The Effect of Drought Policies on Vegetational Health Through Image Segmentation

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Objectives

- **Utilize a DeepLabV3+ segmentation model to identify urban and agricultural land near the Catalonia-Aragon border.**
- **Assess the effects of the 2024 Catalonian drought policies on vegetative health via difference-in-difference analysis with border segment fixed effects.**

Introduction

This project investigates the impact of drought policies on vegetational health in Catalonia. Catalonia has historically faced severe drought conditions, prompting the implementation of rigorous water management policies. The current drought, which commenced in 2023, is the most severe on record, presenting an ever increasing threat to human society, wildlife and vegetation. In February of 2024, the Catalonian Government declared a drought emergency, implementing restrictions on water use for personal, industrial and, importantly, agricultural use [1].

By utilizing the Normalized Difference Vegetation Index (NDVI) to assess vegetation health, we aim to evaluate the effect of these drought policies on vegetational vitality. NDVI measures vegetation's reflectance of red light, with lower reflection generally indicating healthier plants due to greater absorption for photosynthesis.

To analyze the impacts of drought policies, we initially employ the DeepLabV3+ segmentation model to identify urban and agricultural areas which are directly influenced by these water management strategies. In contrast water bodies and wild areas will not be affected by the policies, so should be excluded from our analysis. Subsequently, we employ a difference-in-difference approach, comparing Catalonia's vegetative health to neighboring Aragon, where no similar drought policies were enacted. The study's outcomes are crucial for understanding and crafting future drought management strategies in Mediterranean climates facing similar environmental challenges. Our code can be found on GitHub.

Related Work

- The study in [2] uses a U-Net semantic segmentation model to evaluate the impact of drought on maize crops. This assessment leverages RGB images from UAVs to calculate the NDVI to classify the severity of drought-affected areas.
- [3] use an unsupervised autosegmentation technique on hyperspectral images for predicting agricultural drought and crop yield. The study utilizes a Support Vector Machine to analyze the NDVI and Standard Precipitation Indices derived from segmented images.

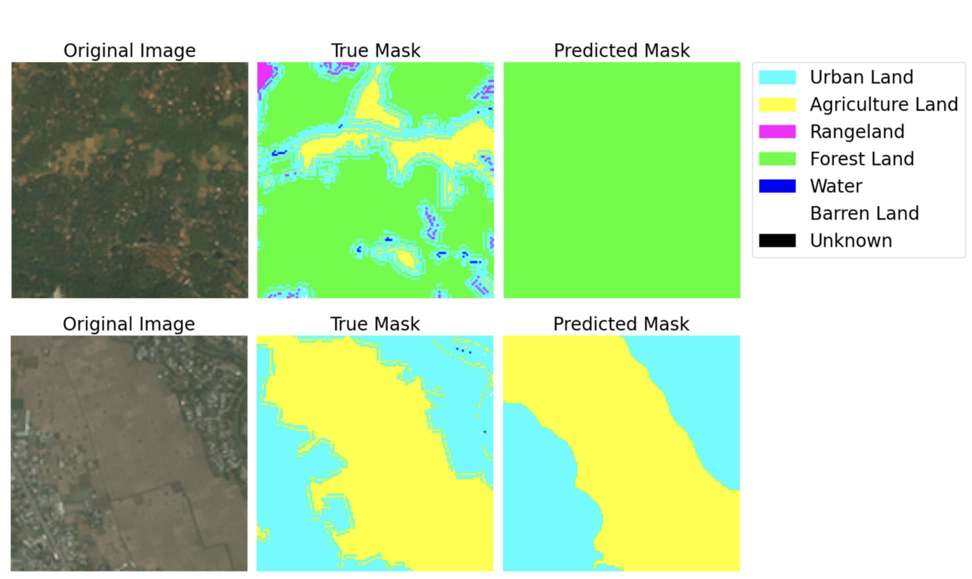

Figure 1:Example of Masks in Validation Set

Image Segmentation

To identify agricultural and urban land, we deploy the DeepLabV3+ model [4]. This model features an advanced encoder-decoder architecture tailored for multi-class semantic segmentation. Semantic segmentation is a computer vision task which involves assigning a label to each pixel in an image based on some pre-defined categories.

The model takes an image as input and processes it through a series of convolutional layers. The encoder progressively reduces the spatial dimensions of the image while capturing high-level semantic information. The decoder then gradually restores the spatial dimensions and detail, using the semantic information to make pixel-level predictions. The advancement of DeepLabV3+ is to employ a dilated convolution to expand the receptive field, enabling the model to capture broader context without increasing the number of parameters.

To adapt DeepLabV3+ to our specific context, we fine-tune the model parameters using the DeepGlobe Land Cover Classification Dataset [5]. This comprises 1,146 Sentinel-2 satellite images paired with masks for land cover annotation in seven classes: urban land, agriculture land, rangeland, forest land, water, barren land, and 'unknown'. This dataset is particularly well-suited for our analysis since our test data also consists of Sentinel-2 imagery. To prepare these images for training, we resize them to a uniform 128x128 pixels, matching our test data's resolution, and introduce random image augmentations—such as flipping and rotation—to enhance model robustness and variability.

The model is trained to minimize the dice loss, a metric which computes the similarity between predicted and true masks, thus promoting better boundary detection and class imbalances handling. We employ the Adam optimizer for its ability to adjust the learning rate dynamically, which is beneficial in handling the noisy gradients that are typical in satellite imagery. After 80 epochs, the model achieves a dice loss of 0.239 in the validation set.

In Figure 1, you can see the model generally identifies the majority class of an image correctly, however can overlook some of the finer details. This is most likely due to the low resolution of the training images which can obscure subtleties in the land cover.

To form our test dataset, we randomly sample 500 areas of $1224m^2$ in Catalonia and Aragon, respectively, using Google Earth Engine. Each area is within 2km of the Catalonia-Aragon border to ensure the sampled land is comparable and differences in the NDVI are attributable to the difference in drought management policies. We then deploy our segmentation model to identify different types of land cover within these areas. Some examples of the test set masks can be seen in Figure 2.

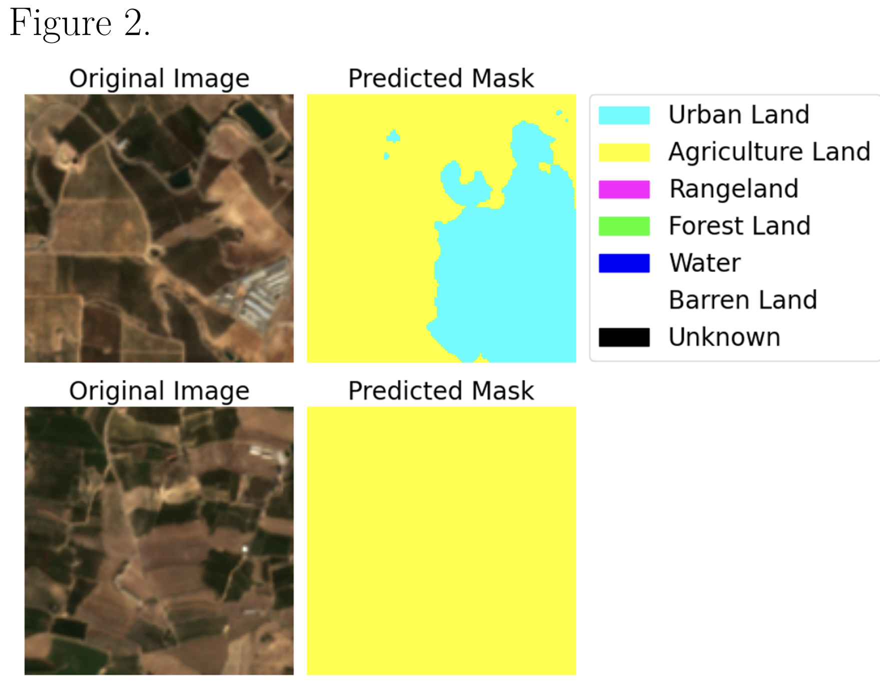

Figure 2:Example of Masks in Test Set

Empirical Framework

We examine the impact of drought policies on vegetation density and health by comparing Catalonia and Aragon during the ongoing 2023-2024 drought. It is assumed that Aragon did not implement similar policies based on our research. Due to inherent differences between the regions, a simple comparison to estimate policy effects would be inadequate. Therefore, we focus our analysis on a narrow area of five kilometers on either side of the Catalonia-Aragon border, which we further divide into 50 equally spaced border segments, see Figure 3. A point on the map corresponds to the centroid of

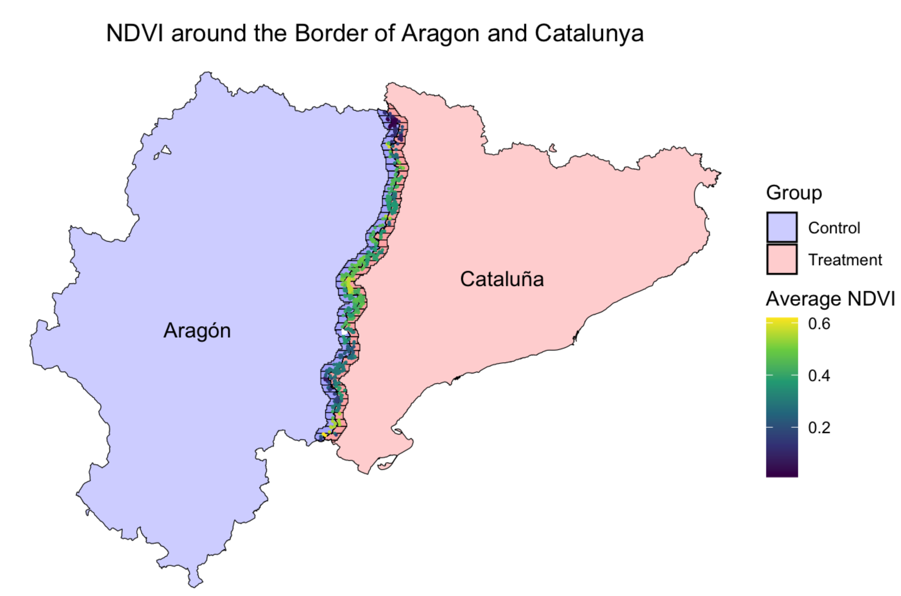

Figure 3:Average NDVI for predicted Urban and Agriculture Areas in the Test Set for the 01.09.2023

In these segments we assume comparable environmental conditions and agricultural practices, despite broader regional differences. Thus, we regard the policies to be locally exogenous. We implement a difference-in-difference approach with border segment fixed effects inspired by [6] controlling for all unobserved factors constant for each border segment but varying across border segments. This methodology allows us to isolate the policy's impact, based on the assumption that the adjacent areas are similar except in their exposure to the policy. Following this methodology we estimate the following regression,

$$y_{ist} = \beta_1\, treat_i + \beta_2\, treat_i \times\, post_t + \, segment_s + \, time_t + \epsilon_{ist}$$

where y_{ist} is our outcome, the average NDVI score for the area predicted as urban or agricultural land in a test set mask. $treat_i$ is our treatment variable, being on the Catalonian side of the border or not. The treatment is further interacted with the variable $post_t$, a dummy taking value one after the policy comes into effect. The coefficient of interest is β_2, which captures the effect of the policy on the Catalonian masks in comparison to the control, Aragon. We further include border segment fixed effects $segment_s$ and time fixed effects $time_t$. We do not include the $post_t$ variable by itself, as it would create perfect multicollinearity with the time fixed effects. We cluster standard errors at the mask level to allow the errors to be correlated over time for each mask.

To make the analysis more robust, additional controls could be beneficial, such as the temperature and socioeconomic data from the municipalities corresponding to the locations of the masks.

For our outcome variable we use the NDVI index data from [7] and extract the first day of each month from September 2023 until June 2024. Thus, we observe the NDVI index for 5 periods prior to the policy's enactment date and 5 periods after.

Results

The drought policy that constitutes our treatment includes severe irrigation limits such as a halt for watering of city parks and gardens [1] and a reduction of 80% of average water use for farmers [8]. Ex ante we believed that these irrigation limits would likely worsen vegetative health, implying a negative treatment effect.

Indeed, we find that vegetational health seems to decrease by 0.02 due to the treatment, as measured by the NDVI index. This effect is displayed in Table 1 and is significant at the 5% confidence level. Thus, vegetational health appears to worsen slightly in response to the drought policies.

Dependent Variable:	Average NDVI
Model:	(1)
Variables	
treat	0.0053
	(0.0048)
treat × post	-0.0212**
	(0.0086)
Fixed-effects	
segment_id	Yes
time	Yes
Fit statistics	
Observations	6,548
R^2	0.58038
Within R^2	0.00222

Clustered (mask_id) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Discussion

The common trend assumption is essential for ensuring the internal validity of the difference-in-difference approach. It asserts that, in the absence of treatment, the control group and the treatment group would exhibit identical trends over time. Violation of this assumption results in biased estimators of the causal effect. Thus, in natural experiments without randomization, it is crucial to challenge the common trend assumption. We argue that including border segment fixed effects enhances the validity of this assumption, as neighboring segments are likely to share similar trends due to factors like soils, weather conditions and agricultural practices.

However, simultaneous policy changes with the start of treatment mean that common trends pre-treatment do not guarantee common trends post-treatment.

Further, our findings primarily reflect short-term impacts due to immediate restrictions on water use. Yet, the policies might still be beneficial in the long term by preserving water resources, preventing more severe drought consequences, and encouraging sustainable water use practices. These measures can help mitigate the overall environmental and economic damage associated with prolonged droughts, ultimately contributing to the resilience and sustainability of the region. Continued monitoring and analysis over extended periods are essential to determine whether these adverse effects persist or if vegetation health can recover with adaptive management strategies and policy adjustments.

Finally, additional work could benefit from having higher resolution satellite imagery to improve the accuracy of the segmentation model and better identify areas which may have been affected by the drought policies.

Conclusion

This project evaluates the impact of the 2024 Catalonian drought policies on vegetative health. We exploit that Catalonia's neighbouring region, Aragon, did not implemented a drought policy and focus on areas close to their shared border. We further limit these areas to urban and agricultural lands, ensuring an analysis of lands directly impacted by the drought policies. For this purpose we employed the DeepLabV3+ image segmentation model, which we fine-tuned with the DeepGlobe Land Cover Classification Dataset to identify land cover classes.

The empirical framework leveraged a difference-in-difference approach with border segment fixed effects. Our results indicate a significant decrease in vegetative health by 0.02 on the NDVI scale due to the drought policies, supporting the hypothesis that severe irrigation limits would negatively impact vegetation. This finding highlights the adverse short term effects of the 2024 drought policies on vegetation in Catalonia. With our project we hope to provide valuable insights for future drought management strategies in Mediterranean climates.

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