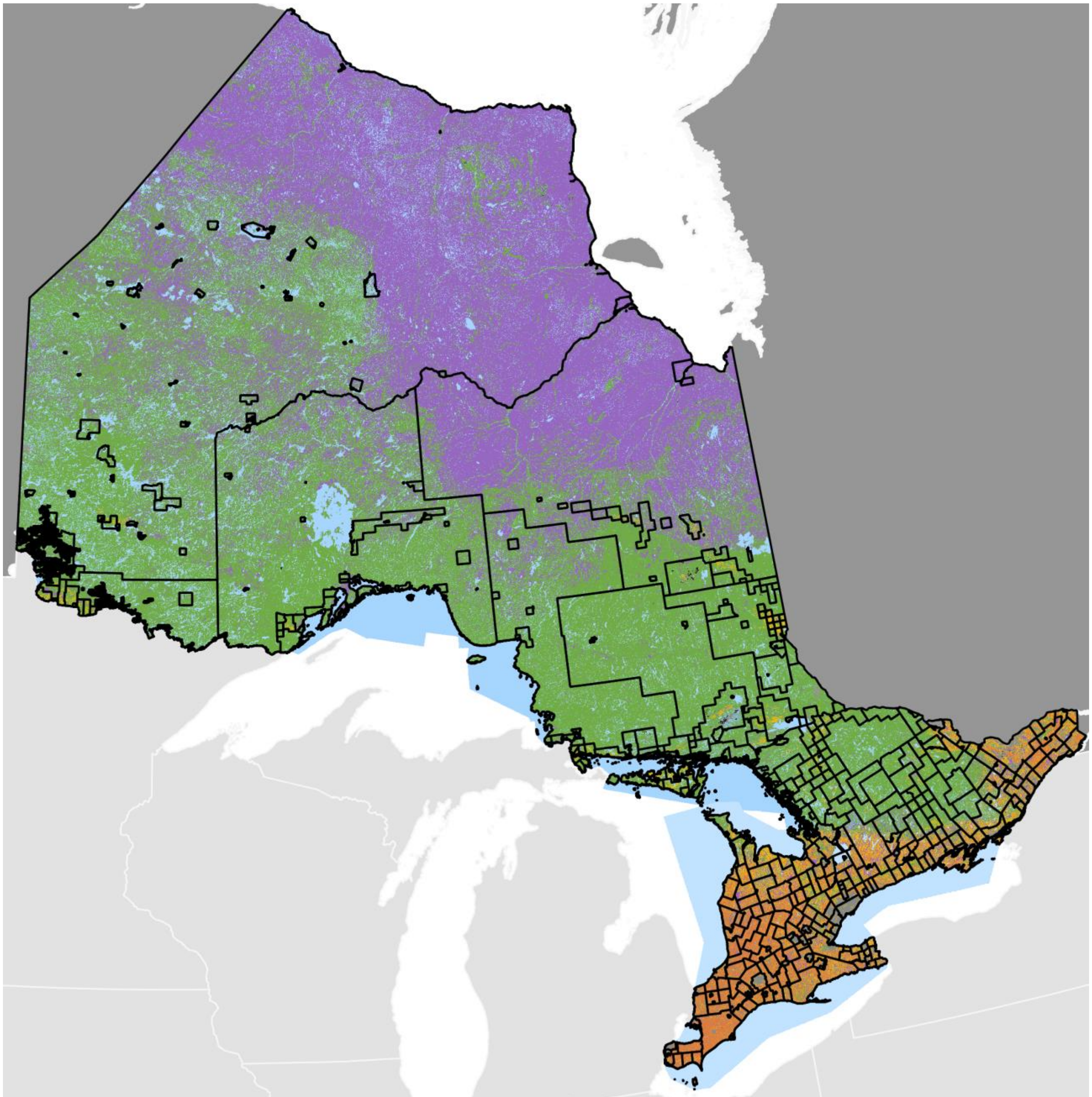

Methodological Handbook: Deriving Ecological Footprint and Biocapacity for Ontario Communities

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For the Rural Ontario Institute.

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Ecological Footprint Initiative
Accounting for sustainability

ROI RURAL ONTARIO INSTITUTE
Vision, Voice and Leadership

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Introduction

Ontario is home to an abundance of ecosystems, species, people, and communities. Different lifestyles and lived experiences flourish because of the considerable size and vast landscapes across the province. Nevertheless, people in Ontario and around the world are experiencing changes in the environment. These changes are because of dependence, over-extraction, and pollution of the Earth's natural resources. If humanity uses the Earth's natural resources within the planet's regenerative capacity and emits an amount of pollution that can be absorbed, then the dependence on the Earth's resources has an improved chance of being sustainable. Ecological Footprint and Biocapacity provide an accounting framework to quantify this dependence and regenerative capacity.

Ecological Footprint measures the area necessary to supply human production and consumption of forest products, lands for infrastructure and settlements, food and other fibres, and the sequestration of anthropogenic carbon emissions. This is compared to Biocapacity, which measures the capacity of lands and waters to sustain Ecological Footprint. These statistics are measured in a single spatial unit, global hectares. Using a single unit allows for comparability between Ecological Footprint and Biocapacity and between times and spaces. Global hectares are also highly scalable. There are examples of this metric used at the global, national, regional, and individual levels. Each year the Ecological Footprint Initiative at York University produces national and global Ecological Footprint and Biocapacity accounts. These open-access data accounts inform people about the state of sustainability around the world.

This project began by piloting Ecological Footprint and Biocapacity accounts for a small number of census subdivisions in Ontario. Once the proof-of-concept design was complete, more accounts were made for the rest of the census subdivisions in Ontario. As the project evolved, automation processes were created to refine the procedures and allow the accounts to be easily replicated. The data is publicly available on the Rural Ontario Institute's Community Wellbeing Dashboard.

These municipal-level accounts are open access, allowing anyone to view and download the data. Having public data is important so it can be used by municipal stakeholders, policymakers, and citizens to inform decision-making in their communities. Ecological Footprint and Biocapacity data is beneficial for municipal decision-makers to understand environmental issues beyond carbon emissions (Kissinger et al., 2013, 1969). Additionally, changes at the institutional level can also help to facilitate individual long-term change (Isman et al., 2018, 1042).

The research was completed in partnership between the Rural Ontario Institute and the Ecological Footprint Initiative. The partnership is part of the International Ecological Footprint Learning Lab, a multi-year global partnership funded by the Social Sciences and Humanities Research Council. This research is part of a larger program at the Rural Ontario Institute, called the Rural Community Wellbeing Project. The main goal of this project is to assist communities in Ontario in evaluating and understanding their well-being individually and collectively by providing access to census subdivision-level data.

Methodology

Overview and Data

This research applies the standards and methodologies for calculating Ecological Footprint and Biocapacity as done in previous accounting and research. Including, the methodologies used to derive the National Ecological Footprint and Biocapacity Accounts (Global Footprint Network, 2009). Additionally, incorporating innovations from Borucke et al. (2013), Lin et al. (2018), Lin et al. (2021), and Miller et al. (2021). This research employs a top-down methodology by downscaling the Ontario Ecological Footprint and Biocapacity Accounts (Ontario EFB Report) (Miller et al., 2021). Downscaling the Ontario EFB Report, required developing scaling metrics using Statistics Canada 2021 census data at the level of the census sub-division.

Several datasets from two data sources were used in this research: Statistics Canada and Ontario GeoHub. See Table 1 for the specific datasets and applications to the data. The Statistics Canada data is primarily demographic and economic data from the 2021 Census that was used to create scaling factors and ratios. Additionally, one vector boundary file from Statistics Canada was used to generate the Biocapacity accounts. The data sets from Ontario GeoHub included one vector data set and two raster data sets. The vector dataset is a boundary file differentiating the three Ecozones in Ontario: Mixed Wood Plains, Ontario Shield, and Hudson-Bay Lowlands. The raster data sets display land cover across Ontario from the Southern Ontario Land Resource Information System (SOLRIS) and the Ontario Land Cover Compilation (OLCC). Both of these raster datasets maintain a spatial resolution of 15 metres by 15 metres. The datasets were interpreted in their raster form and kept at that resolution. The datasets were used independently to report the proportions of various land classifications.

Table 1: Data sources used in this project to downscale the Ontario Ecological Footprint and Biocapacity to the CSD level

Data Sets:	**Source:**	**Applied to Ecological Footprint or Biocapacity**
Southern Ontario Land Resource Information System (SOLRIS) Version 3.0	Ontario GeoHub	Biocapacity
Ontario Land Cover Compilation (OLCC) Version 2.0	Ontario GeoHub	Biocapacity
Ecozone	Ontario GeoHub	Biocapacity
2021 Census Boundary files	Statistics Canada	Biocapacity
2021 Census Profile data	Statistics Canada	Ecological Footprint
Canadian Housing Statistics Program 2019	Statistics Canada	Ecological Footprint
Households and the Environment: Energy Use 2011	Statistics Canada	Ecological Footprint

Scale and Geographies

Ecological Footprint and Biocapacity accounts were created for all 577 census subdivisions (CSDs) in Ontario. The term census subdivision (CSD) describes municipalities, communities, or areas that are treated as municipal equivalents (Statistics Canada, 2021).

Ontario is split into three Ecozones: Mixed wood Plains, Ontario Shield, and Hudson Bay Lowlands. First, the Ecozone that each CSD is located in was determined to derive the appropriate relative Net Primary Production (rNPP) for the forests and wetlands. The methodology for calculating rNPP of different ecosystems is derived from the Ontario EFB Report. Combining the Ontario CSD boundary layer (Figure 1) and the Ecozone boundary layer (Figure 2), resulted in an 'Ecozone-CSD' boundary layer (Figure 3). The Ecozone-CSD boundary layer was used to mask the raster data during the geospatial data processing. In cases where a CSD intersected with an Ecozone boundary, then that CSD was divided.

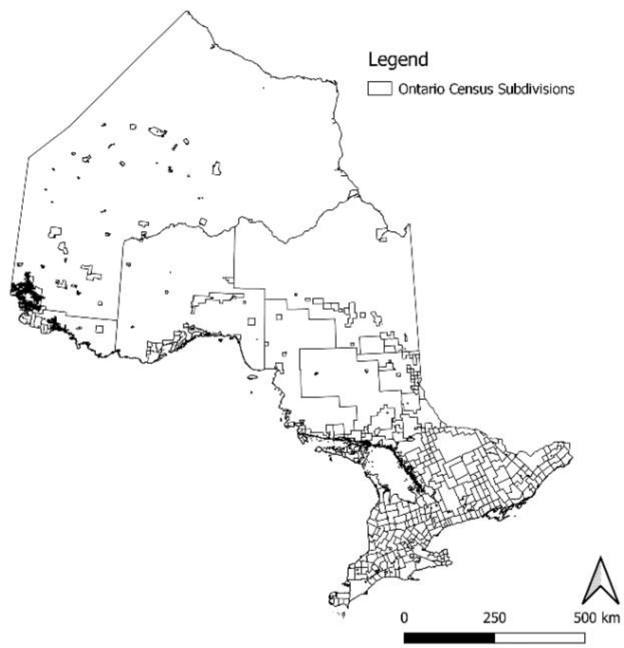

Figure 1: Ontario Census Subdivisions, vector data layer

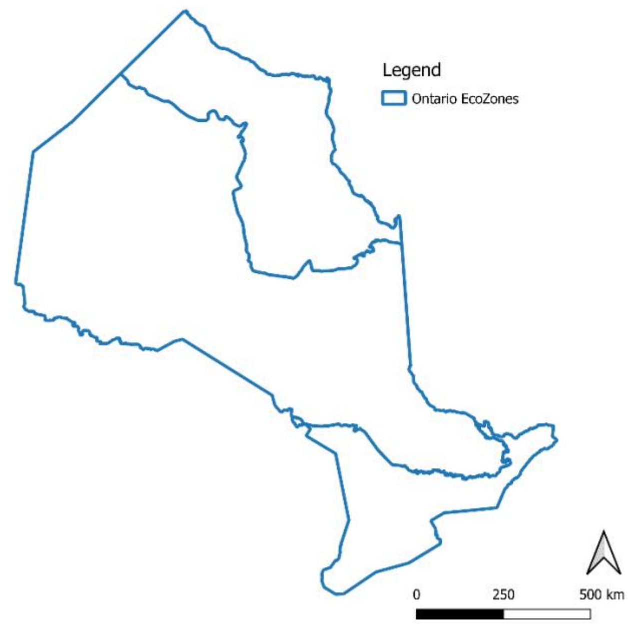

Figure 2: Ontario Ecozones, vector data layer

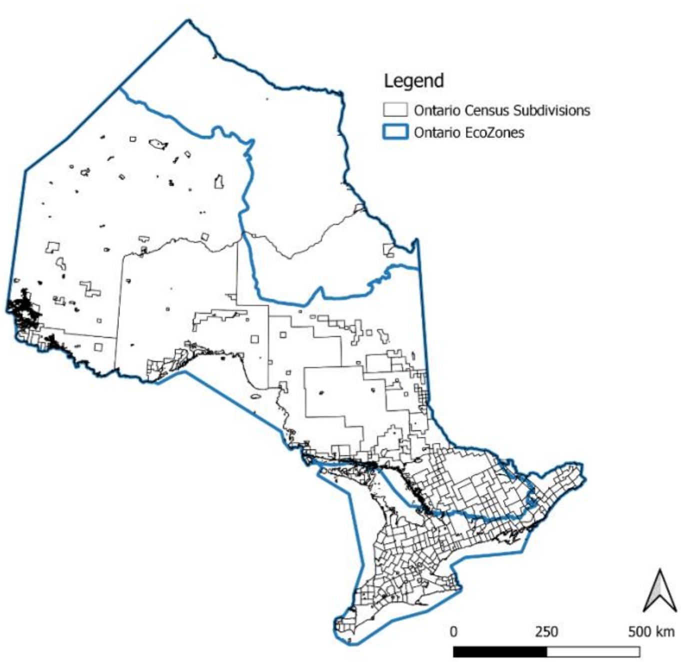

Figure 3: Ontario Ecozones & Ontario Census Subdivisions (Eco-CSDs), two vector data layers.

There were instances where the Eco-CSD area was overlapped by both the OLCC and SOLRIS raster datasets. In these instances, the data source that provided the greatest coverage of the Eco-CSD was used. If both raster datasets provided the same coverage, then SOLRIS was used since it is the most updated dataset.

Top-Down Methodology

The calculations for these accounts used several parameters from the Ontario EFB Report, particularly for calculating Biocapacity. An exceptional methodological innovation was made in the Ontario EFB Report to include wetlands as a Biocapacity component. This methodological innovation was maintained for these CSD-level accounts, such that "the carbon uptake of a hectare of Ontario wetland was converted to an equivalent of carbon uptake from a hectare of Ontario forest." (Miller et al., 2021, 43). Additionally, the Ontario EFB Report established the relative Net Primary Production (rNPP) of biomass of Ontario's forests for each Ecozone in Ontario (Miller et al., 2021, 45). This parameter was used in these CSD-level accounts, without any modifications. See Appendix 2, Figure 8 and Table 21 for the metrics used to calculate the Biocapacity parameters from the Ontario EFB Report.

To calculate the Ecological Footprint of Consumption for these CSD-level accounts, the 2015 Ontario Consumption Land-Use Matrix (CLUM) was downscaled by applying scaling factors and ratios. For a detailed list of the data points, scaling metrics, and applications to the CLUM, see Appendix 1, Tables 7 and 8. Additionally, there is detailed information and equations about how each scaling factor and ratio was developed, in Appendix 1.

Spatial Processing and Automation in QGIS

Table 2: QGIS Extraction Processing providers & Algorithm versions

QGIS version: 3.10.6-A Coruña	GDAL version: 3.0.4
QGIS code revision: ec80021f49	GEOS version: 3.8.1-CAPI-1.13.3
Qt version: 5.11.2	PROJ version: Rel. 6.3.2, May 1st, 2020

QGIS 3.10.6 software was used to process all geographical data files for this research. The raster datasets, SOLRIS and OLCC, were processed separately using reclassed pixel values, to ensure cohesiveness when the dataset's results were presented in the same data collection. See Table 3, for a breakdown of the land classifications and reclassed pixels. The first processing step used the GDAL "Clip Raster by Mask Layer" function, clipping the original raster files to extract raster mask layers for each Eco-CSD. Figure 4 presents the console commands that were used to automate the process of extracting the raster mask layers. This function generates individual raster files for each Eco-CSD. There are some instances where the Eco-CSDs clipped raster files of Eco-CSDs retain higher pixel counts than the Eco-CSD vector boundary. This is a result of the GDAL algorithm rounding up when pixels are selected along the vector boundary. The highest raster input for an Eco-CSD is 100.95% of the original land area.

The second processing step used the QGIS operation 'raster layer unique values report' to batch generate the raster datasets. This operation returns the area (square metres) for each land cover type within each of the raster mask layer Eco-CSDs. Then, using R programming language, the batch-generated table reports were compiled from both datasets. Any supplementary data about the records and report values were attached to filter the records and perform the Biocapacity calculations.

Table 3: SOLRIS and OLCC Land Classifications and Reclassed Pixel Values.

Source	Initial Pixel	Reclassed Pixel	Land Classification Name	Source	Initial Pixel	Reclassed Pixel	Land Classification Name
SOLRIS	11	111	Open Beach/Bar	OLCC	-99	157	(Other)
SOLRIS	21	121	Open Sand Dune	OLCC	-9	247	(Cloud/Shadow)
SOLRIS	23	123	Treed Sand Dune	OLCC	1	1	Clear open water
SOLRIS	41	41	Open Cliff and Talus	OLCC	2	2	Turbid water
SOLRIS	43	43	Treed Cliff and Talus	OLCC	3	3	Shoreline
SOLRIS	51	51	Open Alvar	OLCC	4	4	Mudflats
SOLRIS	52	52	Shrub Alvar	OLCC	5	5	Marsh
SOLRIS	53	53	Treed Alvar	OLCC	6	6	Swamp
SOLRIS	64	64	Open Bedrock	OLCC	7	7	Fen
SOLRIS	65	65	Sparse Treed	OLCC	8	8	Bog
SOLRIS	81	81	Open Tallgrass Prairie	OLCC	10	10	Heath
SOLRIS	82	82	Tallgrass Savannah	OLCC	11	11	Sparse Treed
SOLRIS	83	83	Tallgrass Woodland	OLCC	12	12	Treed upland
SOLRIS	90	90	Forest	OLCC	13	13	Deciduous Treed
SOLRIS	91	91	Coniferous Forest	OLCC	14	14	Mixed Treed
SOLRIS	92	92	Mixed Forest	OLCC	15	15	Coniferous Treed
SOLRIS	93	93	Deciduous Forest	OLCC	16	16	Plantations – Treed Cultivated
SOLRIS	131	131	Treed Swamp	OLCC	17	17	Hedge Rows
SOLRIS	135	135	Thicket Swamp	OLCC	18	18	Disturbance
SOLRIS	140	140	Fen	OLCC	19	19	Cliff and Talus
SOLRIS	150	150	Bog	OLCC	20	20	Alvar
SOLRIS	160	160	Marsh	OLCC	21	21	Sand Barren and Dune
SOLRIS	170	170	Open Water	OLCC	22	22	Open Tallgrass Prairie
SOLRIS	191	191	Plantation – Tree Cultivated	OLCC	23	23	Tallgrass Savannah
SOLRIS	192	192	Hedge Row	OLCC	24	24	Tallgrass Woodland
SOLRIS	193	193	Tilled	OLCC	25	25	Sand/Gravel/Mine Tailings/Extraction
SOLRIS	201	201	Transportation	OLCC	26	26	Bedrock
SOLRIS	202	202	Built Up Area – Pervious	OLCC	27	27	CSD/Infrastructure
SOLRIS	203	203	Built Up Area – Impervious	OLCC	28	28	Agriculture and Undifferentiated Rural Land Use
SOLRIS	204	204	Extraction – Aggregate				
SOLRIS	205	205	Extraction – Peat/Topsoil				
SOLRIS	250	250	Undifferentiated				

Input parameter:

{ 'ALPHA_BAND' : False, 'CROP_TO_CUTLINE' : True, 'DATA_TYPE' : 0, 'EXTRA' : '', 'INPUT' : 'Reclassified_Raster.tif', 'KEEP_RESOLUTION' : False, 'MASK' : 'Ecozone-CSD.shp', 'MULTITHREADING' : False, 'NODATA' : None, 'OPTIONS' : '', 'OUTPUT' : 'Raster_batchmasks.tif', 'SET_RESOLUTION' : False, 'SOURCE_CRS' : None, 'TARGET_CRS' : None, 'X_RESOLUTION' : None, 'Y_RESOLUTION' : None }

Executing iteration:

gdalwarp -of GTiff -cutline MASK.gpkg -cl MASK -crop_to_cutline Reclassified_Raster.tif Raster_batchmasks_.tif

Figure 4: Input parameter and executing iteration used in QGIS, GDAL 'Clip Raster by Mask Layer' to extract the raster mask layers.

Ecological Footprint of Consumption

The Ecological Footprint of Consumption is the area required to supply a given population's consumption patterns. There are six components aggregated together to create Ecological Footprint: cropland, grazing land, fishing grounds, built-up land, forest products, and forest carbon uptake (forest c-uptake) (E. Miller, et al., 2021, 5). See Table 4 for definitions of each component.

Instead of using the term 'carbon', 'forest carbon-uptake' is used to describe the area of forests that are necessary to sequester carbon emissions beyond what is sequestered from the world's oceans (E. Miller, et al., 2021, 5). This is the same methodology used in the national Ecological Footprint and Biocapacity accounts and the Ontario EFB Report. In the national accounts, there is no distinction made for whether the emissions come from coastal territories, instead ocean sequestration pertains to all anthropogenic emissions (E. Miller, et al., 2021, 5).

All Ecological Footprint components are measured in global hectares. A global hectare is a hectare that presents a global average amount of annual biological regeneration. This standardized unit allows for comparisons to be made with other Ecological Footprints and Biocapacity, including at other levels of aggregation, times, and spaces.

Table 4: Components of Ecological Footprint, which are all measured annually in global hectares (global hectares). Adapted from Source: Miller, E., et al. Ontario's Ecological Footprint and Biocapacity: Measures and trends from 2005 to 2015., 2021, 5).

Fishing Grounds	Area of marine and inland waters needed for human consumption of fish, invertebrates, aquatic mammals, and aquatic plants.
Built-Up Land	Area of land occupied by human-built infrastructure, including housing and other buildings, roads and paved areas, and urban greenspaces
Cropland	Area of land needed to grow crops consumed by humans as food and fibres, for crops consumed by pets, and for crops fed to animals and fish that are consumed by humans.
Grazing Land	Area of land needed to feed livestock consumed by humans, beyond the feed supplied by the cropland component.
Forest Products	Area of land needed for forest harvests to derive pulp and timber products.
Forest Carbon Uptake (Forest c-uptake)	Area of forests needed to sequester anthropogenic carbon emissions (beyond emissions sequestered by the world's oceans) from combustion of fuels and electricity generation, plus carbon emissions embodied in traded electricity and globally traded goods inclusive of their global transport emissions.

This report downscales the 2015 Ontario Consumption Land-Use Matrix (CLUM) to measure the Ecological Footprint of consumption for all CSDs in Ontario. The CLUM illustrates consumption spending for a given population in global hectares per capita. The CLUM determines the Ecological Footprint of consumption, distributed amongst the six components, by aggregating almost 200 consumption categories. There are three categories of consumption in the CLUM: household consumption, government consumption, and gross fixed capital formation consumption. Household consumption is spending on goods and services that support a private household. Government consumption refers to government spending on goods and services. Gross fixed capital formation refers to the development of durable infrastructure. Goods and services produced by companies are assumed to be consumed by the government, households, or in the process of forming gross fixed capital (Miller., et al., 2021, 9).

There are various scaling factors and ratios created to downscale the Ontario 2015 CLUM that were derived primarily from Statistics Canada 2021 census data. In some instances, other Statistics Canada research and data were used to support the creation of the scaling factors and ratios. For a list of the specific data tables, data points, and scaling metrics, see Appendix 1 Tables 7 and 8.

The three consumption categories of the CLUM (household, gross fixed capital, and government) were downscaled in accordance with the following methodology and available data. The government consumption category was assumed to be the same for every CSD in Ontario because in theory government consumption should be somewhat equal for each CSD. Although, this is likely not the reality, there is limited data to understand how certain communities are impacted differently by government consumption. The gross fixed capital formation consumption category was modified for all Ecological Footprint components: cropland, grazing land, fishing grounds, forest products, built-up land, and forest c-uptake.

The total household consumption category was modified for the following Ecological Footprint components: (1) cropland, (2) grazing land, (3) forest products, and (4) fishing grounds. The built-up land component was modified by downscaling the following subcategories of the household total: (1) food, (2) housing, (3) personal transportation, (4) goods, and (5) services. The forest c-uptake component of household consumption was modified by directly downscaling these more specific categories of consumption: (1) electricity, gas, and other fuels; (2) operation of personal transport equipment; (3) goods; and (4) services. The forest c-uptake component makes up the largest portion of the Ecological Footprint, thus any modifications will have a greater impact on the total Ecological Footprint. Additionally, there was data available from Statistics Canada that has a direct relationship to specific consumption categories within forest c-uptake, such as data on commuting patterns and durations. Research shows that transportation is the largest consumption category of the forest carbon-uptake component for municipalities in Canada, no matter the energy source (Isman et al., 2018). For these reasons, the adjustments to the forest c-uptake component were made with greater precision.

In total, 19 consumption categories were modified; Table 5 shows the 2015 Ontario CLUM including yellow highlighted cells to display which consumption categories were modified to produce the CSD-level Ecological Footprint. More information on the equations and theory behind the scaling factors can be found in Appendix 1. It is important to note that the Ecological Footprint for individuals has a wide variability, and variability per person cannot be estimated at this time because the necessary statistics are not yet available.

Table 5: Ontario 2015 Consumption Land Use Matrix (CLUM), highlighted cells show which consumption categories are modified to downscale the CLUM. Source: Miller, E., et al., 2021, 50.

2015 Ontario CLUM							
Category of consumption	**Cropland**	**Grazing land**	**Forest products**	**Fishing grounds**	**Built-up land**	**Forest carbon-uptake**	**Total**
Total Ecological Footprint	**0.73**	**0.32**	**1.19**	**0.12**	**0.08**	**4.58**	**7.02**
Household subtotal	**0.65**	**0.29**	**0.50**	**0.11**	**0.04**	**2.98**	**4.57**
Food	**0.44**	**0.17**	**0.04**	**0.08**	**0.00**	**0.26**	**0.99**
Bread and Cereals	0.04	0.00	0.00	0.01	0.00	0.02	0.08
Meat	0.06	0.13	0.01	0.01	0.00	0.04	0.25
Fish and Seafood	0.02	0.00	0.00	0.03	0.00	0.02	0.07
Dairy	0.07	0.02	0.00	0.00	0.00	0.03	0.12
Vegetables, Fruit, nuts	0.18	0.01	0.01	0.02	0.00	0.08	0.31
Other Food	0.05	0.00	0.01	0.01	0.00	0.04	0.12
Non-alcoholic beverages	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Alcoholic beverages	0.01	0.00	0.01	0.00	0.00	0.02	0.04
Housing	**0.01**	**0.00**	**0.16**	**0.00**	**0.01**	**0.47**	**0.65**
Actual rentals for housing	0.00	0.00	0.08	0.00	0.00	0.03	0.11
Imputed rentals for housing	0.00	0.00	0.02	0.00	0.00	0.03	0.05
Water supply and miscellaneous services relating to the dwelling	0.00	0.00	0.01	0.00	0.00	0.03	0.05
Electricity, gas and other fuels	0.00	0.00	0.05	0.00	0.00	0.37	0.43
Services for household maintenance	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Personal Transportation	**0.02**	**0.01**	**0.05**	**0.00**	**0.01**	**1.26**	**1.34**
Purchase of vehicles	0.00	0.00	0.01	0.00	0.00	0.09	0.11
Operation of personal transport equipment	0.01	0.00	0.03	0.00	0.00	0.83	0.88
Transport services	0.00	0.00	0.01	0.00	0.00	0.34	0.36
Goods	**0.07**	**0.03**	**0.09**	**0.00**	**0.01**	**0.36**	**0.57**
Clothing	0.04	0.02	0.01	0.00	0.01	0.15	0.23
Footwear	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Furniture and furnishings, carpets and other floor coverings	0.00	0.00	0.02	0.00	0.00	0.01	0.04
Household appliances	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Glassware, tableware and household utensils	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Tools and equipment for house and garden	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Medical products, appliances and equipment	0.01	0.00	0.00	0.00	0.00	0.04	0.05
Telephone and telefax equipment	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Audio-visual, photographic and information processing equipment	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Other major durables for recreation and culture	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Other recreational items and equipment, gardens and pets	0.00	0.00	0.02	0.00	0.00	0.04	0.07
Newspapers, books and stationery	0.00	0.00	0.02	0.00	0.00	0.02	0.04
Goods for household maintenance	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Tobacco	0.01	0.00	0.00	0.00	0.00	0.01	0.02
Services	**0.12**	**0.08**	**0.15**	**0.02**	**0.01**	**0.63**	**1.02**
Out-patient services	0.00	0.00	0.02	0.00	0.00	0.03	0.06
Hospital services	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Telephone and telefax services	0.01	0.01	0.02	0.00	0.00	0.07	0.11
Recreational and cultural services	0.03	0.02	0.03	0.01	0.00	0.12	0.21
Package holidays	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pre-primary and primary education	0.01	0.01	0.02	0.00	0.00	0.08	0.12
Catering services	0.04	0.03	0.02	0.01	0.00	0.07	0.16
Accommodation services	0.01	0.00	0.00	0.00	0.00	0.01	0.03
Personal care	0.00	0.00	0.00	0.00	0.00	0.06	0.08
Personal effects n. e. c.	0.00	0.00	0.00	0.00	0.00	0.03	0.04
Financial services n. e. c.	0.00	0.00	0.02	0.00	0.00	0.06	0.08
Other services n. e. c.	0.00	0.00	0.01	0.00	0.00	0.07	0.09
Government subtotal	**0.03**	**0.01**	**0.18**	**0.01**	**0.01**	**0.50**	**0.74**
Gross fixed capital formation subtotal	**0.05**	**0.01**	**0.51**	**0.00**	**0.02**	**1.10**	**1.71**

Biocapacity of Lands and Waters

Biocapacity quantifies the potential capacity of lands and waters to sustain Ecological Footprint. Biocapacity is made up of several components including, cropland, grazing land, fishing grounds, built-up land, forest land, and wetlands. These components are comparable to the components that make up Ecological Footprint, with the exception that the forest component of Biocapacity has the dual purpose of measuring the area that can supply products derived from pulp and timber and the area that can sequester anthropogenic carbon emissions. Additionally, another difference in the components is the addition of a wetland component that relates to the ability of wetland ecosystems to sequester carbon emissions.

All Biocapacity components are measured in global hectares. A global hectare is a hectare that represents a global average amount of annual biological production. This standardized unit allows for comparisons to be made with other Ecological Footprints and Biocapacity, and at other levels of aggregation, times, and spaces. Global hectares of Biocapacity can be converted to [or from], a hectare in Ontario or one of the Ontario CSDs using multiple conversion factors, which are related to specific Biocapacity components.

The same methodology was used in the national Ecological Footprint and Biocapacity accounts and the Ontario EFB Report was used to calculate Biocapacity for Ontario CSDs. The one difference from the national accounts is the addition of wetlands as a Biocapacity component. Wetlands make up a significant portion of Ontario's ecosystems and are an important factor in carbon sequestration. The Ontario EFB Report innovated on the methodology of the national Ecological Footprint and Biocapacity accounts to include wetlands as a Biocapacity component. These CSD accounts continued using that innovative methodology. The Footprint Standards (Global Footprint Network, 2009) permit innovations to account for locally significant Biocapacity. To account for wetlands, "data about the annual carbon sequestration of fens and bogs and other wetlands in Ontario were proportioned relative to the annual carbon sequestration rate of forests in Ontario, to quantify the capacity of wetlands to annually sequester carbon." (Miller., et al., 2021, 13).

The same parameters that were used in the Ontario EFB Report were used for these accounts because the same spatial data sources were used. Two data sources were used to find the area of different land cover classifications in Ontario, Southern Ontario Land Resource Information System (SOLRIS) version 3.0 and Ontario Land Cover Compilation (OLCC) version 2.0. To sort the land cover classifications as in SOLRIS and OLCC to the Biocapacity components, first, the land cover classifications are sorted into Biocapacity classes. For specific details on how the different land cover classifications are categorized in relation to Biocapacity components, see Appendix 2 Tables 19 and 20. In total, there are 14 Biocapacity classes that each CSD could have, as is in the Ontario EFB Report. Table 6 presents how the different Biocapacity classes relate to certain land cover types, and what aspect of Ecological Footprint is supported by that Biocapacity class. Some Biocapacity classes do not support any Ecological Footprint component, which includes areas with minimal vegetation, open pits and quarries, and areas not specified in provincial inventories. These correspond to about 0.6% of Ontario's total land.

The built-up land component of Biocapacity is defined as an area populated with human-made infrastructure, largely impervious to water with some urban recreational areas that are pervious. As is done in the Ontario EFB Report and the national Ecological Footprint and Biocapacity accounts, the yield of built-up Biocapacity is equal to the yield of cropland Biocapacity. Built-up areas may include urban green infrastructure that can provide ecosystem services, these services are presumed to contribute globally insignificant sources of Biocapacity. As a result, the built-up Biocapacity component is presumed to only support the built-up footprint and not additional capacity.

Table 6: Components of Biocapacity described in relation to the Ecological Footprint component it supports. Source: Miller, E., et al., 2021, 12).

Biocapacity Class	Includes	Footprint support
Forest: Dense	Coniferous, deciduous, and mixed forests	Forest products or forest carbon uptake
Forest: Disturbed	Forests recently harvested or burned	
Forest: Sparse	Less dense forests amongst other landscapes	
Cropland	Orchards and areas tilled for crops	Cropland
Grazing land	Lands used to graze animals and produce fodder	Grazing land
Grassland	Grasslands not actively being tilled	
Built-up land	Buildings, pavement, manicured landscapes	Built-up land
Freshwater	All of Ontario's lakes and rivers	Fishing grounds
Wetlands: Peat Fens	Less acidic peatlands connected to groundwater flows	Forest carbon uptake
Wetlands: Peat Bogs	Strongly acidic peatlands that are less water-saturated	
Wetlands: Other	Land saturated with water	
Low Biocapacity	Natural areas with minimal vegetation	None
Extraction	Open pits and quarries	None
Unable to determine	Not specified in provincial inventories	None

Conclusion

Ecological Footprint and Biocapacity are important indicators of sustainability, measuring human consumption compared to the capacity of the environment available to sustain that consumption for a given area. The results are presented in a single spatial unit, global hectares, allowing for comparisons between time and space. Additionally, using global hectares enables scalability of Ecological Footprint and Biocapacity. This research used the parameters and metrics in the Ontario EFB Report along with data from Statistics Canada and Ontario GeoHub to scale down the Ontario Ecological Footprint and Biocapacity to the CSD level. Various scaling factors and ratios were created using Statistics Canada data to downscale the 2015 Ontario CLUM. Additionally, this research used the procedures for amalgamating land cover classifications to Biocapacity components, following the rationale of the Ontario EFB Report.

As with any research, there were limitations encountered along the way. The biggest limitation was the lack of data on expenditures within the communities. Instead of this, after-tax income data was used to indicate consumption. If there is data on expenditures that can be incorporated into future editions of these accounts, it would provide greater accuracy. Additionally, the income ratio applied to the 'electricity, gas, and other fuel consumption' category of the forest c-uptake component could be improved by including data on income distribution. A limitation related to Biocapacity is that the land cover 'Alvar' was not amalgamated to a Biocapacity component. For future editions, Alvar should be included as a Biocapacity component.

Having data available to inform decision-making is an essential part of planning for the future. This research aims to provide communities with open-access data that is relevant to them and can be used by local decision-makers.

This research was conducted in partnership with the Rural Ontario Institute and the Ecological Footprint Initiative to produce Ecological Footprint and Biocapacity Accounts for all CSDs in Ontario. This partnership is part of the International Ecological Footprint Learning Lab, a multi-year international partnership funded by the Social Sciences and Humanities Research Council. This work is part of a larger project at the Rural Ontario Institute to provide rural Ontario communities with specific local data about their well-being. The data is available on ROI's Community Wellbeing Dashboard.

Appendix 1: Deriving Ecological Footprint of Consumption

To derive the Ecological Footprint of consumption at the CSD level, the 2015 Ontario Consumption Land-Use Matrix (CLUM) was downscaled using Statistics Canada data. The CLUM is a Multi-Regional Input-Output Analysis organized by the Ecological Footprint components, and three consumption categories: household, government, and gross fixed capital formation consumption. The Statistics Canada data used to downscale the Ontario CLUM included mostly 2021 census data, accompanied with a couple of Statistics Canada reports on housing, energy use, and the environment. The census data was used as it has relevant statistics at the CSD level. Tables 7 and 8 present the census data that was used to derive the scaling metrics and ratios. Table 9 outlines the two additional Statistics Canada reports used to inform the dwelling and household size scaling factors.

The methodology for the scaling factors and ratios was tested before being applied to the Ontario CLUM. The testing process confirmed that any CSD data higher or lower than the Ontario-level data would have the same proportion of change applied to the CLUM. Each scaling factor and ratio has several equations to derive the final output value; these equations have been organized into subsections of Appendix 1 by the name of the scaling factor or ratio. The scaling factors use a weighted sum methodology. In cases where there are multiple scaling factors and ratios applied to one consumption category of the CLUM, then all are multiplied together.

All changes to household subtotal follow a similar rationale, in which the income ratio is being used as an indicator of the level of consumption in the CSD. If the median after-tax income of the CSD is higher than the median after-tax of Ontario, this could signal greater consumption. Whereas, if the median after-tax income of the CSD is lower than the median after-tax of Ontario, it would signal less consumption. Income does not necessarily determine expenditures and consumption, however, there is no data on expenditures for the CSD level in the 2021 census. An improvement for future editions is to include data specifically on expenditures. The income ratio is also applied to the household subtotal for cropland, grazing land, forest products, and fishing grounds. Additionally, the income ratio is applied to the (1) food subcategory of built-up land, (2) personal transportation subcategory of built-up land, (3) goods subcategory of built-up land, (4) services subcategory of built-up land, (5) electricity, gas, and other fuels subcategory of forest carbon-uptake, (6) goods subcategory of forest carbon-uptake, and (7) services subcategory of forest carbon-uptake. The income ratio is used as an indicator of consumption based on the median disposable income of the CSD compared to the median disposable income of Ontario.

The built-up land ratio is used as an indicator of how dense residential housing is in the CSD, by considering the style of dwellings. This is done to account for the less area that is used for people living in denser styles of housing, such as apartment buildings. This ratio is applied to the Housing subcategory of the Built-up land component.

Table 7: Outlining the relationship between the Statistics Canada Census 2021 data and the consumption categories of the 2015 Ontario CLUM (part 1)

Data Table from Statistics Canada 2021 Census	Specific Data Points	Scaling Factors / Ratios	CLUM consumption category impacted
Income statistics for detailed income sources and taxes	Median after-tax income in 2020 among recipients	Income Ratio	• Household subtotal; Cropland, Grazing land, Forest products, & Fishing Grounds • Food subcategory of household; Built-up land • Electricity, gas, and other fuels subcategory of household; Forest carbon-uptake • Personal transportation subcategory of household; Built-up land • Goods subcategory of household; Built-up land & Forest carbon-uptake • Services subcategory of household; Built-up land & Forest carbon-uptake
Commuting duration by main mode of commuting and time arriving at work	Car, truck, or van – as driver	Type of Commuting Scaling Factor	• Operation of personal transport equipment subcategory of household; Forest carbon-uptake component
	Car, truck, or van – as passenger		
	Public transit		
	Walked		
	Bicycle		
	Less than 15 minutes	Duration of Commuting Scaling Factor	• Operation of personal transport equipment subcategory of household; Forest carbon-uptake component
	15 to 29 minutes		
	30 to 44 minutes		
	45 to 59 minutes		
	60 minutes and over		

Table 8: Outlining the relationship between the Statistics Canada Census 2021 data and the consumption categories of the 2015 Ontario CLUM (part 2)

Data Table from Statistics Canada 2021 Census	**Specific Data Points**	**Scaling Factors / Ratios**	**CLUM consumption category impacted**
Population and dwelling counts	Population, 2021 Population, 2016	Change in Private Buildings Ratio	• Gross fixed capital formation subtotal; Cropland, Grazing land, Forest products, Fishing grounds, Built-up land, & Forest carbon-uptake
Structural type of dwelling and household size	Single-detached house Semi-detached house Row house Apartment for flat in a duplex Apartment in a building that has fewer than five storeys Apartment in a building that has five or more storeys Other single-attached house Moveable dwelling Total – occupied private dwellings by structural type of dwelling	(1) Built-Up land Ratio (2) Dwelling type scaling factor (3) Change in Private Buildings Ratio	(1) Housing subcategory of household; Built-up land (2) Electricity, gas, and other fuels subcategory of household; Forest carbon-uptake (3) Gross fixed capital formation subtotal; Cropland, Grazing land, Forest products, Fishing grounds, Built-up land, & Forest carbon-uptake
	1 person 2 persons 3 persons 4 persons 5 or more persons Total – private households by household size	(1) Number of people per household scaling factor (2) Change in Private Buildings Ratio	(1) Electricity, gas, and other fuels subcategory of household; Forest carbon-uptake (2) Gross fixed capital formation subtotal; Cropland, Grazing land, Forest products, Fishing grounds, Built-up land, & Forest carbon-uptake

The 'electricity, gas, and other fuels' consumption category of the forest carbon-uptake component is multiplied by the income ratio, the household size scaling factor, and the dwelling type scaling factor. The income ratio is used as an indicator of the amount of disposable income that a CSD has to spend on electricity, gas, and other fuels in comparison to Ontario. In the future, data on income brackets could be included along with the income ratio. A Nova Scotia study found a noticeable jump in greenhouse gas emissions for households in higher income brackets (Wilson, J., 2013, 886). Finally, the dwelling type and number of people per household are used as indicators because both are found to be signals of GHG emissions (Wilson, J., 2013, 886). Particularly, the number of people per household is found to be one of the biggest indicators of GHG emissions in households (Wilson, J., 2013, 886).

The 'operation of personal transport equipment' consumption category of the forest carbon-uptake component is impacted by the commuting pattern scaling factor and the duration of commuting scaling factor. The data point that has the most impact, is the number of individuals driving vehicles as a personal driver.

Table 9: Additional data points used to inform scaling factors

Other Statistics Canada Data [used to inform scaling factors / ratios]	**Specific Data Points**	**Scaling Factors / Ratios this data informed**	**CLUM consumption category impacted**
Canadian Housing Statistics Program (2019)	Average household size (metres squared)	Dwelling Type Scaling Factor	• Electricity, gas, and other fuels subcategory of household; Forest carbon-uptake
Households and the Environment: Energy Use (2011)	Average household energy use (gigajoules per household size)	Number of people per household scaling factor	• Electricity, gas, and other fuels subcategory of household, Forest carbon-uptake
		Dwelling Type Scaling Factor	
Gross fixed capital formation (2024)	Seasonally adjust annual rates of gross fixed capital formation	Change in private buildings ratio	Gross fixed capital formation subtotal; Cropland, Grazing land, Forest products, Fishing Grounds, Built-up land, & Forest carbon-uptake

Gross Fixed Capital formation sums expenditures on new construction and renovations of residential and non-residential structures, machinery and equipment, intellectual property products, and weapon systems (Statistics Canada, 2024b). This broad categorization is reported by Statistics Canada, and other statistical agencies, following an internationally established methodology of economic accounts that are used to derive statistics of Gross Domestic Product and national economic wealth. Unfortunately, Statistics Canada does not provide this data on a census basis; components of this data are aggregated provincially or nationally. Therefore, local data needed to be estimated, based on available census data. In census year 2021, residential investment represented 37% of total Gross Fixed Capital formation in Canada and Non-residential investment in commercial and industrial buildings represented 31% (Statistics Canada, 2024b). Local residential investment relates to the number of local residents and households, even if it could also include dwellings for non-residents and secondary dwellings. Local commercial investment is a broad category, but it includes investment in commercial retail serving residents, such as stores and malls, restaurants, auto shops, fuel stations, and financial services. This retail portion was not reported by Statistics Canada; we assumed it to be about half of the total. The local portion of Gross Fixed Capital formation, related to changes in local residents, was approximated to be 50%, as the sum of 37% residential investment plus half of 31%. This portion of 50% was assumed to be proportionally related to changes in the number of local residents, represented as the Change in private buildings ratio. The remaining 50% of Gross Fixed Capital formation was allocated to all communities in Ontario on an equal per-capita basis, thereby capturing the portion of commercial investment that was unrelated to local residential development, while also capturing intellectual property products plus expenses on weapon systems.

The change in the private buildings ratio is applied to all 6 components of the gross fixed capital formation as a measure of the creation of private infrastructure. It is assumed that any addition of private buildings demonstrates a subsequent addition of infrastructure in the CSD. A ratio is used to compare the number of private buildings in the CSD to the number of private buildings in Ontario. In some instances, there was a decrease in private buildings because there was a decrease in population between 2016 to 2021 in the CSD. In those situations, it was assumed that the buildings would not necessarily be torn down, and rather 1% was used as a placeholder.

To calculate the total Ecological Footprint of consumption per capita, simply add together the total Ecological Footprint of each component on the CLUM. To find the total Ecological Footprint, simply multiply each footprint component or the total Ecological Footprint by the population of the CSD. Equations 1 and 2 show the formulas for calculating total Ecological Footprint per capita and total Ecological Footprint.

Equation 1: Calculation for Ecological Footprint per capita

Total Ecological Footprint (gha per capita) = Cropland + Grazing land + Forest Products + Fishing Grounds + Built-up land + Forest carbon-uptake

Equation 2: Calculation for total Ecological Footprint

Ecological Footprint (gha) = Footprint component * Population

Income Ratio

The income ratio explores the relationships between the CSD's income compared to Ontario. The income ratio investigates if the CSD's median after-tax income is higher or lower than the median after-tax income in Ontario.

Equation 3: Income ratio

Income Ratio = CSD median after-tax income / Ontario median after-tax income

Type of Commuting Scaling Factor

The commuting pattern scaling factor applies data about the amount of people that commute in different forms, such as driving, biking, or walking. Refer to Table 7 to see the different data points. First, the commuting pattern intensity is found for both Ontario and the CSD, by dividing the number of commuters by the total population for that area. Then the ratio of commuting pattern intensity is calculated, identifying the commuting pattern intensity of the CSD in comparison to Ontario, for each type of commuting.

The next step is to calculate the relative emissions intensity multiplier for each type of commuting. This is done by taking the relative emissions intensity for that type of commuting pattern and dividing it by the base relative emissions intensity. For each type of commuting a relative emissions intensity was estimated based on the type of commuting, using 1 as the highest relative emissions intensity. See Table 10 for the relative emissions intensities. For cycling and walking, 0 was given as there are no emissions generated in that form of commuting. For a person commuting as a driver, a value of 1 was given for emissions intensity. This could be improved by including data on the types of vehicles people are using to commute as drivers. For public transit and commuting as a passenger, an estimation was made based on the driver having a relative emissions intensity of 1.

Then the input values are created for the weighted sum. Each commuting type has an input value created by multiplying the commuting intensity ratio by the relative emissions intensity multiplier and then dividing that by the sum of all the relative emissions intensity multipliers. Once there is an input value for each commuting type, then all the input values are added together to create the output value. The output value is the value that is multiplied by the consumption category in the CLUM.

Equation 4: CSD commuting pattern intensity

CSD Commuting Pattern Intensity = number of commuters for type of commuting in CSD (e.g., car, truck, or van – as a driver)/total population of CSD, 2021

Equation 5: Ontario commuting pattern intensity

Ontario Commuting Pattern Intensity = number of commuters for type of commuting in Ontario (e.g., car, truck, or van – as a driver)/total population of Ontario, 2021

Equation 6: Commuting pattern intensity ratio

Commuting Pattern Intensity Ratio = CSD Commuting Pattern Intensity/Ontario Commuting Pattern Intensity

Table 10: Relative emissions intensity based on the various types of commuting.

Type of commuting	Relative Emissions Intensity
Car, truck, or van – as a driver	1
Car, truck, or van – as a passenger	0.2
Public transit	0.3
Walked	0
Bicycle	0

Equation 7: Commuting pattern relative emissions intensity multiplier

Relative Emissions Intensity Multiplier = relative emissions intensity for that type of commuting (e.g., car, truck, or van – as a driver)/ base relative emissions intensity

Equation 8: Calculating input values for the weighted sum of commuting patterns

Input Values = Commuting Pattern Intensity Ratio * Relative Emissions Intensity Multiplier/sum(all relative emissions intensity multipliers)

Equation 9: Output value for the weighted sum of the commuting patterns

Output Value = sum(all input values)

Duration of Commuting Scaling Factor

The duration of commuting scaling factor applies data about the various lengths of commuting, measuring in minutes. Refer to Table 7 to see the different data points. First, the commuting duration intensity is found for both Ontario and the CSD, by dividing the number of commuters by the total population. Next, the ratio of commuting duration intensity is calculated. This ratio identifies the commuting duration intensity of the CSD in comparison to Ontario, for each category for the duration of commuting.

Then the relative emissions intensity multiplier is calculated for each category of the duration for commuting. This is done by taking the relative emissions intensity for that category of commuting duration and dividing it by the base relative emissions intensity. For each category of duration of commuting a relative emissions intensity was estimated based on the duration of commuting, using 1 as the highest relative emissions intensity. See Table 11 for the relative emissions intensities. For 60 minutes and over, a value of 1 was given to the relative emissions intensity, as this was the option signalling the highest duration of commuting. The rest of the duration categories are determined by finding the mid-point based on the percentile of that category for the commuting duration. For example, less than 15 minutes represents the 25th percentile category and the middle point of 0 to 25 is 12.5, making the relative emissions intensity to be 0.125.

Next, the input values are created for the weighted sum. Each duration of commuting category has an input value that is created by multiplying the commuting duration intensity ratio by the relative emissions intensity multiplier, and then dividing that by the sum of all the relative emissions intensity multipliers. Once there is an input value for each commuting type, then all the input values are added together to create the output value. The output value is the value that is multiplied by the consumption category in the CLUM.

Equation 10: CSD commuting duration intensity

CSD Commuting Duration Intensity = number of commuters for duration category of commuting in CSD (e.g., less than 15 minutes)/total population of CSD, 2021

Equation 11: Ontario commuting duration intensity

Ontario Commuting Duration Intensity = number of commuters for type of commuting in Ontario (e.g., less than 15 minutes)/total population of Ontario, 2021

Equation 12: Commuting duration intensity ratio

Commuting Duration Intensity Ratio = CSD Commuting Intensity/Ontario Commuting Intensity

Table 11: Relative emissions intensity based on the duration of commuting.

Duration of commuting	Relative Emissions Intensity
Less than 15 minutes	0.125
15 to 29 minutes	0.375
30 to 44 minutes	0.625
45 to 59 minutes	0.875
60 minutes and over	1

Equation 13: Relative emissions intensity multiplier for commuting duration

Relative Emissions Intensity Multiplier = relative emissions intensity for that type of commuting (e.g., less than 15 minutes)/ base relative emissions intensity

Equation 14: Calculating input values for the weighted sum of commuting duration

Input Values = Commuting Duration Intensity Ratio * Relative Emissions Intensity Multiplier/sum(all relative emissions intensity multipliers)

Equation 15: Output value for the weighted sum of commuting duration

Output Value = sum(all input values)

Number of People Size Scaling Factor

The household size scaling factor applies data about the number of people that live in a household. Refer to Table 8 to see the different data points for household size. First, the household size intensity is found for both

Ontario and the CSD, by dividing the number of people that live in that household size by the total population of that CSD. Then the ratio of household size intensity is calculated. This ratio identifies the household size intensity of the CSD in comparison to Ontario.

Next, the relative emissions intensity multiplier is calculated, by taking the relative emissions intensity for that category and dividing it by the base relative emissions intensity. See Table 12 for the relative emissions intensities. In 2011, Statistics Canada reported the energy use in households across Canada, splitting information by provinces and territories. This report presents data on the amount of energy being used, in Gigajoules (GJ) for the number of people living in a household in Ontario, see Table 13. To calculate the relative emissions intensity, first, the relative energy use per household is calculated by dividing the energy use by the number of persons in the household. For example, 72 (GJ) is divided by 1 (person), to find the relative energy use for the household size of one person.

Then the relative energy use per household is divided by the base relative energy use per household. The one-person household relative energy use was made the highest possible relative emission intensity of 1. The base relative emissions intensity multiplier for household size is the value for a household size of two persons. A two-person household size was used as the base because this was the household size most common in Ontario.

Next, the input values are created for the weighted sum. Each household size category has an input value created by multiplying the household size intensity ratio by the relative emissions intensity multiplier and then dividing that by the sum of all the relative emissions intensity multipliers. Once there is an input value for each household size category, then all the input values are added together to create the output value. The output value is the value that is multiplied by the consumption category in the CLUM.

Equation 16: CSD household size intensity

CSD Household Size Intensity = number of people living in that household size in CSD (e.g., 2 persons)/total population of CSD, 2021

Equation 17: Ontario household size intensity

Ontario Household Size Intensity = number of people living in that household size in Ontario (e.g., 2 persons)/total population of Ontario, 2021

Equation 18: Household size intensity ratio

Household Size Intensity Ratio = CSD Household Size Intensity/Ontario Household Size Intensity

Table 12: Relative emissions intensity based on the household size

Household Size	Relative Emissions Intensity
1 person	1
2 persons	0.722
3 persons	0.477
4 persons	0.476
5 or more persons	0.431

Table 13: Average household energy use in gigajoules per household size. Source: Statistics Canada, 2011.

Average household energy use (gigajoules per household size)					
Number of people in household	1	2	3	4	5
Ontario Energy Use	72	104	103	137	155

Equation 19: Relative energy use per household in Ontario

Relative energy use per household (in gigajoules / number of persons per household) = energy use / number of person per household

Equation 20: Relative emission intensity for household size

Relative Emissions Intensity = relative energy use per household / base relative energy use per household (relative energy use for one-person household)

Equation 21: Relative emissions intensity multiplier for household size

Relative Emissions Intensity Multiplier = relative emissions intensity for that household size (e.g., 2 persons household size)/ base relative emissions intensity

Equation 22: Input values for the weighted sum of commuting duration

Input Values = Household size Intensity Ratio * Relative Emissions Intensity Multiplier/sum(all relative emissions intensity multipliers)

Equation 23: Output value for the weighted sum of commuting duration

Output Value = sum(all input values)

Dwelling Type Scaling Factor

The dwelling type scaling factor applies data on the various household types. Refer to Table 8 to see the different data points for dwelling type. First, the type of dwelling intensity is found for both Ontario and the CSD, by dividing the number of people that live in that type of dwelling by the total population. Since there are several categories for the type of dwelling, the type of dwelling intensity is found for each type of dwelling category. After finding the type of dwelling intensity for both the CSD and Ontario, then the ratio of the type of dwelling intensity is calculated. This ratio identifies the type of dwelling intensity of the CSD in comparison to Ontario, for each type of dwelling category.

Next, the relative emissions intensity multiplier is calculated by taking the relative emissions intensity for that dwelling type and dividing it by the base relative emissions intensity. For each category of dwelling type, a relative emissions intensity was calculated. See Table 14 for the relative emissions intensities. In 2011, Statistics Canada reported the energy use in households across Canada, splitting information by provinces and territories. This report presented data on the amount of energy being used, (in Gigajoules (GJ), for three styles of homes: an apartment, a multi-unit, and a single-detached dwelling. This data was used to inform the relative emissions intensity values, see Table 16. To calculate the relative emissions intensity, first, the relative energy use per household was calculated by dividing the energy use by the average size of households in Ontario. The Canadian Housing Statistics Program was used to find the average household size in metres squared, see Table 17. For example, 33 (GJ) is divided by 80.08 (m^2), to find the relative energy use for the apartment type of dwelling. As the census data and the Households and Environment Report and the Canadian Housing Statistics Program had differing dwelling types, they were matched together, see Table 15.

Next, the relative energy use per dwelling type is divided by the base relative energy use per dwelling type to calculate the relative emissions intensity. The single detached dwelling's relative energy use was given a base value of 1, making it the highest possible relative emission intensity. This was done since the single detached dwelling is the dwelling type most common in Ontario. Then the input values are created for the weighted sum. The input values are created by multiplying the dwelling type of intensity ratio by the relative emissions intensity multiplier and then dividing that by the sum of all the relative emissions intensity multipliers. Once there is an input value for each dwelling type category, then all the input values are added together to create the output value. The output value is the value that is multiplied by the consumption category in the CLUM.

Equation 24: CSD type of dwelling intensity

CSD Type of Dwelling Intensity = number of people living in that type of dwelling in CSD (e.g., row house)/total population of CSD, 2021

Equation 25: Ontario type of dwelling intensity

Ontario Type of Dwelling Intensity = number of people living in that type of dwelling in Ontario (e.g., row house)/total population of Ontario, 2021

Equation 26: Household type of dwelling ratio

Household Type of Dwelling Ratio = CSD Type of Dwelling Intensity/Ontario Type of Dwelling Intensity

Table 14: Relative emissions intensity based on the type of dwelling

Type of Dwelling (Statistics Canada Census)	Relative Emissions Intensity
Single-detached house	1
Semi-detached house	0.441
Row house	0.441
Apartment or flat in a duplex	0.243
Apartment in a building that has fewer than five storeys	0.243
Apartment in a building that has five or more storeys	0.243
Other single-attached house	0.441
Moveable dwelling	0.243

Table 15: Matching the types of dwellings in the Statistics Canada census to the Statistics Canada reports

Type of Dwelling (Statistics Canada Census)	Household Type (Households and the Environment Report, and Canadian Housing Statistics Program)
Single-detached house	Single-detached dwelling
Semi-detached house	Multi-unit
Row house	Multi-unit
Apartment or flat in a duplex	Apartment
Apartment in a building that has fewer than five storeys	Apartment
Apartment in a building that has five or more storeys	Apartment
Other single-attached house	Multi-unit
Moveable dwelling	Apartment

Table 16: Average household energy use in gigajoules per dwelling type. Source: Statistics Canada, 2011.

Average household energy use (gigajoules per household type)			
Type of Dwelling	Apartment	Multi-unit	Single-detached dwelling
Ontario Energy Use	33	94	136

Table 17: Average household size in metres squared per dwelling type. Source: Statistics Canada, 2019.

Average household size (metres squared)			
Type of Dwelling	Condo Apartments	Row Houses	Single-detached dwelling
Ontario Household Size in metres squared	80.08m^2	125.41m^2	141m^2

Equation 27: Relative energy use per dwelling type in Ontario

Relative energy use per dwelling type (in gigajoules / metres^2) = energy use / metres^2

Equation 28: Relative emission intensity for dwelling type

Relative Emissions Intensity = relative energy use per dwelling type / base relative energy use per dwelling type (relative energy use for single detached dwelling)

Equation 29: Relative emissions intensity multiplier for dwelling type

Relative Emissions Intensity Multiplier = relative emissions intensity for that dwelling type (e.g., Row house)/ base relative emissions intensity

Equation 30: Calculating input values for the weighted sum of commuting duration

Input Values = Dwelling type Intensity Ratio * Relative Emissions Intensity Multiplier/sum(all relative emissions intensity multipliers)

Equation 31: Output value for the weighted sum of commuting duration

Output Value = sum(all input values)

Built-up Land Ratio

The built-up land ratio uses housing data as an indicator of the amount of area that the various styles of housing take up. The intention of this scaling factor is to consider that single-detached housing and similar styles of housing take considerably more land area as compared to apartment buildings and condominiums. First, a relative space intensity was determined to estimate the amount of area taken up for the various housing styles, in relation to a single-detached dwelling, see Table 18.

Table 18: Type of Dwelling based on Statistics Canada 2021 census data matched to the relative space intensity

Type of Dwelling (Statistics Canada Census)	Relative Space Intensity
Single-detached house	1
Semi-detached house	0.75
Row house	0.5
Apartment or flat in a duplex	0.25
Apartment in a building that has fewer than five storeys	0.1666667
Apartment in a building that has five or more storeys	0.0555556
Other single-attached house	0.75
Moveable dwelling	0.25

Then the dwelling types of data points were multiplied by relative space intensity to find the Relative Space Intensity Multiplier, this is done for each dwelling type in each CSD. Following this, the Relative Space Intensity Multipliers are summed for each CSD. Then the CSD Aggregate is calculated by summing all of the Total Relative Space Intensity Multipliers. Finally, the Built-up Land Ratio is calculated by dividing the Total Relative Space Intensity Multiplier by the CSD Aggregate.

Equation 32: Relative Space Intensity Multiplier

Relative Space Intensity Multiplier = relative space intensity for that type of dwelling (e.g. semi-detached house) * number of people that live in that type of dwelling in that CSD

Equation 33: Total Relative Space Intensity Multiplier

Total Relative Space Intensity Multiplier = sum(all relative space intensity multipliers for that CSD)

Equation 34: CSD Aggregate

CSD Aggregate = sum(Total Relative Space Intensity Multiplier for all CSDs)

Equation 35: Built-up Land Ratio

Built-up Land Ratio = Total Relative Space Intensity Multiplier / CSD Aggregate

Change in Private Buildings Ratio

The private buildings ratio applies population and housing data as an indicator of change in buildings. Refer to Table 8 to see the different data points. First, the average household size (per number of people) is calculated for the CSD and Ontario. Next, the number of new residents is calculated for the CSD and Ontario, by subtracting the 2016 population from the 2021 population. Then the number of new private buildings is calculated by dividing the number of new residents by the average household size, for the CSD and Ontario. Then the percentage change of new private buildings is calculated, by dividing the number of new households by the total private households by household size. Finally, the ratio between the percentage change of new private buildings between the CSD and Ontario is calculated. This ratio identifies the change in additional households of the CSD in comparison to Ontario.

Equation 36: Average household size (per number of people) in CSD

Average household size of CSD = CSD population, 2021 / CSD Total – Private households by household size- 100% data

Equation 37: Average household size (per number of people) in Ontario

Average household size of Ontario = Ontario population, 2021 / Ontario Total – Private households by household size- 100% data

Equation 38: Number of new residents in the CSD

Number of new residents in the CSD = CSD population, 2021 – CSD population, 2016

Equation 39: Number of new residents in the Ontario

Number of new residents in Ontario= Ontario population, 2021 – Ontario population, 2016

Equation 40: Number of new households in the CSD

Number of new households in the CSD = number of new residents in the CSD/ average household size in the CSD

Equation 41: Number of new households in Ontario

Number of new households in Ontario = number of new residents in Ontario/ average household size in Ontario

Equation 42: Percentage change of additional households in the CSD

Percentage change of additional households in the CSD = Number of new households in the CSD / Total private households by household size in the CSD

Equation 43: Percentage change of additional households in Ontario

Percentage change of additional households in Ontario = Number of new households in Ontario / Total – Private households by household size in Ontario

Equation 44: Change in private buildings ratio

Change in private buildings ratio = Percentage change of additional households in the CSD / percentage change of additional households in Ontario

Appendix 2: Deriving Biocapacity

The Biocapacity was derived from geospatial data sources accessed from Ontario GeoHub and Statistics Canada. The land cover across Ontario was generated from two raster files, Southern Ontario Land Resource Information System (SOLRIS) version 3 and Ontario Land Cover Compilation (OLCC) version 2. See Figures 5 and 7 for the land cover maps. The same Biocapacity parameters developed in the Ontario EFB Report were able to be used for these CSD-level accounts as the same raster data sources were used. See Figures 6 and 8 for Biocapacity classification maps. Additionally, a vector file from Statistics Canada was used to present the boundaries of the CSD. Finally, it was necessary to determine what Ecozone each CSD is in, so a vector boundary file from Ontario GeoHub was used.

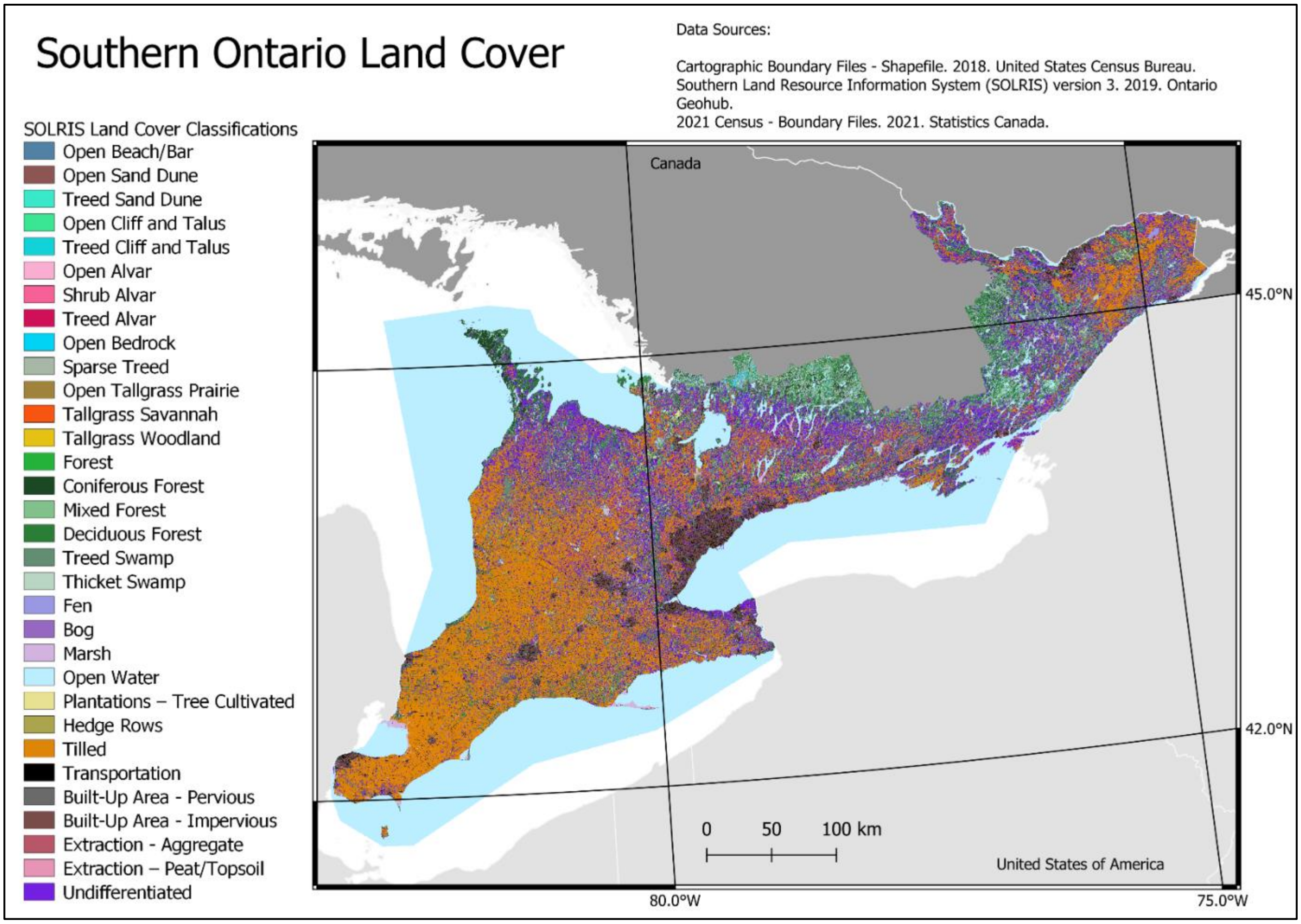

Figure 5: Map of Southern Ontario Land Cover based on the land cover classifications from Southern Ontario Land Resource Information System (SOLRIS) version 3.

In the Ontario EFB Report, an Amalgamated Land Cover (ALC) was generated to classify Ontario into mutually exclusive land classes, these land classes were then allocated to Biocapacity classes (Miller et al., 2021, 38). That ALC and allocation of Biocapacity classes were able to be applied to this research. Tables 19 and 20 show the allocation of ecological land cover from the SOLRIS and OLCC data sources to Biocapacity classes. The Biocapacity classes were amalgamated into Biocapacity components and matched to Ecological Footprint components in the Ontario EFB Report, this is displayed in Table 6.

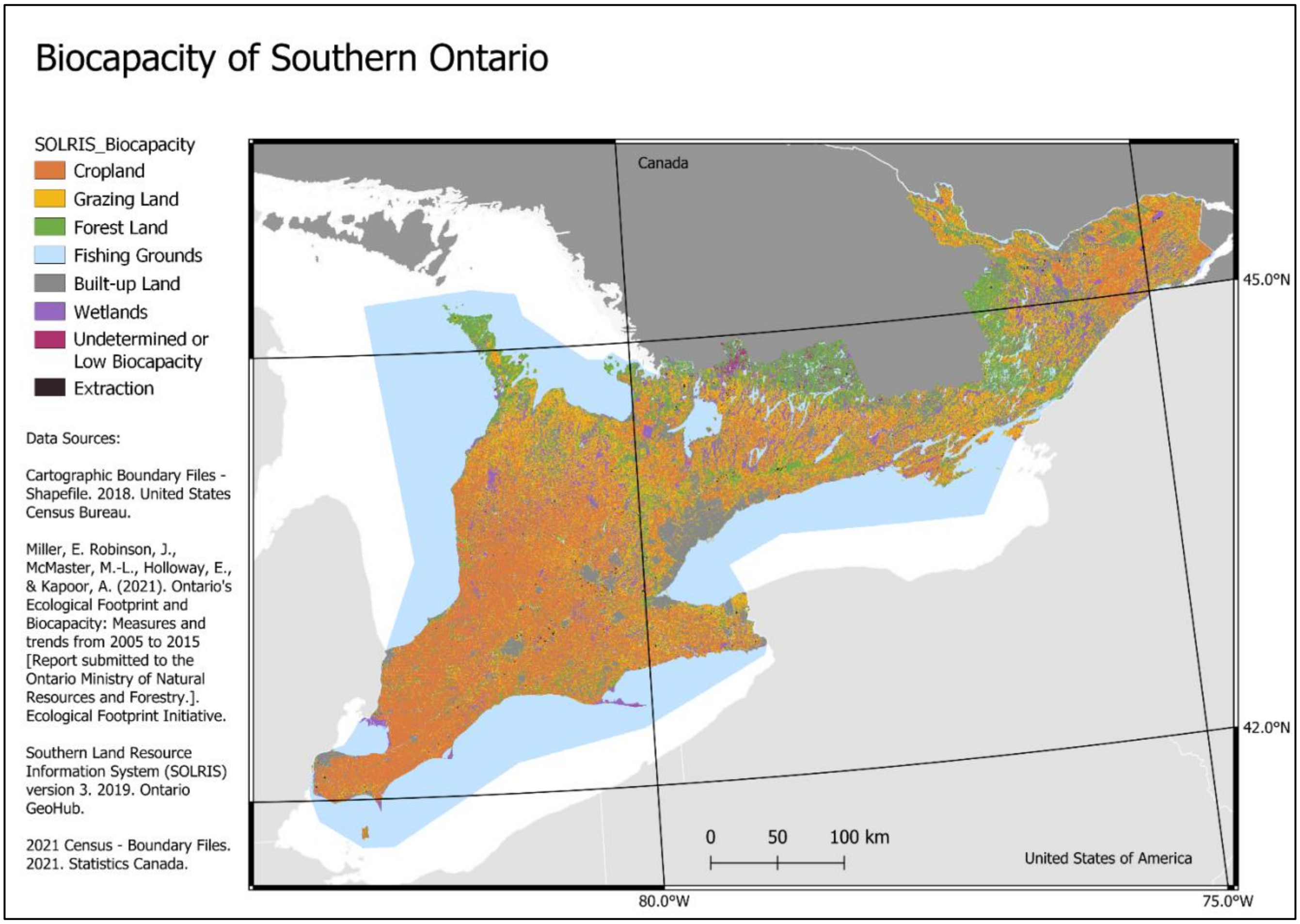

Figure 6: Map of Biocapacity of Southern Ontario based on the land cover classifications from the Southern Land Resource Information System (SOLRIS) version 3.

There are some Biocapacity classifications left blank in Tables 19 and 20; this follows the same methodology in the Ontario EFB Report where some class names were not given a Biocapacity classification. The only case where this created a problem, was for 'Alvar' was reported by OLCC yet not classified in the Ontario EFB Report. In future work on producing Ecological Footprint and Biocapacity accounts in Ontario, research can be done to include this land cover.

The equation to derive Biocapacity in global hectares can be found in Figure 8, along with the definitions of each parameter in the equation. This equation is adapted from the Ontario EFB Report to have CSD hectares rather than Ontario hectares. ONT_rNPP and ONT_RY were metrics established in the Ontario EFB Report, "derived from Ontario-specific data" (Miller et al., 2021, 42). CAN_YF, GLOBAL_IYF, and GLOBAL_EQF parameters are from the National Footprint Accounts in 2021. This method accounts for differences in land productivity in Ontario, relative to the average of the same class of hectares in Canada, relative to the average of the same classes across the planet, and relative to the global productivity of different classes of land. (Miller et al., 2021, 42). The results in global hectares allow for Biocapacity in Ontario communities to be compared to Ecological Footprint and Biocapacity of other spaces and times.

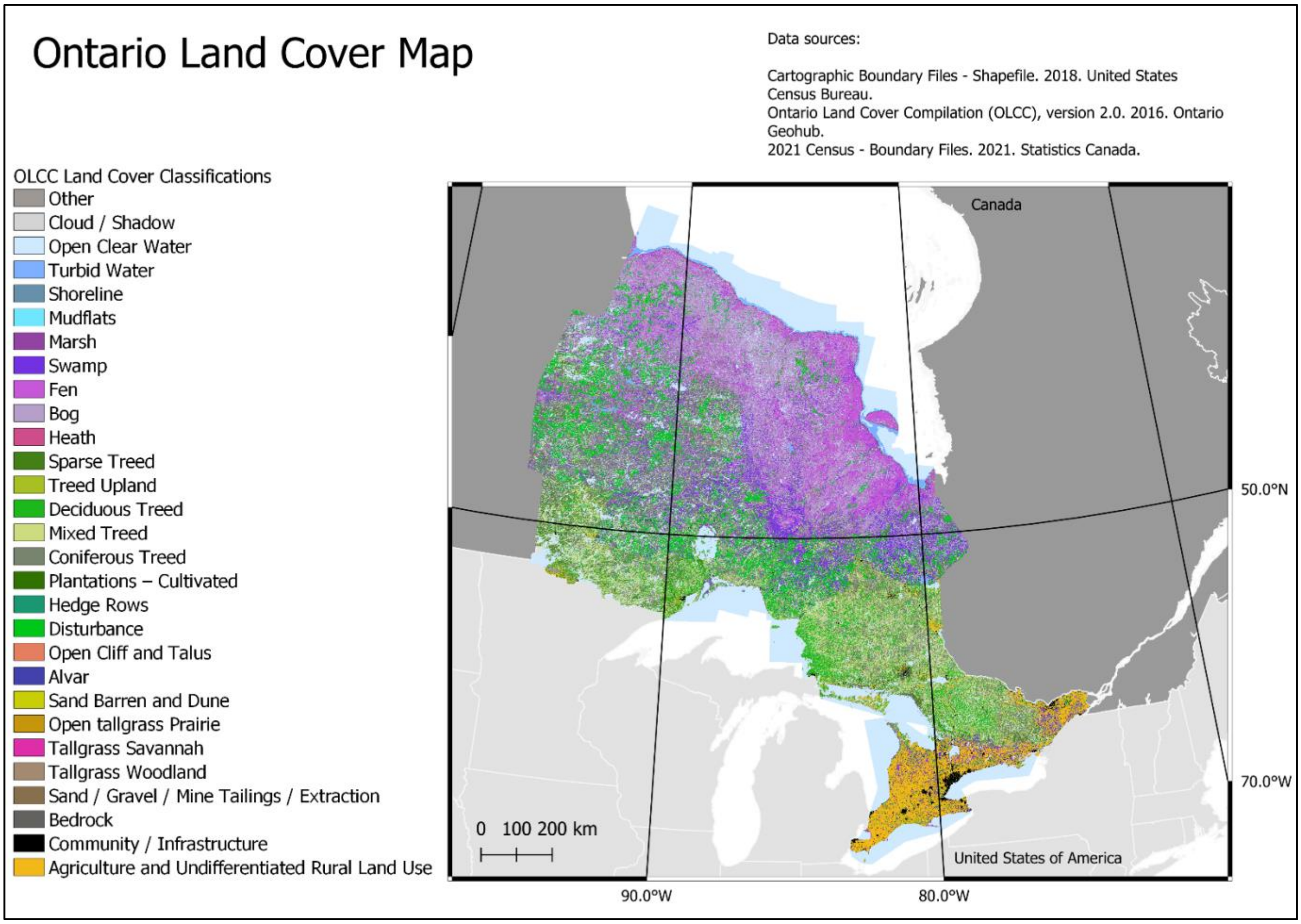

Figure 7: Map of Ontario Land Cover based on the Land Cover Classifications from Ontario Land Cover Compilation (OLCC) version 2.

Table 20 shows the different parameters depending on the Biocapacity class and the Ecozone. The three Ecozones are the Hudson's Bay Lowlands (HBL), the Mixedwood Plains (MWP), and the Ontario Shield (OS). More details on how the ONT_rNPP and ONT_RY were calculated can be found in the technical appendix of the Ontario EFB Report (Miller, et al., 2021, 43-49).

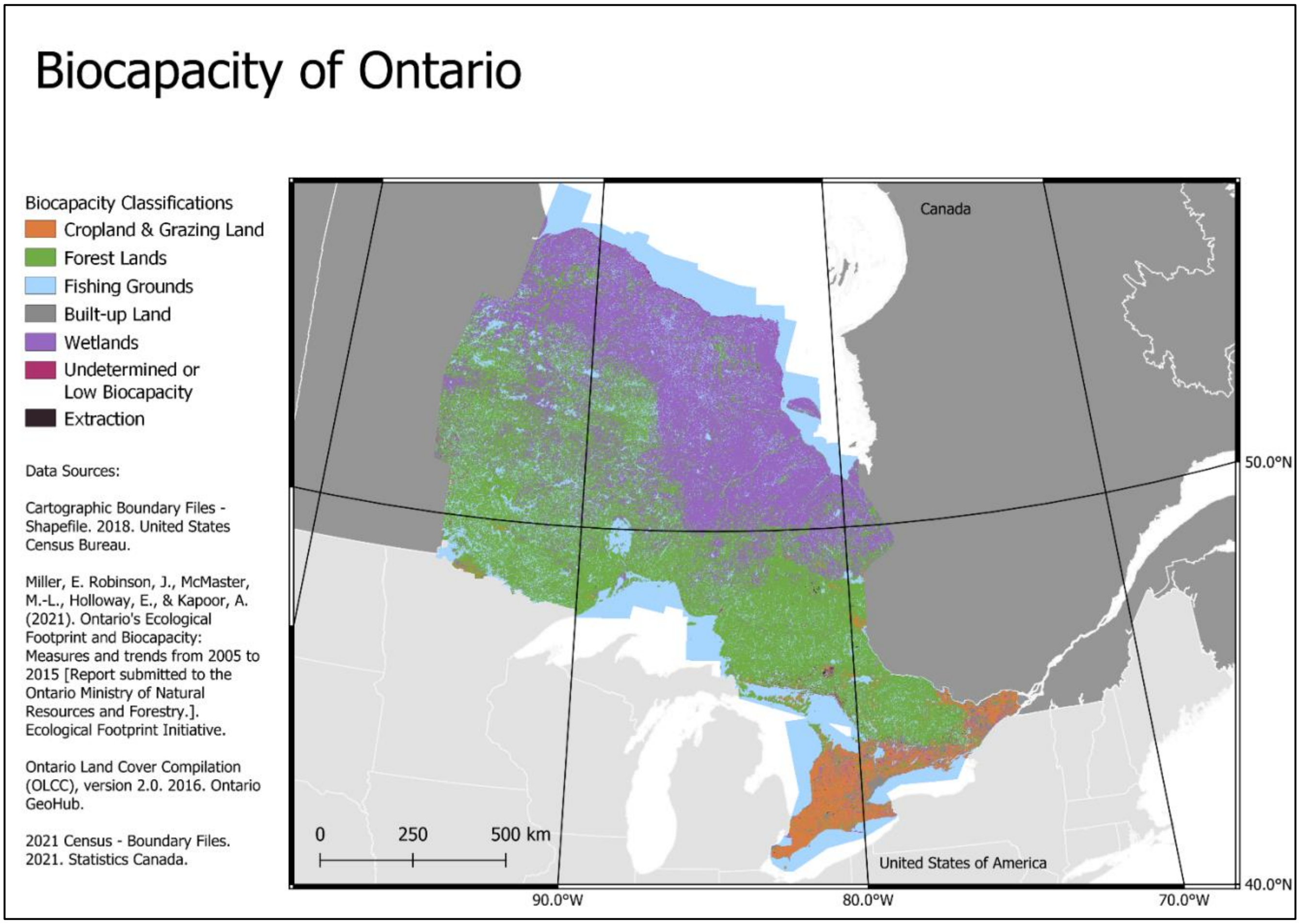

Figure 7: Map of Biocapacity of Ontario based on the land classifications from Ontario Land Cover Compilation (OLCC) version 2.

Table 19: SOLRIS ecological land class matched to Biocapacity classes. Source: Miller, E., et al., 2021, 39.

SOLRIS v3 class name	Biocapacity Classes
Open Beach/Bar	100% Low Biocapacity
Open Sand Dune	100% Low Biocapacity
Treed Sand Dune	65% Low Biocapacity + 35% Forest: Sparse
Open Cliff and Talus	100% Low Biocapacity
Treed Cliff and Talus	60% Low Biocapacity + 40% Forest: Sparse
Open Alvar	
Shrub Alvar	80% Low Biocapacity + 20% Forest: Sparse
Treed Alvar	60% Low Biocapacity + 40% Forest: Sparse
Open Bedrock	100% Low Biocapacity
Sparse Treed	100% Low Biocapacity
Open Tallgrass Prairie	90% Grassland + 10% Forest: Sparse
Tallgrass Savannah	65% Low Biocapacity + 35% Forest: Sparse
Tallgrass Woodland	55% Grassland + 45% Forest: Dense
Forest	100% Forest: Dense
Coniferous Forest	100% Forest: Dense
Mixed Forest	100% Forest: Dense
Deciduous Forest	100% Forest: Dense
Treed Swamp	40% Forest: Sparse + 60% Wetlands: Other
Thicket Swamp	15% Forest: Sparse + 85% Wetlands: Other
Fen	100% Wetlands: Peat Fens
Bog	100% Wetlands: Peat Bogs
Marsh	10% Forest: Sparse + 90% Wetlands: Other
Open Water	100% Freshwater
Plantation - Tree Cultivated	100% Forest: Dense
Hedge Rows	100% Forest: Dense
Tilled	100% Cropland
Transportation	100% Built-up
Built-Up Area - Pervious	100% Built-up
Built-Up Area - Impervious	100% Built-up
Extraction - Aggregate	100% Extraction
Extraction Peat/Topsoil	100% Extraction
Undifferentiated	32% Cropland + 20% Grazing Land + 48% Grassland

Table 20: OLCC ecological land class matched to Biocapacity classes. Source: Miller, E., et al., 2021, 38.

OLCC v2 class name	Biocapacity Classes
Clear Open Water	100% Freshwater
Turbid Water	100% Freshwater
Shoreline	
Mudflats	100% Freshwater
Marsh	100% Wetlands: other
Swamp	30% Forest: Sparse + 70% Wetlands: other
Fen	100% Wetlands: Peat Fens
Bog	100% Wetlands: Peat Bogs
Heath	100% Low Biocapacity
Sparse Treed	100% Forest: Sparse
Treed Upland	100% Forest: Dense
Deciduous Treed	100% Forest: Dense
Mixed Treed	100% Forest: Dense
Coniferous Treed	100% Forest: Dense
Plantations - Treed Cultivated	100% Forest: Dense
Hedge Rows	100% Forest: Dense
Disturbance	100% Forest: Distributed
Open Cliff and Talus	
Alvar	
Sand Barren and Dune	
Open Tallgrass and Prairie	
Tallgrass Savannah	
Tallgrass Woodland	
Sand / Gravel / Mine Tailings / Extraction	100% Extraction
Bedrock	100% Low Biocapacity
CSD Community / Infrastructure	100% Built-up
Agriculture and Undifferentiated Rural Land Use	30% Cropland + 23% Grazing land + 48% Grassland
Other	100% Unable to determine
Cloud / Shadow	100% Unable to determine

Gha = CSD_ha x ONT_rNPP x ONT_RY x CAN_YF x GLOBAL_IYF x GLOBAL_EQF

- Gha is a global hectare
- CSD_ha is the hectares of the census subdivision in Ontario, of a specific Biocapacity class in a specific Ontario Ecozone
- ONT_rNPP is the relative Net Primary Production (RNPP) of forest or wetland area, by Ontario Ecozone as derived from the Ontario EFB Report (Miller et al., 2021, 42).
    - <u>RNPP of a specific type of forest or wetland in a specific Ontario Ecozone</u>
RNPP of a dense forest in Ontario Shield Ecozone
- ONT_RY is the relative yield of an average hectare in Ontario compared to the same in Canada as derived from the Ontario EFB Report (Miller et al., 2021, 42).
    - Ontario Yield / Canada Yield
    - <u>Mass of harvest in Ontario / Area in Ontario harvested</u>
Mass of harvest in Canada / Area in Canada harvested
- CAN_YF is the Canadian Yield Factor from the National Footprint Accounts (NFA) 2021
- GLOBAL_IYF is the Global Inter-temporal Yield Factor from the NFA 2021
- GLOBAL_EQF is the Global Equivalence Factor from the NFA 2021

Figure 8: Equation for calculating Biocapacity in global hectares. Adapted from Miller, E., et al., 2021, 38).

Table 21: Parameters used to generate Ontario Biocapacity in global hectares for the year 2022. Source: (Miller, et al., 2021, 43).

		ONT_rNPP				Parameters from NFA 2021		
Ontario Biocapacity Class	**Related NFA Classification**	**HBL**	**MWP**	**OS**	**ONT_RY**	**CAN_YF**	**GLOBAL_IYF**	**GLOBAL_EQF**
Forest: Dense	Forest	0.85	1.11	1.00	1.03	0.71	1.00	1.28
Forest: Disturbed		0.83	1.08	0.98				
Forest: Sparse		0.53	0.70	0.63				
Cropland	Cropland				1.94	1.19	0.97	2.50
Grazing land	Grazing land				1.96	1.09	1.00	0.46
Grassland								
Built-up land	Built-up land				1.94	1.19	0.97	2.50
Freshwater	Inland water				2.17	1.00	1.00	0.37
Wetlands: Peat Fens	Forest carbon	0.32	0.42	0.38	1.03	0.71	1.00	1.28
Wetlands: Peat Bogs		0.50	0.65	0.58				
Wetlands: Other		0.28	0.37	0.33				

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