Title:

Assessing vegetation phenology trends through traffic camera data: Imputation, analysis, and Comparison with satellite-based observations

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Name of Academic Institution: Newcastle University

Level of study or work: Master of research - dissertation
(Bachelor thesis, master, research, project, etc.)

Information about you (and your team): I'm a researcher from Ecuador, and I am 31 years old (dob: 25/03/1992). I am completing my MRes dissertation at Newcastle University, funded by the EPSRC Centre for Doctoral Training in Geospatial Systems (ref EP/S023577/1). Dr Maria-Valasia Peppa and Dr Doreen Boyd supervise my project. It involves the application of traffic camera data for tracking vegetation phenology, underlining my commitment to innovative and interdisciplinary approaches. Following the conclusion of my MRes, I am excited to progress to a PhD programme this coming September, allowing me to continue my exploration of geospatial technologies in the service of biodiversity conservation.

Area of interest

(Identifying the problem, explain why it is important and the current relevance of the topic, up to 250 words)

The study focuses on understanding the effects of climate change on vegetation phenology. Vegetation phenology, the cyclic and seasonal dynamics of vegetation, serves as a sensitive indicator of environmental changes, and its shifts are significant proxies for climate change impacts [1]. This aligns closely with Sustainable Development Goals 13 (Climate Action) and 15 (Life on Land), further highlighting the relevance of the research [2].

Currently, vegetation phenology monitoring relies heavily on ground-based observations [3], phenocams [4], and satellite imagery[5]. These methods can be resource-intensive and may not provide sufficient temporal and spatial resolution. These methods are often limited or less accurate for areas adjacent to highways and transportation routes, creating a significant knowledge gap.

This research proposes a cost-effective approach, leveraging an existing urban infrastructure - England's traffic monitoring camera network [6]. This study explores the viability of using the data from traffic cameras for monitoring vegetation phenology, thereby repurposing a resource already in place for environmental surveillance.

This innovative approach offers a unique opportunity to gather valuable phenological data at relevant temporal and spatial scales. It not only broadens the application of existing resources but also significantly contributes to our understanding of how vegetation along transportation corridors responds to climate change.

Such continuous and extensive data could further support climate models, policy-making, urban planning, and ecological research, offering timely insights into the impacts of changing climates on vegetation health, which is of paramount importance in the face of global environmental change.

Approach to the problem

(Describe your methodology or technology and how it will solve the problem you identified, up to 300 words)

The approach aims to bridge the gap in traditional vegetation phenology monitoring by harnessing the potential of England's vast traffic camera network [6]. This research repurposes these cameras, intended initially for traffic surveillance, into a network of national ecosystem monitors.

Firstly, a representative sample of 15 cameras from over 3600 was selected, ensuring diverse coverage nationwide and at least a decade's worth of data. After filtering the relevant camera and image data, machine learning techniques for vegetation detection and segmentation within the images were employed.

Following this, the Green Chromatic Coordinate (GCC) was calculated, a robust indicator of plant 'greenness' or health, from the segmented vegetation images. This generates a time series of GCC values representing the changing 'greenness' levels over time, thus depicting different phenophases of the vegetation [7]. Phenophases refer to the key stages in the annual life cycle of vegetation, each associated with a specific range of GCC values.

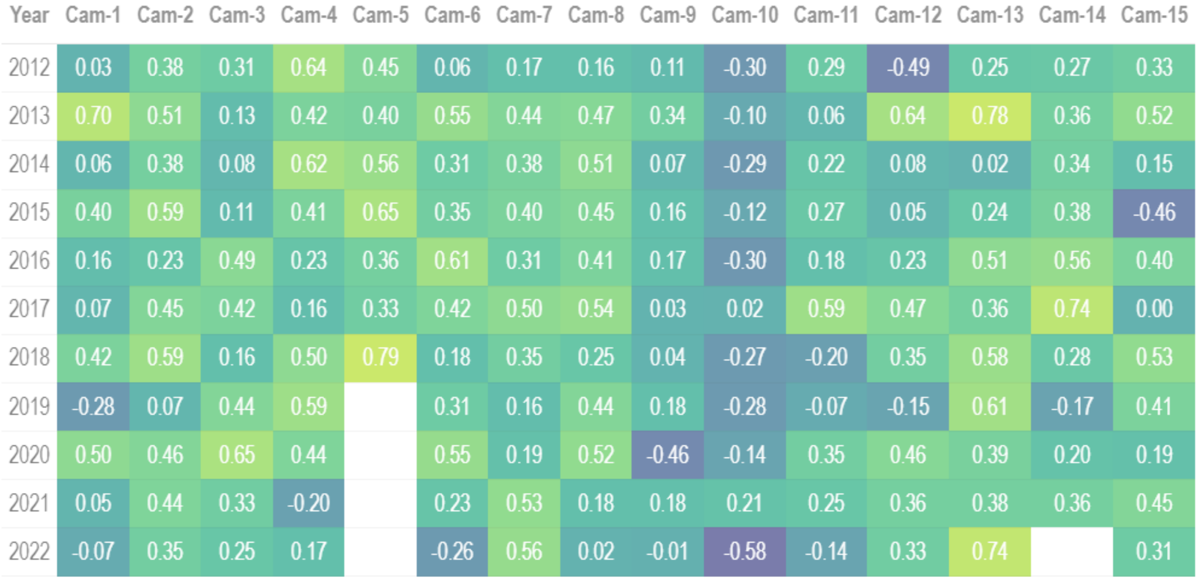
Then, the GCC time series were compared with established satellite-based vegetation indices - the Enhanced Vegetation Index (EVI) and the Normalized Difference Vegetation Index (NDVI), obtained from the MODIS (Moderate Resolution Imaging Spectroradiometer) platform.

This approach offers a combination of existing resources and innovative technology. By leveraging traffic cameras for environmental monitoring, we can significantly reduce the need for new, expensive monitoring equipment. Moreover, the high temporal resolution of traffic camera images allows for more precise phenological monitoring. At the same time, the established nature of GCC, EVI, and NDVI ensures the comparisons' robustness.

Results, conclusions and next steps

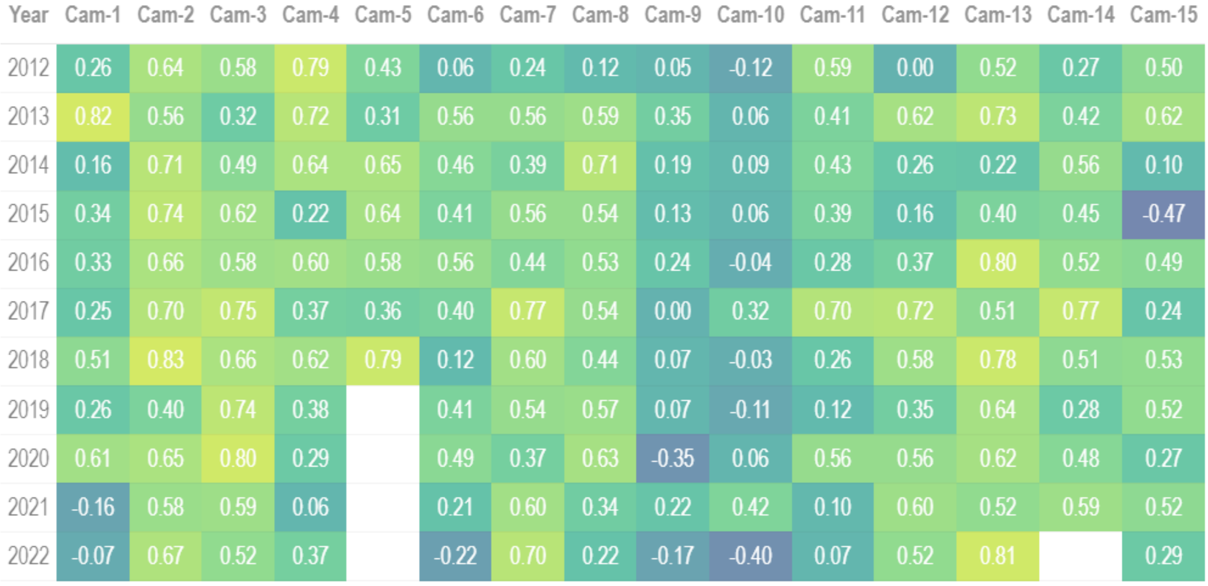
(Present your research results and conclusions of your study, up to 250 words)

Table 1. Yearly correlation table between camera data GCC and MODIS' NDVI: Yearly correlation coefficients between non-smoothed Green Chromatic Coordinate (GCC) data derived from traffic cameras and Normalized Difference Vegetation Index (NDVI) values from MODIS. Blanks represent instances where quality data was unavailable.



Year	Cam-1	Cam-2	Cam-3	Cam-4	Cam-5	Cam-6	Cam-7	Cam-8	Cam-9	Cam-10	Cam-11	Cam-12	Cam-13	Cam-14	Cam-15
2012	0.03	0.38	0.31	0.64	0.45	0.06	0.17	0.16	0.11	-0.30	0.29	-0.49	0.25	0.27	0.33
2013	0.70	0.51	0.13	0.42	0.40	0.55	0.44	0.47	0.34	-0.10	0.06	0.64	0.78	0.36	0.52
2014	0.06	0.38	0.08	0.62	0.56	0.31	0.38	0.51	0.07	-0.29	0.22	0.08	0.02	0.34	0.15
2015	0.40	0.59	0.11	0.41	0.65	0.35	0.40	0.45	0.16	-0.12	0.27	0.05	0.24	0.38	-0.46
2016	0.16	0.23	0.49	0.23	0.36	0.61	0.31	0.41	0.17	-0.30	0.18	0.23	0.51	0.56	0.40
2017	0.07	0.45	0.42	0.16	0.33	0.42	0.50	0.54	0.03	0.02	0.59	0.47	0.36	0.74	0.00
2018	0.42	0.59	0.16	0.50	0.79	0.18	0.35	0.25	0.04	-0.27	-0.20	0.35	0.58	0.28	0.53
2019	-0.28	0.07	0.44	0.59		0.31	0.16	0.44	0.18	-0.28	-0.07	-0.15	0.61	-0.17	0.41
2020	0.50	0.46	0.65	0.44		0.55	0.19	0.52	-0.46	-0.14	0.35	0.46	0.39	0.20	0.19
2021	0.05	0.44	0.33	-0.20		0.23	0.53	0.18	0.18	0.21	0.25	0.36	0.38	0.36	0.45
2022	-0.07	0.35	0.25	0.17		-0.26	0.56	0.02	-0.01	-0.58	-0.14	0.33	0.74		0.31

Table 2. Yearly correlation table between camera data GCC and MODIS' EVI: Yearly correlation coefficients between non-smoothed Green Chromatic Coordinate (GCC) data derived from traffic cameras and Enhanced Vegetation Index (EVI) values from MODIS. Blanks represent instances where quality data was unavailable.



Year	Cam-1	Cam-2	Cam-3	Cam-4	Cam-5	Cam-6	Cam-7	Cam-8	Cam-9	Cam-10	Cam-11	Cam-12	Cam-13	Cam-14	Cam-15
2012	0.26	0.64	0.58	0.79	0.43	0.06	0.24	0.12	0.05	-0.12	0.59	0.00	0.52	0.27	0.50
2013	0.82	0.56	0.32	0.72	0.31	0.56	0.56	0.59	0.35	0.06	0.41	0.62	0.73	0.42	0.62
2014	0.16	0.71	0.49	0.64	0.65	0.46	0.39	0.71	0.19	0.09	0.43	0.26	0.22	0.56	0.10
2015	0.34	0.74	0.62	0.22	0.64	0.41	0.56	0.54	0.13	0.06	0.39	0.16	0.40	0.45	-0.47
2016	0.33	0.66	0.58	0.60	0.58	0.56	0.44	0.53	0.24	-0.04	0.28	0.37	0.80	0.52	0.49
2017	0.25	0.70	0.75	0.37	0.36	0.40	0.77	0.54	0.00	0.32	0.70	0.72	0.51	0.77	0.24
2018	0.51	0.83	0.66	0.62	0.79	0.12	0.60	0.44	0.07	-0.03	0.26	0.58	0.78	0.51	0.53
2019	0.26	0.40	0.74	0.38		0.41	0.54	0.57	0.07	-0.11	0.12	0.35	0.64	0.28	0.52
2020	0.61	0.65	0.80	0.29		0.49	0.37	0.63	-0.35	0.06	0.56	0.56	0.62	0.48	0.27
2021	-0.16	0.58	0.59	0.06		0.21	0.60	0.34	0.22	0.42	0.10	0.60	0.52	0.59	0.52
2022	-0.07	0.67	0.52	0.37		-0.22	0.70	0.22	-0.17	-0.40	0.07	0.52	0.81		0.29

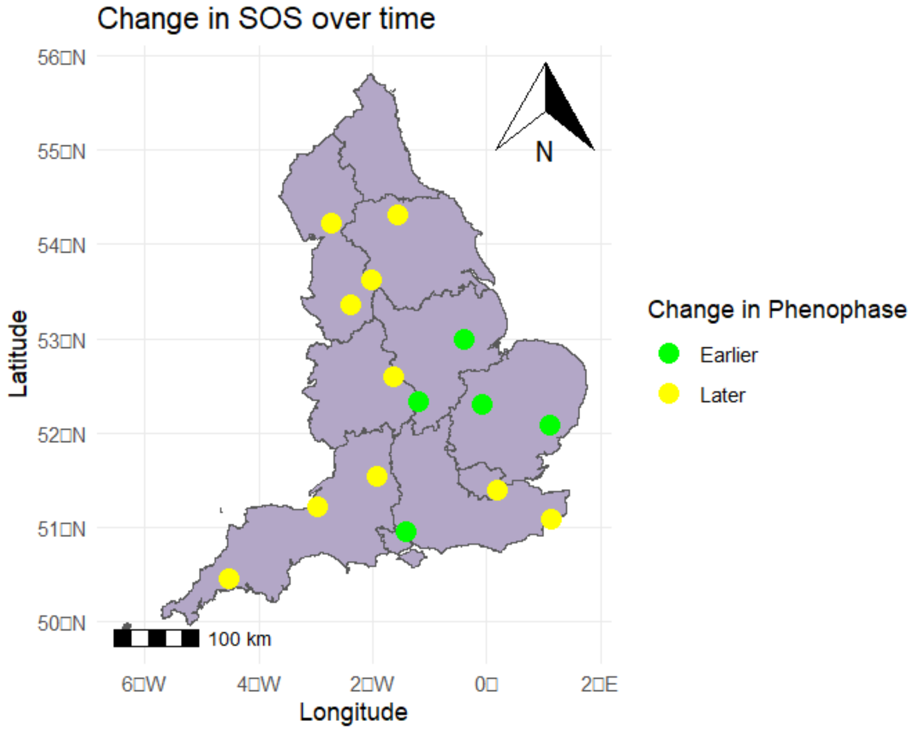


Figure 1. Annual Change – SOS map: Spatial representation of annual changes in the Start of Season (SOS) across the study area, derived from traffic camera data. Each point indicates whether the SOS (marked by an increase in greenness values) occurs earlier or later in the year over the study period.

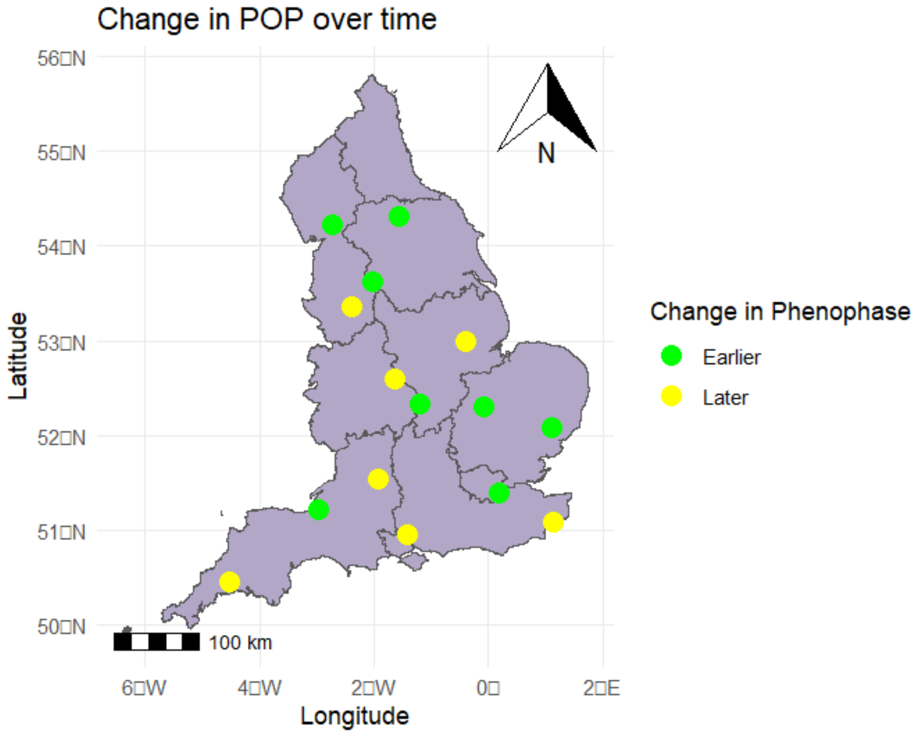


Figure 2. Annual Change – POP map: Spatial representation of annual changes in the Peak of Season (POP) across the study area, derived from traffic camera data. Each point indicates whether the POP (identified as the time of maximum greenness) occurs earlier or later in the year over the study period.

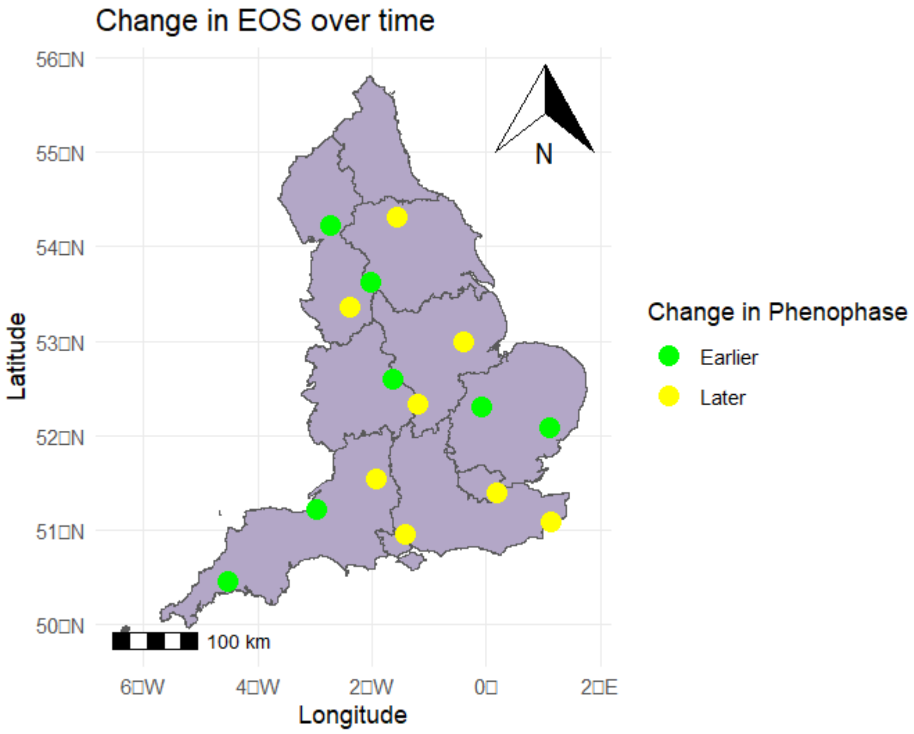


Figure 3. Annual Change - EOS map: Spatial representation of annual changes in the End of Season (EOS) across the study area, derived from traffic camera data. Each point indicates whether the EOS (marked by a decline in greenness values) occurs earlier or later in the year over the study period.

This project bridges the gap between local, field-based observations and larger, satellite-based phenology studies. It also presents a globally applicable strategy, suggesting that other nations could adapt their monitoring infrastructure similarly.

However, it's essential to acknowledge the limitations of the analysis. Once the phenophases have been determined for every camera, a simple linear model was employed to determine trends, which, while offering clear interpretability, may not fully capture the complex nature of vegetation phenology. The influence of non-linear factors such as climatic patterns, changes in land use, and biotic interactions were not considered. As such, the linear model may oversimplify plant responses to changing climatic conditions but serves as an initial trend analysis.

Despite this, the findings (Tables 1 & 2; Figures 1-3) accentuate the immense potential of utilizing existing infrastructure for ecological monitoring. Moreover, to facilitate the accessible exploration of the findings, an interactive viewer is currently in development.

Future research should incorporate non-linear models, validate camera-based observations with ground truth data, improve image processing techniques, and expand the sample size. Ultimately, this research serves as a springboard, encouraging further exploration into how existing urban infrastructure can be harnessed as a valuable asset in environmental monitoring and climate change studies.

References
(Additional information, publications, or links, up to 200 words)

[1] E. E. Cleland, I. Chuine, A. Menzel, H. A. Mooney, and M. D. Schwartz, 'Shifting plant phenology in response to global change', *Trends Ecol. Evol.*, vol. 22, no. 7, pp. 357–365, 2007.
[2] G. Assembly, 'Resolution adopted by the General Assembly on 11 September 2015', *N. Y. U. N.*, 2015, [Online]. Available: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf
[3] L. P. C. Morellato *et al.*, 'Linking plant phenology to conservation biology', *Biol. Conserv.*, vol. 195, pp. 60–72, 2016.
[4] A. D. Richardson, J. P. Jenkins, B. H. Braswell, D. Y. Hollinger, S. V. Ollinger, and M.-L. Smith, 'Use of digital webcam images to track spring green-up in a deciduous broadleaf forest', *Oecologia*, vol. 152, pp. 323–334, 2007.
[5] J. I. Fisher and J. F. Mustard, 'Cross-scalar satellite phenology from ground, Landsat, and MODIS data', *Remote Sens. Environ.*, vol. 109, no. 3, pp. 261–273, 2007.
[6] National Highways, 'Traffic camera/CCTV services - National Highways', Jul. 22, 2020. https://nationalhighways.co.uk/travel-updates/traffic-camera-cctv-services/ (accessed Jun. 26, 2023).
[7] D. E. Morris, D. S. Boyd, J. A. Crowe, C. S. Johnson, and K. L. Smith, 'Exploring the potential for automatic extraction of vegetation phenological metrics from traffic webcams', *Remote Sens.*, vol. 5, no. 5, pp. 2200–2218, 2013.

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