Tree of Heaven (Ailanthus *altissima*)

Investigating The Distribution of Tree of Heaven (ToH) under Future Climate change in the United Kingdom (UK)

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Abstract

Tree of Heaven is an invasive species as it upsets the habitat equilibrium by outcompeting and displacing local habitats. 19 climate variables were chosen for the two different time periods i.e., 1970-2000 (historic) and 2021-2040 (future), to investigate the distribution of Tree of Heaven under future climate change in the UK. The results project the entire UK to be covered by ToH by 2040. 47% of their distribution is explained by climate variables which were calculated to be statistically significant (p<0.001). The increase in the distribution of ToH is in accordance with climate change and the rise in average temperature in the UK. Further localized research is required to understand the relative invasion risks posed by ToH under future climate change in the UK.

Introduction

- Invasive species are widely regarded as one of the most serious threats to biodiversity on the planet (Walker and Steffen, 1999).
- They alter ecosystems, influence ecological processes or overall ecosystem functions, and lead to significant economic losses (Consta´n-Nava et al., 2014). They are the result of human-caused species redistribution for agriculture, forestry, mariculture, horticulture, and leisure, as well as unintended introductions (van Wilgen et al., 2008).
- Invasive alien trees can jeopardise ecosystem services while also providing various and complex services to humans, making it difficult to weigh harm against benefits, particularly when benefits are accompanied by vested interests (Sladonja et al., 2014).
- The Tree of Heaven (scientific name-: Ailanthus *altissima*) is one of Europe's most invasive plant species (Thuiller et al., 2014). In particular, it is classified as an invasive species in the UK (Gov.UK, 2021).
- Tree of Heaven is a native of China and North Vietnam that was intentionally introduced for use as an ornamental plant in the 18th century (Kowarik and Saumel, 2007). It thrives in urban areas and along transportation routes due to accelerated juvenile growth (Burch and Zedaker, 2003) and the ability to endure adverse environmental conditions (Lawrence et al., 1991).
- Its prolific seed production (350,000 per female tree/year) capabilities implies that it can also infiltrate natural areas (Nel et al., 2004). Climate is a prevailing factor in influencing the spread of the ToH globally (Walker et al., 2017), and it grows extensively in warmer climates (Pearson and Dawson, 2003).
- It is therefore important to model climate change as it may alter the distribution of invasive species in future globally.

Objectives

1. Test the following hypothesis by a multivariate regression model by using the historical climate variables.
   H_1 = Climate is a factor in determining the distribution of ToH
   H_0= Climate is not a factor in determining the distribution of ToH

2. What climate variables are the most significant in determining the distribution of ToH?
3. How is the distribution of ToH likely to shift as a result of future climate change?

Table '1'

Bio Climate Variable Code	Bio Climate Variable Name
BIO1	Annual Mean Temperature
BIO3	Isothermality i.e., Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO8	Mean Temperature of Wettest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation

Table '1' shows the 5 climate variables that were used in the final regression model to calculate the future distribution of ToH.

Methods

The observations data points for ToH (downloaded from https://www.gbif.org). 19 no. of historical (1970-2000) and future (2021-2040) climate variables (downloaded from https://www.worldclim.org/data/worldclim21.html at 10-minute resolution) were loaded into the QGIS application.

Step 1-:

- The ToH and climate variable layers were clipped to the UK shapefile. Then, we converted the ToH point data to a continuous format and then, into a point vector layer.
- Then, the density map from the above vector layer was created with a radius of 2 unit. Then, that density map was clipped to the UK again. After that, resampling was done to match the climate layer.

Step 2-:

A multivariate linear regression model was run with 19 climate variables using the above-resampled density map. This step was used to answer **objective 1.**

Step 3-:

- A covariance matrix was formulated with all the 19 variables to find the interrelated variables. Then, any variables having a correlation between -0.7 and 0.7 with each other were excluded from the analysis.
- The remaining variables were-: BIO1 (Annual Mean Temperature), BIO3 (Isothermality i.e., Mean Diurnal Range (Mean of monthly (max temp - min temp))), BIO8 (Mean Temperature of Wettest Quarter), BIO11(Mean Temperature of Coldest Quarter), and BIO12(Annual Precipitation).

Step 4-:

No variables were transformed because logarithmic transformation didn't improve the normal distribution.

Step 5-:

Multiple linear regression models were derived to find which climate variables were significant to determine the ToH distribution. This was to answer **objective 2.**

Step 6-:

- Variables were excluded from the analysis if the AIC (Akaike Information Criterion) score was not lower than the previous models run. After that, the model in which the AIC score of the variables was the lowest was the most significant model.
- Then, the historic and future maps were converted to binary maps by raster calculation (>0). Then, a raster calculation was estimated to get the future distribution of ToH by using 5 significant variables to by using the equation-: **$y=m_i x_i$ (i=1,2,3,4) + c**

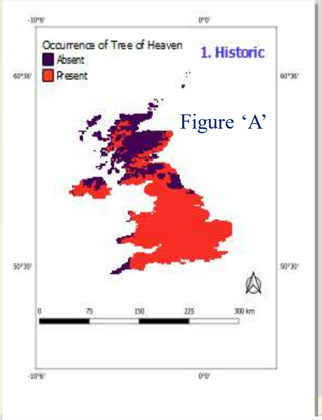
Where y= Future distribution of ToH in the UK

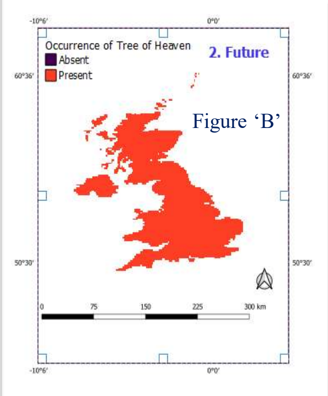
m_i= Slope value= b_i

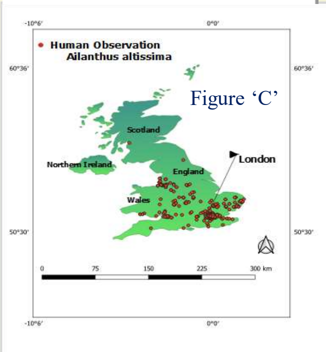
x_i= Clipped raster layer of future climate variables

c= b_0, y-intercept

This was done to answer **objective 3.**







- ***Figure 'A'*** *describes the occurrence of Tree of Heaven (ToH) in the UK generated by the model consisting of historic climate variables. It is clear from the map that ToH is absent in most of the North of the UK.*
- ***Figure 'B'*** *projects the occurrence of ToH in the UK by the year 2040 by the model that includes future climate variables. Almost all of the UK is projected to be covered by ToH by 2040.*
- ***Figure 'C'*** *shows the actual number of Ailanthus altissima (scientific name of ToH) present in the UK.*

Results

- Climate was found to be significant factor in determining the distribution of ToH. ***(n=4328, DF-denominator= 4308, DF-numerator=19, R-squared value= 0.7130, F-ratio= 563.352487)***
- The final model R_{sq} (the strength of correlation) was found to be 0.4738 which means 47. 38% of the variation of ToH is explained by climate variables (p<0.001; statistically significant with 99% confidence).
- Final Model Results-***: n= 4328, DF denominator= 4308, DF numerator= 5, Final R-squared value= 0.473848, F-Ratio= 778.471893, AIC= 40631.145765***
- The current observational data points for ToH (Figure 'C') show that only the density of ToH of South-East part of England, and the density of ToH of South-West of England is comparatively less.
- The density of ToH of Wales is less compared to Central England. Also, the density of ToH Scotland is negligible whereas the density of ToH in Northern Ireland is nonexistent.
- On the other hand, the future regression model (Figure 'B') suggests that there is a major migration in the density of ToH in the northern part of the UK by 2040 because of climate change.
- The model residual error suggests that the historic model has overestimated the density of ToH.

Discussion

- ToH is mostly seen around south-east of England. It is omnipresent in London. Our findings seem to corroborate those of Walker et al. (2017), who found that ToH is more common in densely populated cities and areas with a high human footprint. This high human-mediated disturbance, along with anthropogenic forces such as multiple transit routes and dispersal corridors in built-up areas, have served as effective mechanisms for fostering ToH spread across urban environments in the south-east of the UK (Pearson and Dawson, 2003; Hulme, 2009).
- Almost 47% of the variation of the ToH is explained by the climate variables. This may be due to other possible factors that could affect the distribution of ToH such as land use, human-mediated disturbances (Walker et al., 2017; Nel et al., 2004).
- Because of climate change, it is projected that by the end of the twenty-first century, all parts of the United Kingdom are expected to be warmer, more so in summer than in winter (UK Met Office, 2019). Various literatures have cited that ToH prefers warmer climates. So, the projection of the increased distribution of ToH over the northern part of the UK by 2040 is in accordance with the literatures (Donaldson et al., 2014).
- A risk assessment on ToH can be done on potential cities in the UK where the human footprint is projected to increase or where the average temperature is forecasted to increase comparatively higher than the national average temperature because of climate change (Sudnik-Wojcikowska, 1998). A further economic evaluation of ToH effects in the UK is needed on a localized scale to account for heterogeneous environments (Burch and Zedaker, 2003).
- Various studies have also pointed out that ToH has multiple utilization in various sectors such as herbicidal, insecticidal and medicinal sectors because of its high ecological adaptability. Hence, the potential applications of ToH in environmental restoration may also be carefully investigated (Sladonja et al., 2014; Hijmans and Graham, 2006).

Conclusion

- This modelling study highlights the potential of increased invasion risk of ToH across the UK. However, a key limitation of our model is that it does not consider other factors that can impact the distribution of ToH. As such, further research implementing more complex models may help obtain more accurate estimates of ToH distribution (Nel et al., 2004).
- Additionally, the model overestimates the current distribution of ToH, which may have important implications for environmental managers utilizing the data in this study (Pearson and Dawson, 2003).

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