Tracking Urban Expansion in Portland, Oregon (1984-2017)

Robby Gottesman[a]**, Eric Shierman**[a]
[a]McCullough Research, 6123 SE Reed College Place, Portland, OR, USA, 97202

Abstract. 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 urban development. This analysis demonstrates that the magnitude of Portland's UHI has remained largely unchanged over this period, implying no significant decline in its 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.

Keywords: Smart Growth, Urban Development, Urban Heat Island effect, Metro growth Boundary, Portland, Oregon.

1 Introduction

Portland, Oregon is considered one of America's most environmentally conscious cities.[1] In terms of policy, this consensus is reflected in many of the city's initiatives to limit urban expansion and increase the area of green spaces. The Metro authority manages nearly 17,000 acres of parks, trails and natural areas.[2] The population living in Portland's Metropolitan area has risen by 83% since 1980 (see Fig 1).[3]

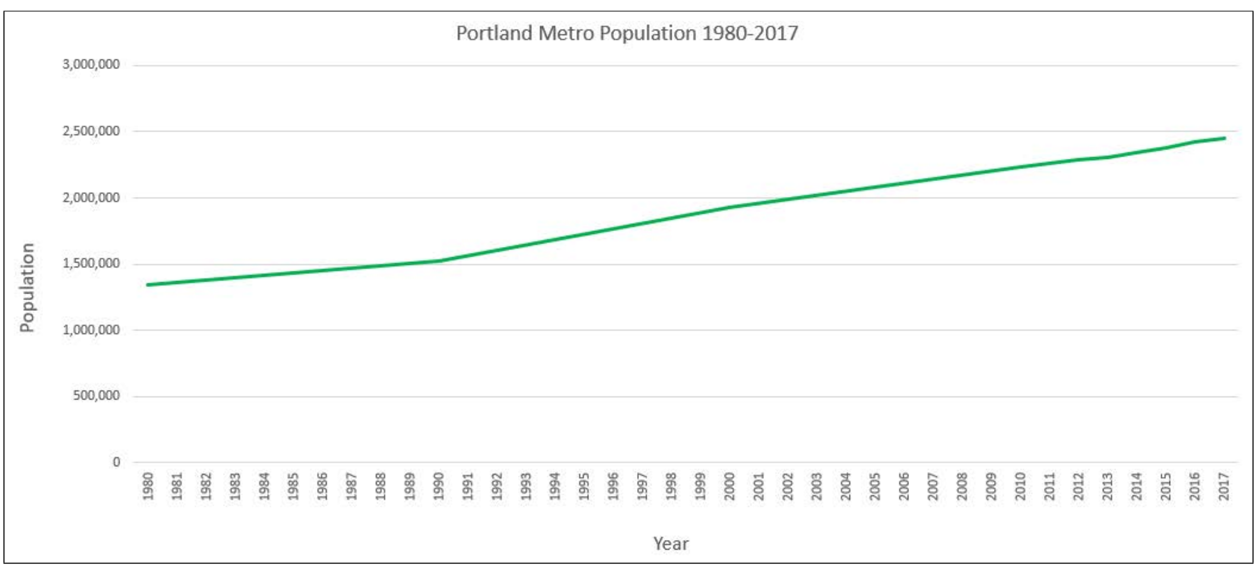

Fig 1 Population of the Portland metro area by year.

The purpose of this paper is to determine the net change in vegetation in the Portland Metro Area from 1984 to today. 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 was first noted by the pioneering meteorologist Luke Howard in 1820.[4] This effect is driven by cities' use of heat-absorbing materials (asphalt, concrete, etc.) to build urban structures, a lack of vegetation, which cool 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 urban expansion.

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) decreases with distance from the city center, the temperature should decrease as a function of distance from the city center.

2 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 thermal data to a

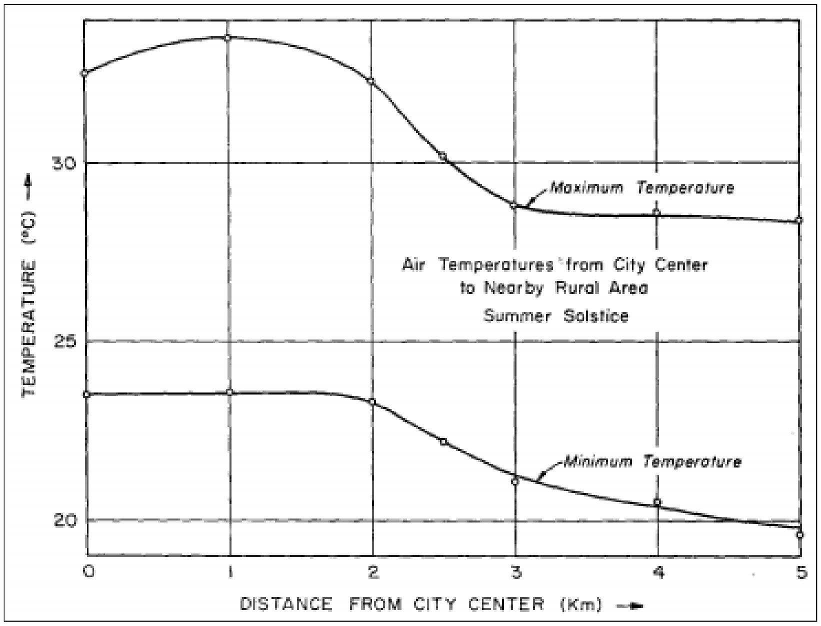

Fig 2 Figure from Myrup's paper showing the temperature falloff as one travels farther from the city center for a hypothetical city.[6]

spectral radiance detected at the satellite:

$$L_\lambda = M_L Q_{cal} + A_L \tag{1}$$

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 satellites thermal sensor by

$$T_{TOA} = \frac{K_2}{\log(\frac{K_1}{L_\lambda} + 1)} \tag{2}$$

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.[7]

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 was followed to correct T_{TOA} for the emissivity of different terrain to determine the land surface temperature T_S.[8]

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. 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.

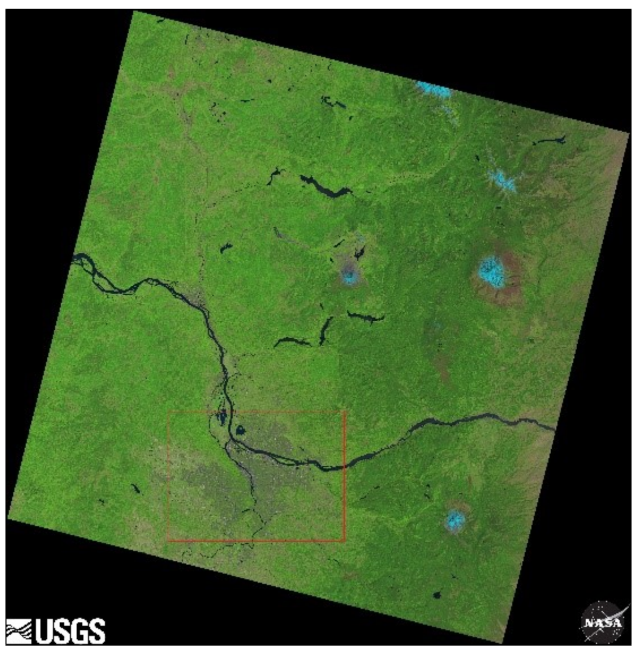

Fig 3 Natural color image taken on 7/14/2017 from Landsat 8. The approximate location and size of the Portland metro area is bounded by a red box.

To account for any effect elevation might have on temperature, elevation data is taken from GMTED2010. The elevation and distance data for a given path are regressed onto T_S to yield a

Fig 4 Natural color image of Portland from 7/14/2017 cropped to show the paths taken for the UHI analysis.

regression of the form

$$T_s = a_d d + a_e e + c. \tag{3}$$

where d is the distance (in km) from Pioneer Courthouse Square and e is the elevation (in meters) at that point. Since this model contains heteroskedasticity, this regression is accomplished using a Generalized Least Squares method. Any regression where the p-value for distance $>$ .05 is dropped from the analysis.

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

$$M_{UHI} = |a_d|. \tag{4}$$

The Enhanced Vegetation Index, a method of determining the amount of vegetation in an area, for

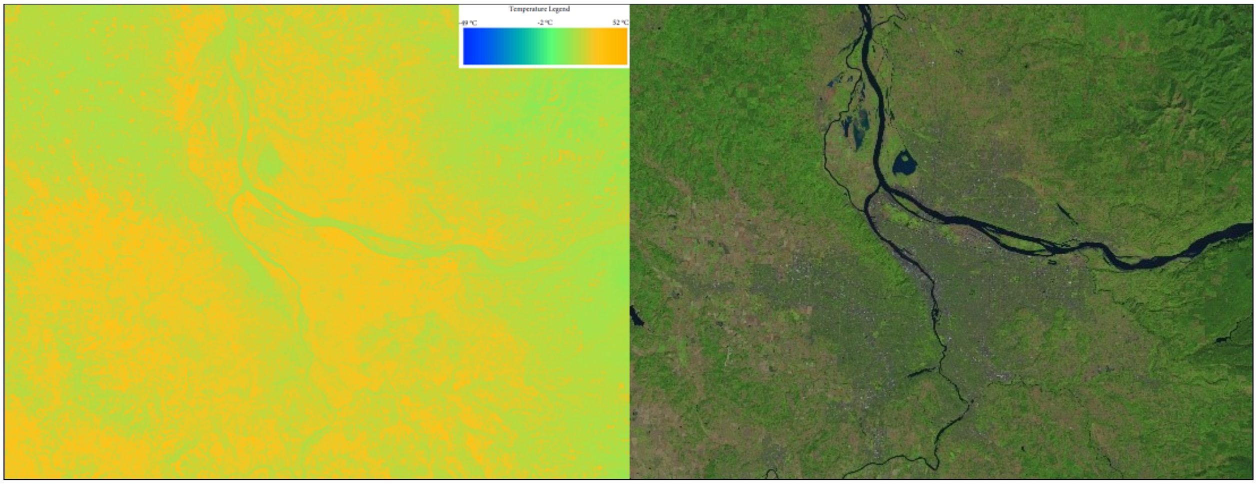

Fig 5 False color thermal image (left) and natural color image (right) of Portland dated 9/13/2016. Note that the dull colored, urban areas register a higher temperature than the surrounding rural greenery.

Portland is also determined from the Landsat 4 TM & Landsat 8 OLI. The EVI of a pixel in our Landsat images is given by:

$$EVI = 2.5\frac{NIR_{ref} - R_{ref}}{NIR_{ref} + 6R_{ref} - 7.5B_{ref} + 1} \tag{5}$$

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.[9]

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

$$NDVI = \frac{NIR_{ref} - R_{ref}}{NIR_{ref} + R_{ref}}. \tag{6}$$

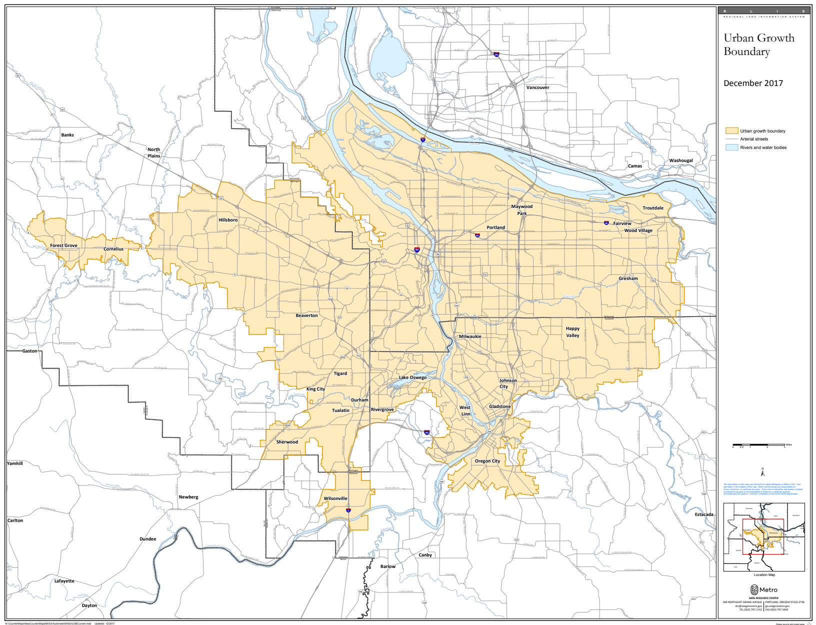

Fig 6 Map of the Portland Metro Area.[10]

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

$$P_v = \left(\frac{NDVI - NDVI_S}{NDVI_V - NDVIS} \right)^2 \tag{7}$$

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. $NDVI_S = 0.2$ and $NDVI_V$ is determined on a case-by-case basis.

3 Methodology

A number programs were written in Python to extract the temperature and vegetation data from each of the images. Setting our origin as Pioneer Courthouse Square (latitude: 45.518 0N, Longitude: 122.679 0W), 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 (Fig. 6) is also extracted from each dataset using a Python algorithm. The metro area has been updated a number of times since 1984, but only the most current boundary is used (circa May 2018). 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.[11]

To determine $NDVI_V$, a histogram is generated of NDVI vs. the number of pixels with that NDVI value. Since the full images of the Portland area include a huge amount of forests and vegetation (see Fig. 3), it is assumed that the NDVI with the largest pixel count is fully vegetated. An example histogram is shown below:

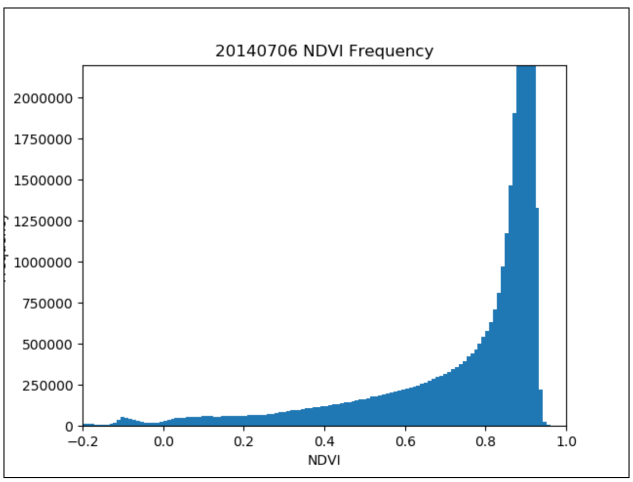

Fig 7 Histogram of NDVI vs. Pixel Count on 7/6/2014.

$NDVI_V = 0.87$ for the date 7/6/2014 (see Fig 7 above). This step is repeated for all images. Since the elevation and temperature data display heteroscedasticity, a generalized least squares regression technique is used to obtain M_{UHI}.

4 Results

Fig. 10 depicts the magnitude of UHI over time for the directions studied. The figure doesn't seem to contain any discernible upward or downward trend, and a regression of the time trend on M_{UHI}

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

Regression Statistics		
Direction	R-Squared	P-Value
East	0.018099	0.314002
Northeast	0.007532	0.517135
North	0.028248	0.224433
Northwest	0.001796	0.765451
West	0.018453	0.629293
Southeast	0.012964	0.399038

for the various directions confirms that all of the regression results are insignificant; implying that there is no general trend upward or downward in time. This stability is supported by a cursory 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. The regression statistics for time onto EVI is also insignificant (p-value=0.405), indicating that there is no evidence of declining vegetation in the Portland Metro Area for the past three decades.

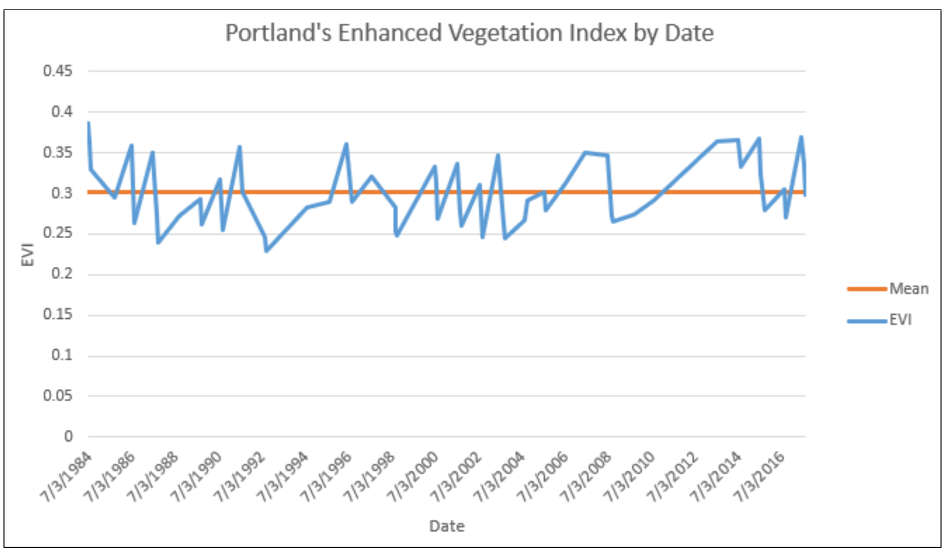

Fig 8 Average EVI of a pixel in the Portland metropolitan area by date. Note that the EVI remains remarkably close to the mean value, implying no general upward or downward trend.

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 16% increase from 2010 to 2013, but the value falls back down to the log-run mean of 34% after 2013.

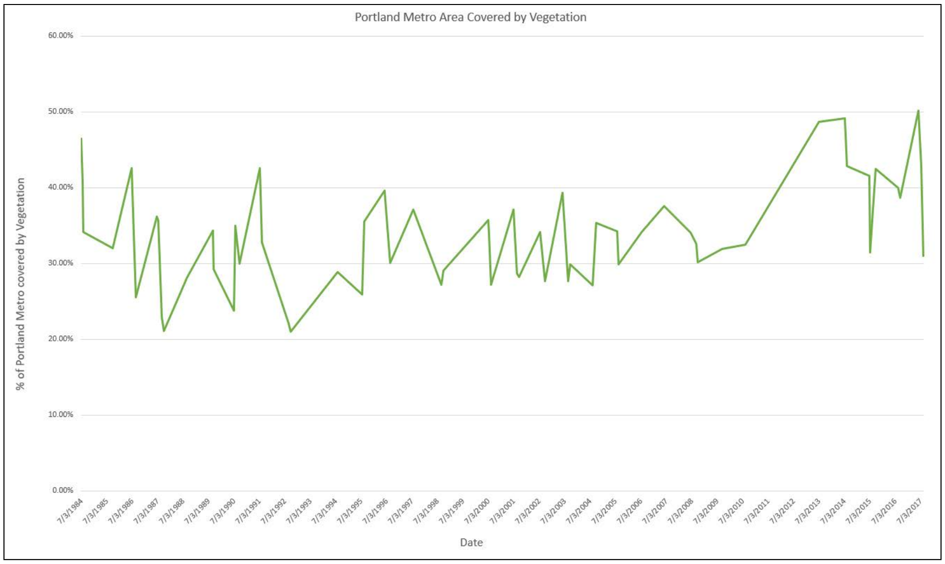

Fig 9 Percentage area of the Portland metro area covered by vegetation by date.

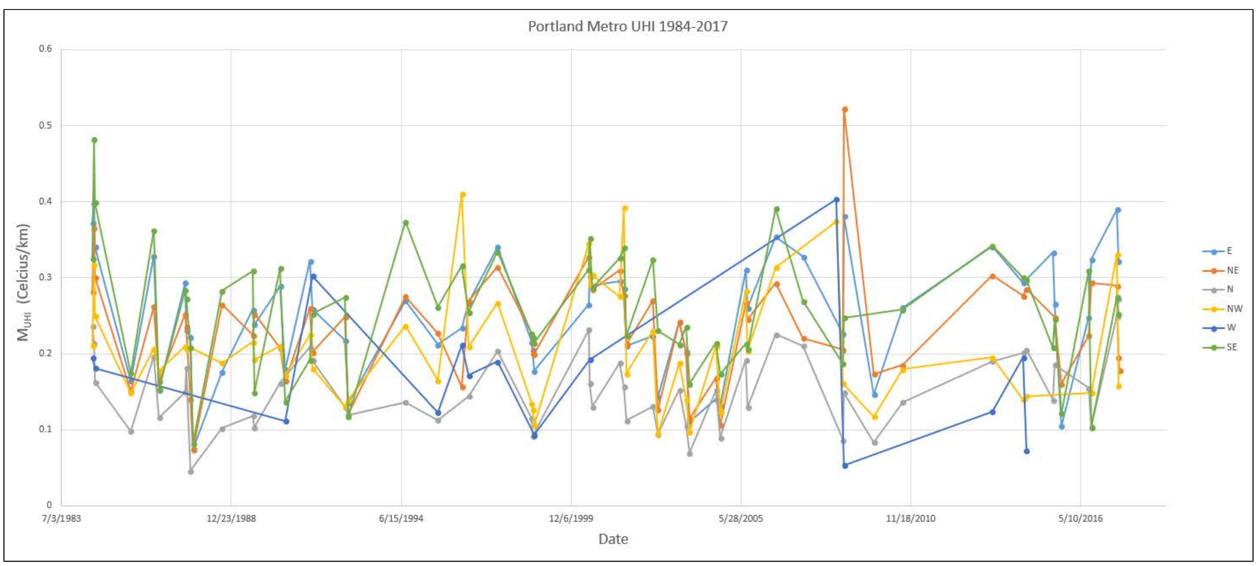

Fig 10 M_{UHI} for various directions versus time. The linear regression of M_{UHI} onto time is insignificant for every direction.

5 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 and implies that Portland's policies to keep its urban expansion's impact on its green spaces have been effective. This may partly be due to the Portland region's urban growth boundary, a law that restricts urban development on Portland's periphery, but even the vegetation indices inside the urban growth boundary have remained stable over the past three decades. We conclude Portland has been able to grow in population without adversely impacting the local vegetation canopy.

References

1 City of Portland, "Green building initiatives." https://www.portlandoregon.gov/bps/41481. Accessed: 2018-06-12.

2 Portland Metro Authority, "Parks and Nature 2016: Building on Metros unique park system with nature at its heart." https://www.oregonmetro.gov/parksandnature2016. Accessed: 2018-06-12.

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." https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk. Accessed: 2018-06-12.

4 L. Howard, *The Climate of London: Deduced from Meterological Observations, Made at Different Place in the Neighborhood of the Metropolis*, W. Phillips, George Yard, Lombard Street, London (1818).

5 K. Deilami, M. Kamruzzaman, and Y. 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**, 30–42 (2018).

6 L. Myrup, "A numerical model of the urban heat island," *Journal of Applied Meteorology* **8** (1969).

7 United States Geological Service, *Landsat 8 (L8) Data Users Handbook*, United States Geological Service (2016).

8 D. Jeevalakshmi, D. S. N. Reddy, and D. B. Manikiam, "Land surface temperature retrieval from landsat data using emissivity estimation," *International Journal of Applied Engineering Research* **12**, 9679–9687 (2017).

9 United States Geological Service, "Landsat surface reflectance level-2 science products." https://landsat.usgs.gov/landsat-surface-reflectance-data-products. Accessed: 2018-06-14.

10 Portland Metro Authority, "Urban growth boundary maps." https://www.oregonmetro.gov/urban-growth-boundary-maps. Accessed: 2018-05-30.

11 United States Geological Service, "Band designations of the Landsat Satellites." https://landsat.usgs.gov/what-are-band-designations-landsat-satellites. Accessed: 2018-05-18.

List of Figures

List of Tables