Exploring Land Use as an Aspect of Community Climate Action

Land Use Greenhouse Gas Inventory

Durham, NH

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Glossary of Key Terms

Carbon-dioxide equivalent – the universal unit for comparing emissions of different greenhouse gases in terms of the global warming potential of one unit of carbon dioxide. This report often refers to carbon-dioxide equivalent (CO2e) values, and particularly metric tons of this unit per year, noted as tCO_2e/yr.[7]

Carbon sequestration – Removal of CO_2 from the atmosphere. This most often happens through photosynthesis in plants and through ocean processes.[7]

Carbon stock – The carbon embodied in a biological system, such as oceans, trees and the atmosphere. A carbon stock that is taking up carbon is called a "sink" and one that is releasing carbon is called a "source"[7]

Emission Factor – A unique value for determining an amount of a GHG emitted on a per unit activity basis (for example, metric tons of CO_2 emitted per kWh of electricity consumed)[7]

Flux per unit area – GHG emissions or reductions over unit area hectare, noted as $tCO_2e/yr/ha$

Greenhouse Gas (GHG) Offset – Discrete GHG reductions used to compensate for (i.e., offset) GHG emissions elsewhere, for example to meet a voluntary or mandatory GHG target or cap. Offsets are calculated relative to a baseline that represents a hypothetical scenario for what emissions would have been in the absence of the mitigation project that generates the offsets[7]

Land Use Classes[8]

- Forest Land: Areas at least 120 feet wide (36.6 meters) and 1 acre (0.4 hectare) in size with at least 10 percent canopy cover (or equivalent stocking) by live trees. Land with such tree area and cover is not classified as forest if completely surrounded by urban or developed lands (such land is classified as Settlements); land that is predominantly under agricultural land use is also not considered Forest.
- Cropland: Areas used for the production of adapted crops for harvest. This category includes both cultivated (row crops, close-grown crops) and non-cultivated (hay, orchards) land.
- Grassland: Areas on which the plant cover is composed principally of grasses; grass-like plants (i.e., sedges and rushes); forbs; or shrubs suitable for grazing and browsing. It includes both pastures and native rangelands.
- Wetland: Land covered or saturated by water for all or part of the year, as well as areas of lakes, reservoirs, and rivers.
- Settlement: Developed areas consisting of units of 0.25 acres (0.1 hectare) or more that include residential, industrial, commercial, and institutional land (including farm buildings and road networks). Also includes tracts of less than 10 acres (4.05 hectares) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land.
- Other Land: Bare soil, rock, ice, and all land areas that do not fall into any of the other five land use categories; carbon stock changes and non-CO2 emissions are not estimated for Other Land, because these areas are largely devoid of biomass, litter, and soil carbon pools.

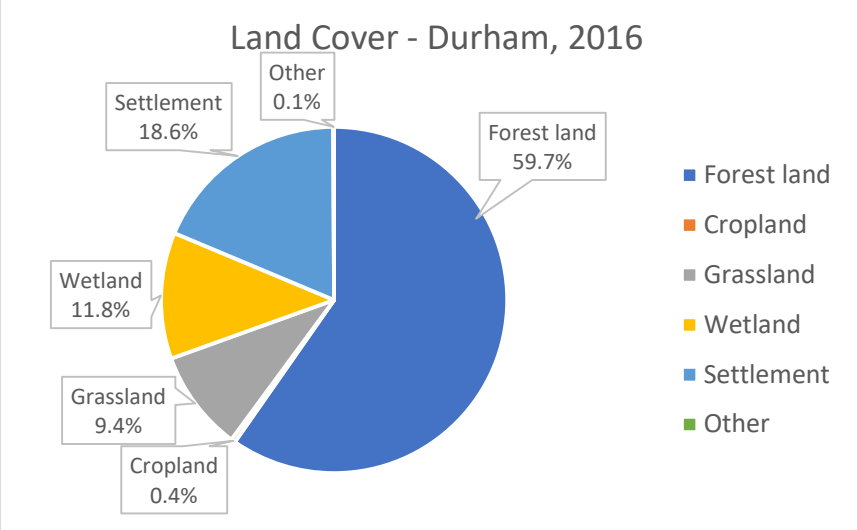
Natural climate solutions/Nature-based solutions – the conservation, restoration, and improved management of land[4]

Executive Summary

The Town of Durham, New Hampshire, is committed to being a leader in sustainability in the face of climate change. In January 2021, Durham joined the Global Covenant of Mayors for Climate and Energy (GCoM), where the Town pledged to reduce greenhouse gas (GHG) emissions and prepare for the impacts of climate change.[1] As part of this commitment, Durham voluntarily chose to complete this Land Use GHG Inventory as an addition to its Community-Wide Greenhouse Gas Inventory completed in early August 2021. By doing this, Durham is acknowledging the importance of nature-based solutions in mitigating the effects of climate change. Not only will this inventory be used as a piece of the foundation that will determine future GCoM deliverables, but it will also serve to inform land use related policy decisions as well as Town land acquisition and conservation designation decisions.

Land Use in Durham

As of 2016, approximately 80.9% of Durham was designated as Forest Land (59.7%), Wetland (11.8%), or Grassland (9.4%), while 18.6% was designated as Settlement, and 0.5% as Cropland (0.4%) or Other Land (0.1%). Future development in Durham is highly constrained due to minimum buffer zones around wetlands, rivers, and streams, large minimum lot sizes, a cumbersome review process for conservation subdivisions, and large amounts of open space under public ownership, conservation easements, or owned by UNH.[16]



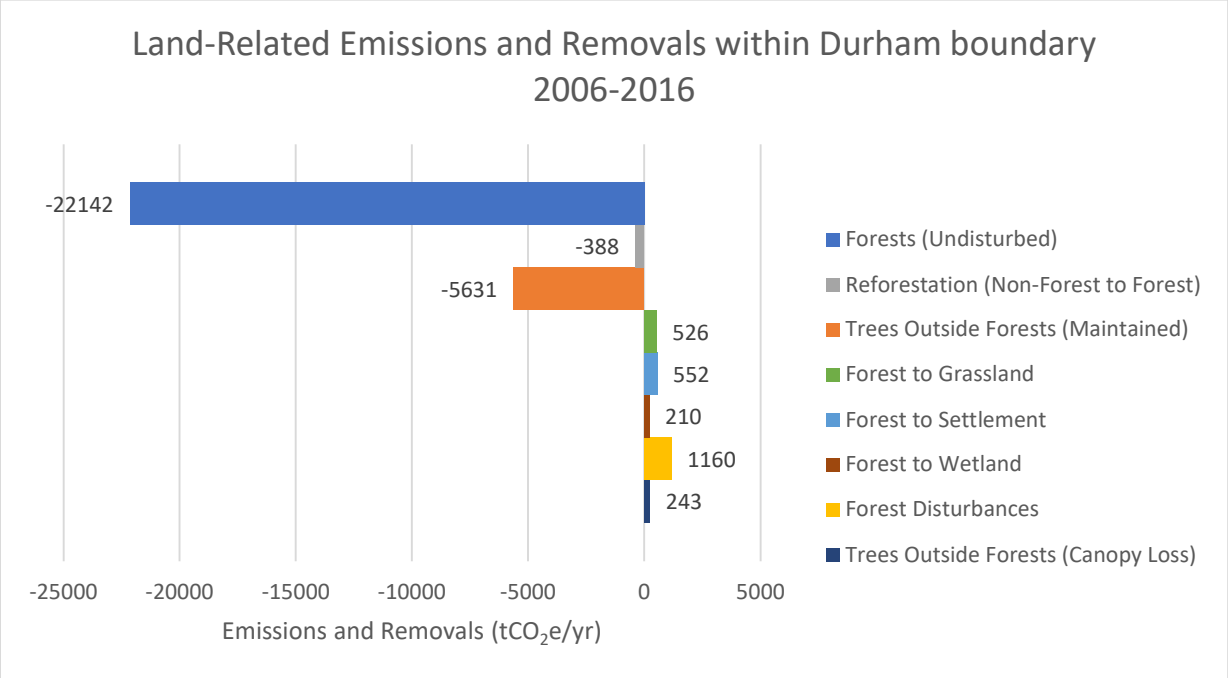
GHG Emissions and Removals

Land use change results in GHG emissions or removals from the atmosphere. Over the inventory period of 2006 to 2016, Durham lost a net 18 hectares of Forest Land and 24 hectares of Wetland, gained a net 13 hectares of Grassland and 28 hectares of Settlement, and had a net zero change in area of Cropland and Other Land. This was a loss of 0.5% of Forest Land and 3.1% of Wetland, and a gain of 2.2% of Grassland and 3.6% of Settlement from 2006 land area levels. Although these are relatively small percentage changes, the *type* of land use change matters because each change contributes differently to GHG emissions and removals.

Over the inventory period, land in Durham removed a total of 28,161 tCO_2e/yr and emitted a total of 2,691 tCO_2e/yr, resulting in a net GHG balance of -25,470 tCO_2e/yr.

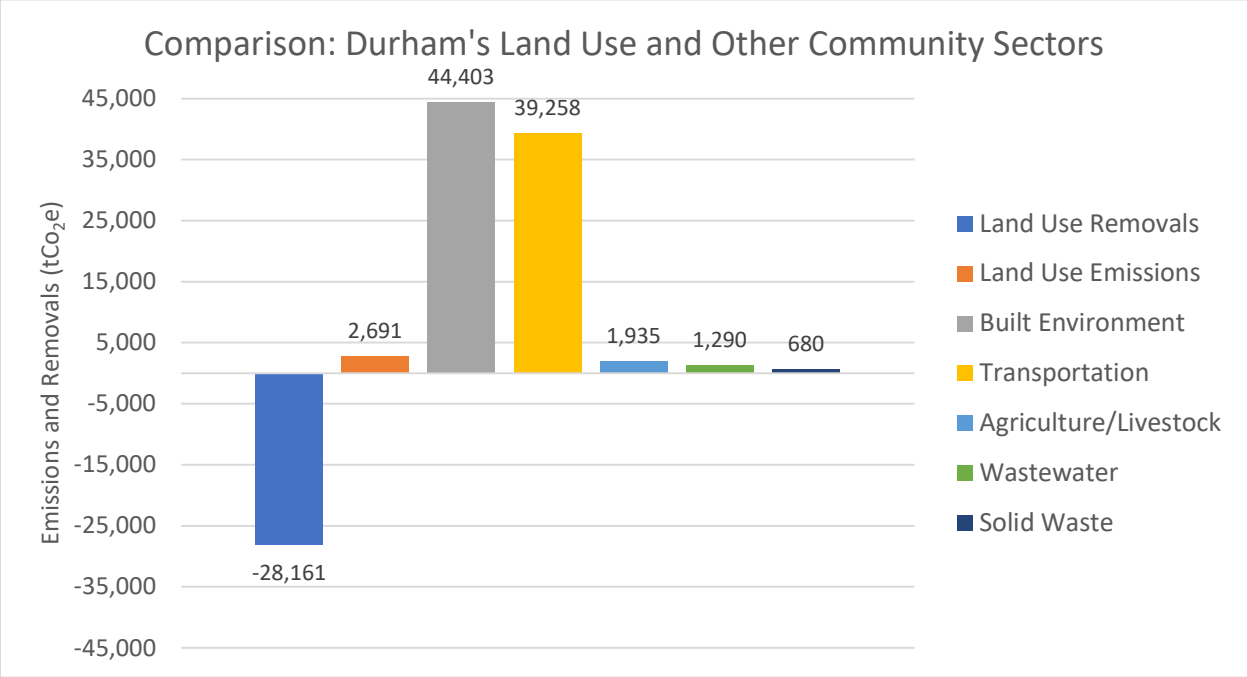
80.0% of removals occurred due to Forest Land remaining undisturbed and Reforestation of Non-Forest Land converted to Forest Land, while 20.0% of removals occurred due to Trees Outside Forests increasing in numbers or being maintained. This highlights that both young and old trees make a difference in Durham. Young, quickly growing trees, which likely make up larger compositions of Trees Outside Forests, sequester and store carbon at high rates, while older, slower growing trees, which likely make up much of Undisturbed Forest Land, sequester carbon more slowly but have a higher carbon storage capacity.[13] In Durham, when normalizing the GHG flux over the area, Trees Outside Forests (maintained/gained canopy) had the highest sequestration flux at -8.7 $tCO_2e/yr/ha$, while Undisturbed Forests had the lowest sequestration flux at -5.9 $tCO_2e/yr/ha$.

47.9% of emissions occurred due to Forest Land being converted to Non-Forest Land (Grassland, Settlement, and Wetland), 43.1% of emissions were due to Forest Disturbances (43.0% from harvesting/other and 0.1% from insects/disease), and 9.0% of emissions were due to tree canopy loss in Trees Outside Forests. Trees Outside Forests (tree canopy loss) had the highest emitting flux at 27.0 $tCO_2e/yr/ha$, while Forest Land to Grassland had the lowest flux at 14.6 $tCO_2e/yr/ha$. Forest Land to non-forest land differed by end land use, with Forest Land to Settlement having the highest flux at 26.3 $tCO_2e/yr/ha$, followed by Forest Land to Wetlands (23.3 $tCO_2e/yr/ha$) and Forest Land to Grassland (14.6 $tCO_2e/yr/ha$). Because both Wetlands and Grassland naturally store carbon over time and serve as an essential habitat for some native New Hampshire species, conversion of Forest Land to either of them is preferred over Settlement.[15]



Comparison to Community-Wide GHG Inventory

When put in context with Durham's Community-Wide GHG Inventory, the only sources of GHG removals occur through Durham's forests and trees, while all other GHG sources cause emissions. Durham's annual removal of CO_2 from forests and trees is equivalent to 32.4% of Durham's non-land related Community-Wide emissions (31.2% including land use), with 25.9% sequestered by Undisturbed Forest Land and Reforestation (25.0% if including land use) and 6.5% sequestered by Trees Outside Forests Maintaining/Gaining Canopy (6.2% if including land use). Although this is good for context, forests and trees should not be considered as direct carbon offsets in climate mitigation efforts because doing so underestimates the actual reductions communities need to make to meet reduction targets. This decreases the perceived need to reduce a community's emissions and can minimize a community's actual efforts of reducing human-caused emissions. In addition to this, tree vulnerability due to the threat of land development, negative impacts from climate change, and invasive species can potentially reduce the future carbon sequestration abilities.



Land Ownership

Land within Durham's Town boundary was divided into four ownership categories: UNH, Town, State, and Other. Organizing Durham into ownership categories helps Durham better understand where emissions and removals are coming from and informs policy and land management recommendations.

Emissions: UNH-owned, Town-owned, and State-owned land contributed to a higher share of emissions than their share of land, while Other-owned land contributed to a lower share of emissions than their share of land. State-owned land had the highest emissions flux per unit area (0.81 $tCO_2e/yr/ha$), while Other-owned land had the lowest emissions flux per unit area (0.36 $tCO_2e/yr/ha$). Differences in emission contributions and fluxes may be due to differing

land use changes as well as the composition of trees based on species-type and age that were impacted based on these changes. This may be better understood by completing a community-wide tree inventory and more closely monitoring these changes over time.

Removals: Town-owned and State-owned land contributed to a higher share of removals than their share of land, UNH-owned land contributed to an equal share, and Other-owned land contributed to a lower share. Town-owned land had the highest removals flux per unit area (-5.22 $tCO_2e/yr/ha$), while Other-owned land had the lowest removals flux per unit area (-4.30 $tCO_2e/yr/ha$). Each ownership category had its largest source of removals from Undisturbed Forest, followed by Trees Outside Forests Maintaining/Gaining Canopy and lastly Reforestation. Therefore, differences in removal rates may be based on the amount, age, and species type of trees within these categories, as well as the area and composition of each land use class.

<u>Recommendations</u>

GCoM requires two deliverables based on the outcome of Durham's GHG inventories: (1) Emission reduction targets and (2) a Climate Mitigation Action Plan. Recommendations from the Land Use GHG Inventory, listed below, as well as the Community-Wide Greenhouse Gas Inventory, published in August 2021, should be incorporated into these upcoming GCoM deliverables.

- Continue to promote forest conservation by enacting policy that avoids forest land fragmentation, limits the conversion of Forest Land to other land use types, prioritizes new development in Settlement over other land use classes, and incentivizes landowners to take advantage of federal and other programs that support forest conservation.
- Maintain and improve carbon sequestration capabilities of Durham's land and increase land resilience to climate change through creating an updated forest inventory and determining forest management scenarios that optimize carbon sequestration and decrease ongoing climate change threats. These efforts, particularly the forest inventory, may be an opportunity to partner with experts from UNH, and can be used to guide policy around land in Durham.
- Leverage community involvement and promote social equity by developing and improving relationships with community groups interested in sustainability, involving the public in decision-making processes for future GCoM deliverables, providing forest management services to forest landowners, and balancing forest conservation with land affordability.
- Prioritize reducing emissions from Durham's largest emitting sectors, transportation and the built environment, and complete a consumption-based GHG inventory to educate residents on their emission impacts. Durham's Energy Committee is already pursuing Community Power Aggregation, where residential electricity would be sourced from renewable energy rather than fossil fuels. Similar efforts should be undertaken to further reduce emissions from this and other sectors.
- Increase resiliency of Town's sustainability efforts through ensuring steady funding sources and designating staff to oversee the efforts. Funding sources may be through savings from sustainability improvements, grants, and state and federal funding.

Introduction

Nature-Based Solutions as a Response to Climate Change

Durham is a town located in Seacoast New Hampshire and is home to approximately 5,900 permanent residents as well as 11,700 students attending the University of New Hampshire (UNH).[2] As a coastal town, Durham is especially conscious of the impacts of climate change and has already taken many steps to become a more sustainable community.[3] One of Durham's most significant actions to date was joining the Global Covenant of Mayors for Climate and Energy (GCoM) in January 2021. By committing to this movement, Durham pledged to implement policies and undertake measures to reduce/limit greenhouse gas (GHG) emissions, prepare for the impacts of climate change, increase access to sustainable energy, and track progress towards these objectives.[1]

Some of the most effective ways to mitigate climate change are through nature-based solutions, i.e., the conservation, restoration, and sustainable management of land. Unlike many engineered solutions, nature-based solutions can address climate challenges at a relatively low-cost while delivering multiple additional benefits for people and the environment. Some benefits include storing carbon, protecting biodiversity, reducing impacts of flooding, reducing air pollution, and providing recreation and health benefits, and there is growing awareness of the importance of nature-based solutions.[4,8] In fact, a 2019 IPCC Climate Change and Land Report notes that all mitigation scenarios limiting global warming temperature to 1.5°C above pre-industrial levels rely heavily on land use change mitigation methods as well as decarbonizing the economy.[4]

Congress and the Biden Administration have recently taken steps to facilitate nature-based solutions to climate change. President Biden's nationally determined contribution, as part of rejoining the Paris Agreement, states "[t]he United States can reduce emissions from forests and agriculture and enhance carbon sinks through a range of programs and measures including nature-based solutions for ecosystems ranging from our forests and agricultural soils to our rivers and coasts."[5] In June 2021, the Growing Climate Solutions Act (GCSA) was passed by the U.S. Senate. This bill encourages nature-based GHG reductions in the agriculture and forestry sectors through providing incentives and support for voluntary action.[6] As of August 2021, the bill is waiting to be passed by the US House of Representatives before being passed by the President and enacted into law.[12] In addition to GCSA, the United States Department of Agriculture (USDA) expanded their existing Conservation Reserve Program in April 2021, which increased payment rates for farmers switching from production to climate change mitigation, as well as increased investments in Regional Conservation Partnership projects, which fund natural resource conservation projects on private land.[6]

Durham has recognized the importance of nature-based climate solutions. After identifying areas of land that were valuable to conserve, over 40% of Durham's land was either permanently protected or owned by Durham or UNH as of 2019.[3] In addition to these efforts, like much of New Hampshire, land within Durham's Town boundary consists largely of forested

land. Because of this, Durham chose to voluntarily conduct this Land Use GHG Inventory to be added to its broader Community-Wide GHG Inventory that was completed in early August 2021. Information from this report will be used to help Durham understand the sequestration capabilities of its land, guide policy decisions, and help inform decisions on the acquisition of land and conservation easement designations. This report, along with the Community-Wide GHG Inventory, will also serve as a foundation for Durham's future GCoM deliverables of Emission Reduction Target Setting and the creation of a Climate Mitigation Action Plan.

Land Use GHG Inventory

A Land Use GHG Inventory is more complicated than an inventory for other sectors due to land use both emitting and removing greenhouse gases, having multiple carbon pools that respond based on management activities and natural disturbances, having high interannual variability, and not having as precise measurements as other sectors.[8]

Changes in land use and land management practices affect these GHG emissions and removals. This is because the net effect of land use (i.e., the summation of emissions and removals) is estimated based on the change in carbon stocks, with the level of carbon stocks differing based on its type of land use. When considering land use, the only removal sources are from trees remaining as trees or from non-tree areas being converted to tree areas. Trees remove CO_2 from the atmosphere by converting it during photosynthesis and into stored carbon as they grow. However, sources of land use related emissions have many potential contributors. Emissions occur when Forest Land or Trees are converted to Non-Forest and Non-Tree areas, or when forested lands are disturbed by events such as harvesting, insects, and disease. This Land Use GHG Inventory measures CO_2 emissions and removals from trees remaining and transitioning to and from forest and non-forest land uses.[7,8]

Trees: Not a Direct Offset

Although trees play a critical role in naturally sequestering carbon from the atmosphere, communities should be cautious in how they view trees with regard to their wider-community GHG inventory. These CO_2 removals should not be applied as a direct offset of other sectors because it reduces the community's perception of how much the community is actually emitting, thus underestimating the actual scale of reductions communities need to make to meet reduction targets. In addition to this, carbon sequestration is part of earth's natural carbon cycle that regulates climate and makes the planet habitable. Therefore, associating all carbon sequestration with offsetting anthropogenic emissions disregards this natural balance, and again underestimates Durham's emissions.

Methods

Protocol

This Land Use GHG Inventory uses the approach and methods provided by ICLEI's US Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions (USCP) Version 1.2 and its associated Appendix J: Forest Land and Trees, released in 2019.[7,8] This publication has moved the field forward, as methods for conducting carbon sequestration and storage inventories of land uses were not standardized until recently, and has allowed Durham to position itself as a leader in applying these methods. ICLEI's online Land Emissions and Removals Navigator (LEARN) Tool[9] follows USCP Appendix J protocols and was used to calculate land use emissions and removals for this inventory. The USCP reporting framework is accepted by GCoM and should be used in any future land use inventories that Durham performs in the future.

Inventory Boundaries

This inventory measures "Scope 1" emissions and removals, which are GHG emissions and removals that are produced within the geographic boundary of the community. To estimate GHG emissions and removals from land use, the land use change over a given time period must first be determined. The inventory analysis period for Durham's Land Use GHG Inventory was chosen to be 10 years (2006-2016), while the analysis period for trees outside forests within the inventory was 5 years (2011-2016) due to data availability. Choosing a longer period helps minimize interannual variability that naturally occurs from seasonal changes, weather patterns, and other events, and can ultimately be used as a baseline to set land-based GHG targets.[8]

Land Use Classes

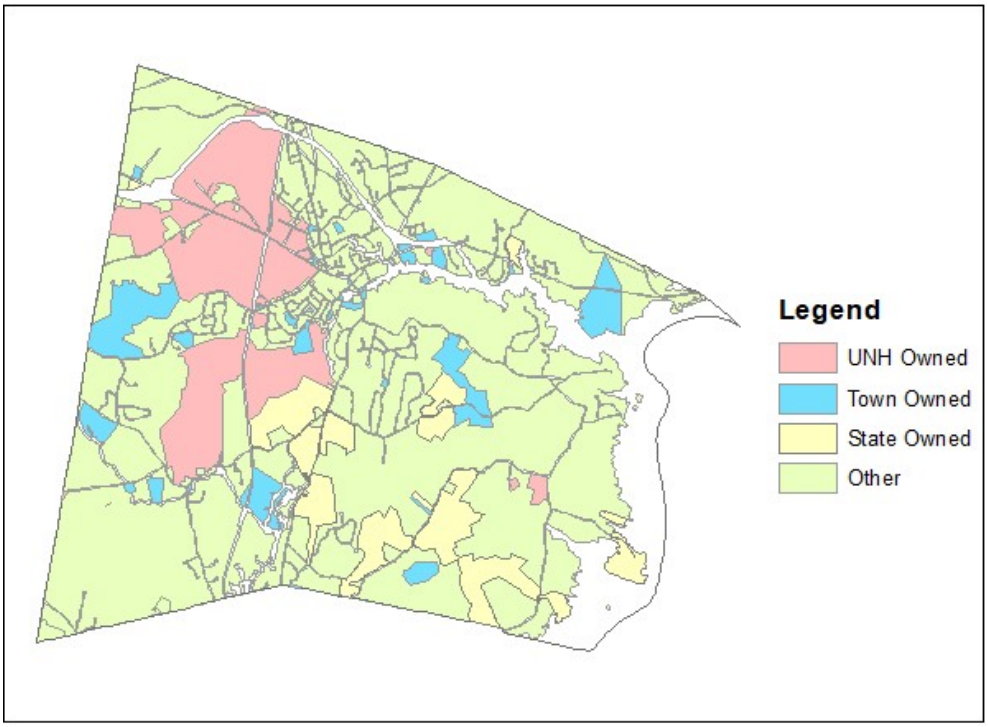
USCP requires the reporting of emissions and removals from land use change for six land use classes: Forest Land, Cropland, Grassland, Wetland, Settlement, and Other Land. Therefore, emissions and removals were estimated by comparing changes in area (measure in hectares) to and from each land use class between the measured years 2006 and 2016. Some land use class changes, such as Settlement to Forest Land, result in GHG removals because of the new land use's ability to sequester carbon, while other land use class changes, such as Forest Land to Cropland, result in GHG emissions due to the land's reduction of carbon stock new land use's reduced ability to sequester carbon.

Ownership Categories

To further analyze land use change and better determine policy recommendations, Durham was divided into four ownership categories, as shown in Figure 1:

1) UNH – owned by the University of New Hampshire
2) Town – owned by the Town of Durham
3) State – owned by the state of New Hampshire, including state of NH fish & game
4) Other – any land that did not fall under the above three categories

Figure 1. Town of Durham by Ownership



Data Input

ICLEI's LEARN Tool is a map-based online tool that pulls data from the National Land Cover Database[10] to provide information on land use change for a given area over a given analysis period. Durham's community boundary and an inventory period 2006-2016 were chosen within the tool to calculate Durham-specific emissions and removals. A report summarizing emissions and removals for each land use change over the boundary and inventory period is then generated by the tool. This process was repeated for ownership categories UNH Owned, Town Owned, and State Owned. Ownership category "Other" was estimated by subtracting outputs from the previous three ownership categories from Durham's community boundary.

Results

Durham Town Boundary

Land Use Change

Before estimating the land-related GHG emissions and removals, a community must determine the area and types of land use change over a given period. Area of land cover change between 2006 and 2016 was determined for each of six land use classes: Forest Land, Cropland, Grassland, Wetland, Settlement, and Other Land.

Over this time, Durham lost land areas designated as Forest Land and Wetland and gained land areas designated as Grassland and Settlement. Land use classes Cropland and Other had a net land cover change of zero. Figure 2 shows the land cover change and Table 1 outlines the net land cover change for each land use class within Durham's town boundary.

Figure 2. Land Cover Change within Durham Town Boundary 2006-2016 (ICLEI LEARN Tool)

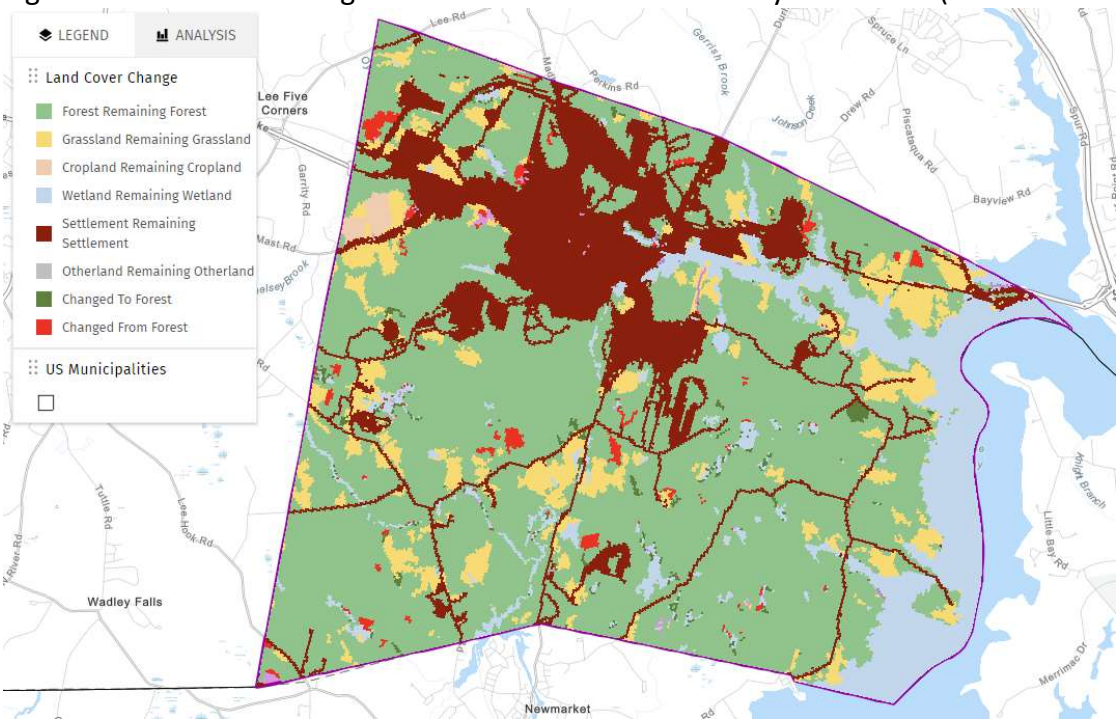


Table 1. Land Coverage and Change by Land Use Class – Durham Town Boundary 2006-2016

Land Use Class	Percent of Land Cover Durham, 2006	Percent of Land Cover Durham, 2016	Land Cover Change
Forest Land	60.0%	59.7%	-18 hectares (-44.5 acres)
Cropland	0.4%	0.4%	0 hectares (0 acres)
Grassland	9.1%	9.4%	+13 hectares (+32.1 acres)
Wetland	12.2%	11.8%	-24 hectares (-59.3 acres)
Settlement	18.2%	18.6%	+28 hectares (+69.2 acres)
Other	0.1%	0.1%	0 hectares (0 acres)

GHG Emissions and Removals

Land use change can result in GHG emissions or removals from the atmosphere. Sources of GHG removals include undisturbed forests, reforestation, and trees outside forests maintaining/gaining their canopy, while sources of GHG emissions include Forest Land being converted to another land use class, loss of trees outside forests, and forest disturbances, such as fire, harvests, or insects/disease. Table 2 and Figure 3 break down the land-related emissions and removals within Durham's Town boundary.

From 2006 to 2016, land within the Durham town boundary sequestered a total of 28,161 tCO_2e/yr and emitted a total of total of 2,691 tCO_2e/yr. This results in a removal flux per unit area of -4.39 tCO_2e/yr/ha and an emission flux per unit area of 0.42 tCO_2e/yr/ha.

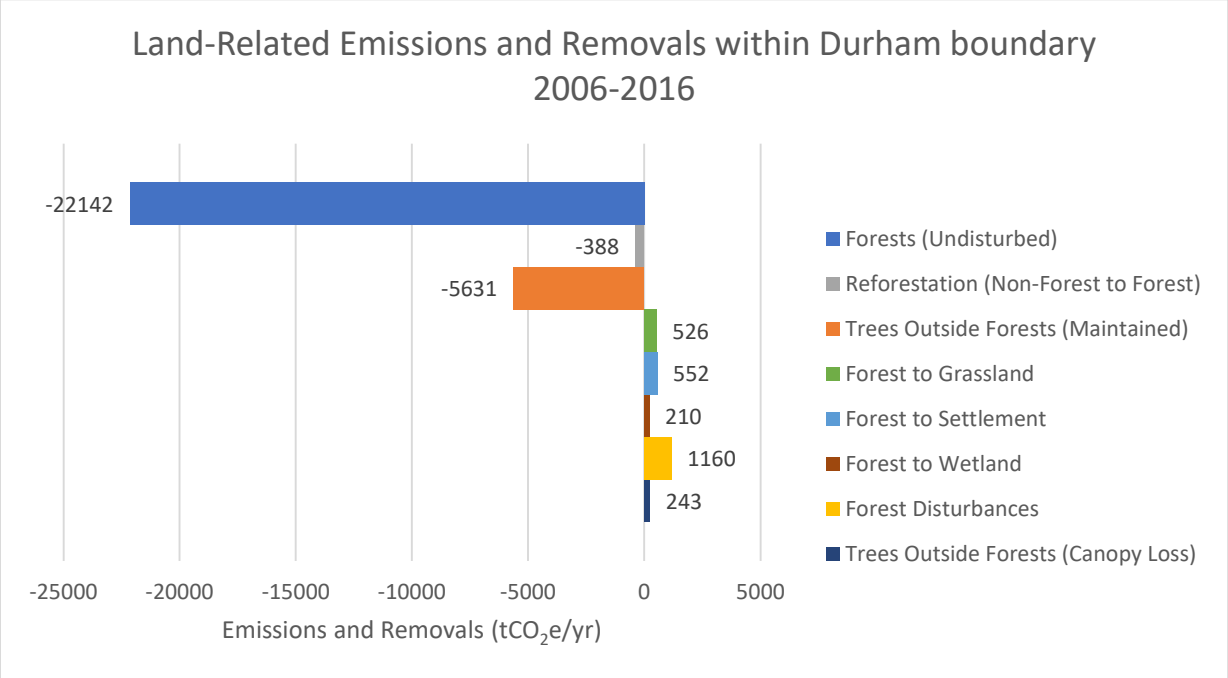
Forest Land accounted for 80.0% of GHG removals through Forest Land remaining Forest Land and Reforestation, and 47.9% of GHG emissions through Forest Land being converted to Grassland, Settlement, and Wetland. GHG Removals by Forest Land occurred from 3735 hectares (98.3% of 2006 area) of Forest Land remaining undisturbed as well as reforestation from 16 hectares of Grassland (4.1% of 2006 area) and 32 hectares of Wetland (5.4% of 2006 area) being converted to Forest Land. No GHG emissions or removals occurred in land use classes Cropland or Other Land because there was no area change. Forest disturbances accounted for 43.1% of GHG emissions: 43.0% from harvests/other and 0.1% from insects.

Trees outside forests accounted for 20.0% of GHG removals through maintaining or increasing the number of trees, and 9.0% of GHG emissions from tree canopy loss. Settlement had the largest percent tree cover (45%), followed by Other Land (19%), Grassland (13%), Wetland (8%), and Cropland (2%). Grassland had the largest area tree canopy loss (4 hectares), followed by Settlement (3 hectares) and Wetland (1 hectare).

Table 2. Greenhouse Gas Summary Table for Durham Town Boundary 2006-2016

Source	Type	Area (hectares)	GHG Flux (tCO_2e/yr)	% Total
Forests (Undisturbed)	Removal	3735	-22142	78.6%
Reforestation (Non-Forest to Forest)	Removal	48	-388	1.4%
Trees Outside Forests (Maintained)	Removal	645	-5631	20.0%
Forest to Cropland	Emission	0	--	--
Forest to Grassland	Emission	36	526	19.5%
Forest to Settlement	Emission	21	552	20.5%
Forest to Wetland	Emission	9	210	7.8%
Forest to Other Land	Emission	0	--	--
Trees Outside Forests (Canopy Loss)	Emission	9	243	9.0%
Forest Disturbances	Emission	47	1160	43.1%
		Total Removals	**-28161**	
		Total Emissions	**2691**	
		Net GHG Balance	**-25470**	

Figure 3. Land-Related Emissions and Removals within Durham boundary 2006-2016



Some land use class changes result in more emissions or reductions than others, as shown in Table 3. For example, in considering Forest converted to Non-Forest land, although Forest Land to Grassland had a larger area change, it resulted in less GHG emissions than Forest Land to Settlement. Land use changes can be more easily compared by looking at the GHG flux per unit area. The highest emissions flux per hectare was trees outside forests losing canopy (27.0 tCO_2e/yr/ha) and the lowest was Forest Land converted to Grassland (14.6 tCO_2e/yr/ha). Considering only Forest Land to Non-Forest Land, Forest Land to Settlement had the highest GHG flux per hectare, followed by Forest Land to Wetland, and Forest Land to Grassland. For removals flux per hectare, Trees Outside Forests had the highest (-8.7 tCO_2e/yr/ha), followed by Reforestation (-8.1 tCO_2e/yr/ha) and Undisturbed Forests (-5.9 tCO_2e/yr/ha).

Table 3. GHG Flux over area by GHG Source

Source	Area (hectares)	GHG Flux (tCO_2e/yr)	GHG Flux/Area (tCO_2e/yr/hectare)
Forests (Undisturbed)	3735	-22142	-5.9
Reforestation (Non-Forest to Forest)	48	-388	-8.1
Trees Outside Forests (Maintained)	645	-5631	-8.7
Forest to Cropland	0	--	--
Forest to Grassland	36	526	14.6
Forest to Settlement	21	552	26.3
Forest to Wetland	9	210	23.3
Forest to Other Land	0	--	--
Trees Outside Forests (Canopy Loss)	9	243	27.0
Forest Disturbances	47	1160	24.7

Ownership Categories: An Overview

Land Ownership Breakdown

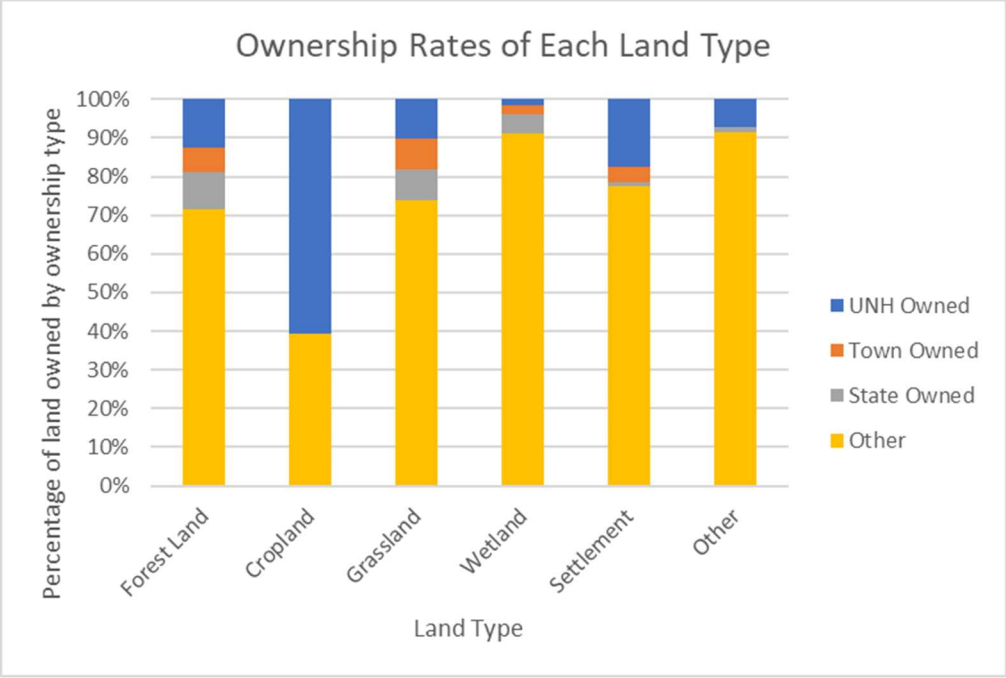
Land within Durham's Town boundary was divided into four ownership categories: UNH, Town, State, and Other. Organizing Durham into ownership categories helps Durham better understand where emissions and removals are coming from and informs policy and land management recommendations. Table 4 and Figure 4 show the ownership rates within each land use class.

Other owns the most land (75.5%), followed by UNH (12.0%), State (7.4%), and Town (5.1%). However, land use class makeup differs by ownership. Other owns the largest area of Forest Land, Grassland, Wetland, Settlement, and Other Land, while UNH owns the largest area of Cropland.

Table 4. Ownership Rates for Each Land Use Class

Owner	% Total Land in Durham	% Total Forest Land	% Total Cropland	% Total Grassland	% Total Wetland	% Total Settlement	% Total Other Land
UNH	12.0%	12.4%	60.7%	10.3%	1.6%	17.4%	7.1%
Town	5.1%	6.2%	0.0%	7.8%	2.2%	2.7%	0.0%
State	7.4%	9.8%	0.0%	8.0%	4.9%	1.2%	1.4%
Other	75.5%	71.6%	39.3%	73.8%	91.3%	78.7%	91.4%

Figure 4. Ownership Rates for Each Land Use Class

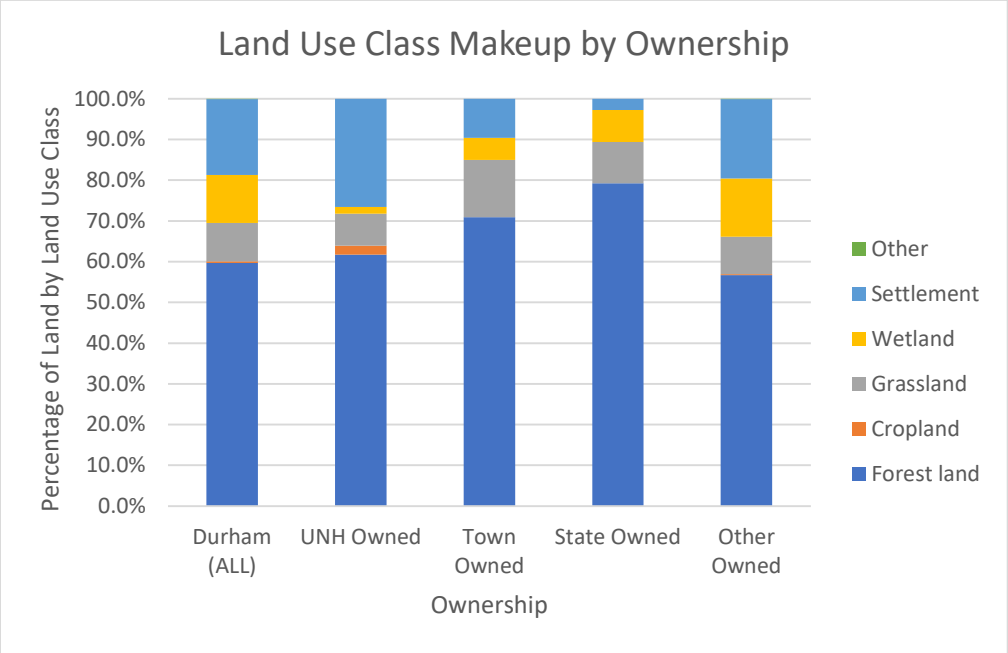


Similarly, each owner has a different makeup of land use classes within their land. Table 5 and Figure 5 shows the composition of land use classes for each ownership category. Each ownership category, as well as all land within Durham's Town boundary, boasts over 50% of their owned land as Forest Land. State owned land has the highest percentage of Forest Land ownership, with 79.2% percent of their total land owned as Forest Land. Other-owned land has the smallest makeup of Forest Land, with only 56.7% designated as Forest Land.

Table 5. Land Use Class Makeup of each Ownership Category

Land Use Class	Durham (ALL)	UNH Owned	Town Owned	State Owned	Other Owned
Forest Land	59.7%	61.7%	70.9%	79.2%	56.7%
Cropland	0.4%	2.2%	0.0%	0.0%	0.2%
Grassland	9.4%	7.9%	14.1%	10.2%	9.2%
Wetland	11.8%	1.6%	5.4%	7.8%	14.3%
Settlement	18.6%	26.6%	9.6%	2.8%	19.4%
Other Land	0.1%	0.0%	0.0%	0.0%	0.1%

Figure 5. Land Use Class Makeup of each Ownership Category



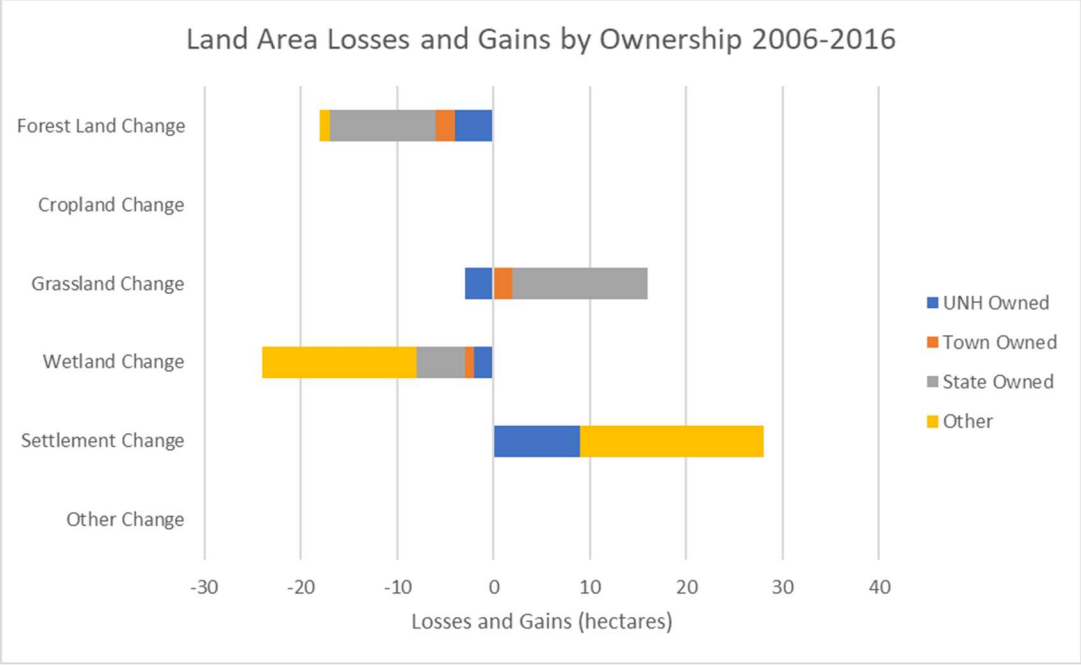
Land Use Change by Ownership

From 2006 to 2016, Durham lost 18 hectares of Forest Land and 24 hectares of Wetland, gained a net 13 hectares of Grassland and 28 hectares of Settlement, and had a net zero change in area of Cropland and Other Land. Table 6 and Figure 6 breaks down these land use losses and gains further by ownership category. Forest Land and Grassland in Durham were most largely impacted because of changes in State-owned land, while Wetland and Settlement were impacted the most due to changes in Other-owned land.

Table 6. Land Area Losses and Gains of Each Land Use Class by Ownership 2006-2016

Owner	Forest Land Net Change (hectares)	Cropland Net Change (hectares)	Grassland Net Change (hectares)	Wetland Net Change (hectares)	Settlement Net Change (hectares)	Other Land Net Change (hectares)
UNH	-4	0	-3	-2	+9	+0.1
Town	-2	0	+2	-1	0	0
State	-11	0	+14	-5	0	0
Other	-1	0	0	-16	+19	-0.1
Total Change	**-18**	**0**	**13**	**-24**	**28**	**0**

Figure 6. Land Area Losses and Gains of Each Land Use Class by Ownership 2006-2016



GHG Emissions and Removals

Land use changes can result in GHG emissions or removals from the atmosphere. Figures 7 and 8 show the contribution of each ownership category to the total GHG emissions and removals. Other owned land contributed to the majority of both emissions and removals overall. Town owned land had the smallest overall contribution to both emissions and removals. Figure 9 breaks this down further by ownership contribution towards each emission and removal source. From left to right, the first five sources are emissions, while the last three sources are removals. Durham's largest emission source, Forest Disturbances, and its largest removals source, Undisturbed Forest, largely occurred in Other owned land.

Figure 7. Emissions by Ownership Category

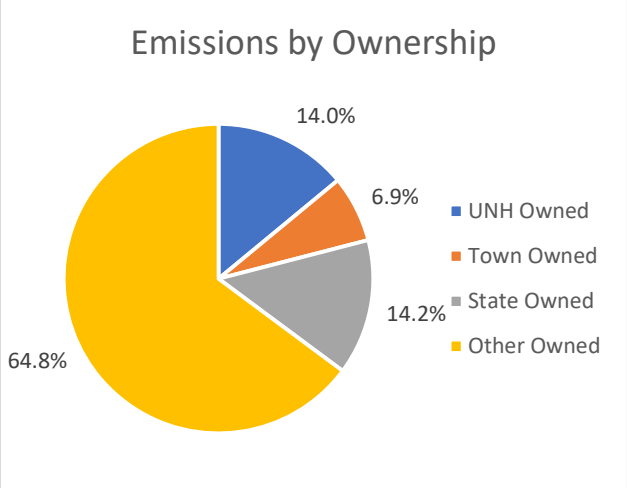


Figure 8. Removals by Ownership Category

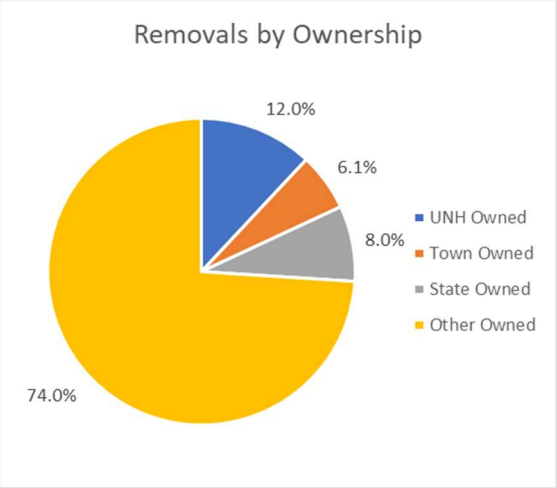


Figure 9. Ownership Emission and Removal Source contributions by Land Use Change

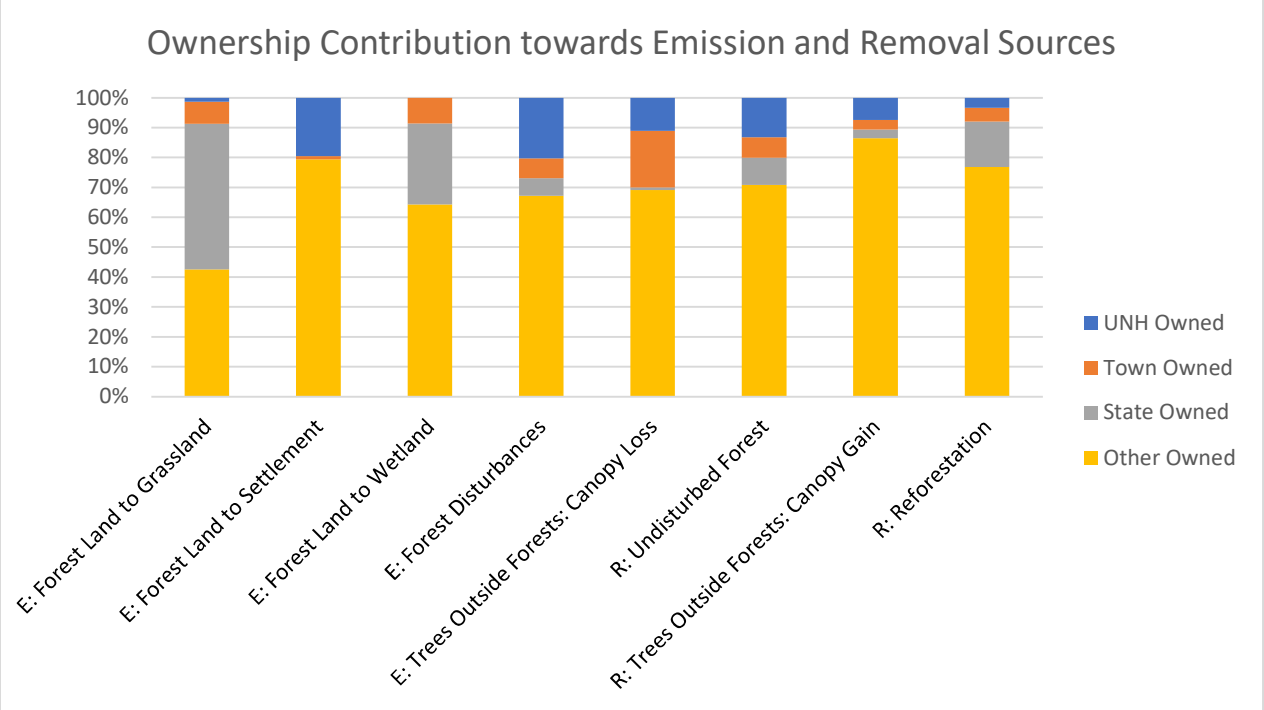


Table 7 provides a summary of the top three sources for each ownership category. Note that the total emissions do not add to 100% for each category because some have more than three sources of emissions. While Durham's top three emission sources were due to Forest Disturbances: Harvests/Other, Forest Land to Settlement, and Forest Land to Grassland, the top three emission sources differed within each ownership category. However, the top three removal sources for both Durham as well as within each ownership category were from Undisturbed Forest Land, Trees Outside Forests Maintaining/Gaining Canopy, and Reforestation, in that order of influence.

Table 7. Top Three Emission and Removal Sources within each Ownership Category

Owner	Emissions Source #1	Emissions Source #2	Emissions Source #3	Totals
Durham (All)	Forest Disturbances: Harvests/Other **43.0%**	Forest Land to Settlement **20.5%**	Forest Land to Grassland **19.5%**	83.0%
UNH-owned	Forest Disturbances: Harvests/Other **62.3%**	Forest Land to Settlement **28.6%**	Trees Outside Forests Canopy Loss **7.2%**	98.1%
Town-owned	Forest Disturbances: Harvests/Other **41.7%**	Trees Outside Forests Canopy Loss **24.6%**	Forest Land to Grassland **20.9%**	87.2%
State-owned	Forest Land to Grassland **67.2%**	Forest Disturbances: Harvests/Other **17.8%**	Forest Land to Wetland **15.0%**	100.0%
Other-owned	Forest Disturbances: Harvests/Other **44.4%**	Forest Land to Settlement **25.1%**	Forest Land to Grassland **12.8%**	82.3%
Owner	Removals Source #1	Removals Source #2	Removals Source #3	Totals
Durham (All)	Undisturbed Forest Land **78.6%**	Trees Outside Forests Canopy Maintain/Gain **20.0%**	Reforestation (Non-Forest to Forest Land) **1.4%**	100.0%
UNH-owned	Undisturbed Forest Land **87.1%**	Trees Outside Forests Canopy Maintain/Gain **12.5%**	Reforestation (Non-Forest to Forest Land) **0.4%**	100.0%
Town-owned	Undisturbed Forest Land **88.3%**	Trees Outside Forests Canopy Maintain/Gain **10.6%**	Reforestation (Non-Forest to Forest Land) **1.1%**	100.0%
State-owned	Undisturbed Forest Land **90.2%**	Trees Outside Forests Canopy Maintain/Gain **7.1%**	Reforestation (Non-Forest to Forest Land) **2.6%**	100.0%
Other-owned	Undisturbed Forest Land **75.2%**	Trees Outside Forests Canopy Maintain/Gain **23.4%**	Reforestation (Non-Forest to Forest Land) **1.4%**	100.0%

Since GHG emissions and removals occur based on area change, and each ownership category had varying land use class compositions, the net GHG flux per hectare for each ownership category differs with each ownership, as shown in Table 8. Town owned land had the largest removals flux per unit area, while State owned land had the largest emissions flux per unit area.

Table 8. GHG Fluxes per Area for Each Ownership Category

	Durham (All)	UNH-Owned	Town-Owned	State-Owned	Other-Owned
Removals per unit area (tCO_2e/yr/ha)	-4.39	-4.36	-5.22	-4.75	-4.30
Emissions per unit area (tCO_2e/yr/ha)	0.42	0.49	0.57	0.81	0.36
Net GHG Flux per unit area (tCO_2e/yr/ha)	**-3.97**	**-3.87**	**-4.65**	**-3.94**	**-3.94**

Ownership Categories: In Focus

UNH Owned Land

UNH-owned land consists of 61.7% Forest Land, 26.6% Settlement, 7.9% Grassland, 2.2% Cropland, and 1.6% Wetland. From 2006 to 2016, UNH owned land accounted for a net loss of 4 hectares Forest Land, 3 hectares Grassland, and 2 hectares Wetland as well as a net gain of 9 hectares Settlement and 0.1 hectares Other Land.

These land use changes on UNH-owned land removed -3,366 tCO_2e/yr and emitted 377 tCO_2e/yr, resulting in a net GHG balance of -2,989 tCO_2e/yr. 87.1% of removals were from Undisturbed Forests, while 62.3% of emissions were from harvest/other Forest Disturbances. These contributions are larger than Durham as a whole, which has 78.6% of its removals from Undisturbed Forests and 43.0% of emissions from harvest/other Forest Disturbances.

UNH-owned land had -4.36 tCO_2e/yr/ha of GHG removals, 0.49 tCO_2e/yr/ha of GHG emissions, and a -3.87 tCO_2e/yr/ha net GHG flux per unit area balance. UNH-owned land ranks third in both removal and emission rates per hectare when compared to other ownership types. UNH-owned land has a lower removal rate, higher emissions rate, and lower net GHG flux per unit area than Durham as a whole.

UNH owns 12.4% of Forest Land, 60.7% of Cropland, 10.3% of Grassland, 1.6% of Wetland, 17.4% of Settlement, and 7.1% of Other Land in all of Durham. UNH owns 12.0% of all land in Durham, but contributes to 14.0% of land-based GHG emissions and 12.0% of land-based GHG removals. Therefore, they are contributing the same share of GHG removals as their share of land, but are contributing to more of the GHG emissions than their share of land, which is mostly occurring due to harvest/other Forest Disturbances.

Town Owned Land

The Town of Durham's land consists of 70.2% Forest Land, 14.1% Grassland, 9.6% Settlement, and 5.4% Wetland. From 2006 to 2016, Town-owned land had a net Forest Land loss of 2 hectares, a net Grassland gain of 2 hectares, and a net Wetland loss of 1 hectare.

Over the inventory period, Town-owned land removed -1,716 tCO_2e/yr and emitted 187 tCO_2e/yr, resulting in a net GHG balance of -1,529 tCO_2e/yr. 88.3% of removals were from Undisturbed Forests, while 41.7% of emissions were from harvest/other Forest Disturbances. The removals were higher than Durham as a whole (78.6% removals from Undisturbed Forests) and the emissions were lower than Durham as a whole (43.0% emissions from harvests/other).

Land owned by the Town had per hectare GHG removal flux of -5.22 tCO_2e/yr/ha, GHG emission flux of 0.57 tCO_2e/yr/ha, and net GHG flux of -4.65 tCO_2e/yr/ha. Town-owned land had the highest removal rate and second highest emission rate when compared to the other ownership categories. Town-owned land had a higher removal rate, higher emissions rate, and higher net GHG flux than all land within Durham's boundary.

The Town owns 6.2% of Forest Land, 7.8% of Grassland, 2.2% of Wetland, and 2.7% of Settlement in all of Durham. The Town does not own any land designated as Cropland or Other Land. Overall, the Town owns 5.1% of all land in Durham and contributes to 6.9% of land-based GHG emissions and 6.1% of land-based GHG removals. Therefore, the Town is contributing more than their share of land's worth to both GHG emissions and removals, which are largely due to harvest/other Forest Disturbances and Undisturbed Forests, respectively.

State Owned Land

State-owned land is composed of 79.2% Forest Land, 10.2% Grassland, 7.8% Wetland, and 2.8% Settlement. Over the inventory period, State-owned land accounted for 11 out of the 18 hectares lost from Forest Land, 5 of the 24 hectares lost from Wetland, and 14 of the 16 hectares gained in Grassland.

State-owned land removed -2,243 tCO_2e/yr and emitted 382 tCO_2e/yr, resulting in a net GHG balance of -1,861 tCO_2e/yr. 90.2% of removals were from Undisturbed Forests, while 67.2% of emissions were from the conversion of Forest Land to Grassland. These contributions are much larger than Durham as a whole, which has 78.6% of its removals from Undisturbed Forests and 19.5% of emissions from Forest Land to Grassland.

Land owned by the State had per hectare -4.75 tCO_2e/yr/ha of GHG removals, 0.81 tCO_2e/yr/ha of GHG emissions, and a -3.94 tCO_2e/yr/ha net GHG balance. State-owned land had the second highest removal rate and the highest emission rate of all ownership categories. State-owned land had higher removal and emissions rates as well as a higher net GHG balance than all land within Durham's boundary.

The State owns 9.8% of Forest Land, 8.0% of Grassland, 4.9% of Wetland, 1.2% of Settlement, and 1.4% of Other Land in all of Durham. The State does not own any land designated as Cropland. While the State owns 7.4% of all land in Durham, they contribute to 14.2% of land-based GHG emissions and 8.0% of land-based GHG removals. Therefore, they are contributing to a higher share of both GHG emissions and removals than their share of land, which largely is due to emissions from the conversion of Forest Land to Grassland and removals from Undisturbed Forests.

Other Owned Land

Other land consists of 56.7% Forest Land, 19.4% Settlement, 14.3% Wetland, 9.2% Grassland, 0.2% Cropland, and 0.1% Other Land. From 2006 to 2016, Other-owned land changed by net 1 hectare and 16 hectare losses of Forest Land and Wetland, respectively, as well as a 19 hectare net gain of Settlement.

Other owned land removed -20,836 tCO_2e/yr and emitted 1,745 tCO_2e/yr, resulting in a net GHG balance of -19,091 tCO_2e/yr. 75.2% of removals were from Undisturbed Forests, while 44.4% of emissions were from harvest/other Forest Disturbances. The removals were lower than Durham as a whole (78.6% removals from Undisturbed Forests) and the emissions were higher than Durham as a whole (43.0% emissions from harvest/other Forest Disturbances).

Per hectare, this is -4.30 $tCO_2e/yr/ha$ of GHG removals, 0.36 $tCO_2e/yr/ha$ of GHG emissions, and a -3.94 $tCO_2e/yr/ha$ net GHG balance. Other-owned land had the lowest removals and emissions rates when compared to all other ownership categories. Other-owned land also had a lower removal rate, emissions rate, and net GHG flux than all land within Durham's boundary.

Other-owned land owns 71.6% of Forest Land, 39.3% of Cropland, 73.8% of Grassland, 91.3% of Wetland, 78.7% of Settlement, and 91.4% of Other Land in all of Durham. While Other-owned land accounts for 75.5% of all land in Durham, it contributes to 64.8% of land-based GHG emissions and 74.0% of land-based GHG removals. Therefore, they are contributing to a lesser share of both GHG emissions and removals than their share of land.

Ownership Summary

Emissions

UNH-owned, Town-owned, and State-owned land contributed to a larger share of emissions than their share of land, while Other-owned land contributed to a smaller share of emissions than their share of land. Differences between emissions contributions may be due to the specific land use changes within each ownership category. The largest contributor to emissions on UNH-owned, Town-owned, and Other-owned land were from harvests/other Forest Disturbances, while State-owned land's largest emitting source was due to the conversion of Forest Land to Grassland.

When comparing ownership categories based on GHG flux per unit area, State-owned land had the highest emissions rate (0.81 $tCO_2e/yr/ha$), while Other-owned land had the lowest emissions rate (0.36 $tCO_2e/yr/ha$). This may be largely due to the composition of species-type and age of the trees that were impacted by the respective land use change. For example, State-owned land's largest emitting source, which contributed to 67.2% of its total emissions, was due to 16 hectares of Forest Land being converted to Grassland. The trees affected by this change may have been different than those affected by Other-owned land's largest emissions source, which contributed to 44.4% of its total emissions, where 29 hectares were affected by harvest/other Forest Disturbances. Differences between these emission rates may be better understood by collecting additional information, such as tree age and species type, through a community-wide tree inventory.

Removals

Town-owned and State-owned land contributed to a larger share of removals than their share of land, UNH-owned land contributed to an equal share, and Other-owned land contributed to a smaller share. The largest contributor to removals within all ownership categories were Undisturbed Forest, followed by Trees Outside Forests Maintaining/Gaining Canopy and lastly Reforestation.

Town-owned land had the highest removal rate per unit area (-5.22 $tCO_2e/yr/ha$), while Other owned land had the lowest (-4.30 $tCO_2e/yr/ha$). As of 2016, 70.9% of Town-owned land was designated at Forest Land and 9.6% was designated as Settlement, while only 56.7% of Other-owned land was designated as Forest Land and 19.4% was designated as Settlement. Since both ownership categories had Undisturbed Forests as their largest contributor to removals, differences in removal rates may be largely due to age and species type impacted as well as the total land and composition of land use classes within each ownership category.

Durham in Context

National Context

Each year in the United States, forest lands remove over 700 million tCO_2e and trees outside forests remove over 120 million tCO_2e from the atmosphere – the equivalent of nearly 10% and 2% of United States' gross emissions, respectively. The United States' land use, due to its vast forest and tree networks, has greater removals of CO_2 than emissions, making it a net sink of CO_2.[7] As shown in this inventory, Durham's forests and trees also have greater CO_2 removals than emissions, making it a net sink of CO_2.

Local Context

The annual CO_2 removals from forests and trees in Durham were -28,161 tCO_2e/yr from 2006 to 2016. To put this into context, that is equivalent to each of the following:[10]

- GHG emissions from 6,124 Passenger vehicles driven for one year
- CO_2 emissions from 3,391 homes' energy use for one year
- CO_2 emissions from 5,115 homes' electricity use for one year
- GHG emissions avoided by 5.9 wind turbines running for a year
- GHG emissions avoided by 1,067,330 Incandescent lamps switched to LEDs each year

Durham's Community-Wide GHG Inventory, completed in early August 2021, covered five emissions categories: Built Environment, Transportation, Wastewater, Solid Waste, and Agriculture and Livestock. The total GHG emissions was 87,566 tCO_2e. Emissions from each category as well as emissions and removals for land use are summarized in Table 9. [2] Note that the only GHG removals occur due to Durham's forests and trees.

Table 9. Summary of Emissions and Removals by Source[2]

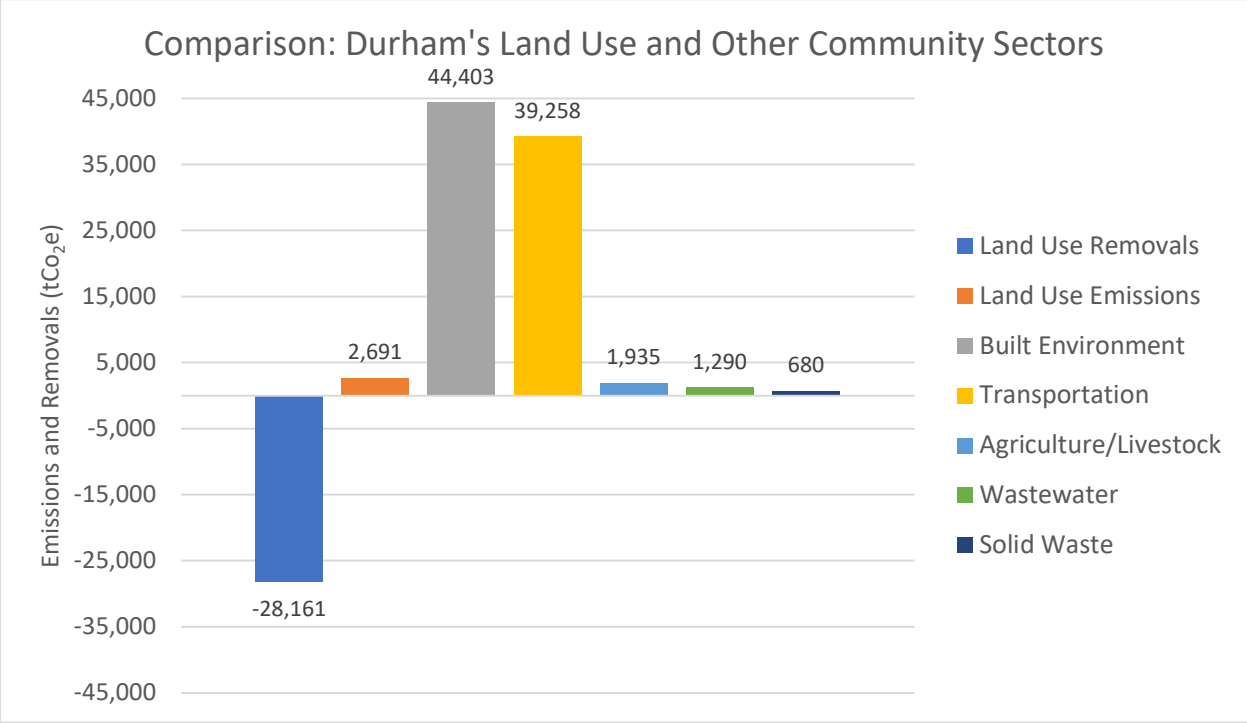
Category	Emissions (tCO_2e)	Removals (tCO_2e)	Percentage of Total
Built Environment	44,403	--	50.7%
Transportation	39,258	--	44.8%
Solid Waste	680	--	0.8%
Wastewater	1,290	--	1.5%
Agriculture/Livestock	1,935	--	2.2%
Total	**87,566**	**--**	**--**
Forests (Undisturbed)	--	-22142	78.6%
Reforestation (Non-Forest to Forest)	--	-388	1.4%
Trees Outside Forests (Maintained)	--	-5631	20.0%
Forest Land to Nonforest	1288	--	47.8%
Trees Outside Forests loss	243	--	9.0%
Forest Disturbances	1160	--	43.1%
Total	**2,691**	**-28,161**	**--**

Table 10 and Figure 10 compare all sectors. The two highest emitting categories were the Built Environment and Transportation, contributing to 49.2% and 43.5% of emissions, respectively. These categories were followed by total Land Use emissions (3.0%), Agriculture/Livestock (2.1%), Wastewater (1.4%), and Solid Waste (0.8%). Durham's annual Land Use removals are equivalent to approximately 31.2% of Durham's total emissions, with 25.0% sequestered by forest land (undisturbed forest land and reforestation) and 6.2% sequestered by trees outside forests (maintaining trees).

Table 10. Summary of all Sectors for year 2019

Category	Emissions/Removals (tCO_2e)	Percentage of Total Emissions
Built Environment	44,403	49.2%
Transportation	39,258	43.5%
Solid Waste	680	0.8%
Wastewater	1,290	1.4%
Agriculture/Livestock	1,935	2.1%
Land Use Emissions	2,691	3.0%
Total Emissions	**90,257**	--
Land Use Removals	-28,161	31.2%
Total Removals	**-28,161**	--

Figure 10. Comparing Land Use to Non-Land Use Emissions and Removals



Recommendations

<u>Promote Forest and Tree Conservation</u>

Trees sequester the equivalent of approximately 31.2% of the annual emissions in Durham – 25.0% from forest land/reforestation and 6.2% from trees outside forests. Therefore, they play an extremely important role in Durham combatting climate change. However, ownership of this crucial land varies (71.6% of Forest Land is owned by Other, 12.4% is owned by UNH, 9.8% is owned by the State, and 6.2% is owned by the Town), which complicates what measures Durham can take. Below are some conservation strategies:

- Avoid forest land fragmentation and prioritize conserving older trees when possible
    - Fragmentation of forest land breaks up habitats and allows for increased sunlight, which in turn can place stress on trees during droughts due to increased soil dryness, attract invasive plant species that increase competition with native species, and attract more white-tailed deer that may eat away the natural habitat and increase tick prevalence in the area. Therefore, if Forest Land must be removed, Durham should avoid fragmentation as its result.
    - Older trees have a higher carbon storage capacity than younger trees, resulting in higher emissions when removed.[13] If old trees in forests are removed for other types of land use, Durham will have higher emissions than if younger trees were removed for the same types of land use.
    - If older trees are removed for other reasons, such as disease, Durham should have plans in place to plant additional trees to make up for this carbon sequestration loss. However, once Forest Land is converted to non-forest land, it is difficult and takes time to convert it back to the carbon sink it once was. In addition, the conversion can result in high costs with an uncertain success rate. Therefore, Durham should promote conservation rather than removal and reforestation as much as possible.
- Town-Owned Land
    - When considering new or expanding development, Durham should prioritize the development on already developed land, such as land in Settlement, over other land use types. When Forest Land must be converted to a non-forest land use, prioritize converting Forest Land to Grassland and Wetland over Settlement.
    - In assessing the feasibility of acquiring new land for conservation purposes, prioritize land with sequestration potential, such as Forest Land and non-forest land with large amounts of trees.
- Non-Town-Owned Land
    - Incentivize landowners to conserve forests when possible. One way is to take advantage of federal programs, such as the Growing Climate Solutions Act, which provides incentives and support for GHG reductions in the agriculture and forestry sectors, the USDA Conservation Reserve Program, which provides payments for farmers switching from production to climate change mitigation, or the USDA Regional Conservation Partnership projects, which fund natural resource conservation projects on private land.[6]

Determine Best Forest Management Scenarios and Improve Land Resilience to Climate Change

The sequestration values in this inventory are based on conditions from 2006 to 2016 and can improve or worsen based on land use change activities as well as the impacts on trees due to climate change threats. Changes in land management strategies that consider these threats can optimize the carbon sequestration capabilities of Durham's trees and forests. Below are a few strategies that can assist in improving Durham's forest management and resilience:

- Update forest management plans and utilize ForGATE to determine future land management scenarios
    - ForGATE is a forest sector GHG accounting tool that considers the life cycle of the forest-sector.[11] A Spring 2021 UNH student-led project analyzed UNH-owned forests and found that both a fully reserved scenario as well as a partial harvest in combination with more reserve scenario sequestered more carbon than the business-as-usual scenario. Durham can consider different land management scenarios of all its forests to maximize their carbon sequestration potential.
    - In order to utilize ForGATE, Durham will need to update its existing town-owned forest management plans as well as create management plans for non-town-owned forests. These plans will include specific tree inventories necessary for ForGATE input and will also guide Durham in developing policies to conserve areas that are most crucial in carbon sequestration and habitat preservation.
- Conduct an updated land use GHG inventory as data becomes available
    - The most recent available data for this inventory was 2016. New data are released approximately every five years. A land use GHG inventory should be performed with every new batch of data. This current report should be used as a baseline for future inventories to measure the effectiveness of future efforts.
- Increase reforestation and tree planting outside of forests
    - This inventory informed us that the highest sequestration per hectare was from trees being maintained outside of forests, with the second highest from tree reforestation. This shows the importance of maintaining and increasing the number of trees in Durham. However, Durham should ensure any reforestation occurs in a sustainable way, avoiding practices such as monoculture planting.
- Plan for effects of climate change and invasive species
    - Durham is already experiencing threats due to climate change. Sea level rise raises groundwater levels, which may increase saltwater pollution and kill trees along the bay; Warmer years and milder winters impact compositions of plant species, as some vines thrive in areas with warmer temperatures and higher levels of CO_2 in the atmosphere and pull down trees in their search for light; Native species that regenerate in shade and wet soils, are threatened by droughts during their seed creation. Small impacts may be contained, but large impacts and tree die-offs can quickly make these threats unmanageable, and possibly out of Durham's control. Durham should determine its largest threats and consider options for reducing or avoiding their occurrence and impact.
    - Invasive species should be documented and accounted for during land management decisions and in the planting of new species. This will be better controlled if a Town-wide tree inventory and management plan is completed.

Leverage Community Involvement to Promote Social Equity

Community involvement is critical in ensuring that the benefits from trees within and outside of forests remain available to residents of Durham. It is also important to ensure that Town decisions are made in an equitable way. Below are a few ways the Town can consider and involve the community:

- Develop and improve relationships with key community groups
    - UNH, the Oyster River Cooperative School District, and many Town committees are incorporating sustainability into their day-to-day efforts. The Town should develop partnerships and join already existing efforts while developing and implementing their own sustainability efforts. For example, Durham Farm Day is a great opportunity to inform residents about the carbon sequestration capabilities of their trees.
- Involve the public in decision-making processes and increase local awareness
    - Since the findings from this report provide a baseline to create future goal setting in response to climate change, the public should be given the opportunity to provide feedback on climate goals and efforts to best fit the Town's solution to the community's needs. While a sustainability webpage has been created to increase awareness, efforts should be made to maintain and update the webpage so residents have an opportunity to be involved.
- Provide forest management services to forest landowners
    - Because Durham only owns 6.2% of Forest Land, there are many other landowners that can impact Durham's sequestration abilities. In developing their own sustainable land use management practices, Durham should also make information available to all other forest landowners to promote sustainable land management practices and increase carbon sequestration.
- Balance forest conservation with land affordability
    - While conserving Forest Land allows for higher carbon sequestration, limiting land development may increase land prices, limiting the affordability of the area. Durham should keep this in mind when developing policies that limit development and plan accordingly, such as allowing for an increase in density.

Focus on Reducing Emissions from other Sources

Since land use emissions and removals can be put in context with other emission sources in the community, Durham can determine priority areas for reducing emissions. Below are a few suggestions:

- Focus on reducing transportation and built environment emissions
    - Transportation and the Built Environment accounted for 45.2% and 50.4% of all non-land use emissions, respectively, and 43.8% and 48.9%, respectively, when accounting for land use emissions. These sectors should be targeted first when Durham determines emission reduction priority areas.
- Incorporate Community Power Aggregation
    - Keene was the first community in NH to adopt a community power plan, which can increase local renewable energy for a community at a competitive price. Great strides have been taken by Durham's Energy Committee this summer to

incorporate Community Power Aggregation in Durham, and it is recommended to continue those efforts as well as explore other ways to further reduce emissions.

- Consumption-Based GHG Inventory
    - A household consumption-based GHG inventory looks at indirect emissions associated with producing each good or service purchased by households in Durham. While not required by the USCP, it is strongly encouraged, as it will help to illustrate the full, life-cycle impacts of activities and serve as an educational tool. By making emissions visible, residents of Durham can make informed decisions on their consumption habits.

<u>Increase Resiliency of Town's Sustainability Efforts</u>

Part of Durham's commitment to GCoM includes participating in ongoing sustainability efforts. After submittal of these GHG inventories, Durham is expected to create emission reduction targets, a climate risk and vulnerability assessment and associated goals in reducing risk, an energy access assessment, and a Climate Action Plan that addresses mitigation, adaptation, and energy access. Durham is then required to report new inventories, assessments, and progress towards initiatives every two years after the submittal of the Climate Action Plan. Below are a few suggestions for making Durham's sustainability efforts more robust:

- Secure funding sources for sustainability efforts and oversight
    - As many of these efforts are outside traditional municipal work, Durham should explore available funding sources to support their efforts. One way to fund ongoing sustainability work is through the reallocation of savings from other sustainability efforts. For example, revenue from electric vehicle charging stations could be used to maintain existing stations, increase the number of stations, or be reallocated to something else, such as installing bike racks. Another way to fund sustainability work is through state and federal grants. These, however, often change due to the agenda of political leaders and may only cover very narrow types of projects. Therefore, Durham should continually search for new outside funding opportunities.
    - In addition to funding particular efforts, Durham should explore opportunities for funding a full-time position. Some grants allow the allocation of funds to cover part or all of a staff member's pay. Another option is to fund the position through cost savings occurring due to sustainability efforts.
- Ensure adequate staffing to continue GCoM and future commitments
    - Currently, Durham is relying heavily on UNH Sustainability Fellows. While fellows have made large strides in Durham's sustainability efforts, turnover of fellows due to the nature of the fellowship term length requires regular training and slows the speed of efforts. With the increase of sustainability initiatives and commitments, a constant, designated staff member could help facilitate meeting deliverables and expanding upon current efforts.

Conclusion

Nature-based solutions can play an important role in mitigating climate change. In Durham, carbon sequestration from trees inside and outside forests equivalent to approximately 31.2% of the annual emissions from the community. This highlights the important role that trees can play in Durham's climate mitigation and adaptation plans, as they are the only source of carbon removals within the Community-Wide GHG Inventory; the remaining sectors only contribute to carbon emissions. However, these carbon removals should not be treated as direct offsets to other sectors because doing so underestimates the actual reductions communities need to make to meet reduction targets. In addition, it does not consider tree's role in the earth's natural carbon cycle that regulates climate and makes the planet habitable. Therefore, associating all carbon sequestration with offsetting anthropogenic emissions disregards this natural balance, and again underestimates Durham's emissions.

The future of trees in Durham relies heavily on choices made by their landowners. 75.5% of all land in Durham is owned by Other, 12.0% is owned by UNH, 7.4% is owned by the State, and 5.1% is owned by the Town. Land use management can have negative or positive impacts on the carbon emissions and removals occurring in Durham. Thus, a seemingly small change of land use can result in a large amount of emissions if it changes from a large carbon sink to a carbon emitter. Durham should focus their efforts on those with the highest emissions or removals as well as those with the highest levels of ownership to ensure the benefits of trees in Durham can be realized both now and in the future.

Durham can build on efforts from this report through promoting forest and tree conservation, determining best forest management scenarios and improving land resilience to climate change, leveraging community involvement to promote social equity, targeting Durham's highest emitting sources in their emission reduction plans, and increasing the resiliency of the Town's current and future efforts through ensuring steady funding sources and adequate staffing.

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Appendices

Appendix A – Methodology: Calculating Land Use GHG Emissions and Removals
Appendix B – USCP Required GHG Inventory Summary Tables

Appendix A

Methodology: Calculating Land Use GHG Emissions and Removals

Emissions and removals from forest land and trees were calculated using the methods outlined in Appendix J: Forest Land and Trees of the US Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions as well as using the online ICLEI LEARN Tool.

Prior to calculating GHG emissions and removals from land use within the land use GHG inventory, a few decisions must be made. These decisions, as well as the steps for estimating GHG emissions and removals for Forest Land and Trees Outside Forests, are outlined below. Durham's decisions within each step are then listed under each decision and step later in this appendix.

Decision 1: Defining the Inventory Analysis Period
Decision 2: Delineating the Land Base
Decision 3: Land Use Classification

Calculating GHG Emissions and Removals from Land Use
Step 1: Consider the need for further stratification.
Step 2: Determine areas of forest-related land use and change over the inventory analysis period (activity data, disaggregated by strata and substrata as appropriate); Estimate tree cover outside forests/urban canopy (activity data)
Step 3: Determine the appropriate emission and removal factors for Forest Land use and change categories (disaggregated by strata and substrata as appropriate); Calculate emission and removal factors for trees outside forests
Step 4: Calculate carbon stock changes from Forest Land and forest-related land use transitions; Calculate the carbon stock change from trees outside forests
Step 5: Calculate non-CO_2 emissions from Forest Land and trees outside forests if appropriate and convert into units of CO_2e
Step 6: Determine whether to include harvested wood products in the inventory; calculate carbon stock changes in the harvested wood product pool if appropriate
Step 7: Estimate total net GHG flux from forests and trees outside forests over the inventory analysis period, and annualize the result into units of tCO_2e/yr

Decision 1: Defining the Inventory Analysis Period
The inventory analysis period must collect information from at least two points in time to compare land use change. USCP recommends the inventory period be 5-10 years to account for interannual variabilities of disturbances and weather. The ICLEI LEARN Tool contained data for the years 2001, 2004, 2006, 2008, 2011, 2013, 2016 for Forest Land, and 2011 and 2016 for Trees Outside Forests.

Forest Land: Durham chose its inventory analysis period as 2006 to 2016. This period was chosen because data for those years were available, it was long enough to account for variabilities, and its start year was close to 2007; the year a UNH student conducted a GHG inventory of sectors covered in the 2021 Community-Wide GHG Inventory.

Trees Outside Forests: Durham chose its inventory analysis period as 2011 to 2016. This period was chosen because they were the only years in which data were available, and it was long enough to account for variabilities per USCP guidance.

Decision 2: Delineating the Land Base
A community must decide which land area to estimate land-related GHG emissions and removals before estimating them. USCP recommends that communities consider all land within their jurisdictional boundaries as "managed land", i.e., land on which human interventions and practices have been applied to perform production, ecological, or social functions. For reporting GHGs, the federal government classifies all land in the US, apart from some in Alaska, as managed.

Durham considered all land within its Town boundary as "managed" and thus included all land within its Town boundary in its land use GHG calculations.

Decision 3: Land Use Classification
USCP recommends categorizing community lands into six land use classes: Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Lands. Land should be designated under only one land use class. If any land area falls under more than one land use class, lands are assigned by the following hierarchy of priority:
Settlements > Cropland > Forest land > Grassland > Wetlands > Other Land

Durham chose to follow USCP recommendations and categorize its lands within the Town boundary into the six land use classes based on the given hierarchy. This categorization was done through the use of the ICLEI LEARN Tool.

Calculating GHG Emissions and Removals from Land Use

Both GHG emissions and removals can occur from land use change and are calculated separately. The net GHG flux is the summation of the GHG emissions and removals from all land within Durham from 2006 until 2016. Below is the basic formula used to calculate the net GHG flux. Each land use change has its own formula to calculate emissions or removals, included in later steps.

$$Net\ GHG\ Flux = GHG\ emissions + GHG\ removals$$

$$GHG\ emissions = \sum_{land} AD \times EF$$

$$GHG\ removals = \sum_{land} AD \times RF$$

Where:
AD = activity data (land area (hectares) over which an activity had occurred)
EF = emission factors (annual change in CO_2e per area)
RF = removal factors (annual change in CO_2e per area)

Step 1: Consider the need for further stratification.

Durham disaggregated the total area of land included in the inventory into smaller units by dividing the land into four ownership categories: UNH-owned, Town-owned, State-owned, and Other-owned. The Other-owned land was further divided into two subcategories: conserved and non-conserved land. Each of these land divisions were intended to provide Durham information about how much land was under their authority and how future policies could impact land outside of their authority.

Step 2: Determine areas of forest-related land use and change over the inventory analysis period (activity data, disaggregated by strata and substrata as appropriate); Estimate tree cover outside forests/urban canopy (activity data)

As mentioned previously, Durham categorized its lands into the six land use classes. Durham utilized a 6x6 land use conversion matrix for reporting, as shown below.[8]

	Forest Land	Cropland	Grassland	Wetlands	Settlements	Other
Forest Land	Forest Land remaining Forest Land	Forest Land converted to Cropland	Forest Land converted to Grassland	Forest Land converted to Wetlands	Forest Land converted to Settlements	Forest Land converted to Other Land
Cropland	Cropland converted to Forest Land	Cropland remaining Cropland	Cropland converted to Grassland	Cropland converted to Wetlands	Cropland converted to Settlements	Cropland converted to Other Land
Grassland	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland remaining Grassland	Grassland converted to Wetlands	Grassland converted to Settlements	Grassland converted to Other Land
Wetlands	Wetlands converted to Forest Land	Wetlands converted to Cropland	Wetlands converted to Grassland	Wetlands remaining Wetlands	Wetlands converted to Settlements	Wetlands converted to Other Land
Settlements	Settlements converted to Forest Land	Settlements converted to Cropland	Settlements converted to Grassland	Settlements converted to Wetlands	Settlements remaining Settlements	Settlements converted to Other Land
Other	Other Land converted to Forest Land	Other Land converted to Cropland	Other Land converted to Grassland	Other Land converted to Wetlands	Other Land converted to Settlements	Other Land remaining Other Land

ICLEI's online LEARN Tool was used to determine land use change data over the inventory period. Land use change data was pulled from the National Land Cover Database (NLCD), produced by the United States Geological Survey, and had a spatial resolution of 30m. This data source was consistent with Durham's needs for land use classes accepted by USCP as well as periodic updates for future inventories.

For Trees Outside Forests, tree canopy maintenance/gain and tree canopy were estimated based on tree crown/canopy cover data from NLCD, produced by the United States Forest Service, and had a spatial resolution of 30m. This data source was consistent with Durham's need for gross, rather than net, tree canopy loss as well as periodic updates for future inventories.

This land use conversion matrix area estimates can later be combined with appropriate emission/removal factors (as outlined in the next steps) to calculate the GHG flux from each land use class change. The results of land cover change within Durham's Town boundary from 2006 to 2016 are included below. The "Total" in blue denotes the total acreage of each land use class in 2016, while the "Total" in green is the total acreage of each land use class in 2006.

	Forest Land	**Cropland**	**Grassland**	**Wetlands**	**Settlements**	**Other Land**	**Total**
Forest Land	3,782	0	36	9	21	0	**3,848**
Cropland	0	28	0	0	0	0	**28**
Grassland	16	0	563	2	7	0	**587**
Wetlands	32	0	2	747	0.6	0.3	**782**
Settlements	0	0	0	0	1,165	0	**1,165**
Other Land	0	0	0	0	0.1	7	**7**
Total	**3,830**	**28**	**600**	**758**	**1,193**	**7**	

Step 3: Determine the appropriate emission and removal factors for Forest Land use and change categories (disaggregated by strata and substrata as appropriate); Calculate emission and removal factors for trees outside forests

The ICLEI LEARN Tool has built-in emissions and removal factors for 9 classifications of forests and trees outside forests for each of the 11 geographic regions of the contiguous United States. Durham falls within the Northeast geographic region of the United States. The list of 9 classifications is below. More information on deriving emission and removal factors can be found within ICLEI LEARN Tool's methods.

Removal Factors (t C/ha)

1) Undisturbed forest remaining forest (by forest type and age class)
    - Removal factors include all ecosystem carbon pools (live above and below-ground biomass, dead wood, forest floor, and soil carbon)
2) Non-forest converted to forest (by forest type and 0-20 age class only)
    - Same removal factor is assigned to all Non-Forest → Forest regardless of land use class
3) Trees outside forests (one value per state)
    - NH-specific data pulled from the annual EPA GHG inventory

Emission factors (t C/ha):

4) Forest converted to non-forest (by forest type and carbon pool)
    - Varies based on type of land use class change; carbon pools include biomass, dead organic matter, and organic soil carbon
5) Loss of trees outside forests (by state and city)
    - Durham used emission factors derived from the city that most closely represents the geographic location and tree canopy (Boston, MA)

6-9) Forest Disturbances from Fire, Insects, Weather, or Harvest (by forest type and age class)

- Harvests/other disturbances are any remaining forests that show tree cover loss that do not overlap with fire or insect/disease damage

The following table lists the emission and removal factors used in calculations for Durham.

Change	Emission Factor (tC/ha)	Removal Factor (tC/ha/year)
Forest Land to Grassland	40.21	--
Forest Land to Settlement	70.80	--
Forest Land to Wetland	62.98	--
Non-Forest Land to Forest Land	--	-2.21
Undisturbed Forest	--	-1.62
Disturbed Forest: Insect/Disease	3.87	--
Disturbed Forest: Harvest/Other	71.26	--
Tree Canopy Loss	70.21	--
Tree Canopy Maintained/Gained	--	-2.38

Note that emission factors are not included for Forest Land to Cropland, Forest Land to Other Land, or Disturbed Forest: Fire because there was a net area change of 0 ha for each category in Durham over the inventory period (2006-2016).

Step 4: Calculate carbon stock changes from Forest Land and forest-related land use transitions; Calculate the carbon stock change from trees outside forests

Carbon stock changes (CO_2 emissions and removals) were calculated for Forest Land remaining Forest Land, Forest Land converted to Non-Forest Land, Non-Forest Land converted to Forest Land, and Tree Canopy Maintain/Gain and Loss for Trees Outside Forests.

Calculating Forest Land Remaining Forest Land Carbon Stock Change (Eq. 2 from USCP App J)

$$\Delta C_{FRF} = \Delta C_{undisturbed} + \Delta C_{disturbed}$$

$$\Delta C_{undisturbed} = \sum_{i=1}^{n} (AD_i \times RF_i \times T)$$

$$\Delta C_{disturbed} = \sum_{i=1}^{n} \sum_{j=1}^{J} (AD_{ij} \times EF_{ij})$$

Where:
ΔC_{FRF} = change in carbon stocks in Forest Land Remaining Forest Land over the inventory period (tC)
$\Delta C_{undisturbed}$ = change in carbon stocks in undisturbed Forest Land Remaining Forest Land over the inventory period (tC)
$\Delta C_{disturbed}$ = change in carbon stocks in disturbed Forest Land Remaining Forest Land over the inventory period (tC)
AD_{ij} = area of Forest Land in stratum *i* (of disturbance type *j*, if applicable) (hectares)
i = 1, 2, 3, …, *n* forest strata
j = 1, 2, 3, … , *J* disturbance types
T= number of years in inventory analysis period
EF_{ij} = emission factor for each disturbance type *j* in stratum *i* (tC/hectare)
RF_i = removal factor for each stratum *i* (tC/hectare/year) (average annual removal factor)

Calculating Forest Land Converted to Non-Forest Land Carbon Stock Change (Eq. 3 from USCP App J)

$$\Delta C_{F \rightarrow NF} = \sum_{i=1}^{n} \sum_{k=1}^{K} AD_{ik} \times EF_{ik}$$

Where:
$\Delta C_{F \rightarrow NF}$ = change in carbon stocks in Forest Land Converted to Non-Forest Land over the inventory period (tC)
AD_{ik}= area of forest stratum *i* converted to non-forest category *k* (hectares)
EF_{ik}= emission factor for each forest stratum *i* converted to non-forest category *k* (tC/hectare)
i = 1, 2, 3…*n* forest strata
k = 1, 2, 3…*K* non-Forest Land categories (i.e., Cropland, Settlement, Grassland, Wetland, Other Land).

Calculating Non-Forest Land Converted to Forest Land Carbon Stock Change (Eq. 4 from USCP App J)

$$\Delta C_{NF \rightarrow F} = \sum_{i=1}^{n} \sum_{k=1}^{K} AD_{ki} \times RF_{ki} \times T$$

Where:
$\Delta C_{NF \rightarrow F}$ = change in carbon stocks in non-Forest Land converted to Forest Land over the inventory period (tC)
i = 1, 2, 3…*n* forest strata
k = 1, 2, 3…*K* non-Forest Land categories
AD_{ki} = area of non-forest category *k* converted to forest strata *i* (hectares)
RF_{ki} = removal factor for each non-forest category k to forest category *i* (tC/hectare/year) (annual average removal factor over inventory analysis period)
T= inventory period; years

Tree Canopy Maintain/Gain and Loss for Trees Outside Forests (Eq. 6 from USCP App J)

$$\Delta C_{TOF} = \Delta C_{trees} + \Delta C_{treeloss}$$

$$\Delta C_{trees} = \sum_{k=1}^{K} AD_{trees\_k} \times RF_k \times T$$

$$\Delta C_{tree_{loss}} = \sum_{k=1}^{K} AD_{treeloss\_k} \times EF_k$$

Where:
ΔC_{TOF} = net GHG flux from trees outside of forests over inventory analysis period T (reflects the net balance of emissions and removals) (tCO2e)
AD_{trees_k} = average area of land with tree canopy cover over the inventory analysis period (hectares)
$AD_{treeloss\_k}$ = area of tree cover loss over the inventory analysis period (hectares)
RF_k = average removal factor (sequestration rate) of trees in non-forest category *k* (tC/hectare/year)
EF_k = average emission factor from loss of trees in non-forest category *k* (tC/hectare)
k = 1,2,3, …, K non-forest strata
T= number of years in the inventory period.

Step 5: Calculate non-CO_2 emissions from Forest Land and trees outside forests if appropriate and convert into units of CO_2e.

The main sources of non-CO_2 emissions from Forest Land and Trees Outside Forests occur from biomass burning (CH_4 and N_2O), soil emissions (N_2O), and forested wetland emissions (CH_4). These types of emissions were assumed to be small to nonexistent in Durham, and thus non-CO_2 emissions were not included in this Land Use GHG Inventory.

Step 6: Determine whether to include harvested wood products in the inventory; calculate carbon stock changes in the harvested wood product pool if appropriate.

Harvested wood products can be calculated to determine emissions and removals as the wood goes through a series of production processes and end-uses with eventual disposal. In Durham, harvested wood products were assumed to be 0.

Step 7: Estimate total net GHG flux from forests and trees outside forests over the inventory analysis period, and annualize the result into units of tCO_2e/yr.

This calculation estimates the average annual net GHG flux from forests and trees outside forests over the inventory period. In Durham's case, this calculated the average annual net GHG flux from 2006 to 2016. This net GHG flux is a summation of the emissions and removals occurring from land use changes.

Calculating Net GHG Flux for Forest Land (Eq. 5 from USCP App J)

$$Net\ GHG\ Flux = \frac{\left[\left(\frac{44}{12}\right)\times(\Delta C_{FRF}+\Delta C_{F\rightarrow NF}+\Delta C_{NF\rightarrow F}+\Delta C_{HWP})\right]+GHG_{nonCO2}}{T}$$

Where:
Net GHG Flux = net GHG flux from forests over inventory analysis period T (tCO_2e/year) (reflects the net balance of emissions and removals)
ΔC_{FRF} = change in carbon stocks in Forest Land Remaining Forest Land over the inventory period (tC)
$\Delta C_{F\rightarrow NF}$ = change in carbon stocks in Forest Land Converted to Non-Forest Land over the inventory period (tC)
$\Delta C_{NF\rightarrow F}$ = change in carbon stocks in Non-Forest Land Converted to Forest Land over the inventory period (tC)
ΔC_{HWP} = carbon additions to and losses from the stock of harvested wood products over the inventory period (tC) – NOTE: Durham assumed this was 0
GHG_{nonCO2} = CH_4 and N_2O emissions from biomass burning during prescribed fires or wildfires and soil N_2O emissions with mineral fertilization and organic amendments on Forest Land (tCO_2e) – NOTE: Durham assumed this was 0
T = total number of years of the inventory analysis period
44/12 = conversion factor to convert units of carbon to CO_2.

Calculating Net GHG Flux for Trees Outside Forests (Eq. 7 from USCP App J)

$$Net\ GHG\ Flux = \frac{\left[\left(\frac{44}{12}\right)\times(\Delta C_{trees}+\Delta C_{treeloss})\right]+GHG_{nonCO2}}{T}$$

Where:
Net GHG flux = net GHG flux from trees outside forests over inventory analysis period T (tCO_2e/year)
T = total number of years of the inventory analysis period
44/12 = conversion factor to convert units of carbon to CO_2

Appendix B

USCP Required GHG Inventory Summary Tables

Per USCP requirements, a summary table of the emission sources and activities included and excluded in this land use GHG inventory is provided below.

Notation Keys for Excluded Emission Sources and Activities

- **IE – Included Elsewhere**: Emissions for this activity are estimated and presented in another category of the inventory. The category where these emissions are included should be noted in explanation.
- **NE – Not Estimated**: Emissions occur but have not been estimated or reported (e.g., data unavailable, effort required not justifiable).
- **NA – Not Applicable**: The activity occurs but does not cause emissions; explanation should be provided.
- **NO – Not Occurring**: The source or activity does not occur or exist within the community.

Legend for Reporting Frameworks Used

Required Activities:

- Five Basic Emissions Generating Activities

Strongly Encouraged:

- **SI** – Local Government Significant Influence
- **CA** – Community-Wide Activities
- **HC** – Household Consumption

Also Encouraged:

- **IB** – In-Boundary Sources
- **GC** – Government Consumption
- **FC** – Full Consumption-based Inventory
- **LB** – Life Cycle Emissions of Community Businesses
- **IS** – Individual Industry Sectors
- **OS** – Create Your Own Story

Emissions Type	Source or Activity?	Included, Required Activities	Included, Under Reporting Frameworks		Excluded	Explanatory Notes (optional)	Emissions (tCO_2e)
			SI	CA			
Forests and Trees Outside of Forests							
Emissions and Removals from Forest Land	Source		✓				-20,082 (Net GHG Balance)
Emissions and Removals from Trees Outside of Forests	Source		✓				-5388 (Net GHG Balance)

Below is a summary table providing GHG emissions/removals and emission/removal factors used for this land use GHG inventory. This inventory uses the approach and methods provided by the US Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions Appendix J: Forest Land and Trees. ICLEI's online LEARN tool utilized these methods to calculate emissions and removals related to land use. Additional information on calculating these numbers is provided in Appendix A of this report.

Source	GHG Flux (tCO_2e/yr)	Emission Factor (tC/ha)	Removal Factor (tC/ha/year)
Forests (Undisturbed)	-22142	--	-1.62
Reforestation (Non-Forest to Forest)	-388	--	-2.21
Trees Outside Forests (Maintained)	-5631	--	-2.38
Forest to Cropland	--	--	--
Forest to Grassland	526	40.21	--
Forest to Settlement	552	70.80	--
Forest to Wetland	210	62.98	--
Forest to Other Land	--	--	--
Trees Outside Forests (Canopy Loss)	243	70.21	--
Forest Disturbances: Fire	--	--	--
Forest Disturbances: Insect/Disease	4	3.87	--
Forest Disturbances: Harvest/Other	1156	71.26	--

Note that information for Forest to Cropland, Forest to Other Land, and Forest Disturbances: Fire are not included in the above table because each had a net land use change of 0 over the inventory period (2006-2016).