

TERM PROJECT

Analyzing Natural Vs. Built Environment at The David Dunlap Observatory Forest

by

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## 1. Introduction

The David Dunlap Observatory Forest, located in my hometown of Richmond Hill, Ontario, Canada, is ideal for studying the dynamics between the natural environment and urban development over time (Figure 1.). This study aims to analyze changes and patterns in vegetation cover and built-up areas within the area of interest using satellite imagery and geospatial analysis techniques. The Observatory lands have experienced much urban sprawl from Toronto in recent years (see Figure 2.). Nearly half of the remaining natural environment was cleared for building in the last decade, leaving a small, degraded environment.

### *1.1 History of the Observatory Forest*

As of 2024, the DDO Park property (area of interest) spans 189 acres (0.765 km<sup>2</sup>) and is bordered by Hillview Drive, Bayview Avenue, 16th Avenue, and the CNR Train tracks (see Figure 2.) (Rosenberg, 2016). Over the years, this area has experienced significant changes in land use, with rapid urbanization encroaching upon once-pristine natural landscapes. Initially established in response to increasing light pollution in downtown Toronto during the 1930s, the Observatory quickly became a hub for astronomical research, with the largest reflector telescope in Canada (Figure 1) (Rosenberg, 2016). To mitigate the effects of light pollution, belts of coniferous trees and experimental plantations were established around the Observatory, gradually transforming agricultural fields into thriving ecosystems of forests and meadows (Rosenberg, 2016). However, with growing urbanization pressures, the Observatory faced challenges preserving its natural surroundings. 2008, the land was sold to a housing developer, sparking community protests and advocacy efforts (Rosenberg, 2016). Eventually, half of the property was designated as DDO Park Lands, safeguarding it for public use. Nevertheless, the surrounding forest experienced substantial deforestation. Today, efforts are underway to repurpose the remaining natural environment into an interactive park, reflecting the city's commitment to balancing conservation with recreational development.

## 2. Methodology

### *2.1 Set-Ups and Parameters*

Landsat 8 Tier 1 surface reflectance imagery from the Google Earth Engine (GEE) platform was utilized, covering the period from 2013 to 2023. This Landsat 8 surface reflectance collection serves as the primary source of satellite imagery data for the analysis. The region of interest (ROI) is specified by the four coordinates that make the properties boundary. These coordinates, stored in the 'cords' variable, are structured as latitude and longitude pairs. Using these coordinates, a Multiline String geometry object named "border geometry" is created to represent the ROI's border. This geometry facilitates spatial filtering of the satellite imagery to focus solely on the relevant area of interest. Additionally, the start and end years, as well as the step size, are defined. In this case, the analysis encompasses Landsat 8 imagery captured between 2013 and 2023 when construction occurred, with a step size of 2 years. This temporal

resolution dictates the frequency at which imagery data will be processed and analyzed, providing a comprehensive view of landscape dynamics over the specified time.

## ***2.2 Calculation of NDVI***

Normalized Difference Vegetation Index (NDVI) was calculated to assess vegetation density and health. NDVI values range from -1 to 1, with higher values indicating vegetation cover. First, the code sets up a list to store NDVI layers for each two-year interval within the specified temporal range. The code then iterates every two years, filtering Landsat 8 imagery to select images within the defined date range and spatial boundary. Cloud cover is minimized by sorting the images and selecting the least cloudy one. Then, a cloud mask and an empty pixel/quality mask are applied to the image. NDVI is then calculated using the Landsat bands B5 (near-infrared) and B4 (red), and visualization parameters are set for the True Color and NDVI layers (Jensen, 2007, p. 385). These layers are added to the map for each two-year increment. Additionally, the border of the area of interest is displayed on the map as a red line, and the map is centered over the area of interest for reference. Finally, the map with all the True colour and the NDVI layers and their controls are displayed for visualization and comparison over time.

In the next cell, the NDVI layer is appended to the `ndvi_layers` list to create time-lapse automation. After all iterations, the list of NDVI layers is converted into an Image Collection. Further, arguments are defined for the parameters required for the animation function. The URL for the NDVI animation is generated using the "getVideoThumbURL" method. Finally, the generated URL and an image representing the NDVI timelapse from 2013 to 2021, each frame depicting a two-year increment, are displayed.

## ***2.3 Calculation of Cumulative NDVI Difference***

The code initializes a variable named `'cumulative_diff'` representing the cumulative difference in NDVI (Normalized Difference Vegetation Index). It then iterates over each two-year interval within the specified temporal range. Within each iteration, Landsat 8 imagery is filtered based on the defined date range and spatial boundary, with cloud and empty pixel masks applied subsequently. NDVI is recalculated for the current year. If it is not the first year, the code retrieves the NDVI for the previous year, calculates the difference between the current and previous NDVI, and accumulates this difference into the `'cumulative_diff'` variable. Visualization parameters for the cumulative NDVI difference are defined. A new map is created, and the cumulative NDVI difference layer and the border geometry are added to the map.

## ***2.4 Classifying between Natural Environment and Built Environment***

This part of the program defines specific NDVI thresholds for each year (adjusted from fine-tuning) (Jensen, 2007). It calculates the area covered by the natural and built environment within a specified region of interest (ROI). Initially, NDVI thresholds are specified for different years to classify vegetation and non-vegetation areas (Jensen, 2007). The total area of the ROI is calculated and converted from square meters to square kilometres. Lists are initialized to store

the area of the natural and built environment for each year. The code then iterates over each two-year interval, filtering Landsat 8 images based on the ROI and date range, applying cloud and empty pixel masks, and calculating NDVI. NDVI values are classified into vegetation and non-vegetation based on the defined thresholds for each year. The area covered by vegetation and non-vegetation within the ROI is calculated using pixel-wise area multiplication and reduction. These areas are then appended to the respective lists. The areas of the natural and built environment are converted from square meters to square kilometres, and the percentage of each environment type relative to the total area of the ROI is calculated and printed for each year. This provides insights into the changing dynamics of natural and built environments within the specified region over time.

### ***2.5 Mapping Natural Vs Built Environment***

The code initializes a new map and iterates over each two-year interval. Again, Landsat eight images are filtered within each iteration based on the defined region of interest (ROI) and date range, with cloud and empty pixel masks applied. NDVI is then calculated using the normalized difference vegetation index formula. NDVI values are classified into vegetation and non-vegetation based on predefined thresholds for each year again. If thresholds are defined, vegetation and non-vegetation layers are added to the map with respective colour palettes. Finally, the map is centred over the ROI, and the ROI border is added to the map along with layer controls.

### ***2.6 Graphing Calculations***

The code creates a bar plot using matplotlib.pyplot to visualize the areas of natural and built environments over a range of years. It compares the areas by plotting them on top of each year. The plot provides a visual representation of how the areas of natural and built environments have changed over time, allowing for easy comparison and analysis of trends. The following cell compares the areas of the natural environment (vegetation) and built environment (non-vegetation) over a range of years. The plot visualizes the changes in these areas over time, with each line representing either the natural or built environment. The x-axis represents the years, while the y-axis represents the area in square kilometres. The plot provides a clear comparison between the two types of environments, allowing for observing trends and patterns over the specified time period.

### ***2.7 Natural Environment Loss***

This cell calculates the difference in the natural environment area every two years by subtracting the natural environment area in the current year from that of the previous year. It then prints the statistics for each two-year increment, indicating the area cleared during that period. After that, a bar plot will be created to visualize the amount of natural environment land cleared during each two-year increment. The x-axis represents the year range (e.g., 2013-2015, 2015-2017), while the y-axis represents the area cleared in square kilometres. Each bar in the plot

corresponds to the time between the two-year increment, showing the extent of land cleared over time.

## ***2.8 Comparing Statistics***

This code calculates and then visualizes various DDO natural environment land aspects over two-year increments. It first calculates the area of DDO natural environment land cleared during each two years and the percentage of forest cleared. Then, it computes the difference in the natural environment area every two years. The code then plots the natural and built environment areas over the years, along with a bar plot showing the cleared area. Additionally, it includes a secondary y-axis to represent the percentage of vegetation lost. The resulting plot comprehensively compares the built environment, natural environment, cleared area, and the percentage of vegetation lost over the specified time range.

## ***2.9 Fragmentation and Patch Analysis***

This code is tasked to analyze vegetation patches over two-year increments. It initializes lists to store the number of patches and the patch size for each increment. Then, it iterates over every two years, filtering Landsat imagery and calculating NDVI. Using predefined NDVI thresholds, vegetation is identified, and a connected pixel clustering algorithm is applied to detect patches. The number of patches and sizes are calculated within the defined region of interest (ROI).

The connected pixel clustering algorithm groups neighbouring pixels with similar characteristics into patches. This algorithm works by iteratively examining adjacent pixels and determining whether they belong to the same patch based on a predefined criterion, such as similarity in spectral properties (e.g., NDVI values). If a pixel meets the criterion for inclusion in a patch, it is added to the patch, and the process continues until no more adjacent pixels meet the criterion. In this code, after identifying vegetation pixels based on NDVI thresholds, the `connectedPixelCount` function is applied to count the number of connected components or patches within the vegetation mask. This function calculates the connected components by iteratively examining neighbouring pixels and determining whether they belong to the same patch based on their connectivity and similarity in vegetation characteristics. Once the patches are identified, the code calculates the number of patches and their sizes within the defined region of interest (ROI) using the Earth Engine API. The size of each patch is computed by multiplying the number of pixels in the patch by the area represented by each pixel, which is determined by the spatial resolution of the imagery (30). Finally, the number of patches and their sizes are stored for further analysis and visualization. The code prints the number of patches and the mean patch size for each two years. It then plots the number of vegetation patches and their sizes over the years, providing insights into the dynamics of vegetation fragmentation and distribution within the specified timeframe.

### 3. Results

The NDVI analysis revealed fluctuations in vegetation density over time, with notable changes outlining the tree clearing and building of the housing development on the east (right) side of the map (Figure 4). The culminating differences in the NDVI map (Figure 4) easily highlights, not just the cleared new development area, but also the areas around the Observatory that were anthropogenically affected over the period. The classification results easily showed the spatial distribution of natural and built environments over time, highlighting areas of urbanization and vegetation loss (Figure 5). There was a notable decrease in the natural environment from 2013 to 2019, but from 2019 to 2021, there was a subtle increase just south of the Observatory (see Figure 5, D and E). This is from the planned planting of trees and attempting restoration of the remaining property the city still owns.

In the graphs displaying the natural vs. built environment in Figure 6 and Figure 7, there is an expected decrease in the natural environment with a direct increase in the built environment over time. What is significant is that Figure 7 reveals the key time (2015) when the region of interest's built environment exceeds the natural environment. This marks the year when the housing developers started building on the property (Rosenberg, 2016).

In addition, Figure 8 shows the amount of natural environment lost between each time interval. This reveals that between 2015 and 2017, there was the most land clearing within the region of interest. It also highlights the addition of a natural environment in 2019-2021 once the park's surrounding area's fields were fixed back up from construction and trees were planted by the city. Figure 9. Compares the amount of natural and built environment, cleared area over time, and percent of the natural environment (vegetation) lost. This graph marks 2019 as a significant year when 74.40% of the forest was lost, at the maximum amount of natural environment lost in the ROI.

The patch analysis displays common deforestation trends of fragmentation within the ROI (see Figure 10 for an example). As the number of patches increases to a maximum of 8 and then decreases over time (Figure 11. A), their size decreases (Figure 11. B). This pattern is in natural environment fragmentation (see Figure 12), which can have numerous effects on ecosystems.

### 4. Discussion

The results of the deforestation analysis provide valuable insights into the transformation of natural environments into built environments. The graphs highlight and mark the significant periods of construction development and land clearing by classifying natural and built environments. They highlight the significant amount of land affected and cleared by the development; even land that was only city property was affected. It also captures efforts of the city to restore a more natural environment from the tree plantings, but certainly not enough to restore the amount lost to the built environment. The analysis also highlights the common

process of habitat fragmentation during land clearing over time. Fragmentation refers to the process by which continuous natural habitats are divided into smaller, isolated patches (Cardinale, 2020, p.276). This fragmentation can occur due to various human activities such as urbanization, deforestation, and land development. In the case of the ROI, increasing the number of patches over time until the maximum is met, as depicted in Figure 11, suggests a common model of land fragmentation of the natural environment (see Figure 12).

This can be seen at the DDO park; over time, the number of patches increases to a maximum of 8 and then decreases over time (Figure 11. A), and their size decreases (Figure 11. B). Fragmentation has several implications for the ecosystem. First, it can lead to habitat loss and degradation, harming the area's flora and fauna. Smaller, isolated patches of habitat may not be able to support the same level of biodiversity as larger, contiguous habitats (Cardinale, 2020, p. 276). This can result in the decline or extinction of certain species within the area. Moreover, fragmented habitats can disrupt ecological processes such as species migration, gene flow, and nutrient cycling. For example, small patches of habitat may not be sufficient to support the movement of wildlife between different areas, leading to genetic isolation and reduced genetic diversity within populations (Cardinale, 2020, p. 276). Fragmentation can also increase the vulnerability of ecosystems to external threats such as invasive species, diseases, and climate change. Smaller, isolated habitat patches are more susceptible to these threats, as they have fewer resources and less resilience to withstand disturbances (Cardinale, 2020, p. 276). The minimum space available for large-bodied animals creates an ecological trap for other smaller species, reducing their survival and reproduction (Cardinale, 2020, p. 276).

## 5. Conclusion

Insights have been gained into the dynamics of natural and built environments in the David Dunlap Observatory Forest through satellite imagery analysis and geospatial techniques. This project contributes to understanding landscape change and informs conservation strategies for preserving ecological integrity in urbanizing areas. In conclusion, the analysis highlights the significance of fragmentation as a driver of change within the ROI. Understanding the impacts of fragmentation on ecosystems is crucial for informed decision-making and sustainable management of natural resources. Conservation efforts to mitigate fragmentation and promote habitat connectivity are essential for preserving biodiversity and ecosystem functioning in the face of ongoing anthropogenic activities.

### Works Cited

- Cardinale, B. J., et al. (2020). *Conservation Biology*. Oxford University Press.
- Fahrig, L. (2003). Effects of Habitat Fragmentation on Biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, 34(1), 487–515.  
<https://doi.org/10.1146/annurev.ecolsys.34.011802.132419>
- Jensen, J. R. (2007). *Remote Sensing of the Environment: An Earth Resource Perspective* (2nd Ed.). Pearson.
- Rosenberg, J. (2016). *David Dunlap Observatory Park Master Plan*. Richmond Hill. Retrieved from [www.richmondhill.ca/en/things-to-do/resources/RHDDO/David-Dunlap-Observatory-Master-Plan.pdf](http://www.richmondhill.ca/en/things-to-do/resources/RHDDO/David-Dunlap-Observatory-Master-Plan.pdf).

## Appendix



Source: Kuthe, Kyle. *David Dunlap Observatory and Administration Building*. May 14th, 2023.

**Figure 1.** The David Dunlap Observatory and administration building is just off to the side.

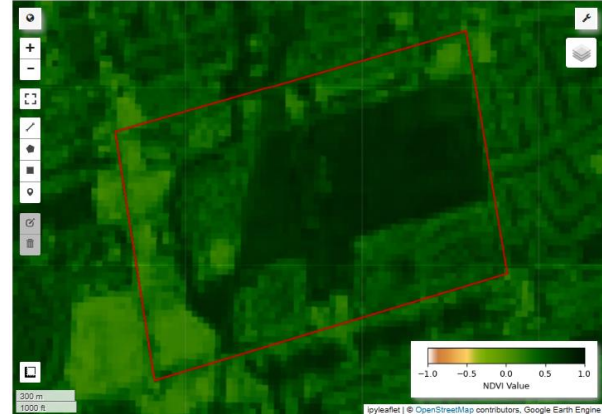


Source: Rosenberg et al. *Master Plan Scope*.

**Figure 2.** The David Dunlap Observatory lands development plan by 2024.



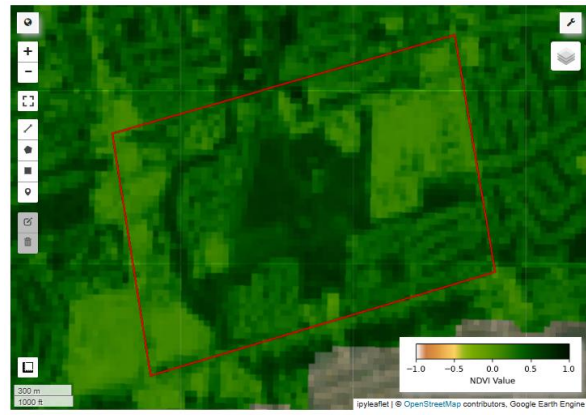
(A)



(B)

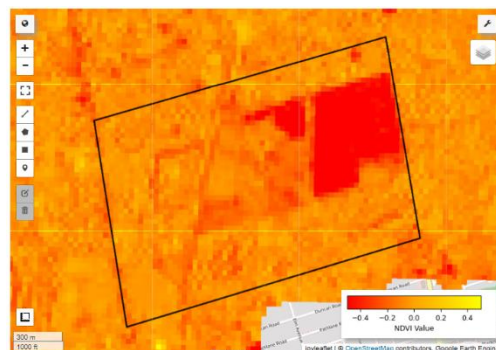


(C)

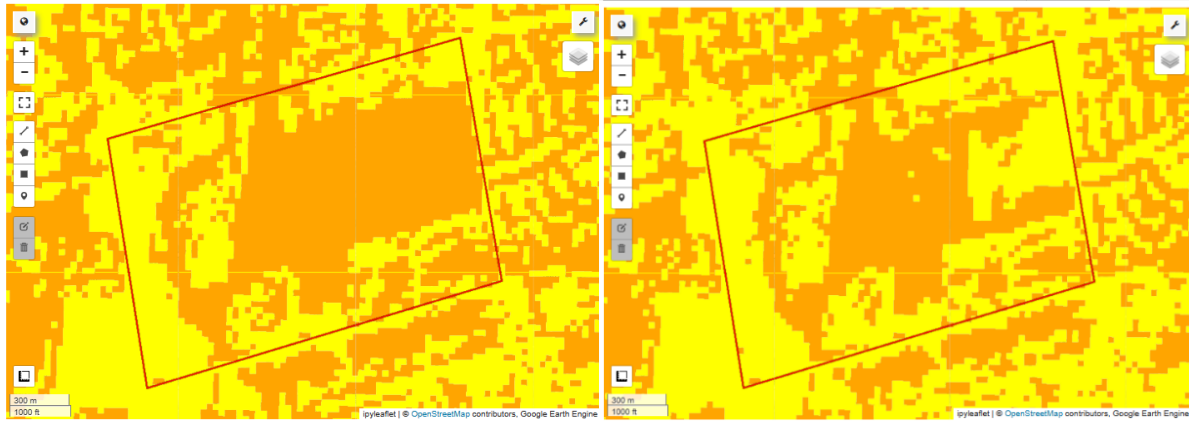


(D)

**Figure 3.** True colour and NDVI maps highlighting the DDO lands and clearing for housing developments from the start (2013, A and B ) to the end (2021 C and D) of the study period.

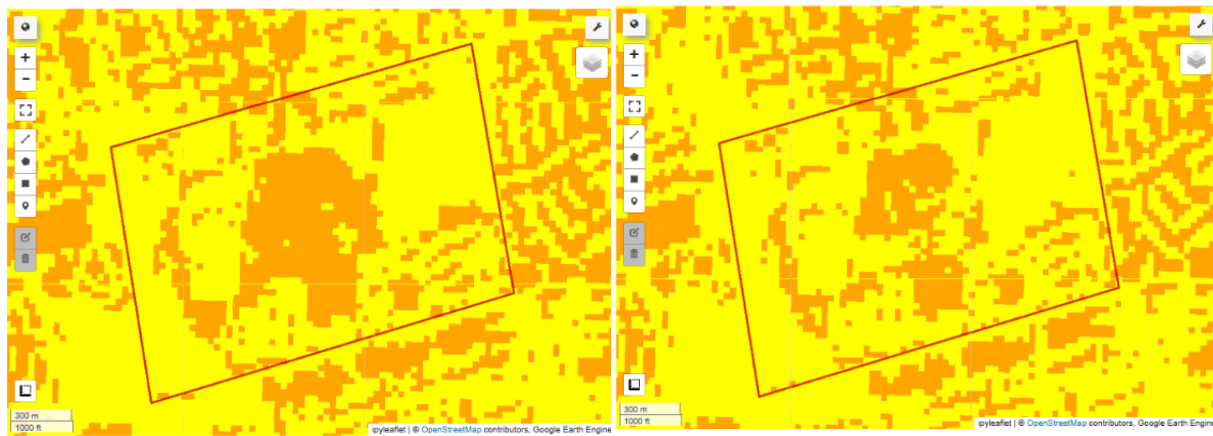


**Figure 4.** Cumulative difference in NDVI values over time, highlighting the main affected areas (red) and the areas less disturbed (yellow-orange) over the period of time (2013-2021).



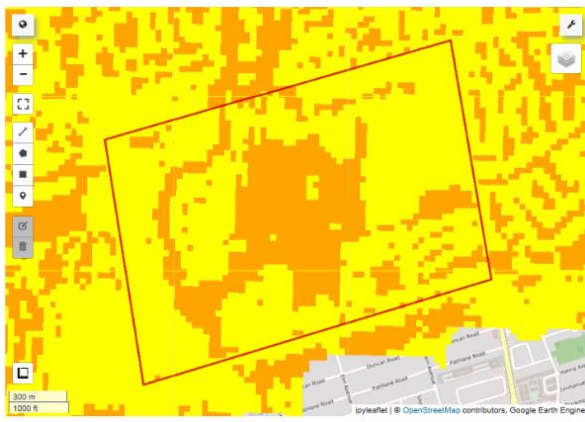
2013 (A)

2015 (B)



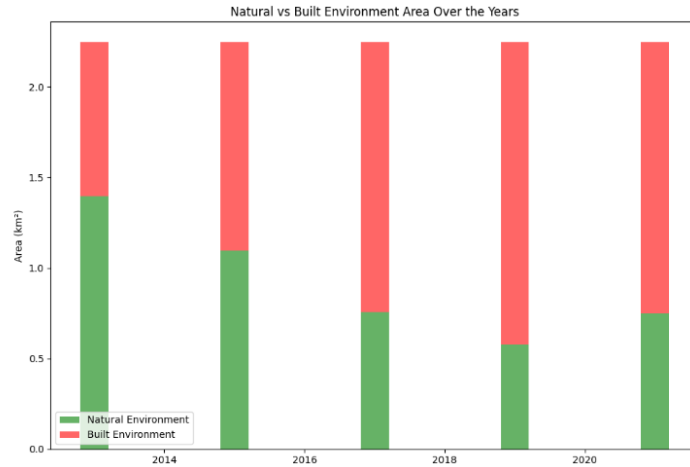
2017 (C)

2019 (D)

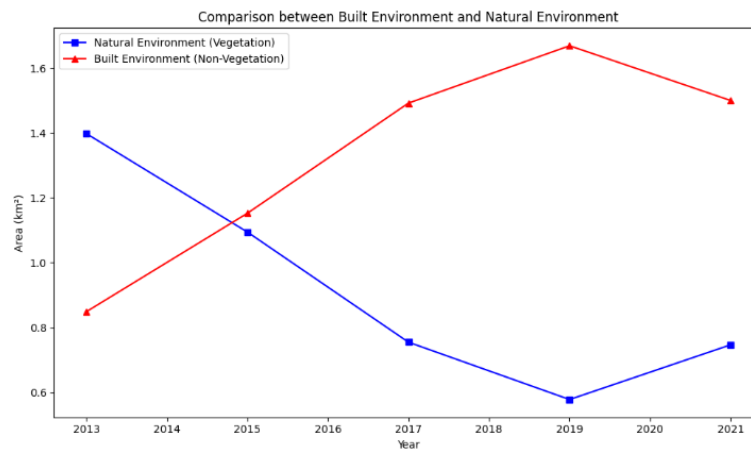


2021 (E)

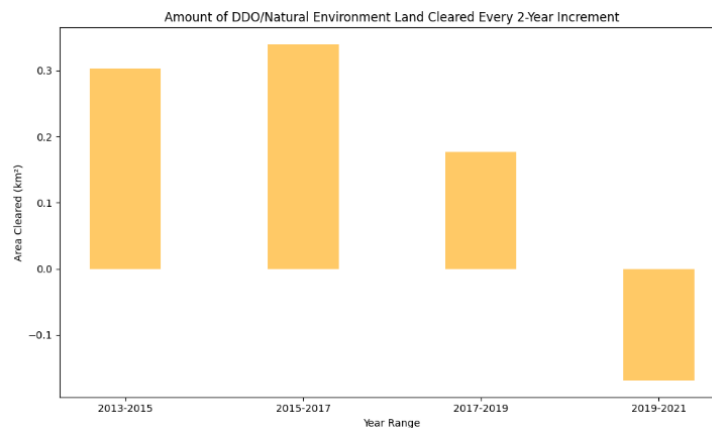
**Figure 5.** Classification between natural environment and built environment (anthropogenic actions occurring).



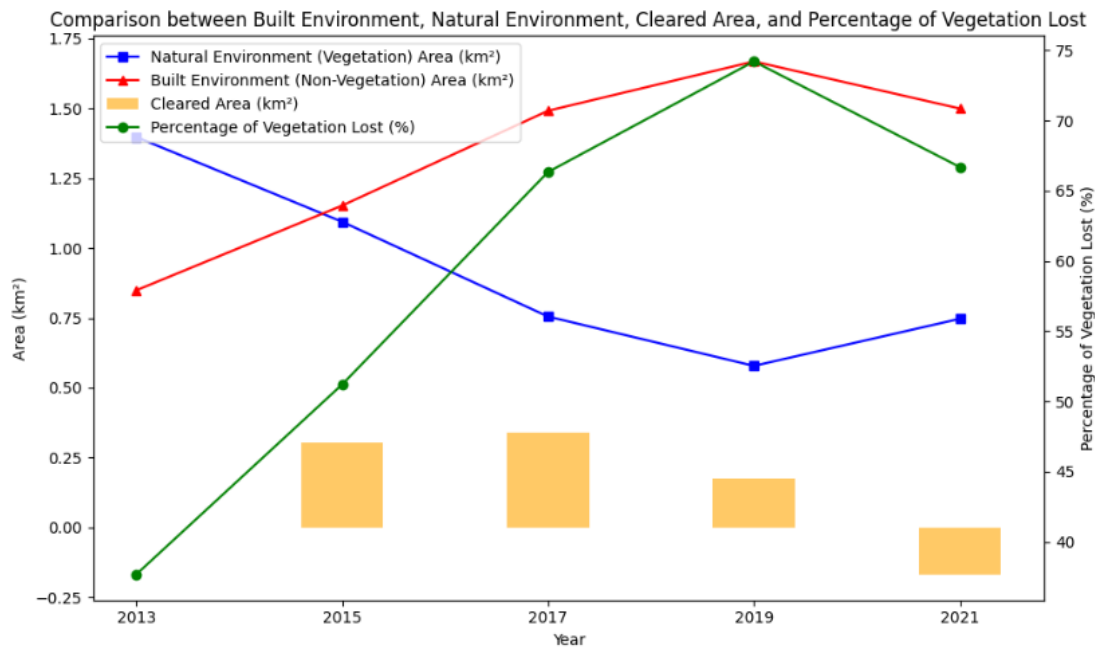
**Figure 6.** A stacked bar graph compares the natural and built environments on the DDO lands (ROI) over the period 2013-2021 (in square kilometres).



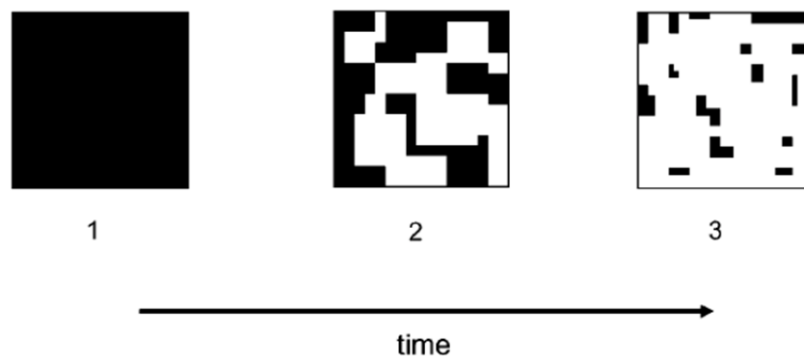
**Figure 7.** Line graph comparing natural and built environments on the DDO lands (ROI) over the period 2013-2021 (in kilometres squared).



**Figure 8.** A bar graph displays the amount of natural environment lost between intervals.

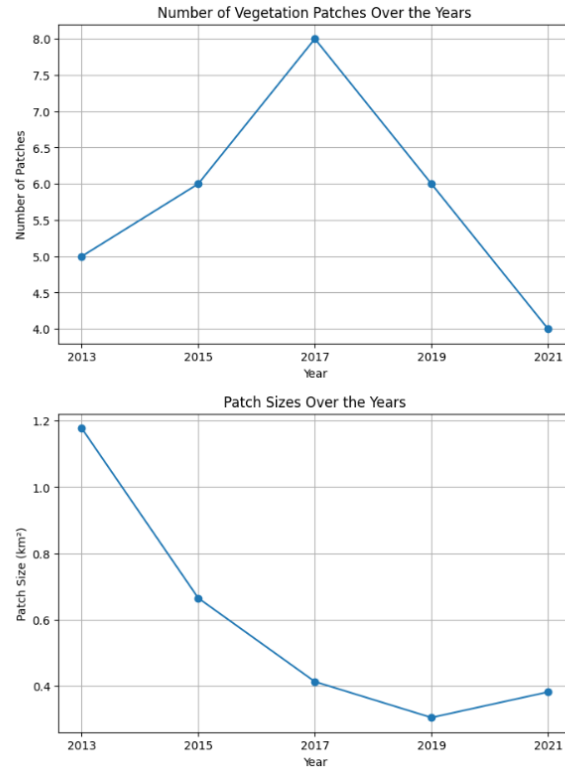


**Figure 9.** A comparison between the natural and built environment shows that the amount of the DDO's natural environment was cleared and the percentage of vegetation lost since 2013.

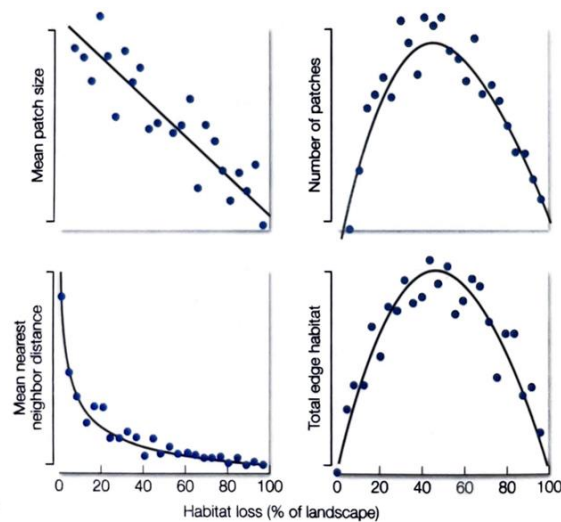


Source: Fahrig, Lenore. *The Process of Habitat Fragmentation*. November 2003

**Figure 10.** Diagram showing the general (hypothetical) process of natural environment fragmentation over time.



**Figure 11. (A)** Line graph visualizing the number of vegetation patched from 2013-2021. **(B)** Mean patch size (kilometres squared) over the period.



Source: Cardinale et al. *Habitat Loss and Patch Configuration*. 2020

**Figure 12.** General model and trend of habitat loss and patch configuration. The four illustrations display how each aspect of patch configuration relates to habitat loss in a landscape (Cardinale et al. 270).