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RE: Documentation of Methods for CAFO Change Detection Dataset

INTRODUCTION

This study classifies the landuse-landcover (LULC) change associated with poultry CAFO installations throughout North Carolina from January 1, 2010 through December 31, 2017 using Landsat-7 and Sentinel-2 satellite imagery. Change detection methods within the remote sensing discipline are especially equipped to identify and quantify these changes over time[1]. In particular, multiple spectral indices were evaluated to select for highest sensitivity between CAFO structures (e.g. metal rooftops) versus its surroundings to maximize signal-to-noise ratio. The Tasseled Cap Brightness (TCB) band of the Tasseled Cap Transformation proved to be most indicative for identifying CAFO structure presence, however, confounding spectral signatures with barren or non-vegetated fields produced additional challenges[2-3]. That said, an observation that larger Tasseled Cap Greenness (TCG) responses of barren or non-vegetated fields relative to CAFO structures provided evidence to exploit this relationship with a normalized difference approach. As such, the Normalized Difference Rural Built-up Index (NDRBI) was created to monitor CAFO structures through time. The NDRBI is calculated as follows:

$$NDRBI = \frac{Tasseled\ Cap\ Brightness - Tasseled\ Cap\ Greeness}{Tasseled\ Cap\ Brightness + Tasseled\ Cap\ Greeness}$$

The Normalized Difference Built-up Index (NDBI) was considered, however, decreased accuracy in areas with barren or fallow fields initiated the need for a custom index (CITE and footnote quote). The following are the applied methods using the NDRBI to create the North Carolina Poultry CAFO Installation Year dataset.

METHODS

1. Create Valid Mask[4]:

a. To evaluate spectral signatures over time and identify the targeted event (a CAFO installation) required precise spatial extent delineations for each of the 3,969 study sites. A Euclidean distance buffer from the EWG-provided locations were not sufficient, thus algorithmically delineating CAFO rooftops was a necessary pre-processing step to optimize signal-to-noise ratio in the final change detection analysis.

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[1] Lu, D., et al. "Change Detection Techniques." *International Journal of Remote Sensing*, vol. 25, no. 12, June 2004, pp. 2365–401. *Taylor and Francis+NEJM*, doi:10.1080/0143116031000139863.

[2] Crist, E. P., and R. C. Cicone. "A Physically-Based Transformation of Thematic Mapper Data—The TM Tasseled Cap." *IEEE Transactions on Geoscience and Remote Sensing*, vol. GE-22, no. 3, May 1984, pp. 256–63. *IEEE Xplore*, doi:10.1109/TGRS.1984.350619.

[3] Zha, Y., et al. "Use of Normalized Difference Built-up Index in Automatically Mapping Urban Areas from TM Imagery." *International Journal of Remote Sensing*, vol. 24, no. 3, Jan. 2003, pp. 583–94. *Taylor and Francis+NEJM*, doi:10.1080/01431160304987.

[4] Google Earth Engine script for all *Create Valid Mask* steps found here: https://github.com/brianadrianwong/nc-cafo/blob/master/ncCafoS2ValidMask.js

b. To increase rooftop delineation precision, Sentinel-2 imagery from the European Space Agency was used because it is 1) freely available, 2) has fine resolution attribute (10-m pixel resolution), and 3) instantaneously accessible via Google Earth Engine[5]. 3,156 images were accessed from January 1, 2017 to December 31, 2017. Each image was cloud-masked and stacked into an *n-dimensional* image-cube, from which the median value was used to create a 2017 median composite.
c. The Tasseled Cap transformation is not available yet for Sentinel-2 imagery so the Normalized Difference Vegetation Index (NDVI) was used to calculate relative vegetation presence for the composite. NDVI ranges from -1 to 1, with higher values representing vegetation. Urban areas are generally between 0.2 - 0.3, so transferring this technique to a search radius provided a way to extract CAFO rooftop extent for each individual 3,969 study sites. To further improve precision, this 0.2 - 0.3 range was optimized for 7 separate regions of North Carolina ranging from 0.23 0.3. Optimization was conducted with manual optical observations for 25 random sites in each of the 7 regions.

2. Change Detection Analysis:

a. Eight annual satellite imagery composites were created of North Carolina using Landsat-7 SR data, one for each year from 2010-2017. To do so, the Tasseled Cap transformation was applied to each image, from which the NDRBI was calculated for each pixel, followed by the annual median composite calculation that was extracted to represent each year's composite. The previously created Valid Mask was then applied in binary form to all of North Carolina to filter for only pixels satisfying the regionally optimized threshold. This selection was then clipped to a 150-meter buffered radius for each individual poultry CAFO site. Although at times, this 150-meter buffer clip might exclude the edges of some larger CAFO sites, minimizing the probability of including non-CAFO rooftops was prioritized. The 150-meter radius was selected from random optical observations of approximately 50 sites.
b. To detect the year of change, a for-loop was applied to all 3,969 CAFO sites to record NDRBI changes from 2010 – 2017. In particular, a single NDRBI value was extracted for each year for each CAFO site, which were calculated in Google Earth Engine and exported to a CSV[6]. A significant increase from one year to the next was expected for CAFO installation events so the first major increase (greater than 125% standard deviation) was classified as the year of change using Excel. Any sites that did not register notable changes were assumed to have existed prior to 2010. Lastly, there were 45 individual CAFO sites with invalid satellite data (areas with no imagery data) likely stemming from a Landsat-7 blind spot areas due to its Scan Line Corrector failure in 2003. Those 45 are marked as NULL. This final analysis accessed 2,473 Landsat-7 images and processed 1,497 of those in the final algorithm.

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[5] Gorelick, Noel, et al. "Google Earth Engine: Planetary-Scale Geospatial Analysis for Everyone." *Remote Sensing of Environment*, vol. 202, Dec. 2017, pp. 18–27. *ScienceDirect*, doi:10.1016/j.rse.2017.06.031.

[6] Google Earth Engine script for *Change Detection Analysis* steps found here: https://github.com/brianadrianwong/nc-cafo/blob/master/ncCafoChangeDetectionLoop.js