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Measured extent of agricultural expansion depends on analysis technique

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Abstract: Concern is rising that ecologically important, carbon-rich natural lands in the United States are losing ground to agriculture. We investigate how quantitative assessments of historical land-use change (LUC) to address this concern differ in their conclusions depending on the data set used through an examination of LUC between 2006 and 2014 in 20 counties in the Prairie Pothole Region using the Cropland Data Layer, a modified Cropland Data Layer dataset, data from the National Agricultural Imagery Program, and in-person ground-truthing. The Cropland Data Layer analyses overwhelmingly returned the largest amount of LUC with associated error that limits drawing conclusions from it. Analysis with visual imagery estimated a fraction of this LUC. Clearly, analysis technique drives understanding of the measured extent of LUC; different techniques produce vastly different results that would inform land management policy in strikingly different ways. Best practice guidelines are needed. © 2017 The Authors. *Biofuels, Bioproducts, and Biorefining* published by Society of Chemical Industry and John Wiley & Sons, Ltd.

Supporting information may be found in the online version of this article.

Keywords: land-use change; LUC; CDL; NAIP

Introduction

Demand for food, feed, fiber, and bioenergy influences the amount of land dedicated to agriculture in the USA. For example, expanded demand for corn ethanol, the production of which in the USA increased from 6 billion liters to 54 billion liters between 2000 and 2014[1] largely as a result of the Renewable Fuel Standard (RFS), has led to concerns that agricultural land in the USA has expanded and encroached upon ecologically important, carbon-rich natural lands such as forests, grasslands,[2] and wet-

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lands.[3,4] To gain an understanding of land-use change (LUC)[5,*] that may have accompanied the expanded production of corn ethanol, researchers have turned to geospatial data sets such as the Cropland Data Layer (CDL),[6] the National Land Cover Database (NLCD),[7] and the National Agricultural Imagery Program (NAIP)[8] to conduct LUC analyses. While the NLCD data set is a US Geological Survey product, the CDL and NAIP are developed by the US Department of Agriculture (USDA).

In addition to the CDL and NAIP data sets, the USDA annually reports the amount of cropland planted in different crops based on farmer surveys (Fig. 1[9]). At an aggregate level, cropland area has stayed relatively constant and crop shifting is evident[10] between 2000 and 2014 as corn ethanol production expanded nine-fold. For example, the amount of cropland producing corn and soy has increased. On the other hand, land producing sorghum, barley, oats, and wheat has declined. One reason for the decline in land planted in these crops is that animal feed is a co-product of both corn ethanol production (distiller's grains solubles) and soy biodiesel production (soy meal), which feed back into the overall system and reduce the need for increased land area planted in feed crops. Furthermore, changes in feeding practices that include animals grazing or feeding on corn stover[11-13] reduce the need for land planted in animal feed. Other influences, including shifting dietary patterns and commodity prices, likely drive these trends as well. It is possible, however, that these data mask cropland expansion because farmers may not report as cropland areas that were previously planted but left fallow as they expand cropland into marginal or native lands. Ideally, using a CDL- or NAIP-based LUC analysis would uncover whether these aggregate trends hold true.

Recently, Lark *et al.*[4] used the CDL and NLCD to examine nationwide LUC between 2008 and 2012. They estimated that cropland has increased by 1.28 million hectares on net with gross land conversion nearly four times greater. (Whereas the net result simply tracks the difference between areas of land classified as agricultural in the initial and final years, the gross result accounts for agricultural land expansion into natural lands while some agricultural land transitions to pasture or another category not counted as agricultural. This land does not return to a 'natural' state.) Lark *et al.*'s[4] findings contradict the USDA data indicating cropland area has been roughly constant between 2008 and 2012 (the net change is 0.38 million hectares).

Given that CDL-based analyses[2,4,14] raise concerns about agricultural land expansion in the Prairie Pothole Region, should policymakers look to these analyses to help create or modify land management policy? Or is the development of new tools that provide better information necessary?

Several factors influence this consideration including the resolution and error of different data sets. The CDL currently has a 30 m resolution and is derived from Landsat satellite imagery. It distinguishes among different crop types (e.g. corn, soy, wheat) but relies on the NLCD for non-agricultural land. The accuracy of the CDL, which has been produced with national coverage since 2008, is tied to algorithms to convert satellite data to land cover classifications. The accuracy is assessed by comparing the results of actual land cover assessed on the ground in random locations to those identified in the CDL itself. Further, the accuracy of the CDL varies by state and changes annually.[15] For the reasons we discuss in this paper, the CDL is not designed for assessing historical LUC but excels at providing an annual snapshot of the state of US land use. Lark *et al.*[4] and Johnston[3] expand on the strong points and disadvantages of CDL-based LUC analyses.

Recognizing the limitations of the CDL, Lark *et al.*[4] modified the data set to limit flagging of LUC that had not occurred by applying a spatial filter and a minimum mapping unit, identifying areas of stable versus intermittent cropland, and omitting of areas that were cultivated as cropland in multiple years. Similarly, only land classified as grassland in the NLCD in multiple years leading up to the starting point of their analysis (2006) was considered as native to avoid flagging conversion of areas that could have been recently in agriculture or planted pasture/hay. It is not clear whether Lark *et al.* applied the same technique to forested lands.

In contrast to the CDL, NAIP data provides one- or two-meter resolution imagery that can be used to assess LUC through visual inspection[16.17] but has no associated quantitative accuracy assessment. NAIP data has been acquired beginning in 2003 on a five-year cycle. A three-year cycle began in 2009. It is possible to use tools, such as those developed by Genscape Inc. and used in this study, to view NAIP imagery for different years side-by-side and identify LUC. It is possible that error would arise through misidentification of land cover on images. Additionally, using

*LUC is the term often used to describe shifts in categories of land use or land cover such as forest land, cropland, grassland, wetland, or settled land. It is an imperfect term because it captures both these types of land classifications. That is, a land classification of cropland implies a land use whereas a classification of forest land is indicative of a land cover. Forest land can of course be unmanaged or be under any number of management regimes, or land "uses." Despite the inadequacy of the term LUC, we use it here to refer to changes in land among the above-listed categories as does the Intergovernmental Panel on Climate Change (IPCC) in good practice guidance.

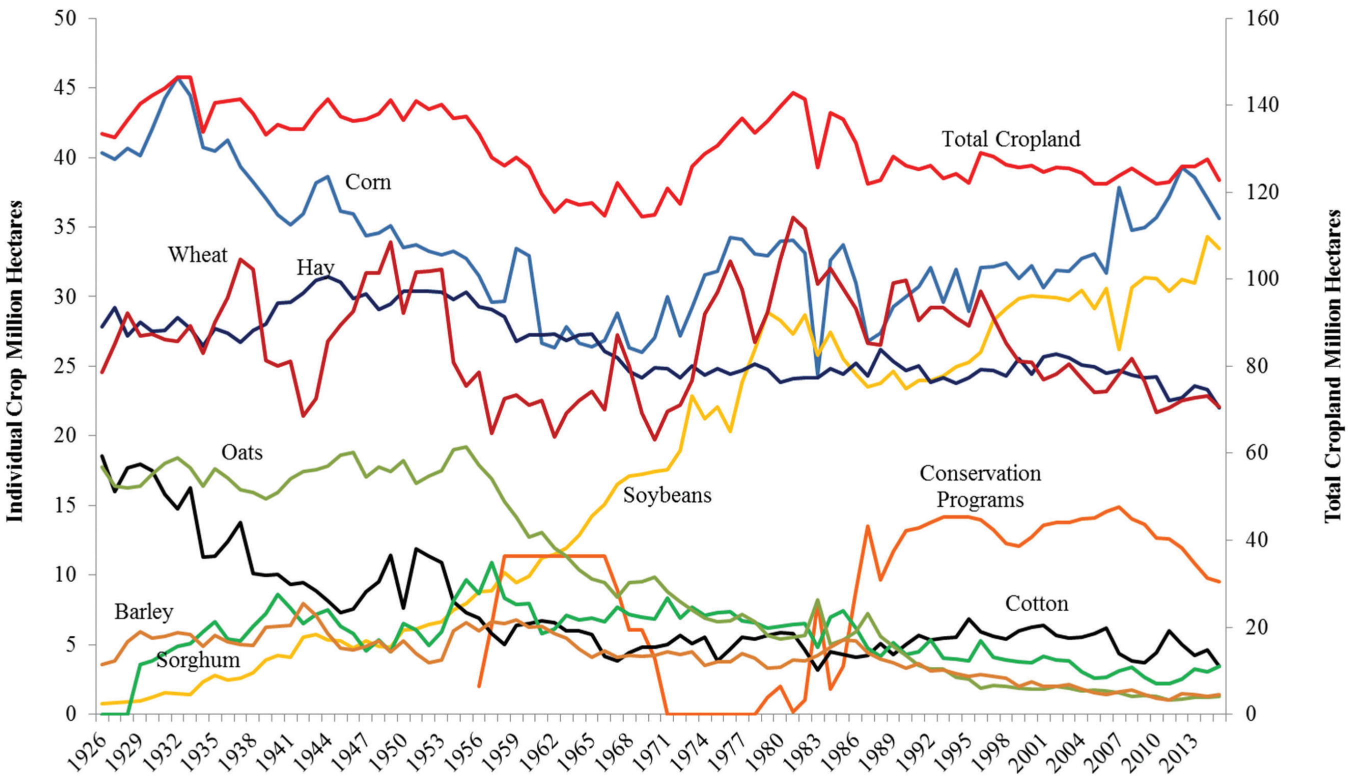

Figure 1. Total cropland hectares and individual crop hectares from 1926 to 2015.[9]

NAIP imagery for large areas would be time consuming whereas CDL data can be processed relatively rapidly.

The Prairie Pothole Region, which spans parts of North and South Dakota, Iowa, Minnesota, Alberta, and Saskatchewan, is the focal point of much of the concern about LUC in the USA because of its ecological importance in providing habitat for migrating birds and mitigating flooding among other roles. This region resides in states that tend to have lower CDL accuracy. Several studies of LUC in this region using the CDL indicate large amounts of grasslands, wetlands, and forests have been converted to agriculture in this region prior to 2013.[2-4] To our knowledge, only one study uses both CDL and NAIP to examine LUC in the Prairie Pothole Region. Reitsma *et al.*[15] consider LUC in South Dakota between 2006 and 2012. They treat the NAIP images as a route to ground-truthing CDL data and find that, while analysis of NAIP imagery shows less cropland expansion than CDL data show, NAIP imagery indicates more loss of grassland, less loss of forests and wetlands, and increases in open water and non-agricultural (e.g. urban) areas. Reitsma *et al.* propose that the differences between NAIP- and CDL-generated estimates of LUC can be attributed to inconsistency in the accuracies of the 2006 and 2012 CDL data sets and challenges a CDL-based analysis could face in a climate transition zone such as South Dakota, which would have higher crop diversity than areas with a stable climate regime. They point out that in LUC assessments with the CDL, accuracy is generally not considered (which is true of Lark *et al.*[4] and Wright and Wimberly[2]) and that only through consideration of this accuracy can CDL-based analyses truly lend insight for use in decision-making.

Reitsma *et al.*[15] took a critical first step in considering how NAIP imagery can inform LUC discussions, but did not explore in-depth or spatially explicit reasons why CDL-based analyses experience difficulty in identifying areas where LUC has occurred. In our analysis, we seek to expand on the comparison of these two methods (NAIP- and CDL-based) for developing LUC estimates in an examination of historical LUC in 20 counties in the Dakotas and Minnesota. These counties were identified through CDL analysis as having the greatest amount of LUC between 2006 and 2014. Comparing these two years may give an indication of LUC since the inception of the RFS. In addition to using these two data sets, we also conducted in-person ground-truthing of current land use at several sites in Minnesota and South Dakota because we believed this additional step was especially important for a highly textured region like the Prairie

Pothole Region. The Supporting Information section contains a complete accounting of the data sources we used and how the data were processed. All data is available in kml files at a project website (http://www.erc.uic.edu/biofuels-bioenergy/MN-ND-SD-20cty). Overall, our objectives were to determine the difference in results analyses produced with these two data sets, examine why these differences exist, and explore advantages and disadvantages of these two different approaches with an eye toward informing their application in decision-making regarding land management, which has important implications for conservation initiatives, production of bioenergy crops, and agriculture in general.

Methods

NAIP imagery was analyzed with the Genscape Inc. Land Use Analysis Tool which allows for side-by-side viewing of aerial imagery of different years from the USDA National Agriculture Imagery Program (NAIP). It allows polygons drawn on an image on one side to be mirrored to the other side and measures the areas of these polygons. The image sets compare 2006 and 2014 for South Dakota and North Dakota and 2006 and 2013 for Minnesota. Entire counties were visually scanned at a 1:32000 scale, zooming to 1:16000 or 1:8000 for closer inspections. Analysts looked for LUCs such as grassland transitioning to agriculture, agriculture transitioning to grassland, agriculture to developed lands (e.g. urban), and seasonal or temporary differences of circumstance, such as flooding, that might confound automated CDL assessment.

The 2006 and 2014 USDA CDL for the 20 counties were also used to assess potential LUC. The CDL is a thematic image generated by the USDA using satellite imagery (typically 30 m resolution Landsat satellite imagery and for a period of time 56 m AWiFS imagery) in which the spectral information from the images are combined with extensive ground truth from the USDA Farm Services Agency to classify land into use types including specific crops.[18] A detailed description of the methods we used to process CDL data is contained in the Supporting Information.

Results

In Fig. 2, we display the total hectares that analyses with different techniques and data sources estimated to have been converted from grassland, forested lands, and wetlands to agriculture in the 20 selected counties between 2006 and 2014. We used CDL data from 2006 and 2014 without alteration and determined the error associated with these results. We also report results determined through examining NAIP imagery for the starting and ending years. Finally, we refined the CDL analysis, following as close as we were able the modifications Lark *et al.*[4] lay out in their recent publication. We refer to results generated with this approach as 'modified CDL' results.

Importantly, the NAIP results include areas of land we could clearly see had transitioned from forested land, wetland, or grassland to agriculture. In some instances, even with visual imagery, it can be very difficult to discern LUC. When in doubt, we counted potentially affected areas as converted to agricultural land to be conservative. The most common observations were the removal of small patches of trees or buffer zones in existing agricultural areas. Wetland loss was less commonly observed. Farmers work the ground around many wetland areas that remain in these regions; these wetlands appear to sequester water. There are also examples of areas in the study region where wetlands are protected or have been rebuilt from lands that appear to have previously been agricultural. Overall, wetland transitions to agricultural land were very minimal. Walsh County, ND had the greatest number of hectares affected, five hectares (~2% of the county). At times, differences in how large a pothole or other wetland is each year complicate identification of affected wetlands. In some cases, it is difficult to discern wetland and wild grassland. In the Supporting Information, Tables S2–S4 break down the results in Fig. 2 out by type. Figures S1–S10 give examples of how CDL- and NAIP-based analyses differ for selected sites and provide examples of when determining LUC or the category of LUC from NAIP-based analysis was difficult. Examination of NAIP imagery also uncovered agricultural lands that had been converted to industrial, urban, or other (non-vegetated) states. In five counties, we observed no such transitions, but in four counties, the hectares in agriculture that had converted to non-vegetative (e.g. industrial or urban) states were more than half of the acres that had converted from forest, wetlands, or grasslands to agricultural land.

Figure 2 clearly illustrates several important points. First, the number of hectares in the potential error associated with CDL-derived results is generally greater than the number of hectares the CDL-based analysis determined had undergone a transition from grassland, forested land, or wetland to agricultural land (Fig. 2(a)). Errors associated with CDL data are expected to be most prominent in areas undergoing transitions in land use. Documented accuracies are typically greater than 90% for agricultural classes and around 85% for non-agricultural classes. The USDA calculates the accuracy for cropland in the CDL using Farm Service Agency-collected ground truth points, but uses the NLCD for non-agricultural areas. The 2006 CDL uses the 2001 NLCD which reports an accuracy of 85.1%.[19] These

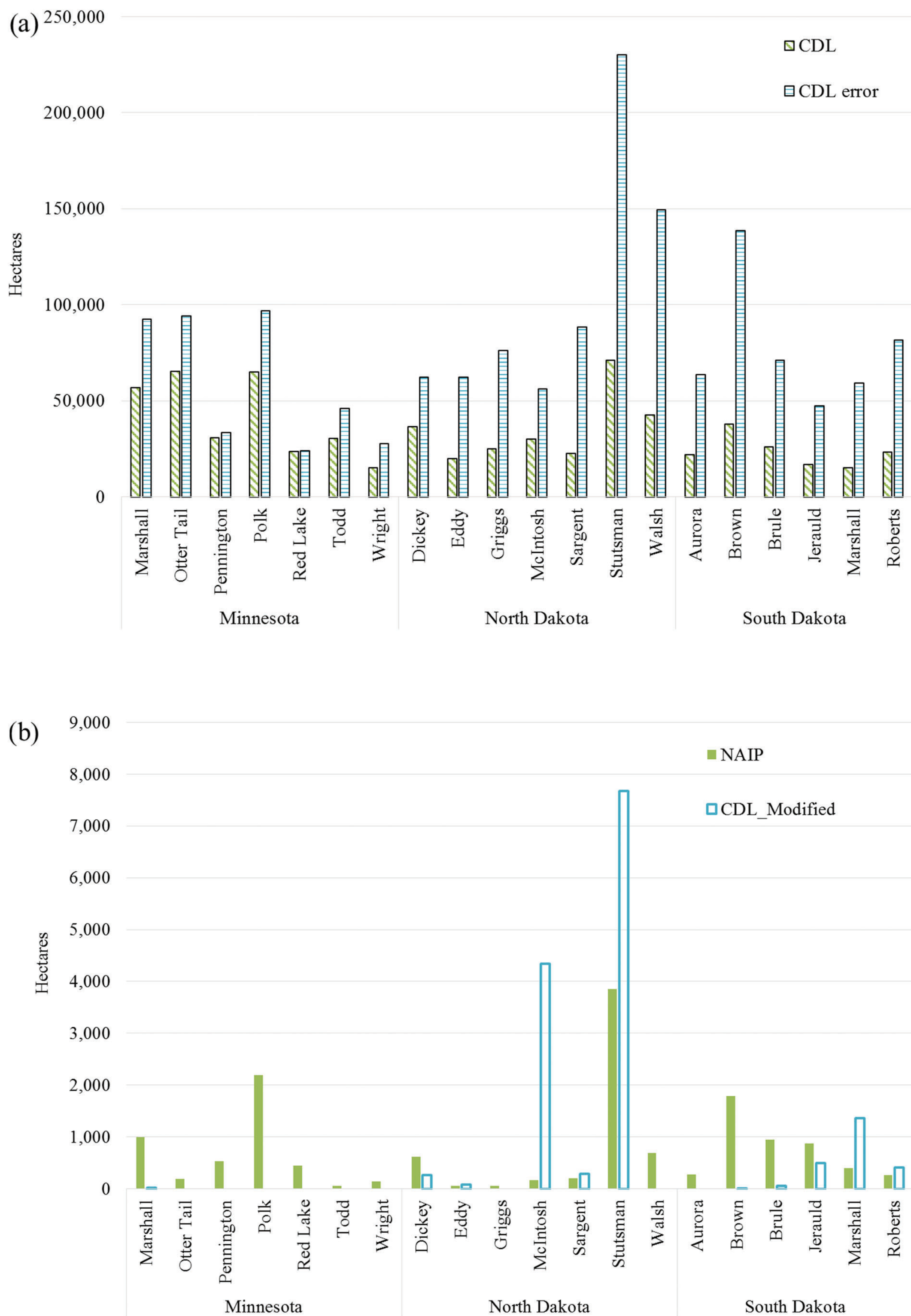

Figure 2. (a) LUC (total grassland, wetland, and forest to agricultural land) as determined with CDL data (green diagonally hatched bars). Error associated with unmodified CDL results shown (blue horizontally hatched bars). (b) LUC as determined with NAIP imagery (green solid bars) and with CDL data with modifications (blue-outlined white bars) as described in the supporting information.

accuracy percentages may seem high but several important considerations must come into play. First, these errors when land areas are compiled (10% to 15% of total land incorrectly identified for instance) will include more land than is typically being transitioned from one class to another (much less than 15% of total land would expect to be converted in a given year). Second, the areas where change is occurring will usually have the highest errors. Finally, the total error for an LUC analysis that uses a change in land use between two years will be the combined error from each year because, if one year's land use data is incorrect, the change will be incorrect regardless of the final year's accuracy.

Given the large amount of error that can be associated with using the CDL to assess LUC, analysts should report the error associated with their results and consider whether valuable conclusions can be drawn if errors are large. Based on our analysis, it is not possible to say conclusively that land transitioned from grassland, forested land, or wetland to agricultural land based on unaltered CDL data because the error is too high.

Secondly, estimates of converted hectares derived from NAIP (Fig. 2(b)) are significantly lower than CDL estimates (Fig. 2(a)). As one example of how a CDL-based analysis could generate overly high estimates of LUC, in the 20 counties over 540 000 ha were delineated as changing from grassland to agriculture. This amount of conversion would indicate large-scale LUC for such a small area (over 12% of the land surface would have been converted from grassland to agriculture). Figure 3 shows areas we identified as having undergone LUC with NAIP as compared to areas the CDL indicates LUC has occurred. This visual image shows clearly how much more limited LUC is when identified through a NAIP-based analysis. We examine the potential reasons behind the differences in CDL-based and NAIP-based results in the following subsection.

Another key point is that when the CDL is modified in the manner in which Lark *et al.*[4] suggest, CDL-based LUC estimates drop dramatically (Fig. 2(b)). Note that although we attempted to follow the modifications Lark *et al.*[4] describe to the CDL results, we were unable to produce exactly their results in part because we used different starting and ending

Figure 3. NAIP results (colored areas) overlayed with CDL-based results (gray areas) for the twenty counties (counties shown in yellow) that were included in the study. Image from Google Earth using image from the National Oceanic and Atmospheric Association.

Table 1. Comparison of results from this study (2006 to 2014), Lark *et al.*[4] (2015) (2008-2012), Reitsma *et al.*[15] (2016) (2006-2012) (thousand ha).

	Forest to Cropland				Wetland to Cropland				Wetland and Forest to Cropland	
	This Study			Lark et al.	This Study			Lark et al.	Reitsma et al.	
	NAIP[a]	CDL	Mod-ified CDL	CDL[b]	NAIP	CDL	Mod-ified CDL	CDL[b]	CDL	NAIP
MN[c]	1.7	249	0.02	5.6	0	38	0	10	NA	NA
ND	0.83	222	13	0.44	0.01	25	0	7.4	NA	NA
SD	1.2	94	2.3	0.47	0	47	0	5.1	416	336

[a]Includes forest and grassland that was converted to cropland.
[b]Lark *et al.*[4] describe their modifications to the CDL in the supporting information to their paper. We attempted to replicate this approach, reporting results as 'modified CDL'.
[c]We used 2013 NAIP imagery because 2014 imagery was not available at the time of analysis.

years (Table 1). The modified CDL results generally demonstrate lower converted hectares than the NAIP-based result and do not identify the same locations for change as the NAIP method or the unaltered CDL method. In essence, refining the CDL analysis technique produces less land flagged as undergoing LUC but the result may not be any more accurate than a result produced without any modification.

While the objective of this paper is not to compare results among different studies that all use different techniques, examine different areas (selected counties versus whole states), and consider different timespans, it is instructive to consider variations in results given these factors. In Table 1, we report the results we generated and those generated by Lark *et al.* and Reitsma *et al*. Lark *et al*. considered the period between 2008 and 2012, whereas Reitsma *et al.* examined the CDL and NAIP imagery for starting and ending years of 2006 and 2012, respectively. Our analysis covers the broadest timespan, 2006 to 2014. Additionally, Lark *et al.*[4] and Reitsma *et al.*[15] examined entire states whereas we considered only selected counties. Based on the latter factor, we expected our results to have lower estimated LUC than Lark *et al.,* but that was not always the case, which could be explained by the difference in timespan. Reitsma *et al.*'s estimates for land that changed from forested land, grassland, and wetland with the CDL for a shorter time period well exceeded our estimates. The variation in these results illustrates the difficulty in developing conclusive estimates of natural lands affected by expansion of agricultural land. It is not clear if one answer can be identified as correct or best.

Discussion

In this section, we present selected case studies (Figs 4 and 5) to highlight how LUC estimate differ depending on analysis technique.

In the first case study (Fig. 4(a)), both the CDL- and modified CDL-based analyses find major land classification changes from grassland to agriculture in Stutsman County, North Dakota. An analysis based on NAIP imagery, however, determined the land had been in agriculture over the entire study period. The second case study (Fig. 4(b)) demonstrates that the CDL and modified CDL techniques did not pick up the clearing of trees from a significantly sized (42 hectares) parcel of land but a NAIP-based analysis did.

Looking at a parcel of land in Polk County, Minnesota highlights further the strengths and weaknesses of the different approaches to examining LUC. The CDL shows a significant portion of grassland was converted to agricultural land between 2006 and 2014 on this parcel (Figs 5(a) and 5(b)). The shaded areas on the image in Fig. 5(e) overlay these results on images that show the land use has been agricultural through the period of 2006 to 2013. The modified CDL-based analysis did not detect any LUC in the area shown in Fig. 5(e). On the other hand, NAIP analysis did detect some land clearing (green polygon, 1 hectare) that was not detected by the CDL at all. The size of the land parcel that was cleared is less than the 30 m resolution of the CDL. The ground-truthed photograph (Fig. 5(c)) shows that there was recent land clearing – so recent that the latest NAIP data set did not include it. In the most recent Google Earth images for this plot of land, scars are evident where trees have been cleared (Fig. 5(d)).

Some factors were observed that might contribute to incorrect land use assignments by the CDL. 2014 saw heavy rains for the study region, and in some counties it was obvious in the NAIP-based analysis that large areas were flooded or had been damaged by flood waters. If an analyst were to use 2014 as the base year for an LUC analysis into the future, a CDL-based analysis could indicate significant wetland loss if the end year was drier compared

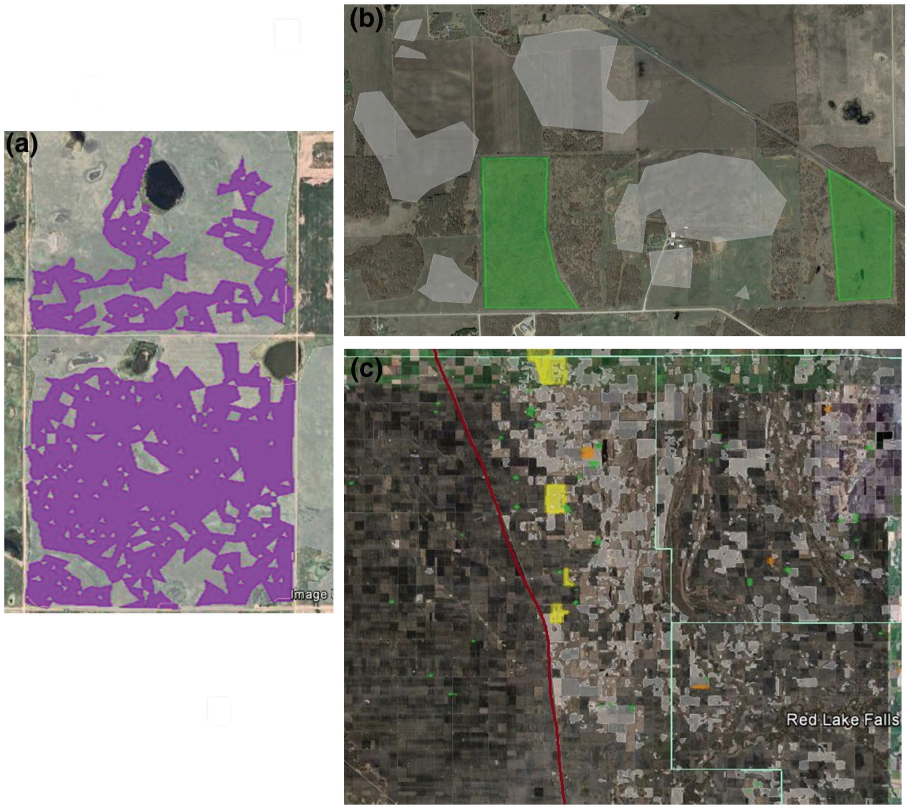

Figure 4. (a) A land parcel (46°57'27.93" N 99°04'52.28"W) in Stutsman County, North Dakota for which the CDL detected a change in land classification, even when the CDL methodology was modified (purple areas), and NAIP-based analysis did not. (b) A land parcel (46°18'19.80"N 95°24'46.64"W) in Otter Tail County, Minnesota in which NAIP-based analysis detected a change in land use that CDL-based analysis did not. (c) An area of Red Lake County, MN (47°57'52.65"N 96°20'51.34" W) that illustrates how a CDL-based analysis (without modification) detects LUC in areas with more topographical features (East of red line) as opposed to flat areas (West of red line). NAIP-based analysis detected changes in the flatter region; CDL-based analysis did not, even with modification with Lark *et al.*[4]'s method. All images from Google Earth using images from the US Department of Agriculture Farm Service Agency ((a) and (b)) and Digital Globe (c).

to 2014. Analysts should choose endpoint years with representative weather to avoid this scenario. Also, the agricultural practices of this region often include fallow years where agricultural lands may appear to be left unused in one year but not in the other. Adjustments to the CDL that Lark *et al.*[4] undertook (e.g. requiring the same class in multiple years to delineate definitive land use) and that we replicated can help reduce this type of error.

Interestingly, the CDL-based analysis seemed to predict a lot of LUC in regions with distinct topographical features. These regions could have more diverse types of land cover considering they are less likely to be planted annually in the same row crops, leading to higher error in the CDL. The land in these areas may also undergo more transition among land types than lands converted to dedicated agriculture, leading to more error in CDL-based analyses. Figure 4(c) highlights the tendency of a CDL-based analysis to flag LUC as occurring in lands that have more topographical features (to the east of the road highlighted in red) as compared to flatter areas (to the west of the road highlighted in red). Moreover, the CDL-based analysis, even after modification, did not identify any LUC in the flat area to the west of the road highlighted in red, but NAIP-based analysis did. Notably, the CDL analysis flagged LUC in an area in North Dakota with an interesting topographical feature called the Missouri Coteau (Fig. S11), which is

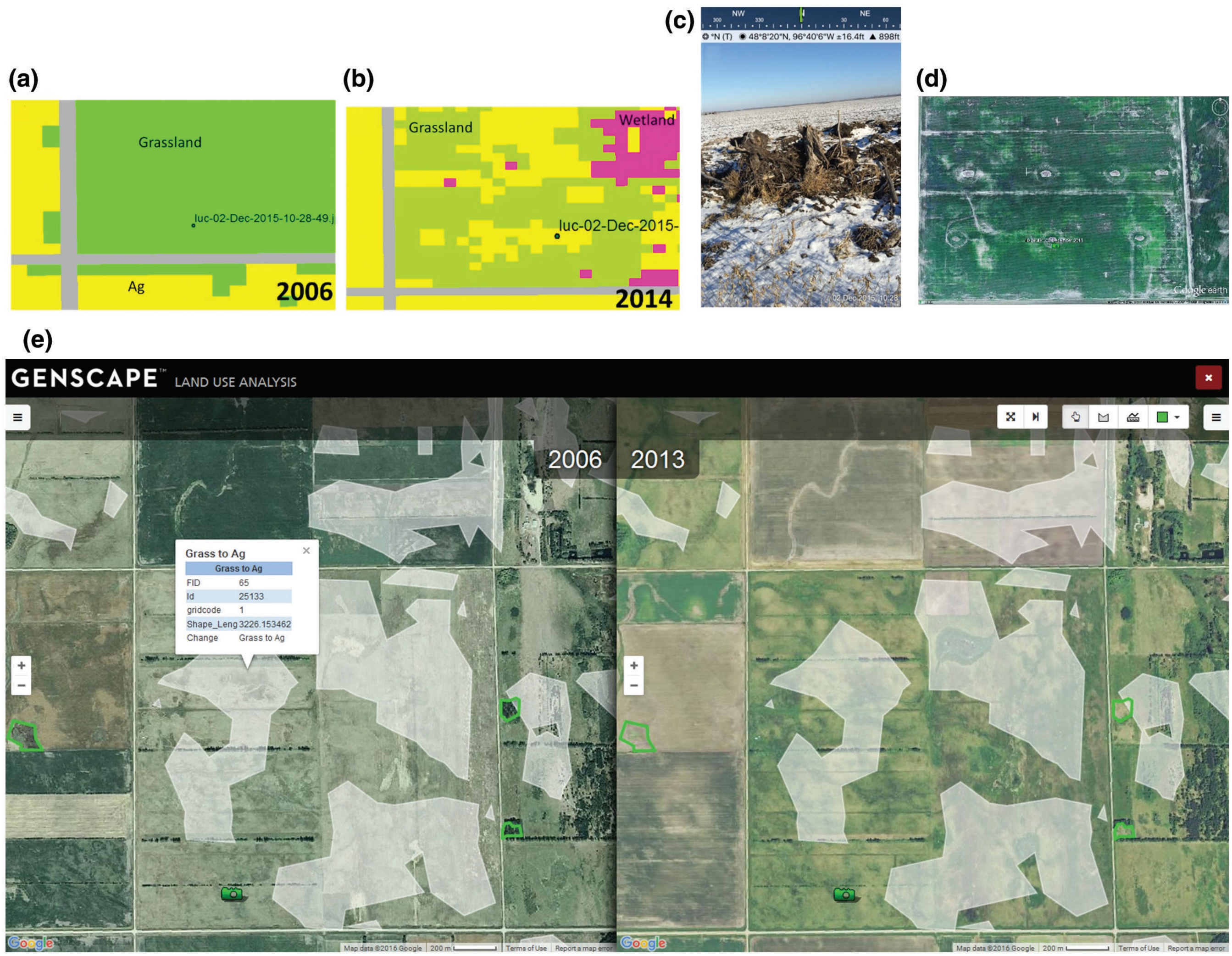

Figure 5. Comparison of information about land status based upon the unmodified CDL ((a) and (b)), ground truthing, a 2015 image from Google Earth (d), and NAIP image (e). The modified CDL-based LUC analysis did not detect any LUC on this land parcel in Polk County, Minnesota (48°08’35.48”N 96°20’51.34”W)

not as fertile as the Drift Prairie. The Coteau has a higher coverage of grassland, leading to a potentially higher number of false positive LUC identifications. Most of this region was outside the scope of our NAIP analysis, but we did analyze the Western half of Stutsman county. Far fewer amounts of LUC were detected with NAIP-based analysis than with the modified CDL analysis for this region.

Conclusion

On its own, the CDL does not provide sufficiently accurate information when used to assess LUC by comparing land classification information in the CDL between two years. Analyses that use CDL data alone will overestimate LUC. Methods like those developed by Lark *et al.*[4] need to be universally applied and associated error should consistently be reported. These methods still flag some LUC that did not occur and fail to detect some LUC that it is on too small a scale. The NAIP-based analysis should provide the most accurate assessment of LUC but faces a limitation of a lag in information availability and some challenges in interpreting images (Figs S7–S10). Selected ground truthing is needed, especially for areas with rich topographical features and significant diversity in land use. Ground truthing can also provide evidence for multiple uses of the same land that are not detectable in either CDL- or NAIP-based analyses such as using corn fields as grazing lands (Figs S12 and S13). Ultimately, local information is irreplaceable, although time-intensive and expensive to obtain. Critically, advancements in technology and data analysis offer to improve how we use data to understand LUC. For example, new, lower-cost satellites that fly lower in the Earth's orbit can produce higher quality, higher resolution images that can be used to identify LUC.[20,21]

Based on our results, using different data sets in isolation would lead to different understandings of LUC in the Prairie Pothole Region. Using only CDL data would lead one to think significant LUC had occurred. Using modified CDL data would lead one to believe some LUC had occurred, but would flag incorrect LUC hotspots. NAIP analysis would provide the most accurate picture of LUC, but would still lag conclusions that could be drawn from local, up-to-date information. These conclusions would likely be true for other areas as well.

Managing land resources to achieve any number of objectives including conservation, maintaining and improving water quality, and producing food, fiber, feed, and energy is a critical and complicated task. Decisions regarding land management should be made keeping in mind limitations of data that inform our understanding of land use and using multiple types of data to validate conclusions. Use of results from unverified studies without error estimates should be limited to avoid decision making based on inaccurate information. The scientific community should confer regarding best practices for LUC analyses to achieve consistent, high-quality results that offer robust insights to policymakers and other stakeholders.

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