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Has Portland Been Demolishing its Green Spaces?

A Remote Sensing Analysis of Portland's Urban Vegetation

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The magnitude of the Urban Heat Island effect (UHI) in Portland, Oregon is determined from June 1984 to September 2017, and used as a proxy for establishing whether vegetation is being demolished to make way for urban development. This analysis demonstrates that the magnitude of Portland's UHI has remained largely unchanged over this period, implying no significant decline in urban vegetation. This is supported by analysis of the Enhanced Vegetation Index (EVI) of the Portland Metro area, which has also remained largely unchanged over the period studied. An estimate of the total area of vegetation detectable via satellite in the Portland Metro is also determined and found to have little variance over time.

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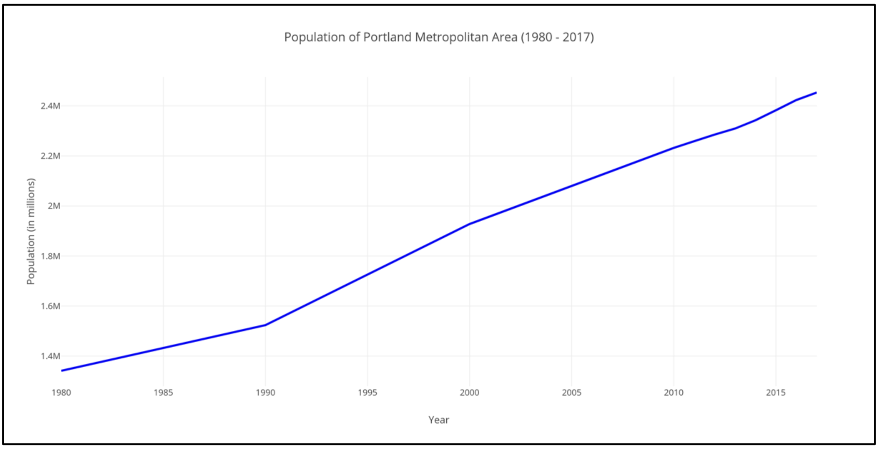
Introduction

Portland, Oregon is considered one of America's most environmentally conscious cities.[1] In terms of policy, this reputation is reflected in many of the city's initiatives to limit urban expansion and increase the volume of green spaces. In 1980, Portland's Bureau of Sustainability and Development set out a comprehensive plan which included the preservation and expansion of open green spaces through designation of special green zones in the city's zoning map.[2] However, there are few metrics to judge the effectiveness of the city's policies on preventing open spaces from being developed. While this plan was in place, the population of the Portland Metro area has nearly doubled:

Figure 1: Population of the Portland metro area by year.[3]



The population living in Portland's Metropolitan area has risen by 83 percent since 1980.[4] This kind of growth might put excessive pressure on the metro areas urban vegetation and green zoning. The rapidly developing city could be clearing all of the green spaces outside of the specially designated zones, making the green zoning policy ineffective for maintaining Portland's urban foliage.

The purpose of this paper is to apply an objective metric to evaluate the net change in vegetation and green spaces in the Portland Metro Area from 1984 to today, and, as an extension, develop a method of evaluating the urban planning of any jurisdiction. If there has been a significant reduction in vegetation, there would be a corresponding increase in the magnitude of the Urban Heat Island Effect (UHI); the observation that urban landscapes are significantly warmer than the surrounding areas. This phenomenon was first noted by the pioneering meteorologist Luke Howard in 1820, and is driven by cities' use of heat-absorbing materials (asphalt, concrete, etc.) to build urban structures, a lack of vegetation, which cools the surrounding area in cities as compared to rural areas, and population density.[5] Since all of these variables are related to urbanization, this opens the possibility of studying UHI as a proxy for the environmental impact of urban expansion on the city's greenery.

A quantitative analysis of UHI was performed by Leonard Myrup in 1969, demonstrating the predicted relation between the ambient air temperature and distance from an urban center.[6] For a city whose urban density (e.g. density of buildings, population, and vegetation) strictly decreases with distance from the city center, the temperature should decrease as a function of distance from the city center. A temperature vs. distance from the Portland Metro area's geographic center plot should follow a similar pattern since the population density of Multnomah County, containing the geographic center of the metro area, is 1,872 $\frac{residents}{squaremile}$, and that of the surrounding counties is significantly less (the next densest is Washington county with 813 $\frac{residents}{squaremile}$).[7] Given temperature data, the magnitude of the urban heat island effect can be estimated as a proxy for the amount of vegetation in the metro area to evaluate the effectiveness of the comprehensive plan's green zoning in maintaining urban vegetation. If Portland's environmental policies are found to be ineffective in conserving natural foliage, then new policies should be pursued.

The Data

Temperature data for Portland, Oregon from June 1984 to September 2017 was determined by analyzing 68 thermal images from band 6 of the Landsat 4 TM & band 10 of the Landsat 8 OLI. All data was taken during the summer (June 21-September 22) to minimize the risk of cloud cover impacting the results. This also reduces the variation in the magnitude of UHI by holding the season constant. All of the data was collected between 11:00 A.M. and 12:00 P.M. PST to minimize variance in the UHI associated with the time of day.

The top-of-atmosphere temperature was determined by first converting the (Howard n.d.) data to a spectral radiance detected at the satellite:

$$L_\lambda = M_L Q_{cal} + A_L$$

where L_λ is the luminosity detected by the sensor, M_L and A_L are quantities determined from the Landsat image's meta data, and Q_{cal} is the intensity of a given pixel. The luminosity is then converted into an uncorrected temperature calculated at the satellite's thermal sensor by

$$T_{TOA} = \frac{K_2}{log\left(\frac{K_1}{L_\lambda} + 1\right)}$$

where T_{TOA} is the uncorrected, top-of-atmosphere temperature, and K_1 and K_2 are quantities derived from the image's meta data.[8]

The humidity of to the north, east, and west of the city center was determined using METARS reported from Portland International Airport (KPDX), Troutdale Airport (KTTD), and Hillsboro Airport (KHIO), respectively. The relative humidity never exceeds 60% across all of the images. Since few clouds were present in the data and the humidity was not close to saturation, we can assume that T_{TOA} is already corrected for atmospheric distortion. The procedure outlined in Jeevalakshmi 2016 was followed to correct T_{TOA} for the emissivity of different terrain to determine the land surface temperature T_S.[9]

Defining Portland's Pioneer Courthouse Square as our origin, the temperature as a function of distance from our origin is determined following a straight-line path to the southeast, east, northeast, north, northwest, and west (Fig. 3). T_S is determined out to 60 km from Pioneer Courthouse Square. A straight-line path to the south and southwest are omitted since only 30 km are available for analysis in those directions.

Figure 2: Natural color image taken on 7/14/2017 from Landsat 8. The approximate location and size of the Portland metro area is bounded by a box toward the bottom of the image.[10]

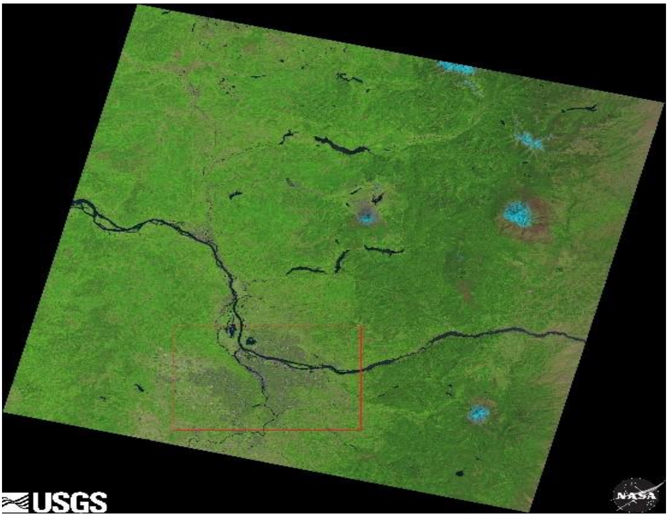
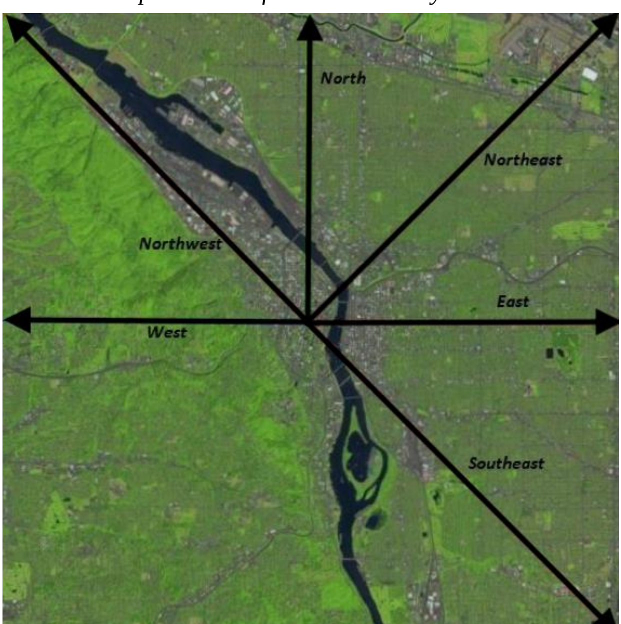


Figure 3: Natural color image of downtown Portland from 7/14/2017 showing the paths taken for the UHI analysis.[11]



To account for any effect elevation might have on temperature, elevation data is taken from GMTED2010.

Methodology

We assume that the land surface temperature, T_S, follows a linear relationship with the distance from the city center:

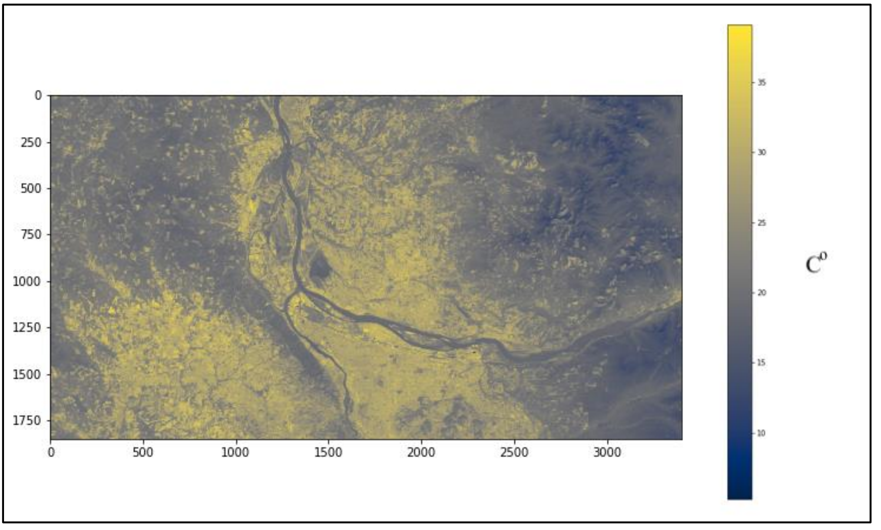
$$T_S = a_d d + a_e e + c$$

where d is the distance (in km) from Pioneer Courthouse Square and e is the elevation (in meters) at that point. A Breusch-Pagan test demonstrates that this model displays heteroskedasticity, and, as a result, this regression is accomplished using an OLS regression with Huber-White standard errors. Weather on any particular day can vary considerably, and the regression of temperature onto distance can be statistically insignificant. Myrup's analysis is relevant when the city's prevailing weather conditions (wind direction, wind speed, heating by the sun, etc.) are approximately homogenous over the whole city. On days where these conditions do not hold true, measuring the intensity of the UHI by the above method will not be accurate. To account for this, any regression where the p-value for a_d > 0.05 is dropped from the analysis.[12]

By definition, a_d is the change in temperature per km from Pioneer Courthouse Square, which is a way of defining the magnitude of UHI. As a result, a_d is taken to be proportional to the magnitude of UHI, and, since $a_d <$ 0, the magnitude, M_{UHI}, is defined to be:

$$M_{UHI} = |a_d|$$

Figure 4: False color thermal image (left)) of Portland dated 9/13/2016. Note that the dull colored, urban areas register a higher temperature than the surrounding greenery.



The larger M_{UHI} is, the larger the difference in land surface temperature between the urban and rural environments. Fig. 4 demonstrates that the densely populated urban areas in Portland are significantly hotter than the surrounding greenery.

Since there are multiple cross-sectional observations (there is a calculated M_{UHI} for each direction) for every time period, a panel data regression is applied with the derived M_{UHI} observations as the dependent variable regressed onto its fixed and time effects. The time effect coefficients from that regression then provide indication if the M_{UHI} has changed since 1984.

The Enhanced Vegetation Index, a method of determining the amount of vegetation in an area, for Portland is also determined from the Landsat 4 TM & Landsat 8 OLI. The EVI of a pixel in our Landsat images is given by:

$$EVI = 2.5\frac{NIR_{ref} - R_{ref}}{NIR_{ref} + 6R_{ref} - 7.5B_{ref} + 1}$$

where NIR_{ref} is the surface reflectance of near-infrared light, $R_{ref}$is the surface reflectance of red light, and B_{ref} is the surface reflectance of blue light. This gives us another proxy for urban growth since a decrease in vegetation cover and increase in the area covered by dull-colored, heat absorbing surfaces are associated with urban expansion. This data is provided as a data set from the United States Geologic Service.[13]

To calculate the area covered by vegetation, another index, the Normalized Difference Vegetation Index (NDVI), is determined. The NDVI of a pixel is:

$$NDVI = \frac{NIR_{ref} - R_{ref}}{NIR_{ref} + R_{ref}}$$

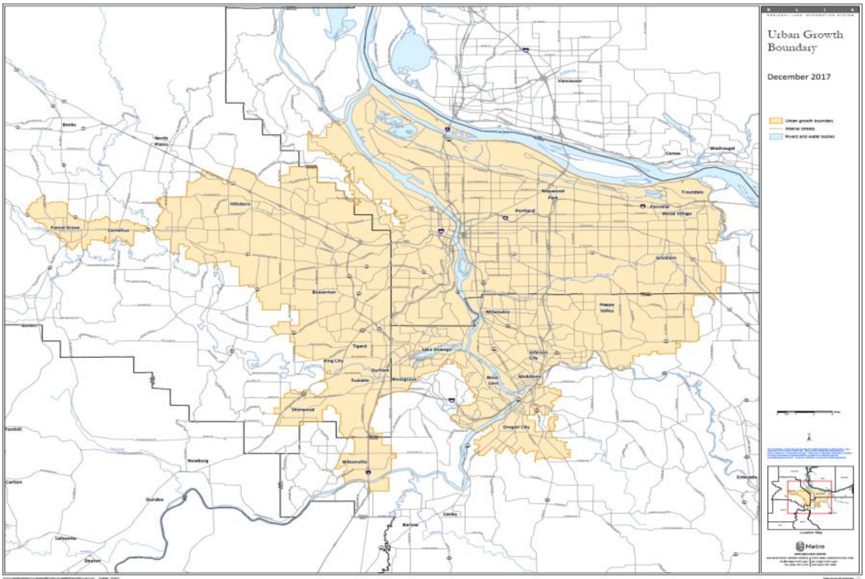
The proportion of a pixel that is covered by vegetation, P_v, is given by:

$$P_v = \frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}^2$$

where NDVI is the Normalized Difference Vegetation Index of the pixel, $NDVI_V$ is the NDVI of a pixel that is completely covered in vegetation, and $NDVI_S$ is the NDVI of a pixel that is completely devoid of vegetation. In accordance with analysis by Xiaolei et al. 2014, $NDVI_S$ is assumed to be 20% and $NDVI_V$ is determined on a case-by-case basis.[14]

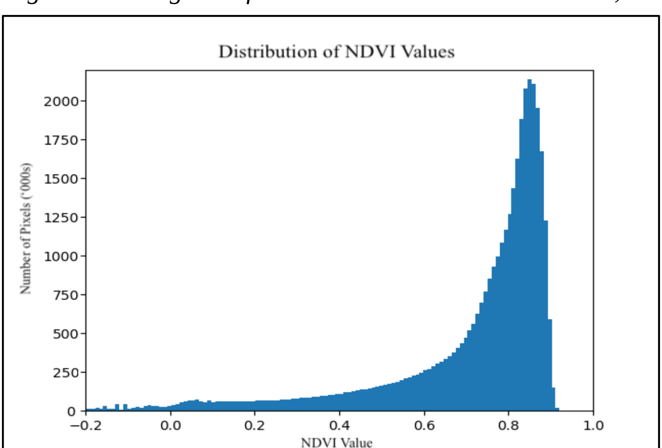
Several programs were written in Python to extract the temperature and vegetation data from each of the images.[15] Setting our origin as Pioneer Courthouse Square (latitude: 45.518° N, Longitude: 122.679° W), the surface temperature is determined out to 60 km in every cardinal direction except for South and Southwest. The Enhanced Vegetation Index of pixels residing in the Portland Metro Urban Growth Boundary is also extracted from each dataset using a Python algorithm. The metro area has been updated several times since 1984, but only the most current boundary is used (circa May 2018), which is visualized in Fig. 5. Each pixel has a length of 30 meters, which gives sufficient resolution to determine upward or downward trends in temperature as a function of distance from Pioneer Square Courthouse.[16]

Figure 5: Map of the Portland Metro Area with the urban growth area highlighted in orange.[17]



To determine $NDVI_V$, and thus P_v, a histogram is generated of NDVI vs. the number of pixels with that NDVI value. Since the full images of the Portland area and its surrounding greenery include a huge amount of forests and vegetation (see Fig. 2), it is assumed that the NDVI with the largest pixel count, the mode of the distribution, is fully vegetated. Fig. 6 shows the distribution of NDVI values on an arbitrary date.

Figure 6: Histogram of NDVI vs. Pixel Count on June 23, 1986



The mode of the NDVI distribution for Figure 6 is 0.87, and so we set $NDVI_V$ to equal 0.87 for the date June 23, 1986. This step is repeated for all images. We can then calculate P_v for the Portland Metropolitan area.

Results

A plot of the time effect coefficients from the panel data regression is shown below:

Figure 7: The magnitude of UHI over time for the directions studied

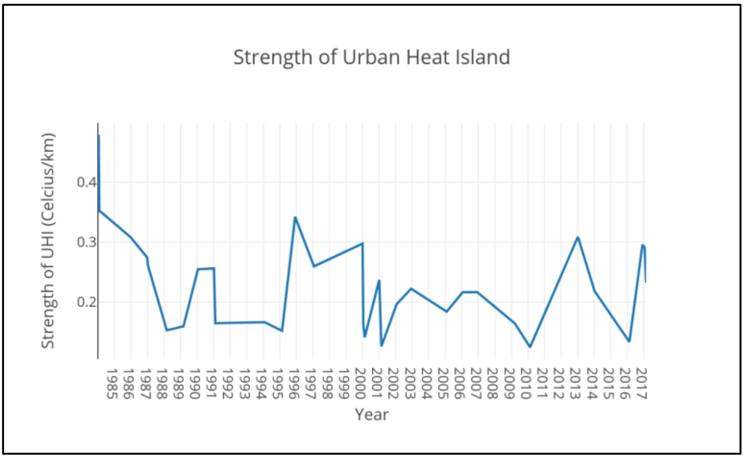


Figure 7 does not seem to contain any discernible upward or downward trend, and a linear regression of the time trend on M_{UHI} for the various directions studied confirms that M_{UHI} has neither steadily increased nor decreased since 1984 (see p-value for time in Table 1):

Table 1: R-squared and p-value of the regression statistics for time onto M_{UHI}.

	Coefficient	Std. Error	p-value
constant	0.1945	0.031	0.000
time	-5.24e-06	4.27e-06	0.219
Adj. R^2	0.021		

Portland's UHI intensity exhibits no general trend upward or downward in time. This stability is supported by an analysis of the average Enhanced Vegetation Index of a pixel in the Portland Metro area (see Fig 8). The mean EVI value is 0.3021 and the standard deviation is only 0.0405, demonstrating that there is little variation in the EVI measurement over time, and, thus, little variation in the amount of vegetation. The p-value for the time variable in the regression of time onto EVI is also insignificant (see Table 2), indicating that there is no evidence of declining vegetation in the Portland Metro Area for the past three decades.

Figure 8: Average EVI of a pixel in the Portland metropolitan area by date. Note that the EVI remains remarkably close to the mean value, implying no general upward or downward trend.

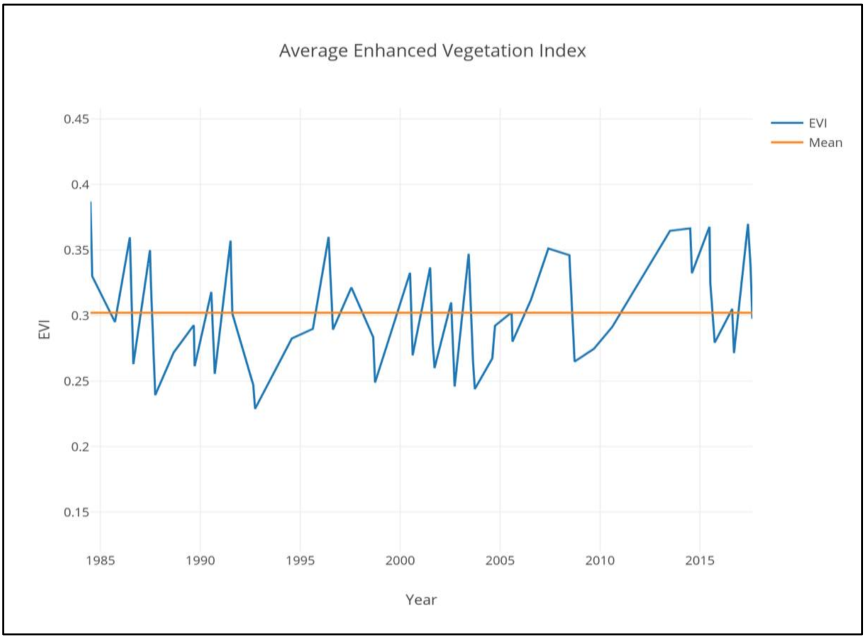


Table 1: R-squared and p-value of the regression statistics for time onto EVI.

	Coefficient	Std. Error	p-value
constant	0.258	0.0521	0.000
time	1.18E-06	1.41-06	0.405
Adj. R^2	0.005		

The value of P_V, the percentage of the Portland metro covered by vegetation by date is shown in Fig. 9. The amount of vegetation detectable via satellite is remarkably steady over the time period 1984 to 2010, and then experiences a 0.16 increase from 2010 to 2013, but the value falls back down to the long-run mean of 0.34 after 2013.

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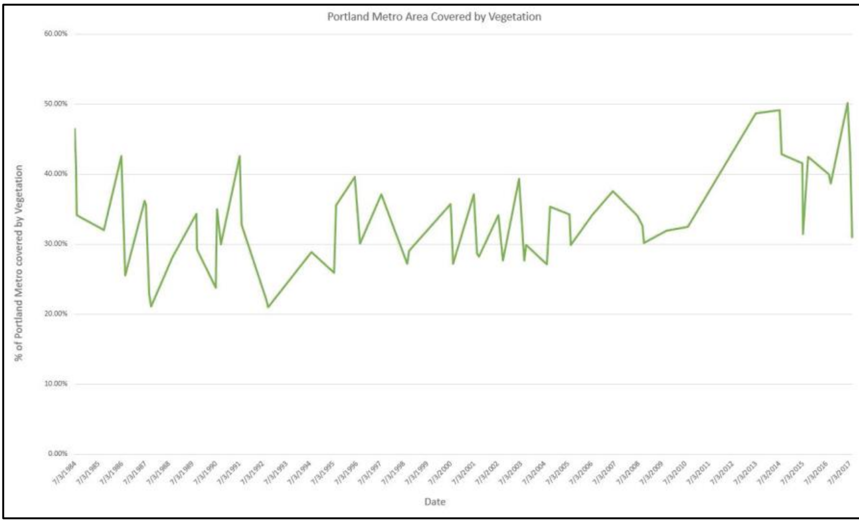
Figure 9: Proportion of the Portland metro area covered by vegetation by date.



It's important to note that if P_V = 40%, then 40% of the Portland metro area isn't literally covered by virgin forest. It is a relative measurement to determine if there is a net loss/gain in vegetation over time.

Conclusion

Overall, there is little evidence that Portland's population growth has required a building boom that has been displacing vegetation. This analysis indicates that Portland has experienced no significant decline in green space due to its urban growth. The possible policy implication is that Portland's efforts to limit its urban expansion's impact on its green spaces have been effective through the combination of zoning green areas and instituting an urban growth boundary.

Even the vegetation indices inside the urban growth boundary have remained stable over the past three decades. Given the stability of both the urban heat island effect and the vegetation index within Portland's urban growth boundary, our results call into question how threatened the Portland area's green spaces were in the first place. Since Portland has been able to grow in population density without adversely impacting the local vegetation canopy, we can conclude that Portland's urban planning policies have been effective in maintaining the city's greenery.

A possible extension of this research is to apply this article's methodology to other large jurisdictions that are surrounded by forest, but lack an urban growth boundary, and have the ability to sprawl outwards with increasing population (e.g. Atlanta, GA). This would allow us to more definitively observe whether an urban growth boundary affects urban green spaces and give more insight into what specific policies conserve urban foliage.

Notes

[1] City of Portland, "Green Building Initiative" (2018), accessed June 12 2018, https://www.portlandoregon.gov/bps/article/243213.

[2] Portland Bureau of Sustainability and Development, "Comprehensive Action Plan Goal 08-Environment. November" (2011), accessed April 20 2019.

[3] United States Census Bureau, "Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2017 - United States -- Metropolitan Statistical Area 2017 Population Estimates," accessed June 12 2018.

[4] Ibid.

[5] Luke Howard, *The Climate of London: Deduced from Meteorological Observations, Made at Different Place in the Neighborhood of the Metropolis* (London: George Yard, Lombard Street, 1818); Kaveh Deilami, Md. Kamruzzaman, and Yan Liu, "Urban Heat Island Effect: A Systematic Review of Spatio-Temporal Factors, Data, Methods, and Mitigation Measures," *International Journal of Applied Earth Observation and Geoinformation* 67 (2018), 30-42.

[6] Leonard Myrup, "A Numerical Model of the Urban Heat Island," *Journal of Applied Meteorology* 8 (1969).

[7] Portland State University, "Certified Population Estimates for Oregon and Counties (2016)" (December 15 2016), accessed April 29 2019, https://www.pdx.edu/prc/sites/www.pdx.edu.prc/files/2016_Cert_Pop_Est_Web_rev.xlsx.

[8] United States Geologic Service, "Band Designations of Landsat Satellites," accessed May 18 2018, https://landsat.usgs.gov/what-are-band-designations-landsat-satellites.

[9] Jeevalakshmi D., Dr. S. Narayana Reddy, and Dr. B. Manikiam, "Land Surface Temperature Retrieval from LANDSAT data using Emissivity Estimation," *International Journal of Applied Engineering Research* 12 (2016), 9679-687.

[10] United States Geologic Service, "Earth Explorer," https://earthexplorer.usgs.gov/.

[11] Ibid.

[12] Leonard Myrup, "A Numerical Model of the Urban Heat Island."

[13] United States Geologic Service, "Landsat Surface Reflectance Level-2 Science Products," accessed June 14 2018, https://landsat.usgs.gov/landsat-surface-reflectance-data-products.

[14] Xiaolei Yu, Xulin Guo, and Zhaocong Wu, 2014, "Land Surface Temperature Retrieval from Landsat 8 TIRS—Comparison between Radiative Transfer Equation-Based Method, Split Window Algorithm and Single Channel Method," *Remote Sensing* 6, no. 10 (2014), 9829-852.

[15] Robby Gottesman, "Portland-OR-Greening-and-Urban-Development" (2018), accessed June 29 2019, https://github.com/Robdei/Portland-OR-Greening-and-Urban-Development.

[16] United States Geologic Service, "Landsat 8 (L8) Data Users Handbook" (2016), accessed May 29 2018, https://www.usgs.gov/land-resources/nli/landsat/landsat-8-data-users-handbook.

[17] Oregon Metro, "Urban Growth Boundary Maps," accessed May 30 2018, https://www.oregonmetro.gov/urban-growth-boundary-maps.

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