Impact of Reforestation on Wildfire Severity in California: A GIS-Based Analysis

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***Abstract*—California, with its diverse landscapes and increasing wildfire threats, faces a critical challenge in managing the spatial dynamics of tree-planting initiatives and fire risk. This study investigates the spatial relationship between urban tree-planting areas and wildfire-severity zones in California using advanced spatial analysis techniques. By integrating data on fire-hazard severity from CAL FIRE and urban tree-canopy cover from the U.S. Department of Agriculture, the analysis employs the Global Moran's I tool using Inverse Distance, K-Nearest Neighbors, and Fixed Distance Band methods to assess spatial autocorrelation patterns. The results reveal a slight positive spatial autocorrelation, indicating that tree-planting efforts are somewhat clustered in areas with varying levels of fire severity. Significant overlaps are found between tree-planting initiatives and high or very high fire-severity zones, suggesting a potential alignment with fire-risk mitigation strategies. Despite these insights, the analysis is constrained by such limitations as high neighbor counts in the Inverse Distance method and data gaps in the Fixed Distance Band method. Future research should address these limitations by refining analytical parameters and incorporating dynamic data to better understand and optimize the spatial relationship between reforestation efforts and wildfire risks. The findings offer valuable implications for improving tree-planting strategies and enhancing environmental sustainability in the context of wildfire management.**

Keywords—Wildfire; Severity; Spatial Autocorrelation.

I. INTRODUCTION

California, known for its vast landscapes and diverse ecosystems, faces an escalating threat from wildfires [1]. These destructive events have increased in frequency and intensity, posing significant risks to communities, wildlife, and natural resources. Understanding the causes and consequences of wildfires is crucial for developing effective mitigation strategies. One emerging area of interest is the potential correlation between tree-planting initiatives and wildfire outbreaks.

Tree planting, often promoted to combat climate change and enhance urban environments, may have unintended consequences if not properly managed. Recent studies, such as those conducted in Chile, suggest that reforestation efforts without adequate consideration of species selection and environmental impact can exacerbate fire severity [2]. Despite these insights, California lacks comprehensive protocols and checks for tree-planting projects, raising concerns about their role in the state's growing wildfire crisis [3].

This geographic information system project aims to explore the spatial relationship between tree-planting initiatives and wildfire outbreaks in California. By integrating data and employing advanced spatial analysis techniques in ArcGIS Pro, including Global Moran's I, K-Nearest Neighbors, and Fixed Distance Band methods, we sought to uncover patterns and potential correlations. The project leverages data on severe-fire areas and urban tree-planting initiatives to identify hotspots and assess the influence of reforestation on fire severity.

Our findings provide valuable insights into the environmental effects of tree-planting initiatives and inform policy recommendations for sustainable reforestation practices in California. Ultimately, this research strives to contribute to a better understanding of wildfire dynamics and support efforts to mitigate their impact on communities and ecosystems.

Section 2 reviews the relevant literature. Section 3 lays out the methods we used in our study. Section 4 discusses the results of our study. Section 5 concludes.

II. LITERATURE REVIEW

California's history with wildfires is both extensive and devastating, marked by significant events that have shaped the state's landscape and policies. In recent years, several wildfires have set new records for size, destruction, and fatality rates, highlighting the increasing severity of these events. The August Complex Fire of 2020, the Dixie Fire of 2021, and the Camp Fire of 2018 are among the most catastrophic in terms of acres burned, structures destroyed, and lives lost (Figure 1). These fires illustrate a troubling trend: wildfires in California are becoming more frequent and intense, largely due to human activities and climate change. The article in [1] provides a comprehensive overview of California's wildfire history, detailing the 20 largest, deadliest, and most destructive fires. It underscores the critical need for informed strategies to prevent and mitigate future wildfires. The data presented, including annual fire counts, acres burned, and suppression costs, offer valuable insights into the escalating wildfire crisis and the urgency of addressing it. The escalating wildfire crisis in California is not an isolated phenomenon; similar trends have been observed globally, notably in Chile.

In examining global reforestation patterns, researchers have identified significant trends and outcomes with broad implications for environmental policy and biodiversity. Investigations into these patterns have revealed that a substantial portion of new forests will likely consist of plantations rather than natural, diverse forests. This shift towards monoculture plantations is largely driven by economic incentives and the demand for specific types of wood and agricultural products. In Chile, for instance, reforestation efforts have led to an increase in tree cover, yet

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this has come at the cost of biodiversity [2]. The dominance of monoculture plantations has reduced the variety of species within these forests, undermining the ecological balance and resilience of the region's natural habitats.

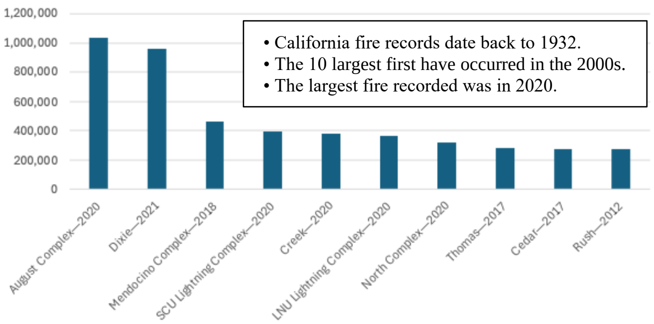

Figure 1. Ten Largest Recorded Fires in California.

While reforestation offers amazing benefits when implemented properly—such as carbon sequestration, soil stabilization, and habitat restoration [4]—Chile's approach has highlighted some critical pitfalls. The country experienced its worst fire season in history in 2024, and experts believe this is largely due to the extensive planting of monoculture forests, which are more susceptible to fire. These findings underscore the need for reforestation strategies that prioritize ecological diversity and sustainability to mitigate the negative impacts on biodiversity and reduce the risk of severe wildfires [2]. The lessons learned from Chile's reforestation challenges underscore the importance of implementing strategic and ecologically sound tree-planting efforts. Poorly designed campaigns could cause more harm than good [3].

Jordan [3] raises critical concerns about large-scale tree-planting campaigns and afforestation subsidies. It highlights that 80% of commitments to the Bonn Challenge, a global initiative aimed at restoring 350 million hectares of degraded and deforested lands by 2030 [5], involve planting monoculture tree plantations, using limited tree mixes focused on specific products like fruit or rubber, and prioritizing plantations over natural forest restoration. These practices might not only fall short of climate goals, but also exacerbate biodiversity loss. The analysis of Chile's Decree Law 701, a significant afforestation program, underscores how poorly designed subsidies can lead to negative outcomes by replacing biodiverse, carbon-rich native forests with less effective plantations [2]. To ensure that tree-planting efforts contribute meaningfully to climate and conservation goals, policies must enforce strict guidelines to prevent the conversion of natural forests into monoculture plantations, thereby promoting genuine ecological restoration and preserving biodiversity. The United States has designated 17 million hectares for restoration while avoiding key biodiversity areas. This trend underscores the need for critically evaluating and improving implementation methods, as seen in California, where current tree-planting strategies do not seem to favor the preservation of natural biodiversity.

Urban tree-planting programs in Los Angeles have been criticized for lacking clear environmental criteria to guide tree selection [6]. This oversight can result in choices that do not support local biodiversity or environmental health. Furthermore, there is no systematic monitoring of the effects of tree planting on the city's environment, making it difficult to assess the success or failure of these initiatives. The Mayor's Tree L.A. (MTLA) program exemplifies these shortcomings, as it lacks a comprehensive, identifiable plan for achieving its goals. Instead, it tends to operate opportunistically, planting trees where partnerships can be established rather than following a strategic, science-based approach [6]. This method may lead to suboptimal outcomes for the urban ecosystem and reduce the overall effectiveness of tree-planting efforts in contributing to urban resilience and sustainability.

III. METHODS

Our methods included data selection, spatial autocorrelation analysis and hotspot analysis.

A. *Data Selection and Acquisition*

We used two key data layers for this analysis. The first layer, detailing fire-hazard severity, was obtained from CAL FIRE's official database [7] and categorizes fire-hazard zones into three classes: moderate, high, and very high. This classification aids in understanding the varying degrees of fire risk across different California regions. The second layer comprises urban tree-canopy data from the U.S. Department of Agriculture [8], created by EarthDefine based on 2018 National Agriculture Imagery Program (NAIP) aerial imagery and light distancing and ranging data collected by the U.S. Geological Survey. The NAIP imagery, captured during the growing season, includes four spectral bands (red, green, blue, and near-infrared) at a 60-cm spatial resolution. Together, these layers offer a comprehensive view of both fire-hazard risks and the extent of urban tree cover, which is crucial for evaluating the intersection of fire management and urban forestry efforts.

B. *Analysis Phase*

The spatial correlation analysis in ArcGIS Pro begins with the preparation of data layers, which includes loading tree-planting areas and fire-severity zones. These layers are fundamental to understanding the geographic relationship between tree-planting efforts and fire-severity levels. Initially, overlay analysis is conducted using the Intersect tool, combining the tree planting and fire-severity layers to create a new layer that highlights intersecting polygons. These polygons represent areas where tree-planting initiatives coincide with different fire-severity zones. Calculating the area of these intersected polygons provides a quantitative measure of the overlap between tree-planting efforts and fire-prone areas.

Next, the analysis summarizes these areas by fire-severity category. The Summary Statistics tool calculates the total area of tree-planting zones within each fire-severity category, producing a summary table (Table 1). This table is crucial as it breaks down the data into understandable segments, showing the extent of tree-planting efforts in areas with moderate, high, and very high fire risk. Calculating the percentages of these areas relative to the total tree-planting area helps illustrate the proportion of tree-planting efforts that fall within each fire-severity category, providing a clearer

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picture of whether tree-planting initiatives are strategically aligned with regions of higher fire risk.

TABLE 1. ARCGIS SUMMARY TABLE

Object ID	Hazard Class	Incidents	Intersect area (m^2)
2	Moderate	784	690,518,868.872831
1	High	584	549,820,249.080611
3	Very high	1,130	895,145,371.297078

The summary table of the intersected areas provides insights about the distribution of tree-planting efforts within different fire-severity zones, along with the frequency of intersected polygons. For instance, there are 584 polygons intersecting with high fire-severity zones, covering a total area of 549,820,249.08 square meters.

These findings are significant as they illustrate both the frequency and proportion of tree-planting efforts located within different fire-severity zones. By calculating the percentages of these areas relative to the total tree-planting area, the analysis provides a clearer picture of whether tree-planting initiatives are strategically aligned with regions of higher fire risk. The data indicates that a notable portion of tree-planting efforts is concentrated in areas with very high fire risk, suggesting a potential alignment with fire-mitigation strategies. However, the presence of tree planting in moderate and high fire-severity zones also underscores the need for careful planning and management to optimize the benefits of these initiatives in reducing fire risks and promoting environmental sustainability.

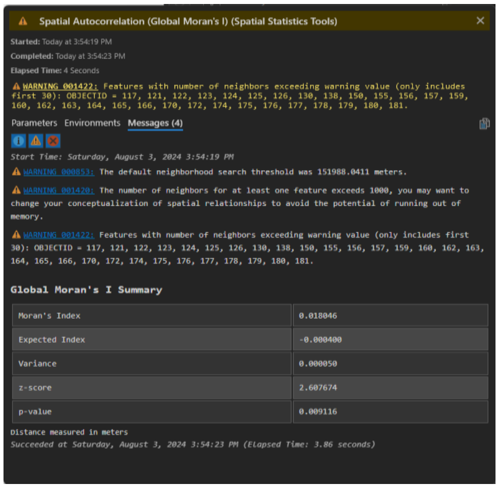
C. *Spatial Autocorrelation: Global Moran's I Tool*

Inverse Distance

We conducted the initial run of the Global Moran's I tool in ArcGIS Pro using the "Intersect_Fire_Tree" layer, focusing on the "Intersect_Area" field (Figure 2). This analysis aimed to assess the spatial autocorrelation of tree-planting and wildfire zones in California. The parameters included the conceptualization of spatial relationships using the Inverse Distance method, with distance measured in Euclidean distance and standardized by Row.

The results indicated a Moran's Index of 0.018046, suggesting a slight positive spatial autocorrelation. The expected index was −0.000400, indicating that any observed clustering is due to random chance. The variance was calculated at 0.000050. The *Z*-score of 2.607674 and the *p*-value of 0.009116 both pointed to a statistically significant clustering pattern, with the *p*-value indicating a less than 1% probability that the observed pattern is due to chance.

However, several warnings were noted during the analysis. The default neighborhood search threshold was set at 151,988.0411 square meters, and at least one feature had over 1,000 neighbors. This high number of neighbors raised concerns about the accuracy of the spatial relationship, indicating that the threshold might need adjustment to refine the analysis and ensure more precise results.



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Spatial Autocorrelation (Global Moran's I) (Spatial Statistics Tools)
Started: Today at 3:54:19 PM
Completed: Today at 3:54:23 PM
Elapsed Time: 4 Seconds
WARNING 001422: Features with number of neighbors exceeding warning value (only includes
first 30): OBJECTID = 117, 121, 122, 123, 124, 125, 126, 130, 138, 150, 155, 156, 157, 159,
160, 162, 163, 164, 165, 166, 170, 172, 174, 175, 176, 177, 178, 179, 180, 181.
Parameters  Environments  Messages (4)
Start Time: Saturday, August 3, 2024 3:54:19 PM
WARNING 000853: The default neighborhood search threshold was 151988.0411 meters.
WARNING 001420: The number of neighbors for at least one feature exceeds 1000, you may want to
change your conceptualization of spatial relationships to avoid the potential of running out of
memory.
WARNING 001422: Features with number of neighbors exceeding warning value (only includes first
30): OBJECTID = 117, 121, 122, 123, 124, 125, 126, 130, 138, 150, 155, 156, 157, 159, 160, 162, 163,
164, 165, 166, 170, 172, 174, 175, 176, 177, 178, 179, 180, 181.

Global Moran's I Summary
Moran's Index       0.018046
Expected Index      -0.000400
Variance            0.000050
z-score             2.607674
p-value             0.009116
Distance measured in meters
Succeeded at Saturday, August 3, 2024 3:54:23 PM (Elapsed Time: 3.86 seconds)
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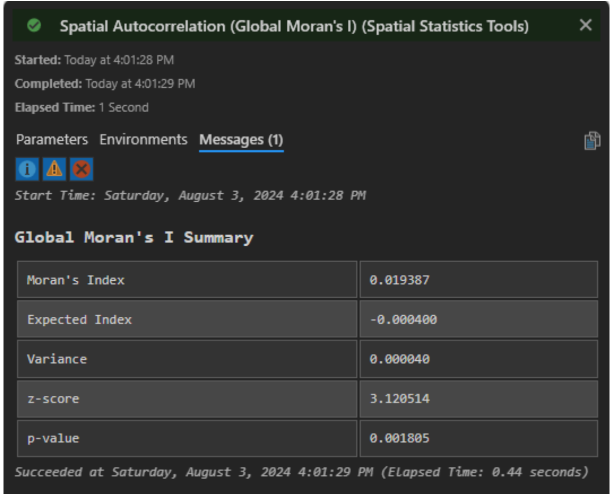
Figure 2. Initial Run of the Global Moran's I Tool.

K-Nearest Neighbor

In the second execution of the Global Moran's I tool, we conducted the analysis using the K-Nearest Neighbors method with a parameter setting of 15 neighbors (Figure 3). The results revealed a Moran's Index of 0.019387, indicating a slight positive spatial autocorrelation. This suggests that areas with higher values of "Intersect_Area" are somewhat clustered together rather than being randomly distributed. The Expected Index was −0.000400, the value one would expect if there were no spatial autocorrelation. The *Z*-Score of 3.120514 and the *p*-value of 0.001805 both signify that this observed pattern is statistically significant. The high *Z*-Score indicates that the Moran's Index is significantly different from what would be expected under the null hypothesis, and the low *p*-value supports the conclusion that the observed clustering is unlikely to be due to random chance. The choice of K-Nearest Neighbors with 15 neighbors allowed for a detailed capture of local spatial patterns, highlighting a notable tendency for similar values to be spatially grouped together.



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Spatial Autocorrelation (Global Moran's I) (Spatial Statistics Tools)
Started: Today at 4:01:28 PM
Completed: Today at 4:01:29 PM
Elapsed Time: 1 Second
Parameters  Environments  Messages (1)
Start Time: Saturday, August 3, 2024 4:01:28 PM

Global Moran's I Summary
Moran's Index       0.019387
Expected Index      -0.000400
Variance            0.000040
z-score             3.120514
p-value             0.001805
Succeeded at Saturday, August 3, 2024 4:01:29 PM (Elapsed Time: 0.44 seconds)
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Figure 3. Second Execution of the Global Moran's I Tool.

Fixed Distance Band

In the third execution of the Global Moran's I tool, we used the Fixed Distance Band method with a threshold

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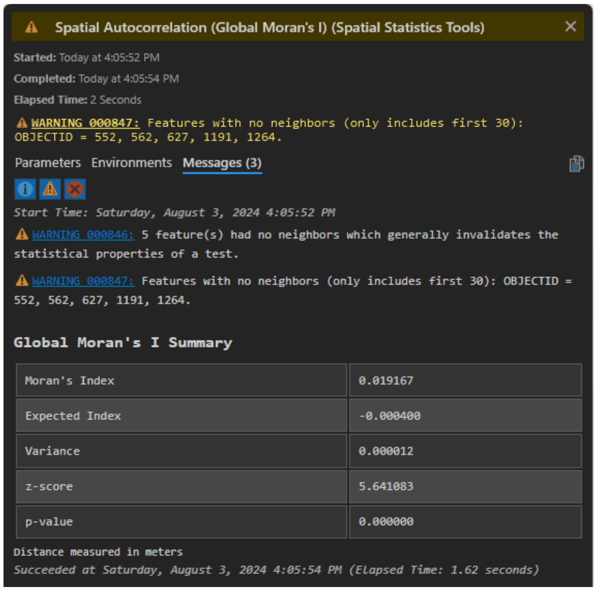
distance of 50,000 meters (Figure 4). This approach defines spatial relationships based on a fixed radius of 50 kilometers, meaning that only features within this distance from each other are considered neighbors. The results showed a Moran's Index of 0.019167, indicating a slight positive spatial autocorrelation. This suggests that areas with higher values of "Intersect_Area" are somewhat clustered together. The Expected Index was −0.000400, the value anticipated under the null hypothesis of no spatial autocorrelation. The *Z*-Score was 5.641083, a high value that points to a statistically significant deviation from the expected index, while the *p*-value was extremely low, virtually zero, underscoring the significance of the observed clustering. However, warnings indicated that five features had no neighbors within the defined distance, which could potentially affect the validity of the analysis for those features. However, the results indicate that the spatial pattern of "Intersect_Area" values is significantly clustered, demonstrating that similar values tend to group together within 50 kilometers.



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Started: Today at 4:05:52 PM
Completed: Today at 4:05:54 PM
Elapsed Time: 2 Seconds
⚠ WARNING 000847: Features with no neighbors (only includes first 30):
OBJECTID = 552, 562, 627, 1191, 1264.

Start Time: Saturday, August 3, 2024 4:05:52 PM
⚠ WARNING 000846: 5 feature(s) had no neighbors which generally invalidates the
statistical properties of a test.
⚠ WARNING 000847: Features with no neighbors (only includes first 30): OBJECTID =
552, 562, 627, 1191, 1264.

Global Moran's I Summary
Moran's Index        0.019167
Expected Index       -0.000400
Variance             0.000012
z-score              5.641083
p-value              0.000000
Distance measured in meters
Succeeded at Saturday, August 3, 2024 4:05:54 PM (Elapsed Time: 1.62 seconds)
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Figure 4. Third Execution of the Global Moran's I Tool.

D. *Hotspot Analysis*

We conducted a hotspot analysis using ArcGIS Pro to identify fire-severity levels within urban tree-planting areas. The analysis involved calculating *Z*-scores to determine areas of high and low fire intensity. We then created a map to visually represent these severity levels, displaying a range of severity from moderate to very high.

The hotspot analysis illustrated in the map (Figure 5A) demonstrates that the most intense fire-severity areas are concentrated in Southern California. This pattern aligns with other findings [6], which highlight the region's elevated fire risk. The analysis indicates that these areas, marked by high *Z*-scores, correspond to regions with significant overlap between urban tree-planting initiatives and high fire-severity zones. This intense clustering may be linked to the lack of specific environmental criteria guiding tree selection in such programs as the MTLA initiative. The absence of a science-based approach and systematic monitoring in these programs potentially exacerbates fire risk, contributing to the high severity levels observed. This observation underscores the need for more strategic and evidence-based tree-planting practices to mitigate fire risks and enhance urban resilience.

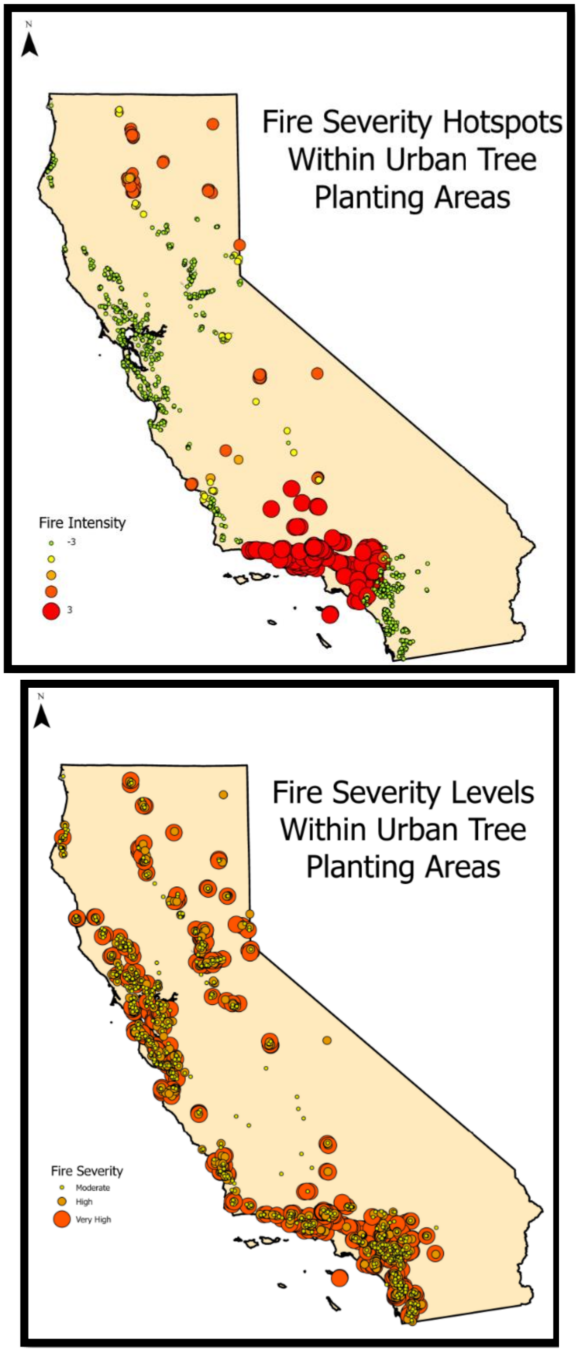

Figure 5. Hotspot Analysis of Wildfires in California.

The second map (Figure 5B) displays circles of three different sizes representing moderate, high, and very high fire-severity levels in areas where the fire-severity layer intersects with the tree-planting layer. While the map shows that high severity is widespread across all intersected areas, the hotspot analysis revealed larger circles concentrated specifically in the Los Angeles area. This discrepancy can be attributed to the spatial clustering identified in the hotspot analysis, which highlighted that the most intense fire severity is significantly more pronounced in certain regions, such as Los Angeles, compared to other areas.

The larger circles in the hotspot analysis represent extreme severity levels, indicating that while high-severity zones are common, Los Angeles exhibits particularly severe fire conditions. This finding is significant as it emphasizes the need for targeted fire-management strategies in high-risk areas. The broader map provides context by showing that high-severity zones are widespread, but the hotspot analysis's focus on Los Angeles underscores the critical nature of fire-resilience efforts in this region, where the intensity of fire activity is notably higher.

IV. RESULTS AND DISCUSSION

A. *Results*

We used several methods of spatial correlation analysis in ArcGIS Pro to assess the relationship between tree-planting areas and fire-severity zones. Initially, the data layers for tree planting and fire severity were overlaid using the Intersect tool, creating a new layer that highlighted intersecting polygons. The analysis quantified the overlap between tree-planting initiatives and different fire-severity zones. The summary statistics revealed that the most significant overlap was in very high fire-severity zones (Table 1).

All three runs of the Global Moran's I tool, using the Inverse Distance, K-Nearest Neighbors, and Fixed Distance Band methods yielded Moran's Indexes notably different from the expected value, suggesting a slight positive spatial autocorrelation. The high Z-Scores and low p-values for these indexes indicate that the observed clustering was statistically significant. However, some warnings raised concerns about various issues, suggesting that the parameters may need adjustment.

B. *Discussion*

The results from the spatial-correlation analysis underscore a consistent pattern of positive spatial autocorrelation across different methods. The Intersect tool revealed that a significant portion of tree-planting efforts overlaps with high and very high fire-severity zones, suggesting a potential alignment with fire-risk mitigation strategies. The Global Moran's I analyses using different methods—Inverse Distance, K-Nearest Neighbors, and Fixed Distance Band—each indicated slight positive clustering of tree-planting areas. The high Z-Scores and low p-values across these methods confirm that the observed clustering is statistically significant and not due to random chance.

The Inverse Distance method raised concerns about potential memory issues due to a high number of neighbors, indicating that adjustments might be necessary for future analyses. The K-Nearest Neighbors method provided a detailed view of local spatial patterns, while the Fixed Distance Band method showed a robust clustering effect, despite some limitations related to features with no neighbors. Overall, these findings suggest that tree-planting initiatives are strategically aligned with areas of higher fire risk, though the analysis also highlights the need for careful consideration of spatial relationships and potential data limitations. The results provide valuable insights for planning and managing tree-planting efforts in the context of wildfire risk, emphasizing the importance of addressing spatial patterns to optimize environmental sustainability and fire-risk reduction.

V. CONCLUSION AND FUTURE WORK

The spatial-correlation analysis conducted using ArcGIS Pro provides valuable insights into the relationship between tree-planting areas and fire-severity zones in California. The findings consistently indicate a slight positive spatial autocorrelation, suggesting that tree-planting efforts are somewhat clustered in areas with greater fire severity. The analysis using the Intersect tool revealed a significant overlap of tree-planting initiatives with high and very high fire-severity zones, pointing to a potential strategic alignment with fire-risk mitigation efforts. The results from the Global Moran's I tool, employing the Inverse Distance, K-Nearest Neighbors, and Fixed Distance Band methods, all corroborate the presence of significant clustering patterns. These results underscore the importance of considering spatial relationships in the management and planning of tree-planting initiatives to effectively address fire risks and promote environmental sustainability.

A. *Limitations*

Despite the significant findings, this analysis is subject to several limitations. The Inverse Distance method raised concerns due to a high number of neighbors, which could affect the accuracy and efficiency of the analysis. Additionally, the Fixed Distance Band method encountered issues with some features having no neighbors within the specified distance, potentially impacting the validity of the results for those features. The presence of such anomalies suggests that the analysis might be influenced by data gaps or parameter settings that may not fully capture the spatial relationships. Furthermore, the static nature of the distance thresholds and neighbor settings may not account for the dynamic and complex nature of fire-severity and tree-planting patterns.

B. *Future Work*

Future research should address the limitations identified in this analysis by refining the parameters and methods used. Adjusting the neighborhood search thresholds and exploring alternative conceptualizations of spatial relationships could enhance the accuracy and robustness of the spatial autocorrelation results. Additionally, incorporating more dynamic and context-specific data, such as real-time fire-risk assessments and variable tree-planting practices, could provide a more comprehensive understanding of spatial patterns. Future work might also consider expanding the analysis to include other environmental factors or geographic regions to validate the findings and develop more targeted strategies for fire-risk mitigation and tree-planting initiatives. Integrating these improvements will help optimize the effectiveness of tree-planting efforts and better inform environmental-management practices.

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