Spatial Analysis of Forest Canopy Loss and Population Change in Puerto Rico (2011-2021)

Introduction

Over the last decade, Puerto Rico has experienced both a decline in population and noticeable changes in forest canopy cover. Many municipalities have seen population decreases due to migration, economic shifts, and natural disasters, while forest cover has fluctuated in complex ways—declining in some areas and recovering in others. This project explores whether there is a connection between these two trends by analyzing percent changes in population and forest canopy cover from 2011 to 2021 across the island.

Methods

Population estimates of Puerto Rico's municipalities for 2011 and 2021 were obtained from the U.S. Census Bureau and joined with the municipality boundaries from the USGS National Boundary Dataset using the sf and dplyr packages in RStudio. The population change was calculated as the percent change from 2011 and 2021. Forest canopy cover data for 2011 and 2021 was obtained from the NLCD Tree Canopy Cover dataset for Puerto Rico. The terra and exactextractr packages were used to calculate the mean canopy cover for each municipality which was then used to calculate the percent change.

In order to understand the relationship between Puerto Rico's population change and canopy cover loss, an initial linear regression model was fitted:

```
model <- lm(Canopy_Decrease_Percent ~ Pop_Change_Percent, data = pop.data)
```

The spatial dependence in the residuals was evaluated using Moran's I in order to account for any spatial autocorrelation. Queen contiguity neighbors and row-standardized spatial weights were used. As spatial autocorrelation was found to be significant within the data, a spatial lag model was fitted using:

```
lag.model <- lagsarlm(Canopy_Decrease_Percent ~ Pop_Change_Percent, data = pop.sp, listw = weights,
method = "eigen")
```

The fitted values and residuals from the spatial lag model were extracted for visualization.

Results

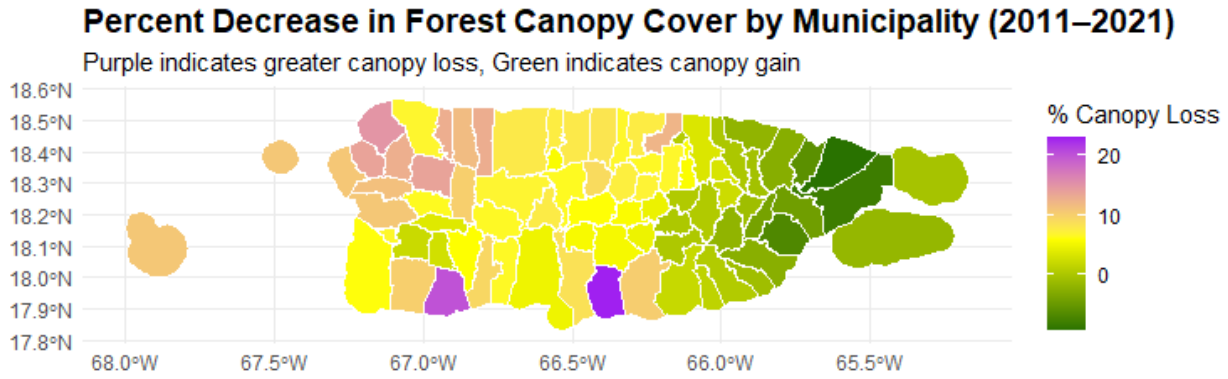

Figure 1

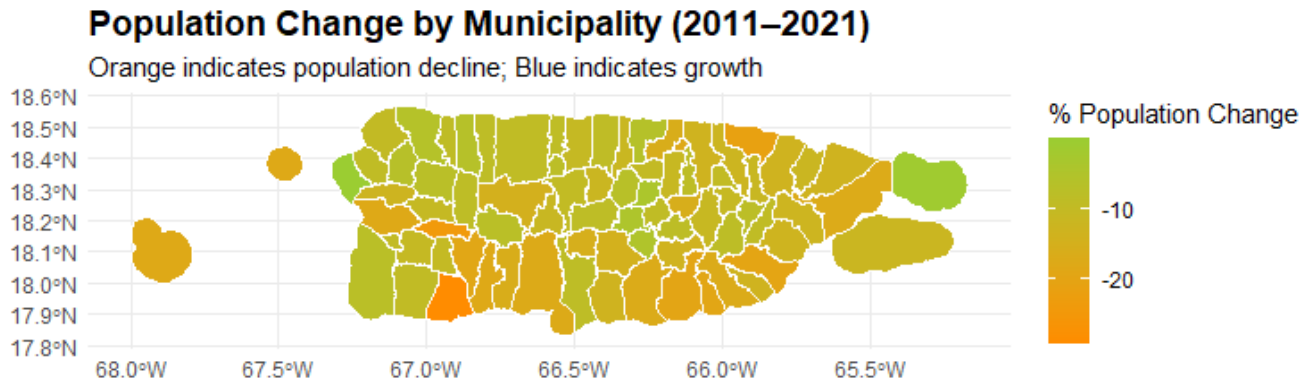

Figure 1

Preliminary data exploration found that Puerto Rico's canopy change varied across the island as seen in Figure 1. On average, the municipalities experienced a ~5% decrease in canopy cover. The maximum canopy loss was ~23%, and the minimum was ~ -9.4%, or a 9.4% increase in canopy cover.

Figure 2 depicts the negative population change throughout the entire island. On average, municipalities reported an ~11.7% decrease. The maximum population decrease was ~29.3% and the minimum was ~0.13%.

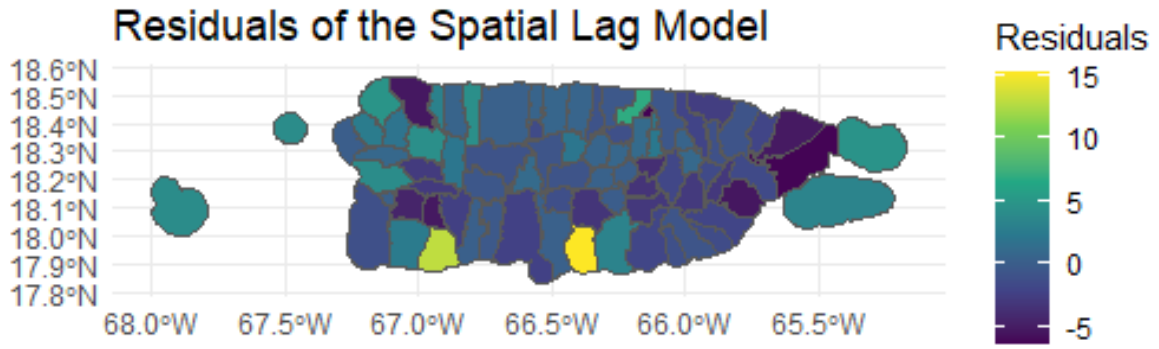

Figure 3

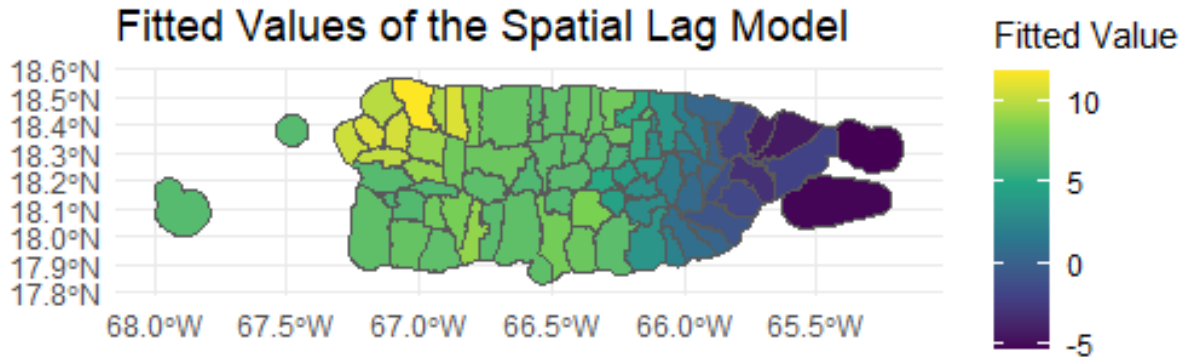

Figure 4

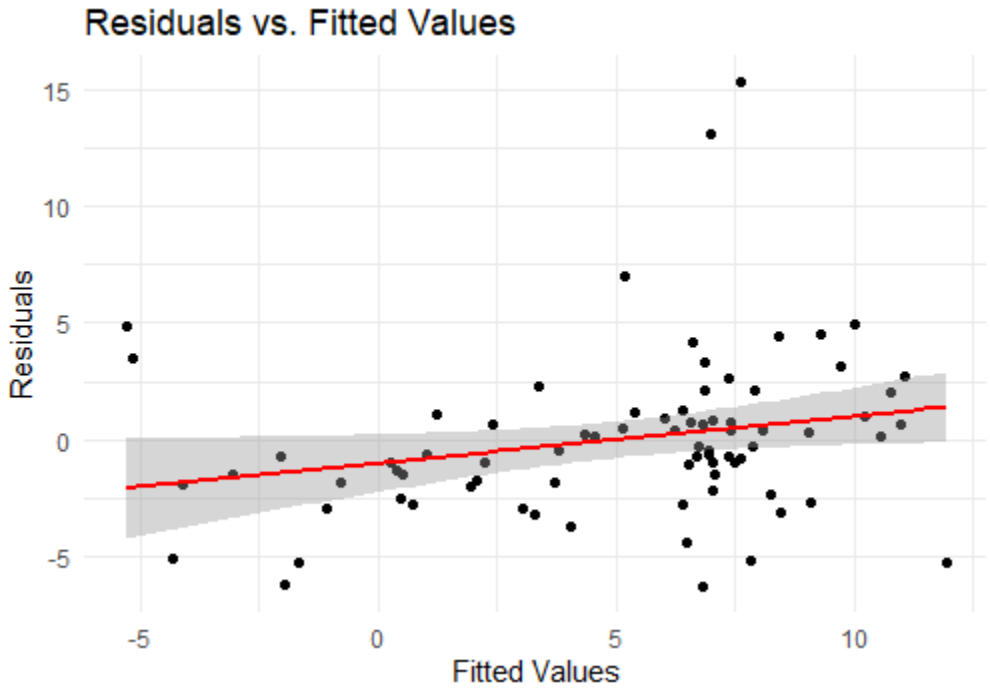

Figure 5

The ordinary least squares (OLS) regression model indicated that population change and canopy loss had a weak correlation. A Moran's I test on the residuals determined significant spatial auto correlation ($I = 0.34$, $p < 0.01$). The spatial lag model yielded a stronger fit with the following results:

- **Spatial autoregressive coefficient (ρ):** 0.79017 ($p < 0.0001$), indicating strong spatial dependence
- **Coefficient for Pop_Change_Percent:** -0.0115 ($p = 0.886$), suggesting no statistically significant relationship with canopy loss
- **Model comparison:** AIC = 440.57 for spatial lag model, vs. AIC = 506.31 for OLS model

Maps of residuals (Figure 3) and fitted values (Figure 4) from the spatial lag model depicted reduced spatial clustering in residuals and a better representation of canopy loss patterns. The scatterplot of observed versus fitted values (Figure 5) showed improved predictive accuracy compared to the non-spatial model.

Discussion

The results showed that while increased population change was hypothesized to influence canopy loss, their relationship was not statistically significant. However, the strong spatial dependence within the canopy change suggested that patterns were shaped by factors shared by municipal neighbors. These factors could include hurricane damage, land development, elevation, or conservation efforts. The spatial lag model demonstrated a much better fit in comparison to the linear regression model.

By focusing on a singular factor in canopy change, much of the greater picture was lost. In order to better understand which factors influence canopy loss, further data must be obtained. Economic factors, infrastructure/urbanization, land development, agricultural practices, hurricane damages, and climate induced temperature/precipitation changes would all serve as potential factors. By analyzing these additional factors, the patterns detected in Puerto Rico's canopy change may be better explained.

Conclusion

This study explored the relationship between Puerto Rico's population and forest canopy change from 2011 to 2021. While population change did not significantly predict canopy loss, spatial autocorrelation was strong. These findings underscore that a single factor cannot serve as an understanding of ecological change. Only with the addition of socioecological variables can Puerto Rico's canopy change be fully understood. Looking forward, the clusters identified may serve as points of interest when analyzing other factors.

Data

U.S. Census Bureau, Population Division. (2021). *Annual estimates of the resident population for Puerto Rico municipios: April 1, 2020 to July 1, 2021 (PRM-EST2021-POP)* [Data set]. U.S. Department of Commerce.

U.S. Census Bureau, Population Division. (2011). *Table 1. Annual estimates of the resident population for municipios of Puerto Rico: April 1, 2010 to July 1, 2011 (PRM-EST2011-01)* [Data set]. U.S. Department of Commerce.

U.S. Forest Service (USFS). (2011, 2021). *National Land Cover Database (NLCD) Tree Canopy Cover (PRUSVI)* [Data sets]. U.S. Department of Agriculture.

U.S. Geological Survey, National Geospatial Technical Operations Center. (2024, November 14). *USGS National Boundary Dataset (NBD) in Puerto Rico State or Territory (published 20241114) Shapefile* [Data set]. U.S. Geological Survey.