grass/pasture cover areas, Figures 6b and 7; Table S3) compared to 1998–2007 (Figures 6a and 7; Table S3). Corn cover exhibited significant net increasing trends in both periods (Figure 7; Figure S3a,b; Table S3). Significant net increases in soybeans were evident in both periods, but the change between 2008 and 2017 was nearly twice that in the earlier period (Figure 7; Figure S3c,d; Table S3). The combined corn and soybeans coverage showed significant net increases in both epochs with increases in epoch 2 nearly double those in epoch 1 (Figure 6c,d, and Figure 7; Table S3). Both durum wheat and sunflower coverages experienced a significant net decrement during epoch 1 compared to epoch 2 (Figure 7; Figure S3e,f,k,i; Table S3); however, the spatial distribution of the durum wheat decreases in epoch 1 suggests that much of these decrease may be artifactual (cf. Figure S3k; Table S3). The epoch 1 map of winter wheat also displays mapping artifacts (Figure S3i; Table S3).

Results of the direct change analysis of CDL cover types in the ND–PPR in the two epoch are reported in terms of percentages in Table S4. The advance of corn during epoch 1 is very large (+51.0%) substantial and soybeans nearly as large (+45.8%). Moreover, the area of no change is less than 10% in each case. In epoch 2, the increase of corn is less compared to soybeans (+11.4% vs. +35.7%). The net increase of combined soybeans and corn area in both epochs is very large, but the advance in epoch 1 is more than in epoch 2 (+52.0% vs. +32.8%), and the area of no change reaching 38.8% in epoch 2 compared to less than half that level in epoch 1 (18.4%). For spring wheat, the net decrease in epoch 2 (−13.0%) was 2.5 times greater than the increase in the earlier epoch (+5.2%). Due to artifacts in epoch 1, we restricted the direct change analysis to epoch 2, which showed a dramatic net decrease (−91.8%). Durum wheat showed net decreases in both epochs but, as mentioned above, the mapping in epoch 1 is suspect. Alfalfa shows a large net increase (+16.6%), and other hay/not-alfalfa posts an even larger expansion (+42.2%), both restricted to epoch 2 only due to data limitations. Wetlands data were not

complete for epoch 1, but the change analysis for epoch 2 shows a substantial net increase (+31.7%) with just 23.8% of the wetlands in the ND-PPR showing no change. Finally, the grass/pasture class shows a modest net increase in epoch 1 (+9.1%), but a substantial net decrease in epoch 2 (−25.2%).



**Figure 6.** Mann–Kendall maps of cover classes for two epochs (E1: 1998–2007 and E2: 2008–2017): (a) E1 for grass/pasture; (b) E2 for grass/pasture; (c) E1 for corn & soybeans combined; (d) E2 for corn & soybeans combined. Each cover class is divided into four categories: significant gains (cyan;  $p < 0.05$ ), non-significant change (gray;  $p > 0.05$ ), significant losses (yellow;  $p < 0.05$ ), with cover class absence in black. Quantitative details about these trends is presented in Figure 7. Similar maps for the remaining crop/land covers is presented in Figure S3 and Table S3.



**Figure 7.** Mann–Kendall trend test crop/land cover area percentage (%) significant changes ( $p < 0.05$ ) using CDL data two epochs (E1 = 1998–2007 and E2 = 2008–2017) for the North Dakotan portion of the US–PPR. Significantly increased (gains in cyan), significantly decreased (losses in yellow), and net change (magenta) trends are presented for each crop/land cover. Note the grass/pasture and combined corn and soybeans exhibit opposite directions and larger magnitude trends. Other hay and wetlands categories have complete data only for the second epoch. Details are presented in Table S3.

## 4. Discussion

### 4.1. Land Cover Persistency

Temporal persistency analysis for grass/pasture class (Figure 8a) and combination of six crop cover classes (corn, soybean, spring wheat, winter wheat, durum wheat, and sunflower; Figure 8b) showed the western US–PPR was dominated by a stable core of grass/pasture (yellow in Figure 8a; cf. Figure 3a). The southcentral and eastern parts of the region displayed unstable but persistent peripheral cover in grass/pasture (magenta in Figure 8a; cf. Figure 3a). This persistency class indicates a temporal change between the focal cover type (grass/pasture in this case) and one or more other cover types (particularly corn and soybeans). Areas along the Red River of the North displayed the absence of grass/pasture cover (black in Figure 8a). The southern half and east-central parts of the US–PPR were dominated by persistent croplands during the study period (Figure 8b), while areas in the western and northwestern parts were non-crop and unstable persistent peripheral areas [28,29].

### 4.2. Land Cover Dynamics in the Prairie Pothole Region

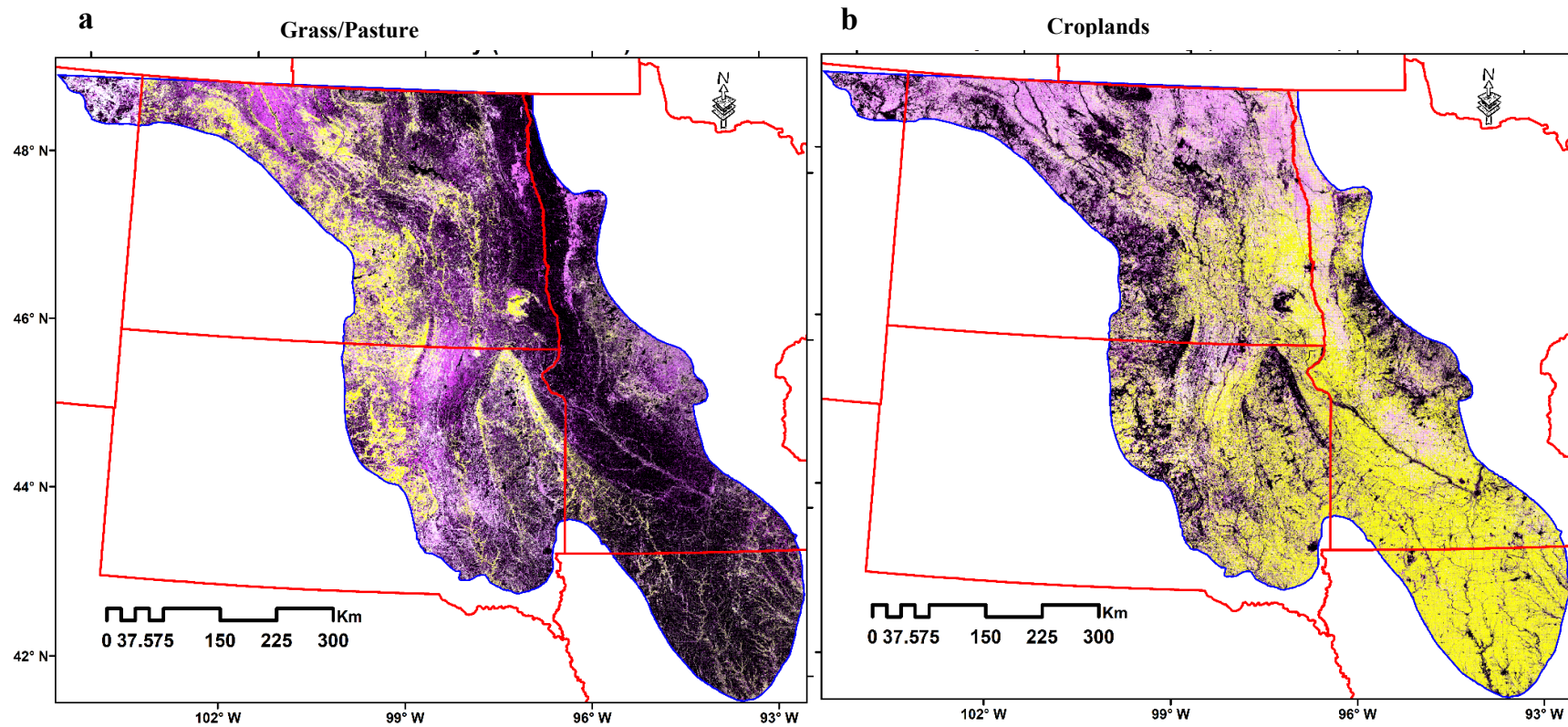
The decrease of grasslands in the US–PPR found in this study is in accordance with previous studies. The conversion of croplands formerly planted to wheat—particularly spring wheat—to corn and soybeans is similar to other studies [20,32], and the strong decreasing trend in winter wheat is even larger than that of the spring wheat. The recent expansion of corn and soybeans in the US–PPR (and the US Midwest more broadly) due to biofuel demand has been reported elsewhere [2,5–7,13,33–35]. However, while various reports have demonstrated decreasing wetlands in US–PPR [5–7,13,33,36], our results revealed that wetlands experienced a 5% significant net increase in the US–PPR over the study period, and particularly in the ND–PPR during epoch 2 (Figure S3m; Table S2).

What might be the sources of this discrepancy? First, there has been a significant increase in precipitation in the US–PPR [37] and the vulnerability of the northern prairie wetlands has long been recognized [38,39]. Second, at Devils Lake in east-central North Dakota, the lake level rose by 10 m between 1991 and 2011, inundating more than 650 km<sup>2</sup> [40]. Land management practices, such as cropland drainage [41], may be partially responsible for the flooding [40]. Third, classification uncertainty may also account for part of the discrepancy. While the CDL data classification accuracy was reported as 90% for major commodities, such as corn, cotton, rice, soybeans, and wheat [14], the heterogeneity of wetlands make them much more difficult to classify [42–45].

A different kind of discrepancy appeared in the form of increasing trends of alfalfa (Figure S2g) and other hay/non-alfalfa crops, contrary to the findings of [20]. Alfalfa and other hay crops are typically grown for local consumption as feed rather than for commodity markets. Alfalfa provides excellent feed and forage for dairy cows, and its areal increase is likely associated with increased local demand arising from substantial changes in dairy farm size within the region. From 2012 to 2017, Iowa and the Dakotas saw a contraction in the number of smaller operations and an increase in the number of larger operations (Table 2). In contrast, Minnesota more than doubled the number of small operations and the number of larger operations sharply increased from 42 to 991 (Table 2).

**Table 2.** Changes in inventories of milk cows at operations with sales of milk in 2012 and 2017. Source: <https://quickstats.nass.usda.gov>.

	1 ≤ x < 20 Milk Cows			x > 1000 Milk Cows		
	2012	2017	Change	2012	2017	change
Iowa	161	85	−76	27	31	+4
Minnesota	317	703	+386	42	991	+949
North Dakota	8	5	−3	2	3	+1
South Dakota	95	60	−35	24	51	+27
Total	581	853	+272	95	1076	+981

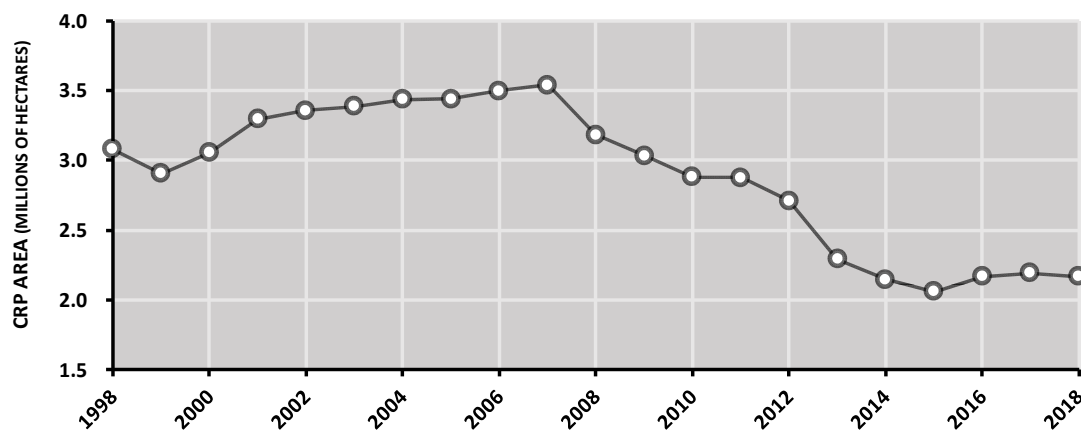


**Figure 8.** Grass/pasture and crop covers persistency map is a false color composite of CDL time series where: Red color plane was assigned to the maximum percentage of cover, Green to the average percentage of cover, Blue to the range of coverage (max %–min %). *Interpretation:* Yellow → stable core areas, White → unstable core areas, Magenta → unstable periphery, Black → cover does not occur. Note that grass/pasture are dominated by shades of magenta to purple indicating higher variation and low average. (cf. Table 1 for interpretative detail.).

Expansion of croplands (corn and soybeans) in the PPR at the cost of grasslands and smaller wetlands may potentially affect the amount, quality, and accessibility of habitat for a variety of wildlife species [6–8,19,36,46]. Grasslands provide versatile ecosystem services, including recreational use, forage for livestock, and water quality improvement services. Grasslands are a significant landscape component for climate change mitigation and adaptation through their high species carrying capacities, ability to mitigate floods, and substantial carbon sequestration benefits. Native prairies are of high conservation value due to their rich biodiversity and millennia of stored soil carbon. As such, protecting native grasslands in the PPR should be a conservation priority by government officials and organizations.

#### 4.3. Land Cover Dynamics Comparison in Time

In the North Dakotan portion of the US–PPR, Epoch 2 (2008–2017) showed a net significant increase of corn and soybeans cover compared to that of Epoch 1 (1998–2007). In contrast, Epoch 2 grass/pasture cover experienced net significant decrement compared to Epoch 1. These findings align with [13] showing about an abrupt decrease of the Conservation Reserve Program (CRP) land enrollments in 2008, after attaining its peak enrolment in 2007 [12]. The same study states that between 2010 and 2013, 30% (more than 530,000 ha) of expiring CRP land parcels were returned to production, mainly of corn and soybeans in the 12-state Midwestern region of the United States that includes the US–PPR [13]. Grasslands were the largest type of CRP land converted (68%), followed by specifically designated wildlife habitats [13]. Arora and Wolter [20] also revealed that annual grassland loss rate between 1985 and 2011 was 1.5%, while sky-rocketing to 5.5% in recent years. The statistical data by USDA Farm Service Agency [FAS; 47] about total area enrolled in the Conservation Reserve Program (CRP) in four states in the US–PPR presented in Figure 9 confirms that lands enrolled in the CRP have been declining since 2008, after peaking in 2007.



**Figure 9.** Sum of total area enrolled in the Conservation Reserve Program (CRP) for 1998–2018 in the four states (Iowa, Minnesota, North Dakota, and South Dakota), where most of the US–PPR can be found [47]. Note the abrupt decreases in area enrolled in CRP between 2007–2008 and 2012–2013.

## 5. Conclusion and Recommendation

We have quantified, characterized, and visualized the changing landscape of the US–PPR using the CDL dataset. Grass/pasture in the US–PPR experienced a statistically significant net decreasing trend of nearly one-third between 2006–2018, particularly after the abrupt enrollment declines in the Conservation Reserve Program land since 2007, the year of peak CRP enrollment (Figure 9). Winter and spring wheat areas also faced statistically significant net decreasing trends. On the other hand, the area under cultivation of corn and soybeans—considered separately and together—showed significant net



increasing trends, particularly after 2007. Alfalfa and other hay/non-alfalfa also experienced statistically significant net increases.

A surprising finding that appears contrary to previous studies is a statistically significant increasing net trend of the area classified as wetlands across the entire US–PPR during the period from 2006 to 2018. This discrepancy that is best understood in a regional context: the substantial increases in precipitation across the region coupled with the rising level of Devils Lake and its collateral inundation of neighboring lands drives the net regional increase in wetlands. The loss of smaller wetlands found in other studies has indeed been occurring due to widespread drainage and conversion to croplands, which bodes ill for wildlife—both native and migratory—that depend on the prairie pothole lakes. The increase of wetlands due to recent flooding does not offset the loss of the wetlands network that makes the PPR an important landscape [36,46].

Our findings help to understand the current status and recent dynamics of grasslands and wetlands and various crop extents within the US–PPR. The shift of farmers’ interest not to re-enroll their lands to CRP, and their preference to allocate their lands for biofuel commodities, such as corn and soybeans, may bring the need to revise agricultural and energy policies [48,49].

Even within the relatively small region of the US–PPR, interstate inconsistencies exist in the CDL data, due to the heritage of independent processing of these data in each state. The CDL remains an important dataset to explore land/cropland change in the US; yet, there is clear research need to generate a “CDL reanalysis” nationally using consistent processing with all available imagery to provide a reference database for agricultural land change that can be used both for research and policy development, evaluation, and implementation [48].

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2073-445X/9/5/166/s1>, Figure S1. Mean land cover percentages from the USDA NASS CDL using 510 m resolution aggregated pixel for the US portion of the Prairie Pothole Region (PPR) between 2006 and 2018. PPR boundary appears in blue and state borders in red. Figure S2. Mann–Kendall trend maps of cover classes between 2006 and 2018. Each cover class is divided into four categories: significant gain (cyan;  $p < 0.05$ ), non-significant change (gray;  $p > 0.05$ ), significant loss (yellow;  $p < 0.05$ ), with cover class absence in black. Quantitative details about these trends are presented in Table S1. Table S1. Crop/land cover percentage (%) that showed a significant increase, significant decrease, net significant change, and no significant change using the Mann–Kendall trend test on CDL data for 2006–2018 for the US–PPR. This table support Figure 5 in the main text. Table S2. Direct change analysis on the US–PPR CDL using the temporal endpoints of 2006 and 2018. Crop/land cover percentage (%) that increased, decreased, net change, no significant change, asymmetry ratio (AR), and predominant change ( $AR > 2.0 \rightarrow$  **increased**;  $AR < 0.5 \rightarrow$  **decreased**;  $0.5 < AR < 2.0 \rightarrow$  mixed). NaN = Not a Number, due to division by zero; na is not available, due to this cover type not being mapped in 2006. Figure S3. Mann–Kendall trend maps of cover classes for two epochs (E1: 1998–2007 and E2: 2008–2017). Each cover class is divided into four categories: significant gain (cyan;  $p < 0.05$ ), non-significant change (gray;  $p > 0.05$ ), significant loss (yellow;  $p < 0.05$ ), with cover class absence in black. Quantitative details about these trends are presented in Table S3. Note that there are no full data in Epoch 1 for either Wetlands or Other Hay/Non-Alfalfa. Table S3. Mann–Kendall trend test crop/land cover area and percentage (%) significant changes ( $p < 0.05$ ) using CDL data two epochs (E1 = 1998–2007 and E2 = 2008–2017) for the North Dakotan portion of the US–PPR. Significant increasing (gains), decreasing (losses), and net change trends are presented for each crop/land cover for each epoch. This table support Figure 7 in the main text. Table S4. Direct change analysis on the ND–PPR CDL using the temporal endpoints in two epochs (E1 = 1998–2007 and E2 = 2008–2017). Crop/land cover percentage (%) that increased, decreased, net change, no significant change, asymmetry ratio (AR), and predominant change ( $AR > 2.0 \rightarrow$  **increased**;  $AR < 0.5 \rightarrow$  **decreased**;  $0.5 < AR < 2.0 \rightarrow$  mixed). NaN = Not a Number, due to division by zero; na=not available, due to this cover type not available during epoch; ds = data suspect, due to apparent artifacts in the cover type.

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