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ASSESSMENT OF ASPEN AND NORTHERN HARDWOODS EXTENT IN THIRTY THREE COUNTIES OF UPPER/LOWER MICHIGAN

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ASSESSMENT OF ASPEN AND NORTHERN HARDWOODS EXTENT IN THIRTY THREE COUNTIES OF UPPER/LOWER MICHIGAN

By

Sara Alian

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

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In Forestry

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This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Forestry.

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Table of Contents

List of Figures

List of Tables

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Abstract

The importance of the United States' wood and wood byproducts as biomass feedstocks is increasing as the concern about security and sustainability of global energy production continues to rise. Thus, second generation woody feedstock sources in Michigan, e.g., hybrid poplar and hybrid willow (*Populus spp.*), are viewed as a potential source of biomass for the proposed biofuel ethanol production plant in Kinross, MI. It is important to gain an understanding of the spatial distribution of current feedstock sources, harvesting accessibility via the transportation infrastructure and land ownerships in order to ensure long-term feedstock extent. This research provides insights into the current extent of aspen and northern hardwoods, and an assessment of potential for expanding the area of these feedstock sources based on pre-European settlement conditions. A geographic information system (GIS) was developed to compile available geospatial data for 33 counties located within 150 miles of the Kinross facility. These include present day and pre-European settlement land use/cover, soils, road infrastructure, and land ownerships. The results suggest that a significant amount of northern hardwoods has been converted to other land use/cover types since European settlement, and the "scattering" of aspen stands has increased. Furthermore, a significant amount of woody biomass is available in close proximity to the existing road network, which can be effectively utilized as feedstock. Potential aspen and northern hardwoods restoration areas are identified in the vicinity of road networks which can be used for future woody feedstock production.

Chapter 1- Introduction

1.1. Global perspective

Producing sufficient energy and transitioning to non-fossil fuel energy sources is a global issue driven by concern about energy security and climate change. Current global energy consumption is dominated by fossil fuels (e.g., oil, gas, and coal). Nonrenewable energy resources are believed to be limited (WEC, 2010), and some predict world oil production will peak around 2030 (Sorrell et al., 2010; Bentley et al., 2009). Hence, new policies and incentives to develop sustainable energy sources and increase their utilization are under development (Scharlemann et al., 2009).

Interestingly, high oil production forecasts by International Energy Agency (IEA), the United States' Energy Information Administration (EIA), and Organization of Petroleum Exporting Countries (OPEC) state that peak oil production is not a serious threat. However, energy security is increasingly an overarching concern since major oil production occurs in many countries experiencing political instability. In order to improve energy security the world needs to spend time and financial resources to diversify the global energy portfolio. However, global energy transition will be challenging since industrial and economic processes depend highly on fossil fuels and their byproducts.

In addition, developing renewable energy resources is important due to global climate change. There is extensive evidence that the world is becoming warmer (IPCC, 2001). Since fossil fuels have large carbon footprints, it is critical for global energy

policies to focus on lower carbon footprint energy sources such as solar, wind, hydropower and biofuels.

Thorough investigations into the potential of replacing fossil fuels with biofuels are needed before substantial changes in energy policies can occur (Tilman et al., 2009). Biofuels are viewed by many as a viable renewable energy source which can be used in the primary energy mix, particularly in the transportation fuel and electricity generation sectors (McKendry, 2002; Hill, 2006).

The use of transportation fuels derived from biomass has been projected to increase by more than 400% by 2035 (IEA WEO, 2010). Energy production from biofuels doubled between 2000 and 2005 and further increased up to 6 times between 2005 and 2010 (Figure 1.1). North, South and Central America are the major producers of biofuel (Figure 1.2). Proponents of biofuels attribute a number of benefits to this energy source including low greenhouse gas (GHG) emissions, improving local energy security and trade balances, and creating opportunities for socio-economic development in rural areas (WEC, 2010). One key factor constraining the use of biomass for energy production is resource availability (WEC, 2010). Furthermore, the choice of feedstock species grown and harvested will determine biomass yield, which is critical for the long term viability of production facilities (Solomon et al., 2007). As a result of these concerns, local and regional woody feedstock availability, both current and future, needs to be better understood before biofuel's share in the energy portfolio can be a projected realistically.

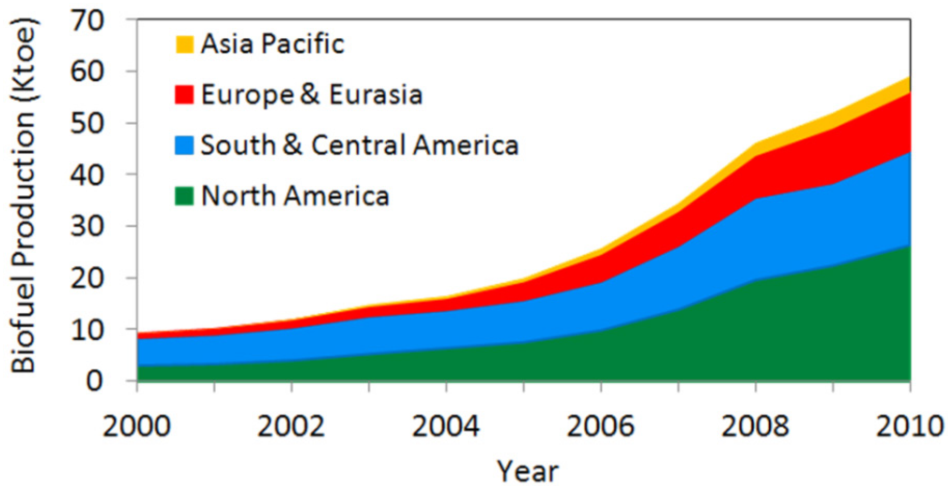

Figure 1.1. Biofuel production between 2000 and 2010 (Source: BP, 2011).

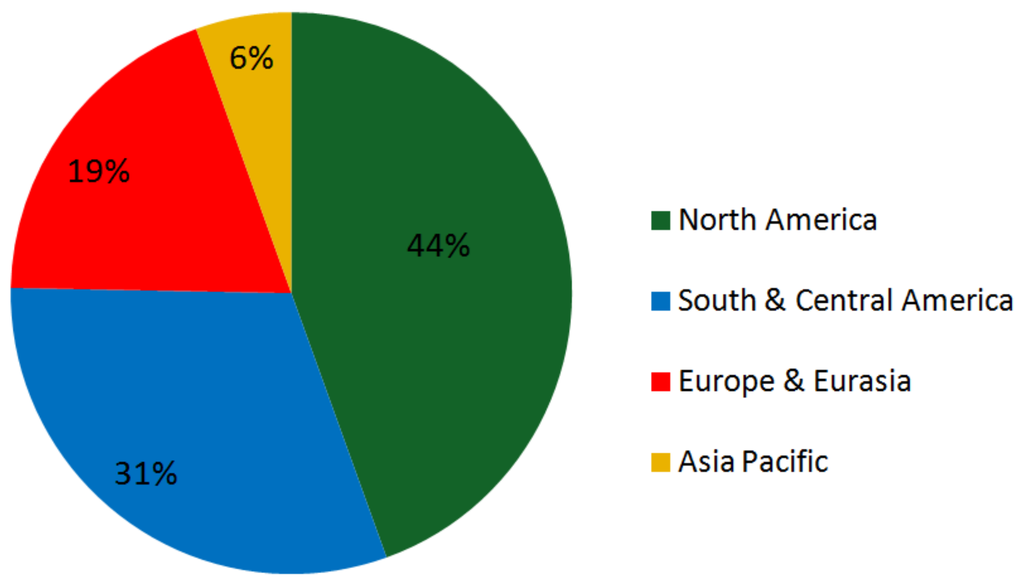

Figure 1.2. Global distribution of biofuel production in 2010 (Source: BP, 2011).

1.2. Bioenergy in the USA

From a historical standpoint, most countries relied heavily on woody biomass to meet their energy needs. In the United States in 1880, almost 60% of energy came from wood. However by the mid-19th century, fossil fuels replaced woody biomass due to their high energy intensity, ease of transportation and use (Simpkins, 2006). Recent biofuel research findings are setting the stage for reintroduction of woody biomass as a key energy source. For example, Bartle and Abadi (2010) demonstrated the superiority of second generation feedstocks (woody crops) to first generation feedstocks (sugar, corn stover, starch and vegetable oils) by illustrating their lower effective cost, sustainability and environmental impacts. Furthermore, first generation biofuel feedstocks are also used as food crops, creating a competition of uses and driving up food prices (Tilman, 2009). Wood chips are likely better resources of ethanol as compared with other green resources such as corn, sugarcane, and soy because of their lower GHG footprint (Scharlemann et al., 2008).

Wood and wood byproducts are one of the important biomass feedstocks in the United States. Over the last 35 years, major changes in energy policy and economy have led the energy market to use wood energy as a competitor with traditional coal-fired and natural gas electricity generation. Zhang et al. (2010) applied a life cycle analysis approach to compare carbon emission of wood pellet firing and coal generating stations in Ontario, Canada. Their research suggests that carbon emissions of coal generating stations are more than ten times greater than that of wood pellet firing plants. Froese et al. (2010) demonstrated the potential for the use of forestry residuals for reducing carbon emissions from power generation in the US Great Lakes States. Mitchell et al. (2012)

argue that harvesting of forests for the purpose of biofuel production may result in a net carbon debt because it will take a shorter time for unharvested forests to store the amount of carbon that would be saved if they were harvested for use for biofuel production. In any case, large scale net carbon emission reductions for generating power from wood residues may be achievable in the long run rather than short term (Mckechnie et al., 2011).

1.3. Woody biomass for bioenergy in Michigan

In Michigan's Upper Peninsula and northern Lower Peninsula there is considerable potential for producing biofuel from feedstock sources such as aspen, northern hardwood species, hybrid poplar, and hybrid willow (Populus *spp*.) since the current rate of growth exceeds the amount harvested (Leefers et al., 2010). Several facilities in Michigan produce electric power from wood fuel (Johnson et al., 2011). Table 1.1 provides information about the location of some of these facilities along with their electric production capacity and wood consumption in Michigan.

Frontier Renewable Resources and Valero Energy Corporation have a joint venture and are constructing a commercial-scale cellulosic ethanol facility in Kinross, Michigan. The facility will convert woody feedstock to ethanol with an initial capacity of 20 million gallons of ethanol per year (Leefers et al., 2010). Historically, this area has been a major producer of pulpwood. During the period of 2003 to 2007, more than 50% of pulpwood production in Michigan took place in the Kinross supply region (Leefers et al., 2010). The pulpwood production trend for the Kinross region, as well as for the state of Michigan has been declining (Leefers et al., 2010). The proposed biofuel production

facility may increase the harvest of aspen and northern hardwoods in the Kinross supply region. Assessment of aspen and northern hardwoods distribution in this region provides insights for sustainable supply of woody feedstock to the biofuel production facility.

Table 1.1. Wood-based electric power production facilities in Michigan (Johnson et al., 2011).

Plant	**Location**	**Production Capacity (kW)**	**Wood Consumption (tons/yr)**
Hillman Power Co.	Hillman	20,000	230,000
Viking Energy/ Lincoln	Lincoln	18,000	150,000
Cadillac Renewable Energy	Cadillac	39,600	375,000
Viking Energy/ McBain	McBain	18,000	150,000
Genesee Power Station	Flint	39,500	300,000
Grayling Generating Station	Grayling	38,000	250,000- 300,000
L'Anse Warden Electric Company, LLC	L'Anse	20,000	65,000

1.4. Objectives

It is critical to gain an understanding of the spatial distribution of the current feedstock sources in terms of volume, accessibility for harvest when considering the transportation infrastructure and land ownerships, distance from the processing facility, and changes in land cover patterns utilizing GIS. Therefore, the objectives of this research are as follows:

- Determine the spatial distribution of the aspen and northern hardwoods forests and their proximity to appropriate transportation networks;
- Compare current distributions to historic distributions to gain insight where potential forest types could be converted to pre-European settlement conditions in order to increase long term feedstock extent to the Kinross facility;
- Identify existing agricultural or underproductive areas which could be converted to feedstock plantations; and
- Identify potential sites where aspen and northern hardwoods forests could be restored to the pre-European condition in order to increase biofuel feedstock production potential.

ArcMap 10.1 is used to create a geographic information system (GIS) to analyze the spatial distribution of aspen and northern hardwoods in 33 Michigan counties within 150 miles of the Kinross facility. Also, the historic and current distribution of the aspen and northern hardwoods and the land use change characterized. Chapter Two details data sources and methods applied for identifying feedstock extent and restoration potential. Chapter Three provides results and discussion, followed by conclusions in Chapter Four.

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Chapter 2- Methodology

2.1. Introduction

This chapter presents the materials and methods used in this study. A description of the study area and the spatial analysis are given. A number of state and federal agencies produce and maintain geospatial information, facilitating the characterization of feedstock forests based on specified criteria such as soil type and proximity to road networks. Various data and the sources from which they were obtained are provided. These include pre-European and present-day land use/land cover, political boundaries, hydrography, transportation network (specifically roads), soils, and land ownerships. A geodatabase was developed to compile the data, and ArcMap 10.1 was used to complete the geospatial processing.

2.2. Study area

The study area is the eastern half of Michigan's Upper Peninsula (UP) and the northern half of the Lower Peninsula (LP). This area is centered on the Frontier Renewable Resources Commercial-Scale Hardwood Cellulosic Ethanol Facility in Kinross, MI, and the facility's long term need for feedstock. The study area includes all or portions of 33 counties within 150 miles from ethanol facility (Figure 2.1).

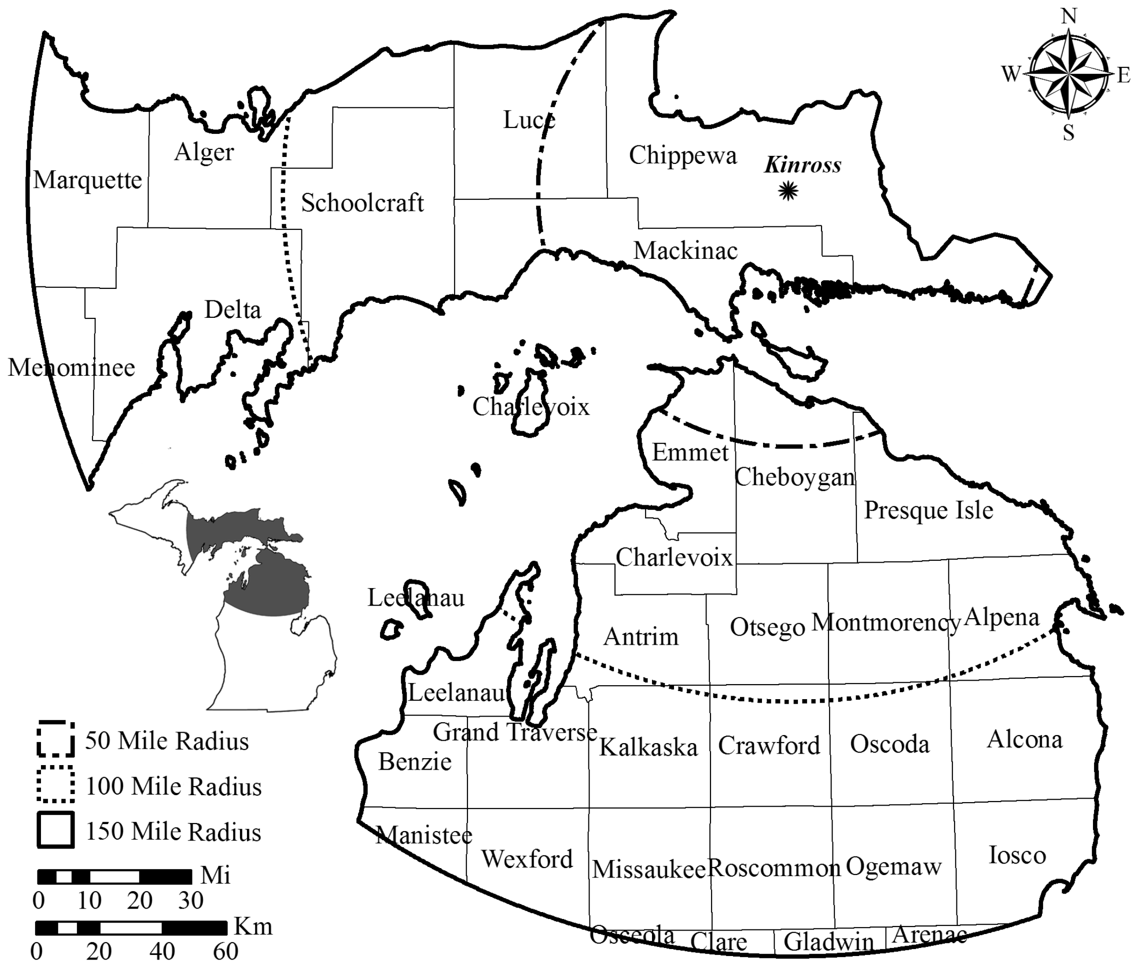

Figure 2.1. Study area in the eastern Upper Peninsula and the northern Lower Peninsula of Michigan, including buffer zones of 50, 100, 150 miles from the Kinross plant (Source: Michigan Geographic Data Library).

2.3. Data and resources

The requisite digital data for the analysis are available from various governmental and geospatial clearing houses (Table 2.1). A description of the data is provided below.

Table 2.1. Data inputs and sources.

Data Type	Source	Date
Land cover (IFMAP)	Michigan Geographic Data Library http://www.michigan.gov/cgi/	2001
Crop data layer	National Agricultural Statistics Service http://www.nass.usda.gov/research/Cropland/SARS1a.htm	2011
Land cover circa 1800	Michigan Geographic Data Library www.mcgi.state.mi.us/mgdl	1978
Digital soil dataset	Natural Resources Conservation Service (NRCS) www.nrcs.usda.gov/	2011
Wetlands	The National Wetlands Inventory (NWI) www.fws.gov/nwi/	2007
Hydrography/ Transportation	Michigan Geographic Data Library www.mcgi.state.mi.us/mgdl	2011
Federal/Native American ownership	Indian land www.nationalatlas.gov	2005
State land	Michigan Geographic Data Library www.mcgi.state.mi.us/mgdl	2001
County geographic extent	Michigan Geographic Data Library http://www.michigan.gov/cgi/	2011

2.4. Land use/cover

Four sources of land use/cover data are utilized in this study, including the Integrated Forest Monitoring, Assessment and Prescription (IFMAP) land use/land cover data from 2001, the Crop Data Layer (CDL) from 2011, pre-European land cover circa 1800 developed by the Michigan Natural Features Inventory, and the National Wetlands Inventory (NWI). IFMAP was developed by the Michigan Department of Natural Resources (MDNR) and provides land use/cover information in a raster format with a 30 m spatial resolution. IFMAP includes 32 land cover classes in a hierarchical classification scheme (MDNR, 2003), providing present-day northern hardwoods association, aspen association, and other land uses. It is recognized that these data are becoming outdated. However, IFMAP is the only land use/cover dataset for Michigan which separates aspen from northern hardwoods; hence its utilization in the research.

The crop land data layer (CDL) 2011 is a product of the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS). The dataset provides a geo-referenced raster file with a 30 m spatial resolution, and contains crop-specific land cover information. Satellite imagery acquired during the growing season from a variety of sources is used to produce the dataset (USDA NASS, 2011). The CDL is produced to provide a detailed classification of agricultural lands identifying the spatial extent of production of various crop types. From this dataset, various corn classes (feed, pop, ornamental and sweet) which are suitable for potential conversion to hybrid popular are identified. Most of the fields are located in the southern portion of the LP study area.

The pre-European settlement dataset provides a basis to characterize land use change between pre-European settlement and current conditions. The Public Land Survey (PLS) conducted by General Land Office (GLO) between 1816 and 1856 provides information about pre-European settlement land cover. Information collected by land surveyors about land cover and other landscape features was interpreted by the Michigan Natural Features Inventory from the original PLS surveyor's notes and a land cover map interpolated. Snetsinger and Ventura (n.d.) investigated the effects of scale on land cover measurements by altering the resolution of present day Landsat based current land cover data set for the state of Wisconsin from 30m x 30m to 805m x 805m (1/2 mile x 1/2 mile). They found that the use of coarser resolution had minimal impact on land cover measurements compared with a case where pre-European data set was compared with 30m x 30m present day land cover. However, caution should be practiced when comparing pre-European settlement and present day land cover data because of possible counter-intuitive trends of land cover change that cannot be explained. One example is the large increase (from 1% to 9%) in the extent of wetlands between pre-European settlement and now in the states of Minnesota and Wisconsin (Snetsinger and Ventura, n.d.).

The National Wetlands Inventory (NWI) is produced by the United States Fish and Wildlife Service (FWS) for mapping the approximate location, type, and areal extent of wetlands and other surface waters. The NWI and associated mapping has been completed utilizing satellite and aerial imagery, topographic information and soils data. Wetlands are typically being managed for conservation and restoration projects, which limits their potential for biofuel feedstock production.

2.5. Digital soils data

Digital soils data are available through Soil Data Mart (http://soildatamart.nrcs.usda.gov/), and is produced by the USDA Natural Resources Conservation Service (NRCS). This dataset provides detailed geo-referenced data by county that have been produced via digitization of remotely sensed imagery incorporated with field data. Soils are grouped into two broad categories: hydric and non-hydric. These are based on drainage condition information provided by the associated components, component existing plants (coeplants), component crop yield (cocropyld), component forest productivity (coforprod), and map unit tables. NRCS defines hydric soils as "those that are sufficiently wet in the upper part to develop anaerobic conditions during the growing season." Aspen grows best in deep, well drained soils (Graham et al., 1963); whereas hydric soils characterizing very wet conditions are moderately suitable for aspen production (Gustafson et al., 2003).

2.6. Road network

A geo-referenced road network is available from the Michigan Geospatial Data Library. Primary and secondary roads were selected to quantify the proximity of aspen and northern hardwoods forests to the transportation network. This is done by creating incremental buffers ranging from ¼ mile up to 5 miles and examining the change in the area of the forests with distance from the road network. Primary roads are "generally divided, limited-access highways within the interstate highway system or under State management, and are distinguished by the presence of interchanges. Secondary roads are

main arteries, usually in the U.S. Highway, State Highway, and/or County Highway system" (US DOC, 2013).

2.7. Land ownerships

The United States National Atlas provides Federal and Native American ownership boundaries. State land boundaries are available from the MDNR. These ownerships are utilized to identify land restricted for expansion of woody feedstock sources. State and national parks, wildlife refuges, military installations and Native American lands cannot be designated for production of aspen and hardwood forests and are excluded from the analyses.

2.8. Geospatial analysis

ArcMap 10.1 is used to extract spatial data for woody biomass sources. Three buffer zones of 50, 100, 150 miles from the Kinross plant are used to characterize extent of aspen and northern hardwoods (Figure 2.1). Geospatial processing of pre-European vegetation (circa 1800), as the native vegetation type data, is performed to determine the historic extent of aspen and northern hardwoods in the study area.

Michigan GeoRef was used as the projected coordinate system for the geospatial processing in order to project the geospatial data layers using a single zone. IFMAP geospatial data available for 2001 are used to identify current extent of aspen and northern hardwoods. The two datasets are compared to identify land use change over time. This comparison is important in that it helps identify places where native aspen and northern hardwoods forests have been converted to other land use types (e.g., marginalized agricultural land), which can be used as a reference for restoration planning.

The areas where changes have occurred are identified, and the type of change determined. Finally, the proximity of aspen and northern hardwoods feedstocks to the transportation network and their location on hydric (wet) and non-hydric soils is analyzed.

The circa 1800 land use/cover layer contains information about the vegetation types from the pre-European settlement era. The data are available by county and are merged to create a seamless polygon for the study area. An attribute field was added to the merged layer to classify the vegetation types into aspen, northern hardwoods, and "other" vegetation types. Finally, the vegetation classes were dissolved to aggregate the vegetation types. The workflow is shown in the Figure 2.2. A similar approach was used to extract present day distribution of aspen and northern hardwoods from IFMAP 2001, as well as farmlands from the CDL 2011 (Figures 2.3 and 2.4).

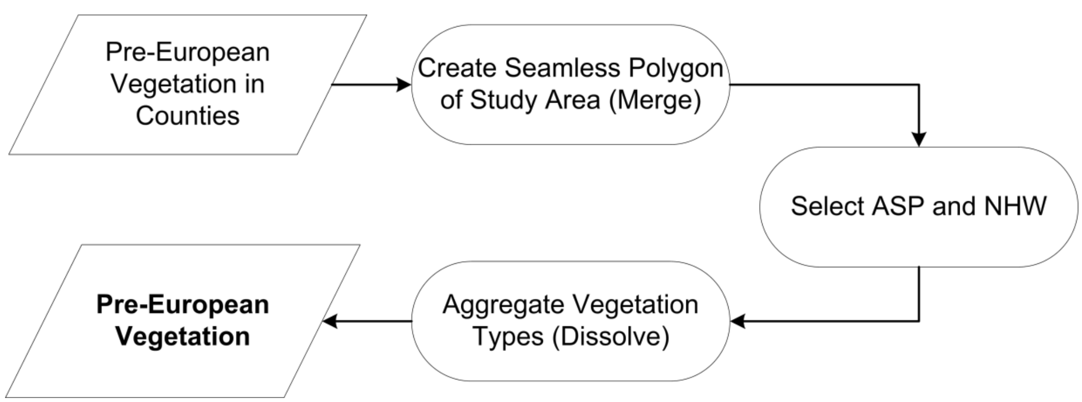

Figure 2.2. Pre-European settlement vegetation data extraction process.

Polygons allow for explicit representation of geospatial features. By contrast, raster files provide an implicit representation of features, which is limited by raster pixel size

(e.g., 30x30 meters). For these reasons, the IFMAP and CDL raster files were converted to polygons.

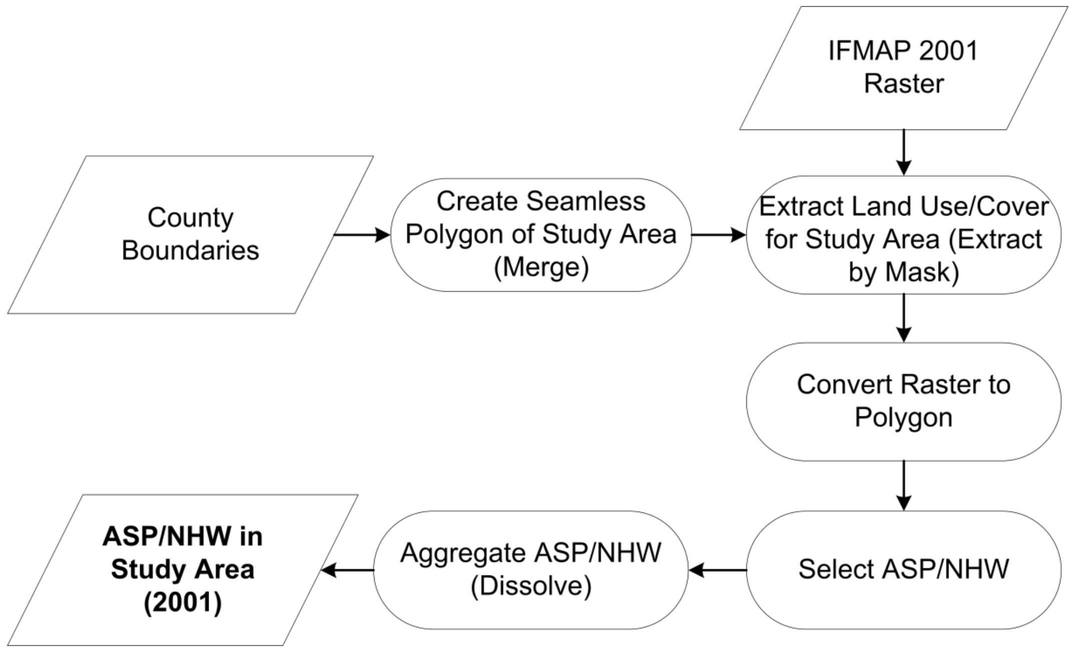

Figure 2.3. Land use/cover 2001 vegetation data extraction process.

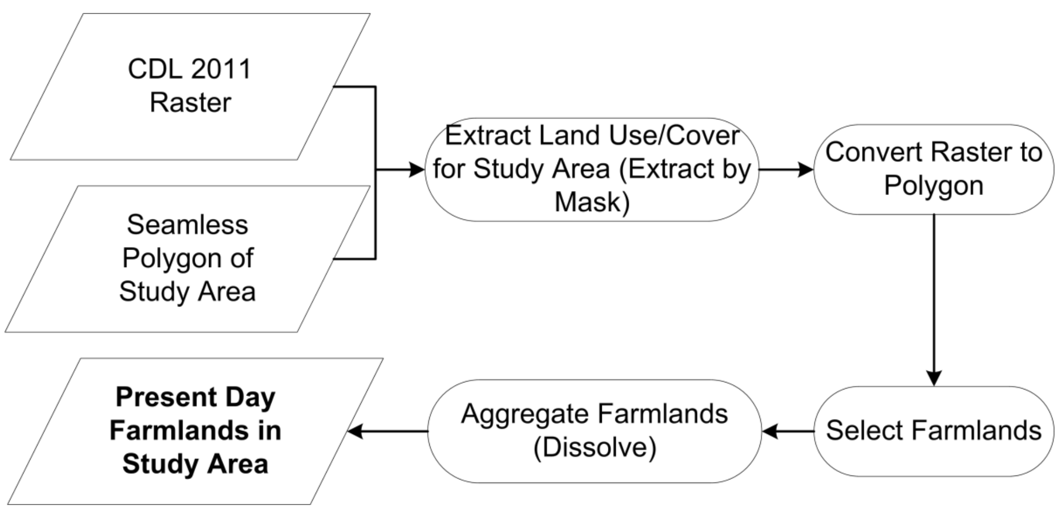

Figure 2.4. Present day farmland extraction from CDL 2011 raster.

Figure 2.5 illustrates the procedure for determining change from pre-European settlement aspen and northern hardwoods to modern day land use/cover types. First, common aspen and northern hardwoods areas between pre-European settlement and present day land use/cover are erased because these are areas essentially unchanged. Second, present day land use/cover polygons within the remaining pre-European settlement aspen and northern hardwoods are extracted. These areas were classified into agricultural land, forestland, barren, urban and built-up, wetland, and rangeland.

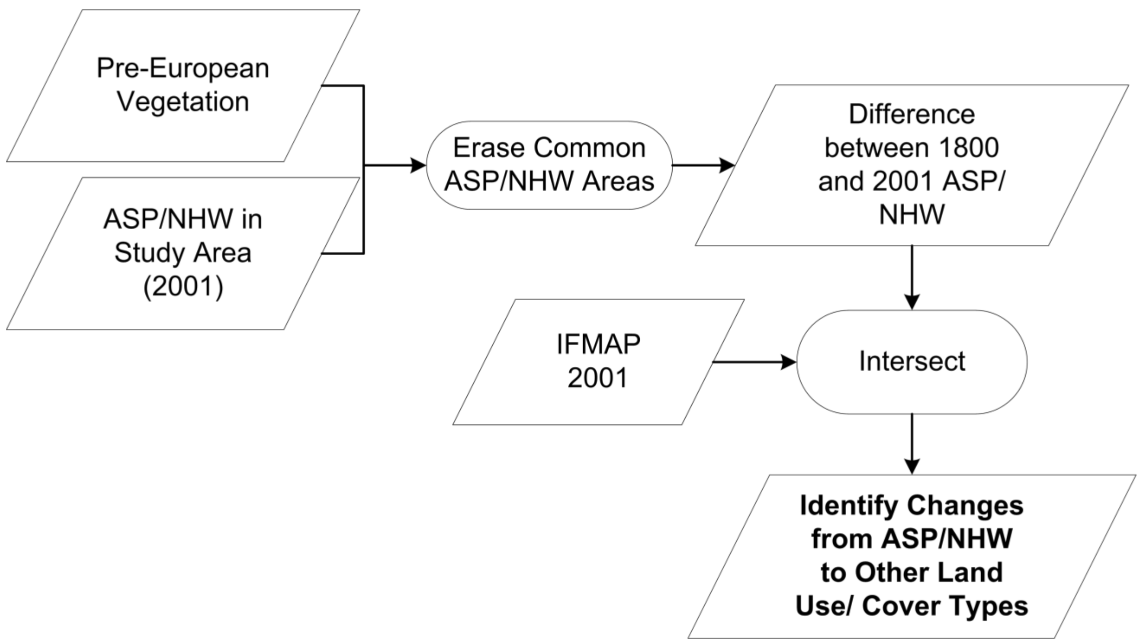

Figure 2.5. Characterization of pre-European settlement land cover change from aspen and northern hardwoods to other land use/cover types.

Present day aspen and northern hardwoods proximity to primary and secondary roads are characterized by creating incremental width buffers around the road network. The procedure is repeated using pre-European settlement vegetation as a first step for identifying potential feedstock source restoration areas (Figure 2.6). In the next step, areas that were covered with aspen and northern hardwoods in the pre-European era but have changed to other land use/cover types are identified (Figure 2.7).

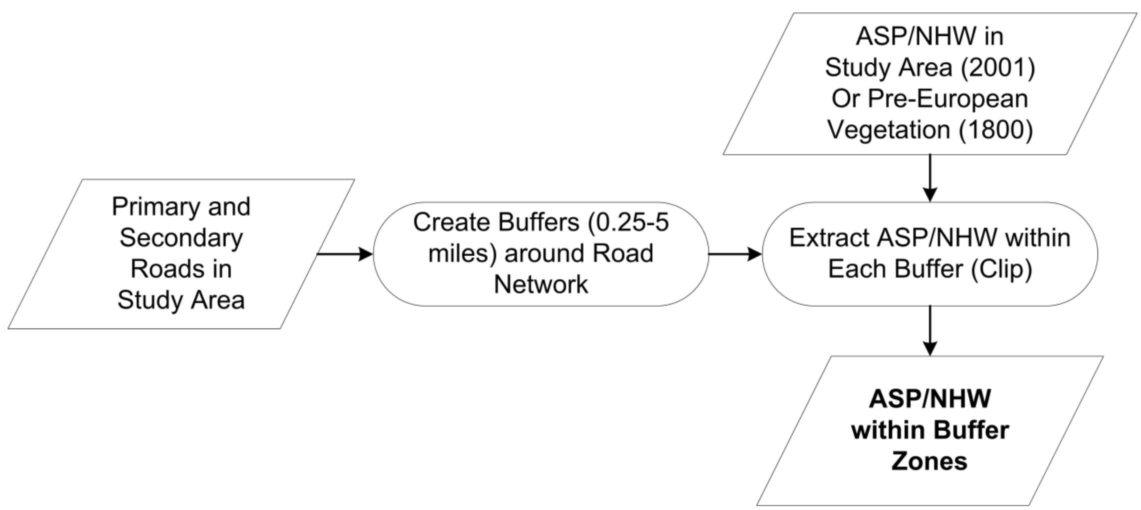

Figure 2.6. Flowchart for identifying proximity of pre-European settlement and present day aspen and northern hardwoods to the road network.

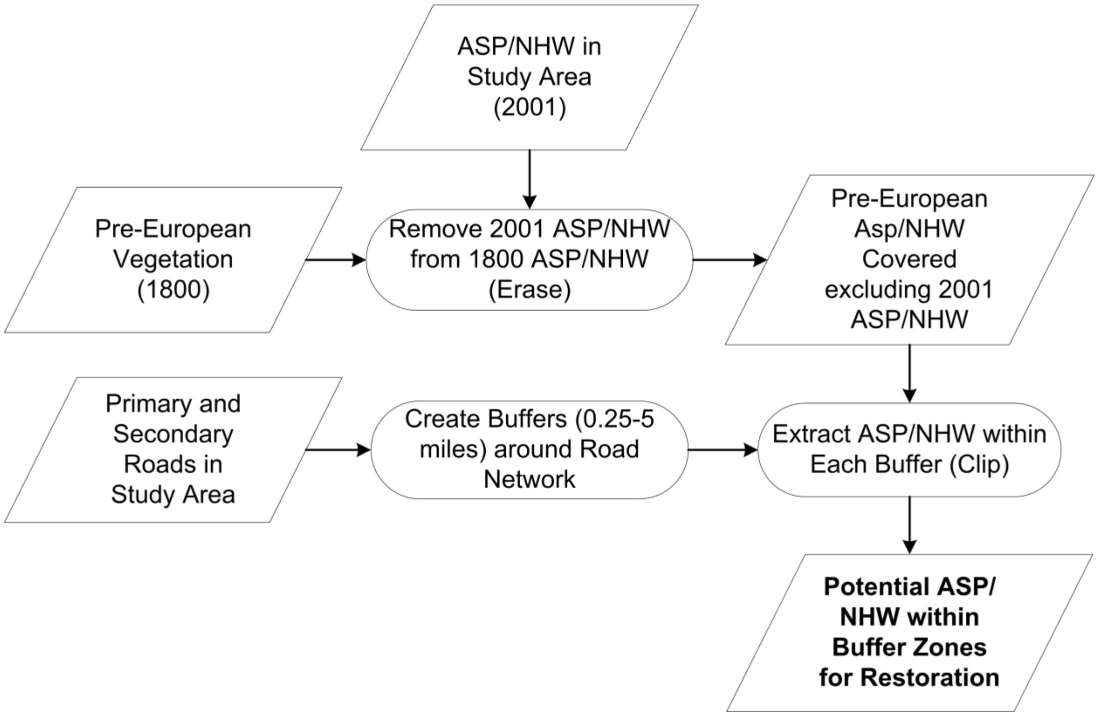

Figure 2.7. Flowchart for identifying potential feedstock restoration areas based on comparison between pre-European settlement and present day vegetation.

The last step in finding suitable areas for potential feedstock sites is to characterize soil characteristics, as well as determine if the land is accessible for restoration. Figure 2.8 shows the procedure for identifying areas with suitable soils (e.g., good and fair) with different moisture content (i.e., hydric and non-hydric). A seamless polygon of the soil data are created from soil data layers. The obtained soil data are converted into a seamless polygon with a comprehensive attribute table. Finally, non-accessible areas such as agricultural lands, urban areas, military facilities, wetlands, national parks, Native American lands, and wildlife refuges are excluded. The remaining areas around the road network are recommended areas for feedstock source restoration.

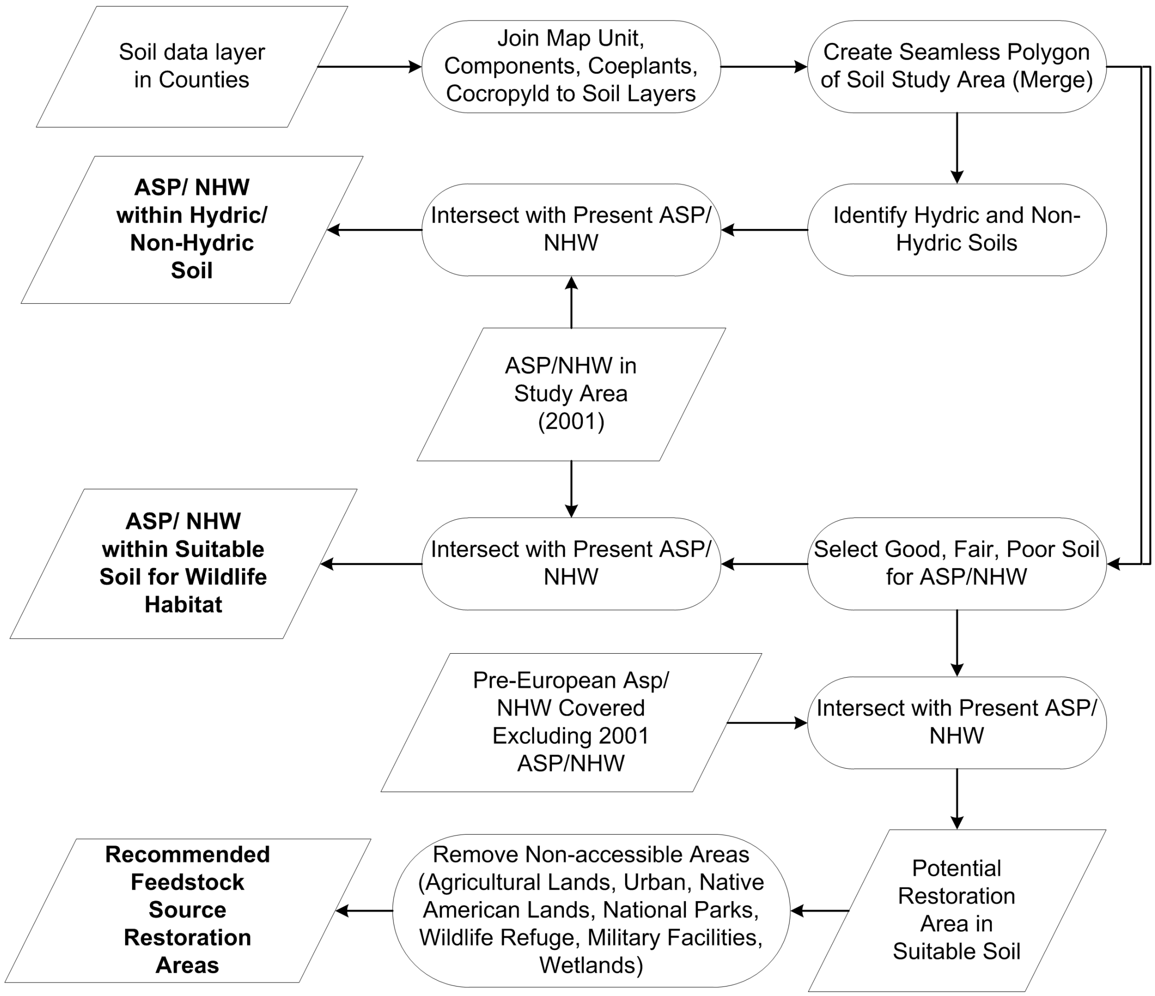

Figure 2.8. Flowchart for identifying potential feedstock restoration areas based on soil characteristics, land accessibility, and comparison between pre-European settlement and present day vegetation.

2.9. References

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Chapter 3- Results and Discussion

3.1. Introduction

The compiled land use/cover data are used to characterize aspen and northern hardwoods extent in 2001 and the pre-European settlement era. The results show a significant amount of northern hardwoods converted to other land use/cover types since European settlement, and aspen stands are less contiguous. Furthermore, a significant amount of woody biomass is available in close proximity to the existing road network, which can be effectively utilized as feedstock for the Kinross plant. Potential aspen and northern hardwoods restoration areas are identified in the vicinity of roads, which can be evaluated for future and increased woody feedstock production.

3.2. Aspen and Northern Hardwoods Distribution Circa 2001

Leefers and Vasievich (2010) used 4,975 measured inventory plots to analyzed timber resources and availability within 150 miles from the Kinross biofuel production facility. They identified 3.3 million ha (8.3 million ac) of timber land area in the study region of which 48% are located in the UP and 52% in the LP. Furthermore, their estimates suggest that there are approximately 0.2 billion cubic meters (6.4 billion cubic feet) of growing stock volume of hardwoods in the study region. The analysis of aspen and northern hardwoods presented in this thesis focuses only on spatial extent of these feedstock sources. Approximately, a total of 1,254,525 ha (3,100,000 ac) of aspen and northern hardwoods were identified by the current analysis in the study area. The main reason for the discrepancy between the timberland area estimated by Leefers and

Vasievich (2010) and this study is due to the fact that the former analysis includes both hardwoods and softwood species in the study area.

Aspen and northern hardwoods associations are two individual land use classes from a total of 32 classes in the IFMAP (circa 2001) land use/cover map. Since aspen and northern hardwoods sites are the focus of this study, all remaining land uses and covers were reclassified as “others.” There are large contagious stands of northern hardwoods ~124,610 ha (307,918 ac) in the northern part of the study site in the UP (~30% of the northern hardwoods in the UP study area). The sizes of these stands are between 10,000-67,640 ha (24,711- 167,142 ac). The large stands in the western part of the LP of Michigan are ~131,100 ha (323,955 ac). These stands are between 1,000- 18,060 ha (2,471- 44,627 ac) large and they contain ~38% of the northern hardwoods in the LP. There are a few large aspen stands in the range of 1,000-3,370 ha (2,471- 8,328 ac) in the UP and LP study areas.

Also, there are small northern hardwoods stands between 1-1,000 ha (2.5- 2,471 ac) scattered throughout the area. A total of 564,165 ha (1,394,082 ac) of aspen and northern hardwoods is identified in the UP, and 689,890 ha (1,704,755 ac) in the LP study areas. Appendix A summarizes aspen and northern hardwoods distribution in the 33 counties within the study area. Table 3.1 summarizes the breakdown of aspen and northern hardwoods distribution within the specified buffer zones of 50, 100, and 150 miles from Kinross plant. Figure 3.1 shows that scattered aspen stands are located throughout the study area.

Table 3.1. Aspen and northern hardwoods distribution within buffer zones of 50, 100, and 150 miles from Kinross plant.

Location	Feedstock	50 miles	50-100 miles	100-150 miles	Total
UP	ASP (ha)	81,500	36,000	50,000	167,500
	NHW (ha)	79,200	136,200	181,265	396,665
	Total (ha)	**160,700**	**172,200**	**231,265**	**564,165**
	ASP (ac)	201,390	88,960	123,550	413,900
	NHW (ac)	195,700	336,560	447,915	980,175
	Total (ac)	**397,090**	**425,520**	**571,465**	**1,394,075**
LP	ASP (ha)	11,620	148,600	185,000	345,220
	NHW (ha)	10,780	164,700	169,190	344,670
	Total (ha)	**22,400**	**313,300**	**354,190**	**689,890**
	ASP (ac)	28,710	367,200	457,145	853,055
	NHW (ac)	26,640	406,990	418,100	851,700
	Total (ac)	**55,350**	**774,190**	**875,245**	**1,704,755**

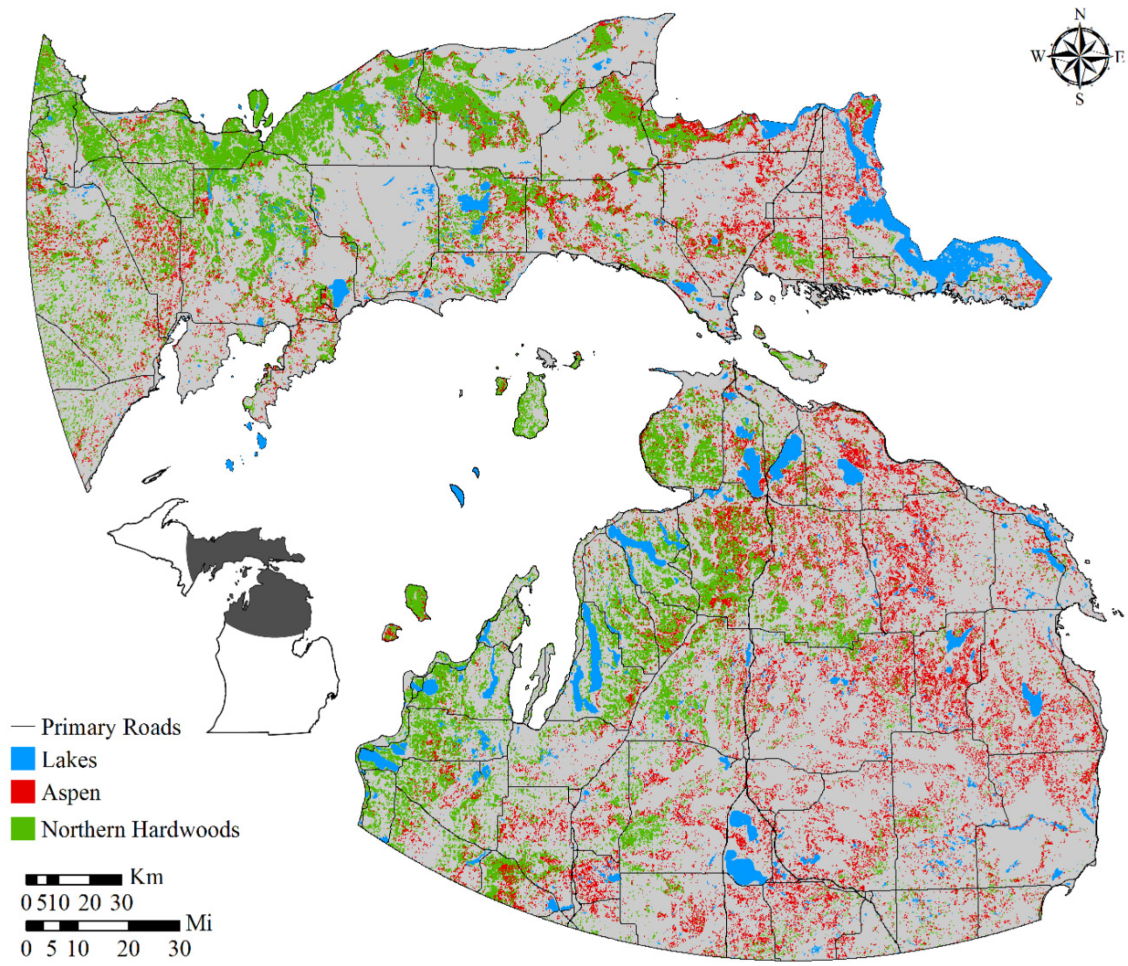


Figure 3.1. 2001 Aspen and northern hardwoods stands in the UP and LP study areas.

3.3. Current agricultural lands suitable for potential feedstock production

Croplands in the study area are mostly classed as prime farmlands or locally important farmlands. The land in prime farmlands has the best combination of physical and chemical characteristics suitable for high yields of different crops (USDA NRCS, 2013). Locally important farmlands are those that provide locally important agricultural

crops, although these lands are not identified as important at national or state levels. Using the Cropland Data Layer (CDL) 2011, the spatial extent of corn fields (feed, pop, ornamental and sweet corns) was calculated in the UP and LP study area in Michigan because these areas may be potentially suitable for hybrid poplar plantations. Approximately 1% of the croplands in the UP study area are corn fields > 2 ha (5 ac). These corn fields are mainly located in the western part of the study area. In the LP study area, ~12 % of croplands are corn located mainly in the northern, eastern, and southern parts; 22% of the corn fields are located within 100 mi of the Kinross plant (Figures 3.2 and 3.3). According to land use data from the CDL 2011 aspen is currently being planted in northeastern Presque Isle County and southwestern Benzie County of the LP study area (Figures 3.4 and 3.5).

3.4. Aspen and northern hardwoods distribution circa 1800

The pre-European land cover map interpreted by the Michigan Natural Features Inventory is used to determine the historical distribution of aspen and northern hardwoods, as well as land use/cover change. The pre-European settlement data shows extensive northern hardwoods stands located in the northern, southern, and western part of the UP study area (Figure 3.6). There were > 754,000 ha (1,863,167 ac) of northern hardwoods and ~30,000 ha (74,131 ac) of aspen prior to pre-European settlement in the UP study area. Significant amounts of northern hardwoods stands ~1,417,000 ha (3,501,469 ac) were available in the western part of the LP, along with small patches of aspen ~33,500 ha (82,780 ac) scattered in the central, northern, and eastern part of the LP (Figure 3.7).

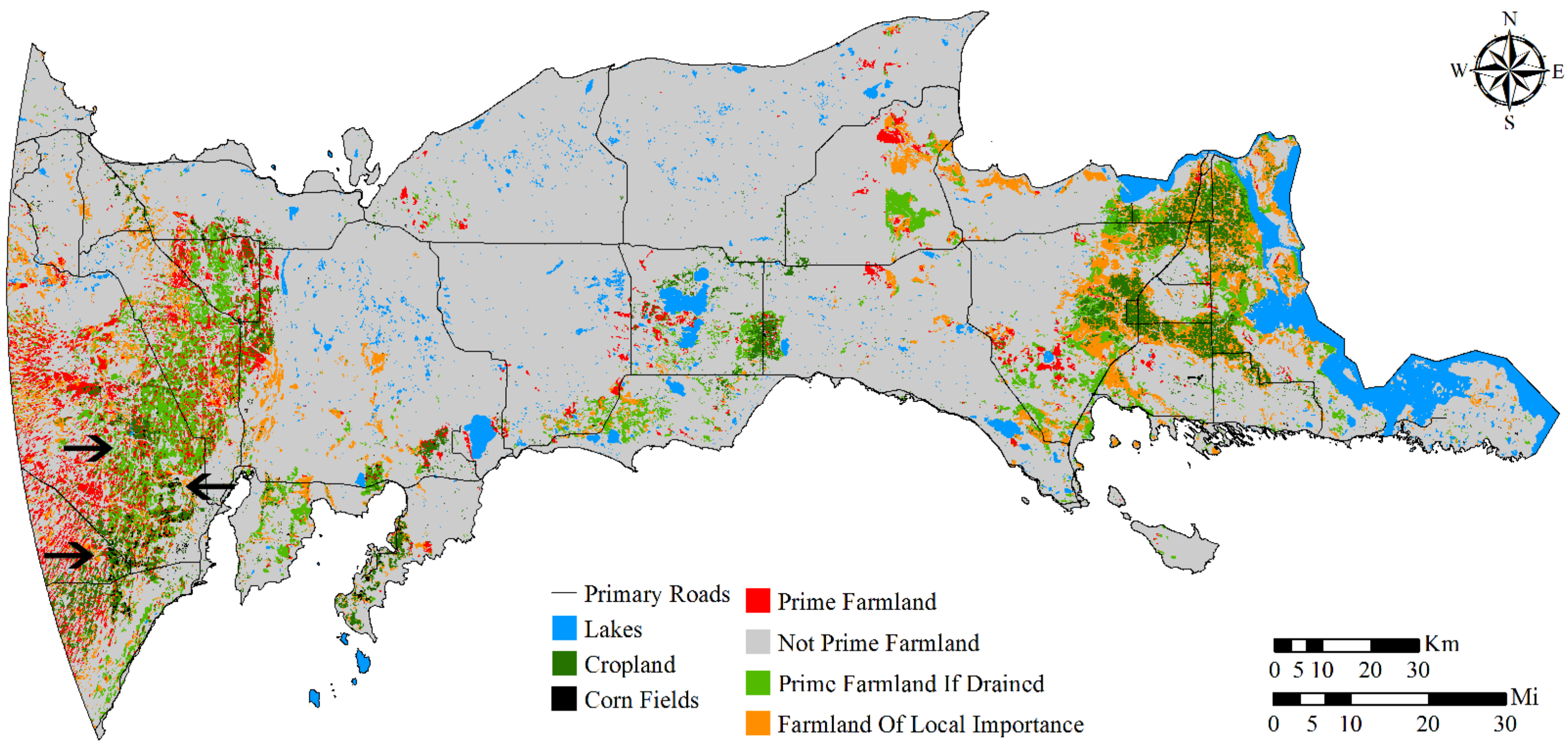


Figure 3.2. Corn and other crops in 2011. Also, shown are areas of farmland currently underutilized in the UP study area.

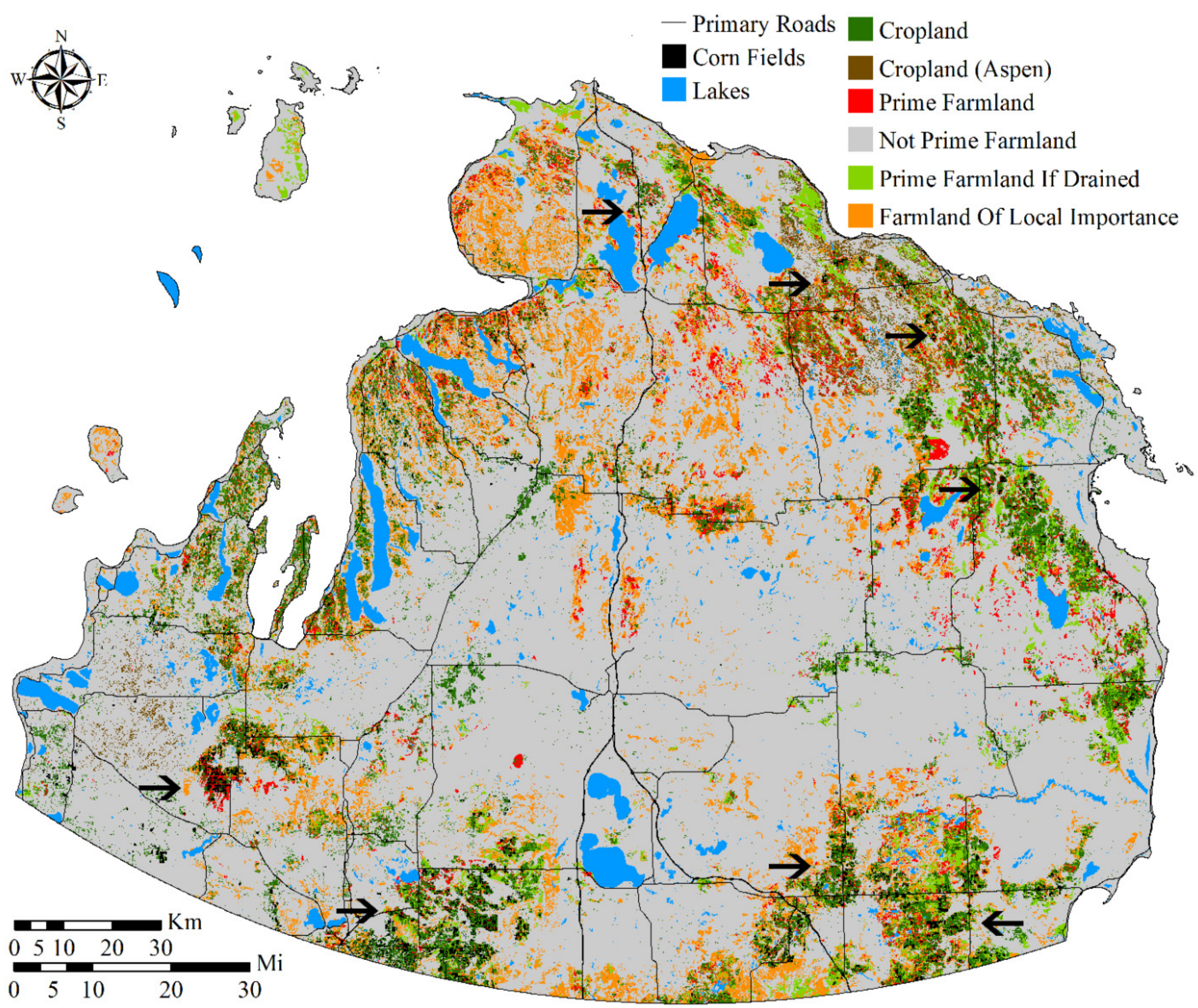


Figure 3.3. Corn and other crops in 2011. Also, shown are areas of farmland currently underutilized in the LP study area.

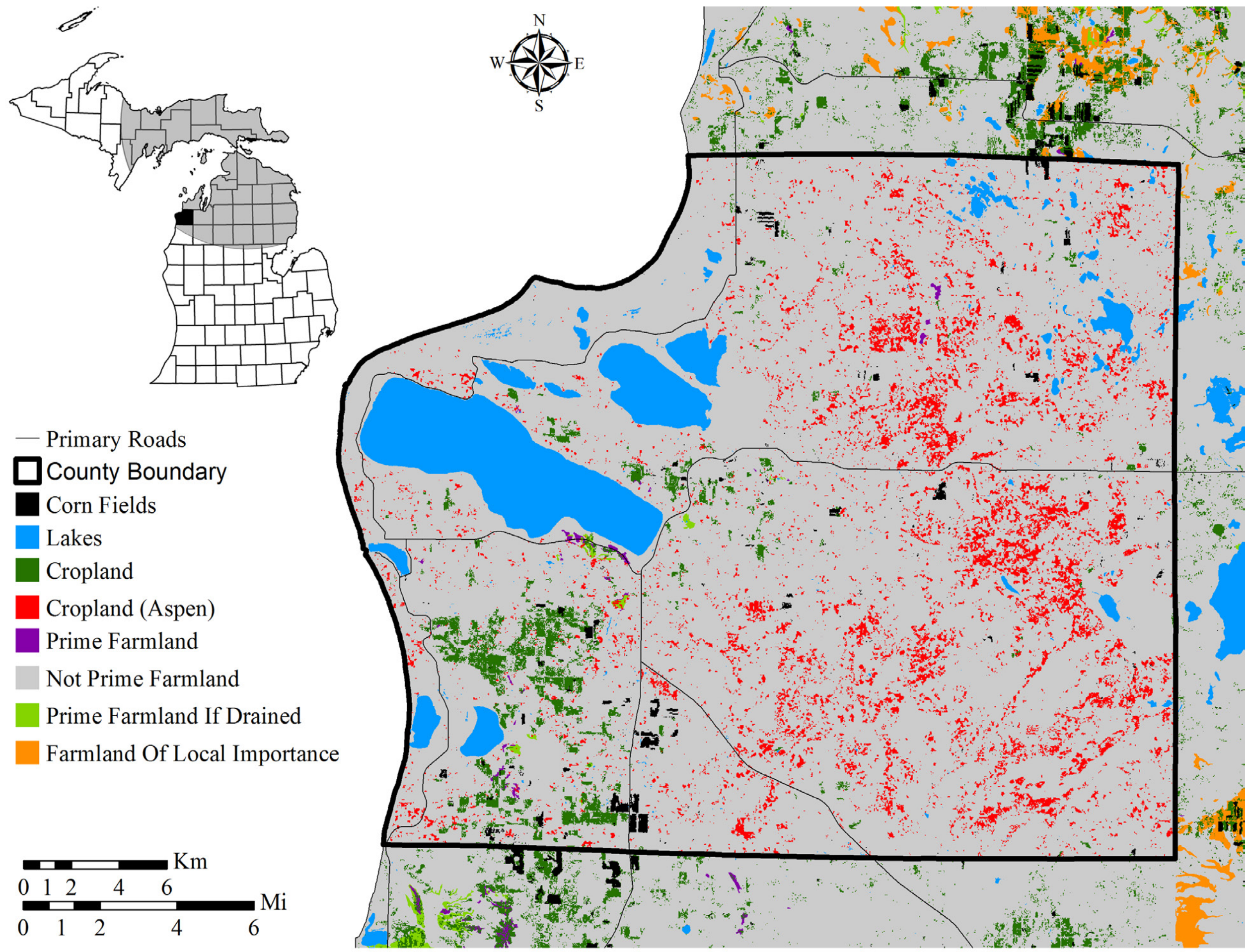


Figure 3.4. Aspen and other crops in 2011 in Benzie County in the LP study area.

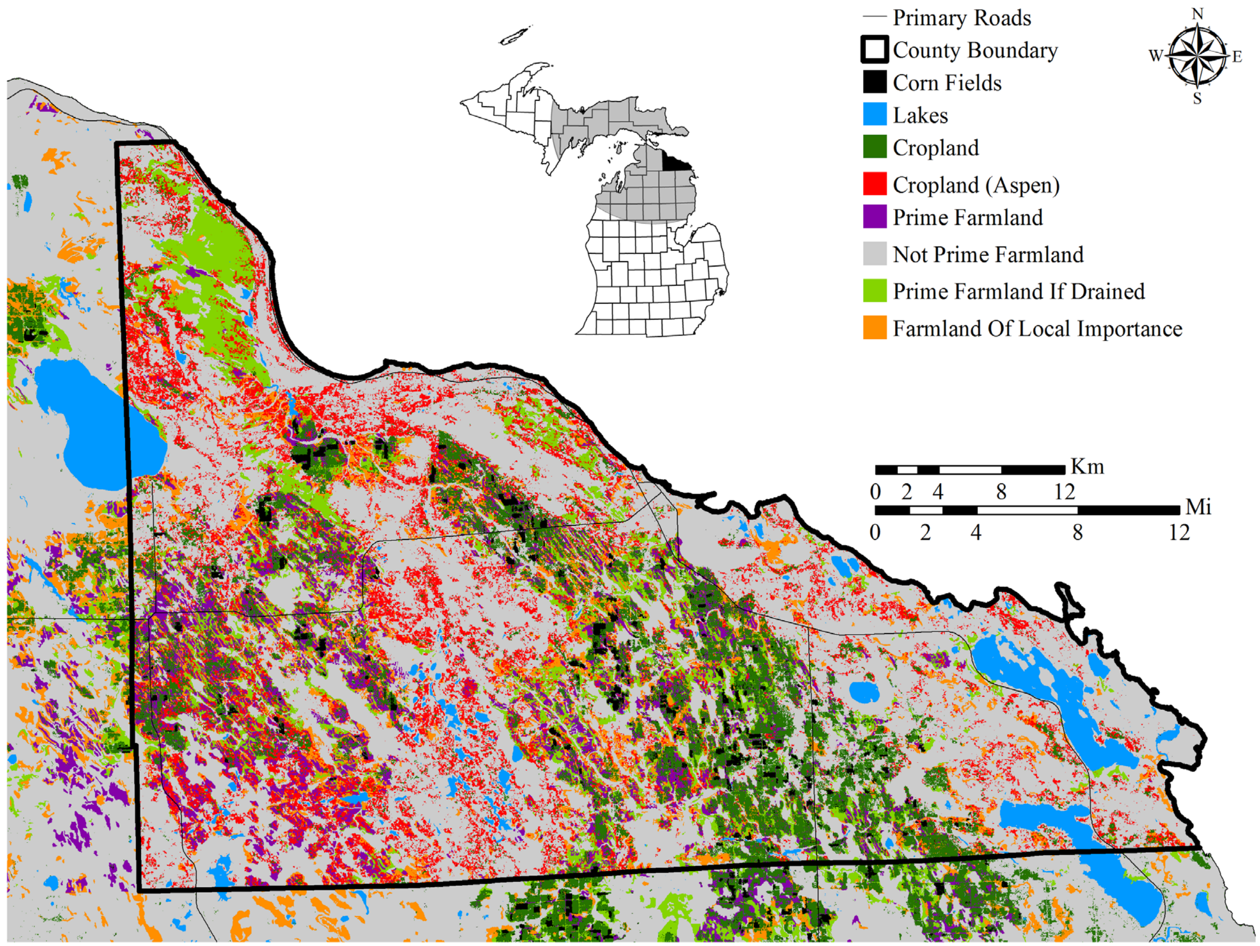


Figure 3.5. Aspen and other crops in 2011 in Presque Isle County in the LP study area.

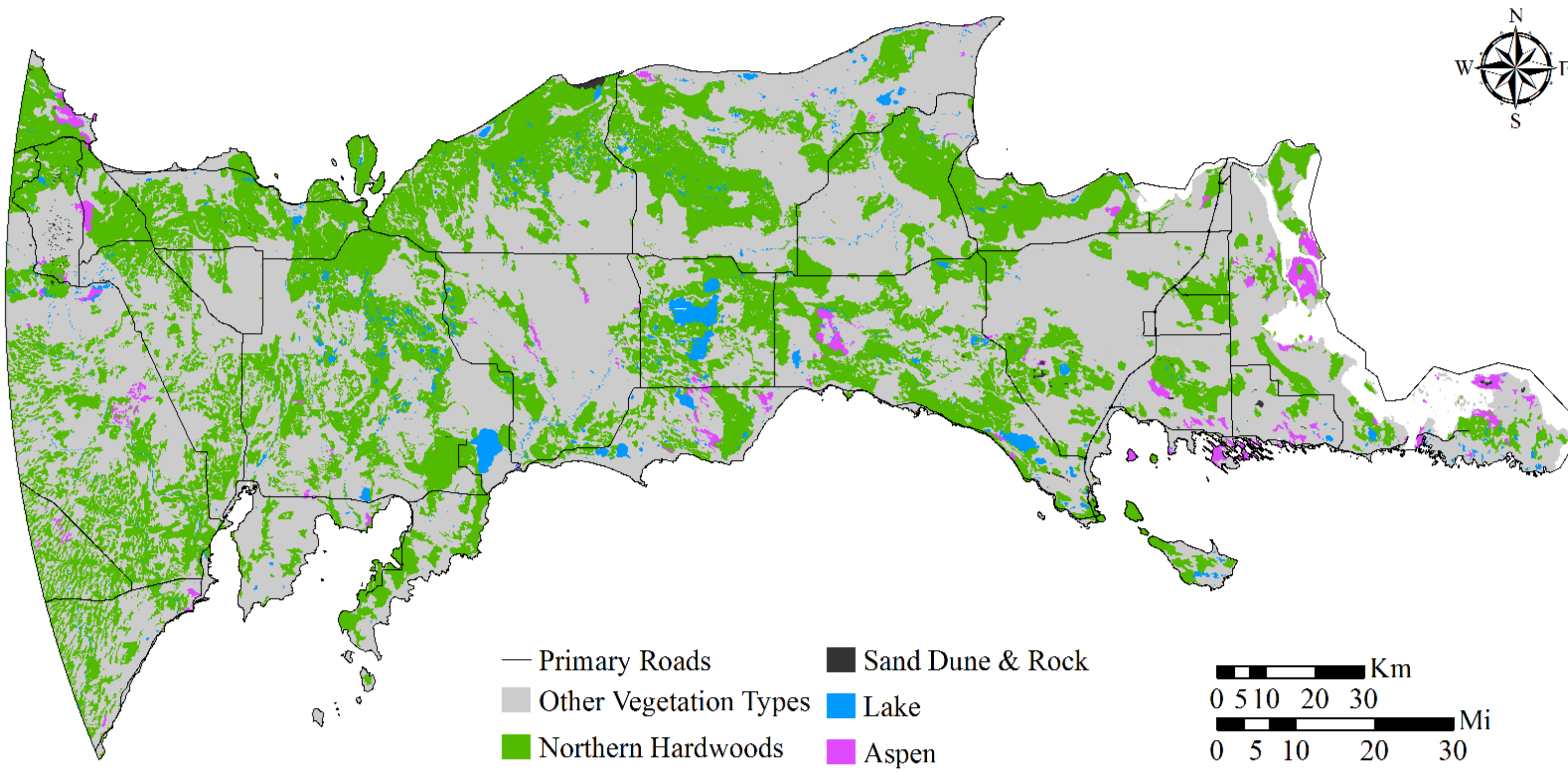


Figure 3.6. Pre-European aspen and northern hardwoods distribution in the UP study area.

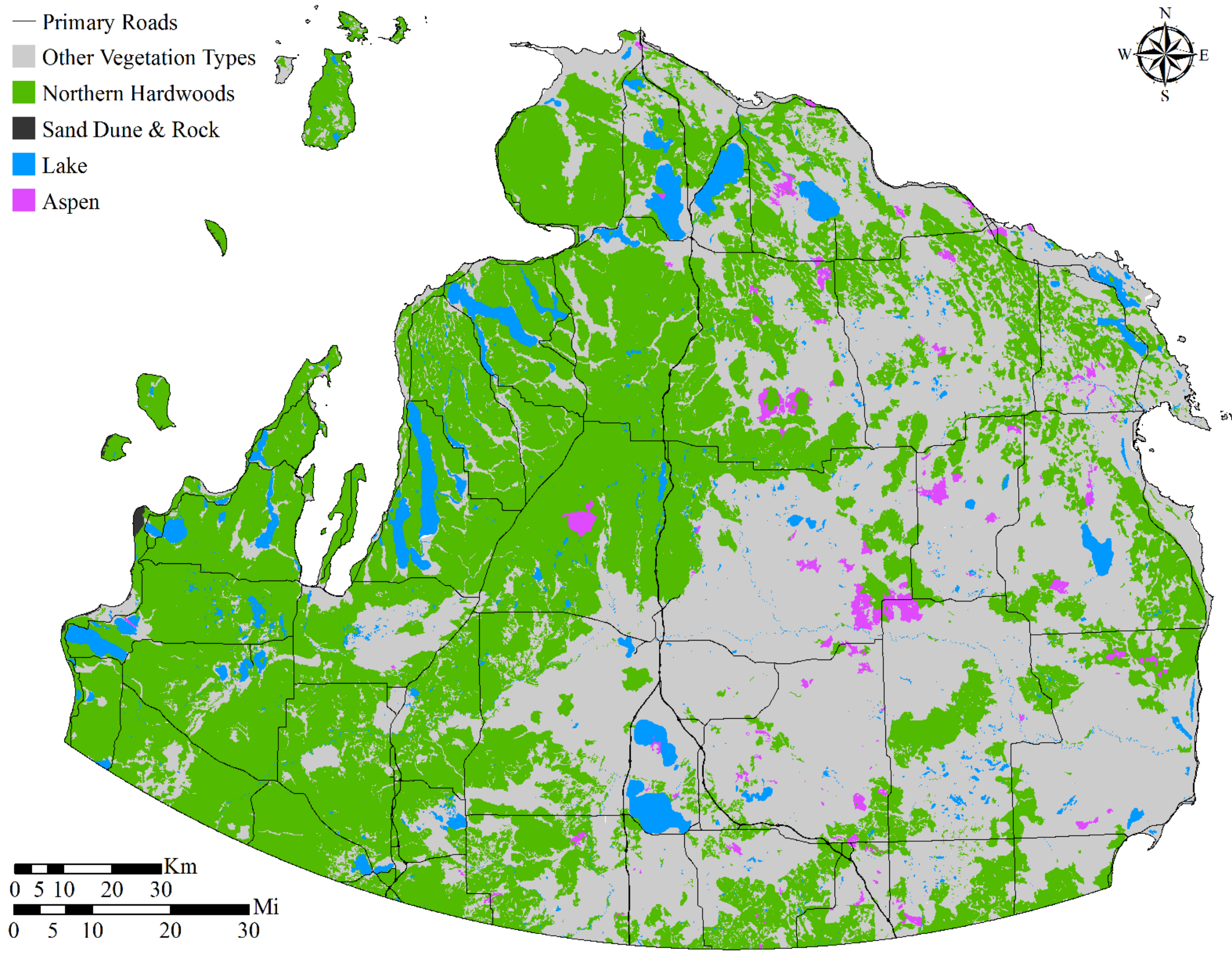


Figure 3.7. Pre-European aspen and northern hardwoods distribution in the LP study area.

A comparison between the IFMAP and pre-European data shows that there are aspen and northern hardwoods areas that have remained unchanged. In other areas, aspen and northern hardwoods covers have changed to other land uses/covers. Furthermore, IFMAP shows small areas of aspen and northern hardwoods that were covered with other vegetation types in the pre-European settlement era. Table 3.2 compares the size of these three areas.

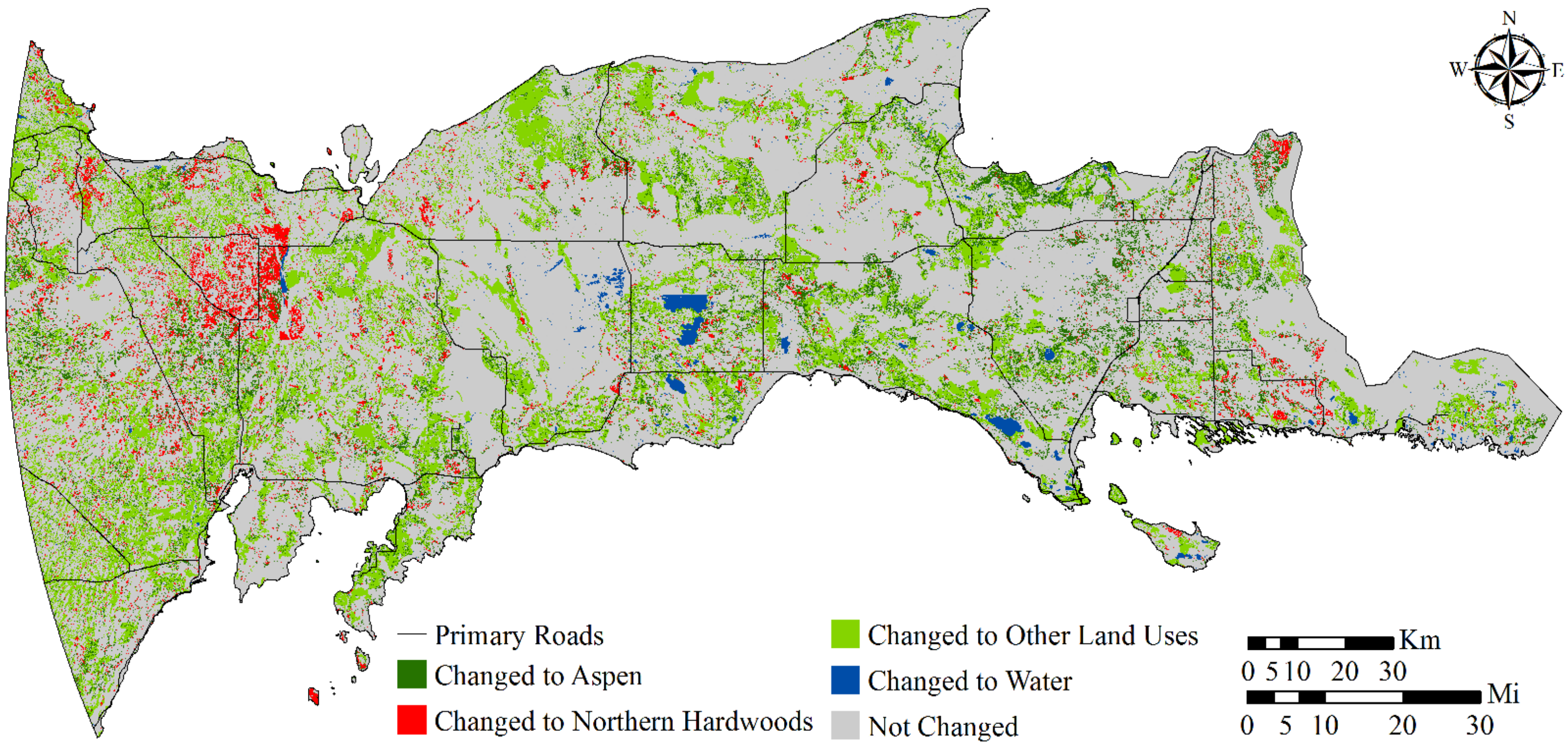
Table 3.2. Aspen and northern hardwoods change between circa 1800s and 2001.

Location	ASP/NHW Change	Feedstock	Area (ha)	Area (ac)
UP	Common ASP/NHW areas between circa 1800s and 2001	ASP	7,000	17,300
		NHW	411,415	1,016,630
	ASP/NHW in circa 1800s and not in circa 2001	ASP	22,740	56,190
		NHW	342,780	847,030
	ASP/NHW in circa 2001 and not in circa 1800s	ASP	73,990	182,835
		NHW	72,550	179,275
LP	Common ASP/NHW areas between circa 1800s and 2001	ASP	7,020	17,340
		NHW	480,315	1,186,885
	ASP/NHW in circa 1800s and not in circa 2001	ASP	26,530	65,560
		NHW	936,595	2,314,380
	ASP/NHW in circa 2001 and not in circa 1800s	ASP	174,030	430,030
		NHW	28,620	70,720

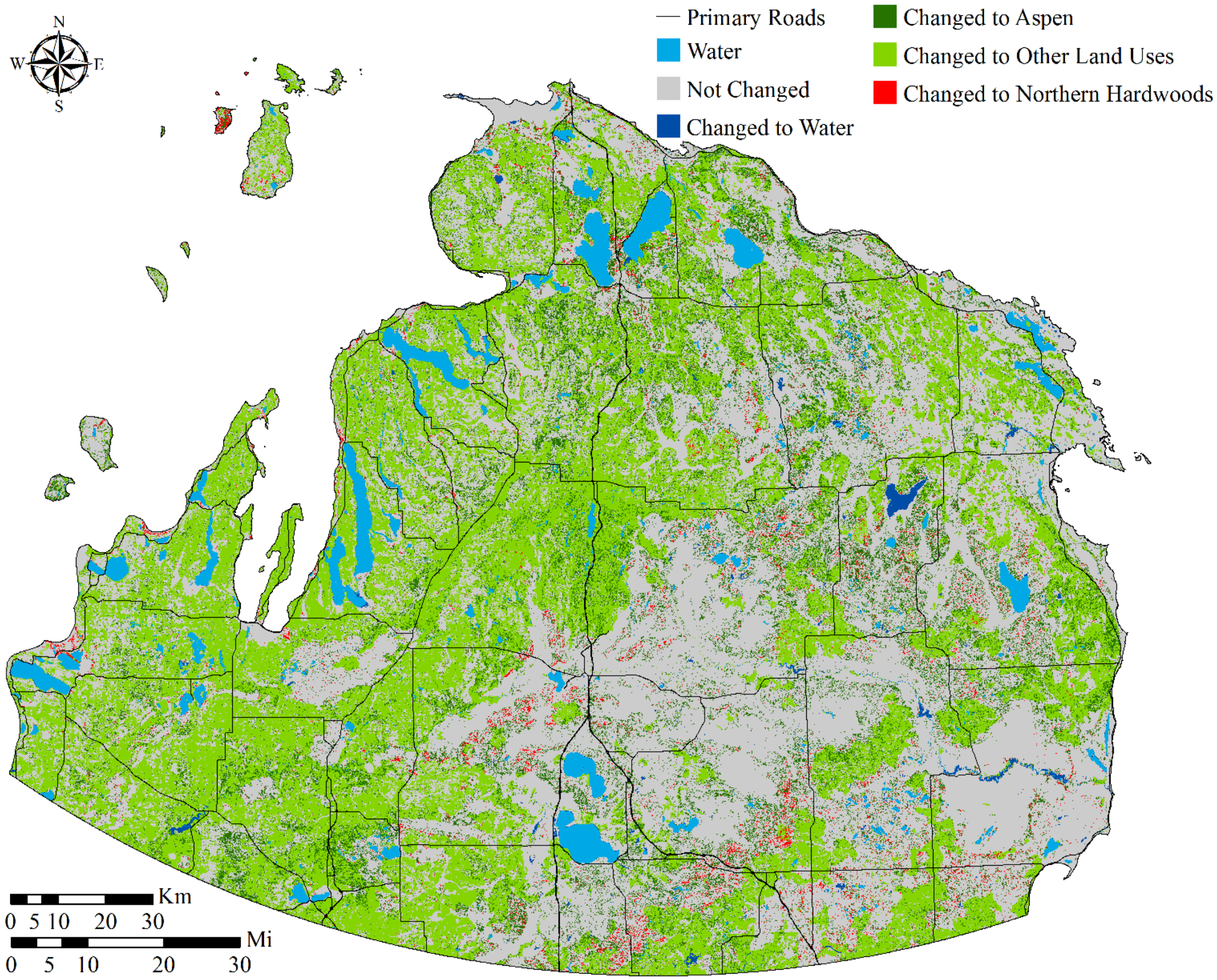
Fifty-four percent of the northern hardwoods and 24% of the aspen has been converted to other land uses in the UP study area (Table 3.3). In the LP, 34 % of the pre-European northern hardwoods and 21% of the aspen has been converted. Significant proportions of the pre-European aspen and northern hardwoods lands in the study area have changed to other forested lands (such as conifer plantations), rangelands and agricultural lands. Figures 3.8 and 3.9 provide maps of land use changes to aspen and northern hardwoods, and other land use types between pre-European settlement era and circa 2001 in the UP and LP study areas. Land use changes to other land use types in the UP and LP study areas are shown in detail in Figures 3.10 and 3.11.

Table 3.3. Land use change from hardwood and aspen to other land uses between circa 1800 and circa 2001.

Location (Feedstock)	**Unit**	**Land Use/Cover**					
		Forested	**Agricultural**	**Barren**	**Rangeland**	**Urban**	**Wetland**
UP (ASP)	**ha**	15,950	515	310	3,600	860	1,300
	ac	39,390	1,300	770	9,000	2,140	3,200
UP (NHW)	**ha**	213,240	32,240	3,530	71,450	12,070	8,850
	ac	526,925	79,670	8,725	176,560	29,820	21,870
LP (ASP)	**ha**	13,400	2,810	480	5,630	770	500
	ac	33,120	6,950	1,190	13,900	1,900	1,220
LP (NHW)	**ha**	389,535	215,745	6,844	264,200	43,960	12,350
	ac	962,560	533,120	16,910	652,845	108,620	30,525



Figures 3.8. Land use change to aspen and northern hardwoods, and other land use types between pre-European settlement era and circa 2001 in the UP study area.



Figures 3.9. Land use change to aspen and northern hardwoods, and other land use types between pre-European settlement era and circa 2001 in the LP study area.

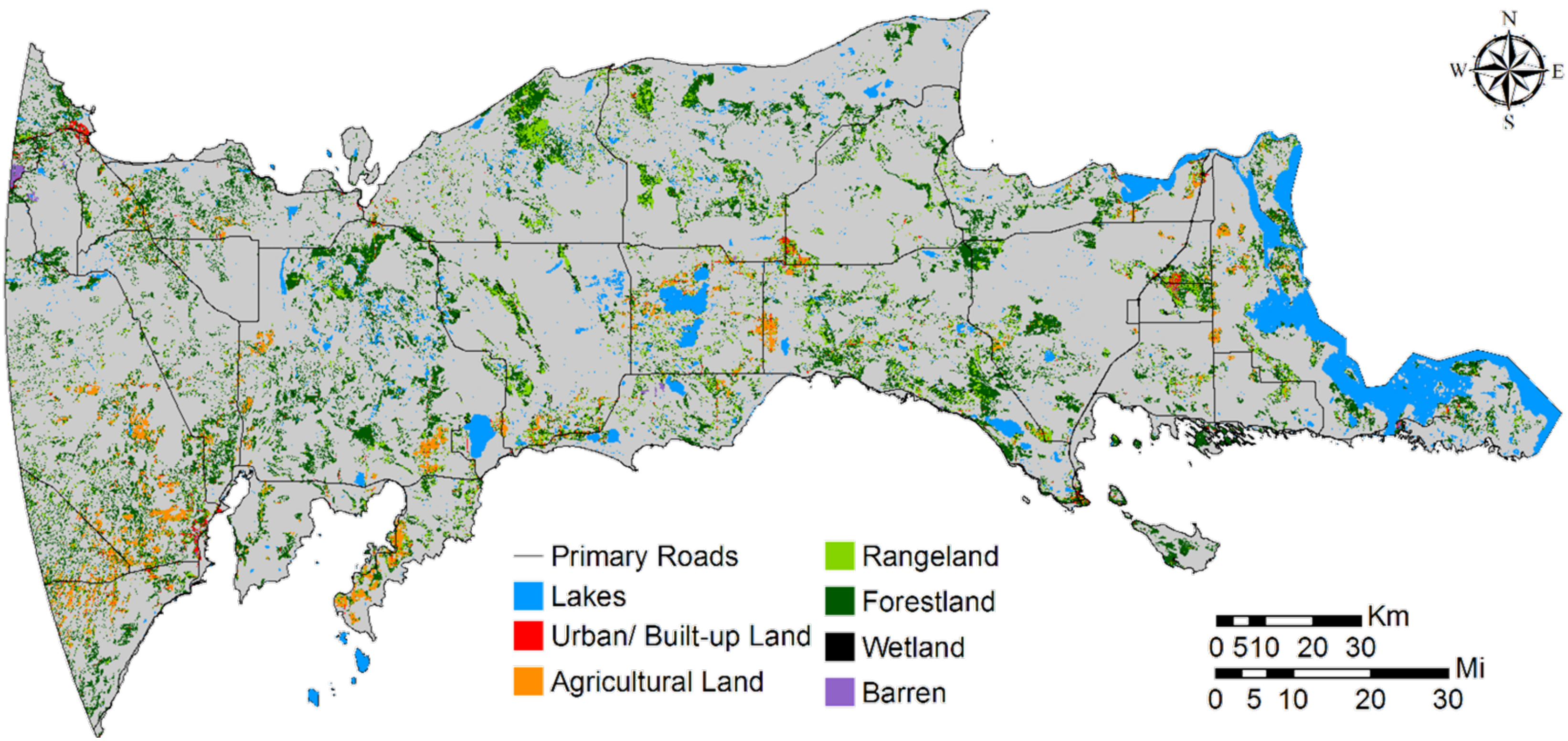


Figure 3.10. Land use changes to other land use types in the UP study area between pre-European settlement and circa 2001.

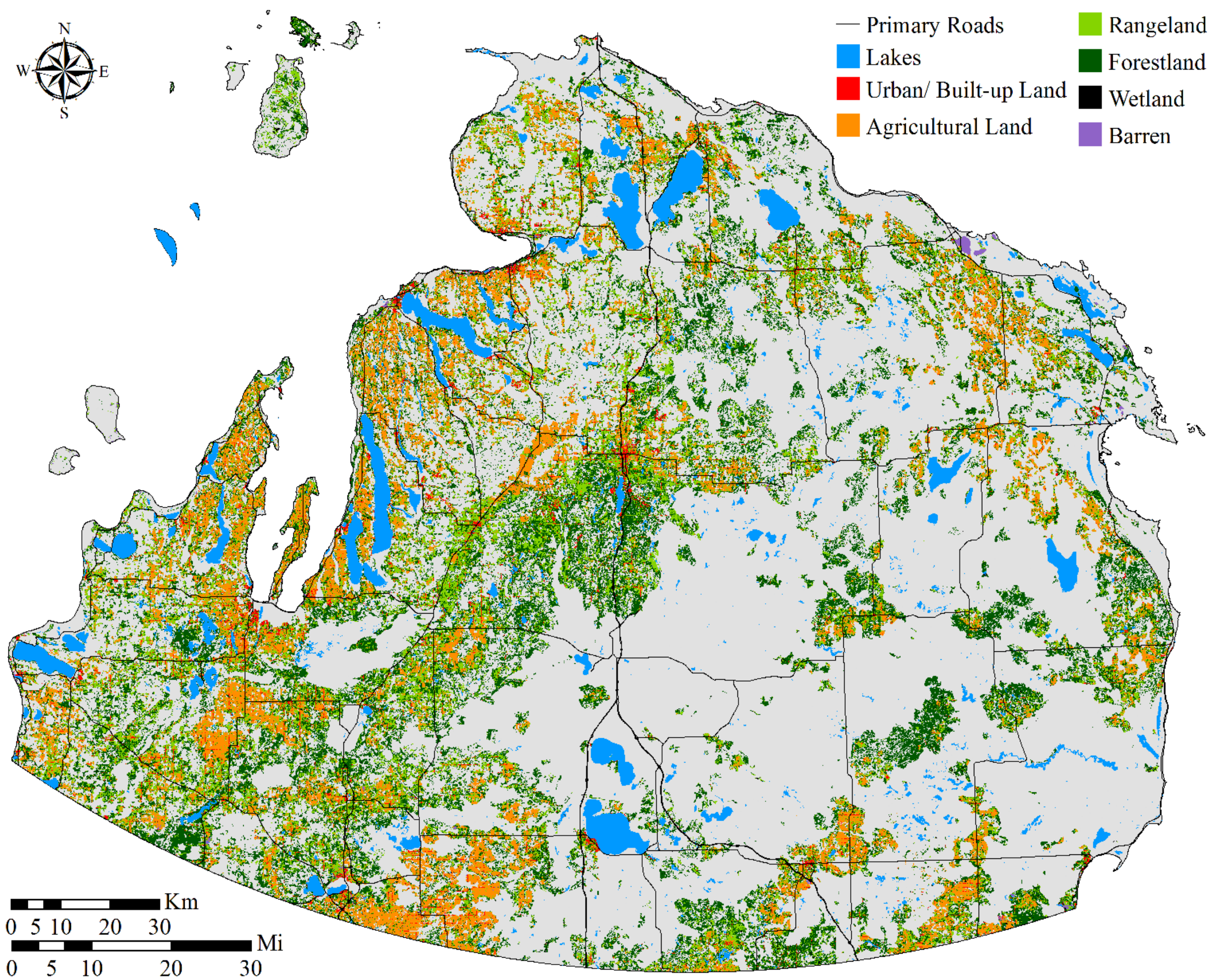


Figure 3.11. Land use changes to other land use types in the LP study area between pre-European settlement and circa 2001.

3.5. Feedstock sources around existing road networks

Table 3.5 summarizes the present amount of aspen and northern hardwoods within incremental distance buffers from the primary and secondary road network in different soil types (hydric and non-hydric soils) in the UP and LP study area. The table excludes lands that are have restricted access such as wildlife refuges, military installations and national and state parks and Native American lands. The analysis shows that most of the aspen and northern hardwoods, i.e., >175,000 ha (432,433 ac) and >372,000 ha (919,228 ac) in the UP and LP, respectively, is available within 0.25 mile of a primary or secondary road. Most of the feedstock sources are located on non-hydric soil sites (Table 3.4). Feedstock extent sharply declines as distance from the road network increases (Figure 3.12a and 3.12b). The results show these feedstock volumes are within economically viable distances to the existing road network (Figures 3.13 and 3.14).

Table 3.4. Incremental aspen and northern hardwoods distribution (ha and ac) on hydric and non-hydric soils for different distances (mi) from road network in the UP and LP study areas using IFMAP data.

Location (Feedstock)	**Soil**	**Unit**	**Miles**									**Total**
			0- 0.25	**0.25-0.50**	**0.25-0.75**	**0.75-1.00**	**1.00-1.50**	**1.50-2.00**	**2.00-3.00**	**3.00-4.00**	**4.00-5.00**	
UP (ASP)	Hydric	ha	13,486	9,600	5,019	3,337	3,740	1,939	1,073	155	27	*38,376*
		ac	33,324	23,722	12,402	8,245	9,242	4,791	2,651	383	66	*94,829*
	Non-Hydric	ha	43,404	29,051	17,459	11,399	14,280	6,885	4,256	951	79	*127,764*
		ac	107,254	71,787	43,142	28,168	35,287	17,013	10,517	2,350	195	*315,711*
UP (NHW)	Hydric	ha	8,262	6,034	4,036	2,856	3,925	2,125	1,567	637	74	*29,516*
		ac	20,416	14,910	9,973	7,057	9,699	5,250	3,872	1,574	183	*72,936*
	Non-Hydric	ha	110,083	76,430	48,416	33,383	43,192	24,356	17,783	4,100	996	*358,739*
		ac	272,021	188,862	119,638	82,491	106,730	60,185	43,943	10,131	2,461	*886,462*
LP (ASP)	Hydric	ha	15,551	10,233	3,689	1,621	1,231	402	280	33	63	33,103
		ac	38,427	25,286	9,116	4,006	3,042	993	692	82	156	81,799
	Non-Hydric	ha	162,262	86,896	30,116	12,709	9,890	3,965	3,119	399	103	309,459
		ac	400,958	214,724	74,418	31,405	24,439	9,798	7,707	986	255	764,689
LP (NHW)	Hydric	ha	5,758	3,019	677	250	109	21	8	118	220	10,180
		ac	14,228	7,460	1,673	618	270	52	20	292	544	25,155
	Non-Hydric	ha	188,539	103,798	27,067	6,547	2,595	626	353	89	333	329,947
		ac	465,889	256,490	66,884	16,178	6,412	1,547	872	220	823	815,316

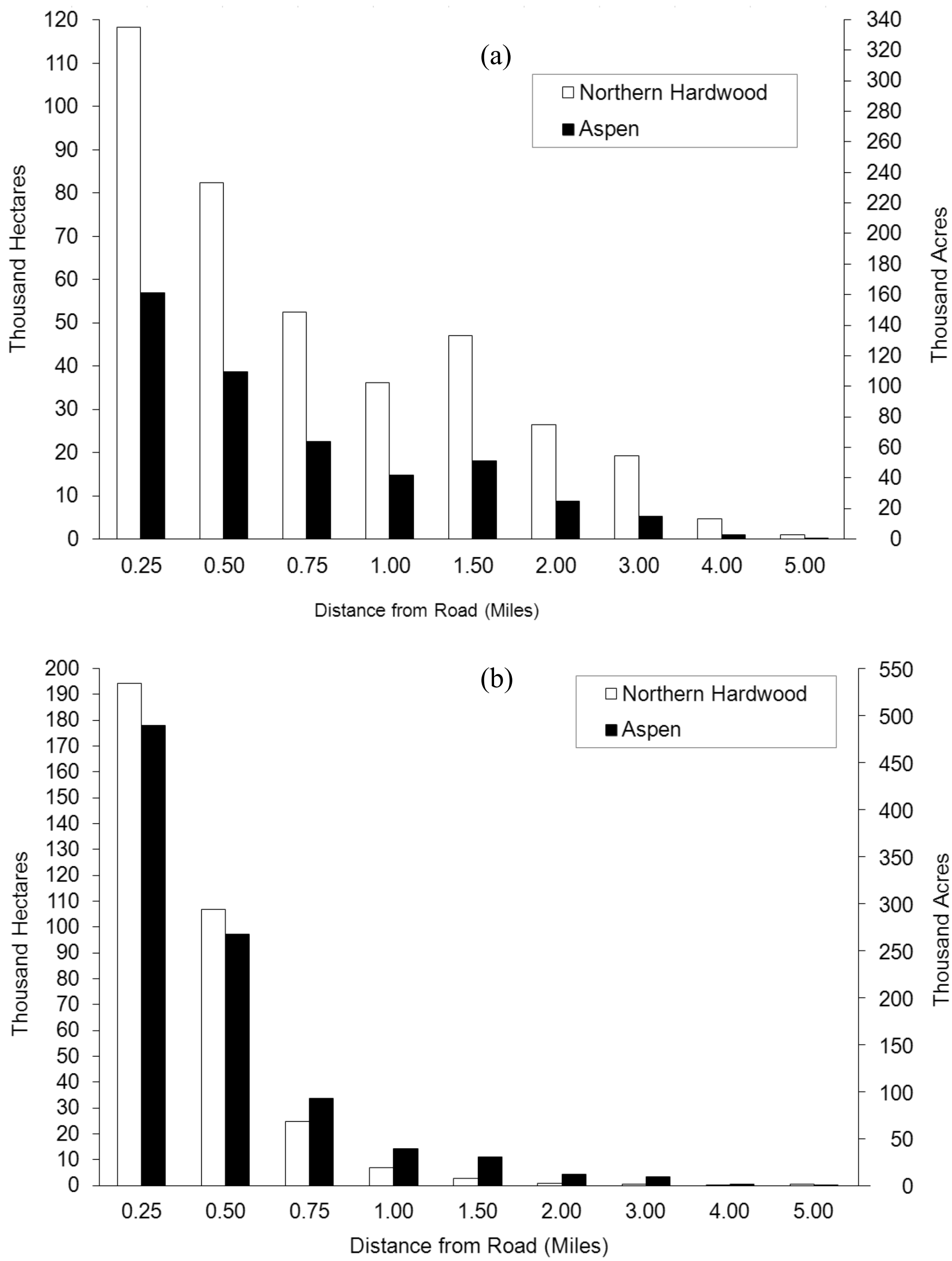


Figure 3.12. Proximity of aspen and northern hardwoods to the road network in the UP (a) and LP (b) in the study area using IFMAP data.

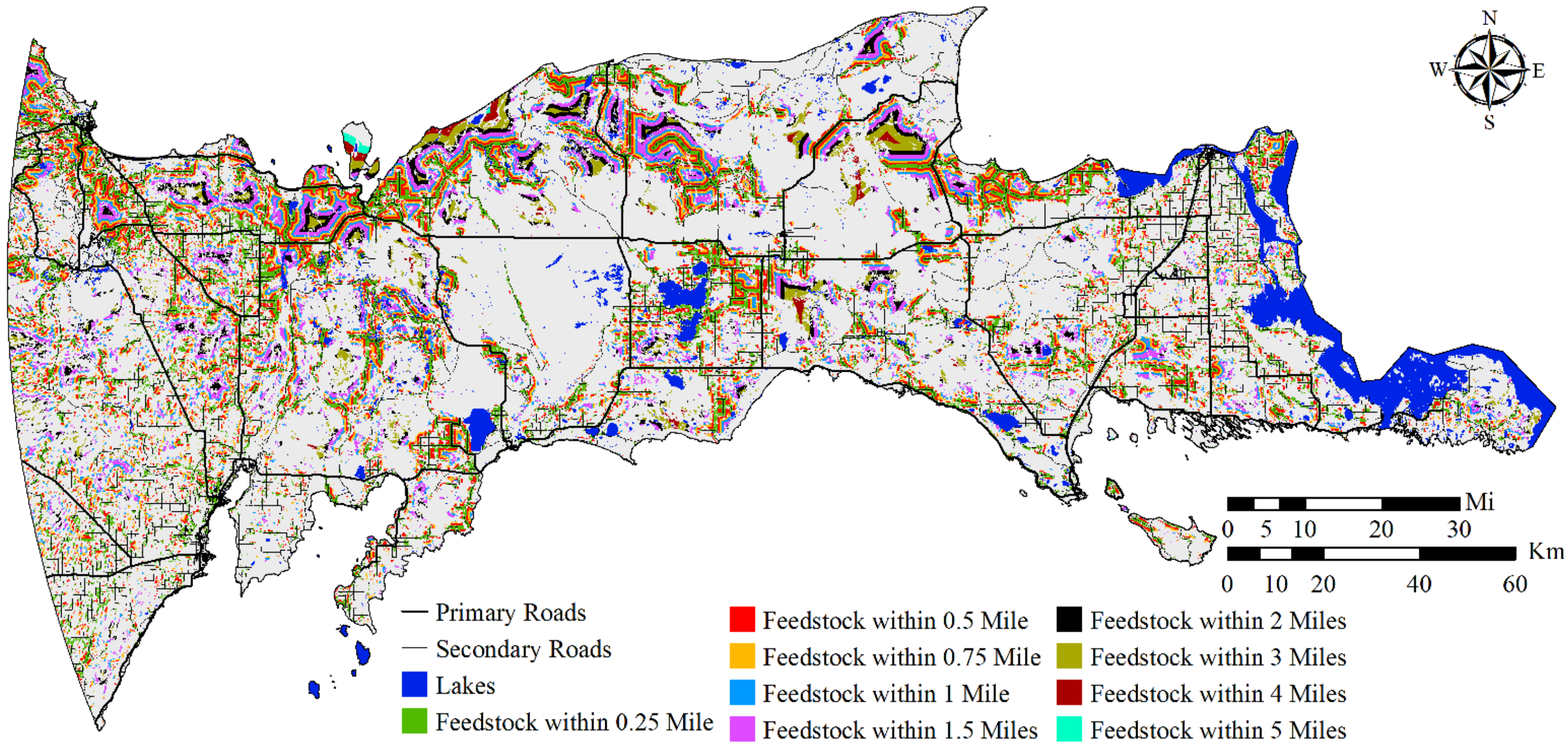


Figure 3.13. Aspen and northern hardwoods proximity to the road network in the UP study area.

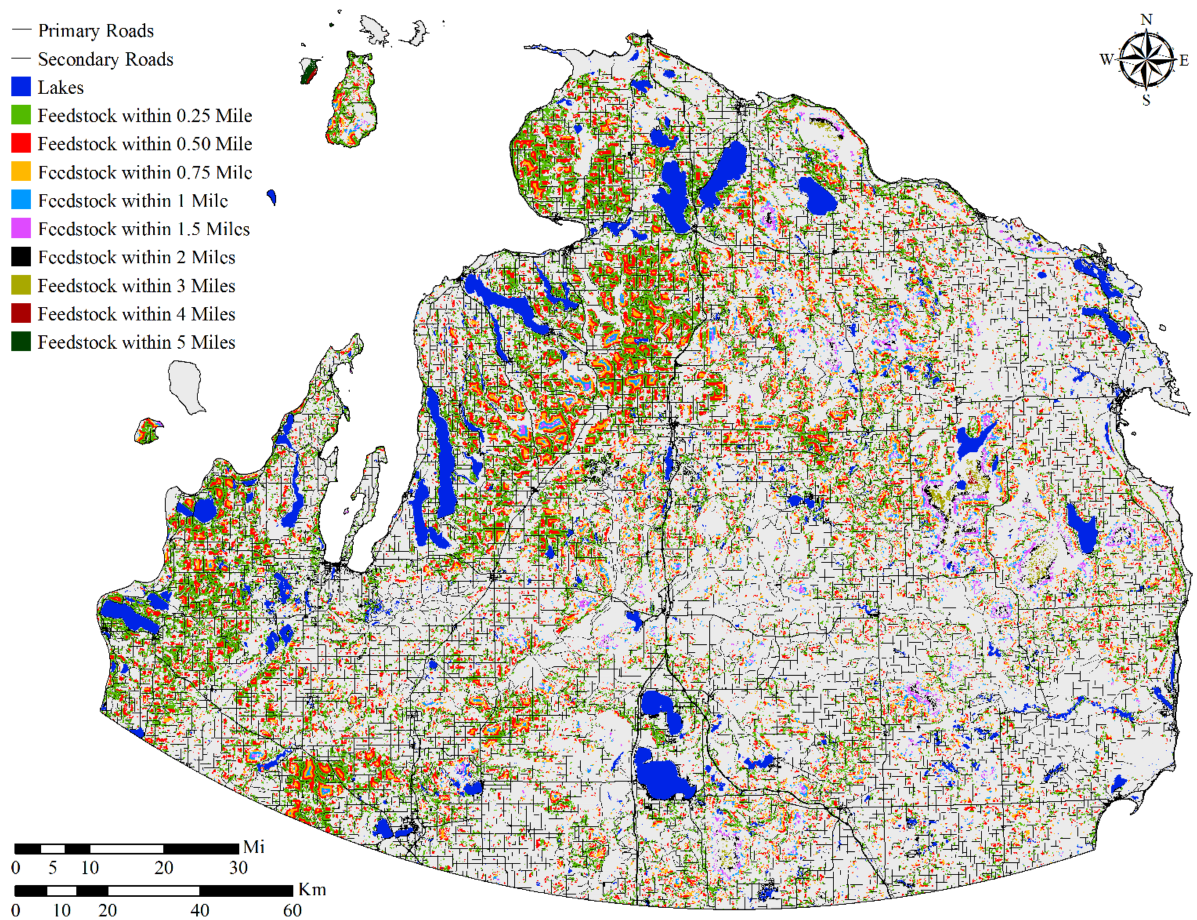


Figure 3.14. Aspen and northern hardwoods proximity to the road network in the UP study area.

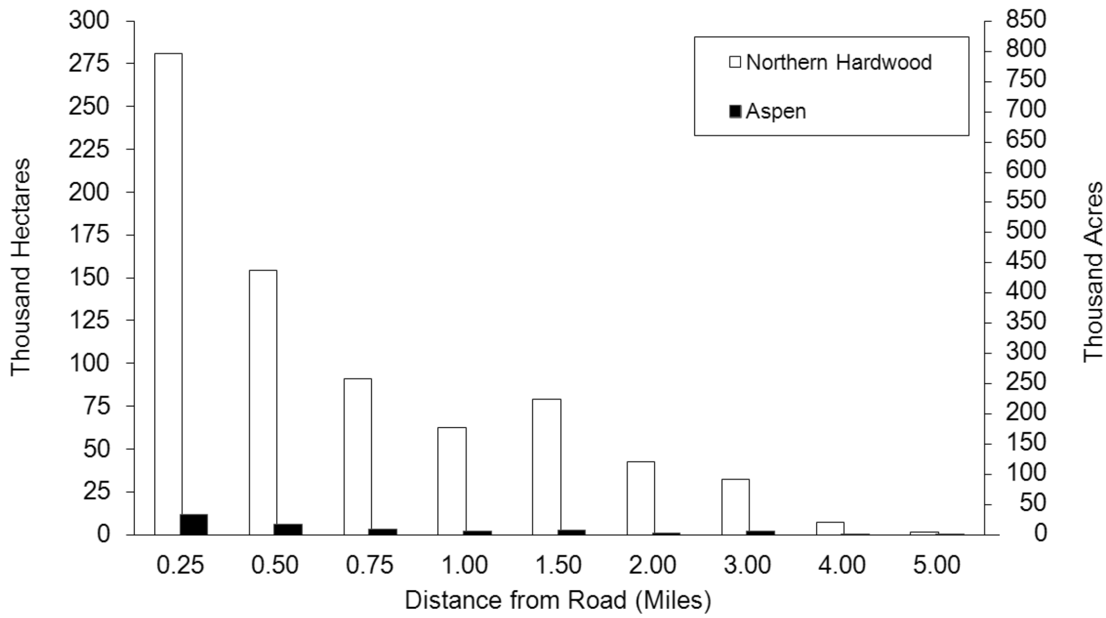
3.6. Potential feedstock source restoration areas

Pre-European settlement aspen and northern hardwoods forest location and extent can provide guidance in estimating the area's potential for feedstock production. In order to identify potential aspen and northern hardwoods forest restoration areas with convenient access to roads, the historical extent of northern hardwoods and aspen in relation the road networks is characterized. This is done by overlaying the present-day road networks on the pre-European settlement land cover, and estimating incremental changes in the amount of aspen and northern hardwoods forests around the road network. The results indicate significant potential aspen and northern hardwoods restoration areas exist within one mile of the road network, which could potentially increase the feedstock extent by over 100% and 45% in the UP and LP study areas, respectively. Table 3.5 and Figures 3.15a and 3.15b show a decreasing extent of aspen and northern hardwoods extent with distance from road network. Figures 3.16 and 3.17 show the locations of buffers around the road network.

Table 3.5. Incremental proximity of pre-European aspen and northern hardwoods to the road network in the UP and LP study areas.

Location	Miles	Aspen		Northern hardwoods	
		(ha)	(ac)	(ha)	(ac)
UP	0- 0.25	11,878	29,351	281,074	694,548
	0.25-0.50	5,918	14,624	154,370	381,456
	0.25-0.75	3,436	8,491	91,231	225,436
	0.75-1.00	2,104	5,199	62,735	155,021
	1.00-1.50	2,824	6,978	79,180	195,658
	1.50-2.00	1,110	2,743	42,741	105,615
	2.00-3.00	1,764	4,359	32,423	80,119
	3.00-4.00	170	420	7,444	18,395
	4.00-5.00	373	921	1,398	3,455
LP	0- 0.25	19,503	48,193	954,895	2,359,593
	0.25-0.50	8,605	21,263	328,527	811,807
	0.25-0.75	2,812	6,949	75,183	185,781
	0.75-1.00	1,150	2,842	26,385	65,199
	1.00-1.50	604	1,493	14,818	36,616
	1.50-2.00	284	702	4,642	11,471
	2.00-3.00	397	981	3,890	9,612
	3.00-4.00	195	482	746	1,843
	4.00-5.00	0	0	485	1,200

(a)



(b)

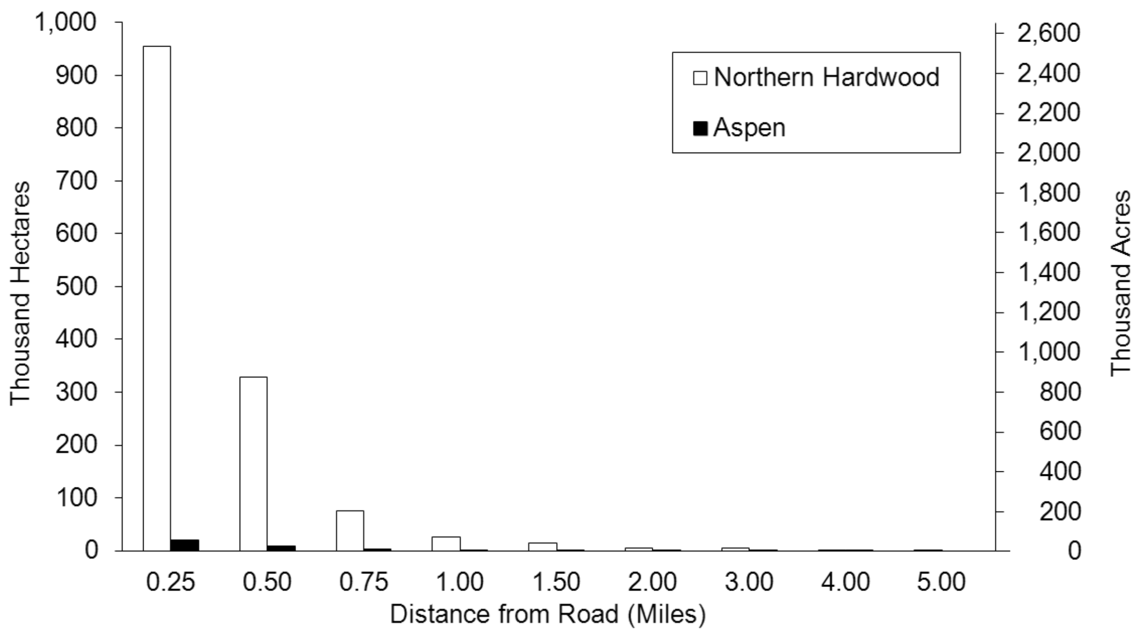


Figure 3.15. Proximity of Pre-European settlement aspen and northern hardwoods areas to the road network in the UP (a) and LP (b) study area.

In order to provide further insight about potential restoration areas with reference to hydric and non-hydric soils, present day soil data were overlain on the pre-European settlement land cover. This was done to obtain a rough estimate of the number of hectares of aspen and northern hardwoods located on hydric and non- hydric soils. Assuming the areal extent of the present-day hydric and non-hydric soil types is representative of soil conditions in the pre-European settlement era, it was found that ~14% of the pre-European settlement aspen and northern hardwoods forests in the UP study area were growing on hydric soils, while about 84% were on non- hydric soils. In the LP study area, about 7% of the aspen and northern hardwoods forests were located on hydric soils, and about 91% were on non- hydric soils. Of the present-day aspen and northern hardwoods forests, which are significantly less abundant compared with pre-European settlement era, approximately 12% are on hydric soils and 87% on non- hydric soils in the UP, and 6% are on hydric soils and 93% on non-hydric in the LP study areas.

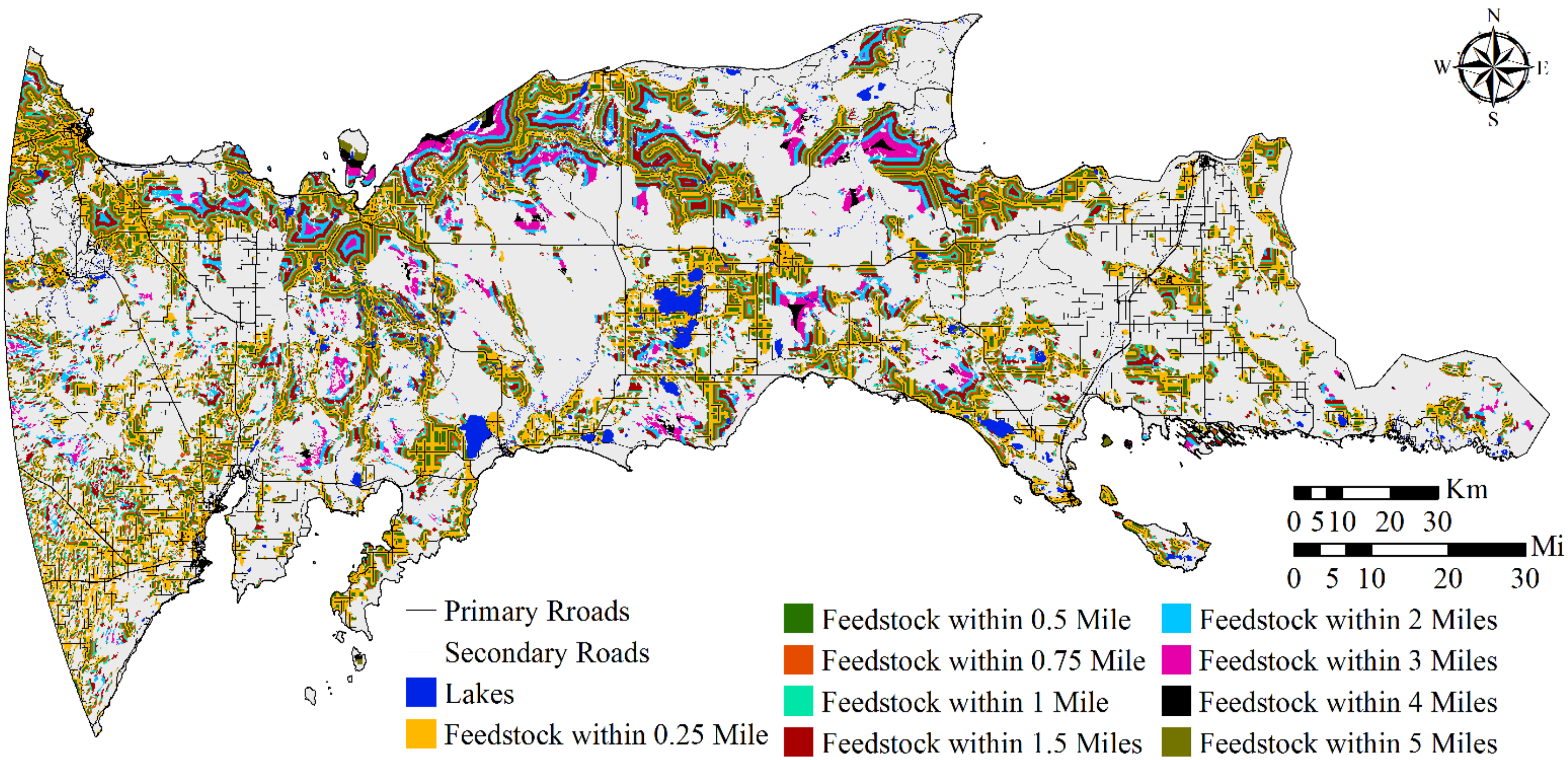


Figure 3.16. Pre-European settlement aspen and northern hardwoods proximity to the road network in the UP study area.

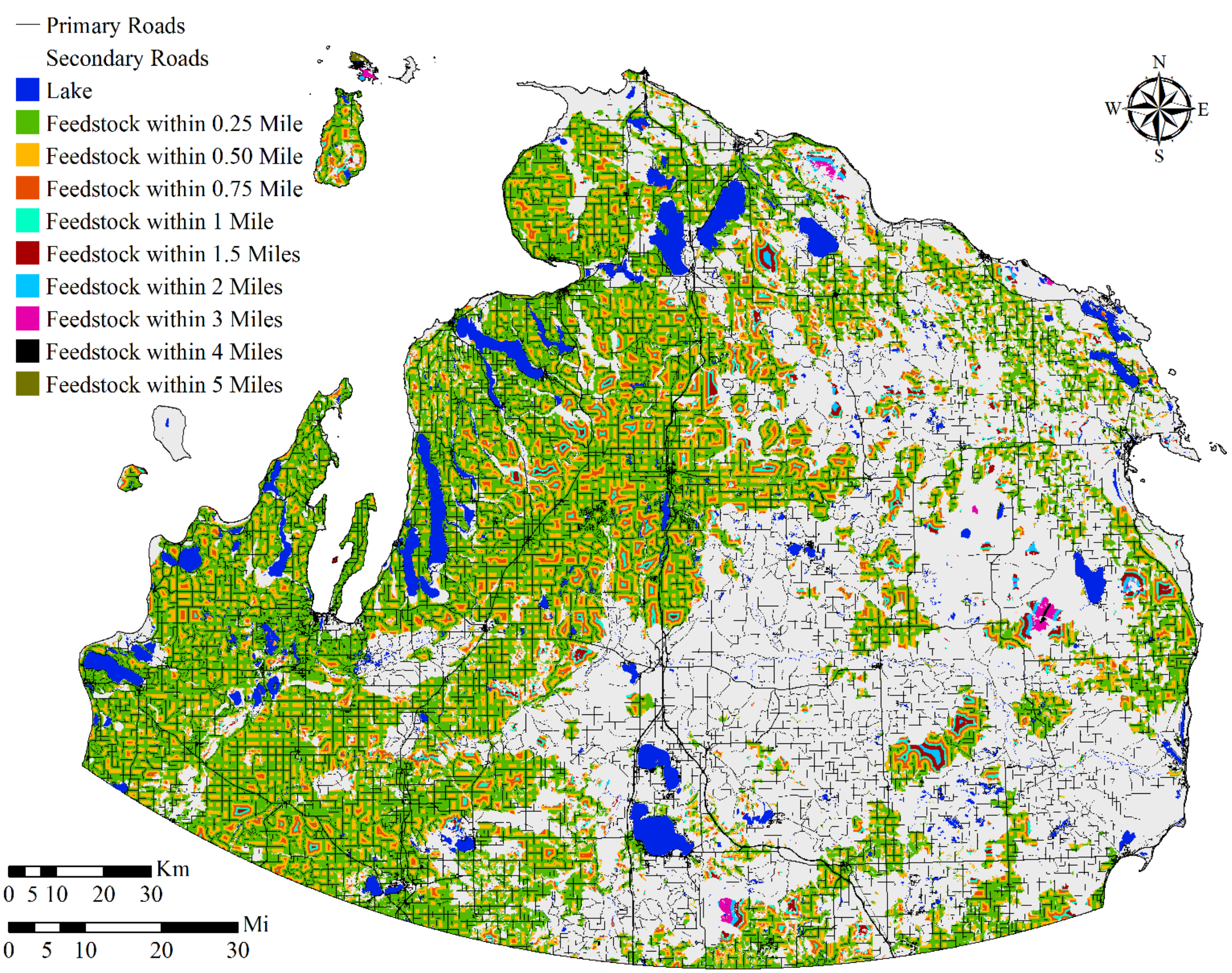


Figure 3.17. Pre-European settlement aspen and northern hardwoods proximity to the road network in the LP study area.

3.7. Land ownerships

The study area includes private ownership as well as federal (e.g., national forests, wildlife refuges, national parks and military installations), state (parks, forests and wildlife areas), and Native American lands (Figure 3.18).

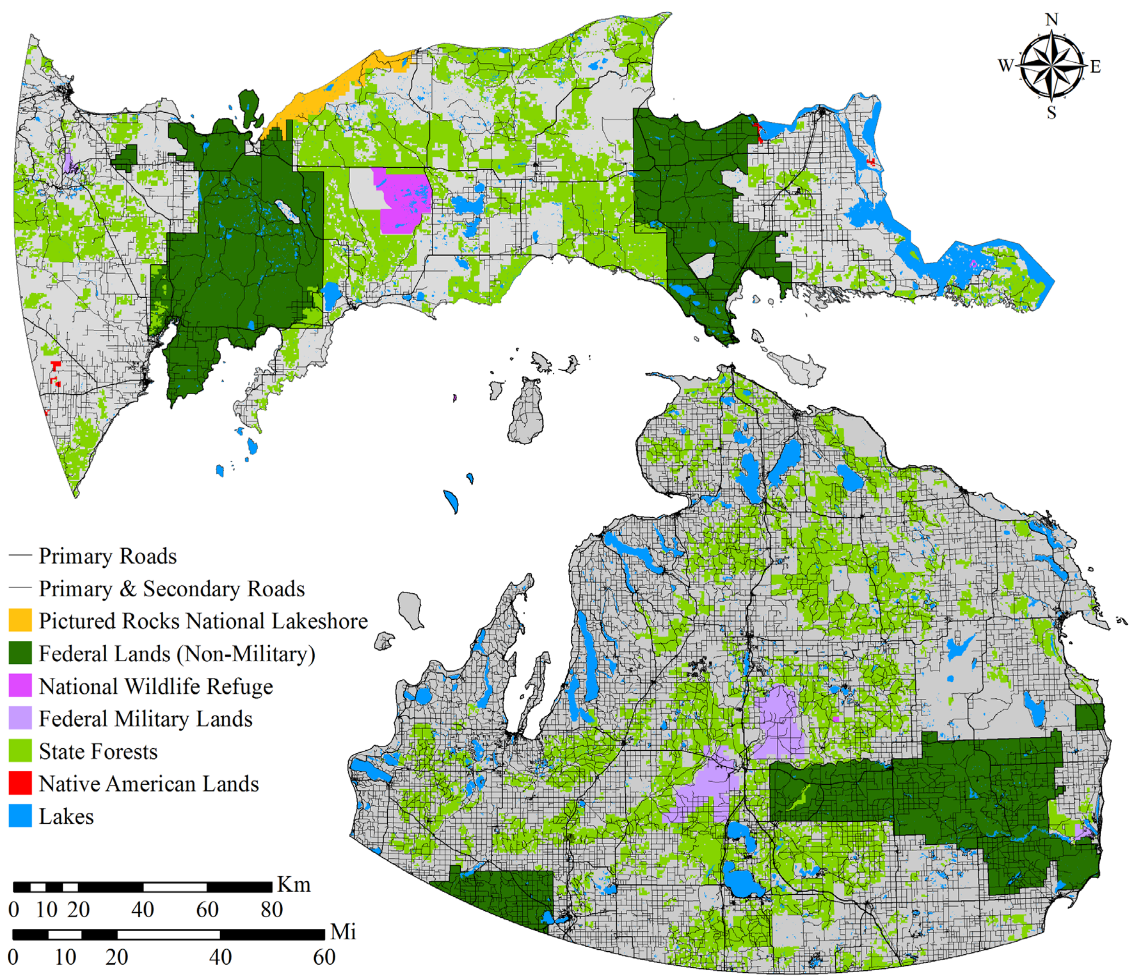


Figure 3.18. Land ownerships in the UP and LP study areas.

Figure 3.19 and 3.20 show the aspen and northern hardwoods extent within federal and state lands in the study area. These areas can be classified into accessible and non-accessible areas for feedstock production. Accessible areas for feedstock production consist of national and state forests which can be used depending on available harvesting policies. National forests cover about 24% of the UP and 11% of the LP study areas. About 26% and 8% of the aspen and northern hardwoods forests are located in the federal lands in the UP and LP study areas, respectively. State forests cover approximately 24% of the UP and 22% of the LP study areas, including about 17% of the total aspen and northern hardwoods in the UP, and 26% in the LP study areas.

Non-accessible areas are those where access is limited or management policies do not include timber harvesting, including national and state parks, military installations, wildlife refuges, and Native American owned land. Pictured Rocks National Park (~1% of the UP study area) is an example of the non-accessible areas identified within the study area, which includes ~1.4% of the total aspen and northern hardwoods. A small proportion of the aspen and northern hardwoods in the UP and LP study areas (about 1.2%) is located within military installations, which cover about 1.1% of the UP and LP study areas. Wildlife refuge takes about 1.3% of the study area, providing less than 0.2% of aspen and northern hardwoods in the UP and LP study areas. Native American Lands cover an insignificant area (about 0.1%) of the UP study area. The non-accessible areas cover a total of ~2.7% of the study area, comprising approximately 2% of the area's total aspen and hardwood association. Table 3.6 summarizes non-accessible lands and the amount of aspen and northern hardwoods association (circa 2001) within them.

Table 3.6. Non-accessible lands in the study area and the corresponding amount of aspen and northern hardwoods association (circa 2001) within them.

Non-accessible land	**Percent of study area (%)**	**Percent of total ASP and NHW (%)**	**ASP and NHW Area**	
			(ha)	**(ac)**
Pictured Rocks National Park	1.0	1.4	17,557	43,384
Military Installations	1.1	0.7	8,778	21,692
Wildlife Refuge	0.5	<0.1	<1,254	3,099
Native American Lands	0.1	0	0	0

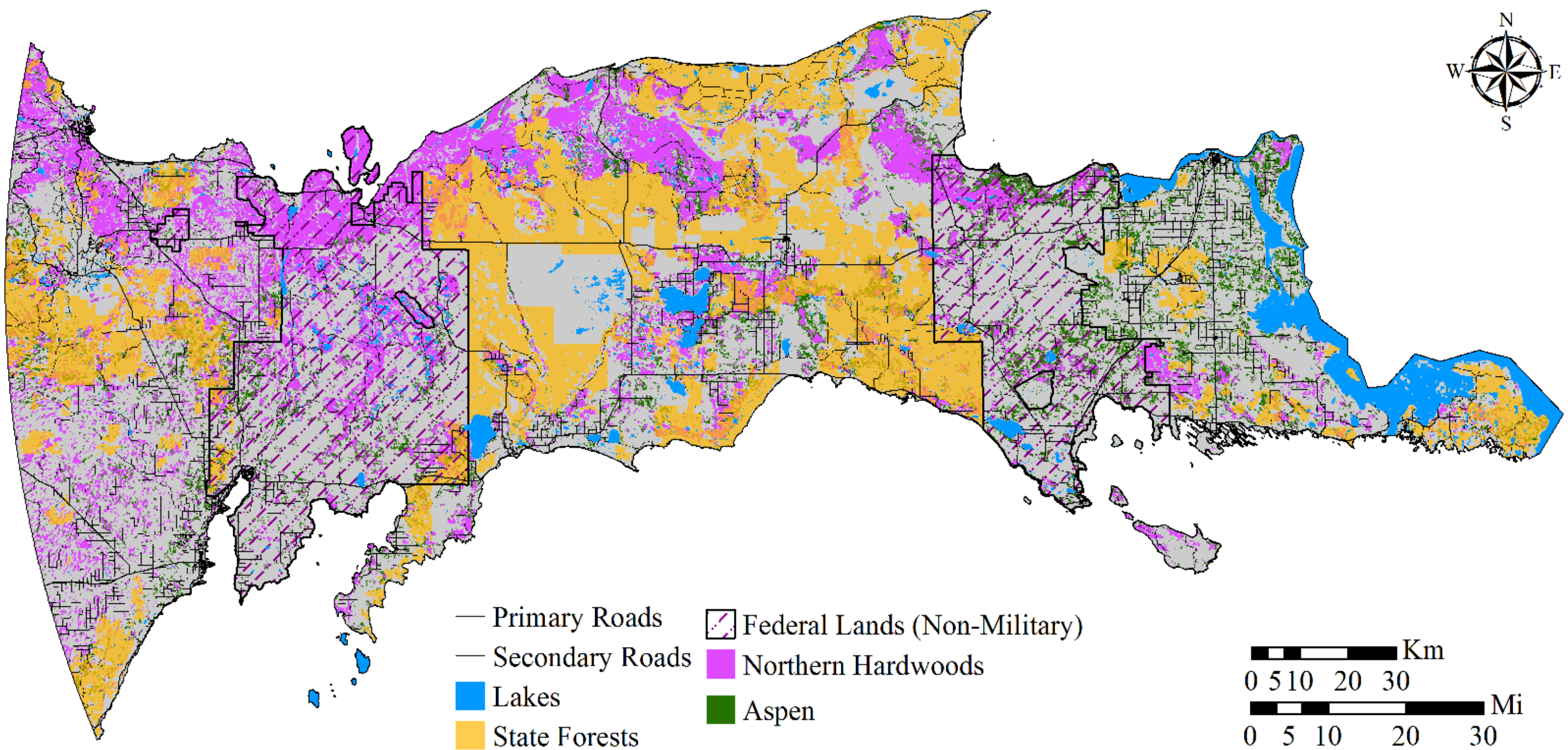


Figure 3.19. Aspen and northern hardwoods extent on federal lands in the UP study area.

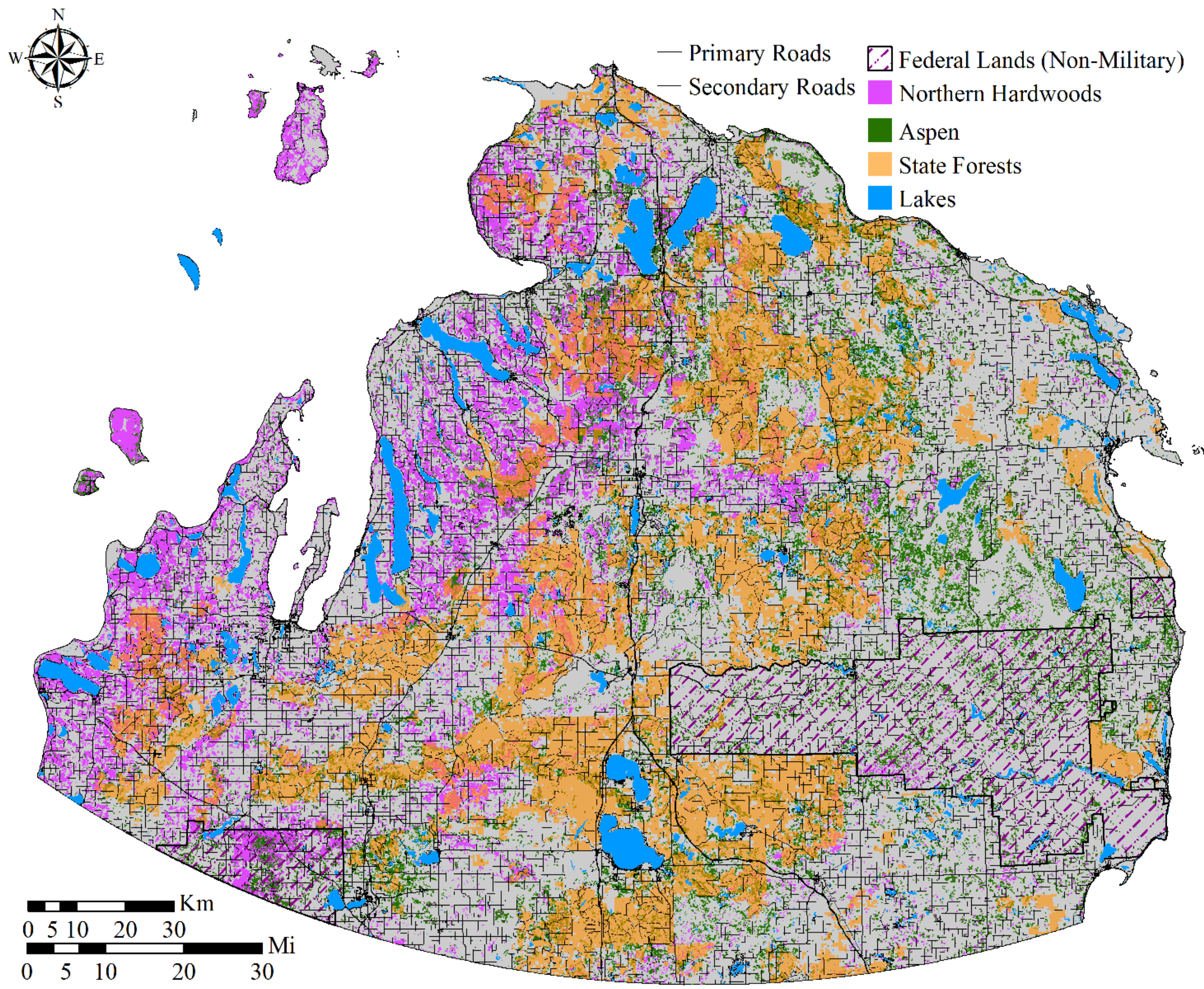


Figure 3.20. Aspen and northern hardwoods extent in federal lands on the LP study area in 2001.

To identify potential aspen and northern hardwoods restoration sites in government ownership, boundaries of these areas were overlaid on the pre-European land cover. About 784,000 and 1,450,000 ha of the aspen and northern hardwoods forests were identified in the UP and LP, respectively. About 27% of the Upper Peninsula's aspen and northern hardwoods and 7% of the LP's feedstock sources in 1800 were located within the federal lands. Also, 18% of the feedstock sources in the UP, and 17% in the LP are located within the state lands. A small proportion of aspen and northern hardwoods forests are located inside the wildlife refuge (about 0.5%) and military installation lands (about 1.1%) in the UP and LP. The results of this analysis suggest a 28% decrease in the aspen and northern hardwoods in the UP study area, and a 43% decrease in the LP study area as compared with circa 1800, which can potentially be restored for feedstock production. Figures 3.21 and 3.22 show the location of federal and state lands on the pre-European map.

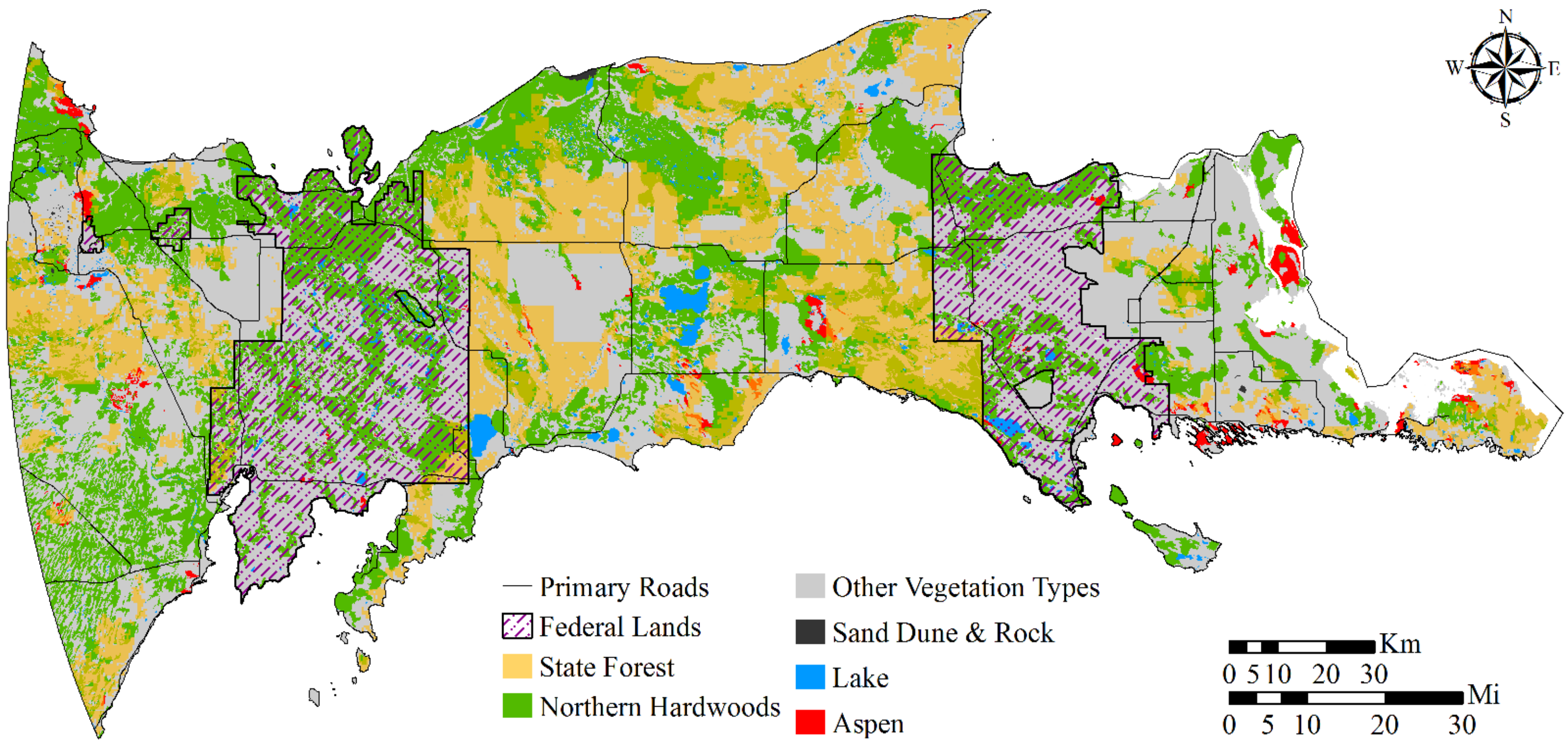


Figure 3.21. Pre-European aspen and northern hardwoods distributions within current federal and state lands in the UP study area.

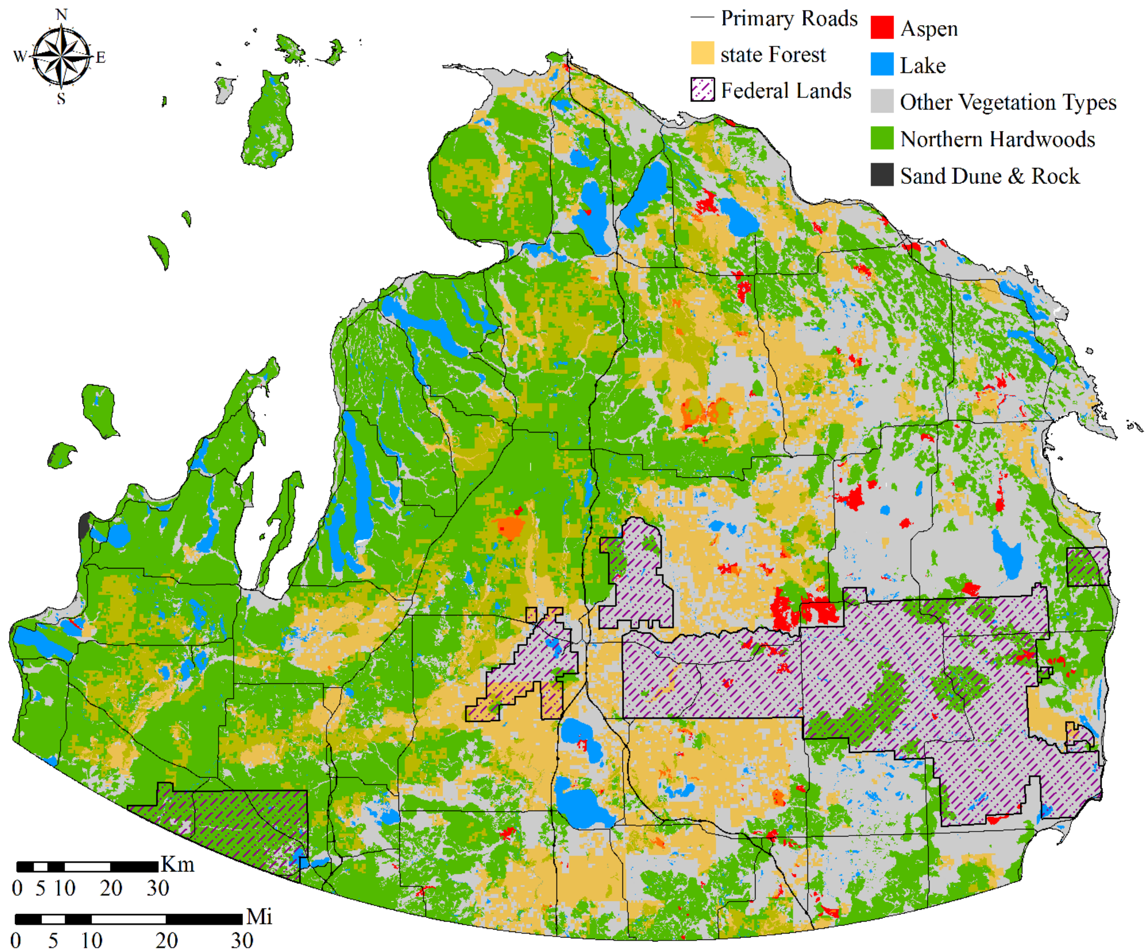


Figure 3.22. Pre-European aspen and northern hardwoods distributions within current federal and state lands in the LP study area.

3.8. Wetlands, hydric and non-hydric soils

Other restrictions for land use in feedstock production are the wetland conservation and restoration programs. Part 303 of Michigan's wetland statute, Wetlands Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, provides a legal definition for wetlands, i.e., "land characterized by the presence of water at a frequency and duration sufficient to support, and that under normal circumstances does support, wetland vegetation or aquatic life, and is commonly referred to as a bog, swamp, or marsh." This legal definition of wetlands applies to public and private lands regardless of zoning or ownership.

Furthermore, characterization of hydric and non-hydric soil types is potentially important for determining the type of feedstock plantation. More than half of the UP (53%) and one third (37%) of the LP study areas are wetlands. Despite the abundance of wetlands, they contain a small proportion of the aspen and northern hardwoods feedstock sources in the study area, i.e., ~110,700 ha (273,545 ac) (9.5%) in the UP and ~80,500 ha (198,919 ac) (11%) in the LP study area. Likewise, the amount of aspen and northern hardwoods forests in hydric soils is insignificant. About 87% of aspen and northern hardwoods in the UP and 94% in the LP study areas is located in non-hydric soils (Figure 3.23 and 3.24). The feedstock sources in hydric and non-hydric soils are shown separately in Figure 3.25.

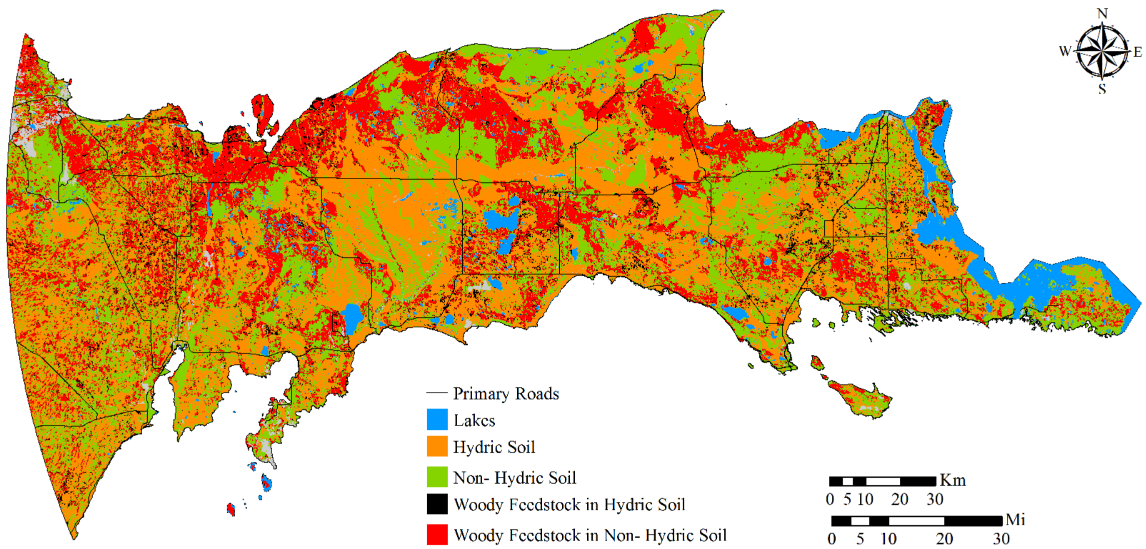


Figure 3.23. Aspen and northern hardwoods in hydric and non-hydric soil in the UP study area.

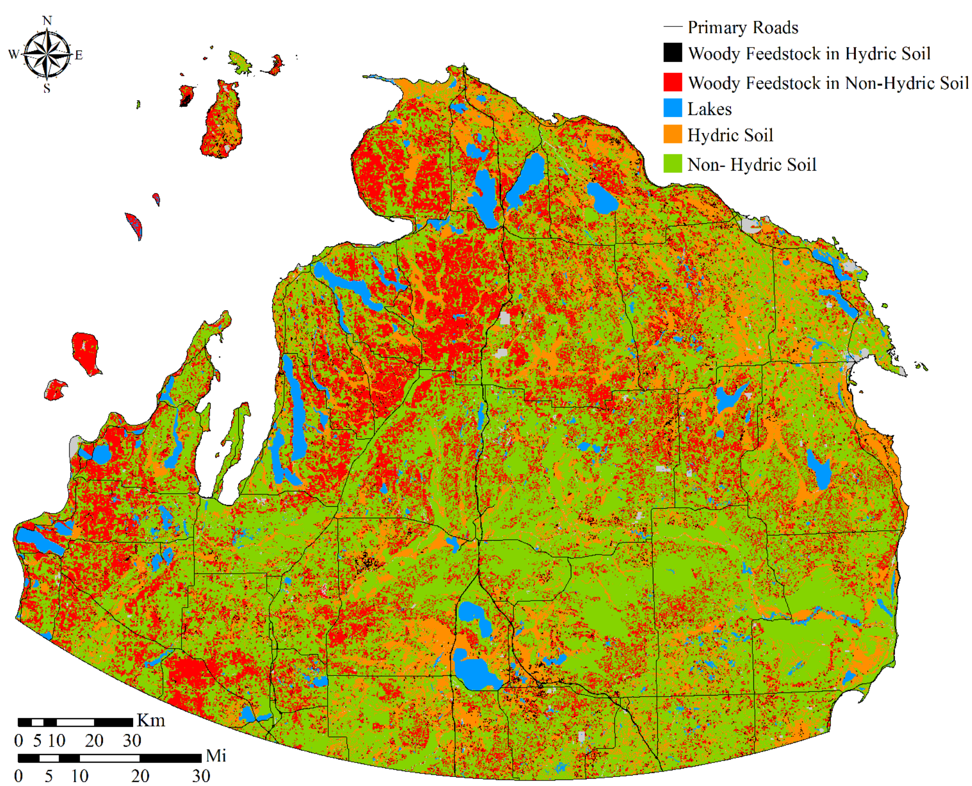


Figure 3.24. Aspen and northern hardwoods in hydric and non-hydric soil in the LP study area.

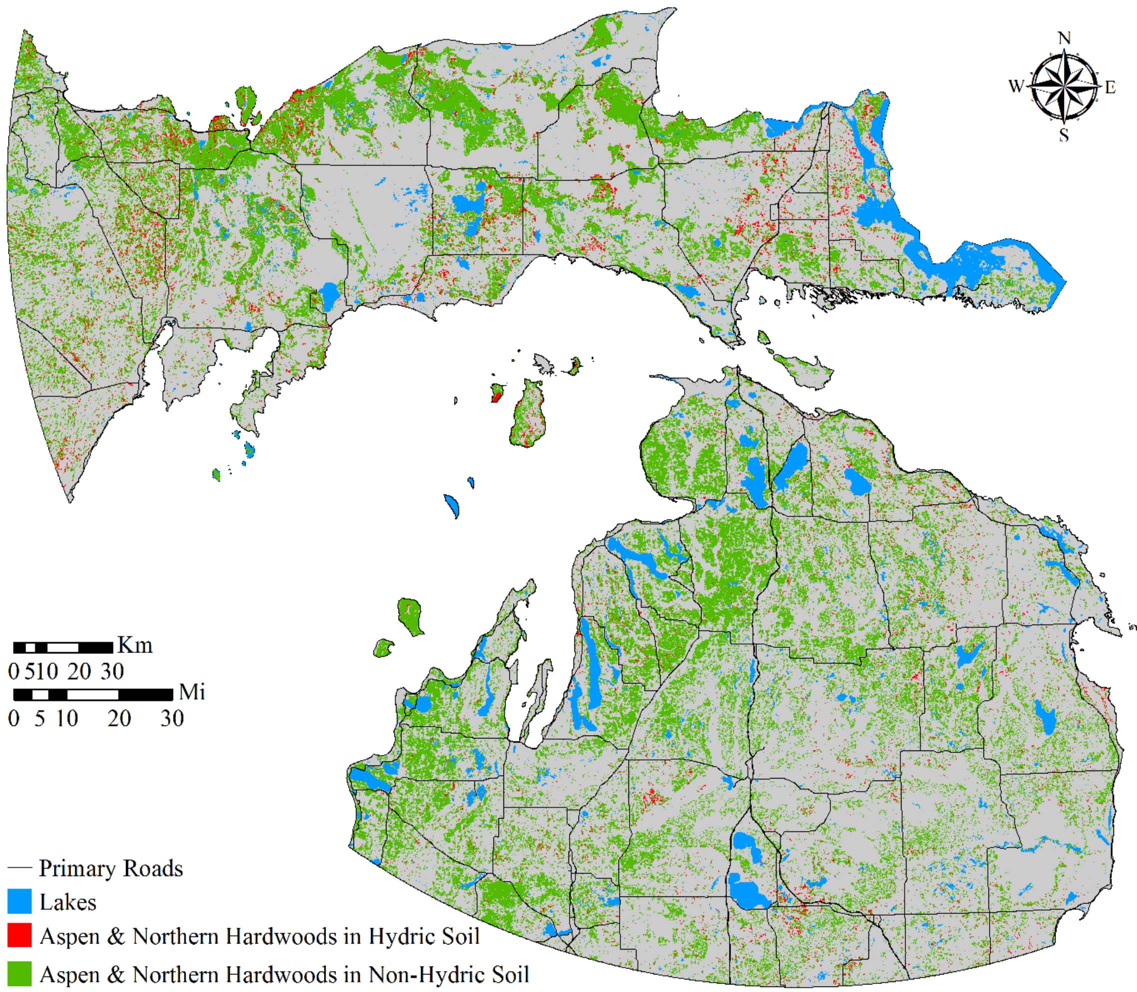


Figure 3.25. Aspen and northern hardwoods association in hydric and non-hydric soils in the study area.

3.9. Hardwood Site Suitability

Soil suitability for northern hardwoods plantation has been classified into four groups, i.e., good, fair, poor, and very poor. These ratings indicate the amount of management effort needed for successful establishment of intended elements of the

wildlife habitat. A rating of good will require least management effort to provide satisfactory habitat conditions, whereas a rating of fair means that the desired habitat elements can be established in most places with some management effort. A rating of poor indicates that habitat establishment may be successful in most places subject to continuous and intensive management practices. Very poor soils are most unlikely to support elements of the desired habitat and unsatisfactory restoration effort can be expected despite intensive management. Most of the currently available aspen and northern hardwoods in the study area is are located in the good and fair soils (Figures 3.26 and 3.27). Likewise, the potential restoration areas, obtained from comparing pre-European land cover and IFMAP land cover 2001, are mostly located in good and fair soil types as shown in Figures 3.28 and 3.29. This suggests that aspen and northern hardwoods restoration for woody feedstock production can be satisfactorily accomplished without intensive land management.

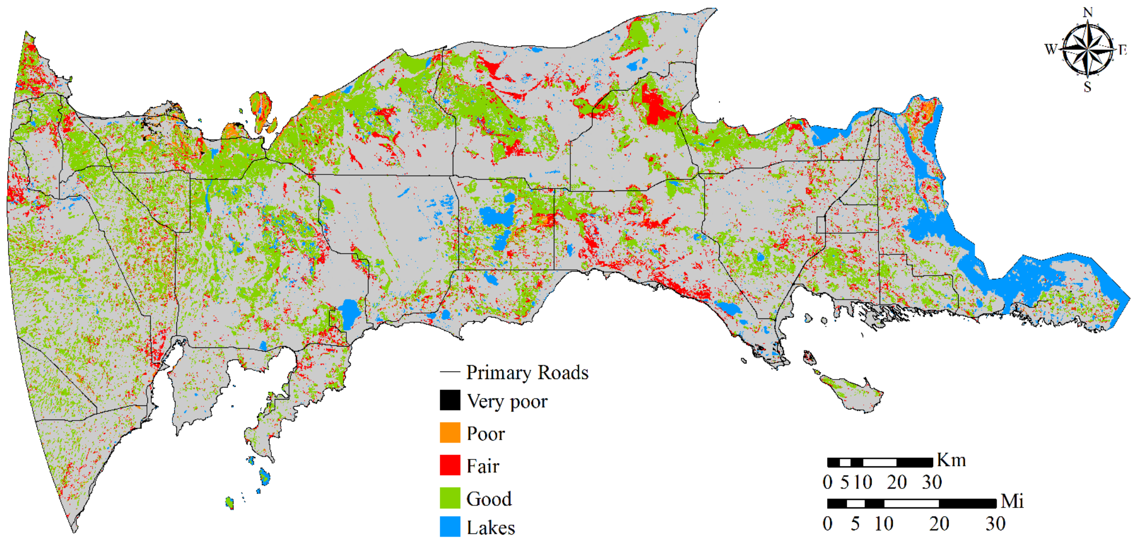


Figure 3.26. Aspen and northern hardwoods extent on different soil suitability classes for establishing these cover types in the UP study area.

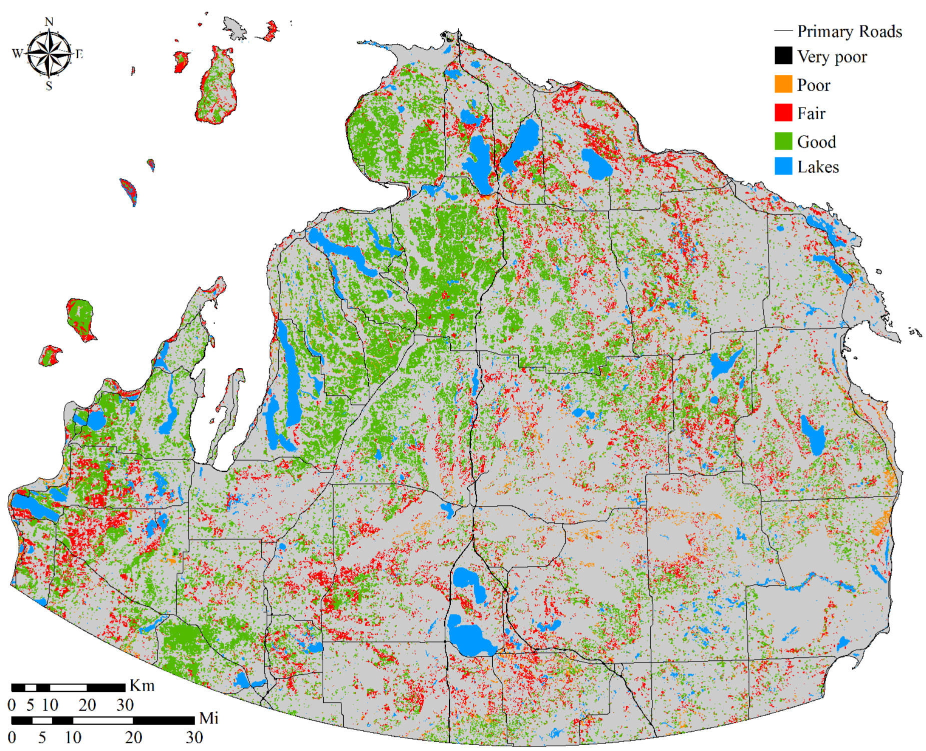


Figure 3.27. Aspen and northern hardwoods extent on different soil suitability classes for establishing these cover types in the LP study area.

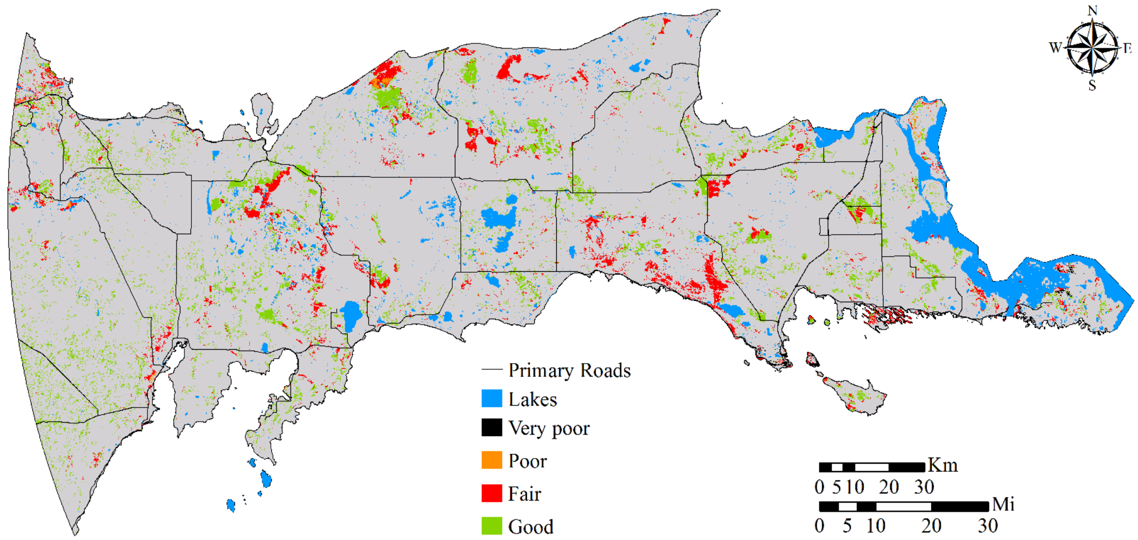


Figure 3.28. Potential restoration areas in the UP study area based on 1800s and 2001 data.

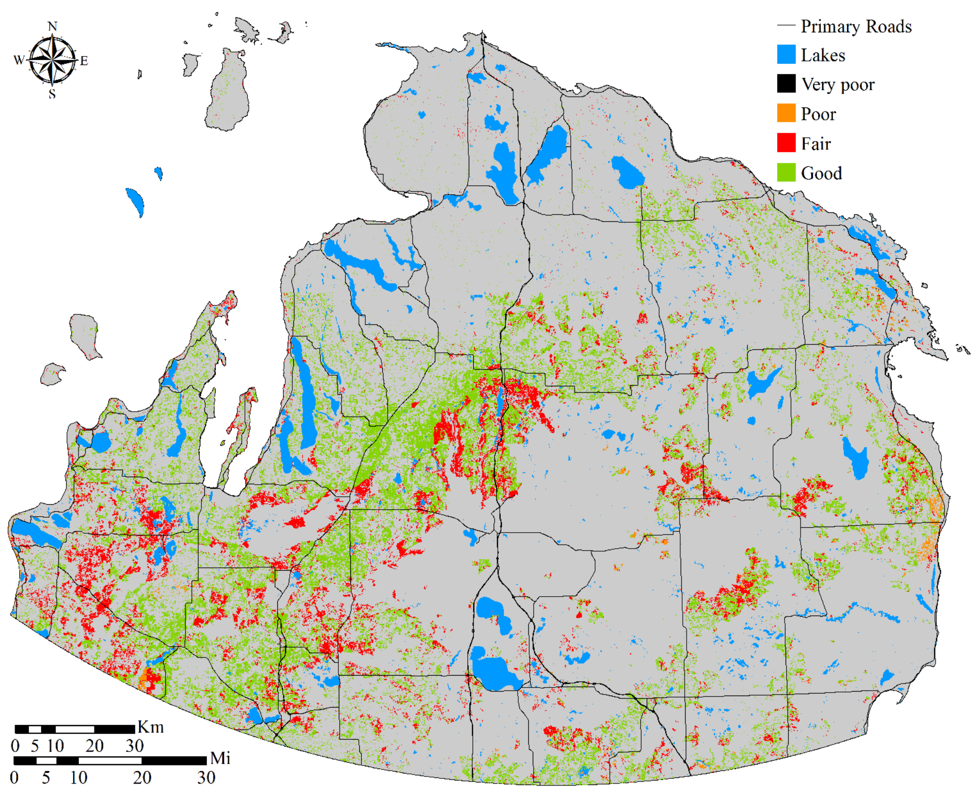


Figure 3.29. Potential restoration areas in the LP based on 1800s and 2001 data.

3.10. Proposing sites for woody feedstock source restoration

Table 3.7 and figures 3.30 and 3.31 present the feedstock source restoration potential of the study area. These areas are recommended for aspen and northern hardwoods plantation as they are not located within national parks, wetlands, wildlife refuges, Indian lands, and federal military lands, agricultural, and urban areas. Furthermore, these recommended restoration areas are in close vicinity of the existing road network. The recommended sites in the UP study area are mostly located within 100 miles from the Kinross ethanol plant, within 0.25 mile of the primary and secondary roads. The majority of the recommended sites in the LP study area are located farther from Kinross, i.e., between 100 -150 miles of the Kinross ethanol plant, within the 0.25 mile of the primary and secondary roads.

Table 3.7. Incremental aspen and northern hardwoods in the recommended restoration sites (ha) in the UP and LP study areas.

Miles	LP (ha)	LP (ac)	UP (ha)	UP (ac)
0.25	301,931	827,593	77,647	212,830
0.50	93,338	255,840	35,340	96,867
0.75	22,513	61,708	20,009	54,845
1.00	9,020	24,724	13,111	35,937
1.50	5,404	14,812	15,187	41,628
2.00	2,094	5,740	7,291	19,985
3.00	2,136	5,855	6,144	16,841
4.00	199	545	963	2,640
5.00	3	8	380	1,042

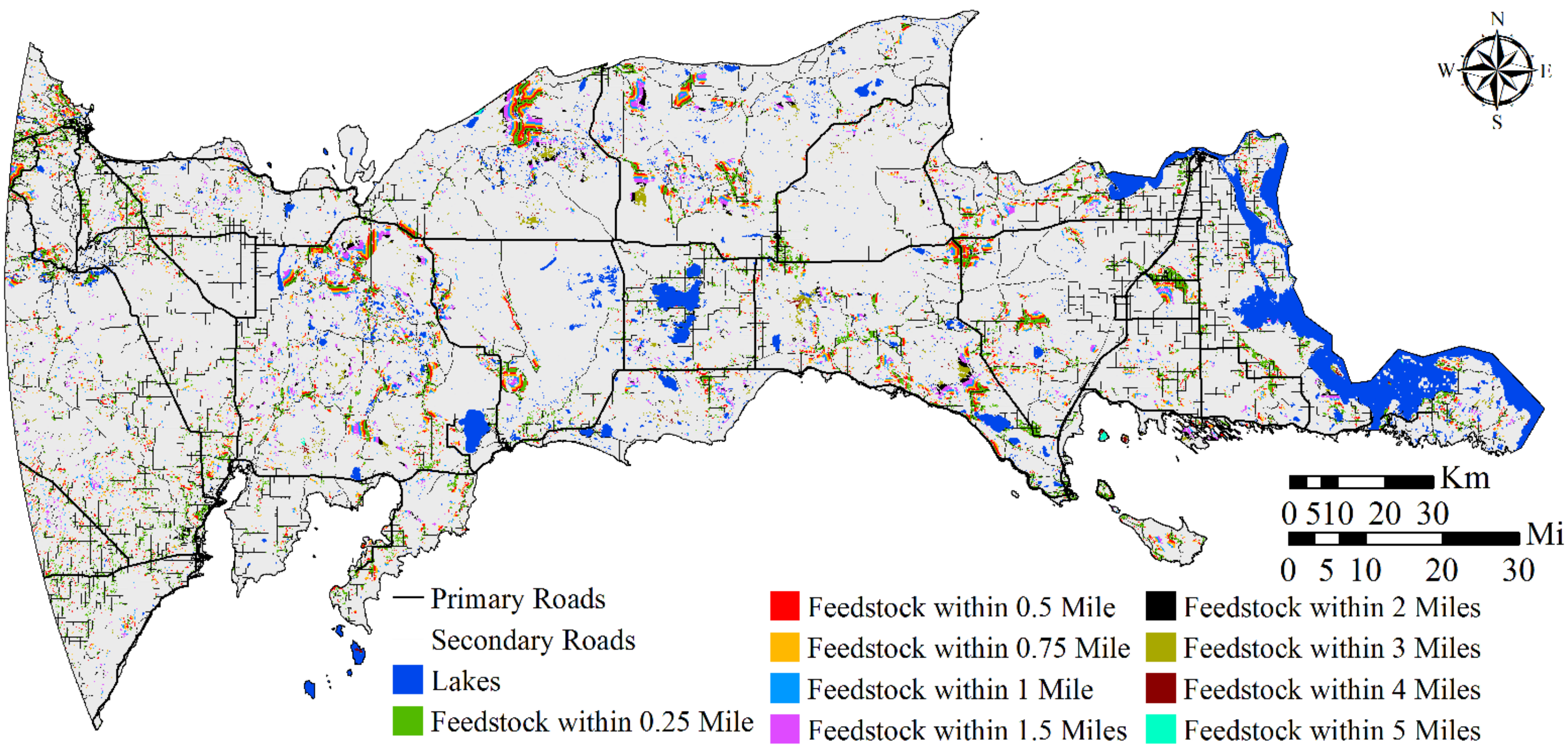


Figure 3.30. Proposed sites using the potential sites (Figure 3.26) for feedstock source restoration in the UP based on 1800s and 2001 data.

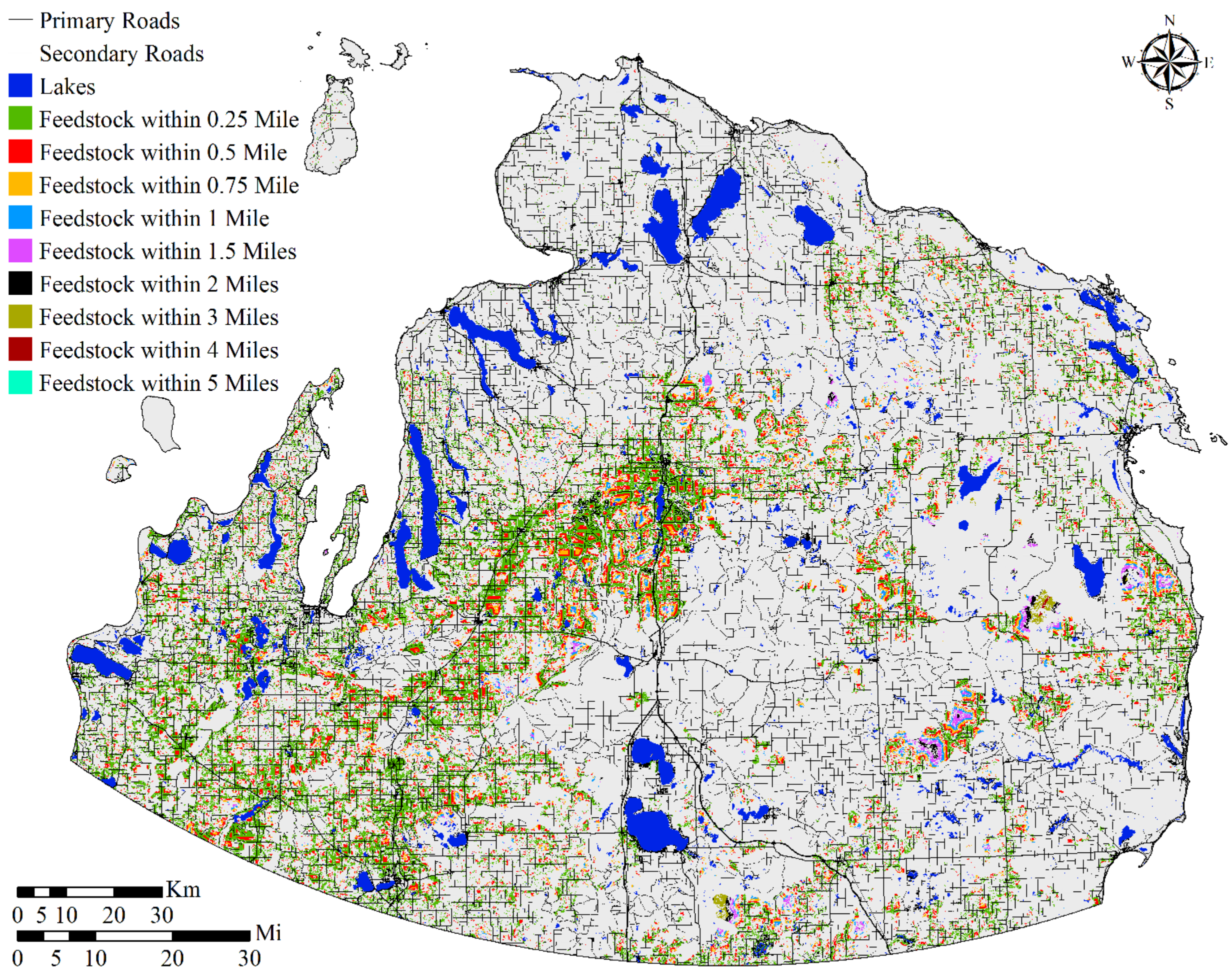


Figure 3.31. Proposed sites using the potential sites (Figure 3.27) for feedstock source restoration in the LP based on 1800s and 2001 data.

3.11. Reference

Leefers. L.A. and J.M. Vasievich. 2010. Timber Resources and Factors Affecting Timber Availability and Sustainability for Kinross, Michigan. Report prepared for the Feedstock Supply Chain Center of Energy Excellence. Kinross Project 2 Report, Version 2.0., East Lansing, MI: Michigan State University, Department of Forestry. 55 p.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDANRCS), 2013. *National soil survey handbook (NSSH)*, title 430-VI. Lincoln, Nebraska <http://soils.usda.gov/technical/handbook/> (accessed on 1 July 2013).

Chapter 4- Conclusions

Instability of production and price of oil, as well as environmental concerns such as anthropogenic climate change necessitate efforts to expand the global energy mix and finding sustainable energy sources. The need for expanding biofuel production is increasing as the world prepares to diversify the global energy mix to increase security and sustainability of energy production. The Americas produces a large share of the world's biofuel.

The state of Michigan, with its vast feedstock sources of northern hardwoods, hybrid poplar, and hybrid willow (*Salix spp.*) is an area where biofuel production can be expanded. However, extent of sufficient feedstock sources and the potential for long-term feedstock production need to be characterized before biofuel production initiatives such as Kinross ethanol production plant can be developed and operated.

Understanding the spatial distribution of the current feedstock sources, in terms of coverage area, accessibility for harvest when considering the transportation infrastructure and land ownerships, is important for long-term feedstock production in the area. This thesis provides the results of a geospatial analysis of aspen and northern hardwoods association extent, as well as the potential for restoring these woody feedstock sources to pre-European settlement condition in areas with convenient access to transportation infrastructure.

A GIS was developed to compile present day (circa 2001) and pre-European settlement (circ 1800s) land use/cover, soils, road infrastructure, and ownership data for

33 counties located within 150 miles of the Kinross facility. The land use change between pre-European settlement and circa 2001 was characterized, and suitable areas for aspen and northern hardwoods association development were identified with respect to soil condition and land ownerships and land use/cover criteria.

The results suggest that a significant amount of northern hardwoods has been converted to other land use and cover types since European settlement, and the scattering of aspen stands has increased. Furthermore, a significant amount of woody biomass is available in close vicinity of the existing road network, which can be effectively used as feedstock for the Kinross ethanol production facility. Potential aspen and northern hardwoods forest restoration areas were identified in proximity to road networks, which can support future woody feedstock production. The insights from this work provide a basis for expanding woody feedstock sources in the study area.

Appendix A.

County level aspen and northern hardwood distribution

Table A-1. Aspen and northern hardwoods distribution for the counties within the study area.

County	Feedstock	Hectares	Acres
Alger	ASP	9,755	24,105
	NHW	117,011	289,143
	Total	***126,766***	***313,248***
Chippewa	ASP	50,755	125,420
	NHW	41,515	102,585
	Total	***92,270***	***228,005***
Delta	ASP	26,360	65,135
	NHW	39,265	97,027
	Total	***65,625***	***162,162***
Luce	ASP	14,435	35,665
	NHW	49,690	122,785
	Total	***64,125***	***158,450***
Mackinac	ASP	33,385	82,497
	NHW	35,940	88,807
	Total	***69,325***	***171,304***
Marquette	ASP	15,200	37,570
	NHW	58,250	143,940
	Total	***73,450***	***181,510***
Menominee	ASP	2,940	7,270
	NHW	14,020	34,640
	Total	***16,020***	***41,910***
Schoolcraft	ASP	14,571	36,010
	NHW	40,960	101,220
	Total	***55,531***	***137,230***
Alcona	ASP	31,326	77,410
	NHW	2,920	7,220
	Total	***34,246***	***84,630***
Alpena	ASP	16,500	40,775
	NHW	2,795	6,910
	Total	***19,295***	***47,685***
Antrim	ASP	8,335	20,600
	NHW	40,720	100,625
	Total	***49,055***	***121,225***
Arenac	ASP	1,033	2,555
	NHW	927	2,293
	Total	***1,960***	***4,848***
Charlevoix	ASP	4,955	12,240
	NHW	32,840	81,155
	Total	***37,795***	***93,395***
Benzie	ASP	6,725	16,620
	NHW	37,875	93,595
	Total	***44,600***	***110,215***
Cheboygan	ASP	36,230	89,520
	NHW	21,670	53,555
	Total	***57,900***	***143,075***

Table A-1. Continued.

County	Feedstock	Hectares	Acres
Clare	ASP	3,845	9,500
	NHW	1,835	4,540
	Total	***5,680***	***14,040***
Crawford	ASP	13,860	34,250
	NHW	4,820	11,912
	Total	***18,680***	***46,162***
Emmet	ASP	13,695	33,840
	NHW	35,260	87,125
	Total	***48,955***	***120,965***
Gladwin	ASP	2,945	7,275
	NHW	1,210	2,990
	Total	***4,155***	***10,265***
Grand Traverse	ASP	4,495	11,110
	NHW	14,405	35,595
	Total	***18,900***	***46,705***
Iosco	ASP	9,265	22,895
	NHW	2,755	6,815
	Total	***12,020***	***29,710***
Kalkaska	ASP	13480	33310
	NHW	22490	55575
	Total	***35,970***	***88,885***
Leelanau	ASP	3,240	8,005
	NHW	31,535	77,925
	Total	***34,775***	***85,930***
Manistee	ASP	3,093	7,643
	NHW	10,397	25,692
	Total	***13,490***	***33,335***
Missaukee	ASP	16,660	41,162
	NHW	13,640	33,708
	Total	***30,300***	***74,870***
Montmorency	ASP	30,672	75,792
	NHW	11,340	28,025
	Total	***42,012***	***103,817***
Ogemaw	ASP	16,240	40,130
	NHW	7,050	17,425
	Total	***23,290***	***57,555***
Osceola	ASP	50	130
	NHW	277	685
	Total	***327***	***815***
Oscoda	ASP	18,659	46,107
	NHW	2,295	5,672
	Total	***20,954***	***51,779***
Otsego	ASP	18,537	45,806
	NHW	20,449	50,530
	Total	***38,986***	***96,336***

Table A-1. Continued.

County	Feedstock	Hectares	Acres
Presque Isle	ASP	33,286	74,432
	NHW	4,566	11,138
	Total	***37,852***	***85,570***
Roscommon	ASP	22,707	56,111
	NHW	1,688	4,171
	Total	***24,395***	***60,282***
Wexford	ASP	18,609	45,984
	NHW	18,940	46,801
	Total	***37,549***	***92,785***