Using Land Cover Analysis through Remote Sensing and Ground Observations

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Abstract

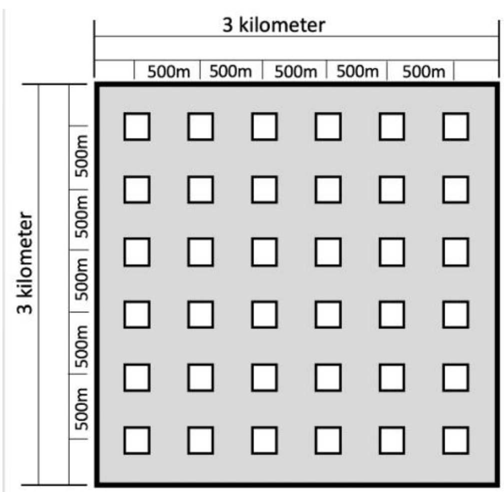
Over the last two decades, the world population has increased by approximately 1.5 billion, representing a staggering 15% rise. Subsequently, land cover has undergone significant changes, resulting in an increase in impervious surfaces in the form of buildings, sidewalks, roads, etc. How does this urban development affect plant ecosystems? Looking backwards at case study locations helps us understand the changes arising from urban sprawl. Each location can be analyzed before, during, and after periods of urban growth. The progression of urbanization can be measured and monitored using several tools, including the 1984-2024 Multi-Resolution Land Characteristics (MRLC) National Land Cover Database (NLCD) Viewer, various layers available in Earthmap digital software from the baseline year 2020, and the 1984-2025 Landsat satellite imagery supplemented by ground observations collected through GLOBE Observer. Nine different nine km^2 kernels are divided into 36 evenly spaced 100 m^2 areas of interest (AOI) and 1 centroid location. The geometry is converted into a GeoJSON file, allowing for repeatable operations within each dataset. The United States population is projected to increase by roughly 40 million people in the next 30 years, indicating urbanization will continue. It is essential to investigate sustainable approaches to create a balance between urban development and the ecosystems it displaces. By utilizing investigated approaches and materials that prioritize sustainability, we can harmonize the relationship between urban development and the plant ecosystems that we aim to protect.

Introduction

Land is one of the most valuable resources to the human race. Land is the foundation for everything humans build. It provides humankind with valuable minerals, a foundation to grow food, fresh water, and most importantly, a place for humans to live. As the population continues to rise, so does the necessity for living areas, such as places to raise families, buy groceries, and work. This rising necessity results in the creation of suburbs and urban areas. With the development of these cities also comes enormous changes in the land cover. Forests are bulldozed to make shopping malls and entire hills can be cut down to lay the foundation for neighborhoods. There is no question that the development of suburban towns and urban cities is expanding at a rapid rate. This expansion into new areas doesn't always favor the plant species that were originally there or their habitats. This conflict between expansion and plant life is most apparent in the development of neighborhoods. In previously uninhabited areas, plants are displaced to make room for roads, homes, and other buildings that a town may require to function well. However, no two towns in the world are identical. Hence, our team utilized our diverse geographical locations in order to understand the varieties of expansion and land cover across the United States. Landscape information was extracted from remote sensing satellite data, ground-truth photos, and manual classification tools to study the 9 case-study locations (Wang et al., 2010). Upon reviewing the landscape information, it was evident that in specific locations, such as Leander, Texas, and Dublin, California, this expansion occurred in the early 21st century. In contrast, areas like Bernardsville, New Jersey, and Detroit, Michigan, have experienced a consistent expansion since the mid to late 20th century, resulting in varying patterns of plant life developing. In total, nine sites were researched: Austin, TX; Bernardsville, NJ; Detroit, MI; Dublin, CA; Frisco, TX; Leander, TX; Sandy, UT; San Diego, CA; and Portland, OR. This paper seeks to find patterns and discrepancies within the land cover of our diverse dataset as a result of urban expansion and discussing the corresponding changes in surrounding plant life.

Methods & Materials

Changes in land cover through different stages of urban growth were recorded and analyzed in case-study locations utilizing several platforms, including: ArcGIS, Google Earth Engine, EarthMap, GLOBE Observer, Multi-Resolution Land Characteristics (MRLC) National Land Cover Database (NLCD) Viewer, Collect Earth Online. Each participant created a $9km^2$ AOI kernel that consisted of 36 evenly spaced points and one center coordinate, totalling 37 distinct locations (Figure 1). Each AOI was enclosed within a $100m^2$ bounding box and stored in the NASA SEES Earth System Explorers 2025 ArcGis database.



(Figure 1: Area of Interest Kernel, including 36 points [Note: does not show center])

To allow for repeatable data extractions, each AOI grid was stored as a GeoJSON and Comma Separated Value (CSV) file for integration across multiple applications previously mentioned. The GLOBE Observer application was utilized to capture ground-truth images as close as possible to the AOIs within the bounding box. Ground-truth photos were recorded in the Upward, Downward, North, East, South, and West directions at each sampling point. If locations were inaccessible due to private property restrictions or natural barriers, the respective ground photos do not appear in our analysis for accuracy (Low et al. 2021).

Screenshots of graphed satellite data and mapped satellite data from different EarthMap filters for each location's bounding box were compiled. Four main filters were used: Worldview-4's Meta 1m Tree Canopy, Sentinel 1 and 2's 10m World Cover, Sentinel 1 and 2's 10m Dynamic World, and Sentinel 1 and 2's 10m ESRI (Kontgis et al. 2021; Brown et al. 2022; ESA et al. 2020; Tolan, et al. 2023). These filters are used to assess the land cover composition of an area. When the filters are layered with an AOI map, they provide insight into the land cover profile of that area. This, in turn, can be used to determine whether an area has more of an urbanized or non-urbanized profile. The year 2020 was used as a baseline for all four datasets in order to ensure agreement within each area.

Landsat Time Series (LTS) data were used to measure and analyze land cover change in the AOIs during the period of 1984 to 2025. To gather the LTS data for each AOI, the longitude and latitude coordinates of the AOI's centroid were uploaded to Google Earth Engine, which generated an LTS map and Normalized Burn Index (NBR) graph of the region in each consecutive year from 1984 to 2025 (Gorelick 2017). The NBR graphs track NBR change over time in years. Graphs were generated for all 37 AOIs for each city. NBR indicates the strength/health of a plant ecosystem. Higher NBR values correlate with healthier vegetation. Scattered values on the graph typically mean that vegetation is uncontrolled, while clustering tends to mean controlled vegetation.

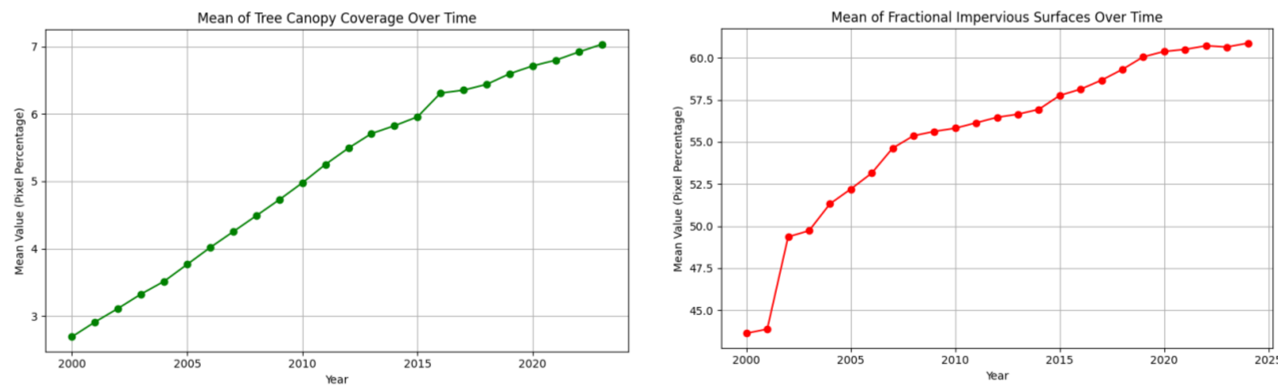
Additionally, the Collect Earth Online software was used to manually classify the land cover profile of each location using aerial photos. The software broke each AOI 100 square meter kernel into 100 sub-points. From there, each point was magnified to a scale of 20m for consistency. Then, all 3,700 generated points ($37\ points\ *\ 100\ subpoints$) were classified into one of the following categories: Trees_CanopyCover, bush/scrub, grass, cultivated vegetation, Water>lake/ponded/container, Water>rivers/stream, Water>irrigation ditch, shadow, Unknown, Bare Ground, Building, Impervious Surface (no building), or Wetlands (Saah 2019). Then, each filled 100 square meter point was assigned a confidence score. Lastly, each $100m^2$ point was assigned percentages of land cover based on the classifications of the 100 sub-points.

The progression of urbanization was measured by tracking the percentage increase in impervious surface pixels and tree canopy pixels using the Multi-Resolution Land Characteristics (MRLC) National Land Cover Database (NLCD) package. MRLC provides NLCD data from the years 1984-2024. The bounding box for each AOI was input to MRLC using the respective latitude and longitude coordinates. However, it is possible that the entire grid was not covered by MRLC since it rounded to five decimal places for longitude and latitude, whereas the rest of the services offered more accuracy, location-wise. The Annual NLCD package was downloaded, offering sub-packages that presented comprehensive overviews of each AOI across various categories, such as land cover use trends, impervious surface expansion, tree canopy development, spectral changes, and more. To answer the research question, the sub-packages of Fractional Impervious Surfaces (FIS) and Tree Canopy Cover (TCC) were selected to demonstrate the change in urbanization and the change in ecosystem size. Each sub-package presented data of a specific land cover type (tree canopy or impervious surface) in the form of a 'heatmap' that displayed its concentrations in the region. The download also provided statistical data in .xml files. From here, Erram developed code in Google Colab in order to extract the mean percentage from the .xml files for each year and present them as graphs using MatPlotLib.

Results and Data

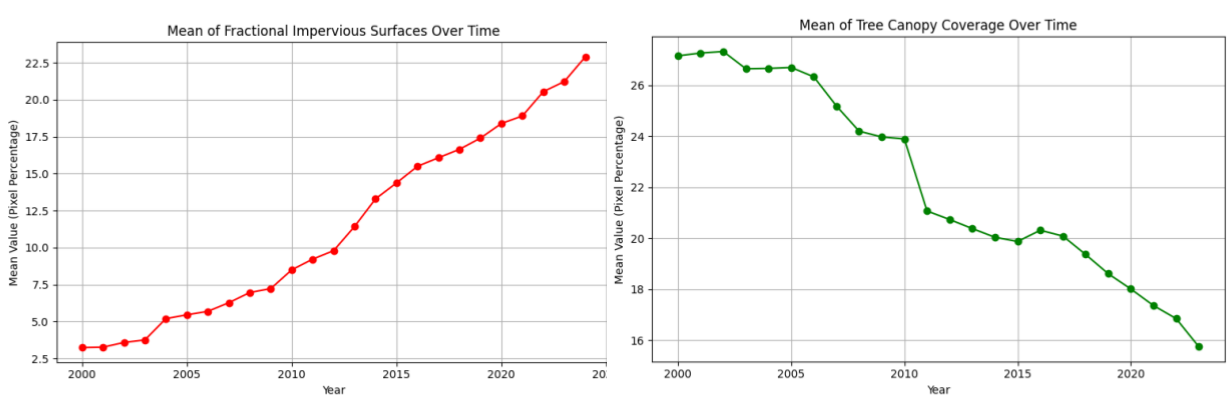
The data and results gathered from various team members provided diverse perspectives on how urban sprawl interacts with ecosystems. Furthermore, because of the varying locations of each team member, the data gathered by each member differed significantly. These two factors allowed identification and analysis of many diverse interactions between urban sprawl and plant ecosystems. For example, Dublin, CA; Portland, Or; and Detroit, MI were located in areas where urban sprawl brought more vegetation to the area– or are currently making strides to do so. It was concluded that the need for landscaping and amenities like parks was the cause of this. However, the vegetation induced by urbanization is not growing or shrinking normally. Looking at the LTS data, it becomes clear that this vegetation is maintained by humans in the area. This was concluded from the lack of scattering in the LTS NBR graphs. In Portland, efforts to increase greenery are present in the grass roofs implemented across the city. Such efforts attempt to offset the extreme urban character of the area. Similar projects to increase greenery through urban integration can be seen in Detroit.

There, community initiatives were formed to bring more green into the city, thus changing the land cover dynamics of the area and providing for some ecosystem. However, these efforts are too local or small-scale to show up in satellite datasets like Worldcover or Dynamic World. Dublin, CA, displays a unique case study in which suburban development exclusively brought plant population growth (Figure 2). The city's start as a farming town consisting of almost all grasslands with barely any plant biodiversity made it so that the introduction of neighborhoods and shopping malls automatically increased plant life. Amenities such as shade, backyards, landscaping, and citizen-cultivated gardens caused a boom in plant population and plant biodiversity.



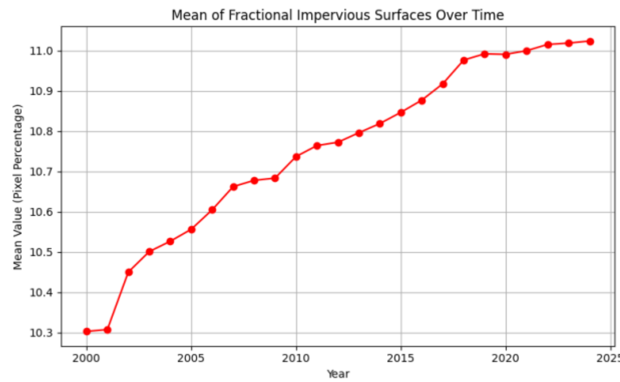
(Figure 2: Graphs from Dublin, CA representing the changes in tree canopy and impervious surfaces in the area over time)

On the other hand, there are areas like Frisco, Texas, where the original ecosystems were replaced with almost all impervious surface, with little vegetation added. Austin, TX data showed a similar trend to Frisco, with greenery being replaced by impervious surfaces like buildings and roads. One of the most shocking instances of this can be seen in Leander, TX where grassland was converted into the Ronald Reagan Highway in the span of one year (Figure 3). From that jumping point, extreme urbanization followed. The LST image chips show the construction of new neighborhoods and buildings every year, forcing out the previous ecosystems that had been there and replacing them with impervious surface, buildings, and human-maintained greenery.



(Figure 3: Graphs from Leander, TX representing the changes in tree canopy and impervious surfaces in the area over time)

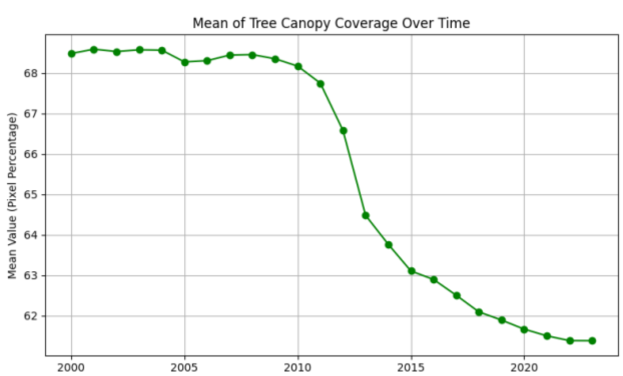
Lastly, there is a middle ground that our data pointed to within Bernardsville, NJ. This middle ground presented itself as a harmonious relationship between both urban expansion and ecosystem growth (Figure 4). Bernardsville was represented in many different ways by the four Earthmap datasets. Worldcover classified it as nearly all forest/greenery, while ESRI classified it as nearly all impervious surfaces and buildings. Collect Earth Online demonstrates a mix, but indicates that tree canopy primarily takes up the vast majority of 100 square meter points. MRLC's NLCD packages demonstrate another trend that shows the land cover has had an increase in impervious surface and decrease in canopy cover over time, but both changes were extremely small. Of these small changes, there were significant rises and drops in the mid-2010s, but they have essentially leveled out within the past 5 years. Thus, Bernardsville is capable of retaining the majority of its greenery despite expansion, where it currently rests at around 61.5% of total land cover. The large drop in canopy cover(~5%) was likely the result of expansion projects, as similar trends have not been seen since. Hence, the expansion of one does not drastically hinder the other, like in other areas such as Leander (Figure 3). Nor is this vegetation necessarily a result of urbanization, as the LST shows high scattering– representing natural growth– which draws contrast to Portland and Dublin. Of course, some of the greenery is intentional, but the vast amount of points that display scatter show that there is also an abundance of unintentional greenery as well.



(Figure 4: Graphs from Bernardsville, NJ representing the changes in tree canopy and impervious surfaces in the area over time)

Discussion

Initially, the predicted outcome was that the increased urban development would reduce plant growth. Rather, the variety of findings from nine AOI locations displayed that the relationship between urban growth and plant life is dependent on more factors than originally thought. Hence, variables such as local planning and development patterns could explain trends rather than a universal truth across the locations. While some AOI locations portrayed a trend of urban development replacing plant life due to a surge in impervious surfaces and buildings, other locations demonstrated a relationship in which both variables increased. In these areas, urban development was paired with high plant growth and an increase in plant biodiversity. Dublin, California, for instance, displayed a boom in plant life, where the amenities that come with urban sprawl did nothing but boost plant biodiversity over time (Figure 2). The city's lack of vegetation



in the past made urban development a vessel for plant ecosystems to start developing. Utilizing plants in creative ways, like using trees for shade and bushes as road dividers, while also developing many parks with diverse flower bushes and different trees, were urban development strategies used in Dublin, CA, that displayed a positive effect.

The boom in plant life in places like Dublin, CA, may also be due to community organizations such as the HOA placing landscape requirements on certain neighborhoods. For example, most neighborhoods have consistent vegetation that is determined before construction, such as in-built gardens or pine trees integrated between each doorstep. In both scenarios, community priorities and maintenance played a key role. In areas where communities desired to cultivate plant life with growth projects and landscape requirements, increased vegetation was observed. Therefore, the negative correlation between urban development and plant life that we first assumed only exists based on the community type.

An important takeaway is that purely satellite and remote sensing data are insufficient to provide the full outlook on environmental patterns. GLOBE Observer photos taken from the ground (ground-truth) were vital as a real-time medium to view current trends in the AOIs. In several cases, satellite data did not render the desired resolution to gain a clear understanding of the location's land use or vegetation patterns. GLOBE photos taken from upward, downward, and cardinal directions essentially added context to the data, creating a base for analysis. The photos also allowed research to be more specific than satellites offered, as the images were readily available for hyperspecific viewing of land cover, whereas the satellite data tended to show generalizations due to its limited temporal and spectral aspects. This inherently means that they will be unreliable in certain areas. However, the images alone are not enough ground to make inferences either. Those images are heavily reliant on accessibility– meaning that if an area is under private property, it is virtually inaccessible– and availability, meaning that it would be hard to take photos of every single square meter of an AOI grid like satellites can. Hence, neither system is without its flaws, but together they can paint a picture.

The variation between different cities cements the idea that sustainable urban development is not a conceptual idea; it is an imperative step cities must take toward a prolonged future. There is no excuse for areas not to try and implement solutions to preserving ecosystems despite expansion. Resources such as LTS data, NLCD datasets, and remote sensing as a whole can function together to allow local governments and policymakers to make informed decisions toward land use, canopy preservation, and urbanization. Citizen scientists also play an important role, as they are the ones with the power to conduct research and then present it to their towns, counties, or other bodies in control of development. Urban growth is inevitable, and whether its impacts are positive or negative is dependent on how ecological communities are upheld and preserved in conjunction.

As previously discussed, Bernardsville is somewhat of a middle ground since both impervious surfaces and greenery (canopy) do not drastically increase or decrease yearly, showing retention, especially in the past 5 years (Figure 4). However, large construction projects are relatively few and far between. Looking at the LST graphs, the last time there was major construction was in 1986. The town is currently planning to build affordable housing in a major construction project. While this may seem like a threat to plant ecosystems, the project is taking place in areas that have already been built up. The town is essentially taking down current buildings and replacing them with new ones. This may lead to some short-term ecosystem damage, but the effects will not be anywhere near as drastic as they were in AOIs like Leander

(Figure 3). While the goal of this decision may not have been to preserve ecosystems, it inadvertently does. Hence proving once again that balance is possible.

Conclusion

Initially, we predicted that there would be a negative correlation between urban development and plant growth. However, through our research, we observed different trends in the relationship based on the type of community we observed. In some areas, like Frisco, Texas, our predictions were supported; the rise of suburban development led to a decrease in plant life. In other communities, like Dublin, California, urbanization led to an increase in vegetation density and health (Figure 2). Factors such as the HOA placing landscape requirements on certain neighborhoods, and community priorities for maintaining vegetation play key roles in the survival of plant life in a region. In the end, we can now say that the relationship between urban/suburban development and plant ecosystems can vary widely based on community type and circumstances. Cities should implement measures to protect plant life even as they develop a region, since increased greenery through urban integration reflects healthier environmental relationships, more sustainable building practices, and ultimately a more beautiful, connected living space.

Citations

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Badges

- **I Work With Satellite Data**
    - Our project relied heavily on using satellite data. One of the largest portions of our data aggregation was confirming that our ground observations of land cover matched with the aerial photos and ground observations. We used multiple satellite datasets, such as the ESA WorldCover, Dynamic World, and ESRI 2017/2024 Land Cover form the Sentinel 1 and 2 satellites, Meta/WRI Global Canopy Height from the Worldview-4 satellite, and Landsat time series data from Landsat satellites 5-9. Our work would not have been possible without this data. Landsat informed lots of our research by providing a scale for how healthy vegetation was in certain areas across certain years– indicated by extremely high NBR values– and how naturally it was acting– indicated by scattered NBR values. Our data collection would not have been possible without satellite data.
- **I am a STEM Storyteller**
    - We created blog posts which combined text and images to convey a variety of topics that relate to our research. For example, some interns wrote blogs that described the patterns and systems they used to gather their ground observations since it was relatively free-range. Other blogs discussed the contents of each researcher's data from the satellite packages, ground observations, and other sources of data. These blogs served as a way for each individual to share their research with the world in a friendly and inviting way. Researchers also completed a Community Chronicle in which they published a StoryMap through ArcGIS. These maps showcased the socio-economic and climate profiles of an area. This allowed researchers to grow closer to their community and encouraged them to present their data as an engaging presentation for others. The creation of this project also enabled context for certain areas of our research discussion as certain anomalies on maps could easily be explained (construction, housing developments, etc.).
- **I Work With a STEM Professional**
    - Our team worked closely with STEM professionals from NASA including Peder Nelson, a researcher and instructor at Oregon State University, Rusty Low, a senior scientist at the Institute for Global Environmental Strategies in Arlington, Virginia, and Cassie Soeffing, a Senior Science Educator at the Institute for Global Environmental Strategies. These mentors provided invaluable help throughout the research and writing process. Peder introduced us to the tools we needed such as GLOBE Observer, Earthmap, and ArcGIS, optimized our methodology and research question, and answered our questions with both detail and enthusiasm. Through our mentors, we also gained certification opportunities in fields such as data ethics and team science, important background knowledge, and connections to other researchers in our area. Lastly, these people brought

constant excitement and encouragement to our work, inspiring us to persist through challenges in our research and continue to be curious.