Forest Characteristics and Carbon Storage within the Obtawaing Biosphere Region

by

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Abstract

This study presents a comprehensive spatial dataset comprising over 100 files from 30 different themes, encompassing key geographic features alongside physical data such as ecoregion, geology, and terrain. Additionally, forest and land cover/use, as well as biomass and primary production data, were meticulously integrated into the dataset. Through detailed boundary editing, standardized data processing procedures, and multiple version backups, the compiled geospatial database serves as a robust and accessible resource for the Obtawaing Biosphere Reserve (OBR) community, enabling further research endeavors.

The study also investigated the spatial distribution and temporal dynamics of carbon storage within the OBR using comprehensive spatial analysis and statistical modeling. Leveraging a diverse range of spatial datasets, including land cover, biomass, and primary production data, we examine the variability in carbon characteristics across biosphere zones and over time. Our analysis reveals significant differences in land-cover distributions among biosphere zones, with the core zone exhibiting the highest proportion of forest cover. Furthermore, examination of carbon characteristics highlights distinct spatial patterns and temporal trends, with the core zone maintaining stable carbon densities while the buffer and transition zones display greater variability.

The conclusions of this study underscore the importance of utilizing available datasets to enhance our understanding of carbon dynamics within the OBR, providing valuable insights for land management and conservation strategies. Recommendations include prioritizing the standardization of carbon measurement methodologies and fostering collaboration within the OBR community to address emerging challenges and opportunities in carbon management and conservation.

Acknowledgments

I extend my deepest gratitude to Dr. Kathleen Bergen for her unwavering patience, invaluable guidance, and meticulous mentorship throughout this practicum. Her expertise, dedication, and willingness to provide detailed assistance have been instrumental in shaping this project.

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1. Introduction

1.1 Background and rationale

Biosphere reserves are a global network coordinated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) Man and the Biosphere Programme and were founded to address “How can we reconcile conservation of biodiversity and biological resources with their sustainable use?” (UNESCO 1996). The original University of Michigan Biological Station (UMBS) Biosphere Reserve designated by UNESCO in 1979 was limited to primarily the 4,200 ha UMBS property (Heinen and Vande Kopple 2003). In 2017, after submitting a periodic 10-year review to UNESCO on its fulfillment of Biosphere Reserve criteria, the UMBS Biosphere Reserve received recommendations for an outward-looking and expanded management model (UNESCO, 2019). Following the recommendation, the UMBS Biosphere Reserve was re-envisioned and rebranded as Obtawaing Biosphere Reserve (OBR) in 2021, becoming a much larger and more inclusive Biosphere Region (Jiménez and Frederickson 2022; Tallant 2019; Sherbourne 2021). It is now comprised of several protected ‘core areas’ (including UMBS) nested in a larger multi-use buffer and transitional extent; together, these areas comprise over 23,000 km^2 (2.3 million ha) of forest and other land uses in northwestern lower Michigan and the eastern Upper Peninsula (Figure 1).

The stewards of the expanded OBR lands are also considerably more multifaceted than UMBS alone. They are comprised of local, state, and federal land management agencies and entities; land conservancies; tribal lands and leadership; large industrial and investment landowners; and small non-industrial private landowners. Approximately 65% of forested land in Michigan is privately owned. The new name ‘Obtawaing,’ an Anishinaabe word meaning ‘the half-way or meeting point’, was suggested by the United Tribes of Michigan (Jiménez and Fredrickson 2022). Over the past year UMBS, SEAS, and OBR steward and rights-holder partners began to define the geographic extent and their vision. Like UMBS, a core interest of these diverse partners is the state, condition, and health of the region’s forests and the forest carbon and other sustainability opportunities and risks associated with them.

1.2 Goal and objectives

To support ongoing collective OBR strategies, relevant data and information are now needed at the OBR-wide scale. This drives the research questions for this practicum: 1) What is the spatial distribution of forest characteristic of the new broader OBR region? 2) How are the spatial distributions and magnitudes of forest biomass/carbon plus other key forest characteristics distributed among different biosphere zones? We expect that geospatial data and visualization and OBR-wide statistics may form the first steps in an integrative approach to addressing OBR start-up needs and these initial research questions. Our specific objectives at this stage are to:

1. Compile regional-scale geospatial datasets customized to the newly re-envisioned OBR.
2. Analyze the characteristics of forest distribution and carbon storage in the OBR
3. Provide results as GIS databases, statistical summaries and map layouts; solicit steward-partner input and feedback on future geospatial framework directions.

2. Study Area

Stretching from the Sleeping Bear National Lakeshore across the Mackinac Straits to Sugar Island near Sault Ste. Marie, the OBR encompasses a substantial portion of northwestern lower Michigan and the eastern Upper Peninsula. Bordered by Lake Michigan to the west and Lake Huron to the east, the region spans latitudes 44.15°N to 46.77°N and longitudes 86.34°W to 83.19°W. Elevation in the OBR ranges from 127 to 515 meters, with slopes range from 0° to 41° (U.S. Geological Survey, 2019).

The study area within the OBR exhibits a diverse range of vegetation, including dense forests, open shrubland and grasslands, and rich forested wetlands (Dewitz, 2023). Forest cover predominates, providing habitats for a variety of wildlife species and ecosystem services. The OBR contains a complex and intertwined network of water systems, influenced by glacial processes and geological formations (Graves, Dean, Smedsrud, & Yrad, 2022). Watersheds and subwatersheds define the movement and storage of water across the landscape, ultimately draining to common outlets. These water systems connect Michigan's inland waterways to the

Great Lakes, serving as vital conduits for ecological processes and human activities within the region.

The OBR contains tribal reservations, townships, and population centers such as Traverse City, Charlevoix, Petoskey, and Sault Ste. Marie. Within the region, several core protected areas encompass diverse ecosystems and serve various management purposes, all surrounded by a mix of land-use types in the buffer and transition zones. This new OBR design creates an interesting mosaic of lands and partners, and represents a realistic approach to sustainable development in the expanded "areas of influence" surrounding the cores and buffers.

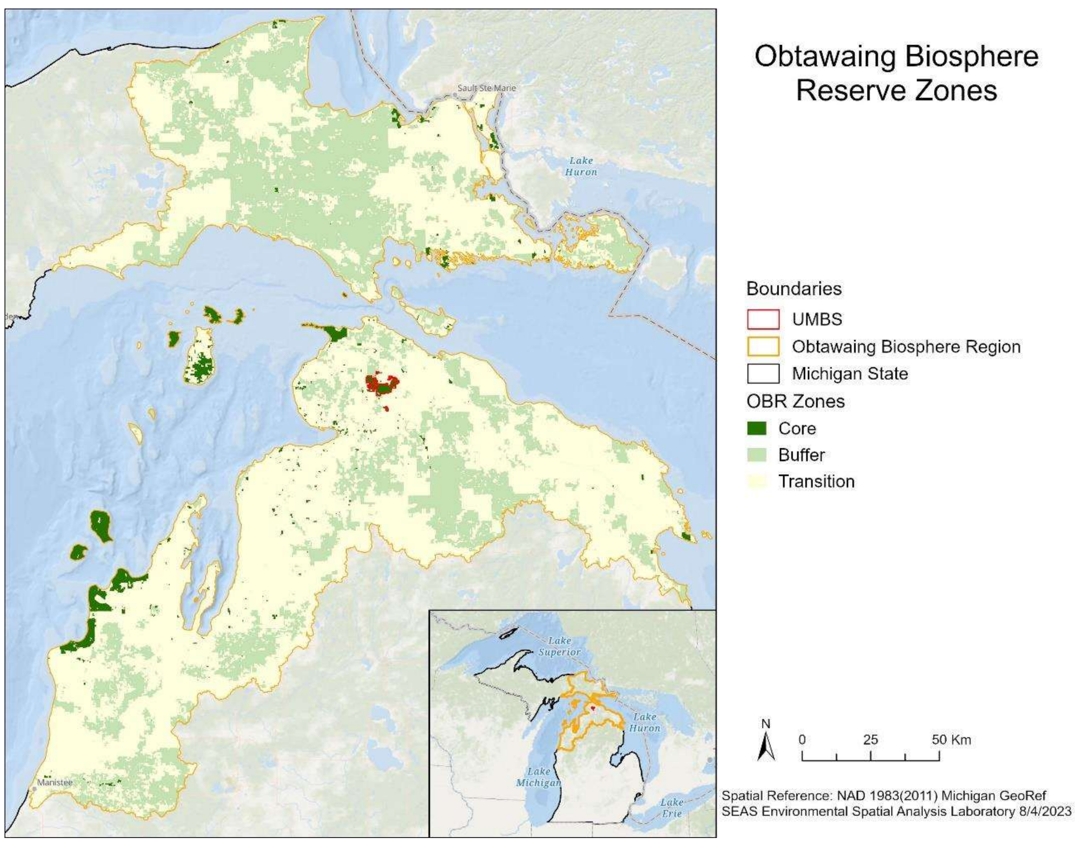


Figure 1. Obtawaing Biosphere Regional Boundary. The study area includes lands in both the upper and lower peninsulas of Michigan, and all the islands with an area exceeding 1 hectare.

3. Data and Methods

3.1 Spatial and quantitative datasets

A comprehensive spatial dataset was compiled, encompassing key geographic feature boundaries alongside physical data such as ecoregion, geology, and terrain. Additionally, forest and land-cover/use, as well as biomass and primary production data, were included in the dataset. To ensure accessibility and facilitate future updates, the compilation was restricted to publicly available source data.

Most spatial data within the dataset were created to be inter-converted between vector and raster formats, enabling versatility in analysis methods. Additionally, an aligned version has been prepared for all raster data within the extents of the OBR and UMBS, ensuring conformity with the land-cover raster sourced from the National Land Cover Database (NLCD). This alignment facilitates raster modeling on a standardized grid across the entire OBR and UMBS areas. The full list of data contained within the database is provided in Table 1.

Table 1. Datasets in the new OBR Geospatial Data Framework. Accessible via: ArcGIS Hub Link. All map layouts are provided in the appendices.

Content/ Theme	Extent/s	Source	Date/s	Format/s	Raster Spatial Resolution /s
		General			
GLB & GLB_US Boundary	GLB GLB_US	The GLAHF spatial database - Great Lakes Watershed Boundaries	n/a	vector .shp	n/a
MI Boundary	MI	ESRI(manually refined)	n/a	vector .shp	n/a
OBR Boundary	OBR		n/a	vector .shp	n/a
UMBS Boundary	UMBS	UMBS	n/a	vector .shp	n/a
MI Roads	MI OBR UMBS	Michigan GIS Open Data - MDOT RH 2023 GDB	2023	vector .shp	n/a
MI Cities and Towns	MI OBR UMBS	Michigan GIS Open Data - Minor Civil Divisions (Cities & Townships)		vector .shp	n/a
MI Counties	MI OBR UMBS	Michigan GIS Open Data - Counties(v17a)		vector .shp	n/a
OBR Zones	OBR	Huron Pines	2023	vector .shp	n/a
		Physical			
Ecoregions Level III	GLB MI	EPA - Ecoregions of North America	2010	vector .shp	n/a
Ecoregions Level IV	MI OBR UMBS	EPA - Level III and IV Ecoregions of the Continental United States	2013	vector .shp raster	30 m
Regional Landscape	MI OBR	Matthaei Botanical Gardens and Nichols Arboretum - Regional	2020	vector .shp	n/a

Ecosystems of MI	UMBS	Landscape Ecosystems of Michigan, Minnesot and Wisconsin			
Quaternary Geology	MI OBR UMBS	Michigan GIS Open Data - Quaternary Geology Map	2023	vector .shp	n/a
Gridded SSURGO raster	MI OBR UMBS	Gridded Soil Survey Geographic (gSSURGO) Database		raster	10 m
Elevation	GLB MI OBR UMBS	USGS 3D Elevation Program - 1 arc-second DEM		raster	30 m
Slope	GLB MI OBR UMBS	Derived from Elevation		raster	30 m
Aspect	GLB MI OBR UMBS	Derived from Elevation		raster	30 m
Great Lakes	GLB	GLAHF spatial database		vector	
Lakes	MI OBR UMBS	Michigan GIS Open Data - Michigan Lake Polygon		vector .shp raster	30 m
Rivers and Streams	MI OBR UMBS	Michigan GIS Open Data - Hydrography Lines(v17a)		vector .shp raster	30 m
Forest- and Land-Cover/Use					
Land Cover	GLB_US MI OBR UMBS	US Multi-Resolution Land Characteristics (MRLC) Consortium - NLCD Land Cover	2001 2011 2019 2021	raster .img	30 m
Land Change	GLB_US MI OBR UMBS	MRLC - NLCD Land Cover Change Index	2001 2011 2019	raster .img	30 m
Forest Cover	GLB_US MI OBR UMBS	MRLC - NLCD Tree Canopy Cover	2011 2019 2021	raster .tif	30 m
Impervious	GLB_US MI OBR UMBS	MRLC - NLCD Percent Developed Imperviousness	2001 2011 2019	raster .img	30 m
North America Land Cover	GLB	MRLC - North American Land Change Monitoring System	2020	raster .img	30 m
Pre-European Settlement Vegetation Ungrouped	MI OBR UMBS	Michigan GIS Open Data - MI Vegetation 1800	2019	vector .shp raster	30 m
Pre-European Settlement Vegetation Grouped	MI OBR UMBS	Michigan GIS Open Data - MI Vegetation 1800	2019	vector .shp raster	30 m

Biomass & NPP					
NPP	GLB MI OBR UMBS	The Land Processes Distributed Active Archive Center (LP DAAC) - MODIS/Terra Net Primary Production Gap-Filled Yearly L4 Global 500 m SIN Grid	2001 2010 2019 2022	raster	500 m 30 m
GPP	GLB MI OBR UMBS	LP DAAC - MODIS/Terra Net Primary Production Gap-Filled Yearly L4 Global 500 m SIN Grid	2001 2010 2019 2022	raster	500 m 30 m
Biomass	GLB_US MI OBR UMBS	NASA North American Carbon Program (NACP) National Biomass and Carbon Dataset - V.2 (NBCD 2000), U.S.A., 2000	2000	raster	30 m
Biomass	GLB_US MI OBR UMBS	NASA National Forest Carbon Monitoring System (NFCMS) - Conterminous USA, 1990-2010	2010	raster	30 m

Land-cover data was mapped to visualize the forest distribution in OBR (Figure 2a, 2b). The National Land Cover Database (NLCD) provides nationwide data on land cover and land-cover change at a 30m resolution with a 16-class legend based on a modified Anderson Level II classification system (Homer et al. 2007; Homer et al. 2015; Dewitz 2023). The dataset underwent reclassification from its initial 20 categories into two distinct versions aimed at improving representativeness. Version 1 has seven land-cover types which are Lakes/Water, Developed/Urban, Shrubland/Grassland, Forest, Agriculture, Forested Wetland and Marsh. Version 2 is more generalized with four types which are: Lakes/Water, Developed/Urban, Forest (which include Forest and Forested Wetland in version 1) and non-Forest.

In investigating carbon-related characteristics within the OBR, the study mapped aboveground biomass (AGB) (Figure 2c), gross primary productivity (GPP) (Figure 2d), and net primary productivity (NPP) (Figure 2e). Biomass data was obtained from two sources: the National Biomass and Carbon Dataset for the Year 2000 (NBCD 2000) and the National Forest Carbon Monitoring System (NFCMS). The NBCD 2000 dataset includes two biomass layers derived from the Forest Inventory and Analysis Database (FIADB) Tree Table and nationally consistent allometric equations (NCEs) by Jenkins et al. (2003). Both layers represent above-ground, live, dry biomass, with units in kg/m^2 (Kellndorfer et al. 2013). The NFCMS biomass layer reflects the carbon fraction of above-ground woody biomass, with units in $g\ C/m^2$ (Williams et al. 2020). Aboveground biomass denotes the total dry mass of living vegetation above the soil surface within a defined area. Conversion factors of 0.5 and 0.001 were applied to the NBCD and NFCMS data, respectively, to standardize units to Mg C/ha.

Furthermore, NPP and GPP data were sourced from the MODIS/Terra Net Primary Production Gap-Filled Yearly L4 Global 500 m SIN Grid dataset. These data are available as HDF files, featuring layers for NPP, GPP, and quality control. NPP quantifies the organic matter produced by plants through photosynthesis after accounting for respiration, while GPP represents the total organic matter produced before considering respiration losses. NPP and GPP layers both report the annual sum of above-ground and below-ground productivity as a carbon fraction (Running and Zhao 2022). Scale factors were applied to ensure NPP and GPP layers were expressed in units of Mg C/ha/yr. These attributes serve as vital indicators of ecosystem productivity, offering insights into its carbon storage capacity.

3.2 Chi-square analyses of relationships between land-cover types and biosphere zones

To understand broad-scale relationship over the entire study region, we used pie charts plus chi-square statistical tests of independence to shed light on over- or under-representation of different land-cover types within biosphere zones. Distributions of land-cover types from the National Land Cover Dataset for the years 2001, 2011, and 2021 within the three biosphere zones were first quantified and visualized. Then, multiple chi-square models were conducted using ‘chisq.test()’ in R to test whether land-cover types were present in significantly different proportions within biosphere zones, and whether land-cover types were present in significantly different proportions over years with in same zone category. We tested the null hypothesis that distributions were the same for each land-cover type in the particular model. To not inflate significances, we performed all tests on a stratified random sample of factor data raster cells.

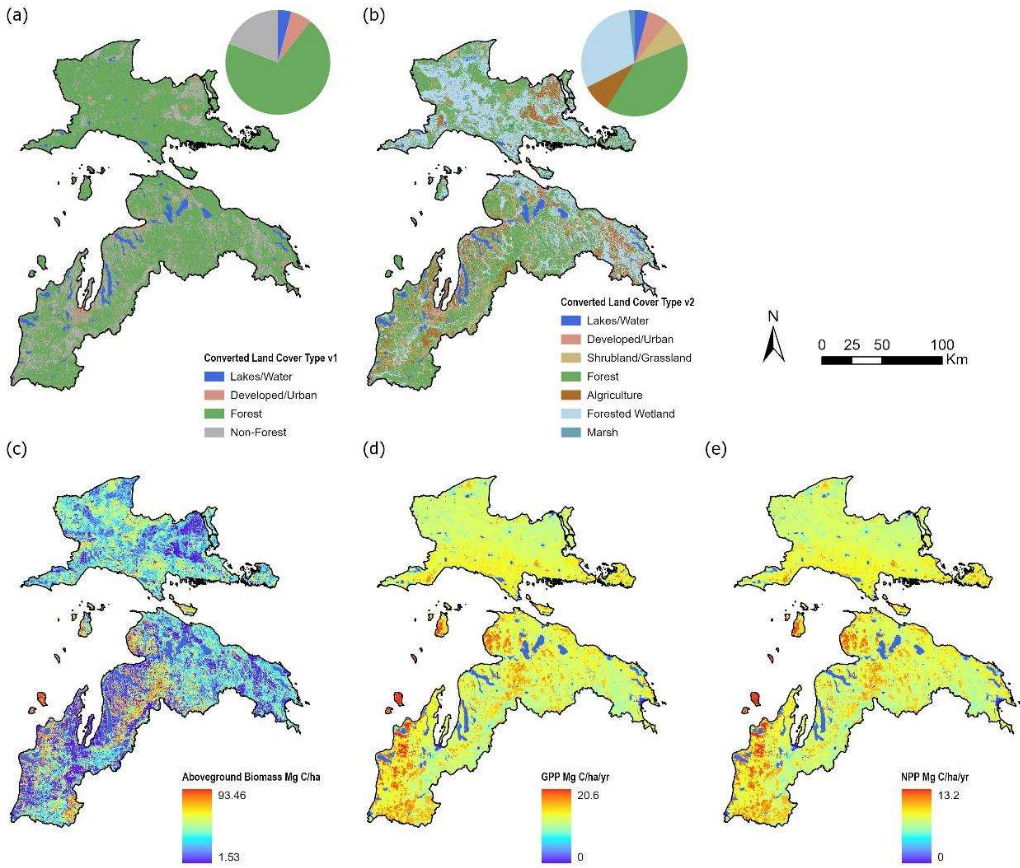


Figure 2. Maps illustrating land-cover and forest characteristics in the study region, featuring the most recent data available in the dataset (land cover: NLCD 2021; GPP and NPP: MODIS 2022; AGB: NFCMS 2010). Pie charts display the distributions within the entire study region.

3.3 Analysis of variance for carbon characteristics in the biosphere zones

To check if the carbon characteristics distributed evenly in different zones or in same zone over years, box plots were made and several analysis of variance (ANOVA) models were conducted using 'aov()' in R with AGB, NPP and GPP data within different biosphere zones and from different years. The null hypothesis is that distributions were the same for each land-cover type in the particular model. Turkey's post-hoc tests were performed to figure out the differences between each category. The models were also run on the random sample to avoid inflating significances.

4. Results and Discussion

4.1 Spatial variation in land-cover distributions and chi-square relationships within biosphere zones

The chi-square tests revealed significant differences in the distribution of land-cover types across biosphere zones in 2021 ($\chi^2 = 131.01$, $p < 2.2e-16$). However, when examining the temporal trends of land-cover types within each zone, the chi-square tests did not yield significant results ($p > 0.05$ for all three years), indicating relatively consistent proportions of land-cover types over the years within each zone category.

As depicted in the pie charts (Figure 4), the core zone consistently exhibits the highest proportion of forest distribution, exceeding 51% for all three years. In contrast, the buffer zones show a lower proportion of forest, approximately around 47%. The transition zone consistently has the lowest forest distribution, hovering around 36%. However, the buffer zone displays the highest proportion of forested wetland, approximately 41%, followed by the core zone with approximately 31%. The transition zone has the lowest proportion of forested wetland, occupying only around 25% of the zone.

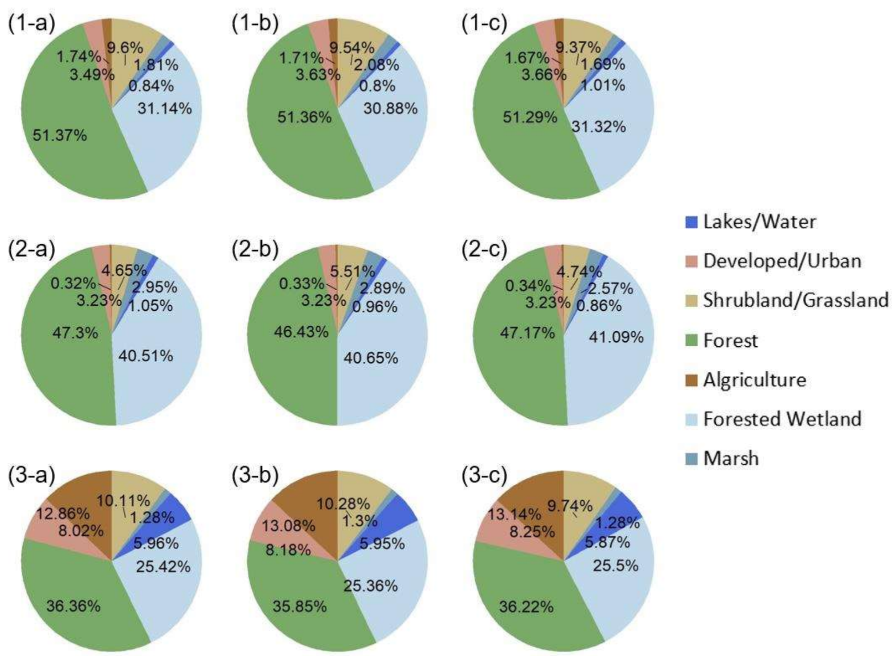


Figure 3. Land-cover distribution sourced from NLCD in OBR across different zones: (1) core zone, (2) buffer zone, (3) transition zone, for the years (a) 2001, (b) 2011, (c) 2021.

4.2 Carbon characteristics across biosphere zones

The OBR harbors a substantial total forest ecosystem carbon reserve, amounting to 213,783,682 metric tons, with an average carbon density of 51.6 metric tons per acre in 2010 (Williams et al. 2020). However, this carbon stock is not uniformly distributed across the region; rather, there exist distinct hotspots and areas exhibiting overall higher or lower carbon density. The results of ANOVA tests underscored significant differences in carbon characteristics among different biosphere zones.

These tests revealed substantial variances in AGB distributions across biosphere zones, notably between the Transition Zone and both the Core and Buffer Zones, particularly evident in the years 2000 and 2010 and aligned with land-cover distribution patterns. Additionally, notable distinctions emerged in GPP and NPP distributions across zones, with significant differences observed in these attributes within the Transition Zone compared to the other two zones.

Furthermore, the analysis of GPP and NPP data over three different years indicated dynamic changes in carbon characteristics over time. The Core Zone exhibited the most stable carbon distribution, experiencing only slight increases in GPP and NPP from 2001 to 2010. In contrast, the Buffer Zone displayed the highest variability, with both GPP and NPP experiencing significant increases from 2001 to 2010, followed by decreases from 2010 to 2022. These findings highlight the complex dynamics of carbon cycling within the biosphere region and underscore the importance of ongoing monitoring and adaptive management strategies to sustainably manage carbon stocks and mitigate potential environmental impacts.

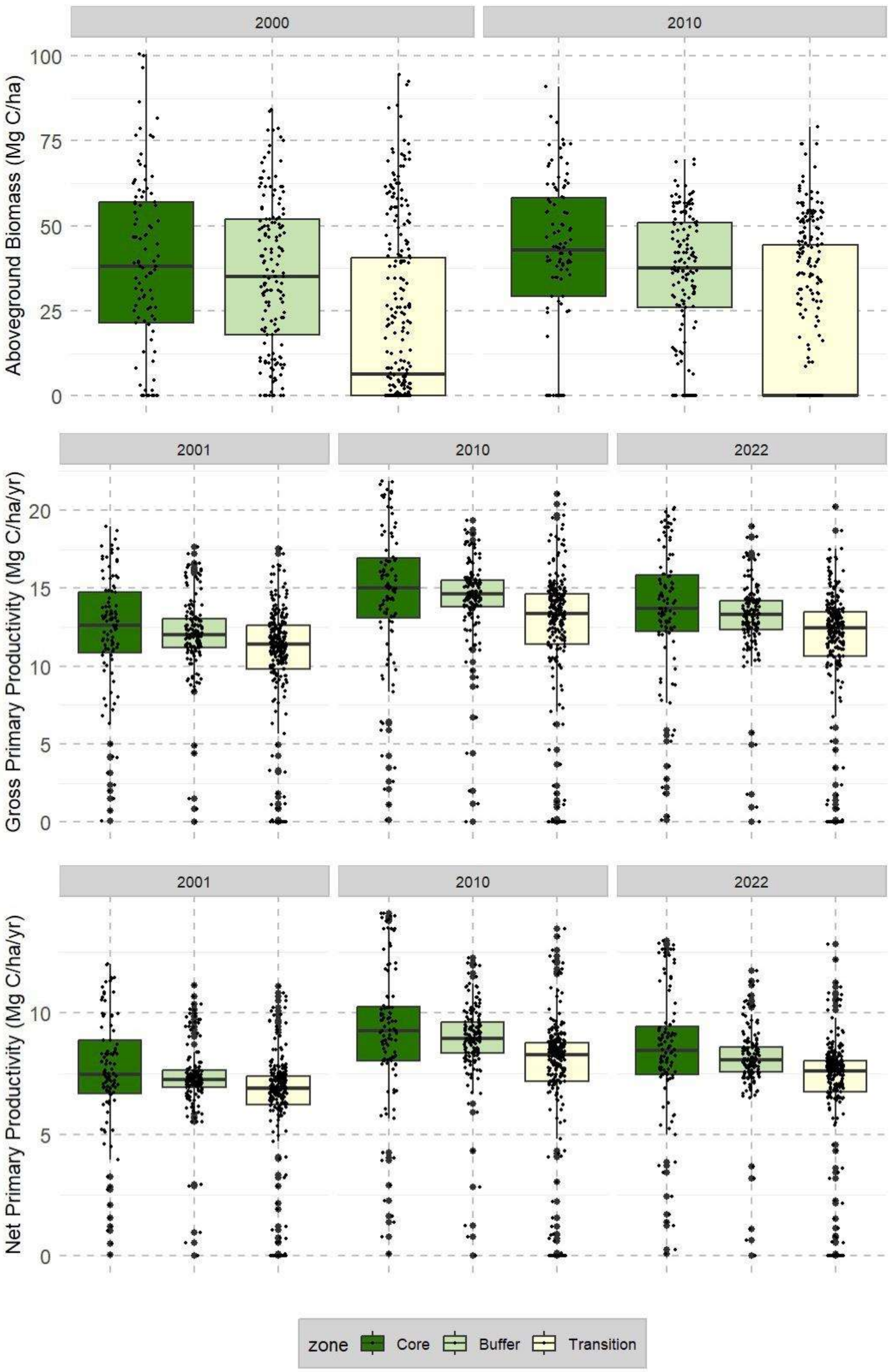


Figure 4. Aboveground biomass (source: NBCD, NFCMS), gross primary production and net primary production (source: MODIS) within different OBR zones over the years.

Table 2. ANOVA tests for carbon characteristics within biosphere zones/ over years (2001, 2010, 2022). AGB data is from NBCD and NFCMS dataset, GPP and NPP data is from MODIS products. Significant pairs are with a p value less than 0.05.

Tests	Variables	Mean Square	F value	Sig.	Post-hoc significant pairs
1	2000 AGB within different zones	15552	25.42	< 0.001	Transition - Core, Transition - Buffer
2	2010 AGB within different zones	17605	31105	< 0.001	Transition - Core, Transition - Buffer
3	2022 GPP within different zones	281.12	17.66	< 0.001	Transition - Core, Transition - Buffer
4	temporal analysis of GPP within core zone	153.75	7.945	< 0.001	2001 - 2010
5	temporal analysis of GPP within buffer zone	208.14	29.25	< 0.001	2001 - 2010 2022 – 2010 2001 - 2022
6	temporal analysis of GPP within transition zone	191.16	9.35	< 0.001	2001 - 2010
7	2022 NPP within different zones	126.36	21.3	< 0.001	Transition - Core, Transition - Buffer
8	temporal analysis of NPP within core zone	64.96	8.322	< 0.001	2001 - 2010
9	temporal analysis of NPP within buffer zone	91.78	35.03	< 0.001	2001 - 2010 2022 – 2010 2001 - 2022
10	temporal analysis of NPP within transition zone	77.09	10.34	< 0.001	2001 - 2010 2022 - 2010

4.3 Discussion

This study provides valuable insights into the spatial distribution of carbon storage and temporal variations within the OBR. Our analysis reveals a heterogeneous distribution of carbon across the OBR, with concentrations notably prominent in core zones along the west coast of the Lower Peninsula and surrounding smaller islands (see Figure 2c, 2d, 2e). Carbon storage within the core zone appears more stable, likely attributable to its higher proportion of forested land compared to other zones, with most of the core areas being officially managed protected areas.

However, there are limitations associated with the carbon storage indicators used in this study. As demonstrated in Table 3, the NPP data retrieved from MODIS exhibit significant differences compared to data reported via fieldwork. To facilitate comparison between different data sources, aboveground, belowground, and total NPP of dry matter and carbon fraction were calculated accordingly, assuming carbon mass to be 50% of dry matter, with aboveground mass accounting for 60% of the total and belowground for 40%. Despite differences between years, the NPP data from MODIS were significantly higher than that retrieved from fieldwork, potentially introducing confusion in further research.

One possible reason for the discrepancies is that the definition of AGB and NPP differs across different datasets. In Dronova's and Nave's work, measurements were converted to the annual increment of woody biomass (woody ANPP) of sampled species using allometric equations (Dronova et al. 2011; Nave et al. 2017). In addition to live mass increment, Gough's work also includes foliar losses to herbivory detritus mass production which is the sum of leaf, fine and course woody debris, and fine root litter production, this makes the values were higher than the other two studies (Gough et al. 2008). The MODIS product, however, is a cumulative composite of GPP/NPP values based on the radiation use efficiency concept (Running and Zhao 2022).

Another contributing factor to the observed differences is the quality of the methodologies employed. Methodological constraints for fieldwork were identified as limiting the certainty of below-ground carbon storage estimates (Gough et al. 2008). MODIS data uses a spatially non-linear interpolation of coarse-resolution meteorological data aiming to improve data quality, potentially introduces biases and leads to overestimation of NPP in heterogeneous landscapes. Temporal differences also contribute to these disparities as the timing of satellite data acquisition may not align perfectly with ground-based measurements. The sampling time periods for fieldwork varied from three months to several years, while MODIS data are derived from 8-day periods, potentially complicating efforts to ensure data consistency and conduct meaningful temporal analyses of biomass trends over time.

For further monitoring and research regarding carbon storage within the OBR, it is advisable to utilize data from the same product or data source when conducting temporal analyses to maintain consistency and reliability. Remote sensing data like Gross Primary

Production (GPP) and NPP provided by MODIS can be of great help in this kind of research. On the other hand, field-based measurements tailored to the unique characteristics of the OBR region can offer complementary information that enhances our understanding of carbon distribution patterns. Fieldwork allows for the collection of site-specific data on vegetation composition, structure, and biomass, which can be crucial for validating and refining remote sensing estimates.

To enhance the reliability of biomass data and gain a deeper understanding of the carbon potential of the OBR, future research efforts should prioritize the development of standardized methodologies for carbon measurement and reporting within the OBR community. This standardization will ensure consistency and comparability across studies, allowing for more robust assessments of carbon stocks and fluxes over time. Moreover, facilitating data sharing and collaboration within the broader OBR community is essential for building a comprehensive understanding of carbon dynamics in the region. By pooling resources and expertise, researchers can leverage diverse datasets and methodologies to address complex research questions and inform decision-making processes effectively. Establishing a centralized database that houses standardized carbon data and stewardship information would facilitate data sharing and promote collaboration among stakeholders, ultimately leading to more informed land management decisions and conservation strategies.

Table 3. Carbon characteristics in the UMBS compiled from different data sources. Below-ground biomass was estimated where needed to compare above- and below-ground and totals. ANPP: Aboveground Net Primary Production, BNPP: Belowground Net Primary Production, DM: Dry Matter.

Source	Method	ANPP DM g/ m^2/yr	BNPP DM g/ m^2/yr	Total NPP DM g/ m^2/yr	ANPP Carbon g C/ m^2/yr	BNPP Carbon g C/ m^2/yr	Total Carbon g C/ m^2/yr
MODIS NPP 2001	Remote Sensing	974	650	1624	487	325	812
MODIS NPP 2011	Remote Sensing	1144	764	1908	572	382	954
Dronova, Bergen, Ellsworth 2011	field	530	353	883	265	177	442
Nave et al. 2017	field	230	153	383	115	77	192
Gough et al. 2008	field	842	560	1402	421	280	701

5. Conclusion

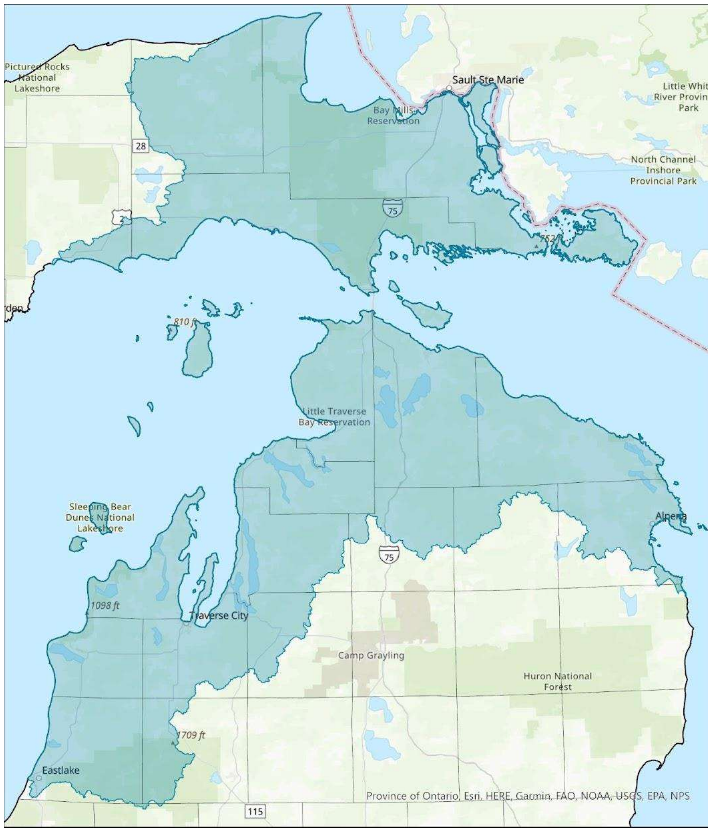
The outcomes of this project bear significant implications for both research and management within the Obtawaing Biosphere Reserve (OBR). The establishment of a comprehensive geospatial database stands as a cornerstone for ongoing endeavors in research and management within the OBR. By consolidating diverse datasets into a centralized platform, the geodatabase enhances accessibility and consistency, facilitating spatial analyses that are easy to share and collaborate on among stakeholders. This facilitates the derivation of valuable insights for decision-making processes.

Moreover, this spatial analysis enhances our understanding of the spatial patterns of forest and carbon-related characteristics within the region, providing crucial baseline information for future monitoring and conservation efforts. Informed decision-making processes regarding land management, conservation planning, and sustainable development can leverage the insights garnered from spatial analysis to prioritize conservation areas and implement targeted management strategies.

Furthermore, this project fosters collaboration and engagement among a wide array of stakeholders, including local communities, government agencies, and conservation organizations. By actively involving stakeholders in the research process and disseminating the results, this study fosters a sense of ownership and collective responsibility for the conservation of the OBR.

Future research endeavors could focus on integrating additional datasets, such as species distribution and detailed stewardship data, which would greatly enhance the ecological management and planning of the region. Additionally, investigating the long-term impacts of climate change on forest ecosystems within the OBR is crucial. Ongoing monitoring efforts and adaptive management strategies will be essential for effectively responding to emerging challenges and opportunities in the region.

6. Appendices: Layouts of Data with OBR Extent in the Geospatial Database

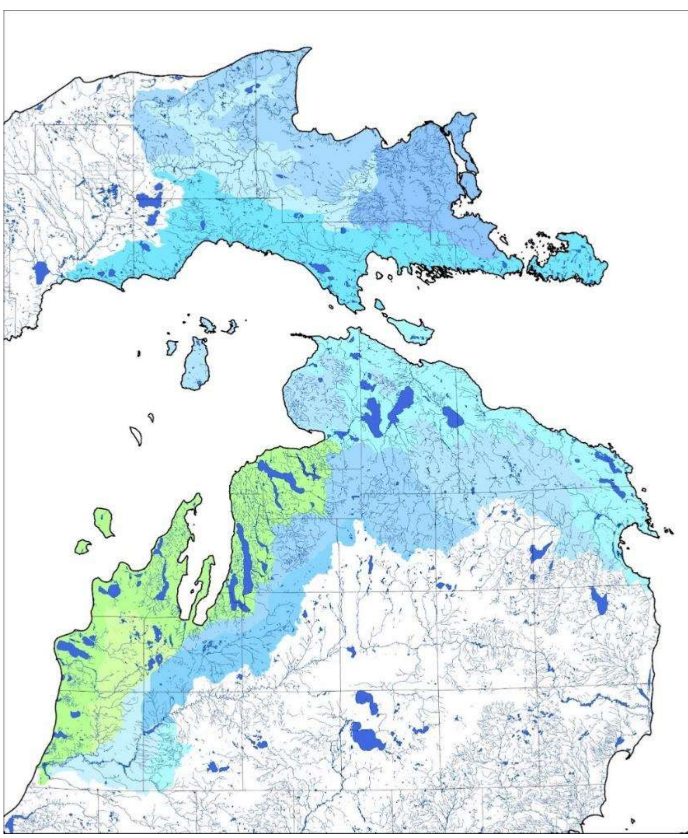


Obtawaing Biosphere Region Boundary

- Obtawaing Biosphere Region
- Michigan Counties

N 0 25 50 Km

Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 8/2/2023



Obtawaing Biosphere Region EPA Ecoregions

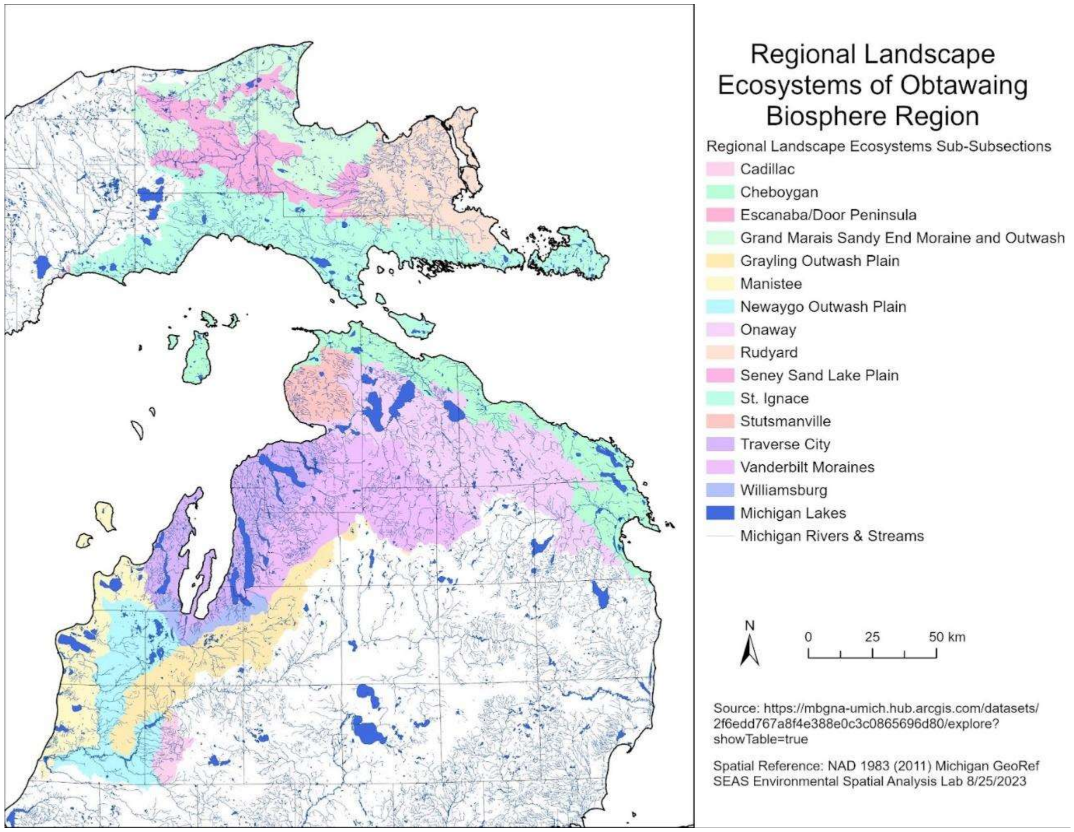
EPA Ecoregions Level IV

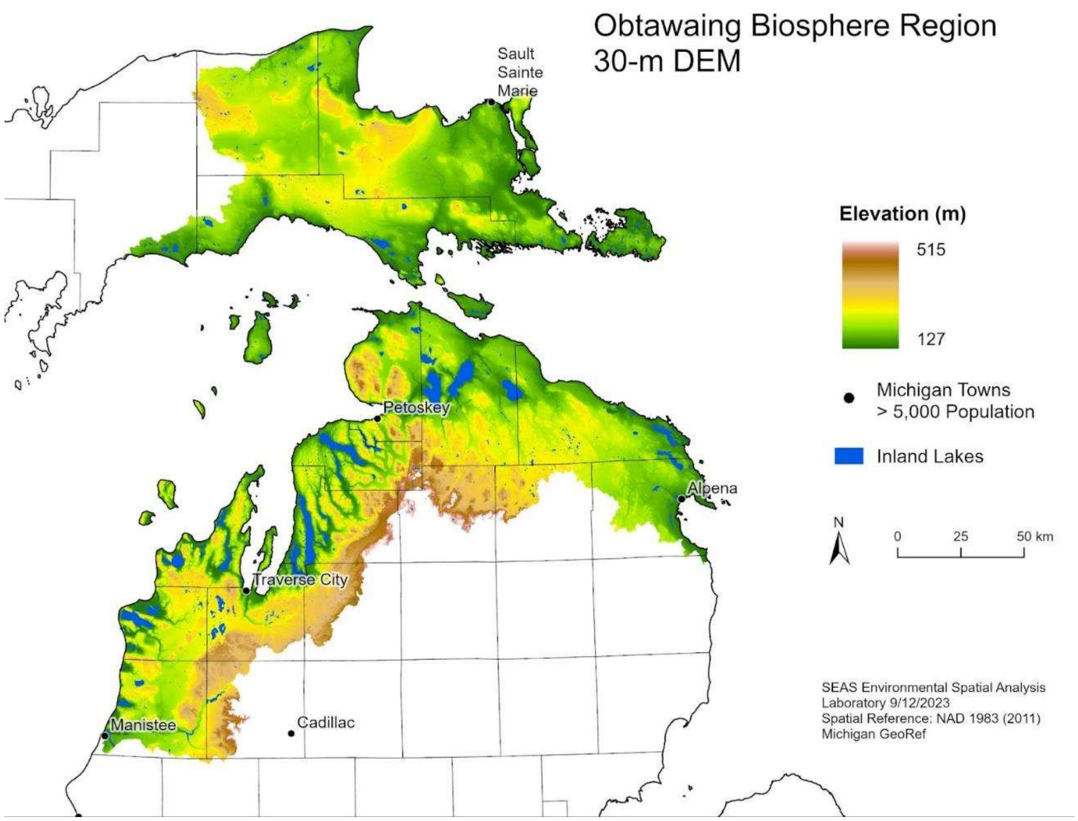
- 50aa Menominee-Drummond Lakeshore
- 50ab Cheboygan Lake Plain
- 50ac Onaway Moraines
- 50ad Vanderbilt Moraines
- 50ae Mio Plateau
- 50af Cadillac Hummocky Moraines
- 50ag Newaygo Barrens
- 50x Grand Marais Lakeshore
- 50y Seney-Tahquamenon Sand Plain
- 50z Rudyard Clay Plain
- 51m Manistee-Leelanau Shore
- 51n Platte River Outwash
- Michigan Lakes
- Michigan Rivers & Streams

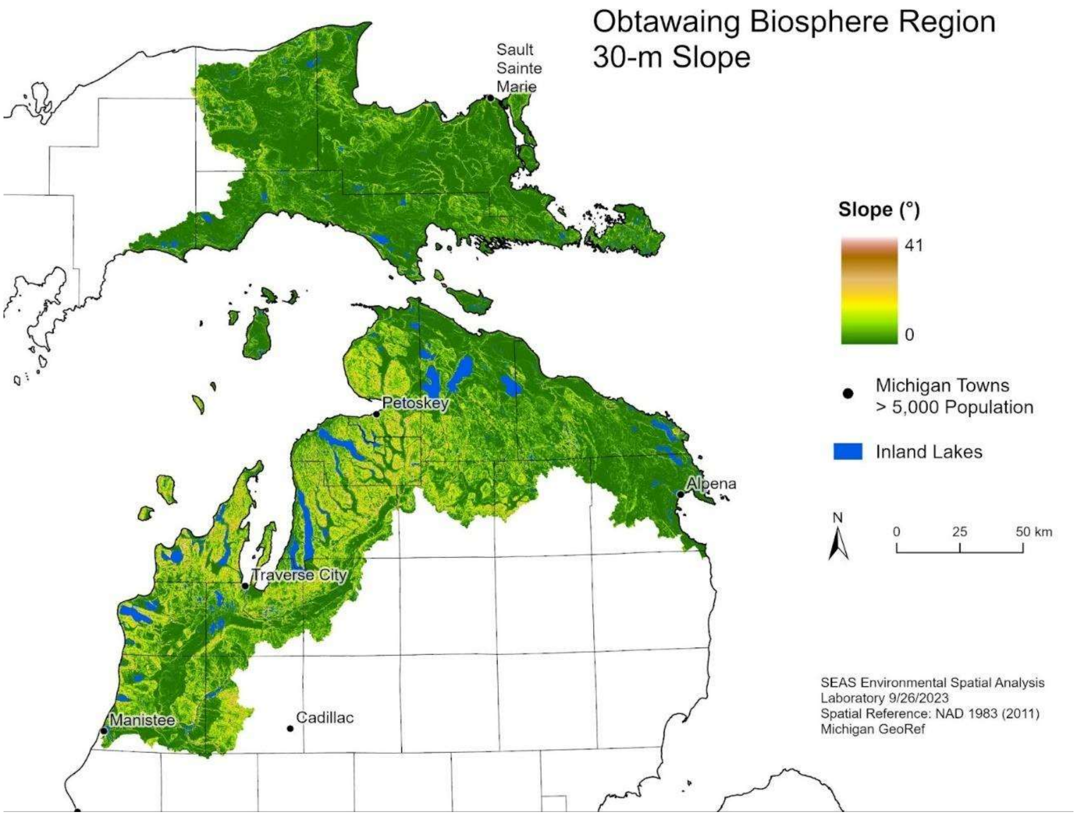
N 0 25 50 km

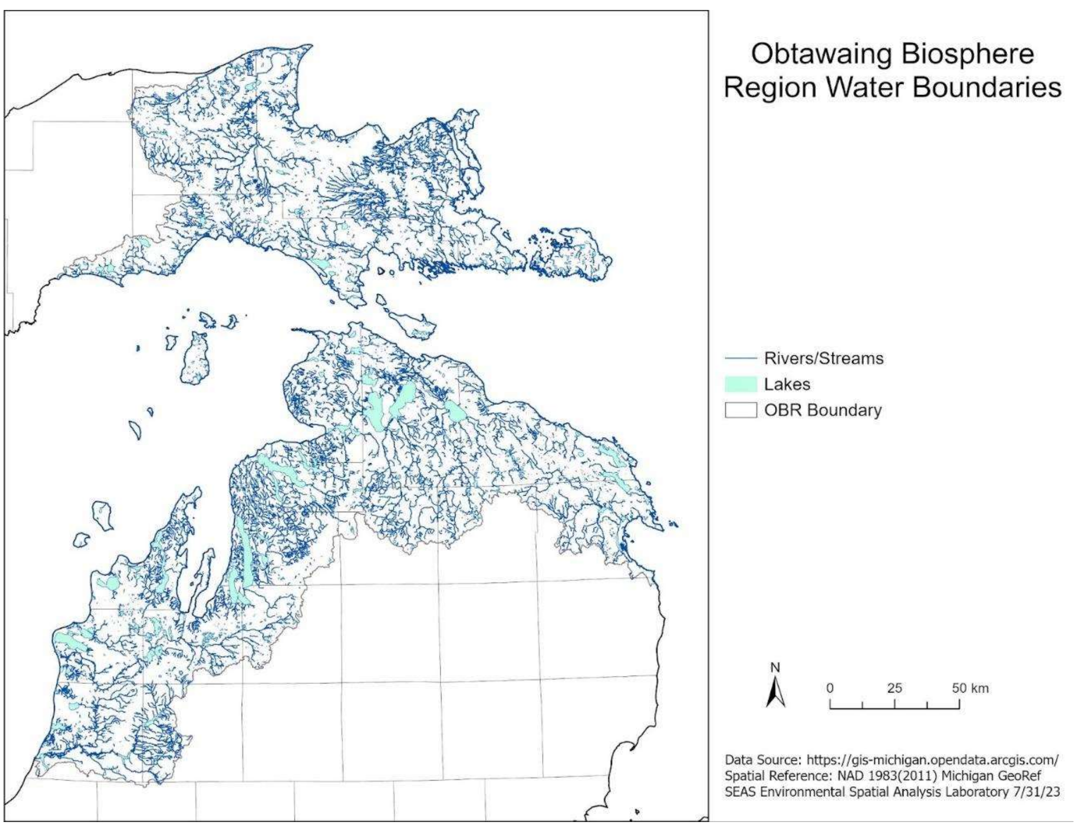
Source: https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

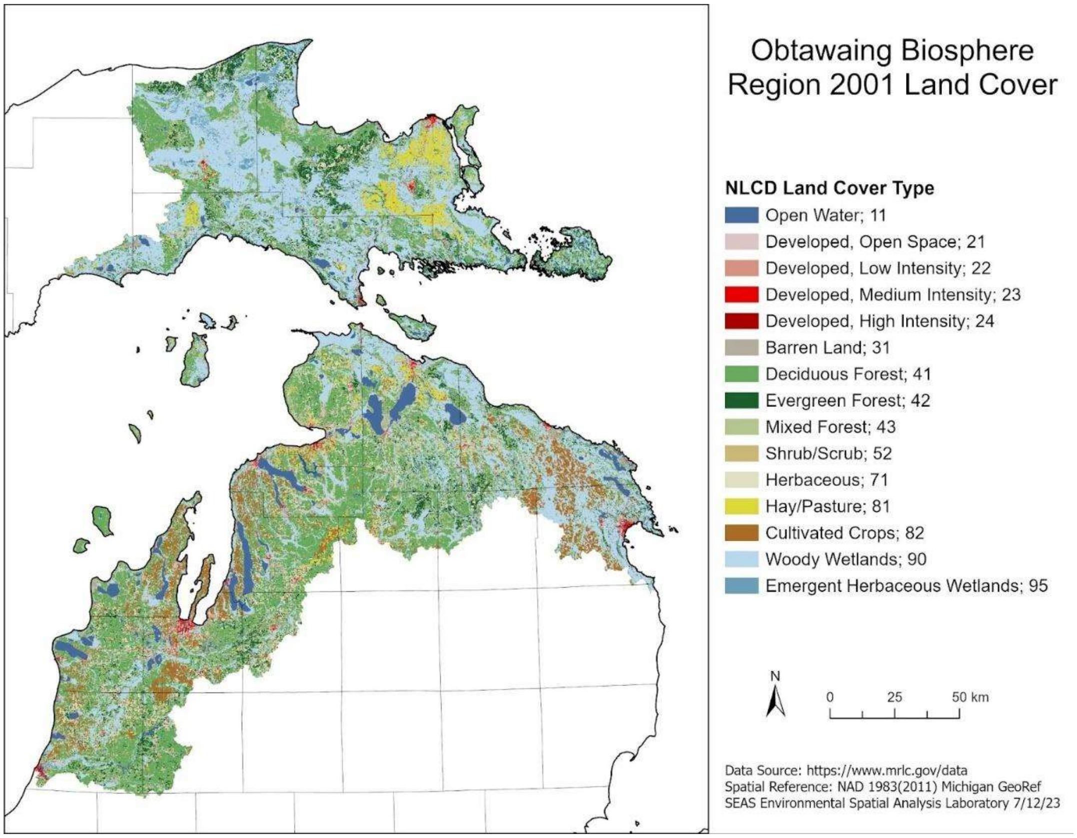
Spatial Reference: NAD 1983 (2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Lab 8/16/2023

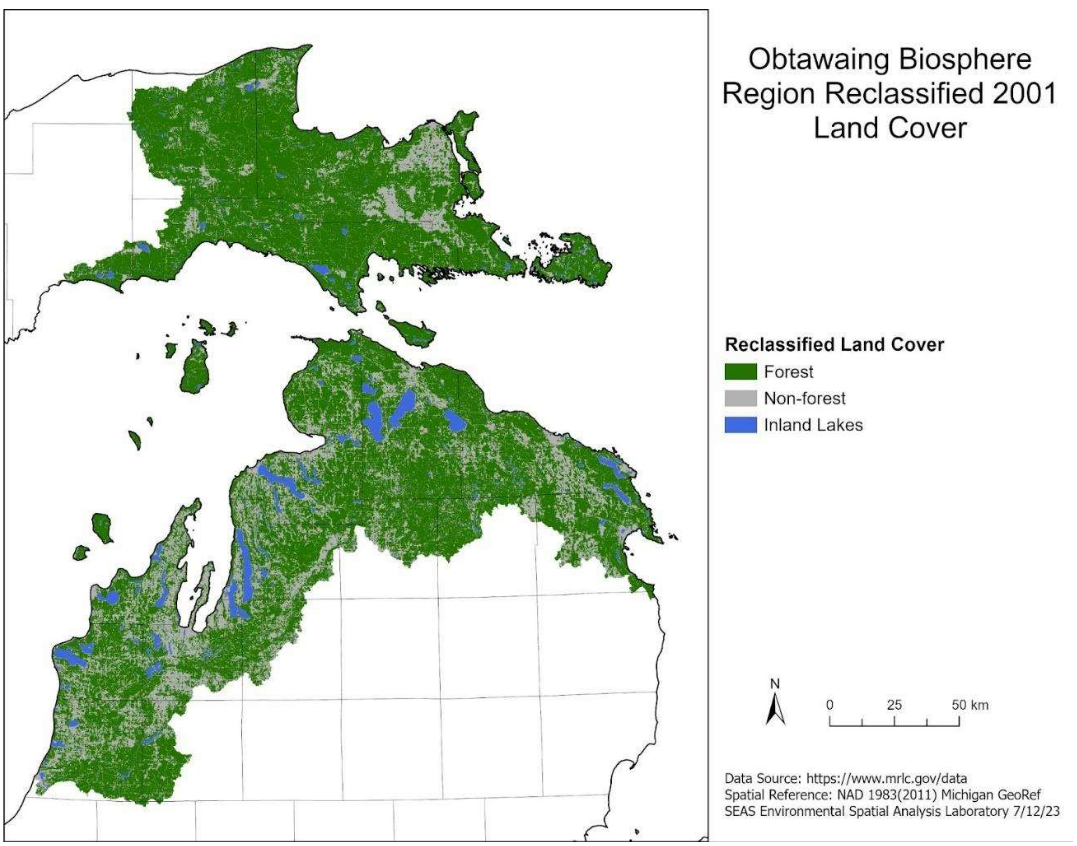

Regional Landscape Ecosystems of Obtawaing Biosphere Region
Regional Landscape Ecosystems Sub-Subsections
Cadillac
Cheboygan
Escanaba/Door Peninsula
Grand Marais Sandy End Moraine and Outwash
Grayling Outwash Plain
Manistee
Newaygo Outwash Plain
Onaway
Rudyard
Seney Sand Lake Plain
St. Ignace
Stutsmanville
Traverse City
Vanderbilt Moraines
Williamsburg
Michigan Lakes
Michigan Rivers & Streams
N
0 25 50 km
Source: https://mbgna-umich.hub.arcgis.com/datasets/2f6edd767a8f4e388e0c3c0865696d80/explore?showTable=true
Spatial Reference: NAD 1983 (2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Lab 8/25/2023

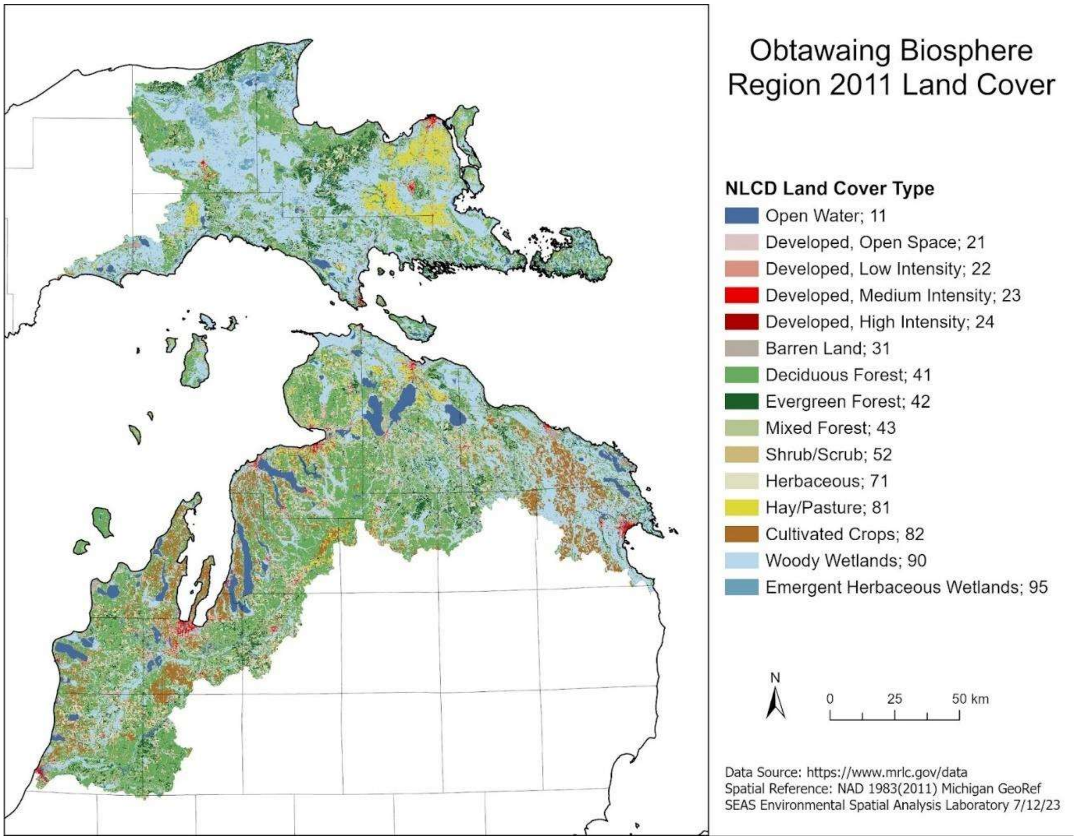

Obtawaing Biosphere Region
30-m DEM
Sault Sainte Marie
Petoskey
Alpena
Traverse City
Manistee
Cadillac
Elevation (m)
515
127
Michigan Towns > 5,000 Population
Inland Lakes
N
0 25 50 km
SEAS Environmental Spatial Analysis Laboratory 9/12/2023
Spatial Reference: NAD 1983 (2011) Michigan GeoRef

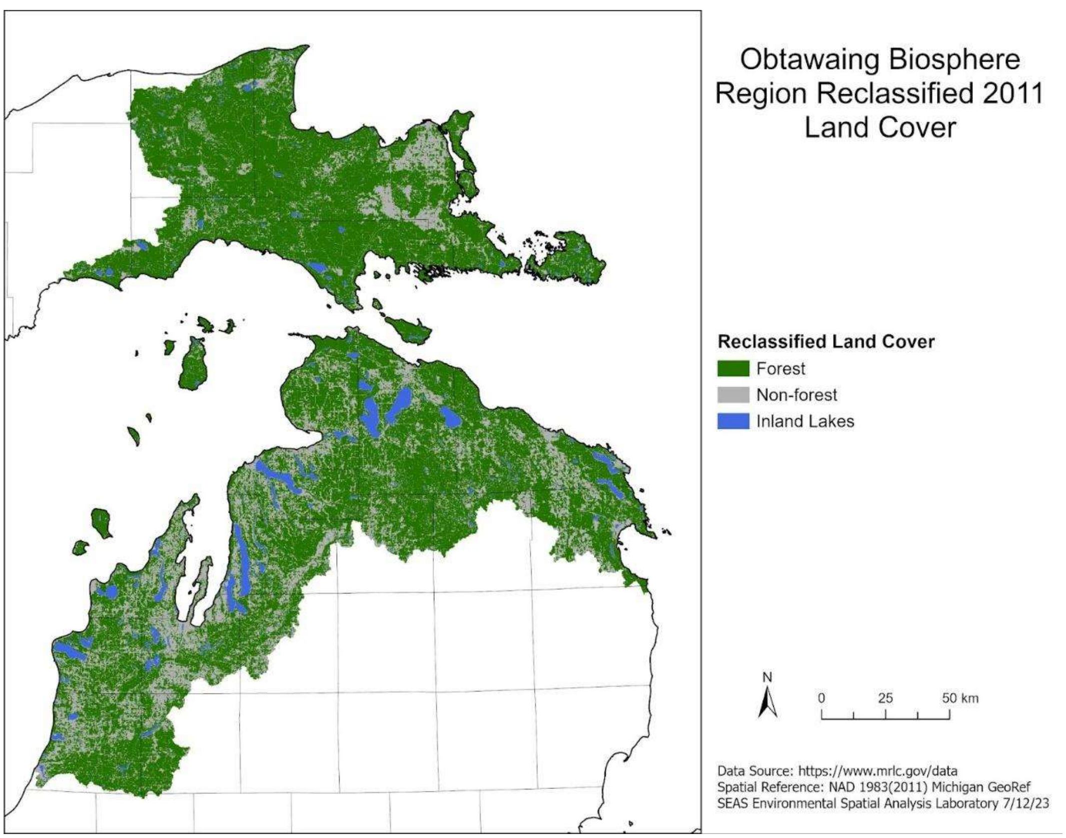

Obtawaing Biosphere Region
30-m Slope
Sault
Sainte
Marie
Slope (°)
41
0
Michigan Towns
> 5,000 Population
Inland Lakes
Petoskey
Alpena
Traverse City
Manistee
Cadillac
N
0
25
50 km
SEAS Environmental Spatial Analysis
Laboratory 9/26/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef

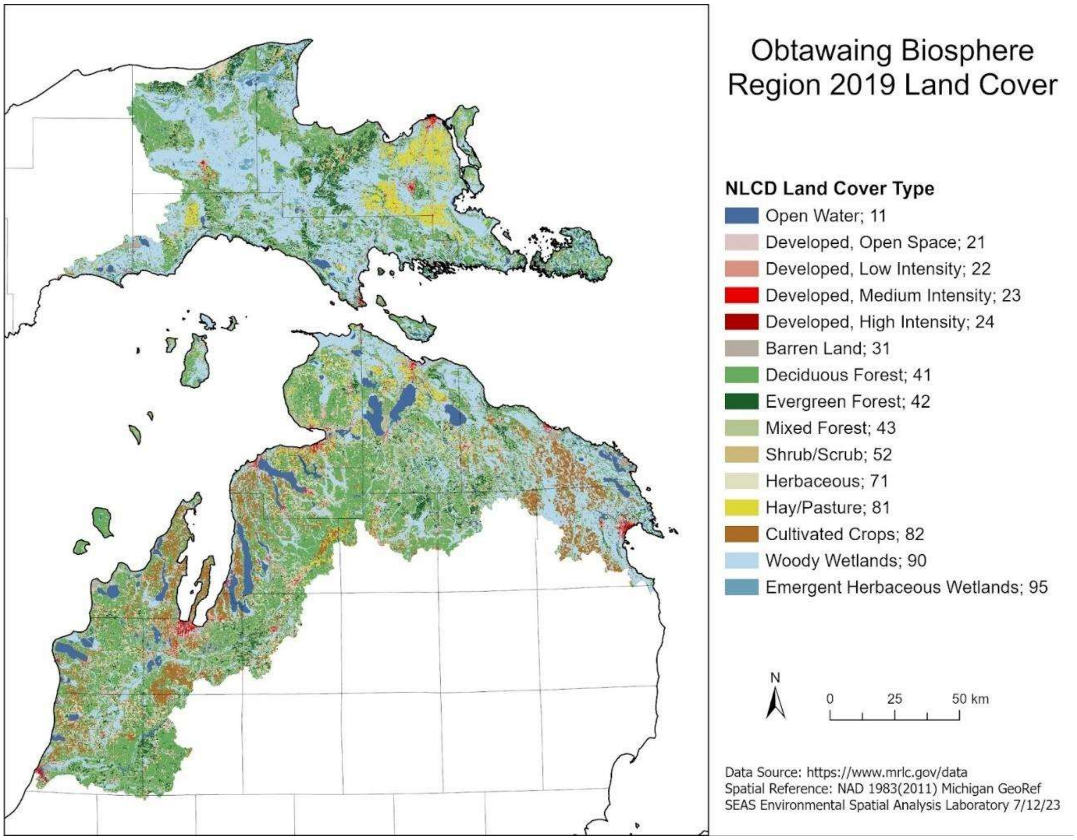

Obtawaing Biosphere
Region Water Boundaries
Rivers/Streams
Lakes
OBR Boundary
N
0
25
50 km
Data Source: https://gis-michigan.opendata.arcgis.com/
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/31/23


Obtawaing Biosphere Region 2001 Land Cover
NLCD Land Cover Type
Open Water; 11
Developed, Open Space; 21
Developed, Low Intensity; 22
Developed, Medium Intensity; 23
Developed, High Intensity; 24
Barren Land; 31
Deciduous Forest; 41
Evergreen Forest; 42
Mixed Forest; 43
Shrub/Scrub; 52
Herbaceous; 71
Hay/Pasture; 81
Cultivated Crops; 82
Woody Wetlands; 90
Emergent Herbaceous Wetlands; 95
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

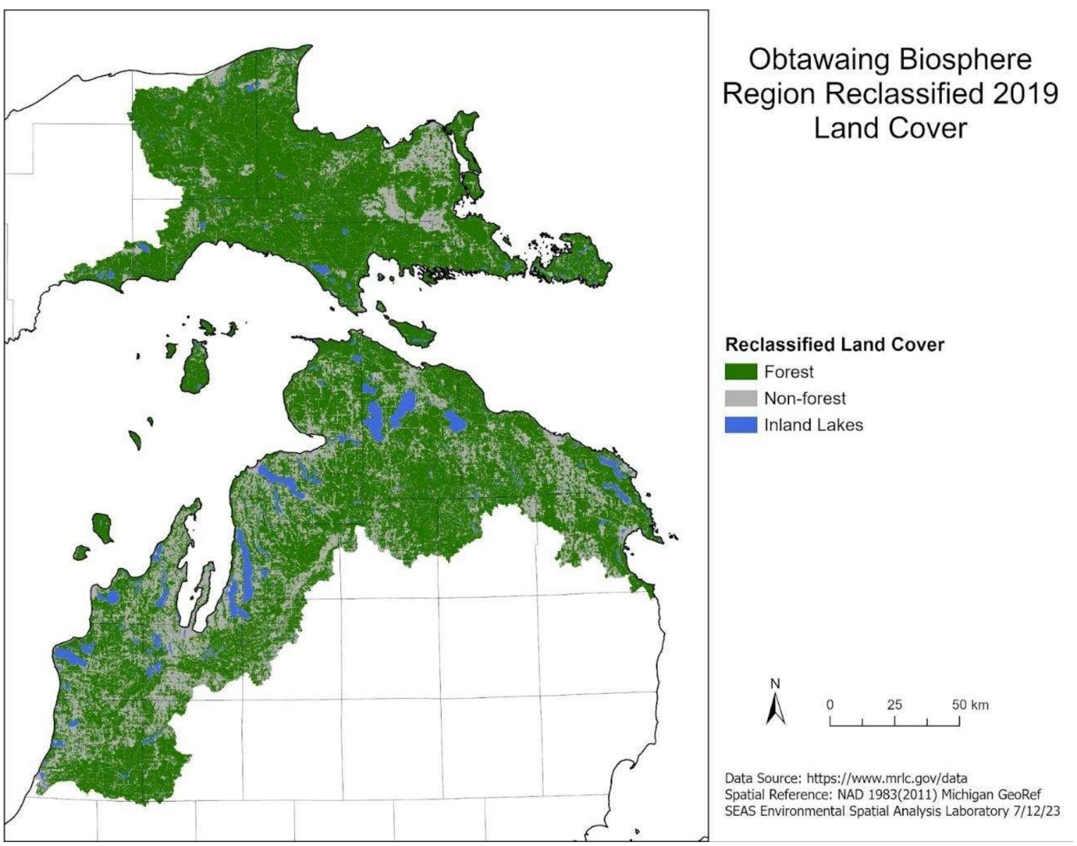

Obtawaing Biosphere Region Reclassified 2001 Land Cover
Reclassified Land Cover
Forest
Non-forest
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23


Obtawaing Biosphere Region 2011 Land Cover
NLCD Land Cover Type
Open Water; 11
Developed, Open Space; 21
Developed, Low Intensity; 22
Developed, Medium Intensity; 23
Developed, High Intensity; 24
Barren Land; 31
Deciduous Forest; 41
Evergreen Forest; 42
Mixed Forest; 43
Shrub/Scrub; 52
Herbaceous; 71
Hay/Pasture; 81
Cultivated Crops; 82
Woody Wetlands; 90
Emergent Herbaceous Wetlands; 95
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

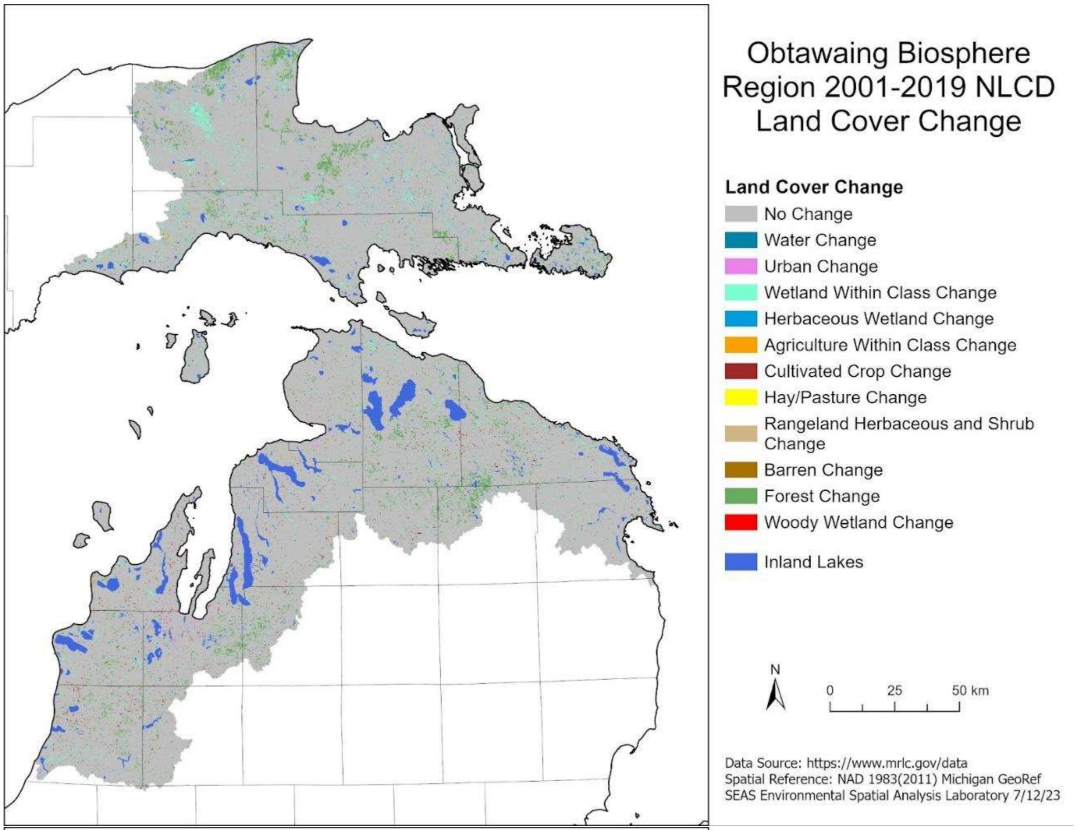

Obtawaing Biosphere Region Reclassified 2011 Land Cover
Reclassified Land Cover
Forest
Non-forest
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

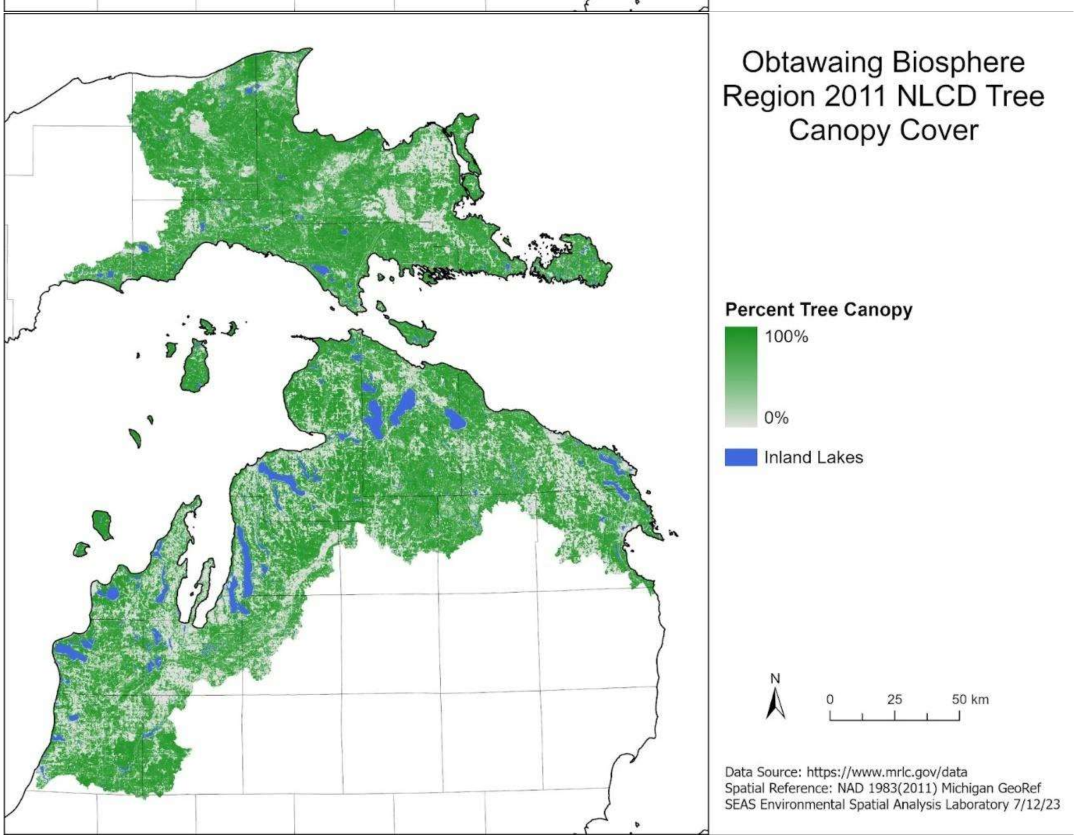


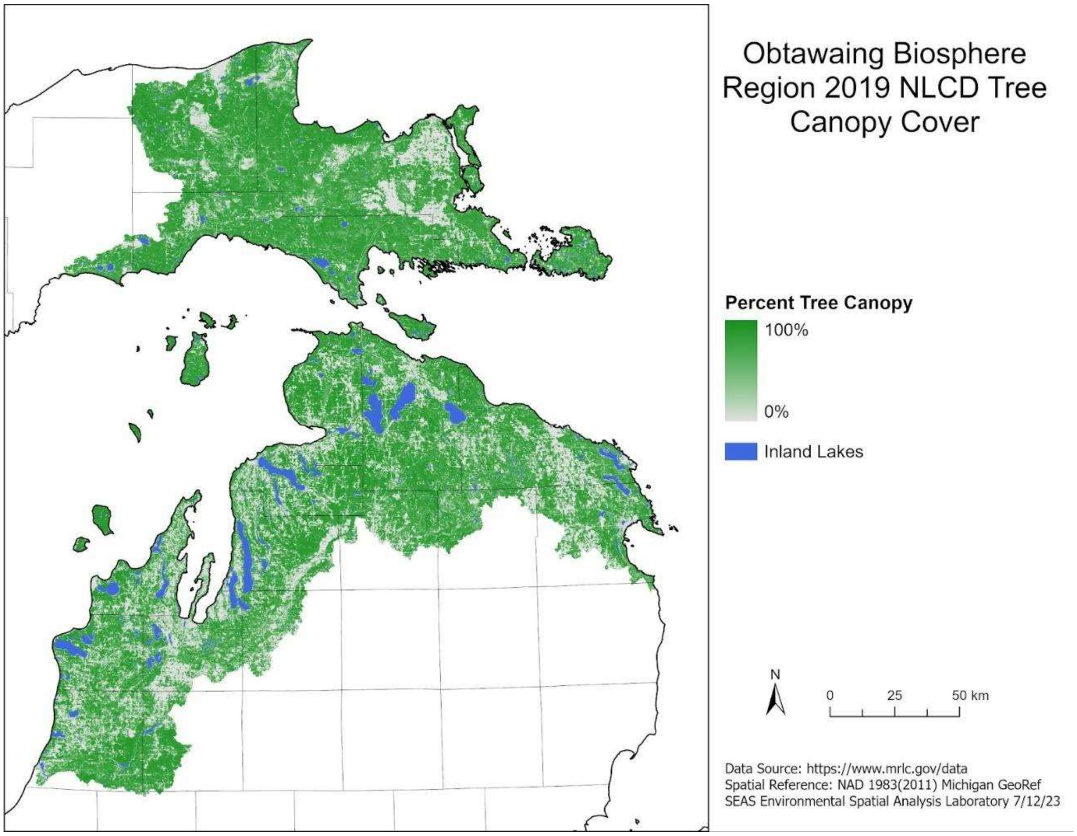
Obtawaing Biosphere Region 2019 Land Cover
NLCD Land Cover Type
Open Water; 11
Developed, Open Space; 21
Developed, Low Intensity; 22
Developed, Medium Intensity; 23
Developed, High Intensity; 24
Barren Land; 31
Deciduous Forest; 41
Evergreen Forest; 42
Mixed Forest; 43
Shrub/Scrub; 52
Herbaceous; 71
Hay/Pasture; 81
Cultivated Crops; 82
Woody Wetlands; 90
Emergent Herbaceous Wetlands; 95
N
0 25 50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

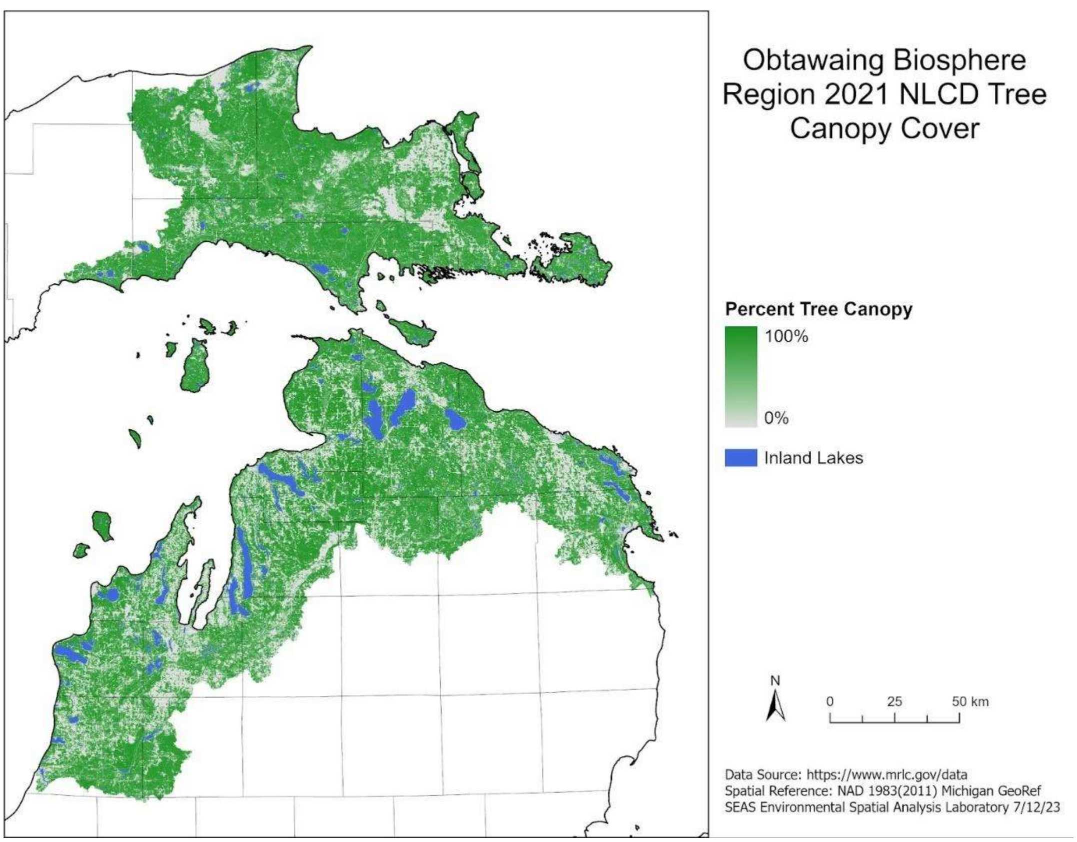


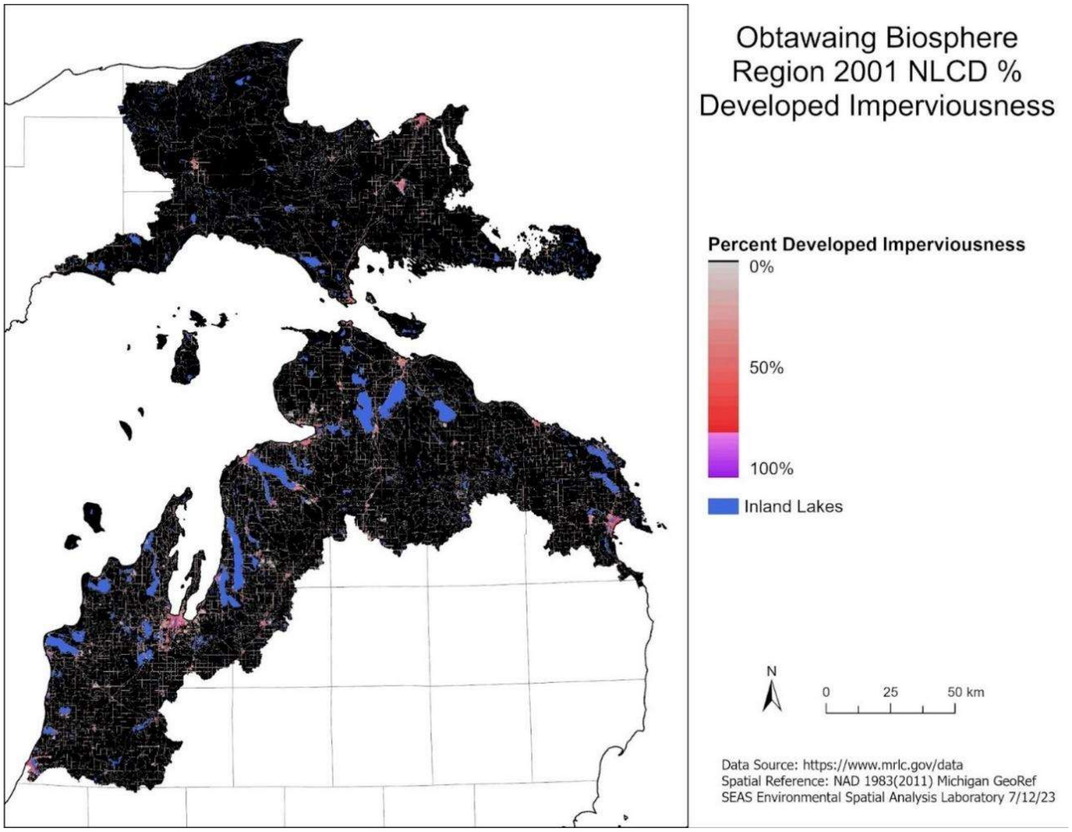
Obtawaing Biosphere Region Reclassified 2019 Land Cover
Reclassified Land Cover
Forest
Non-forest
Inland Lakes
N
0 25 50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

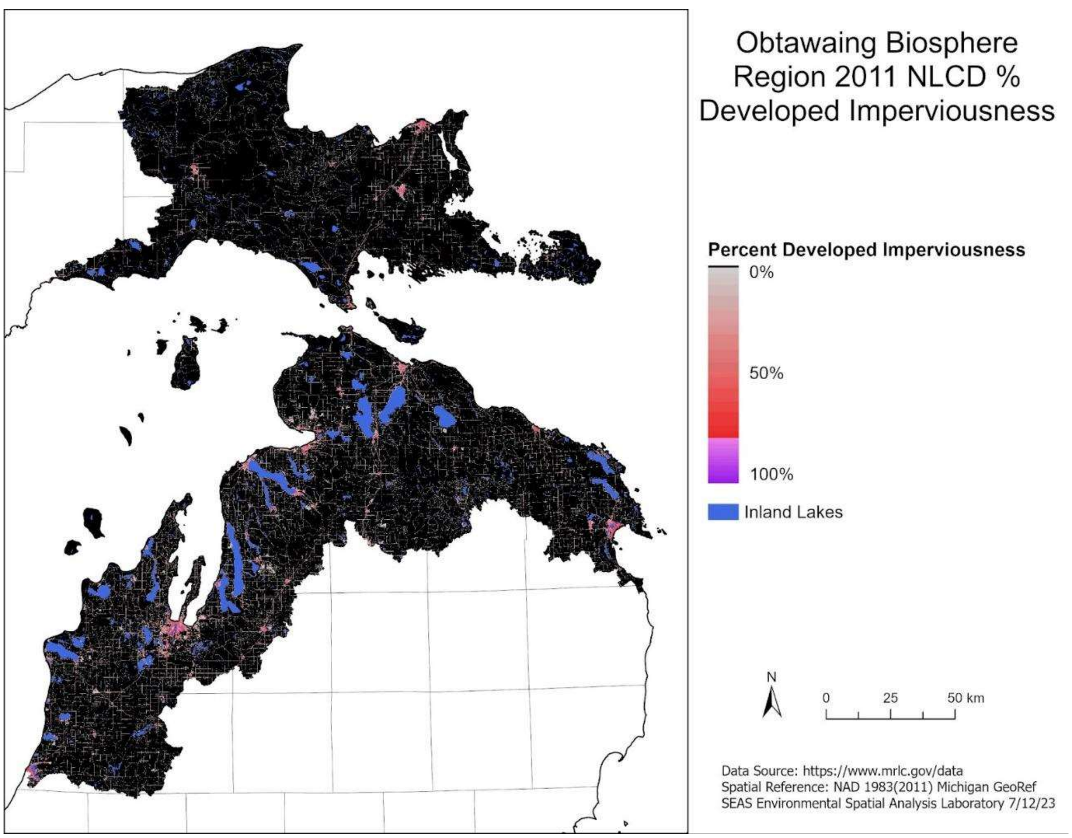

Obtawaing Biosphere Region 2001-2019 NLCD Land Cover Change
Land Cover Change
No Change
Water Change
Urban Change
Wetland Within Class Change
Herbaceous Wetland Change
Agriculture Within Class Change
Cultivated Crop Change
Hay/Pasture Change
Rangeland Herbaceous and Shrub Change
Barren Change
Forest Change
Woody Wetland Change
Inland Lakes
N
0 25 50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

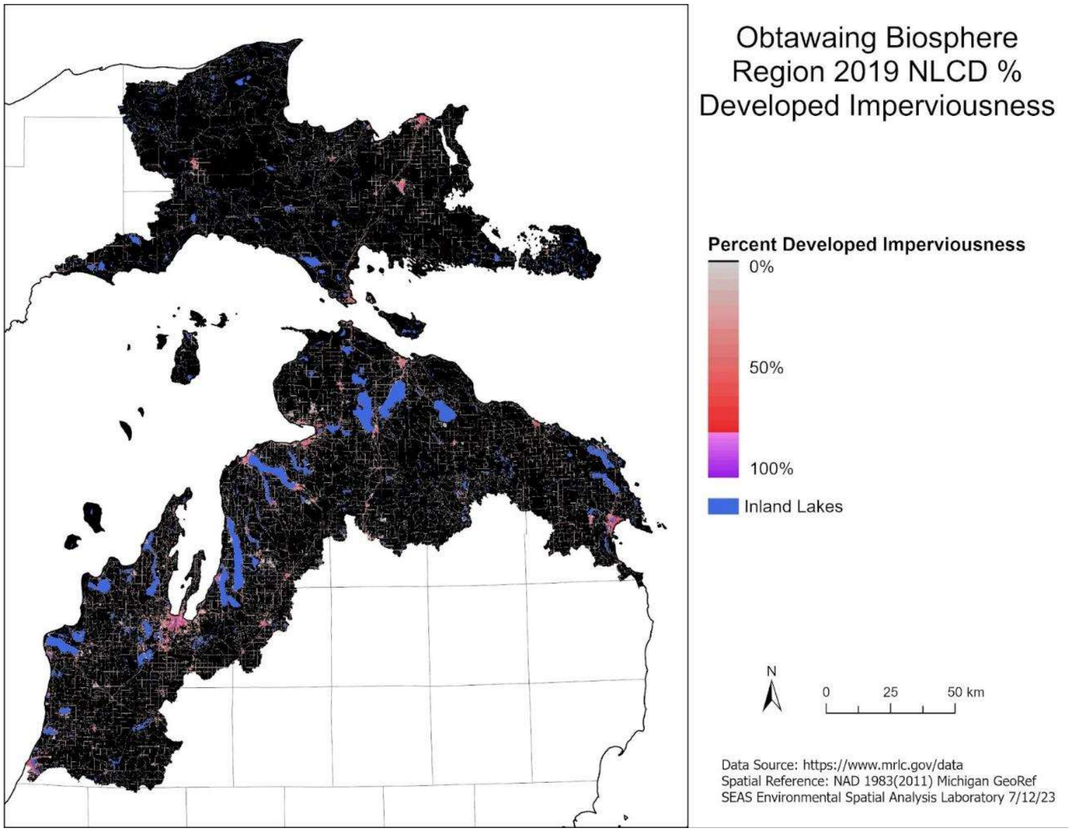

Obtawaing Biosphere Region 2011 NLCD Tree Canopy Cover
Percent Tree Canopy
100%
0%
Inland Lakes
N
0 25 50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

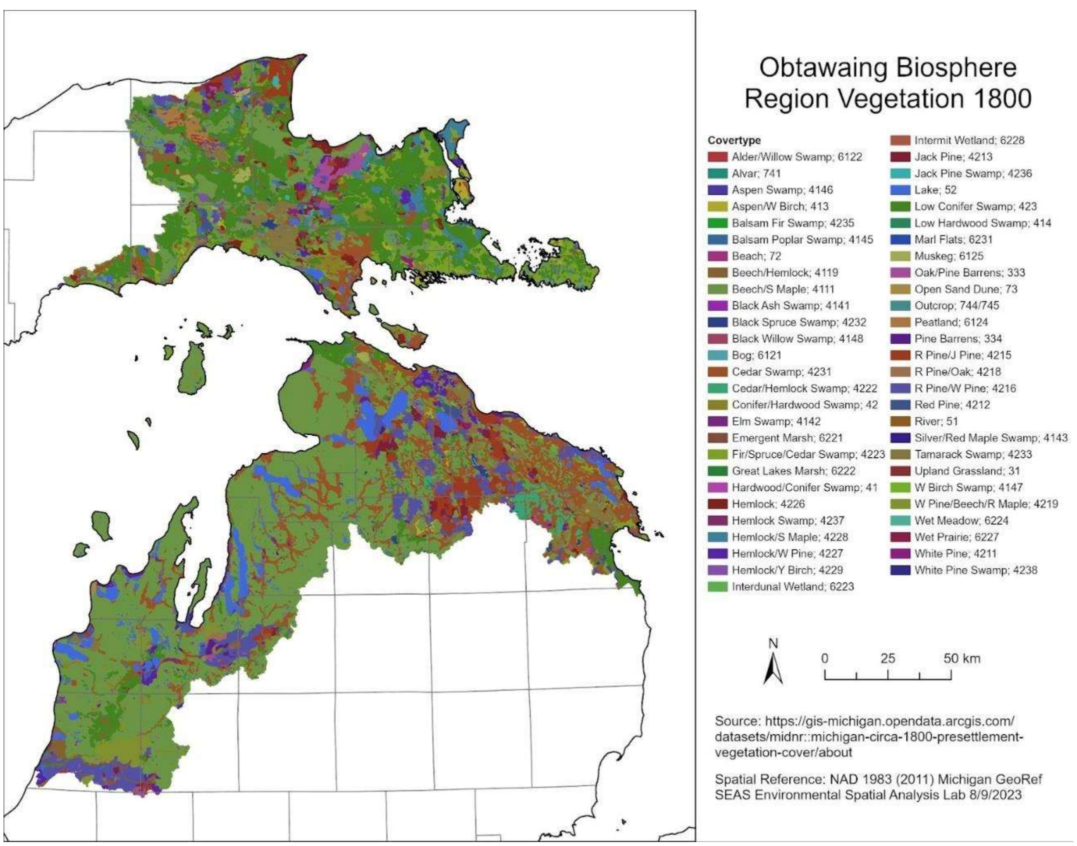

Obtawaing Biosphere Region 2019 NLCD Tree Canopy Cover
Percent Tree Canopy
100%
0%
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

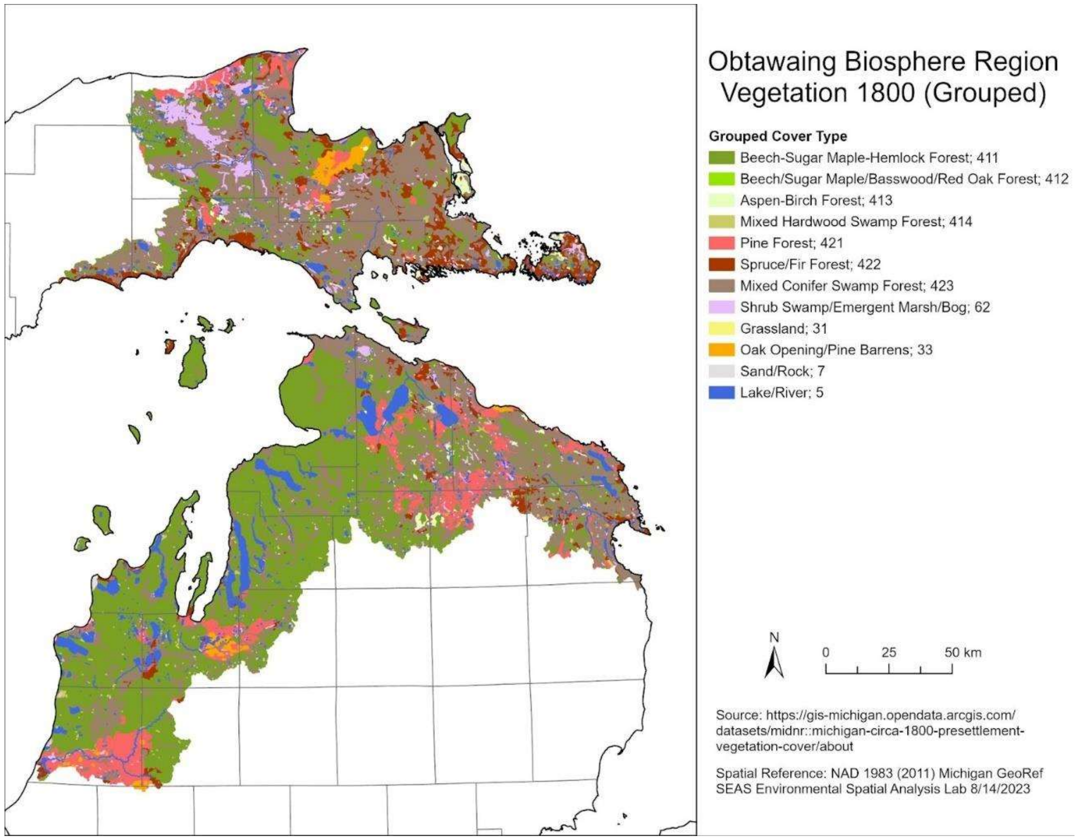

Obtawaing Biosphere Region 2021 NLCD Tree Canopy Cover
Percent Tree Canopy
100%
0%
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

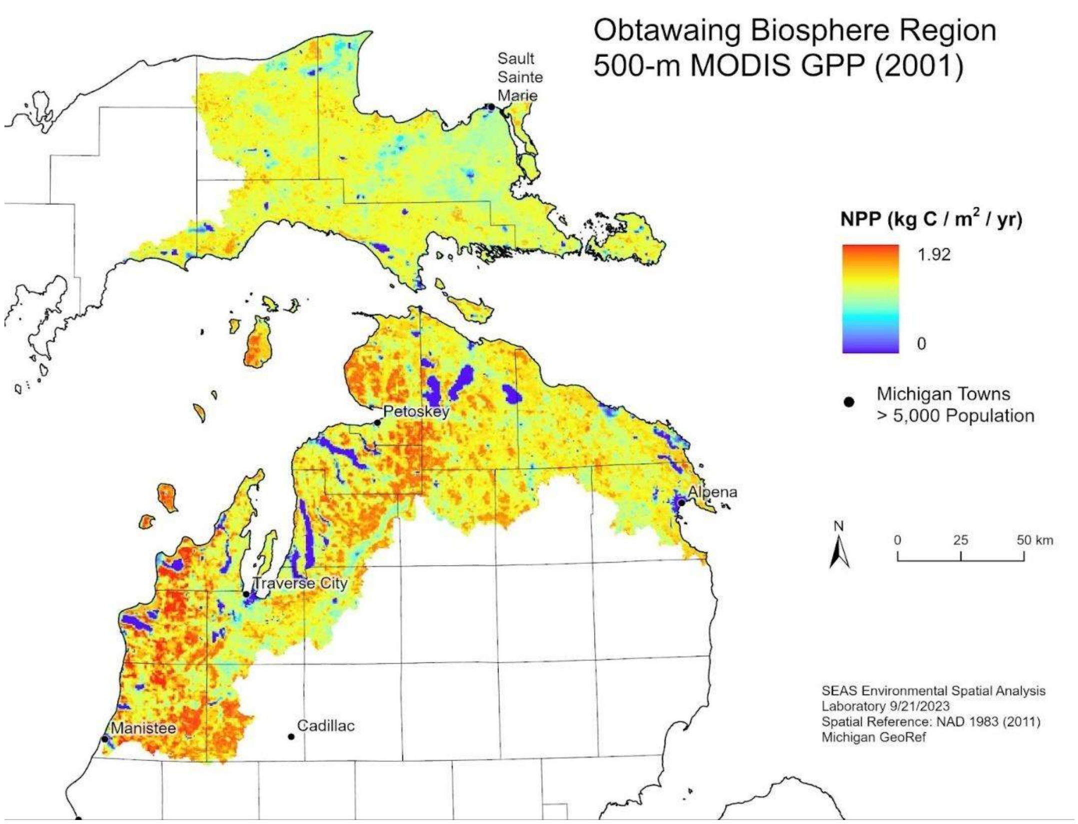

Obtawaing Biosphere Region 2001 NLCD % Developed Imperviousness
Percent Developed Imperviousness
0%
50%
100%
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

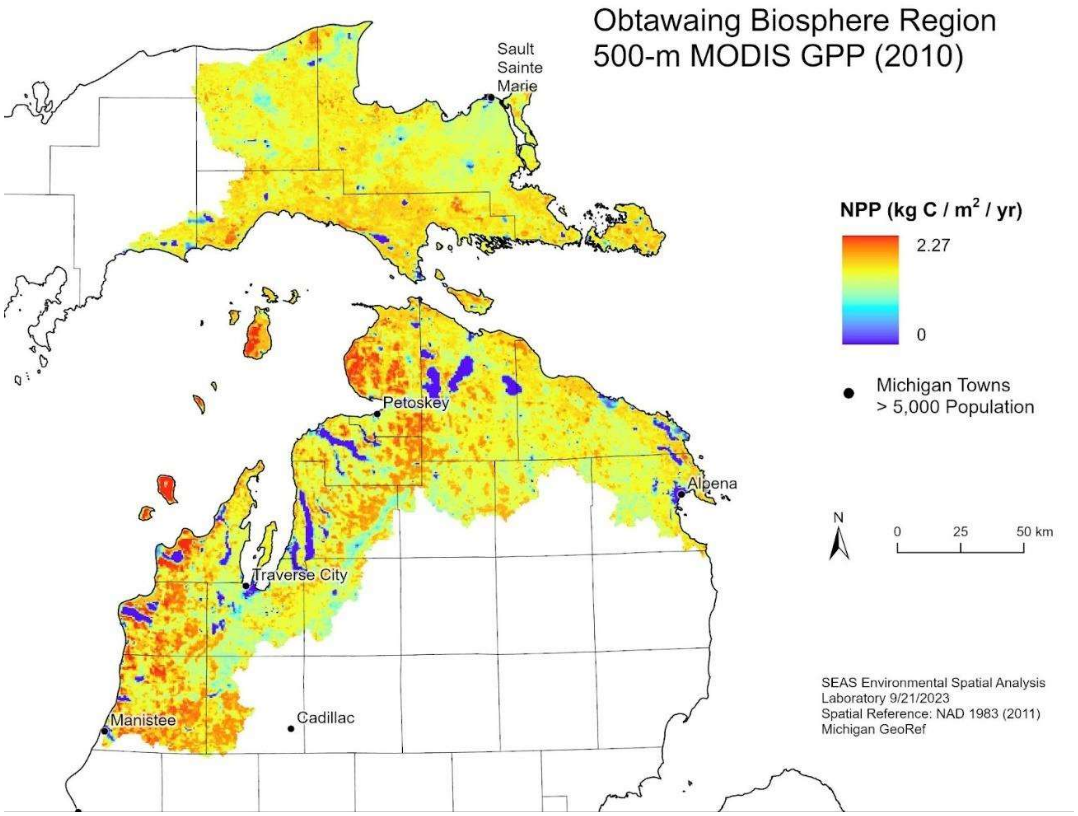

Obtawaing Biosphere Region 2011 NLCD % Developed Imperviousness
Percent Developed Imperviousness
0%
50%
100%
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

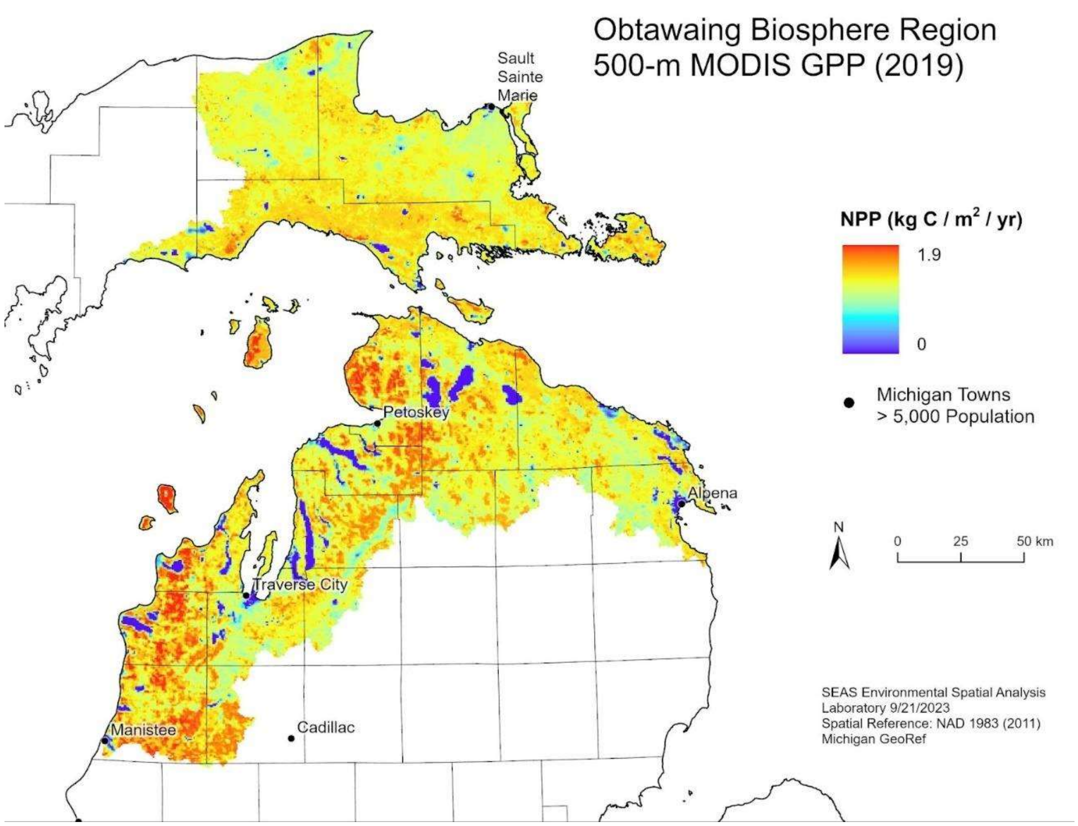

Obtawaing Biosphere Region 2019 NLCD % Developed Imperviousness
Percent Developed Imperviousness
0%
50%
100%
Inland Lakes
N
0
25
50 km
Data Source: https://www.mrlc.gov/data
Spatial Reference: NAD 1983(2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Laboratory 7/12/23

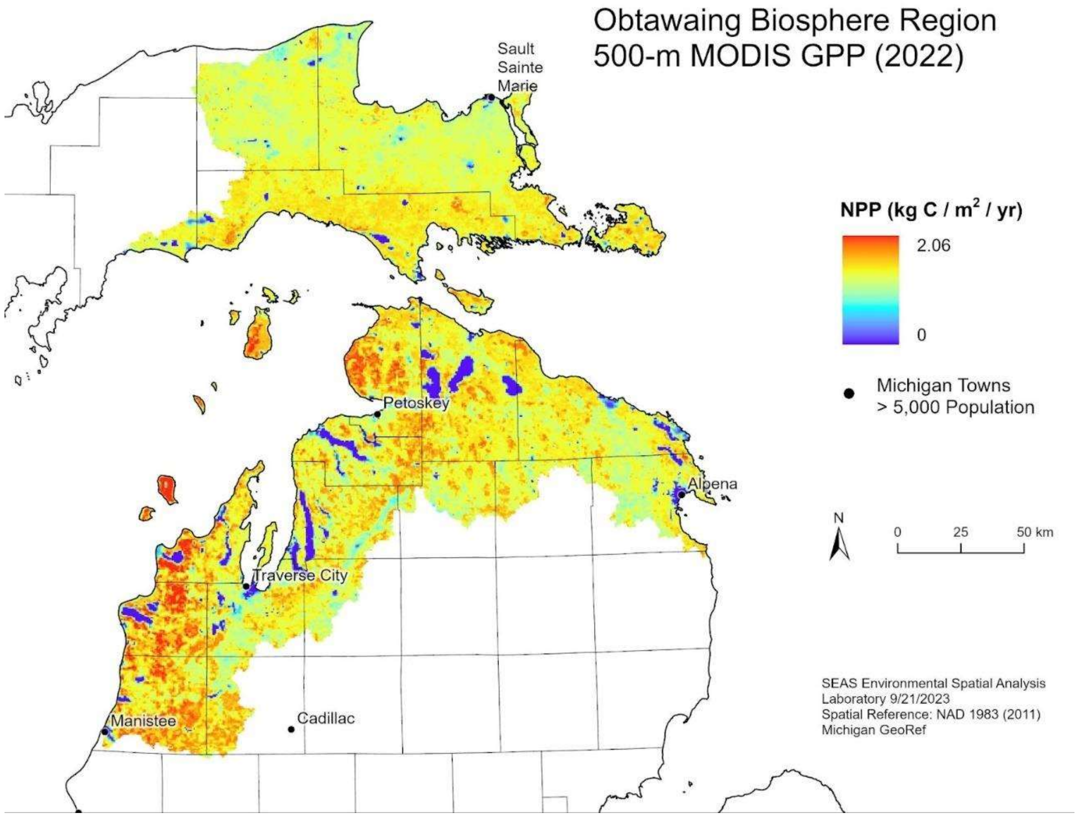

Obtawaing Biosphere Region Vegetation 1800
Covertype
Alder/Willow Swamp; 6122
Alvar; 741
Aspen Swamp; 4146
Aspen/W Birch; 413
Balsam Fir Swamp; 4235
Balsam Poplar Swamp; 4145
Beach; 72
Beech/Hemlock; 4119
Beech/S Maple; 4111
Black Ash Swamp; 4141
Black Spruce Swamp; 4232
Black Willow Swamp; 4148
Bog; 6121
Cedar Swamp; 4231
Cedar/Hemlock Swamp; 4222
Conifer/Hardwood Swamp; 42
Elm Swamp; 4142
Emergent Marsh; 6221
Fir/Spruce/Cedar Swamp; 4223
Great Lakes Marsh; 6222
Hardwood/Conifer Swamp; 41
Hemlock; 4226
Hemlock Swamp; 4237
Hemlock/S Maple; 4228
Hemlock/W Pine; 4227
Hemlock/Y Birch; 4229
Interdunal Wetland; 6223
Intermit Wetland; 6228
Jack Pine; 4213
Jack Pine Swamp; 4236
Lake; 52
Low Conifer Swamp; 423
Low Hardwood Swamp; 414
Marl Flats; 6231
Muskeg; 6125
Oak/Pine Barrens; 333
Open Sand Dune; 73
Outcrop; 744/745
Peatland; 6124
Pine Barrens; 334
R Pine/J Pine; 4215
R Pine/Oak; 4218
R Pine/W Pine; 4216
Red Pine; 4212
River; 51
Silver/Red Maple Swamp; 4143
Tamarack Swamp; 4233
Upland Grassland; 31
W Birch Swamp; 4147
W Pine/Beech/R Maple; 4219
Wet Meadow; 6224
Wet Prairie; 6227
White Pine; 4211
White Pine Swamp; 4238
N
0
25
50 km
Source: https://gis-michigan.opendata.arcgis.com/datasets/midnr::michigan-circa-1800-presettlement-vegetation-cover/about
Spatial Reference: NAD 1983 (2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Lab 8/9/2023

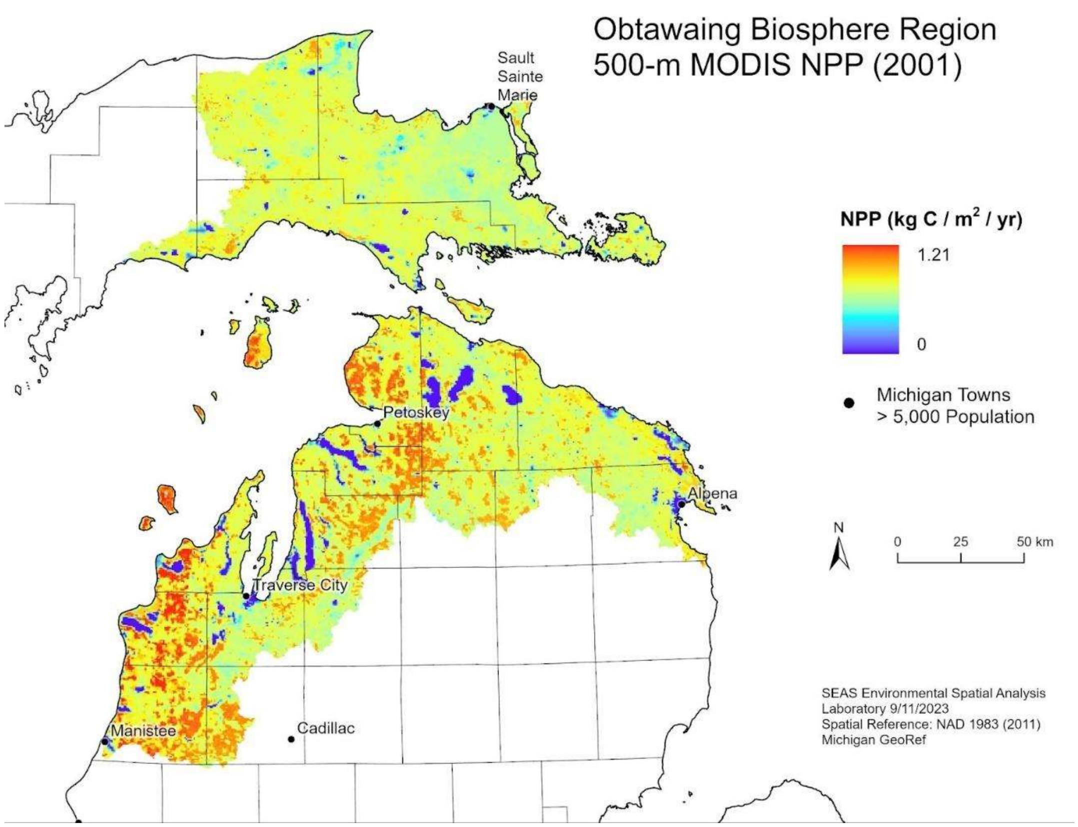

Obtawaing Biosphere Region
Vegetation 1800 (Grouped)
Grouped Cover Type
Beech-Sugar Maple-Hemlock Forest; 411
Beech/Sugar Maple/Basswood/Red Oak Forest; 412
Aspen-Birch Forest; 413
Mixed Hardwood Swamp Forest; 414
Pine Forest; 421
Spruce/Fir Forest; 422
Mixed Conifer Swamp Forest; 423
Shrub Swamp/Emergent Marsh/Bog; 62
Grassland; 31
Oak Opening/Pine Barrens; 33
Sand/Rock; 7
Lake/River; 5
N
0 25 50 km
Source: https://gis-michigan.opendata.arcgis.com/datasets/midnr::michigan-circa-1800-presettlement-vegetation-cover/about
Spatial Reference: NAD 1983 (2011) Michigan GeoRef
SEAS Environmental Spatial Analysis Lab 8/14/2023

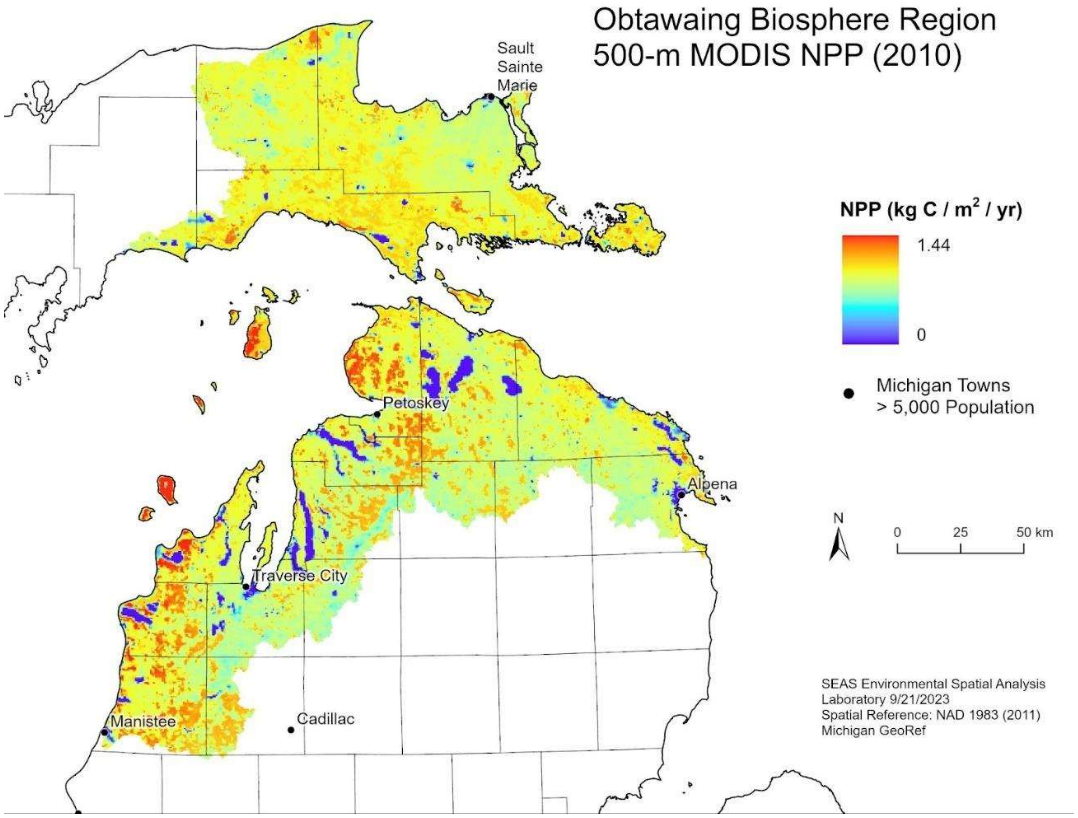

Obtawaing Biosphere Region
500-m MODIS GPP (2001)
Sault Sainte Marie
Petoskey
Alpena
Traverse City
Manistee
Cadillac
NPP (kg C / m² / yr)
1.92
0
Michigan Towns > 5,000 Population
N
0 25 50 km
SEAS Environmental Spatial Analysis Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011) Michigan GeoRef

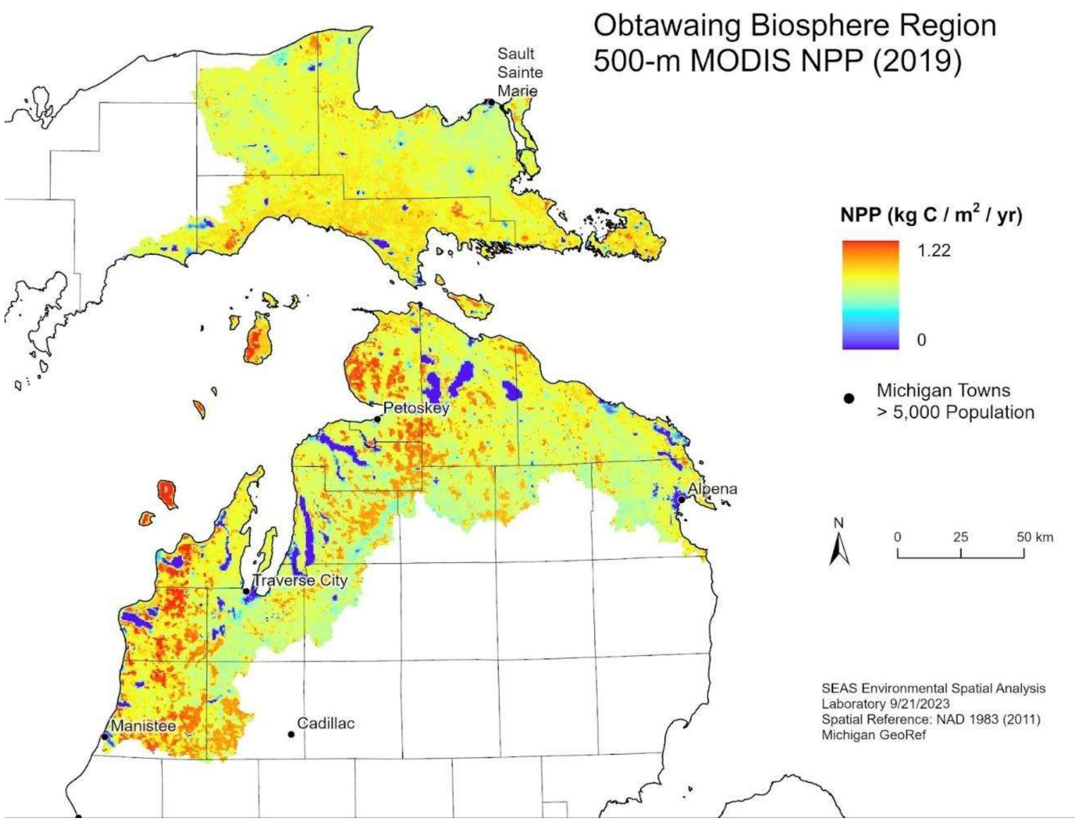

Obtawaing Biosphere Region
500-m MODIS GPP (2010)
Sault
Sainte
Marie
NPP (kg C / m² / yr)
2.27
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
Manistee
Cadillac
SEAS Environmental Spatial Analysis
Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef

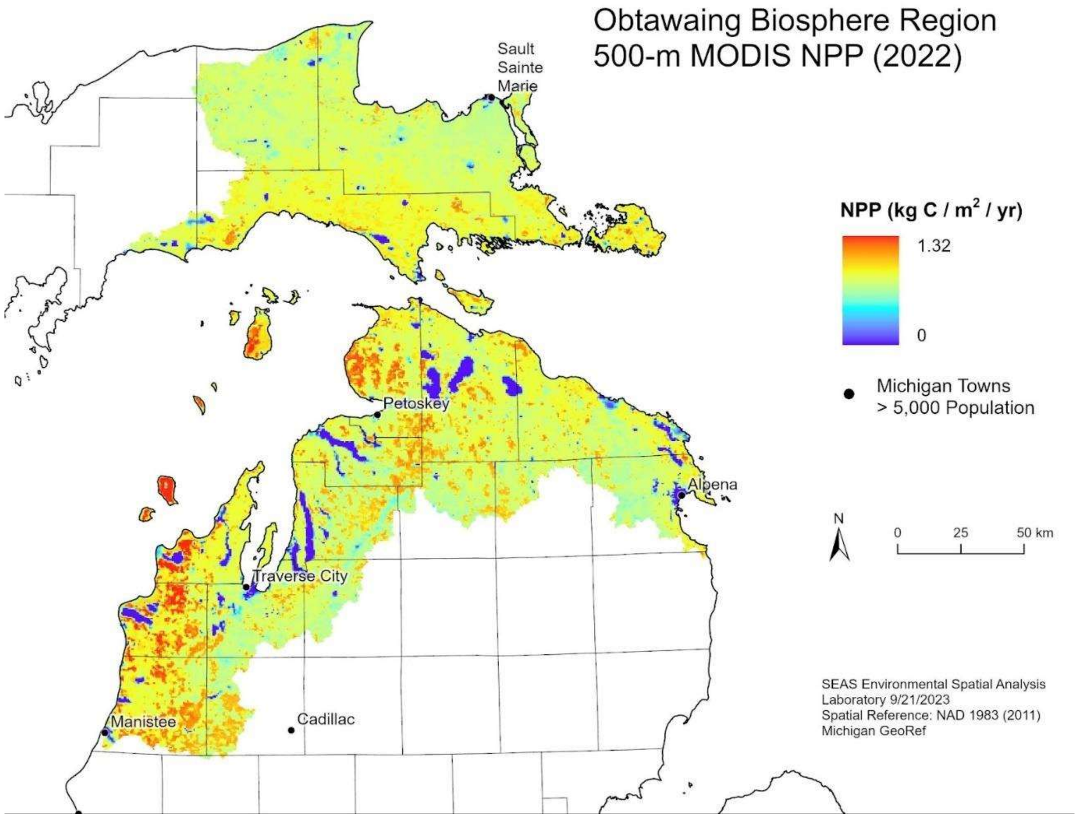

Obtawaing Biosphere Region
500-m MODIS GPP (2019)
Sault
Sainte
Marie
NPP (kg C / m² / yr)
1.9
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
Manistee
Cadillac
SEAS Environmental Spatial Analysis
Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef

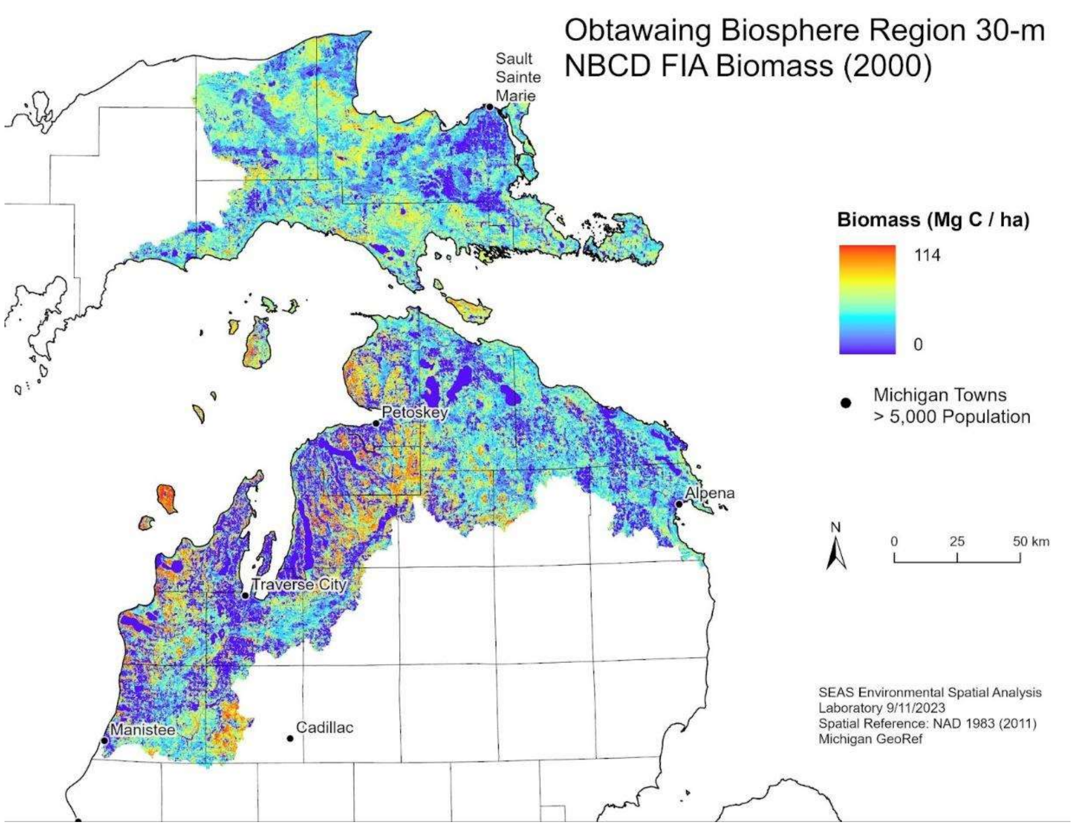

Obtawaing Biosphere Region
500-m MODIS GPP (2022)
Sault
Sainte
Marie
NPP (kg C / m² / yr)
2.06
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
SEAS Environmental Spatial Analysis
Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef
Manistee
Cadillac

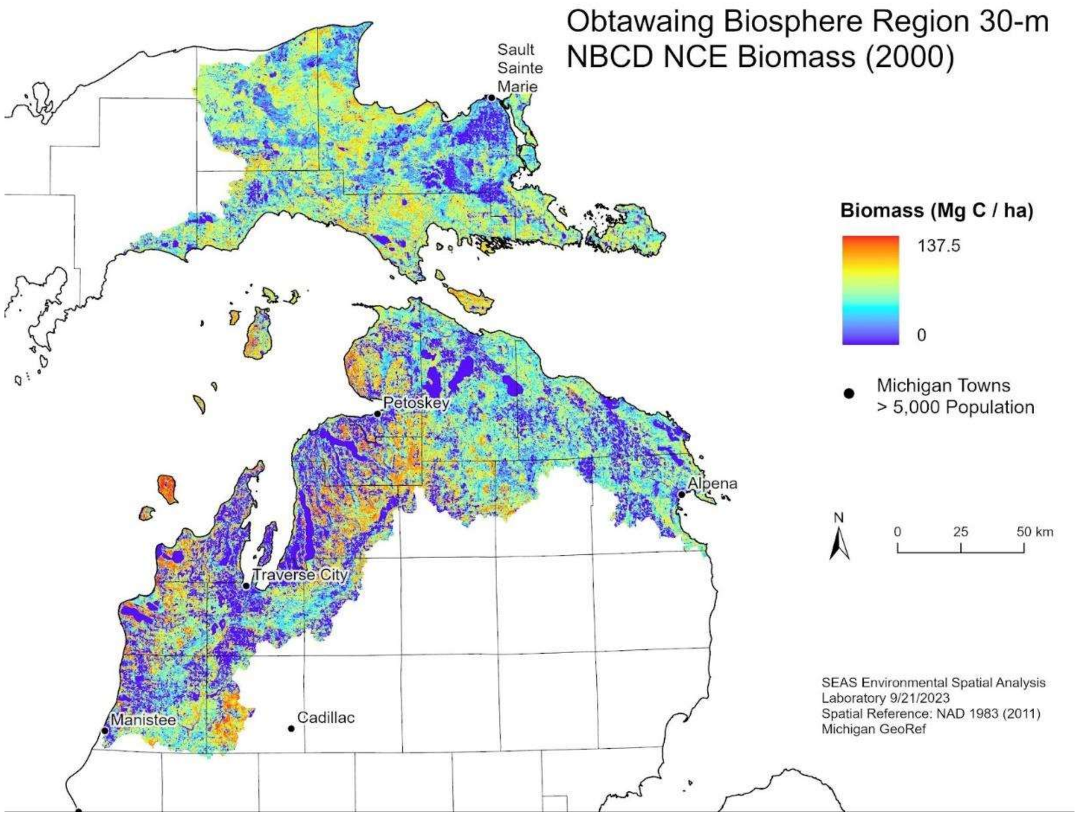

Obtawaing Biosphere Region
500-m MODIS NPP (2001)
Sault
Sainte
Marie
NPP (kg C / m² / yr)
1.21
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
SEAS Environmental Spatial Analysis
Laboratory 9/11/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef
Manistee
Cadillac

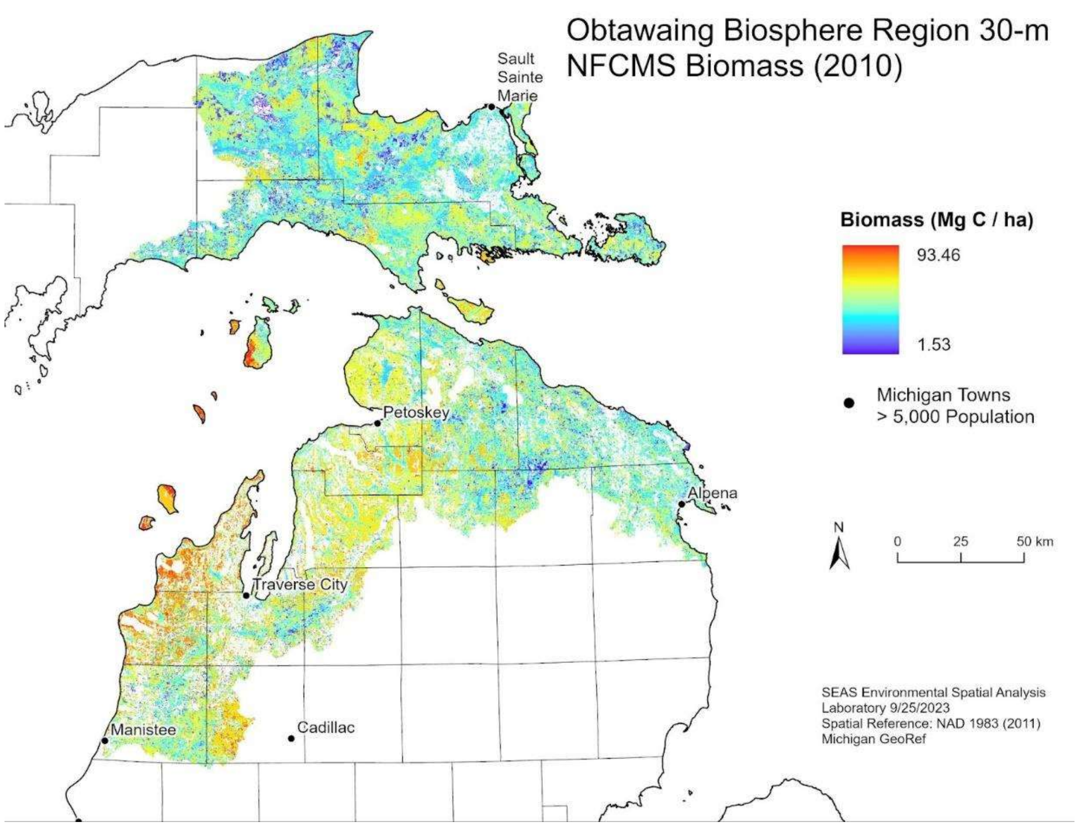

Obtawaing Biosphere Region
500-m MODIS NPP (2010)
Sault Sainte Marie
Petoskey
Alpena
Traverse City
Manistee
Cadillac
NPP (kg C / m² / yr)
1.44
0
Michigan Towns > 5,000 Population
N
0 25 50 km
SEAS Environmental Spatial Analysis Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011) Michigan GeoRef


Obtawaing Biosphere Region
500-m MODIS NPP (2019)
Sault Sainte Marie
Petoskey
Alpena
Traverse City
Manistee
Cadillac
NPP (kg C / m² / yr)
1.22
0
Michigan Towns > 5,000 Population
N
0 25 50 km
SEAS Environmental Spatial Analysis Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011) Michigan GeoRef


Obtawaing Biosphere Region
500-m MODIS NPP (2022)
Sault
Sainte
Marie
NPP (kg C / m² / yr)
1.32
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
Traverse City
Manistee
Cadillac
N
0
25
50 km
SEAS Environmental Spatial Analysis
Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef


Obtawaing Biosphere Region 30-m
NBCD FIA Biomass (2000)
Sault
Sainte
Marie
Biomass (Mg C / ha)
114
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
Traverse City
Manistee
Cadillac
N
0
25
50 km
SEAS Environmental Spatial Analysis
Laboratory 9/11/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef


Obtawaing Biosphere Region 30-m
NBCD NCE Biomass (2000)
Sault Sainte Marie
Biomass (Mg C / ha)
137.5
0
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
SEAS Environmental Spatial Analysis
Laboratory 9/21/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef
Manistee
Cadillac


Obtawaing Biosphere Region 30-m
NFCMS Biomass (2010)
Sault Sainte Marie
Biomass (Mg C / ha)
93.46
1.53
Michigan Towns
> 5,000 Population
Petoskey
Alpena
N
0
25
50 km
Traverse City
SEAS Environmental Spatial Analysis
Laboratory 9/25/2023
Spatial Reference: NAD 1983 (2011)
Michigan GeoRef
Manistee
Cadillac

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