



Wetland Losses Due to Row Crop Expansion in the Dakota Prairie Pothole Region

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Abstract Agriculture is the greatest source of wetland loss in the Prairie Pothole Region of North and South Dakota (Dakota PPR). Demand for corn ethanol, expiration of agricultural conservation contracts, and increasing commodity prices may have stimulated alteration of wetlands for row crop production. The purpose of this study was to determine recent wetland-to-row-crop transition rates within the Dakota PPR, using GIS analysis to intersect the 2011 National Agricultural Statistics Service's Cropland Data Layer (CDL) with wetlands mapped by the U.S. Fish & Wildlife Service's National Wetlands Inventory (NWI) and the U.S. Geological Survey's National Land Cover Database (NLCD). The NWI depicts wetlands as they existed in the 1980s, whereas the NLCD depicts wetlands as of 2001. On an annualized basis, the NWI wetland loss rate was 0.28 % (−5,203 ha/yr) and the NLCD wetland loss rate was 0.35 % (−6,223 ha/yr). Fewer losses occurred along the western and northern edges of the Dakota PPR, which are less conducive to row crops due to climate and topographic limitations. The map of apparent wetland losses generated by this study provides a means for monitoring and enforcement agencies to quickly identify potential violations of compliance with Swampbuster or other wetland regulations.

Keywords GIS · Agriculture · Imagery · Corn · Soybeans

Introduction

Conservationists in the Prairie Pothole Region of North and South Dakota, USA (Dakota PPR) have observed ongoing

losses of wetlands by alteration for agricultural crops. Provisions of the U.S. Farm Bill have deterred, but by no means eliminated, wetland drainage for crop production. In its report on the status and trends of U.S. wetlands for 2004 to 2009, the U.S. Fish & Wildlife Service noted that “losses of freshwater marsh...outdistanced gains in certain portions of the country including the prairie pothole region” (Dahl 2011). Efforts to improve drainage of farm fields as a result of economic and climatic conditions contributed to the loss of freshwater marshes in agricultural areas.

There are a number of reasons for row crop expansion into Dakota wetlands. First, it is difficult to maneuver large farm machinery around small potholes. Second, genetic improvements have enabled farmers to grow cold and drought tolerant crop varieties, shifting the geographic center of the U.S. corn belt northwest since the end of the 19th century (Reilly et al. 2003). Third, ethanol production has increased demand for corn, because the 18 ethanol refineries in the eastern Dakotas all rely on corn. Fourth, the price of corn and soybeans more than tripled in the decade between 2002 and 2012, providing a strong incentive to grow row crops in wetlands. Finally, subsidized crop insurance protects farmers from revenue losses when they plant areas that become too wet to harvest (Faber et al. 2012).

Despite anecdotal evidence of wetland loss in the Dakota PPR, quantitative evaluation of loss rates for the region has been lacking. National Wetlands Inventory (NWI) maps of wetlands in the region were prepared from aerial photos taken mostly in the 1970s and 1980s, and were updated for only a minor fraction of the Dakotas. The U.S. Geological Survey's (USGS) National Land Cover Database (NLCD) was updated from 2001 to 2006 (Xian et al. 2009), but focused on “developed” lands, not natural or agricultural land cover. Wetland maps were prepared by U.S. Department of Agriculture offices to monitor compliance under the “Swampbuster” provisions of the Food Security Act of 1985 and subsequent

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farm bills, but they are incomplete and unavailable to the general public due to their proprietary information content. Permits are generally not required under §404 of the U.S. Clean Water Act for agricultural uses of isolated wetlands. Thus, wetland losses to row crops have gone largely undetected in the Dakota PPR.

The purpose of this paper is to determine the rate of wetland loss due to expansion of corn and soybeans, the major row crops in North and South Dakota. The NWI and NLCD 2001 digital data were used to determine the location of wetlands, and the U.S. Department of Agriculture's Cropland Data Layer (CDL) was used to determine the current location of corn and soybeans. Areas where NWI or NLCD-mapped wetlands are currently croplands were considered to be wetland losses. In preparation for this analysis, I also evaluated the reliability of the CDL in correctly depicting current croplands in historical wetlands. It should be noted that the reversibility of land use changes was *not* evaluated, and the term "wetland loss" could include wetlands that have only lost a degree of ecological function due to recent cropping as well as those that have been completely drained via direct hydrologic manipulation such as drainage ditches and/or tile drainage.

Materials and Methods

Study Area

The undulating PPR landscape was covered by continental glaciers during the Wisconsin and earlier glacial episodes, which left behind a nearly level plain of thick till and other glacial deposits. Major physiographic regions include the Drift Prairie, Glacial Lake Agassiz, Missouri Coteau, and Prairie Coteau (a coteau is a hilly moraine left from glacial stagnation) (Fig. 1). There are numerous natural lakes in the region, the largest of which is Devils Lake, ND (depth \approx 16.2 m, area \approx 855 km²). The landscape is dotted by numerous wetlands, sometimes exceeding 38 per km² (Johnson et al. 1997). Ditches and subsurface tile drains are installed to artificially drain wetlands where physically and economically feasible. Although the PPR extends from north-central Iowa to central Alberta, eastern North and South Dakota represent the region's U.S. core due to extensive wetland drainage in Iowa and Minnesota.

The Dakota PPR consists of lands in North and South Dakota east of the Missouri River, the approximate limit of glaciation. The Dakota PPR study area was defined using a digital ecoregion database for the Dakotas (U.S. EPA 1996), excluding ecoregions that lie west of the Missouri River.

Digital Data

Seamless 2010 and 2011 CDL data were downloaded from the CropScape portal of the National Agricultural Statistics

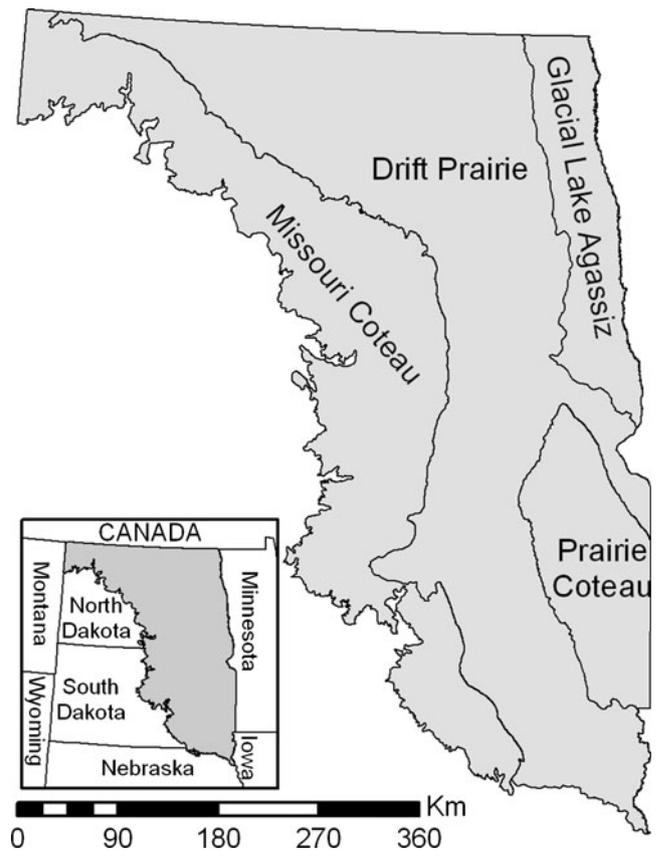


Fig. 1 The Dakota PPR, showing location and major physiographic regions

Service (USDA NASS 2012), and then clipped with the study area polygon defined by the ecoregion database. The CDL is produced annually from satellite imagery taken at multiple dates during the growing season, contemporary agricultural training data from the Farm Service Agency, and non-agricultural training data from the 2001 or 2006 NLCD (Johnson and Mueller 2010; Boryan et al. 2011). Landsat 5 TM (30 m pixels) was the primary image source for the 2010 CDL, supplemented by Advanced Wide Field Sensor (AWiFS) imagery from the Indian Remote Sensing satellite IRS-P6 (56 m pixels). For the 2011 CDL, images from the Disaster Monitoring Constellation's Deimos-1 and UK-DMC 2 sensors (22 m pixels) were used in conjunction with Landsat 5 TM imagery to generate the 30-m resolution CDL layer. Metadata for each CDL product in North and South Dakota reported that corn and soybeans were mapped with producers' and users' accuracies \geq 90.9 % (Table 1).

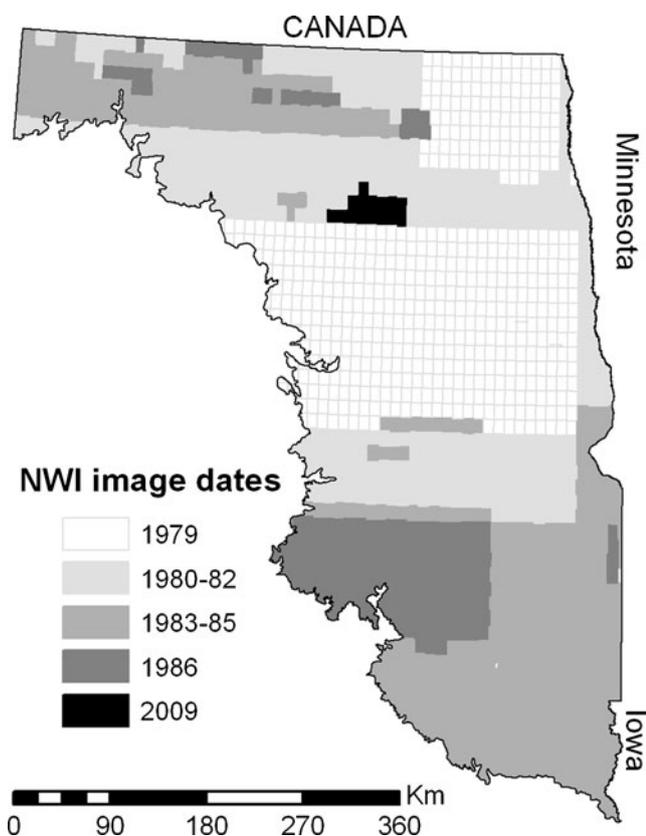
The National Wetlands Inventory (NWI) and the National Land Cover Dataset (NLCD) were used as sources of wetland data. The NWI depicts wetlands, lakes, and rivers as vector polygons, and has greater wetland spatial resolution and classification detail than does the NLCD. The NWI provides a snapshot of wetlands as they existed 25 to 32 years ago because the aerial photos used to generate NWI maps were taken in the

Table 1 Accuracy statistics for corn and soybean mapping, summarized from 2010 to 2011 CDL metadata for North Dakota and South Dakota

Crop	North Dakota		South Dakota	
	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)
2010 Corn	91.00	95.24	93.63	92.94
2010 Soybeans	95.43	95.89	94.00	94.49
2011 Corn	90.91	93.89	95.54	93.34
2011 Soybeans	95.74	93.59	95.23	95.55

1970s and 1980s. The NWI data and accompanying metadata were downloaded as ArcGIS shapefiles for the two states (NWI 2012). The metadata included a shapefile of image dates used for delineation (Fig. 2). A spatial join was used to transfer these metadata to a digital file of USGS 7.5 min topographic map boundaries for the region, which was subsequently used in annualized loss rate calculations (see below).

The 2001 NLCD is a general land use/land cover database which includes three classes of wetlands and lakes (Homer et al. 2007; Wickham et al. 2010): #90 woody wetlands, #95 emergent herbaceous wetlands, and #11 open water. The open water category contained water bodies ranging from <0.5 ha to the size of Devils Lake. The NLCD is derived from Landsat Thematic Mapper satellite imagery, which has a pixel resolution of 30 m.

**Fig. 2** Aerial photo dates used for NWI map preparation

Annual Palmer Hydrological Drought Index data were obtained from the National Climatic Data Center (NCDC 2012) as a means of interpreting climatic conditions at the time of source map preparation. The Palmer Hydrological Drought Index shows long-term cumulative drought and wet conditions (Karl 1986). It uses a 0 as normal; drought is shown by negative numbers (−4 is extreme drought) and excessive wetness is shown by positive numbers (+4 is extremely moist).

GIS Processing and Error Analysis

Data were analyzed in ArcGIS 9.3.1 (ESRI, Redlands, CA) in the native projection used to produce the CDL (USA Contiguous Albers Equal Area Conic USGS version, NAD83 datum), using a variety of GIS methods (Johnston 1998). The NWI vector files for ND and SD were clipped with the Dakota PPR boundaries for their respective states to exclude wetlands that were out of the region and eliminate duplicate representations of wetlands that extended across the ND-SD state border. After recalculating polygon areas, I summarized the attributes by wetland type (Table 2). The NLCD raster files were also clipped with the Dakota PPR boundary and summarized by class.

Table 2 Cumulative areas of wetlands mapped by NLCD and NWI in the Dakota PPR

Code	Description	Area, km ²	% of Region
NLCD:			
11	Open water	8331	3.9 %
90	Woody wetlands	720	0.3 %
95	Emergent herbaceous wetlands	8805	4.1 %
	NLCD all wetlands & water	17856	8.3 %
NWI:			
L1, L2	Lacustrine	2797	1.3 %
R2, R4	Riverine	249	0.1 %
PUS	Palustrine unconsolidated shore	4	0.0 %
PAB, PUB	Palustrine pond	760	0.4 %
PFO, PSS	Palustrine forested/shrub wetland	173	0.1 %
PEM	Palustrine emergent wetland	14341	6.6 %
	NWI all wetlands & water	18324	8.5 %

For each CDL date used, pixels mapped as corn or soybeans within the Dakota PPR were reclassified to a value of one, setting all other pixels to zero (= cornbean layer). The ND and SD NWI shapefiles were merged, then intersected with the cornbean layer by using the ArcGIS Spatial Analyst tool “extract by mask” to extract all pixels from the cornbean layer that had been mapped as wetland by NWI. In the resulting raster file, all pixels with a value of 1 represented wetland losses (i.e., wetlands that became row crops) and all pixels with a value of 0 represented extant wetlands. The NLCD is a raster data layer, so I used “raster calculator” to multiply the cornbean layer by the NLCD, summarizing the pixel counts for open water, woody wetlands, and emergent herbaceous wetlands to identify wetland losses.

Any spatial data layer may contain mapping errors, so an error analysis was conducted to determine if true wetland losses occurred at areas where CDL-mapped corn or soybeans had been NWI-mapped wetlands. The purpose was not to analyze map accuracy per se, because crop-specific accuracy statistics are included with CDL metadata (Table 1), and wetland mapping accuracy has already been assessed for NLCD (Wickham et al. 2010) and NWI (Stolt and Baker 1995; Kudray and Gale 2000; Johnston and Meysembourg 2002; Martin et al. 2012). Rather, the primary purpose was to detect errors of commission where CDL had incorrectly mapped a wetland as corn or soybeans. To do this, I used the raster-to-polygon conversion tool to generate polygons for contiguous corn and soybean pixels that had been mapped as wetland by NWI, and evaluated each individual loss with area ≥ 10 ha. To evaluate possible CDL errors, I displayed these apparent wetland losses over aerial photos of the National Agricultural Imagery Program (NAIP), using the earliest available NAIP date (2003 or 2004) and the most recent NAIP date that was included in the i-cubed Nationwide Prime imagery within the ArcGIS World Imagery map service (ESRI, Redlands, CA). These apparent wetland losses were also displayed over U.S. Geological Survey Digital Raster Graphics, a digital version of 1:24,000 topographic maps, to evaluate possible NWI errors (i.e., lands mapped as wetland that were probably not wetland because their slopes exceeded 2.3 %). Although this process could also have been done using NLCD-designated wetlands, I considered NWI to be an adequate representation of wetlands for the purpose of evaluating CDL errors of commission.

Annualized wetland area lost was calculated by dividing cumulative losses by the number of years elapsed. For the NLCD, the area of wetland losses was summed across the Dakota PPR and divided by 10 (i.e., 2001 to 2011). For the NWI, the ArcGIS Spatial Analyst tool “zonal statistics” was used to calculate cumulative wetland loss for each 7.5 min quadrangle ($n=1,755$). The cumulative wetland loss was divided by the time since NWI image acquisition to annualize the loss area, and summed across quadrangles. Annual area losses for the Dakota PPR were divided by initial

wetland area mapped by each wetland data source to calculate annual percentage loss rates.

Results

Wetland Abundance

Both the NWI and NLCD depicted wetlands and water as covering about 8.5 % of the Dakota PPR (Table 2). Palustrine emergent wetlands were by far the predominant vegetation class, whereas woody wetlands were a minor component of both inventories. Wetlands occurred throughout the region; lowest wetland densities occurred on the Glacial Lake Agassiz plain, where agriculture is intense (Fig. 3). Fewer wetlands were mapped by NLCD than by NWI in the South Dakota PPR.

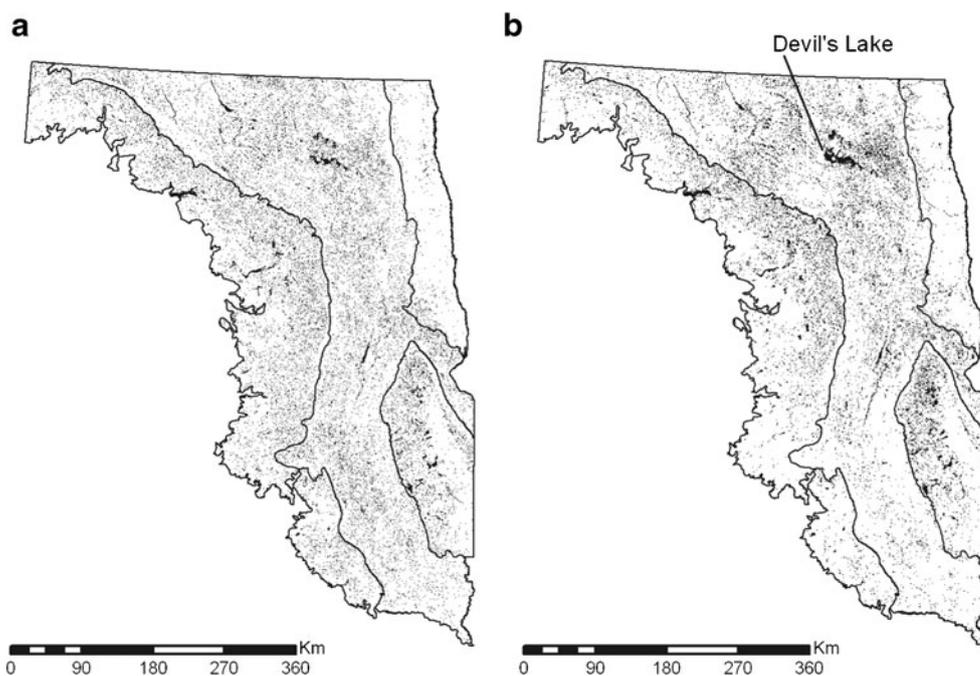
More area was mapped as water by NLCD than by NWI (Table 2). The area of Devil’s Lake in North Dakota was visibly larger on the NLCD map than on the NWI map, a difference caused by real changes as water levels rose and flooded lands adjacent to the lake (Anonymous 2012). The Palmer Hydrological Drought Index showed that conditions were wetter when the NLCD maps were prepared: the 2001 imagery was taken after a succession of eight wetter-than-normal years, whereas the NWI was prepared using imagery taken during a more normal climate period (Fig. 4).

Error Analysis

In 2010, there were 168 polygons with areas ≥ 10 ha where NWI-mapped wetlands were CDL-mapped row crops (Table 3). Aerial photo inspection showed that 142 polygons (83.8 % of the area examined) were actual wetland losses, where historical wetlands became cropland. For example, a 65-ha ephemeral pond northwest of Hillsboro, North Dakota was mapped as an emergent wetland by NWI, but was completely ditched and cropped as of 2010 (Fig. 5). However, 26 of the polygons (16.2 % of the area examined) were incorrectly mapped as cropland by the 2010 CDL, twice the error rate reported by the USDA metadata (Table 1). Lush cattail stands were sometimes mapped as corn, possibly because of similar spectral properties that would confuse CDL satellite image analysis. Wet pastures with natural vegetation were sometimes mapped as row crops. Particularly egregious errors included a partially vegetated sandbar island in the Missouri River southeast of Yankton, South Dakota that was erroneously mapped as a mosaic of corn and soybeans (36 ha), and a sewage lagoon for the city of Fargo, ND that was mapped as soybeans (30 ha). This error rate and the seriousness of the errors were considered unacceptable, so no loss rates were computed using the 2010 CDL data.

There were fewer errors observed using the 2011 CDL: 10 errors out of 142 polygons examined, 6.8 % of the area

Fig. 3 Wetland and deep water in the Dakota PPR. **a.** As mapped by NWI. **b.** As mapped by NLCD



examined (Table 3). The improvement between 2010 and 2011 could have been due to the change in satellite imagery used to prepare the 2011 CDL; the metadata showed no other changes in procedure or ancillary data used in the preparation of the 2011 CDL versus the 2010 CDL. Two NWI errors were detected, constituting 1.4 % of the 2,372 ha area examined (Table 2). These error rates were considered acceptable, and I used only the 2011 CDL as the basis for computing wetland loss rates. The aerial photo inspection also showed that 83 % of the wetland losses identified by the 2011 CDL/NWI comparison had occurred prior to 2003/2004, the earliest NAIP date.

Wetland Loss Rates

For the NWI/CDL 2011 comparison, 1,345 km² of NWI-mapped wetlands and water bodies became corn or soybeans,

7.4 % of the wetland area originally mapped. The NLCD/CDL 2011 comparison showed a loss of 622 km² (3.5 % of the wetland area originally mapped), but that comparison represented a shorter evaluation period (10 years) than the 25 to 32 year time period represented by the NWI/CDL 2011 comparison.

On an annualized basis, the NWI wetland loss rate was 0.28 % (–5,203 ha/yr). Fewer losses occurred along the western edge of the region, which is less conducive to row crops because it receives less precipitation and has greater topographic relief than areas farther east (Fig. 6a). The northern portion of the Dakota PPR also experienced few wetland losses attributable to corn and soybean expansion, presumably because its colder temperatures are less conducive to row crops. The annualized NLCD wetland loss rate was 0.35 % (–6,223 ha/yr), slightly greater than the annualized NWI loss rate. Increasing corn prices may have stimulated more rapid wetland losses during the 2000 decade represented by NLCD: the weighted average price per bushel of corn increased from \$1.97 in 2001 to \$6.22 in 2011, a linear

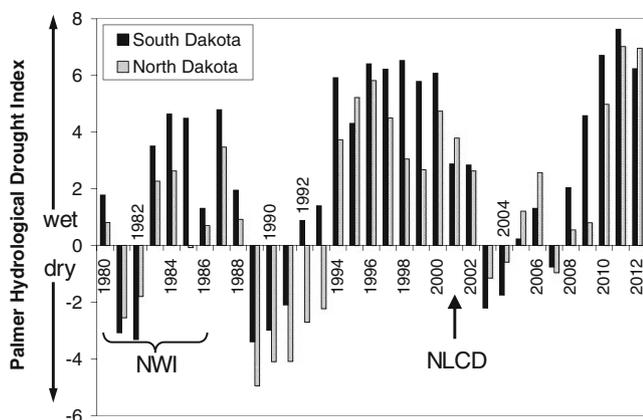
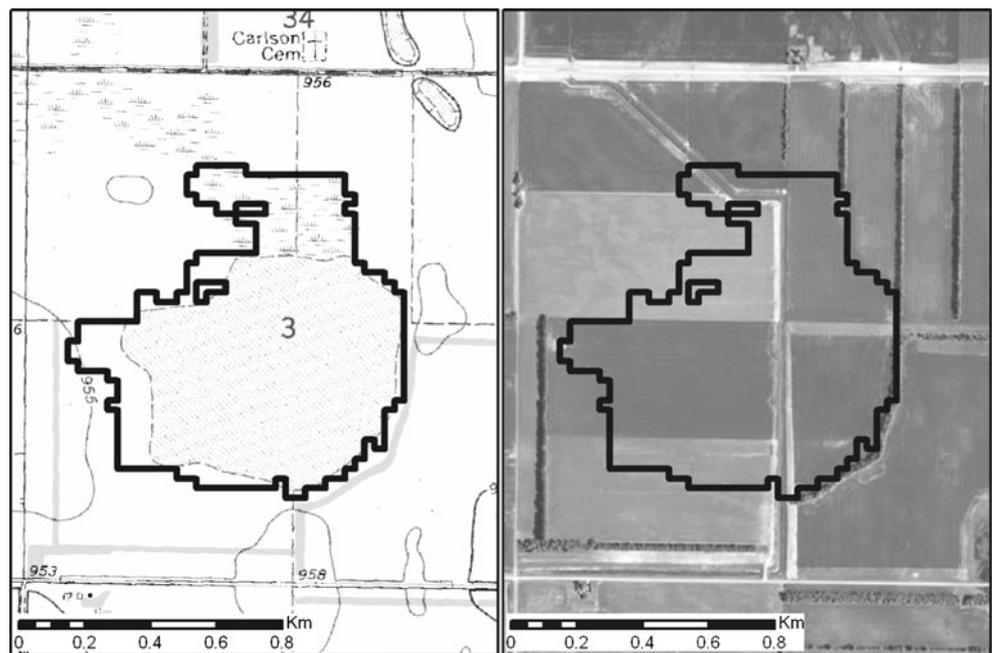


Fig. 4 Palmer Hydrological Drought Index for North Dakota (ND) and South Dakota (SD), March 1980 to March 2012 (NCDC 2012)

Table 3 Error analysis conducted by inspecting areas where CDL-mapped corn or soybeans had been NWI-mapped wetlands

CDL date	Polygons evaluated	Area evaluated, ha	NWI incorrect, % of area evaluated	CDL incorrect, % of area evaluated	Percent of wetland area that became crops before 2003
2010	168	3023	0.0 %	16.2 %	73.2 %
2011	142	2372	1.4 %	6.8 %	83.2 %

Fig. 5 An example of wetland loss, Traill County, North Dakota. A 65-ha wetland northwest of Hillsboro, ND that was mapped as an ephemeral pond on the 1967 USGS topographic map and PEMAd by the National Wetlands Inventory was completely gone by 2010. The outline of wetland loss is displayed over a U.S. Geological Survey Digital Raster Graphic (left) and a 2010 NAIP aerial image (right)

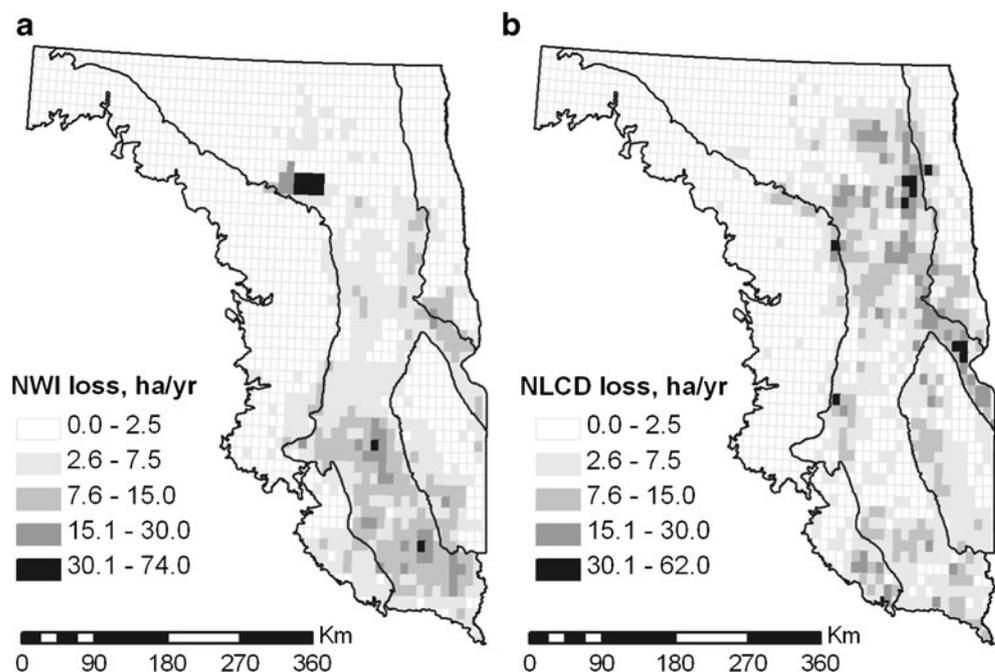


increase of \$0.38/yr, but corn prices fluctuated between \$1.50 and \$3.24 per bushel from 1979 through 2000 with no significant long-term trend (<http://www.ers.usda.gov/topics/crops.aspx>). As with the NWI/CDL 2011 comparison, wetland loss rates were minimal along the western and northern edge of the Dakota PPR (Fig. 6b).

Despite the similar annual rates of wetland loss observed between the two data sets, there were some differences in the spatial locations of the greatest losses. Wells County in north central North Dakota stands out as having an anomalously high rate of wetland loss on

the NWI map (Fig. 6a), but that is explained by the short time period analyzed; it was the only NWI area that had been updated with current imagery (Fig. 2) (Tiner 2009). Already noted was the tendency of the NLCD to map fewer wetlands in South Dakota (Fig. 3), which resulted in lower NLCD loss rates there (Fig. 6b). Conversely, within the North Dakota drift prairie NLCD tended to map as wetland large areas of level ground with grassy vegetation that could only marginally be considered wetland, so NLCD loss rates were higher there than NWI loss rates.

Fig. 6 Annualized wetland losses per 7.5 min quadrangle in the Dakota PPR. **a.** Using NWI-mapped wetlands. **b.** Using NLCD-mapped wetlands



Discussion

Agriculture has long been a major cause of wetland loss, but the U.S. rate of wetland loss due to agriculture has decreased during recent decades (Dahl and Johnson 1991; Dahl 2000, 2006). This decrease has been attributed to implementation of the Swampbuster provisions of the 1985 Food Security Act and its subsequent versions, as well as agricultural set-aside and land retirement programs (Dahl 2011). However, problems with Swampbuster were acknowledged soon after its implementation (Goldstein and Hartmann 1994), and compliance monitoring and enforcement have been lax in some areas (GAO 1994). Swampbuster was judged to be “not effective” to “moderately effective” by 64 % of Plains States respondents in a 2002 Congressional survey of NRCS State Technical Committee members (GAO 2002).

This study confirms ongoing losses of wetlands due to agricultural expansion in the Dakota PPR. The annual wetland loss rate, ~ 0.3 % /yr, is similar to the rate of native grassland conversion to cropland observed in the PPR, 0.4 % /yr (Stephens et al. 2008). A study of wetland losses in the Minnesota PPR done using NWI and 2007 aerial photos similarly documented an overall wetland loss rate of 4.3 %, with losses as high as 15 % in the Prairie Coteau ecological subsection (Oslund et al. 2010). Wetness is an environmental factor that has deterred past row crop utilization of wetlands (Baker and Capel 2011), but technological advances and economic disincentives to conserve are pushing farmers to expand their row crop acreage (Yu and Belcher 2011).

U.S. Federal Government policies are likely to accelerate future use of wetlands for row crops. Many wet meadows were included as set-aside under the Cropland Reserve Program (CRP), but CRP contracts will expire on 7,217 km² in North Dakota and 2,598 km² in South Dakota from 2012 to 2019 (USDA Open Gov 2010). In addition, the U.S. Energy Independence and Security Act of 2007 requires that the total amount of biofuels added to gasoline increase to 36 billion US gallons by 2022, up from 4.7 billion US gallons in 2007. This mandated demand for ethanol will increase pressure to grow biofuel crops in wetlands.

This study did not evaluate the means (e.g., drainage ditch, tile drains) or permanence of wetland transitions to agriculture. Based on the number of flooded farm fields observed during aerial photo inspection for the error analysis, some of these areas may be “farmed wetlands,” areas that are plowed and planted to crops when feasible, but not artificially drained. This study also did not evaluate agriculture-to-wetland transitions, areas where submergence or agricultural abandonment led to local gains in wetland area, such as occurred around Devils Lake and Waubay Lakes. Thus, the results reported are transitions from wetlands to row crops, not net exchanges.

Utilizing existing GIS databases for this analysis has the advantage that the source data are readily available, quality controlled, and widely accepted. However, the differing mapping conventions of the existing GIS databases may introduce bias in change detection analyses because of the way that land use is perceived. For example, a lowland pasture might be mapped as hay/pasture instead of herbaceous wetland by NLCD. This difference in mapping conventions is not an error, but could reduce computed rates of wetland loss because less land is initially classified as wetland. Similarly, smaller wetlands might be overlooked by NLCD because its minimum mapping unit is 5 pixels (0.45 ha), larger than that of NWI (target mapping unit area of 0.1 to 0.4 ha) (Tiner 1997).

An alternative approach would have been to use raw data such as satellite images or aerial photos to analyze a randomly selected set of points at two different time periods. This approach reduces the risk of incorporating bias and errors that could have been made in products such as NLCD, NWI and CDL, and is an excellent means of generating statistical loss rates. However, such a method is less transferable (because few people have the necessary image interpretation skills), and cannot generate a map showing the *locations* of wetland losses to row crops. The map of apparent wetland losses generated by the present study provides a means for monitoring and enforcement agencies to quickly identify potential violations of compliance with Swampbuster or other wetland regulations.

In the long run, climate may have the greatest influence on wetland-to-crop transitions in the Dakota PPR. In southeastern South Dakota, the Palmer Hydrological Drought Index went from an “extremely moist” value of 5.53 in August 2011 to “extreme drought” (−4.53) a year later (NCDC 2012). Such drastic hydrologic changes stress row crops (and wetlands) in regions like the Dakota PPR where irrigation is uncommon, and may ultimately determine the profitability of row crop farming in the region.

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