Assessment of Forest Cover Change on Carbon Capture in the Youngstown Metropolitan Area

By

Jeniffer Nkopio

Submitted in Partial Fulfillment of the Requirements

for the Degree

Master of Science

in the

Environmental Science Program

Youngstown state university

May, 2022

Assessment of Forest Cover Change on Carbon Capture in the Youngstown Metropolitan Area

Jeniffer Nkopio

I hereby release this thesis to the public. I understand that this thesis will be made available from the OhioLINK ETD center and the Maag Library Circulation Desk for public access. I also authorize the University and other individuals to make copies of this thesis as needed for scholarly research.

Signature:

Jeniffer Nkopio, Student Date

Approvals:

Dr. Peter K. Kimosop, Thesis Advisor Date

Dr. Felicia P. Armstrong, Committee Member Date

Dr. Colleen E. McLean, Committee Member Date

Dr. Lauren Schroeder, Committee Member Date

Dr. Salvatore A. Sanders, Dean of Graduate Studies Date

Abstract

Anthropogenic increases in greenhouse gases, especially carbon dioxide, have been associated with rising global temperatures. These changes have led to desertification, heat waves, ecosystem disruption, intensification of severe weather, and loss of agricultural productivity. To mitigate against these adverse effects, carbon sequestration approaches such as afforestation and reforestation are being explored in landscapes, including urban ecosystems.

The amount of forest cover and carbon storage was evaluated for the Youngstown Metropolitan Area (YMA), located in northeast Ohio. Four urbanized sub-watersheds of the Mahoning River within the YMA were chosen. The amount of forest cover for each sub-watershed for the years 2001 and 2019 was determined using ArcGIS Pro and a 50-year land cover projection was generated using the TerrSet software. Results indicate that YMA lost approximately 40ha (5,330ha to 5,290ha) of forest cover between 2001 and 2019, while developed areas gained 200ha (from 18,400ha to 18,600ha) between the same period.

While the Dry Run Creek is the only sub-watershed in the study area with an increased forest area (from 1,420ha in 2001 to 1,460ha in 2019), the Crab Creek sub-watershed registered the highest decrease (from 1,760ha to 1,720ha) during the same period. Currently, the area under forest cover in the Crab Creek sub-watershed is the largest (1,720ha or 17.2km^2), storing approximately 60,700t of carbon. On the other hand, the Andersons Run-Mill Creek sub-watershed has the lowest forest area 524ha (5.24km^2), sequestering up to 18,500t of carbon. By 2069, the area under forest cover in Crab Creek is predicted to decrease by 70ha (from 1,720ha in 2019 to 1,650ha in 2069), while

developed land area would increase by 90ha (from 3,350ha in 2019 to 3,440ha in 2069). Although 90.3% of Andersons Run-Mill Creek sub-watershed is expected to be developed by 2069, forest cover is predicted to occupy 6.9% of its landscape.

This study showed that urbanization in the YMA will continue to increase and the amount of forest cover, despite their significant roles in carbon sequestration, will decrease. Several areas within the YMA that are currently under forest cover will be replaced by developed land uses. There is, therefore, a need to increase the amount of forest cover in the region through reforestation in order to mitigate against adverse effects of climate change.

Acknowledgement

First, I would to express my sincere gratitude to my dedicated and respected advisor Dr. Peter Kimosop; thank you bountiful for the support and advice and for always encouraging me to perfect my thesis. My heart cannot fully convey how grateful I am to my honorable Thesis committee, Dr. Felicia Armstrong for always being there for me throughout my graduate academic journey. Special recognition to Dr. Colleen McLean and Dr. Lauren Schroeder for their advice, guidance and constant support, thank you very much.

Thank you, Maag Library, for creating a conducive environment where I was able to do most of my studies.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The release of greenhouse gases (GHGs) has led to increased global temperatures. According to the United States Environmental Protection Agency (EPA, 2022), trapping of heat by GHGs in the lower atmosphere, leads to global warming. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report has projected that an increase of more than 1.5˚C in global temperatures would likely devastate vulnerable populations and ecosystems. Some consequences of global warming include droughts, expansion of deserts, heat waves, ecosystem disruption, increase in severe weather, and loss of agricultural productivity (IPCC, 2022). Although some GHGs occur naturally (e.g., water vapor) (Cretan, 2018), the majority are associated with anthropogenic activities such as burning of biomass, draining of wetlands, deforestation, soil cultivation, combustion of fossil fuels, decay of organic matter, and cement manufacturing. The GHGs whose concentrations in the atmosphere have increased since the pre-industrial period include methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). These gases are usually released into the atmosphere through combustion of fossil fuels (Pacala & Socolow, 2004), land use change, and deforestation. The concentration of GHGs in the atmosphere has increased dramatically and exponentially, especially since the industrial revolution of the 1850s. Carbon dioxide emissions have increased by approximately 31%, from 280 ppmv in 1850s to 380 ppmv in 2005, to the current rate of 419ppmv (Figures 1 and 2) (Global Monitoring Laboratory, 2022; WMO, 2006; IPCC, 2007).

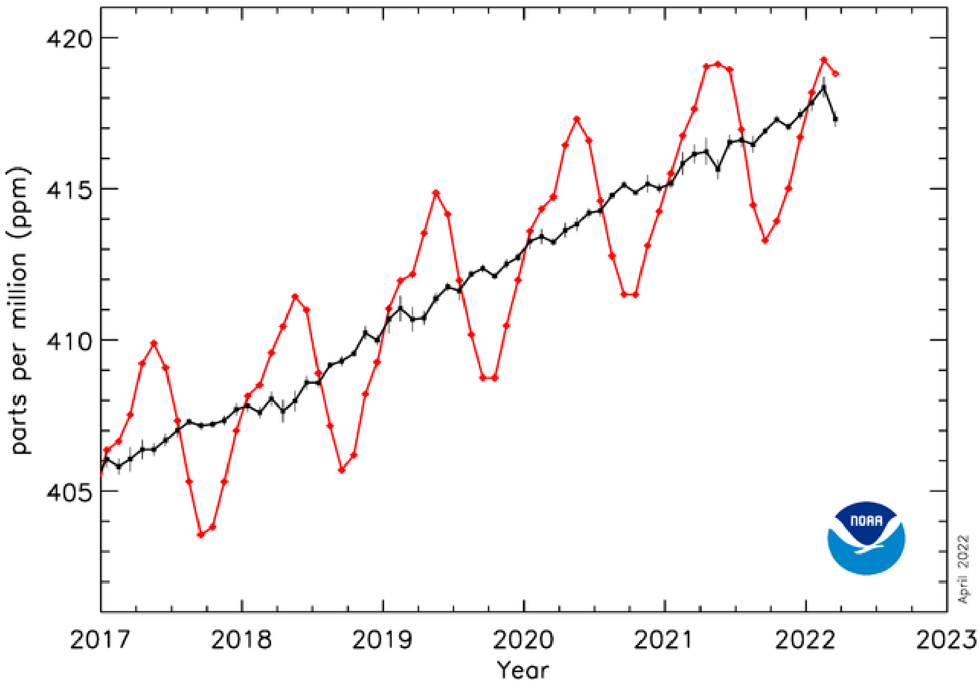

Figure 1: Monthly Mean CO_2 at Mauna Loa Observatory as of April 2022
Source: Global Monitoring Laboratory (2022)

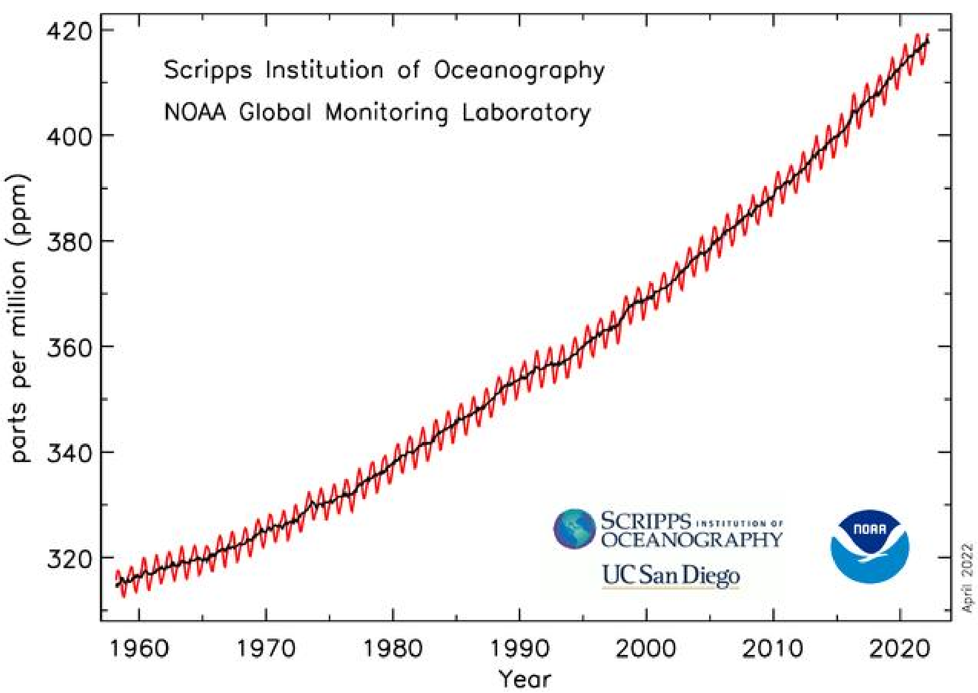

Figure 2: Trends in Atmospheric CO_2 at Mauna Loa Observatory as of April 2022
Source: Global Monitoring Laboratory (2022)

Currently, the main sources of CO_2 are associated with burning of fossil fuels, transportation, and home heating (Bauer & Volkart, 2017). The concentration of other greenhouse gases such as CH_4 and N_2O have steadily increased since the industrial revolution (WMO, 2006; IPCC, 2007). However, CH_4 emissions from waste management, contribute approximately 4% of the total global GHGs emissions (UNEP, 2012). The emission pattern of GHGs is expected to continue particularly with population increases, urbanization, deforestation, and agricultural intensification. There is, therefore, a need for carbon sequestration approaches to mitigate against increasing global temperatures.

Carbon Sequestration

Carbon sequestration involves the storage of atmospheric carbon dioxide in long term carbon pools that can later be released to the atmosphere. This process can either be naturally or anthropogenically driven (Lal, 2008). In biotic sequestration, plants and micro-organisms effectively remove CO_2 from the atmosphere. This includes oceanic sequestration where CO_2 is sequestered through photosynthesis (Turner, 2015) and terrestrial sequestration by plants and soils, with forests considered major carbon sinks (Krishnamurthy & Machavaram, 2000). Subsequently, interventions including afforestation and reforestation are viable options for sequestering carbon in terrestrial landscapes (Lamb et al., 2005; Nolan et al., 2021). The process of photosynthesis in terrestrial biomes is mainly determined by the ability of plants to store atmospheric carbon dioxide and accumulate biomass. Approximately 120PgC that is transferred annually during photosynthesis is either taken in by plant respiration or used for bacterial breakdown. By sequestering about 7% of this amount, terrestrial landscapes have the potential to offset annual anthropogenic emissions of approximately 9.1 PgC.

The amount of carbon sequestered by plants and soils may be traded for credits (Gressel 2007). In Europe and the United States, there is an elaborate carbon market, for instance, the Chicago Climate Exchange (Breslau, 2006; Johnson & Heinen, 2004). Carbon trade conversations have shifted their policies and conversations towards lowering GHGs emissions (Kerr, 2007; Kintisch, 2007) by, for example, imposing taxes on carbon emissions and transacting carbon credits. Although carbon trading in the west is more elaborate, resource scarce countries in Sub-Saharan Africa and Asia stand to benefit substantially. For instance, trading carbon credits may provide income to farmers and an incentive to invest in forest restoration while promoting a better quality of life. The need for sustainability worldwide has led to changes especially in forest cover. Systematic analysis of land use changes over time, purposes to uncover general principles for predicting new land use changes (Lambin et al., 2008).

Chapter 2: Literature Review

Carbon (iv) Oxide

According to Wofsy (2001), the rate of emission from combustion of fossil fuels increased by almost 40% between 1980 and 2000. Global carbon pools are interlinked and strongly influenced by anthropogenic distresses such as land use change and burning of fossil fuels. Production of CO_2 is captured by plant respiration and decay of organic matter in the soil (Domke et al., 2018). Human induced carbon emission is stabilized by either retention of CO_2 in the atmosphere or in aquatic systems, or assimilation by terrestrial basins such as forests (USDA, 2017).

Carbon Cycle

Carbon cycle involves the movement of carbon in elemental (e.g., graphite) and combined states (e.g., carbon dioxide) on Earth (Figure 3). Carbon is found in living matter, dissolved water and air as CO_2. It is also found in various minerals in form of carbonates (e.g., calcium carbonate). Carbon cycle begins with fixation of atmospheric CO_2 by photosynthesis, which is carried out by plants and certain microorganisms. During this process, CO_2 reacts with water molecules to form carbohydrates, releasing a free oxygen to the atmosphere. The process can be summarized by the equation: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.

The amount of carbon stored in the soil is approximately 2,300 gigatons per year, plants store up to 550 gigatons per year whereas the amount transferred to the atmosphere via respiration is approximately 60 gigatons per year (Figure 3). A share of carbon that is fixed by plants is consumed by animals (Creţan, 2018), which in turn is released as CO_2

during respiration. When a plant or an animal dies, the carbon in their tissues is oxidized to CO_2 and released to the atmosphere.

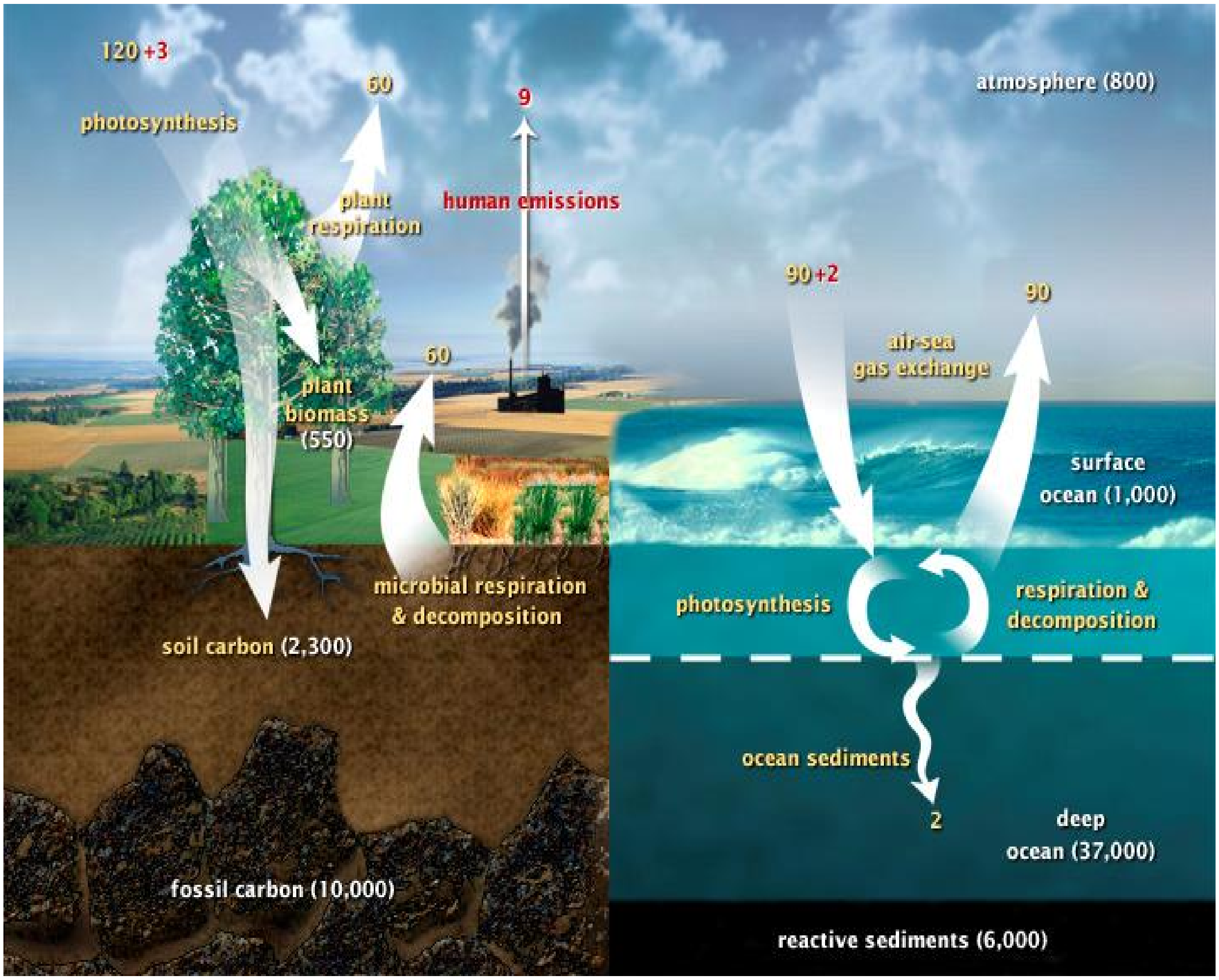

Figure 3: Carbon cycle showing natural fluxes (yellow), human contributions (red), stores carbon (white). The values are in gigatons of carbon per year.

Source: NASA https://earthobservatory.nasa.gov/features/CarbonCycle

The pattern of marine carbon circulation is different from terrestrial circulation. Deep oceans, for example, have the potential to store up to 37,000 gigatons of carbon per year. The phytoplankton not only require plentiful supplies of phosphorus and nitrogen, but also trace amounts of metals including iron (Williams et al., 2006). Conversely, within land, soil productivity is mostly limited by the availability of fresh water, phosphorus, and to some degree, availability of other nutrients in the soil.

Strategies for Carbon Capture

Efforts to minimize adverse effects associated with atmospheric carbon emissions involves chemical, technological and biological adaptation or mitigation strategies. Adaption measures are informed by land use changes (Wieder et al., 2015) while mitigation strategies are measures undertaken to capture or reduce carbon emissions. Reducing emissions involves efficient use of energy and replacement of fossil fuels with either low or no-carbon energy sources. Carbon can also be sequestered through the transfer of atmospheric CO_2 into oceanic, geologic, terrestrial, and chemical pools (Schrag, 2007); hence, cannot be easily leaked back into the atmosphere.

Forests in the Global Space

Forests perform various vital roles such as reducing surface water runoff, climate regulation, biodiversity maintenance, carbon sequestration, soil protection, and nutrients storage. Only 31% of the total land cover is covered by forests, including anthropogenic forests such as urban forests which are under threat from urbanization (FAO, 2012). Urban dwellers view urban forests as a vital infrastructure that enhances ecosystem services and functions including carbon sequestration, air quality improvement, mitigation of surface rainwater runoff, improvement of city aesthetics, and reduction of noise pollution (McPherson et al., 1997). Rowntree and Nowak (1991) noted that urban forests store approximately 800 million tons of carbon.

Conserving energy and mitigating against carbon emission is an important step towards environmental sustainability (Akbari et al., 1990). Forest cover, for example, help cool buildings, hence reducing energy consumption. The approximately 100 million mature trees in urban areas of the U.S. have contributed to an annual decrease in energy consumption of approximately 30 billion kWh (Akbari et al., 1990). Forests are important for hydrologic processes as they reduce stormwater runoffs, flooding, stormwater treatment costs, and water quality problems. Additionally, forest cover affects evapotranspiration by increasing its rates (Fletcher & Sarkar, 2013; McGrane 2016; Pataki et al., 2011; Peters et al., 2011) and can provide a cooling effect, extenuating urban heat island (Gunawardena et al., 2017).

Old-Growth Forests

As organic matter is decomposed by the soil microorganisms, CO_2 is released into the atmosphere through respiration. Trees sink CO_2 in their tissues in their life span. Variabilities in carbon sequestration is associated with forest soil ability to store CO_2, the age of tree, the rate of CO_2 release in decaying matter, and tree species (Gilbreath, 1995). The age of the forest influences the amount of CO_2 sequestered. Due to their maturity and sizes, old-growth forests capture more carbon in a much slower rate.

Fallen leaves from trees enrich the soils with carbon. Deciduous leaves decompose rapidly within 3 years (Curtis & Gough, 2018), however, decomposition products and refractory organic compounds may last much longer as soil organic matter. The maximum rate of sequestration will occur during the maximum rate of biomass accumulation and maximum net productivity (Norby et al., 2002), but as the forest matures, the rate of sequestration declines.

Forest Cover in United States

In the United States, forests occupy approximately a third of the entire landscape. Forest ecosystems play a vital role in offsetting the carbon emissions. This has been constant since 2005 despite economic-wide declines of CO_2 emissions. The ability of forests to capture carbon in the United States, is gradually decreasing (Nave et al., 2019). Mitigation measures such as afforestation and reforestation have been projected to increase the impact of carbon sequestration by forests (Law et al., 2018), leading to buildup of CO_2 in soils and biomass. The increase of forested cover increases both the ecosystem services and functions (Kabisch et al., 2019). However, there have been implementation challenges associated with land use changes and their management objectives.

Droughts and other natural events such as heat waves have been associated with tree mortality in forests in the western United States (Allen et al., 2010; Weed et al., 2013). Drought render trees and forests vulnerable across entire biomes, hence causing deaths to different plant species (Choat et al., 2012; Klos et al., 2009). Forest ecosystems are vital resources for groundwater recharge, species habitat, flood control, and climate regulation (Jones et al., 2010; Price, 2011). Persistence of these natural occurrences have been studied to better understand the adaptation of groundwater-dependent species (Vose et al., 2015) including greasewood (*adenostoma fasciculatum*), salt cedar (*tamarix spp.*), rabbitbrush (*chrysothamnus spp.*).

Presently in the United States, the federal government aims to plant approximately 65 million seedlings per year according to (Domke, 2020), whereas states and the private sector aims for about 1.1 billion seedlings every year (Chazdon et al., 2016). Collectively, the estimated 1.2 billion trees planted on forest land sequester between 16 and 28 million metric tons of CO_2 each year.

Carbon Dioxide Capture and Vegetation Types

Vegetation can reduce approximately 90% of incoming solar radiation (Nguyen & Pearce 2012). Tree canopies can cool the local environment especially in area that are predominantly urban (Nowak & Dwyer, 2007). The cumulative amount of CO_2 that is fixed differs from one vegetation type to the other. For example, tropical rain forests capture between 1 and 2 kg of CO_2 for each meter square of land surface, an estimation equal to the amount of CO_2 of an air column of similar area ranging from the earth's surface to the atmosphere. Desert landscapes capture approximately 1% of the amount captured by tropical forests. The global landmass captures approximately 20 to 30 billion metric tons of carbon per year (Pan et al., 2011).

Carbon sequestration differs with forest age, forest type, and tree sizes. Evergreen and tropical rain forests have a greater potential for carbon capture (Viriyabuncha et al., 2002). Deciduous forests in the boreal ecosystems capture 178 gCm^2 per year, while humid evergreen forests capture approximately 130 gCm^2 per year. Additionally, semi-arid evergreen forests store up to 43gCm^2 per year (Luyssaert et al., 2007). Links of carbon capture and tree size have also been studied, revealing deciduous forest sequestering carbon with tree sizes ranging from 40 to 60 cm (Terakunpisut et al., 2007). Previous research at the North Appalachian Experimental Watershed, showed that the top 0.2m soil under deciduous forests may have a large potential to sequester soil organic carbon through biochemical protection mechanisms (Lützow et al., 2006; Tan et al., 2004).

However, in comparing biomass and carbon sequestration in different forest ecosystems, vegetation of shorter lifespan usually less than 1 year, includes deciduous leaves, flowers, and seeds included in forest liter production, while life spans greater than 1 year including evergreen leaves, cones, branches, bark, and stem wood, contains more biomass since they are present throughout the year with less net production. Under the same temperature system, an evergreen forest is estimated to be a stronger sink than a deciduous forest. A study done by Hyvönen et al. (2007) concluded that a young forest less than 25 year of age sequesters carbon more strongly than an old forest.

Urban Forests and Micro-Forests

In urban areas, green landscapes are being incorporated into urban infrastructure design (Kuser, 2006). Urban forests in the U.S. are estimated to capture up to 10.3 tCO_2/ha/a (Nowak et al., 2013). However, forest restoration techniques, such as the Miyawaki Method tested planting smaller, densely, biodiverse and fast-growing vegetation across the world (Ottburg et al., 2018; Schirone et al., 2011). It was found out that the potential for carbon storage from both the Miyawaki micro forests and its soils tops 598 tCO_2/ha and a sequestration potential of approximately 5.1 tCO_2/ha/a (Manuel, 2020). Still, there is inadequacy of peer reviewed research that fully support this concept. The variability of carbon capture for green roofs, for example, ranges between 0.3 and 7.1 $kgCO_2/m^2/a$ (Heusinger & Weber, 2017; Luo et al., 2015).

Problem Statement

Despite advancements in environmental monitoring, measuring carbon that is sequestered by urban forests remains a challenge due to the interaction of various dynamics within an urban landscape. The purpose of this research is to evaluate the effect of increasing urban forests on the amount of carbon capture in Youngstown, a Rust Belt city. The city has experienced significant population changes in the recent past. For instance, while the current population is listed at approximately 60,000, its population exceeded 160,000 between 1930s and 1960s. Subsequently, the urban landscape of Youngstown and its environs has changed considerably.

Research Hypotheses

H1: Based on historical trends and using a projection model, the forest cover in Youngstown Metropolitan Area will decrease by 2069**.**

H2: Converting open, low, or moderately developed areas to urban forest will increase the ability of the Youngstown Metropolitan Area to sequester carbon.

Objectives

This research objectives are:

- To evaluate the amount of forest cover in the Youngstown Metropolitan Area.
- To analyze forest cover changes for the period 2001 – 2019.
- To quantify the amount of carbon capture in relation to forest cover.
- To identify viable areas for tree planting.
- To predict a 50-year forest cover change and associated amount of carbon capture.

Chapter 3: Methodology

The Youngstown Metropolitan Area

The Youngstown Metropolitan Area (YMA) is located in the Mahoning River Watershed (Figure 4). This area has had a long history of steel manufacturing and milling dating back to the mid-1800s. The region became a favorable steel production area due to its proximity to the Mahoning River and immediacy to Ashtabula Harbor on Lake Erie. The port received iron ore and coal from different mining areas in Ohio, Pennsylvania, Minnesota, and West Virginia. A decline in steel consumption eventually led to a decline in steel production in the 1970s.

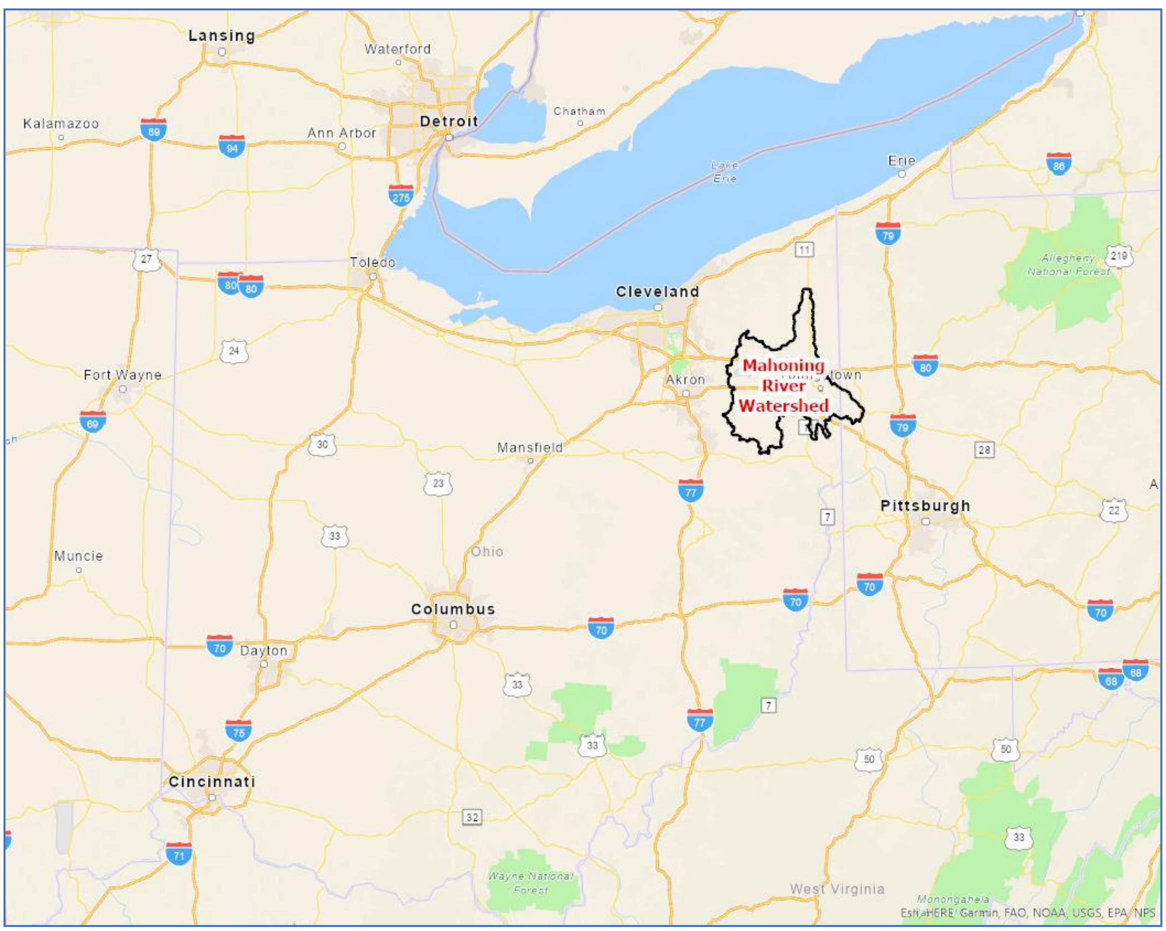

Figure 4: The Mahoning River Watershed

The Mahoning River Watershed flows through seven counties in northeastern Ohio. The major municipalities within the watershed include Youngstown, Warren, Alliance and Lordstown. While the eastern part of the watershed is predominantly urban, the western portion of the watershed is a mixture of forests, hay and pasture, cultivated crops, and urban development. Sections of the lower Mahoning River watershed, comprising of the Little Squaw Creek, Andersons Run-Mill Creek, Dry Run, and Crab Creek sub-watersheds are part of the Youngstown Metropolitan Area (Figure 5). These sub-watersheds are the focus of this study. The total area for the four sub-watersheds is 258km^2, with developed and forested areas occupying 185.8 km^2 and 49.8km^2, respectively.

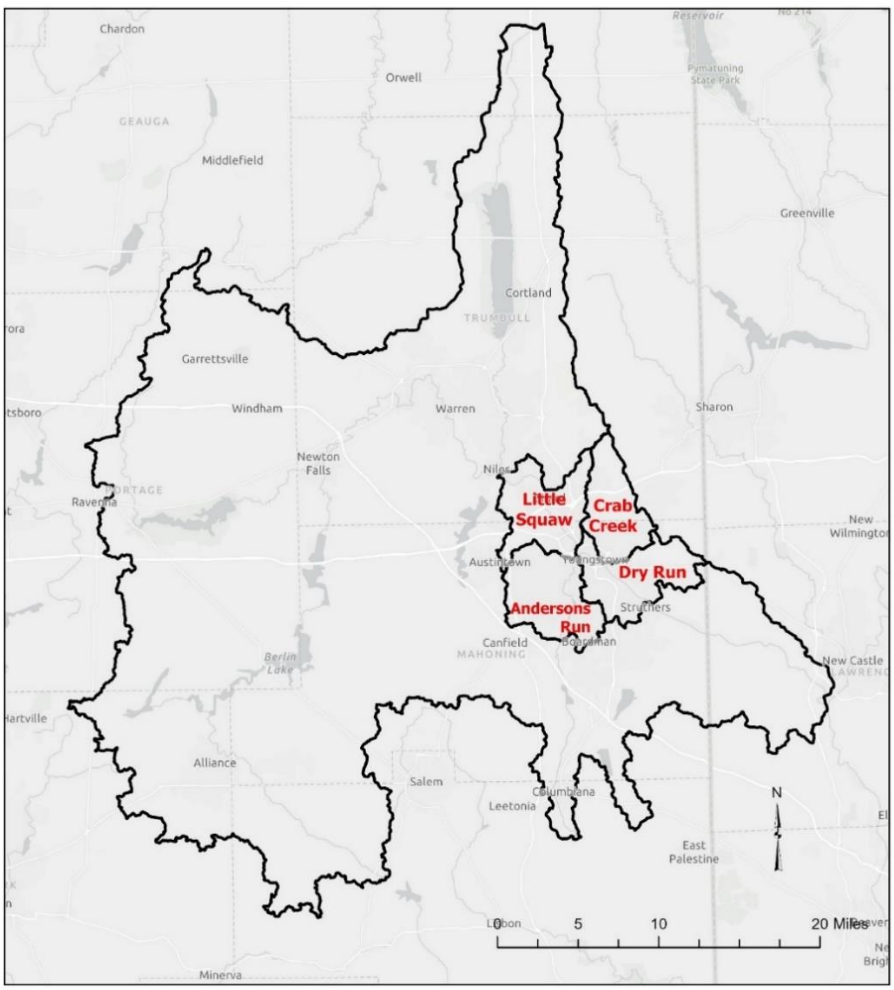

Figure 5: The four sub-watersheds in the Youngstown Metropolitan Area

Data

The land use and land cover data that was used in this study was obtained from the USGS National Land Cover Database (NLCD) through the Multi-Resolution Land Characteristics (MRLC) Consortium website: https://www.mrlc.gov/. The NLCD data for the years 2001, 2011, and 2019 was used in this research.

Land Cover Area Estimation, Accuracy and Precision

Land cover datasets for the years 2001, 2011 and 2019 were used to estimate the area under different land uses. These land uses have been classified according to a modified Anderson Land Use/ Land Cover classification system, consisting of eight class categories (water, developed, barren, forest, shrubland, herbaceous, planted/cultivated, and wetlands). The NLCD allocates numbers (e.g., 11, 12, 21, 22, etc.) to represent various land uses for identification purposes. A summary of these classes are presented in Table 1.

Table 1: The National Land Cover Database classification system

Class	**Classification**
Water	11 Open Water *
	12 Perennial Ice/Snow
Developed	21 Developed, Open Space *
	22 Developed, Low Intensity *
	23 Developed, Medium Intensity *
	24 Developed, High Intensity *
Barren	31 Barren Land (Rock/Sand/Clay) *
Forest	41 Deciduous Forest *
	42 Evergreen Forest *
	43 Mixed Forest *
Shrubland	51 Dwarf Scrub
	52 Shrub/Scrub *
Herbaceous	71 Grassland/Herbaceous *
	72 Sedge/Herbaceous
	73 Lichens

	74 Moss
Planted/Cultivated	81 Pasture/Hay * 82 Cultivated Crops
Wetlands	90 Woody Wetlands * 95 Emergent Herbaceous Wetlands *

* Land use types present in YMA
Source: Multi-Resolution Land Characteristics (MRLC) Consortium (mrlc.gov)

The NLCD data used in this study has an accuracy of 78.8%, 82%, and 86.4% for the 2006, 2011, and 2019 data, respectively (Wickham et al., 2021). The level of accuracy for these datasets can lead to some degree of uncertainty, especially those relating to area quantifications and measurement. Since these datasets were generated using Landsat data with spatial resolution of 30 meters, the area under each pixel equates to 900 m^2 (30m*30m). For the developed class, for example, the total number of pixels under open space (21 Developed, Open Space), low intensity (22 Developed, Low Intensity), medium intensity (23 Developed, Medium Intensity), and high intensity (24 Developed, High Intensity) were summed and multiplied by 900 m^2 (30m*30m). These calculations were performed using the ArcGIS Pro software. The amount of area under forest for the years 2001, 2011, and 2019 were obtained and subsequently used to estimate the amount of carbon captured. ArcGIS Pro was also used to estimate the amount of land cover changes occurring between two time periods (e.g., 2001 and 2011, 2011 and 2019, or 2001 and 2019).

Since uncertainties of these datasets could compromise the level of accuracy for the output, demolition data from the City of Youngstown for the period 2006-2021 was used to approximate the amount of land available for tree planting within YMA's city limits. The assumption is that these areas have not been rebuilt or converted to other land uses.

Estimating the Amount of Carbon Capture

Consistent estimation of carbon stock is vital for mitigating against greenhouse gas emissions (Radtke et al., 2017). Approximating the amount of carbon stock for forest cover can be defined using five categories (Vashum & Jayakumar, 2012), namely a) above ground biomass characterized by all living biomass including the understory, seeds, foliage, stems, barks and branches, soil organic carbon of all the living materials therein to a depth of 1 meter, not including the rough roots, b) below ground biomass characterized by all living organisms, for example, coarse living roots with a diameter larger than 2 millimeters, c) carbon storage pools, estimated using litter of all biomass (non-living) with 7.5 centimeters diameter or less at a cut joint on the ground, d) dead wood, including biomass that is non-living either lying on the ground, standing or found in the soil cover, and e) harvested wood, both the in use harvested wood products are included when approximating carbon flux/change.

A study by Nowak and Crane (2002) using field data from 10 cities in the United States noted that urban forests in different states sequester different amounts of carbon. For Ohio, the amount of carbon storage is estimated at 35.4 tons per hectare. This amount of carbon storage is recognized by the U.S. Department of Agriculture (USDA) and the U.S. Forest Service (USFS) (see. https://www.fs.usda.gov/treesearch/pubs/15521) and is used to calculate carbon storage in the sub watersheds of the YMA.

Predicting Future Land Cover for the YMA

Most prediction methods utilize information from historical records, photogrammetry, satellite imagery, etc. Other land use and land cover scenarios have been obtained through regression or process-based models. In this study, the Land Change

Modeler (LCM) which is integrated into the TerrSet software was used to predict a 50-year land cover map for the YMA. TerrSet is a software developed by Clark Labs (https://clarklabs.org/) at Clark University. To generate a 50-year map (2069) for the region, an earlier land cover image (2001) and a later land cover image (2019) is required.

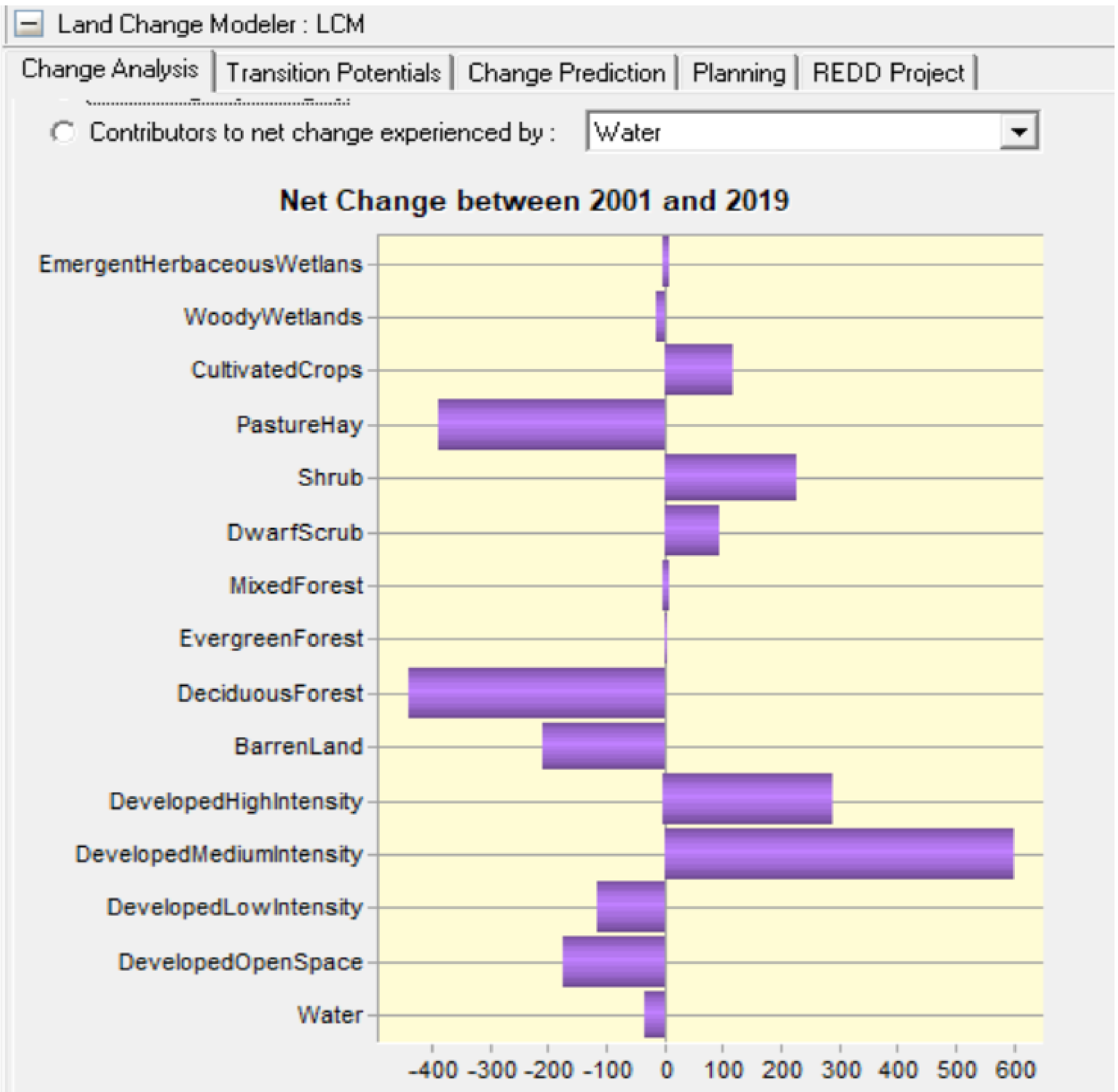

Figure 6: Change analysis model showing gains and losses between 2001 and 2019

The Markovian Transition Estimator (Markov) was used to generate a transition probability matrix, a transition areas matrix, and conditional probability maps (Figure 7).

These outputs are needed for generating the 2069 prediction in Cellular Automata/Markov Change Prediction (CA_Markov) model (Figure 8). The 2069 map generated through TerrSet was subsequently exported to ArcGIS Pro, where the area under different land uses were obtained.

The change analysis from the LCM for the period 2001 and 2019 is presented in Figure 6. The values at the bottom of the diagram represents the number of pixels.

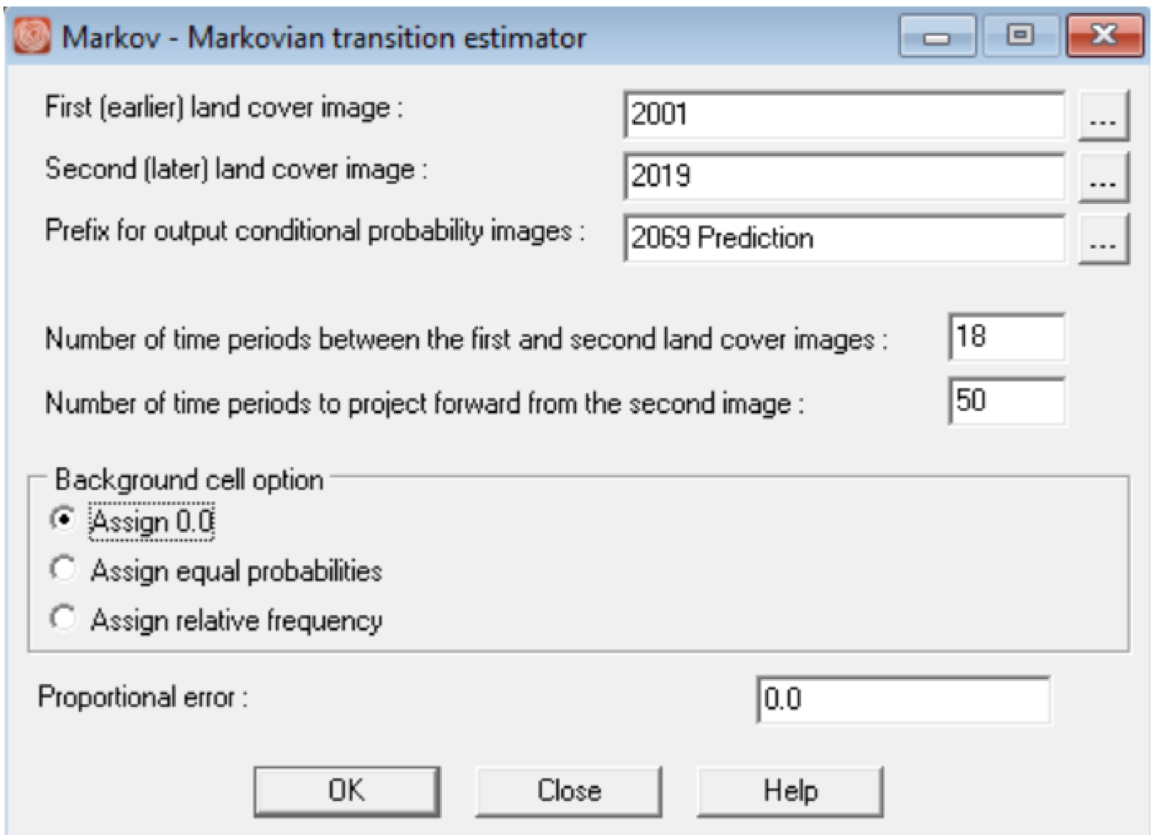

Figure 7: Markovian transition estimator (Markov)

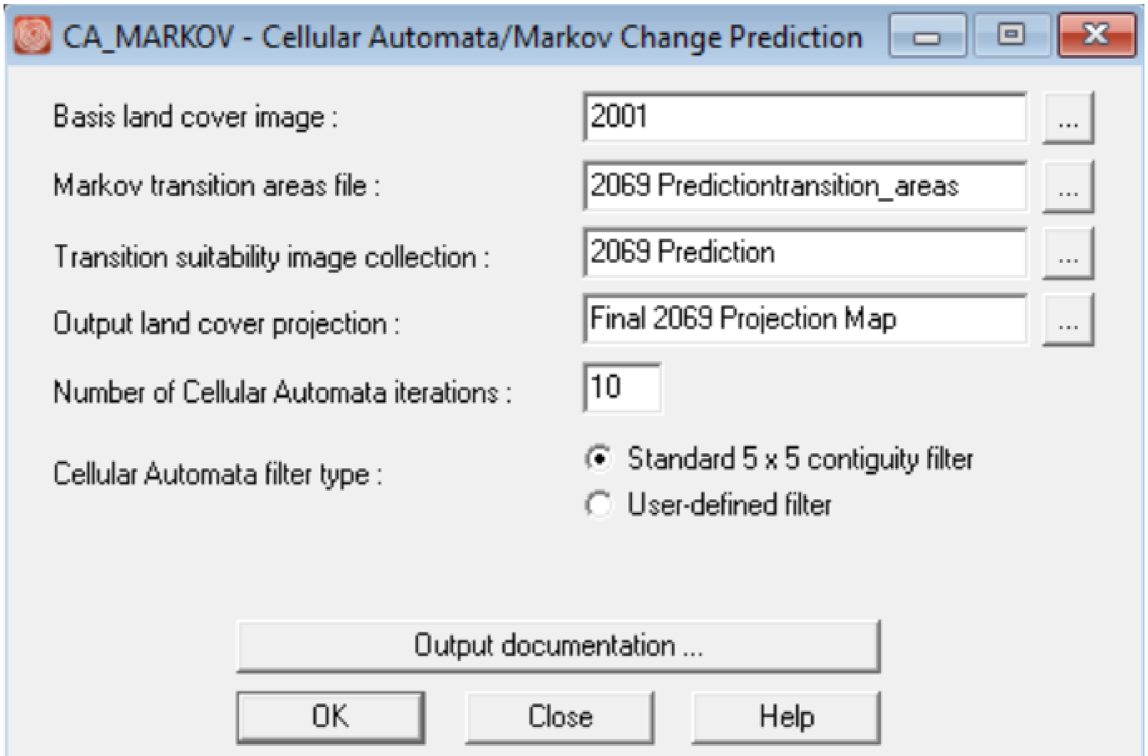

Figure 8: Cellular Automata/Markov change prediction (Ca_Markov)

Chapter 4: Results

Forest Cover Changes for the Years 2001, 2011 and 2019

A decrease was observed in deciduous forest cover between 2001 and 2011 (Table 2, Figure 9). Shrubs did not record any increase in area between 2001 and 2011. Shrubs are defined by the NLCD as vegetation dominated with trees in their early development or inhibited by climatic conditions. In contrast, there was an increase of approximately 70ha in forest cover area between 2011 and 2019 (from 5,220 ha to 5,290ha), increasing the total sequestered carbon by approximately 2,000t. The total area under forest cover between 2001 and 2019 decreased by 40ha, reducing the amount of carbon captured.

Table 2: Amount of forest cover and carbon storage for YMA for years 2001, 2011, and 2019

	2001		**2011**		**2019**	
Land use	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Deciduous Forest	49.2	19.1	47.5	18.4	47.6	18.5
Evergreen Forest	0.1	0.0	0.1	0.0	0.1	0.0
Mixed Forest	2.4	0.9	2.4	0.9	2.4	0.9
Shrubs	0.5	0.2	0.6	0.2	0.8	0.3
Grassland/ Herbaceous	1.1	0.4	1.6	0.6	2.0	0.8
Total	**53.3**	**20.7**	**52.2**	**20.2**	**52.9**	**20.5**
Hectares (ha)	**5,330**		**5,220**		**5,290**	
Carbon storage (t)	**189,000**		**185,000**		**187,000**	

1 km^2 = 100 ha

Carbon storage for urban forests in Ohio = 35.4 t/ha

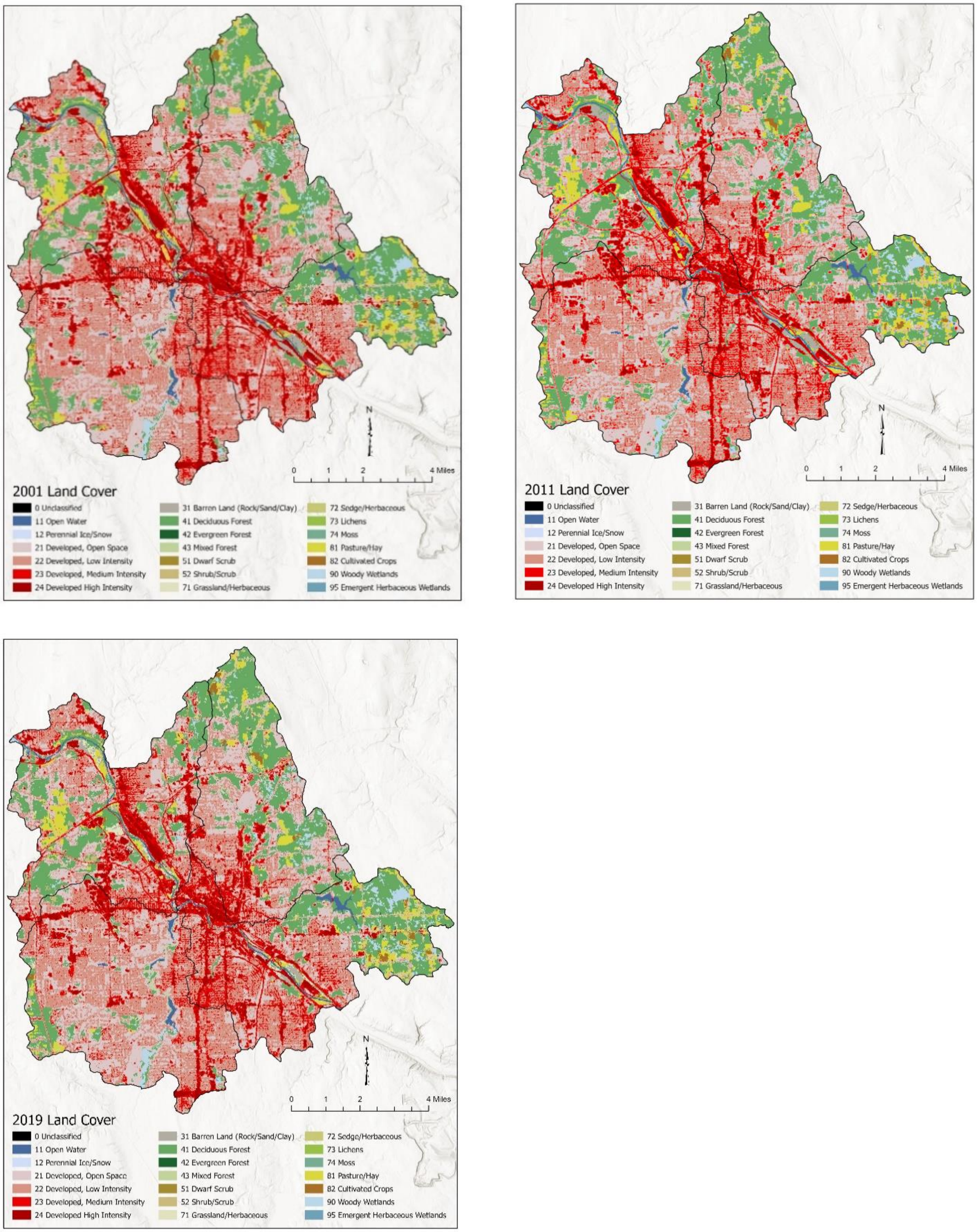

Figure 9: Land cover maps for the YMA for the years 2001, 2011, and 2019

Developed land cover in the YMA has been increasing since 2001. According to NLCD, developed land uses are classified into four major categories, (1) developed open spaces where total developed area accounts for 20% of the total land cover, (2) developed low intensity, (3) developed medium intensity, and (4) developed high intensity. Developed open spaces land use is a mixture of constructed environments, and the dominant vegetation type is grass. The YMA registered an increase of 200ha (from 18,400ha to 18,600ha) in developed land uses between 2001 and 2019 (Table 3).

Table 3: Developed land use for the years 2001, 2011, and 2019

	2001		**2011**		**2019**	
Land use	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Developed, Open Space	57.4	22.2	57.3	22.2	56.7	22.0
Developed, Low Intensity	83.2	32.2	83.3	32.3	82.9	32.1
Developed, Medium Intensity	31.3	12.1	32.5	12.6	33.4	12.9
Developed, High Intensity	11.8	4.6	12.4	4.8	12.8	5.0
Total	**184**	**71.2**	**186**	**71.9**	**186**	**72.0**
Hectares (ha)	**18,400**		**18,600**		**18,600**	

Developed low intensity land use is characterized by built structures and vegetation and constitutes primarily of single-family housing units. While an increase in developed low intensity land cover was observed between 2001 and 2011 (from 8,320ha to 8,330ha), a decrease of approximately 40ha (from 8,330ha to 8290ha) was observed between 2011 and 2019.

Developed medium intensity land cover, which constitutes a mixture of built environment and vegetation cover, registered an increase of 12ha (from 3,130ha to 3,250ha) between 2001 and 2011. This land cover is the most common in the YMA.

Developed high intensity land uses are highly developed and contains apartment complexes, commercial and industrial establishments, and row houses. The total land cover of impervious surfaces in this land cover is between 80% and 100%. According to the NLCD data, developed and high intensity land cover, registered and increase of about 1.01km^2 between 2001 and 2019.

Land Cover for Sub-Watersheds in the YMA for the Years 2001 and 2019

The sub-watersheds examined in this study include Dry Run Creek (Figure 10, Table 4 & 5), Crab Creek (Figure 11, Table 6 & 7), Andersons Run-Mill Creek (Figure 12, Table 8 & 9), and Little Squaw Creek (Figure 13, Table 10 & 11).

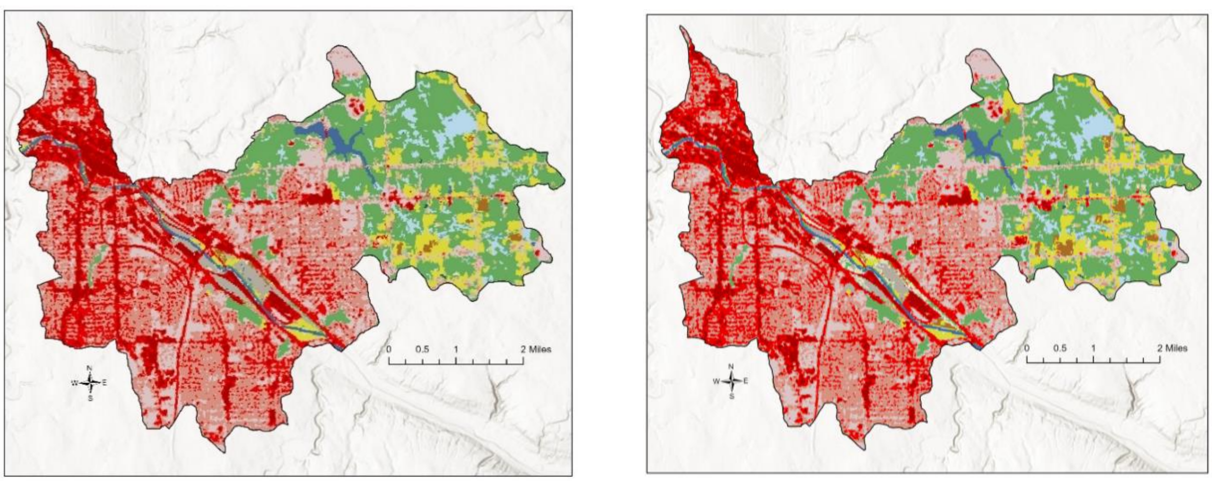

Figure 10: Land cover maps for the Dry Run Creek for the years 2001 (left) and 2019 (right)

The amount of forest cover in Dry Run Creek increased by 40ha (from 1420ha to 1460ha) between 2001 and 2019, leading to approximately increase of 1,400t (51,700t - 50,300t) in the amount of carbon sequestered. Between 2011 and 2019 the amount of carbon sequestered increased by 1,400t (from 50,300t to 51,700t) due to an increase in forest cover (Table 4).

Table 4: Forest cover and carbon storage for Dry Run Creek for the years 2001, 2011, and 2019

Land use	2001		2011		2019	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Deciduous Forest	13.3	20.2	13.0	19.8	13.2	20.2
Evergreen Forest	0.0	0.0	0.0	0.0	0.0	0.0
Mixed Forest	0.6	0.9	0.6	0.9	0.6	0.9
Shrubs	0.1	0.2	0.2	0.3	0.1	0.2
Grassland/Herbaceous	0.2	0.3	0.4	0.6	0.6	0.9
Total	**14.2**	**21.6**	**14.2**	**21.6**	**14.6**	**22.2**
Hectares (ha)	**1,420**		**1,420**		**1,460**	
Carbon storage (t)	**50,300**		**50,300**		**51,700**	

1 km^2 = 100 ha

Carbon storage for urban forests in Ohio = 35.4 t/ha

Table 5: Developed land uses for Dry Run Creek for the years 2001, 2011, and 2019

Land use	2001		2011		2019	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Developed, Open Space	8.9	13.5	8.8	13.3	8.6	13.1
Developed, Low Intensity	18.8	28.6	18.7	28.5	18.6	28.3
Developed, Medium Intensity	11.2	17.1	11.4	17.4	11.6	17.7
Developed, High Intensity	4.2	6.4	4.4	6.7	4.5	6.8
Total	**43.1**	**65.6**	**43.3**	**65.9**	**43.3**	**65.9**
Hectares (ha)	**4,310**		**4,330**		**4,330**	

In the Dry Run Creek, a notable decrease by 30ha (from 890ha to 860ha) was observed in developed open spaces between 2001 and 2019. These are areas described to contain golf courses, parks and single family-units. Medium intensity developments recorded the most increase (from 1,120ha to 1,160ha) between 2001 and 2019.

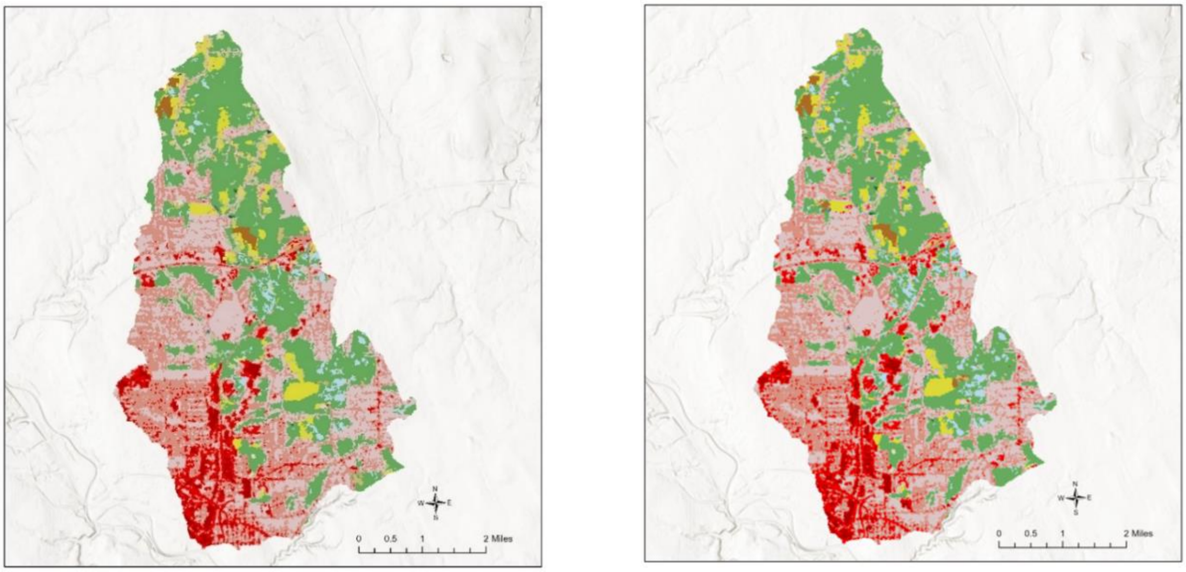

Figure 11: Land cover maps for Crab Creek for the years 2001 (left) and 2019 (right)

Table 6: Forest cover and carbon storage for Crab Creek for the years 2001, 2011, and 2019

	2001		**2011**		**2019**	
Land use	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Deciduous Forest	16.1	29.5	15.6	28.5	15.7	28.8
Evergreen Forest	0.0	0.1	0.0	0.1	0.0	0.1
Mixed Forest	1.1	2.0	1.1	2.0	1.1	2.0
Shrubs	0.2	0.3	0.2	0.3	0.2	0.3
Grassland/Herbaceous	0.2	0.4	0.3	0.6	0.2	0.3
Total	**17.6**	**32.2**	**17.2**	**31.5**	**17.2**	**31.5**
Hectares (ha)	**1,760**		**1,720**		**1,720**	
Carbon storage (t)	**62,300**		**60,900**		**60,900**	

1 km^2 = 100 ha
Carbon storage for urban forests in Ohio = 35.4 t/ha

Between 2001 and 2019, approximately 40 ha (from 1,760ha to 1,720ha) of forest cover was lost in Crab Creek (Table 6), equating to a carbon capture loss of approximately 1,400t (62,300t - 60,900t). There was, however, a decrease in deciduous forest cover from 1,610ha to 1,570ha between 2001 and 2019. On the other hand, the area under mixed forest cover did not change during the same period (Table 6).

Table 7: Developed land use for Crab Creek for the years 2001, 2011, and 2019

Land use	**2001**		**2011**		**2019**	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Developed, Open Space	14.3	26.2	14.4	26.3	14.3	26.2
Developed, Low Intensity	13.4	24.5	13.5	24.8	13.4	24.6
Developed, Medium Intensity	4.0	7.3	4.2	7.8	4.3	8.0
Developed, High Intensity	1.3	2.3	1.3	2.4	1.4	2.6
Total	**32.9**	**60.3**	**33.4**	**61.3**	**33.5**	**61.3**
Hectares (ha)	**3,290**		**3,340**		**3,350**	

Crab Creek is one of the YMA sub-watersheds that experienced an increase in total developed area between 2001 and 2019 (from 3290 to 3350ha). Similarly, an increase of 30ha (from 400ha to 430ha) in medium developed land cover was recorded in Crab Creek during the same time period. Conversely, areas of low intensity development registered an increase of 10 ha (from 1,340ha to 1,350 ha) between 2001 and 2011 and a similar decrease between 2011 and 2019. Likewise, developed open spaces did not record any changes between 2001 and 2019.

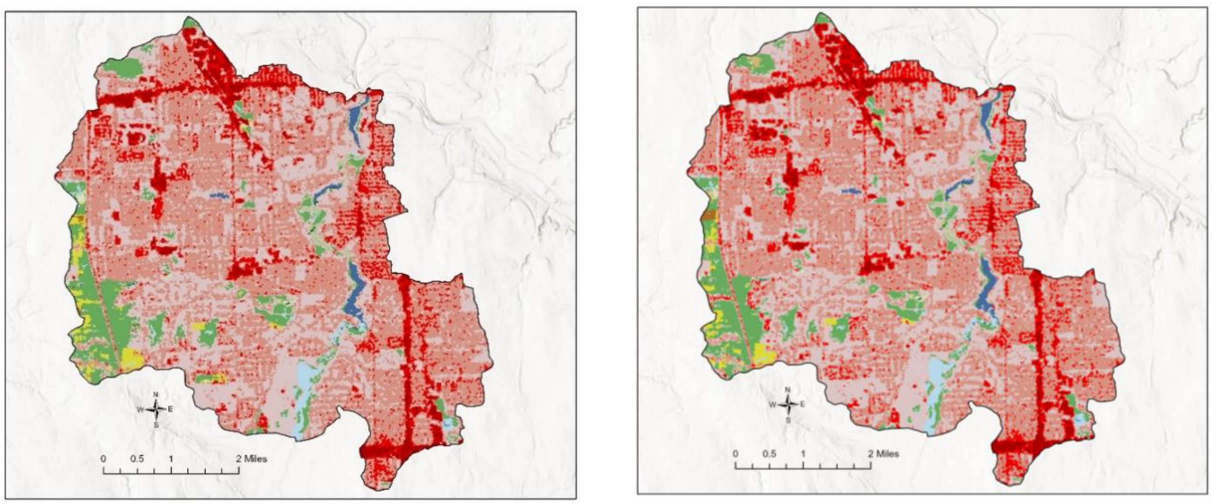

Figure 12: Land cover maps for the Andersons Run-Mill Creek for the years 2001 (left) and 2019 (right)

Table 8: Forest cover and carbon storage for Andersons Run-Mill Creek for the years 2001, 2011, and 2019

Land use	2001		2011		2019	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Deciduous Forest	4.9	7.0	4.5	6.5	4.5	6.4
Evergreen Forest	0.0	0.0	0.0	0.0	0.0	0.0
Mixed Forest	0.4	0.6	0.4	0.6	0.4	0.6
Shrubs	0.0	0.0	0.0	0.0	0.1	0.2
Grassland/Herbaceous	0.2	0.3	0.2	0.3	0.2	0.2
Total	**5.5**	**7.9**	**5.2**	**7.5**	**5.2**	**7.5**
Hectares (ha)	**552**		**524**		**524**	
Carbon storage (t)	**19,500**		**18,500**		**18,500**	

1 km^2 = 100 ha

Carbon storage for urban forests in Ohio = 35.4 t/ha

Forest cover of the Andersons Run-Mill Creek watershed decreased by 0.4% between 2001 and 2019 (Table 8). The decrease in forest cover from 552 ha to 524ha during this period, led to a carbon storage decrease of approximately 1,000t (from 19,500t to 18,500t), however, no forest cover changes occurred between 2011 and 2019. While deciduous forest cover shows the highest decrease in forest cover (7.0% to 6.4%) between 2001 and 2019, shrubs increased by 0.2% between 2001 and 2019. Also, between 2011 and 2019, the area under forest cover showed no changes, therefore, no carbon storage changes occurred during this period.

Table 9: Developed land use for Andersons Run-Mill Creek for the years 2001, 2011, and 2019

	2001		2011		2019	
Land use	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Developed, Open Space	20.5	29.2	20.4	29.1	20.2	28.8
Developed, Low Intensity	32.2	45.9	32.3	46.0	32.3	46.0
Developed, Medium Intensity	7.3	10.4	7.6	10.8	7.8	11.1
Developed, High Intensity	2.4	3.5	2.5	3.6	2.6	3.7
Total	**62.4**	**88.9**	**62.8**	**89.5**	**62.8**	**89.5**
Hectares (ha)	**6,240**		**6,280**		**6,280**	

The total developed area within the Andersons Run-Mill Creek was 89.5% of the land cover in 2019, an increase of 0.6% between 2001 and 2019. Developed open spaces decreased by 0.1% and 0.3% between 2001 and 2011 and 2011 and 2019, respectively. Both low, medium and high intensity developed land use noted an increase in land cover. High intensity recorded an increase of 0.1% between 2001 and 2011 and a similar increase between 2011 and 2019. Developed medium intensity increased by 0.4% from 2001 and 2011 and 0.3% between 2011 and 2019. The developed low intensity land cover is the dominant land cover in Andersons Run-Mill creek, covering 46.0% of the sub-watershed.

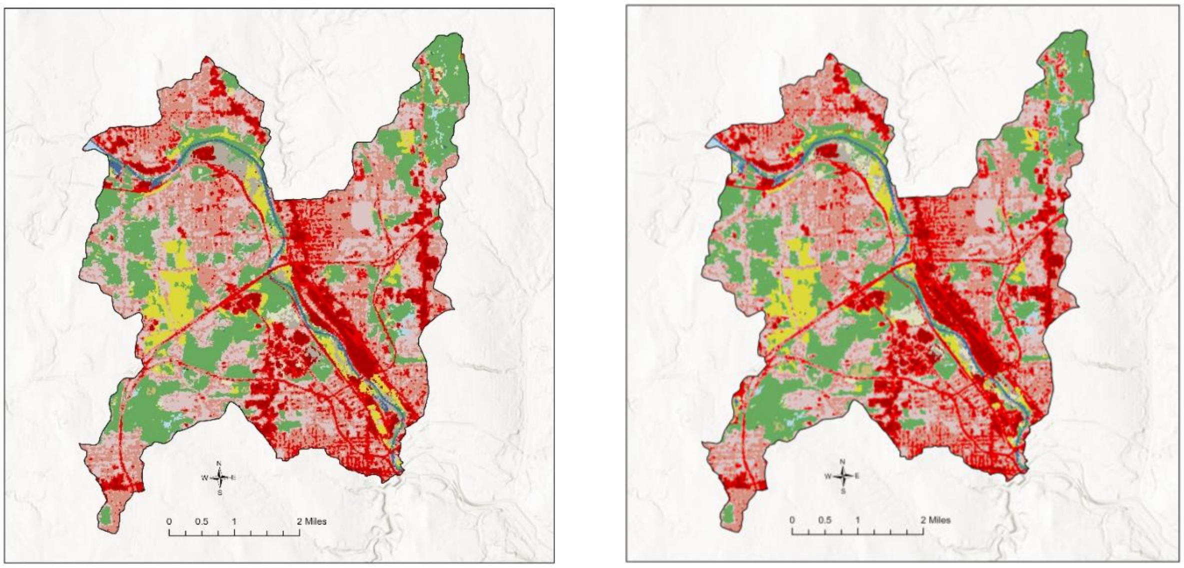

Figure 13: Land cover maps for the Little Squaw Creek for the years 2001 (left) and 2019 (right)

Table 10: Forest cover and carbon storage for Little Squaw Creek for years 2001, 2011, and 2019

	2001		**2011**		**2019**	
Land use	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Deciduous Forest	15.0	22.1	14.4	21.3	14.2	21.0
Evergreen Forest	0.0	0.0	0.0	0.0	0.0	0.0
Mixed Forest	0.3	0.4	0.3	0.4	0.3	0.4
Shrubs	0.2	0.3	0.2	0.3	0.4	0.6
Grassland/Herbaceous	0.5	0.8	0.6	0.9	1.1	1.6
Total	**16.0**	**23.6**	**15.5**	**22.9**	**16.0**	**23.6**
Hectares (ha)	**1,600**		**1,550.0**		**1,600**	
Carbon storage (t)	**56,600**		**54,900**		**56,600**	

1 km^2 = 100 ha
Carbon storage for urban forests in Ohio = 35.4 t/ha

There was no significant change in the total amount of forest cover in the Little Squaw Creek between 2001 and 2019. However, both grassland/herbaceous vegetation and shrubs noted a 0.8% (0.8% - 1.6%) and a 0.3% (0.3% - 0.6%) increase in land cover, respectively from 2001 to 2019. While deciduous forest recorded a decrease of 1.1% (22.1% - 21.0%), evergreen forest did not record any changes during the same time period. Subsequently, the amount of carbon storage increased by 1,593t (56,600t to 54,900t between 2011 and 2019, with grassland/herbaceous and shrubs observing the highest increase in vegetative cover.

Table 11: Developed land use for Little Squaw Creek for the years 2001, 2011, and 2019

Land use	**2001**		**2011**		**2019**	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Developed, Open Space	13.8	20.3	13.8	20.4	13.6	20.1
Developed, Low Intensity	18.8	27.8	18.8	27.8	18.6	27.5
Developed, Medium Intensity	8.9	13.1	9.3	13.7	9.7	14.3
Developed, High Intensity	3.9	5.8	4.1	6.1	4.3	6.4
Total	**45.3**	**67.0**	**46.0**	**67.9**	**46.2**	**68.3**
Hectares (ha)	**4,530**		**4,600**		**4,620**	

Developed land cover in Little Squaw Creek (Table 11) increased by 1.3% between 2001 and 2019. By 2019 developed low intensity was the most dominant land cover with a total land coverage of 27.5%. Between 2001 and 2019, medium intensity developed areas recorded the highest change in 18 years (1.2%). However, a reduction was observed for developed open spaces from 20.3% to 20.1% between 2001 and 2019. Over the same period, high intensity developed areas noted an increase of 0.6% (from 5.8% to 6.4%).

The Future Land Cover Map for the YMA in 2069

A 50-year projection of the YMA land cover (Figure 14), shows a 230ha decrease in forest area (from 5,290ha to 5,060ha) between 2019 and 2069 (Table 12 and 13). Developed areas, mainly comprising of medium and high intensity developments, are expected to increase from 18,600ha to 19,000ha. Apartment complexes, industrial plants, and single-family units will dominate this landscape in 2069. The area under deciduous forest will reduce from about 4,800ha in 2019 to approximately 4,570ha in 2069, whereas mixed forest and shrub will both register an increase in land cover from 320ha in 2019 to 330ha in 2069. Although the developed land cover in the Little Squaw Creek will show the highest increase (180ha) between 2019 and 2069, forest cover is predicted to decrease by 100ha (from 1,600ha to 1,500ha) during the same period. The total forest area loss in the YMA between 2001 and 2069 will be approximately 250ha (from 5,310ha to 5,060ha), while developed areas will account for 600ha (from 18,400ha to 19,000ha) gain during the same period.

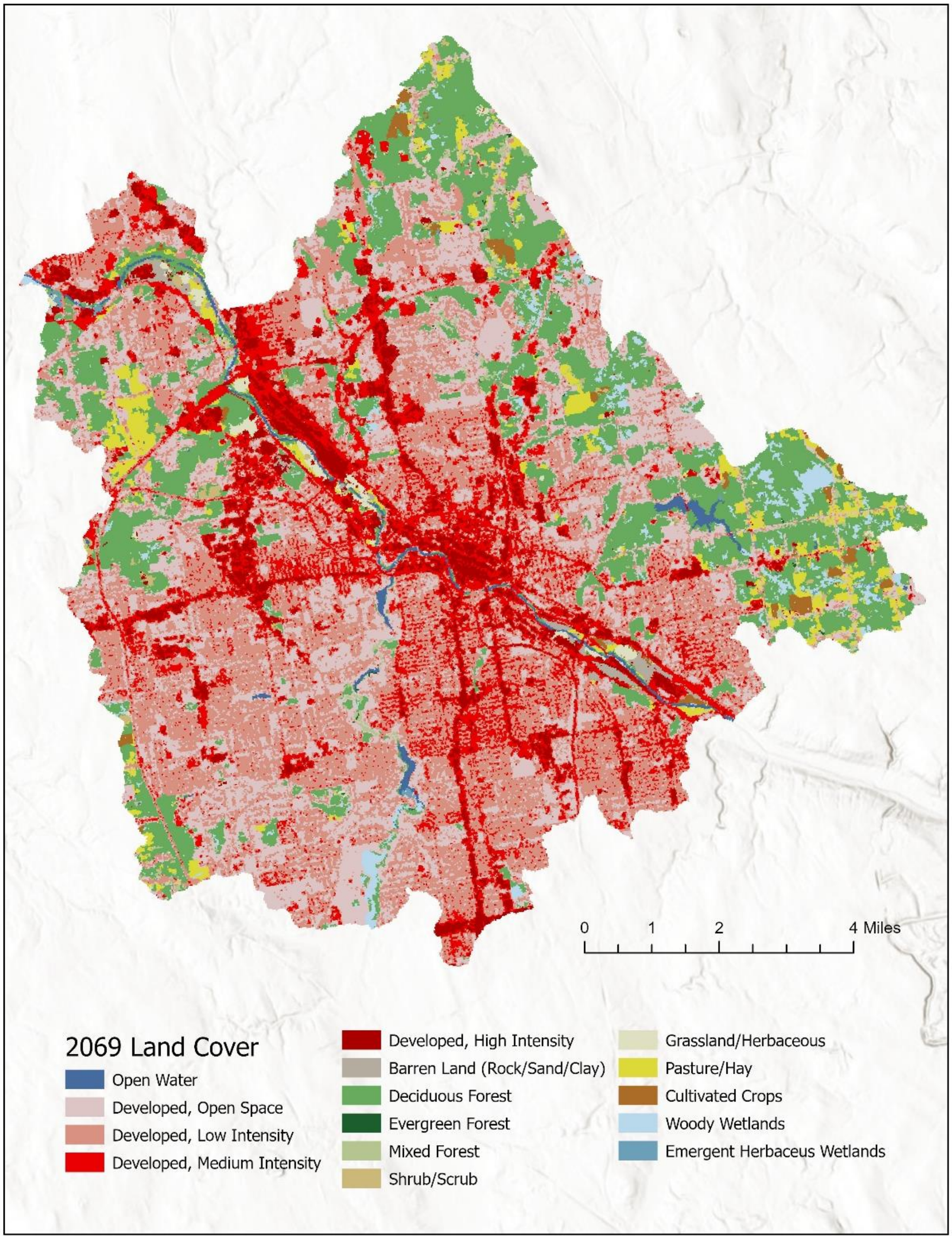

Figure 14: The 2069 land cover map for the Youngstown Metropolitan Area

Table 12: Land cover comparison between 2019 and 2069 prediction for the YMA

Land use	**2019**		**2069**	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**
Open Water	2.4	0.9	2.2	0.9
Developed, Open Space	56.7	22.0	55.6	21.6
Developed, Low Intensity	82.9	32.1	82.4	31.9
Developed, Medium Intensity	33.4	12.9	37	14.3
Developed, High Intensity	12.8	5.0	14.6	5.6
Barren Land (Rock/Sand/Clay)	1.6	0.6	1.4	0.6
Deciduous Forest	47.6	18.5	45.7	17.7
Evergreen Forest	0.1	0.0	0.1	0
Mixed Forest	2.4	0.9	2.4	0.9
Shrub/Scrub	0.8	0.3	0.9	0.3
Grassland/Herbaceous	2.0	0.8	1.5	0.6
Pasture/Hay	9.4	3.6	7.8	3
Cultivated Crops	1.2	0.5	1.8	0.7
Woody Wetlands	4.4	1.7	4.4	1.7
Emergent Herbaceous Wetlands	0.2	0.1	0.3	0.1
Total	**258**	**100**	**258**	**100**

Table 13: Predicted land cover area for the sub-watersheds in YMA in 2069

	Andersons Creek		**Crab Creek**		**Dry Run Creek**		**Little Squaw Creek**	
Land use	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Open Water	0.5	0.7	0.0	0.0	1.0	1.6	0.7	1.0
Developed, Open Space	20.1	28.7	14.4	26.4	8.4	12.9	12.6	18.7
Developed, Low Intensity	32.3	46.1	13.6	24.9	18.5	28.3	17.9	26.5
Developed, Medium Intensity	8.1	11.6	4.8	8.9	12.1	18.5	11.9	17.6
Developed, High Intensity	2.7	3.9	1.6	2.9	4.6	7.1	5.6	8.3
Barren Land (rock/Sand/Clay)	0.0	0.0	0.0	0.0	0.8	1.2	0.6	0.9
Deciduous Forest	4.3	6.1	15.1	27.7	13.1	20.0	13.2	19.5
Evergreen Forest	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Mixed Forest	0.4	0.6	1.1	2.0	0.6	0.9	0.3	0.4
Shrub/Scrub	0.1	0.1	0.2	0.3	0.1	0.2	0.5	0.7
Grassland/Herbaceous	0.1	0.1	0.1	0.3	0.3	0.5	1.0	1.5
Pasture/Hay	0.6	0.8	1.7	3.2	3.0	4.5	2.5	3.8
Cultivated Crops	0.1	0.1	0.7	1.3	0.8	1.3	0.1	0.2
Woody Wetlands	0.8	1.1	1.2	2.1	2.0	3.0	0.5	0.7
Emergent Herbaceous Wetlands	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.2
Total	70.1	100	54.5	100	65.6	100	67.5	100

Mapping Viable Areas for Tree Planting

Youngstown's steel production and industrialization supported a growing population that reached its peak in 1930 with a population of 170,000. However, Youngstown's economic prowess in steel production begun to decline at the beginning of the 20th century to about 67,000 in 2022. The decreasing population in the city of Youngstown opened space for tree planting. With the shrinking population, most houses are abandoned and eventually demolished.

From the Youngstown demolition data between 2006 and 2021 (Figure 15), Andersons Run-mill creek has 1,332 buildings demolished, totaling 105ha. Assuming these lots have not been rebuilt, these areas could be viable spaces for tree planting, storing approximately 3,720t of carbon. The demolished buildings in Crab Creek are 1,558, occupying an area of 205ha with the potential to sequester approximately 7,260t of carbon. The demolished buildings in Dry Run Creek are 3,065, totaling 319ha with the potential of sequestering up to 11,300t of carbon, assuming these spaces have not been converted to any other land use. Lastly 561 buildings were demolished in the Little Squaw Creek, occupying 78ha with the potential to sequester approximately 2,760t of carbon. Therefore, YMA could utilize approximately 707ha of available spaces from demolition of buildings for tree planting, hence boosting its forest cover.

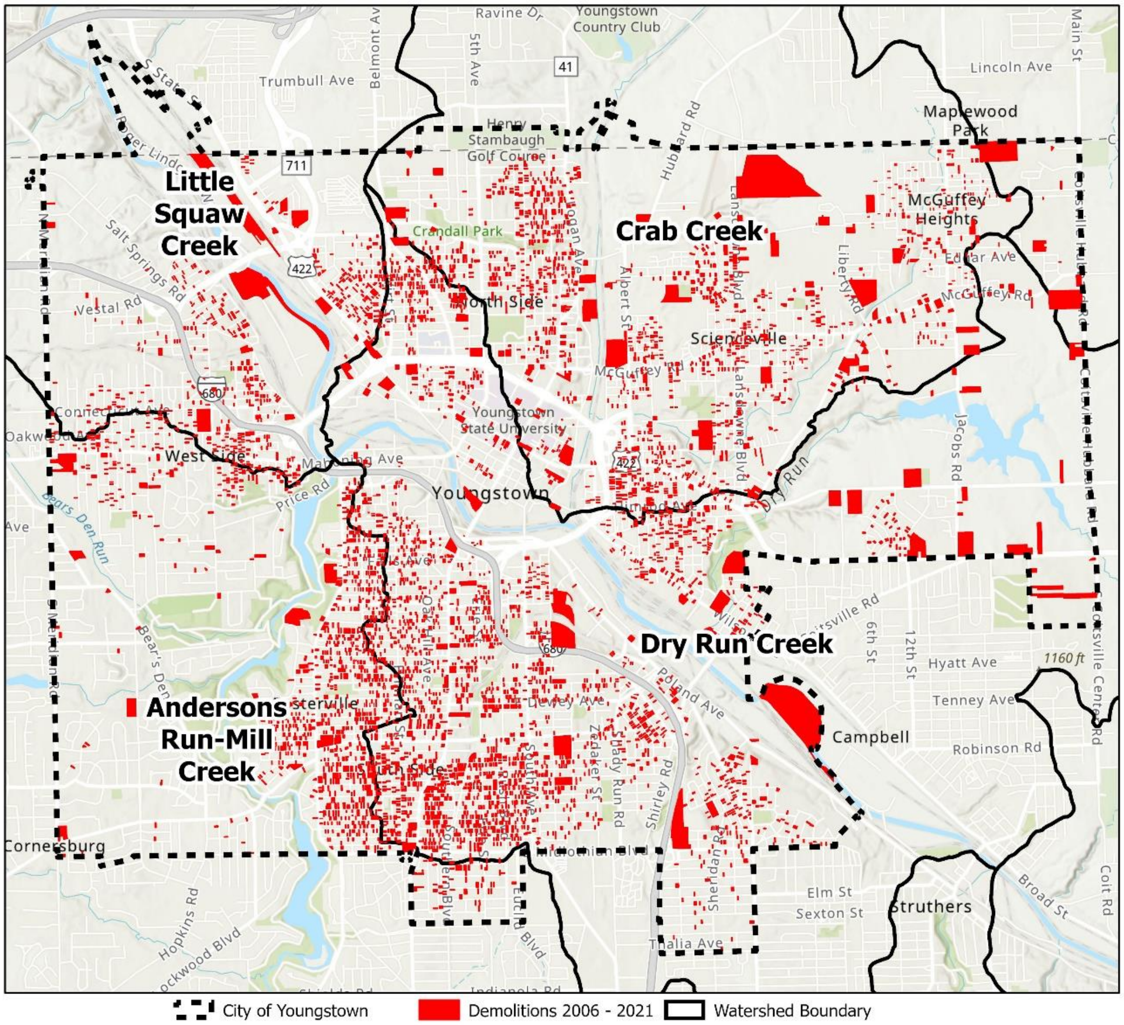

Figure 15: Building demolitions in City of Youngstown 2006 – 2021

In predicting feasible areas for tree planting, the area under forest in 2019 is compared with the projected forest area in 2069. An increase in forest cover is therefore interpreted to mean viability for tree planting as this land use type is the best favorable for tree growth. Barren land, for example, according the NLCD description is sandy, rocky and are characterized with clay soil, strip mines, glacial debris, sand dunes, gravel pits and other buildups of earthen material. This cover type also has a low vegetation survival rate of less than 15%. Areas with mixed forests are characterized by vegetation cover of more than 20%, and trees greater than 5m high are the most dominant. Evergreen and deciduous forests account for less than 75% of the tree cover, therefore, such areas are considered favorable for tree planting. Grassland also known as herbaceous landcover with grass dominating over 80% of the total vegetation cover can, according to NLCD, be utilized for grazing. Herbaceous land uses are considered favorable for tree planting. Emergent herbaceous wetlands, as described by NLCD, are areas whose perennial herbaceous total cover accounts for more than 80% of the total vegetative cover. They are characterized by hydric soil and remains saturated with water throughout the year.

The area under evergreen forest, mixed forest and scrubs is predicted to remain virtually the same in 2069. The Andersons Run-Mill Creek will lose approximately 0.31 km^2 of forest cover between 2019 and 2069, equating to a carbon capture loss of 1,100t. The area under mixed forest and shrub is expected to remain constant in 2069 while the grassland/herbaceous land cover area will decrease, rendering them not viable for tree planting. NCLD describes shrubs as zones dominated by vegetation cover of 5 meters high or less, canopy which is more than 20% of total vegetation (e.g., young trees in their early stages of growth and those trees that exhibit stunted growth brought about by environmental conditions). Since there is already vegetation growth, the assumption is that the soil type and the general landscape will promote tree growth if planted.

In Crab Creek, the area under shrubs and evergreen forest is expected to remain constant in 2069, unlike the area under deciduous forest and grassland, which is predicted to lose approximately 0.65km^2 and 0.02km^2, respectively. However, an increase of 0.02 km^2 in total area is expected with mixed forests, making these areas viable for future tree planting. By 2069 Crab Creek will see a reduction in total area under forest land use that range from 17.2 km^2 to 16.5 km^2. This projection estimates a reduction in carbon storage of about 2,300t between 2019 and 2069.

The total forest area in the Dry Run Creek in 2069 is projected to reduce by 0.41 km^2. The area under mixed forest, shrubs and herbaceous vegetation is expected to reduce from 1.34km^2 to 1.06 km^2 by 2069, therefore, not viable for tree planting. However, the area under evergreen and mixed forest will remains constant (0.62 km^2) in Dry Run Creek in 2069, making it feasible for tree planting.

By 2069, total area under forest cover in the Little Squaw Creek is expected to reduce by 1.06 km^2. This reduction will mainly occur in areas with deciduous forests (1.02 km^2) and grassland herbaceous (0.09 km^2) land cover. Also, mixed and evergreen forests are expected to remain virtually the same in 50 years' time, however, the area under shrubs is predicted to increase by about 0.06 km^2, making the area viable for future tree planting.

Chapter 5: Discussion and Conclusion

Monitoring of land use changes in various landscapes ultimately impacts the functioning of ecosystems in provision of services (Hoyer et al., 2014). Afforestation and reforestation programs have been identified as feasible strategies for climate change mitigation. Understanding these strategies, their potential to store carbon long term, predict forest cover change, (Reyer et al., 2009); and identify viable areas for tree planting is vital, not only for improvement of ecosystems functions and services, but also to inform better land use management practices and policy. These programs have the potential to better secure carbon emissions storage for a sustainable future.

The forest cover in the YMA has shown a general decrease between 2001 and 2019. Similar studies have shown wide deforestation particularly in evergreen forest beginning the year 2001, (Aide et al. 2013); whereas continuous and vigorous loss of forest have been observed in tropical rain forest in other parts of the World. Developed spaces, however, have increased as more forest land is gradually depleted due to urbanization. In 2001, for example, the total area under forest was 5,300 hectares, however, only 10 years later, 114ha of forest land had been lost. During the same period, developed land uses had increased by approximately 100ha (from 18,400ha to 18,500ha).

This study targeted four sub-watersheds encompassing the city of Youngstown. The Dry Run Creek is the only sub-watershed that recorded a gradual increase in forest cover between 2001, 2011 and 2019. The demolition data further provided additional 319ha, area that could potentially be used for reforestation. Although Crab Creek lost approximately 43ha (1760ha – 1720ha) of forest cover between 2001 and 2019, a total area of 205ha was established from demolition of unfunctional buildings in the Youngstown. Utilizing these spaces for tree planting could be a better rehabilitation measure.

Compared to Crab Creek which had the largest forest area in 2019, the Andersons Run-Mill Creek has less forest area. With an area of 524ha, a 50-year projection of the Andersons Run-Mill Creek shows a decrease in forest cover of approximately 31ha (from 524ha to 493ha), storing approximately 17,500t of carbon. Developed open spaces which includes constructed material, but mostly occupied by vegetation, is expected to decrease in 2069. The total area of demolished buildings and available for tree planting in the Anderson Run-Mill Creek is 205ha. The Little Squaw Creek had the second largest forest area (1,600ha) in 2019. The sub-watershed had the least area (78ha) of demolished buildings. Utilization of these areas for tree planting could be a mitigation strategy, hence promoting conservation of biodiversity and increase forest resilience (Ravindranath, 2007).

Forest Cover Change 2001 - 2019

Similar studies on carbon capture and storage have shown that younger vegetation store less carbon compared to old grown vegetation but have a high rate of carbon capture (Bonner et al 2013; Huang et al., 2018). Although most studies focused on forest of mature pristine condition, hardwood harvesting for economic gain on their products have been suggested to possibly increase carbon storage and capture (Keith et al., 2014).

Among the different tree species identified in the 2006 Ohio forest inventory, the oak hickory group is the most dominant species, occupying more than half of forest areas in the State (Widmann, 2009). These species comprise northern red and white oak, walnut, white ash, red maple, and yellow poplar. Red and Sugar maple are the most abundant in

Ohio. Climate change as a global driver to most biodiversity loss, brings about alteration to many ecological systems, therefore, affecting its functions (Pacala et al., 2002). Similar studies have shown that a forests with diverse species are more resilient to these predictable climatic changes (Kanowski et al., 2008; Thompson et al., 2009). Youngstown Metropolitan Area, under the same land use practices is predicted to record a decline in forest cover by 2069, while developed areas are predicted to increase. There is therefore a critical need for reforestation and afforestation in order to increase forest cover in the study area.

Between 2001 and 2019, the Youngstown Metropolitan Area lost approximately 34ha of forest area, most of which were deciduous forests. The four sub-watersheds examined include Crab Creek, Dry Run Creek, Andersons Run-Mill Creek and Little Squaw Creek. These sub-watersheds are the most urbanized and currently store approximately 187,000t of carbon. This amount of carbon is expected to decrease to approximately 179,000t by 2069. Evergreen forests which are dominated by trees with heights more than 5 meters, are projected to be contained within the same area size in 50 years. According Osuri et al. (2020), comparing the total above ground carbon storage between evergreen and deciduous forest, the former was found to store the highest carbon per unit area.

Increasing tree cover in urban landscapes as a strategy to regulate local climate has manifested both advantages and disadvantages. Research has shown that lack of adequate spaces in cities this could be a limited to smaller scale, compared to the global strategies that would have a greater impact in mitigating against the effects of greenhouse emissions (Pataki et al., 2021). Urban tree planting could therefore be a feasible approach in adaptation measures to climate change. Furthermore, studies have shown that despite the limited spaces for urban foresting, there sole prospects to expand urban tree in areas that had establishments demolished, abandoned in urban spaces (Ferrini et al., 2021). Addressing issues of urban spaces shrinking is could further enable urban forest regrowth hence to appreciate both social and ecological benefits (Haase et al., 2018).

Carbon Storage and Forest Cover

The impacts of climate change throughout the world have been exacerbated by urbanization. For instance, combustion of fossil fuels and presence of artificially built environments, make urban areas more susceptible to climate change compared to rural areas (Nowak, 2000). Anthropogenic changes brought about by population pressure, further accelerates the accumulation of CO_2 in the atmosphere. As such, growing more trees has the potential to reduce atmospheric carbon accumulation (Moulton et al., 1990). Trees act as sinks as they fix carbon during photosynthesis and store surplus carbon in their tissues as biomass. As forests grow, die, and decompose, sustainability of the disposable carbon dioxide becomes dynamic over time.

A study by Nowak et al. (2002) estimated that approximately 700 million metric tons carbon is stored by trees in U.S. cities. About 8.5% of the carbon is stored in cities located in the northeast. Also, approximately half of the 53.5 tC/ha sequestered by U.S. forests is stored in urban forests. Examination of the amount of carbon sequestered by urban forests, therefore, helps to assess their potential in reducing the amount of atmospheric carbon dioxide. With urbanization, urban forests perform an important role, not only in the quality of the environmental, but also in human health. Forests in urban areas sequester carbon emissions, hence regulating local climates while combating climate change (Nowak, 2002; Osuri et al., 2020). Anthropogenic carbon prints have led to reduction of forest cover in the YMA since 2001. In 2019, the total forest area in the YMA was estimated at 5,290ha, storing about 187,000t of carbon.

Converting the open ($56km^2$), low ($82km^2$) and moderately ($37\ km^2$) developed areas based on the 2019 NLCD data, will provide 17,500ha ($175km^2$ *100 ha) of land viable for urban forest expansion. These areas could sequester approximately 619,500tC/ha (17,500 ha *35.4t/ha) in the Youngstown Metropolitan Area (YMA), if trees were to be planted on areas that have experienced demolitions.

The amount of forest area in the YMA in about 50 years' time is expected to decrease significantly due to urban development; hence, the availability of area for forest expansions diminishes. Although this study has shown forest cover decreases with increasing development, the population in YMA has been decreasing since 1960. The demolition due to the shrinking urban spaces was used to estimate the amount of land available for tree planting in YMA.

Hypotheses Acceptance or Rejection

H1: Based on historical trends and using a projection model, the forest cover in Youngstown Metropolitan Area will decrease by 2069 - **Rejected.**

H2: Converting open, low, or moderately developed areas to urban forest will increase the ability of the Youngstown Metropolitan Area to sequester carbon - **Accepted**.

Based on the 50-year projection, the YMA will potentially experience an increase in forest cover of approximately 707ha. This increase is assumed to occur in vacant lots rendered viable due to building demolitions. While total forest area in the YMA shows a decrease in 2069, there is greater potential to utilize demolished land spaces for tree planting. However, growing new forests may be limited, not only, by the region's socio-economic factors, but also by environmental conditions associated with natural disasters such as floods or pest infestation. These occurrences could potentially delay the growth of biomass, hence affecting the ability of the new forest to sequester carbon.

Future Recommendations

- Rehabilitating the lost forest areas that are favorable for tree growth will be a step towards informing climate change mitigation and adaptation.
- Having a dialogue with the policy makers on the adverse effects of climate change and the need to act and act now.
- Assessment of other land use types within the YMA for tree planting spaces and map them out for future tree planting (pasture lands and croplands by possibly practicing and integrating other farming practices, for example silviculture).
- Barren land use types as mapped by NLCD could be rehabilitated and made conducive for tree planting in the future.
- Further in-depth forest analysis is required to ascertain the total forests density and health to identify and map out areas that could be used to establish forests.

Although this study showed a decrease in forest cover in YMA by 2069, data on demolitions in the city of Youngstown was used to evaluate the amount of area available in the four sub-watersheds within city limits. Planting trees on the available 707ha would potentially sequester 25,000t/ha.

References

Aide, T. M., Clark, M. L., Grau, H. R., López-Carr, D., Levy, M. A., Redo, D., ... & Muñiz, M. (2013). Deforestation and reforestation of Latin America and the Caribbean (2001–2010). Biotropica, 45(2), 262-271.

Akbari, H., Rosenfeld, A. H., & Taha, H. (1990). Summer heat islands, urban trees, and white surfaces.

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., ... & Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest ecology and management, 259*(4), 660-684.

Bauer, C., & Volkart, K. (2017). Carbon capture and storage. Laboratory for energy systems analysis, Paul Scherrer Institut (PSI), Switzerland.

Breslau, K. (2006). It can pay to be green: Clean air means profit at the climate exchange. Newsweek, 22 May 2006, p. 45.

Chazdon, R. L., Broadbent, E. N., Rozendaal, D. M., Bongers, F., Zambrano, A. M. A., Aide, T. M., ... & Poorter, L. (2016). Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. *Science Advances, 2*(5), e1501639.

Choat, B., Jansen, S., Brodribb, T. J., Cochard, H., Delzon, S., Bhaskar, R., ... & Zanne, A. E. (2012). Global convergence in the vulnerability of forests to drought. *Nature, 491*(7426), 752-755.

Creţan, I. A. (2018). Considerations Regarding Global Warming and Climate Change. Volume 63 (77) issue 2.

Curtis, P. S., & Gough, C. M. (2018). Forest aging, disturbance and the carbon cycle. *New Phytologist, 219*(4), 1188-1193.

Domke, G., Williams, C. A., Birdsey, R., Coulston, J., Finzi, A., Gough, C., ... & Woodall, C. W. (2018). Forests. In Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report.[Cavallaro, N.; Shrestha, G.; Birdsey, R.; Mayes, MA; Najjar, RG; Reed, SC; Romero-Lankao, P.; Zhu, Z., eds. Washington, DC, USA: US Global Change Research Program., 365-398.

Domke, G. M., Walters, B. F., Nowak, D. J., Smith, J., Ogle, S. M., Coulston, J. W., & Wirth, T. C. (2020). Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 5 p., 227, 1-5.

EPA (Environmental Protection Agency) (2022). Basics of climate change. https://www.epa.gov/climatechange-science/basics-climate-change

FAO (Food and Agriculture Organization of the United Nations). (2012). Smallholders and Family Farmers.

Fletcher, D., & Sarkar, M. (2013). Psychological resilience. *European psychologist*, 18, 12-23.

Gilbreath, K. (1995). Life Cycle Assessment, Energy, and the Environment from a Pulp and Paper Mill's Perspective. In *Forest Products Society Annual Meeting: Portland, Ore*.

Global Monitoring Laboratory. (2022). Trends in atmospheric carbon dioxide https://gml.noaa.gov/ccgg/trends/

Gressel N. (2007).From greener productions to carbon trading: sustainable energy careers *Science* 315; 868-869.

Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment*, 584, 1040-1055.

Heusinger, J., & Weber, S. (2017). Extensive green roof CO2 exchange and its seasonal variation quantified by eddy covariance measurements. *Science of the Total Environment*, 607, 623-632.

Hoyer, R., & Chang, H. (2014). Assessment of freshwater ecosystem services in the Tualatin and Yamhill basins under climate change and urbanization. *Applied Geography*, 53, 402-416.

Hyvönen, R., Ågren, G. I., Linder, S., Persson, T., Cotrufo, M. F., Ekblad, A., ... & Wallin, G. (2007). The likely impact of elevated [CO2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review. *New Phytologist, 173* (3): 463-480.

IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press.

IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104.

Johnson, E., & Heinen, R. (2004). Carbon trading: time for industry involvement. *Environment International, 30*(2), 279-288.

Jones, K. B., Slonecker, E. T., Nash, M. S., Neale, A. C., Wade, T. G., & Hamann, S. (2010). Riparian habitat changes across the continental United States (1972–2003) and potential implications for sustaining ecosystem services. *Landscape Ecology, 25*(8), 1261-1275.

Kabisch, N., Kraemer, R., Masztalerz, O., Hemmerling, J., Püffel, C., & Haase, D. (2021). Impact of summer heat on urban park visitation, perceived health and ecosystem service appreciation. *Urban Forestry & Urban Greening*, 60, 127058.

Kerr, R. A. (2007). Scientists tell policymakers we're all warming the world.

Kintisch, E. (2007). Report backs more projects to sequester CO2 from coal. *Science,* 315, 1481

Klos, R. J., Wang, G. G., Bauerle, W. L., & Rieck, J. R. (2009). Drought impact on forest growth and mortality in the southeast USA: An analysis using Forest Health and Monitoring data. *Ecological Applications, 19*(3), 699-708.

Krishnamurthy, R. V., & Machavaram, M. (2000). Is there a stable isotope evidence for the CO2 fertilization effect? *Journal of Earth System Science, 109*(1), 141-144.

Kuser, J. E. (Ed.). (2006). Urban and community forestry in the northeast. 2nd ed. New York: Springer

Lal, R. (2008). Carbon sequestration, Philos. T. Roy. Soc. B, 363, 815–830.

Lamb, D., Erskine, P. D., & Parrotta, J. A. (2005). Restoration of degraded tropical forest landscapes. *Science, 310*(5754), 1628-1632.

Lambin, E. F., & Geist, H. J. (Eds.). (2008). Land-use and land-cover change: local processes and global impacts. Springer Science & Business Media.

Law, B. E., Hudiburg, T. W., Berner, L. T., Kent, J. J., Buotte, P. C., & Harmon, M. E. (2018). Land use strategies to mitigate climate change in carbon dense temperate forests. *Proceedings of the National Academy of Sciences, 115*(14), 3663-3668.

Luo, X., Wang, M., & Chen, J. (2015). Heat integration of natural gas combined cycle power plant integrated with post-combustion CO2 capture and compression. *Fuel,* 151, 110-117.

Lützow, M. V., Kögel-Knabner, I., Ekschmitt, K., Matzner, E., Guggenberger, G., Marschner, B., & Flessa, H. (2006). Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions–a review. *European Journal of Soil Science, 57*(4), 426-445.

Luyssaert, S., Inglima, I., Jung, M., Richardson, A. D., Reichstein, M., Papale, D., ... & Janssens, I. A. (2007). CO2 balance of boreal, temperate, and tropical forests derived from a global database. *Global Change Biology, 13*(12), 2509-2537.

Manuel, C. (2020). The Miyawaki Method–Data & Concept. Urban Forests Company.

McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrological Sciences Journal, 61*(13), 2295-2311.

McPherson, E. G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., & Rowntree, R. (1997). Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems, 1*(1), 49-61.

Nave, L. E., Walters, B. F., Hofmeister, K. L., Perry, C. H., Mishra, U., Domke, G. M., & Swanston, C. W. (2019). The role of reforestation in carbon sequestration. *New Forests, 50*(1), 115-137.

Nguyen, H. T., & Pearce, J. M. (2012). Incorporating shading losses in solar photovoltaic potential assessment at the municipal scale. *Solar Energy, 86*(5), 1245-1260.

Nolan, C. J., Field, C. B., & Mach, K. J. (2021). Constraints and enablers for increasing carbon storage in the terrestrial biosphere. *Nature Reviews Earth & Environment, 2*(6), 436-446.

Norby, R. J., Hanson, P. J., O'Neill, E. G., Tschaplinski, T. J., Weltzin, J. F., Hansen, R. A., ... & Johnson, D. W. (2002). Net primary productivity of a CO2-enriched deciduous forest and the implications for carbon storage. *Ecological Applications, 12*(5), 1261-1266.

Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution, 116*(3), 381-389.

Nowak, D. J., & Dwyer, J. F. (2007). Understanding the benefits and costs of urban forest ecosystems. In Urban and community forestry in the northeast (pp. 25-46). Springer, Dordrecht.

Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. *Environmental Pollution,* 178, 229-236.

Osuri, A. M., Gopal, A., Raman, T. S., DeFries, R., Cook-Patton, S. C., & Naeem, S. (2020). Greater stability of carbon capture in species-rich natural forests compared to species-poor plantations. *Environmental Research Letters, 15*(3), 034011.

Ottburg, F., Lammertsma, D., & Wegman, R. (2018). Meetnet Biodiversiteit Zaanstad (No. 2866). Wageningen Environmental Research.

Pacala, S., & Socolow, R. (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science, 305*(5686), 968-972.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., ... & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science, 333*(6045), 988-993.

Pataki, D. E., McCarthy, H. R., Litvak, E., & Pincetl, S. (2011). Transpiration of urban forests in the Los Angeles metropolitan area. *Ecological Applications, 21*(3), 661-677.

Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., McDonnell, M. J., Pincetl, S., ... & Whitlow, T. H. (2021). The benefits and limits of urban tree planting for environmental and human health. *Frontiers in Ecology and Evolution, 9* (155).

Peters, G. P., Aamaas, B., Berntsen, T., & Fuglestvedt, J. S. (2011). The integrated global temperature change potential (iGTP) and relationships between emission metrics. *Environmental Research Letters, 6*(4), 044021.

Price, K., Jackson, C. R., Parker, A. J., Reitan, T., Dowd, J., & Cyterski, M. (2011). Effects of watershed land use and geomorphology on stream low flows during severe drought conditions in the southern Blue Ridge Mountains, Georgia and North Carolina, United States. *Water Resources Research, 47*(2).

Radtke, P., Walker, D., Frank, J., Weiskittel, A., DeYoung, C., MacFarlane, D., ... & Westfall, J. (2017). Improved accuracy of aboveground biomass and carbon estimates for live trees in forests of the eastern United States. Forestry. *An International Journal of Forest Research, 90*(1), 32-46.

Ravindranath, N. H. (2007). Mitigation and adaptation synergy in forest sector. *Mitigation and Adaptation Strategies for Global Change, 12*(5), 843-853.

Reyer, C., Guericke, M., & Ibisch, P. L. (2009). Climate change mitigation via afforestation, reforestation and deforestation avoidance: and what about adaptation to environmental change? *New Forests, 38*(1), 15-34.

Rowntree, R. A., & Nowak, D. J. (1991). Quantifying the role of urban forests in removing atmospheric carbon dioxide. *Journal of Arboriculture. 17* (10): 269-275., 17(10).

Schirone, B., Salis, A., & Vessella, F. (2011). Effectiveness of the Miyawaki method in Mediterranean forest restoration programs. *Landscape and Ecological Engineering, 7*(1), 81-92.

Schrag, D. P. (2007). Preparing to capture carbon. *Science, 315*(5813), 812-813.

Tan, Z. X., Lal, R., Izaurralde, R. C., & Post, W. M. (2004). Biochemically protected soil organic carbon at the North Appalachian experimental watershed. *Soil Science, 169*(6), 423-433.

Terakunpisut, J., Gajaseni, N., & Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum national forest, Thailand. *Applied Ecology and Environmental Research, 5*(2), 93-102.

Turner, J. T. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump. *Progress in Oceanography,* 130, 205-248.

UNEP (United Nations Environment Programme) (2012). The Emissions Gap Report 2012. A UNEP Synthesis Report, United Nations Environment Programme.

USDA (United States Department of Agriculture). (2017). Considering forest and grassland carbon in land management. General Technical Report WO-95.

Vashum, K. T., & Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests-a review. *Journal of Ecosystem & Ecography, 2*(4), 1-7.

Viriyabuncha, C., Vacharangkure, T., & Doangsrisen, B. (2002). The evuation system for carbon storage in forest ecosystem in Thailand (I. aboveground biomass). Sivilculture Research Division, Royal Forest Department, Bangkok.

Vose, J. M., Miniat, C. F., Luce, C. H., Asbjornsen, H., Caldwell, P. V., Campbell, J. L., ... & Sun, G. (2016). Ecohydrological implications of drought for forests in the United States. *Forest Ecology and Management,* 380, 335-345.

Weed, A. S., Ayres, M. P., & Hicke, J. A. (2013). Consequences of climate change for biotic disturbances in North American forests. *Ecological Monographs, 83(*4), 441-470.

Widmann, R. H. (2009). *Ohio forests, 2006* (Vol. 36). US Forest Service.

Wieder, W. R., Cleveland, C. C., Smith, W. K., & Todd-Brown, K. (2015). Future productivity and carbon storage limited by terrestrial nutrient availability. *Nature Geoscience, 8*(6), 441-444.

Williams, C. A., Gu, H., MacLean, R., Masek, J. G., & Collatz, G. J. (2016). Disturbance and the carbon balance of US forests: A quantitative review of impacts from harvests, fires, insects, and droughts. *Global and Planetary Change*, 143, 66-80.

Wickham, J., Stehman, S. V., Sorenson, D. G., Gass, L., & Dewitz, J. A. (2021). Thematic accuracy assessment of the NLCD 2016 land cover for the conterminous United States. *Remote Sensing of Environment,* 257, 112357.

WMO. (2006). WMO greenhouse gas bulletin: the state of greenhouse gases in the atmosphere using global observations through 2005. Technical report, world meteorological organization, environnement division, atmospheric research and environment programme and world data center for greenhouse gases, Japan Meteorological Agency.

Wofsy, S. C. (2001). Where has all the carbon gone? *Science*, 292(5525), 2261-2263.