



A Cautionary Tale: A Recent Paper’s Use of Research Based on the USDA Cropland Data Layer to Assess the Environmental Impacts of Claimed Cropland Expansion

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Executive Summary

- A recent study by Zhang et al. (2021) assessed the environmental impacts of purported cropland expansion in the Midwest between 2008 and 2016. The study built on previous research that used the USDA Cropland Data Layer (CDL) to estimate the extent of such expansion, particularly the conversion of grassland to cropland.
- The USDA (2021) issued a warning about using the CDL for assessments involving non-agricultural land cover categories, stating, “Unfortunately, the pasture and grass-related land cover categories have traditionally had very low classification accuracy in the CDL.”
- Nevertheless, researchers have attempted to develop a framework to increase the accuracy of the CDL-based assessment. Research by Lark et al. (2020) using such methods served as the foundation of the assessment by Zhang et al. (2021).
- The inability of these methods to increase the CDL’s accuracies were demonstrated through an investigation of CDL classification certainty for different locations in Iowa. This revealed that in earlier CDLs, cropland in Iowa’s southcentral Agricultural Statistics District (ASD) was underestimated, while non-cropland was grossly overestimated. Both were mapped more accurately as the CDL improved over time. Therefore, the cropland expansion claimed by Lark et al. (2020) and adopted by Zhang et al. (2021) has a high potential of being false change due to poor classification certainty in the earlier CDL.
- The CDL suffers from accuracy and certainty issues that severely hinder its use for estimating change over time. Other data sets, such as the National Resources Inventory (NRI), are available and designed for temporal change assessment.
- Given these issues, policy makers should exercise caution in referencing studies that have performed or integrated land cover/use change analysis that relies on the CDL, such as Lark et al. (2020) and Zhang et al. (2021).

Introduction to Land Cover and Land Use Assessment

Land cover and land use inventories are an important component to the economic, social, political, and environmental wellbeing of the nation. It is important to distinguish between land cover and land use: land cover is best described as the physical characteristics of the land surface (e.g., grassland), while land use is concerned with the anthropogenic activity on the land surface [e.g., grassland in the Conservation Reserve Program (CRP)] (EPA 2018). Understanding the changes in the dynamics of land cover and land use play a key role in the decision-making process for policy makers at different levels of government. In the U.S., there are two types of land cover and land use data sets that are produced to monitor these important national resources: (1) survey-based assessments; and (2) remote sensing-based products. Examples of survey-based assessments include, but are not limited to, the U.S. Department of Agriculture (USDA) NRI, USDA Census of Agriculture, and those reflected in the USDA National Agricultural Statistics Service QuickStats database. Lastly, remote sensing-based products consist primarily of the Multi-Resolution Land Characteristics Consortium National Land Cover Database (NLCD) and the USDA CDL. Each of these data sets have their strengths and weaknesses, all of which are beyond the scope of this report. However, the main points to understand about these two types of data sets are as follows: (1) many of them have differences in the definitions used to determine the wide varieties of land covers and land uses; and (2) the survey-based data sets are statistically derived to be estimations of acreages at coarse geographies (e.g., county level or larger), while the remote sensing-based data sets are much higher resolution and spatially explicit (e.g., 30-meter resolution). Due to the finer spatial resolution and visual nature of the remote sensing products, these data sets have gained popularity in assessing land cover and land use across the conterminous U.S.

In 2008, the USDA began to produce a national level, 30-meter CDL on an annual basis (previous versions were coarser resolution and only mapped certain states in high agricultural production areas, such as the Midwest). As reported by Lark et al. (2017), there has been an uptick in land cover/use change analyses that utilize the CDL after the national-level mapping began in 2008. This uptick since 2008 in peer-reviewed publications has increased by almost 700% on Google Scholar databases, by nearly 600% on PubAg servers for USDA publications, and approximately 400% on the Web of Science data portal (Lark et al. 2017). Over the past decade, many CDL-based land cover/use change assessments have gained momentum within academic, political, and environmental circles (See, for example, Wright and Wimberly 2013; Johnston 2014; Lark et al. 2015; Morefield et al. 2016; Wright et al. 2017). Several of these aforementioned studies were highlighted in the EPA (2018) *Biofuels and the Environment 2nd Triennial Report* to U.S. Congress. Furthermore, the common theme from the findings in all of these research papers was an assertion that an increasing U.S. agricultural footprint was displacing potential sensitive non-agricultural lands (i.e., grasslands, wetlands, etc.). Additionally, these studies attempted to associate this expansion with biofuel production since 2007, based on the Renewable Fuel Standard 2 (RFS2) under the Energy Independence and Security Act (EISA) of 2007. Currently, the newest research that has been conducted using the CDL for assessing land cover/use change was published by Lark et al. (2020). Again, this study reported a continuing cropland expansion across the U.S. from 2008-2016. Moreover, a recent study by Zhang et al. (2021) relied heavily on the CDL-based acreage change estimated by Lark et al. (2020) to assess the environmental impacts of soil erosion, fertilizer leaching/runoff, and loss of soil organic carbon (SOC) due to estimates of cropland expansion.

Due to the popularity and increased use of the CDL, this report will outline several key factors that present serious issues and concerns with the findings that are being presented by researchers that

are promoting the use of remote sensing-based products for estimating land cover/use change, especially with the CDL. Of major importance, the USDA (2021) has issued a warning about using the CDL for assessment of non-agricultural phenomenon, specifically grass related land cover categories:

“Unfortunately, the pasture and grass-related land cover categories have traditionally had very low classification accuracy in the CDL. Moderate spatial and spectral resolution satellite imagery is not ideal for separating grassy land use types, such as urban open space versus pasture for grazing versus CRP grass. To further complicate the matter, the pasture and grass-related categories were not always classified definitionally consistent from state to state or year to year.”

The following sections of this report will highlight several key concerns with using the CDL for estimating land cover/use change. First, a discussion and comparison of the CDL and the NRI will be presented to establish the differences in these data sets to measure land cover and land use change based on definitions of different land covers and land uses. Next, an assessment of the accuracy and certainty in the mapping capabilities of the CDL will be presented for different ASDs in Iowa from 2008, 2013, and 2017. These examples will showcase the limitations of using the CDL for temporal land cover/use change assessment, which will reveal the underlying issues with previous CDL-based research, and ultimately, the most current Lark et al. (2020) and Zhang et al. (2021) research.

CDL and NRI: Differences in Land Cover and Land Use Categories

Based on the final rule of the RFS2 under the EISA of 2007, feedstocks for renewable fuels were restricted to existing agricultural lands (EPA 2010). From this rule, EPA (2010) defined existing agricultural lands as: (1) *cropland* – both cultivated and non-cultivated; (2) *pastureland* – forage plants for grazing or hay production; and (3) *CRP land* (see the final rule for more detailed definitions). These definitions under RFS2 of existing agricultural lands are important because they define the availability of a pre-existing agricultural footprint for the production of feedstocks for renewable fuels. Given this EPA definition, it is paramount that any land cover/use study has the capabilities to differentiate these complex land cover/use types to truly evaluate the changes on the landscape over time.

As previously mentioned, the CDL has historically encountered low accuracy when mapping non-agricultural landscapes, especially different grass types (USDA 2021). Because of this serious underlying issue, USDA (2021) has directed researchers that are studying non-agricultural land covers to instead utilize the NLCD. It should be noted that accuracy assessments of the NLCD have resulted in fairly high accuracies for any single year in the data set (Wickham et al. 2017; Wickham et al. 2021). However, and most importantly, poor-to-moderate mapping accuracies of this product have been shown when assessing land cover/use change *between different years* (Wickham et al. 2017; Wickham et al. 2021). Nevertheless, based on the limitations of these remote sensing reliant products, researchers (e.g., Wright and Wimberley 2013; Lark et al. 2015; Wright et al. 2017; Lark et al. 2020; Zhang et al. 2021) have developed a methodological framework of post-classification processes that claims to increase the accuracy of the CDL-based land cover/use change assessment. The basic concept of the methods implemented is the aggregation of specific individual land cover classes to superclasses (i.e., cropland and non-cropland). Lark et al. (2021), suggested that this superclass aggregation

increases the temporal accuracy of national cropland mapping to 97% or higher for all years since national CDL mapping started in 2008. However, the non-cropland superclass displayed a temporal trend of poor to increasingly higher accuracies over time, and displayed high error rates with the cropland superclass in earlier CDLs (this will be discussed in further detail in a following section). With all of this said, it is important to note that the CDL consists of two main grass type classes: other hay/non-alfalfa (class 37) and grassland/pasture (class 176). Not only does the USDA (2021) inform their users that the CDL has displayed historically low accuracies mapping these grass types of land cover, but also the two main grass classes in the CDL can consist of a wide variety of grass types of land covers/uses, such as non-managed/native grasses, non-cultivated hayland, CRP, pasture for grazing, etc. While beyond the scope of this paper, it is important to note that these different grassland types can have widely varying soil carbon profiles (e.g., native grasslands would likely be associated with more carbon-rich soils, while the soils associated with pasture and CRP land would likely have less stored carbon). Due to the ambiguity of these two main grass classes (class 37 and 176 mentioned above) and the low historical accuracy of the CDL, land cover/use change assessments using the CDL undoubtedly encounter serious issues in capturing the true dynamics of any potential change to or from these grass type classes.

On the other hand, the NRI is a survey-based tabular data set that is produced by the USDA and has been identified by the EPA (2018) as being advantageous for temporal land cover/use analyses because it does not suffer from methodological changes inherent in other survey-based assessments. Furthermore, the NRI is specifically designed to track the *in and out* movement of different land cover/uses with one another over time and is ultimately well suited for land cover/use trend analysis. The definitions of land cover/use categories within the NRI are extensive and can be subcategorized for very detailed assessments. For example, non-cultivated cropland (e.g., hayland) and CRP can be tracked independently from other more natural grasslands, like native species of grasses or other types of non-managed grass environments. In other words, the NRI offers a more comprehensive understanding of the in and out movement of different land covers/uses and gives the researcher more confidence in the type of land cover/use change that has occurred from one point in time to another. It must be noted that the NRI is not without its own shortcomings. The NRI is a statistical estimation (based on sampling) of land covers and land uses with an associated margin of error, which may result in a given year's acreage estimation to be less accurate than a different data set. However, the strength of the NRI is that the estimations of the trends are more accurately depicted when compared with other datasets.

Assessing the Certainty of the CDL for Different ASDs in Iowa from 2008, 2013, and 2017

Given the historic inaccuracies of the CDL to map non-agricultural phenomenon, a detailed investigation of the CDL was conducted on different locations in Iowa. Iowa was selected for several reasons. First, due to the physical geography of Iowa, the northern and southern portions of the state have drastically different landscapes (e.g., soils, topographic relief, hydrology, etc.). There is high production agriculture in the northern region of Iowa, with large well-defined boundaries for agricultural fields and less intermixing of different land covers/uses. Whereas, the southern portion of Iowa has marginal lands due to poor soil quality with more variable topography, which results in irregular field shapes and sizes, and co-location

with other land covers/uses, such as grasslands, forests, etc. Next, Iowa was selected because southern Iowa has been highlighted as a hotspot of change in many of the CDL-based land cover/use change analyses (e.g., Lark et al. 2015; Wright et al. 2017; Lark et al. 2020; Zhang et al. 2021). Ultimately, these CDL-based land cover/use change assessments have claimed that southern Iowa (along with northern Missouri) is one of the main regions of cropland expansion (Figure 1), with Zhang et al. (2021) showing some of the most impactful environmental effects (i.e., soil erosion, nitrogen and phosphorus loss, and SOC loss from cropland expansion) in this region as well. As a reminder, these environmental effects presented by Zhang et al. (2021) were built on the land cover/use change assessment conducted by Lark et al. (2020), which utilized the CDL in an attempt to estimate cropland expansion from 2008-2016. Thus, any inaccuracies and misclassification errors in Lark et al. (2020) were inherently accepted and repeated by Zhang et al. (2021).

To analyze the CDL in different locations of Iowa, this case study utilized the methods described by Lark et al. (2021) to measure the certainty of the CDL over time. The methods used investigated the CDL superclass (aggregated to cropland or non-cropland) accuracies and the CDL confidence layer to produce a pixel-by-pixel value that expressed the certainty of that pixel being correctly classified. The equation used was: *Certainty = Superclass Accuracy x Pixel Confidence*. The output values for a given pixel ranged from 0 to 1, with 1 being 100% certain that it was correctly classified. These certainty values were calculated for each pixel in the north central and south central ASDs in Iowa for 2008, 2013, and 2017 (Figure 1). These calculations utilized the superclass aggregation process since previous research (e.g., Lark et al. 2015; Wright et al. 2017, Lark et al. 2020; Lark et al. 2021) has claimed that the superclass aggregation process increases mapping accuracies. Lastly, there are two types of accuracy to consider with remote sensing-based products; these will be described in the simplest terms: (1) Overestimation – also called user accuracy with associated commission error; and (2) Underestimation – also called producer accuracy with associated omission error.

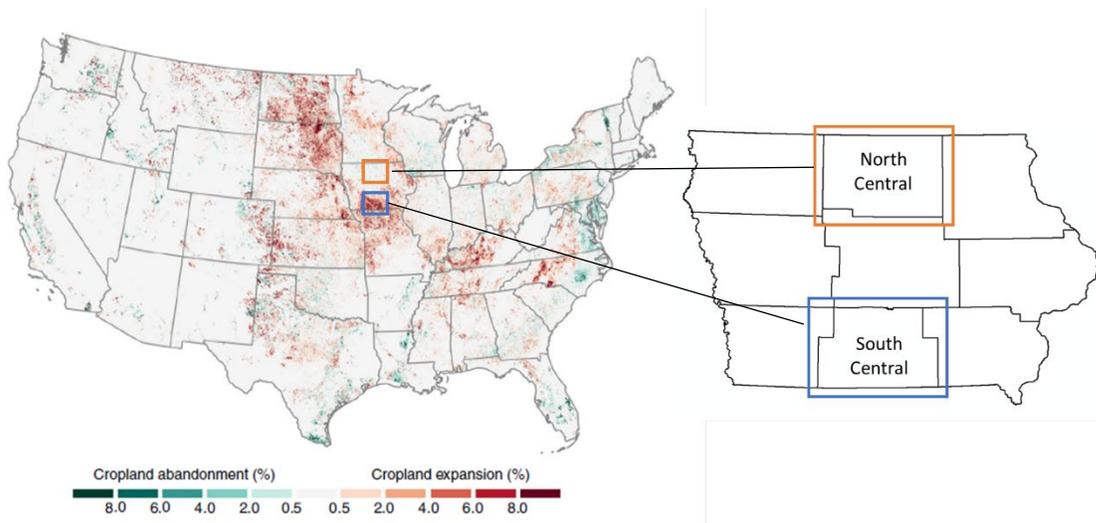


Figure 1: Lark et al. (2020) 2008-2016 net cropland conversion as a percentage of total land area in 3 km x 3 km cells (left) with blue and orange block identifiers of the north and south central ASDs in Iowa (right).

Results from the analysis of certainty revealed that different locations in Iowa displayed various levels of certainty for mapping cropland and non-cropland (Figures 2 and 3, which are scaled with the same break values and color scheme for comparative purposes). The north central ASD in Iowa (Figure 2) displayed generally high and stable producer and user certainty values across all three time periods, with small areas of lower certainty along rivers and streams. The north central ASD was predominantly cropland (>76.9% of total area for all years), which was associated with the higher certainty values. Interestingly, the lower certainty values in the north central ASD followed rivers and streams, which were ultimately non-cropland classes, such as forests, wetlands, or grass type areas.

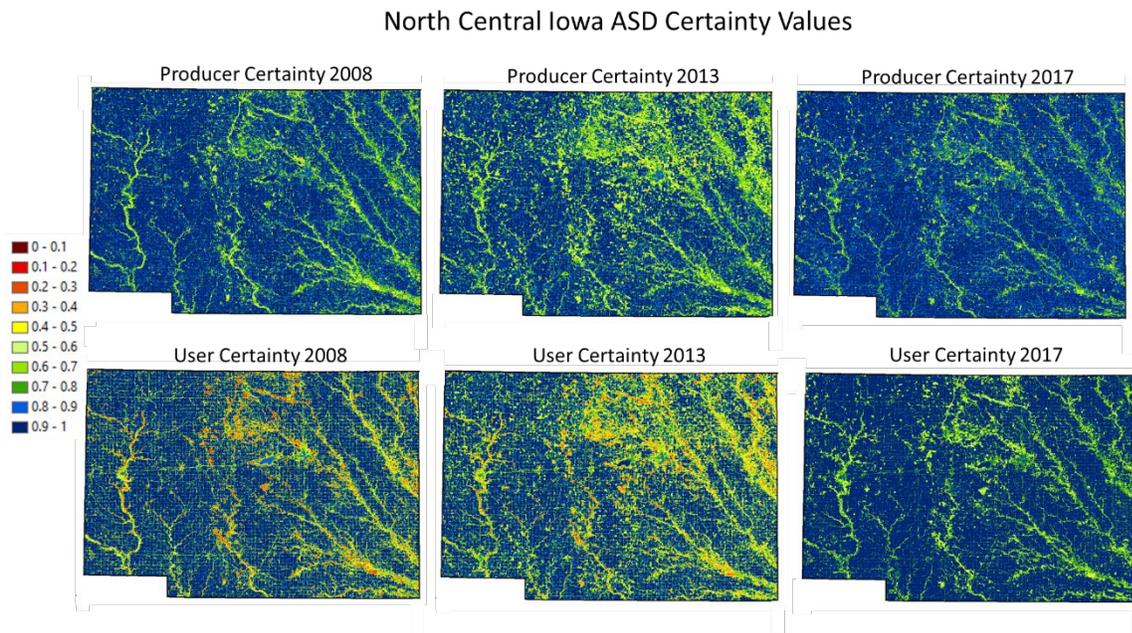


Figure 2: Producer and user certainty values for north central ASD of Iowa from 2008, 2013, and 2017. Pixel size is 30-meter resolution and represents the percentage of certainty of a given pixel’s classification (lower values equal less certainty and high values represent greater certainty).

However, the south central ASD (Figure 3) exposed the vast uncertainty for mapping both cropland and non-cropland classes in this region of Iowa. The producer certainty in the south central ASD was moderate in 2008 and 2013, and increased to relatively high certainty by 2017, with smaller pockets of low certainty scattered throughout the ASD. The user perspective displayed poor certainty values in 2008, with poor-to-moderate certainty in 2013, and finally moderate-to-high certainty by 2017. The majority of the land cover in the south central ASD was non-cropland (>62.3% of the total area for all years). Generally, the south central ASD showed that cropland and non-cropland displayed moderate producer certainty, which slightly increased over time, while the user certainty showed that 2008 had poor certainty that increased substantially by 2017.

South Central Iowa ASD Certainty Values

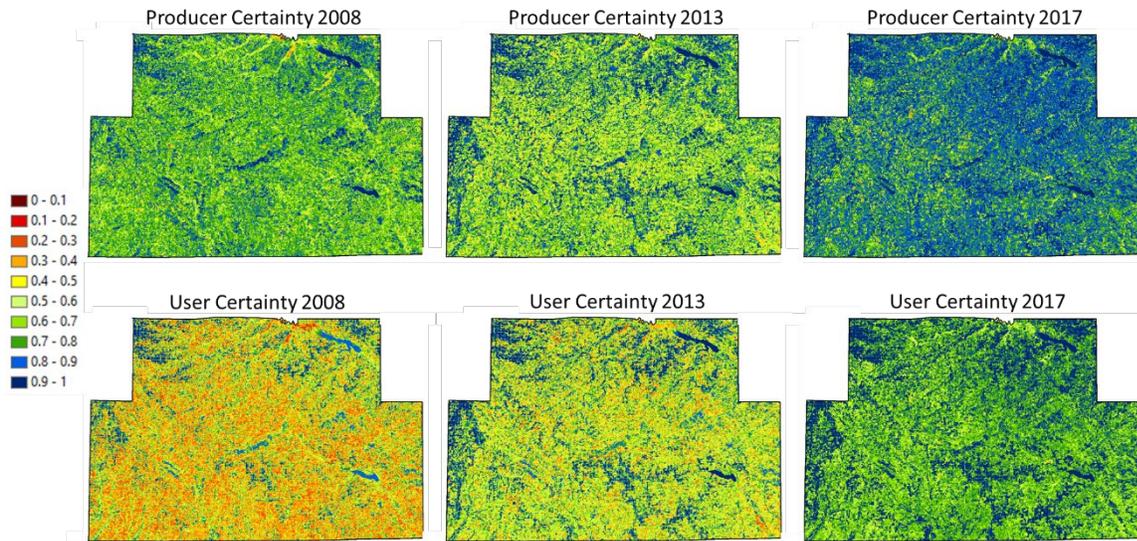


Figure 2: Producer and user certainty values for south central ASD of Iowa from 2008, 2013, and 2017. Pixel size is 30-meter resolution and represents the percentage of certainty of a given pixel’s classification (lower values equal less certainty and high values represent greater certainty).

Table 1 shows the breakdown of the mean producer and user certainty for both ASDs over all three years, with associated acreages for each superclass [subclasses of cropland and non-cropland were included to match the land covers/uses presented by Zhang et al. (2021)].

Table 1: Cropland and Non-Cropland mean certainty values for north and south central ASDs in Iowa from 2008, 2013, and 2017.

	Category	Producer Certainty 2008	User Certainty 2008	Acres 2008	Producer Certainty 2013	User Certainty 2013	Acres 2013	Producer Certainty 2017	User Certainty 2017	Acres 2017
North Central	Cropland	91.13%	93.16%	3,075,343	87.68%	88.80%	2,992,377	89.52%	95.26%	3,116,260
	Com	91.85%	93.60%	1,850,987	89.74%	90.77%	1,772,345	90.29%	96.04%	1,826,558
	Soybeans	90.80%	92.97%	1,211,369	85.24%	86.38%	1,205,685	89.64%	95.17%	1,263,123
	Non-Cropland	70.97%	39.83%	815,083	66.83%	44.34%	898,086	76.61%	64.86%	774,152
	Other Hay/Non Alfalfa	35.47%	19.65%	599	42.82%	38.23%	1,586	40.03%	35.20%	1,654
	Grassland/Pasture	61.77%	25.06%	400,949	55.99%	30.00%	460,980	72.56%	57.21%	306,184
	Overall	86.91%	81.99%	3,890,426	82.87%	78.54%	3,890,463	86.95%	89.21%	3,890,412
South Central	Cropland	72.36%	75.72%	950,335	75.01%	76.70%	1,336,391	78.87%	85.03%	1,317,464
	Com	77.38%	78.86%	422,758	78.20%	79.10%	638,534	82.72%	87.98%	611,616
	Soybeans	74.76%	76.55%	463,762	78.20%	79.25%	595,060	83.00%	88.12%	602,824
	Non-Cropland	71.50%	41.12%	2,600,255	65.86%	52.07%	2,214,253	81.16%	70.77%	2,233,082
	Other Hay/Non Alfalfa	43.64%	24.17%	16,260	59.64%	53.26%	463,786	66.63%	58.59%	321,414
	Grassland/Pasture	67.17%	27.25%	1,646,562	47.58%	25.50%	694,847	83.80%	66.08%	898,810
	Overall	71.73%	50.38%	3,550,590	69.30%	61.34%	3,550,644	80.31%	76.06%	3,550,546

Of importance in this table is two fundamental observations from the certainty analysis. First, cropland was mapped with high and stable producer and user certainty in north central Iowa (87-95%); however, cropland in the south central ASD of Iowa was mapped with comparatively lower certainty in 2008, increasing moderately over time. In the end, this revealed that cropland in the south central ASD of Iowa was being underestimated in the earlier CDLs, with the CDL estimations for cropland acreage improving over time. Second, non-cropland had moderate and slightly increasing producer certainty, along with poor user certainty that increased significantly over time in both the north and south central ASDs. Ultimately, the drastic increase in user certainty means that in the 2008 CDL, non-cropland was being grossly overestimated.

Furthermore, as the CDL improved over time, non-cropland was being mapped more accurately with less overestimation. It must be noted that the south central ASD had about 300% more non-cropland (and substantially higher acreages of grass type land covers) than the north central ASD in all three years, which means a larger area of misclassification in the earlier 2008 CDL occurred in the south central ASD of Iowa. Therefore, much of the cropland expansion in southern Iowa that was presented by Lark et al. (2020) and assessed by Zhang et al. (2021) has a high potential of being false change due to poor classification certainty in the earlier CDL.

The Current State of the Art for Land Cover and Land Use Change Assessment

As this report has indicated, there are many different data sets available to researchers to conduct land cover/use change analyses and all have different strengths and weaknesses. However, it is clear, based on the certainty analysis discussed here, that older remote sensing-based products (e.g., earlier national CDLs) present a very challenging set of issues to overcome when trying to interpret the results from change assessments when compared with more accurate and higher certainty CDLs from a later date in time. Both the CDL and NLCD have shown accuracy improvements over time due to increased temporal satellite imagery acquisition, higher spatial resolution, sensor improvements, more robust classification methods, etc. Based on these classification enhancing improvements over time, the current archive of CDL and NLCD products are more appropriate for mapping and understanding area estimations of land cover for an individual year as opposed to attempting to assess change over time, especially when assessing changes to or from grass types of land cover/use.

Not only does the CDL suffer from accuracy and certainty issues that severely hinder the use for temporal change assessment, but definitionally the CDL has limited capabilities to truly differentiate the complex diversity of different grass types at the current state of the art. Other data sets, such as the NRI, have a robust categorization of different land surfaces and their uses, which allows for a more detailed assessment of the in and out movement between the dynamic land categories. Some studies have even assessed the relationship between the CDL and NRI for acreage changes involving cropland and non-cropland. Copenhagen et al. (2021) showed that the CDL and NRI had a weak-to-moderate relationship when assessing total cropland acreage change by state from 2007-2012 ($R^2 = 0.697$) and 2012-2017 ($R^2 = 0.278$). More importantly, there was a decreasing relationship when applying the post-classification techniques used by other researchers that were actually attempting to increase the CDL accuracy (e.g., Lark et al. 2015; Wright et al. 2017; Lark et al. 2020). Furthermore, in a report to the EPA, Pearson et al. (2020) showed that when assessing the NRI for changes to cropland, CRP accounted for approximately 80% of cultivated cropland acreage gains from 2007-2015. This is important because any cropland change being estimated in CDL-based land cover/use assessments cannot identify the impact of transitioning CRP back into production within an existing agricultural footprint (unless the research has access to the Farm Service Agency's Common Land Unit polygons, which are not publicly available).

Ultimately, the CDL's definitions of grass type environments are overly simplistic [an issue that has been recognized by the USDA (2021)], and the ability of the CDL to map and discriminate different grasses has been historically low (with high potential for false change being identified in places like southern Iowa). These two serious issues present a compounding

problem when utilizing the CDL for land cover/use change assessment. Moreover, using CDL-based land acreage changes to assess environmental impacts, as presented by Zhang et al. (2021), encounters a problematic roadblock with the underlying data that their environmental analysis was built on in the first place. Researchers should be cautious when using remote sensing-based products for change assessment, especially when other data sets, such as the NRI, are available and specifically designed for temporal change assessment. Furthermore, policy makers should also be cautious to utilize studies that have conducted land cover/use change analysis with the CDL, such as Lark et al. (2020) and Zhang et al. (2021).

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