Measurement of Changes in Forest Fragmentation Caused by Road Construction Between 2000 and 2014 Using GIS in St. Johns County, Florida.

by

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ABSTRACT

Forests play a crucial role in maintaining the natural balance. They have essential features and structures used in the protection of flora and fauna. Human activities such as road construction disrupt ecosystems and negatively impact natural habitats. Roads cause forest fragmentation, and as a result of this, fragmentation has various negative effects on the natural habitat. These effects lead to loss of biological diversity, road mortality, habitat loss, fragmentation, and air pollution. The major goal of this study was to analyze changes in forest area, forest fragmentation, and forest road impacts using GIS for St. Johns County, Florida, between the years of 2000 and 2014.

In this study, an approach combining road-based metrics, landscape metrics, and LULC change analysis St Johns County was applied. With analyzing LULC change, it is seen that especially the settlement areas increase, while forest types are decreased by about 9% When the loss of forest types is examined, they were generally converted into settlement areas. Interestingly, some forest types follow conversion to other forest types. Result of analysis at class metrics level provided detailed information about changes in fragmentation. In each forest type, road density and road length were generally increased, and distance to nearest roads decreased. According to results changes in habitat fragmentation are much larger than expected based on habitat loss.

CHAPTER ONE

INTRODUCTION

Roads directly and indirectly adversely affect the species, habitats, physical, and chemical properties of ecosystems. Road impacts can be classified as either primary or secondary effects (Coffin, 2007; Gucinski et al., 2001). Primary effects describe impacts directly caused by the construction or presence of a road, such as: habitat loss and fragmentation from road construction, modified hydrology, soil erosion, and noise pollution. Secondary effects describe impacts associated with or indirectly caused by roads, such as: the transport of people to the previously undisturbed area and the related damage (smuggling, hunting, grazing, etc.) (Eker et al., 2010). Roads can behave as obstacles that adversely affect the movement of animals and biodiversity, thus causing degradation in landscapes. Road construction and improvement increase the accessibility of remote areas (Freitas et al., 2010). Roads are thus considered agents of deforestation which accelerates forest fragmentation, and reduce regrowth (Freitas et al., 2010). Fragmentation has general effects on abiota and biota (Rutledge, 2003). Biotic effects are those that impact organisms, such as plants and animals. Abiotic effects are impacts on hydrology, soil, and atmosphere.

Forest loss and fragmentation result in a range of ecological and environmental impacts. Fragmentation is an important global issue for the conservation of forests. It is one of the single most important factors leading to the loss of biodiversity in forests (Reddy et al., 2013). The process of habitat fragmentation is known to be a significant threat to ecological functioning, biodiversity conservation, and proximate threats to ecosystems, respectively (Hanski, 2011; Ojoyi, 2014). As a result of the habitat fragmentation caused by roads, there can be some problems such as restricting wildlife mobility, disrupting gene flow (Mech and Chesh, 2014) and disrupting metapopulation dynamics (Hanski, 2011).

Landscape metrics maintain a means of quantifying and defining forest fragmentation. The most common method of calculating these metrics is through the use of a GIS.

CHAPTER TWO

LITERATURE REVIEW

2. 1. Overview of Road Ecology

Road ecology is based on ecology, engineering, geography, and planning (Coffin, 2007) which results in different definitions. In the social sciences, it studies the urban planning process and the successful implementation of scientific recommendations, which means it focuses on environmental changes with connections to roadways, and transportation systems (Forman et al., 2003; Karlson, 2015). In the sciences, it focuses on the impacts of roads on ecological processes including effect zones, habitat fragmentation and connectivity, and animal mortality (Karlson, 2015). According to Forman (1998), ecological research is based on evidence that roads have a striking impact on ecosystem components and processes, and that the causes of these impacts are related to both engineering land use planning, and transportation policies. Overall, road ecology examines the relationship between the natural environment and the road system.

Roads, vehicles, and the environment serve as the key elements of road ecology (Forman and Sperling et al., 2003). These combinations describe the interaction of organisms and environment with roads and vehicles. Road networks are indeed widespread globally; an important part of the ecological literature is based on studies in the road impact regions (D’Amico et al., 2018). Road ecology covers various research areas such as wildlife-vehicle collisions, road avoidance, landscape connectivity, and habitat fragmentation, barrier effects, biological invasions, and pollution (Forman and Alexander, 1998; Forman et al., 2003; D’Amico et al., 2018). Road ecology is also concerned with the effectiveness of mitigation measures and the study of potential benefits for wildlife coexisting with road-networks (Forman and Alexander, 1998). It is essential to assess the ecological impacts of roads, while also taking into account the physical, socio-economic, and legal context (van der Ree et al., 2011). The overall objective of road ecology research is to measure the ecological impacts of roads in order to prevent, minimize, and compensate for the negative effects on individuals, populations, communities, and ecosystems (van der Ree et al., 2011).

2. 2. Ecological Effect of Roads

2. 2. 1. Road Impacts

Although roads and roadsides provide a habitat for some animals (Coffin 2007), the presence of roads generally negatively affect species, habitats, and physical and chemical characteristics of ecosystems. Road impacts can be classified as either primary or secondary (Gucinski et al., 2001; Coffin, 2007). Primary effects describe impacts directly caused by the construction or presence of a road, such as a habitat loss and fragmentation from road construction, modified hydrology, soil erosion, and noise pollution. Secondary effects describe impacts associated with or indirectly caused by roads, such as the transport of people to the previously undisturbed area and the related damage (smuggling, hunting, grazing, etc.) (Echeverria et al., 2008). Ecological effects of roads can also be classified as abiotic or biotic (Coffin 2007). Biotic effects are those that impact organisms, such as plants and animals. Abiotic effects are impacts on hydrology, soil, and atmosphere.

The environmental impact of roads, regardless of how they are classified, includes spatial and temporal dimensions (Daigle, 2010). The spatial effects of the roads are changing, because the species' habitat requirements and ecosystem characteristics are different. Impacts can be local or comprehensive. For example, less mobile wildlife species tend to have smaller habitats, while broader mammal and bird needs tend to spread to macro environments.

2. 2. 1. 1. Biotic Impacts.

There are four main categories of primary road effects on biota (Roedenbeck et al., 2007): (1) wildlife-vehicle collisions; (2) impedance to movement; (3) disturbance and habitat degradation caused by noise, dust, light, and heavy metal pollution; and (4) habitat loss caused by disturbance effects in the broader environment and from the occupation of land by the road (Jones, et al., 2000; Roedenbeck et al., 2007), and disturbance caused by roadway lighting (Scanes, 2018).

Habitat Fragmentation and Loss

Road infrastructure has a direct impact on ecosystem structure, dynamics and factors, including species composition. First, roads lead directly to loss of habitat because of the physical occupation of the road (Madadi et al., 2017). Second, roads cause habitat fragmentation which is a severe threat to ecosystems, especially forests. Fragmentation occurs in conjunction with loss of area, and is a dynamic process where organisms' habitats are gradually reduced to smaller patches that are isolated and affected more by their edge effects (Echeverria et al., 2008). This alters the inputs and outputs of physical resources as a function of the size, number, shape, and configuration of the resulting patches (Rutledge, 2003).

Forest fragmentation refers to the amount and spatial configuration of treed-vegetation and is caused by both natural and anthropogenic processes (Hermosilla et al., 2019). Roads lead to fragmentation of habitat, and significant roads can create movement barriers to seed dispersal

(Wójcicki et al., 2018). Forest fragmentation can be associated as a state or as a process. Increased forest fragmentation is due to the separation of adjacent forest areas into smaller and more isolated parts of different sizes and shapes. This has been shown to reduce habitat quality, biodiversity, and species richness, which can cause declines in forest conditions and functions (Hermosilla et al., 2019).

Fragmentation as an important global issue for the conservation of forests. It is one of the single most important factors leading to the loss of biodiversity in forest landscapes (Reddy et al., 2013; Frazier and Kedron, 2017), with several species being predicted to be highly vulnerable (Reddy et al., 2013). This has long term impacts on species numbers, species abundance, as well as exposing natural ecosystems to external risks, like parasitism, and the dominance of invasive species (Ojoyi, 2014). This process can lead to an increase in the isolation of habitats and a change in ecosystem functioning that endangers plant species, mammals, and birds. Roads are thus considered agents of deforestation, accelerating forest fragmentation and reducing forest regrowth (Freitas et al., 2010).

Impacts on Wildlife

Roads can have negative impacts on wildlife through both direct and indirect mechanisms which can reduce most of the benefits provided by habitat (Boston, 2016). The direct impacts are primarily through vehicle strikes (fatal collisions with vehicles) that kill or maim animals (Forman et al., 2003; Boston, 2016; Gonçalves et al., 2018). Indirect effects of roads on wildlife do not necessarily cause physical harm to individual animals, but prevent or limit their natural movements and activities (Boston, 2016). Roads can physically block and distort their movements (Wójcicki and Borowski,2018). Vehicle strikes can have a significant impact on wildlife populations, mainly on higher standard roads through forested areas where vehicles drive at a higher speed which is one of the leading causes of death in large animals. Road-killed animals have been of concern to biologists (Seiler, 2001). One way to effectively reduce roadkill is to build wildlife corridors which will help animals to travel across roads enabling migration, colonization, and the interbreeding of plants and animals. This will help animal pass over roads and reduce mortality rates, playing a vital role in the maintenance of biodiversity (North East New South Wales, 2004).

2. 2. 1. 2. Abiotic Impacts.

Roads influence the abiotic factors of landscapes including the hydrology, sediment mechanics and debris transport, chemistry of water and air, microclimate, noise level, wind, and light next to the roadside (Rutledge, 2003). The extent and intensity of the impacts vary according to the location of the road in relation to slope patterns, dominant winds, and surrounding land cover (Forman and Alexander, 1998). Other ecological effects include visual disturbance, and pollution, which reduces the suitability of adjacent areas for wildlife (European Commission, n.d.).

Hydrology

Roads have significant hydrological impacts, and the interactions between forest roads and water lies at the center of several issues surrounding the environmental effects of roads. According to Eker (2010) and Gucinski (2001), roads have a direct impact on hydrological regimes, and water quality (erosion, sediment transport, and chemical contamination). The effect of forest roads on water quality can be grouped into acute and chronic sources (Boston, 2016). Acute sources of water pollution are linked with road failures that reach the start of water through debris slides. Sources of chronic pollution may be due to cut or fill slopes, the ditch or road surfaces. Construction works change soil density, landscape relief, surface and groundwater flows which may affect ecosystems, vegetation and fauna on larger areas. Wetlands and riparian habitats are very sensitive to changes in hydrology as caused by roads. Road cuttings may drain aquifers, increase soil erosion, and modify disturbance regimes (Seiler, 2001). Consequently, roads reduce surface and groundwater recharge, degrade surface water quality, and contaminate drinking water.

Air Pollution

Road systems have a different effect on the atmosphere around it. Roads produce significant amounts of dust and chemical pollution, and fossil fuels burned by cars and trucks driving on roads is a significant source of atmospheric pollutants and greenhouse gasses. Road construction is destructive to habitat and is a major cause of deforestation, resulting loss in the of carbon storage. Pollutants affecting biota include noise, light, sand, dust and other particulates, metals such as Pb, Cd, Ni and Zn, and gases such as CO and NO_x (Spellerberg, 1998). Physical effects of large particles, such as dust and, sand can affect plants through cell destruction and blocked stomata (Farmer 1993). Dust may affect photosynthesis, respiration, and transpiration (Spellerberg, 1998). The direct effects of road traffic gases (SO2, C02, CO, NO_x, and Hydrocarbons) on biota other than humans have been researched (Spellerberg, 1998). Effects on plant growth and species composition have been observed as a result in changes its atmosphere near roads (Sarkar, Banerjee & Mukherji 1986; Angold's 1997).

Heavy Metals (Trace Metals)

Heavy metals can wash off or seep through a road impact aquatic ecosystem. Chemicals can also make it into the air from roadways and impact the atmosphere from vehicles, road maintenance, management practices, and chemical spills. For example, sodium chloride application on roadways has been a significant source of chemical pollution in cold weather climates. Chemical spills from trucks and autos are another source of chemicals pollution from roads (Cheung & Wong 1984).

2. 3. Measuring Spatial Impacts of Roads Using GIS

2. 3. 1. Summary of Landscape Metrics

Alexander Von Humbdolt first described the landscape as "all of the characteristics of a land" (Gökyer, 2013). Landscapes are defined through a combination of anthropogenic and natural disturbances, land ownership, land use, landforms, and land cover. Farina (2000) describes the landscape as "heterogeneous land area consisting of clusters of interaction between ecosystems" (as cited by Gökyer, 2013). Landscapes are dynamic systems (Gökyer, 2013), and roads are essential components of the landscape; they fragment habitats into pieces, facilitate the spread of invasive species, changing hydrology and affect land-use patterns (Newman et al., 2014). At the landscape scale, roads cause fragmentation by removing habitat and creating splitting otherwise continuous vegetation. Humans affect them continuously. Due to intense human influences, the pressure on the landscape has continued to increase. Consequently, landscapes are altered over time. Landscape ecology is an ecological discipline that deals with the spatial distribution of organisms, models and processes. (Gökyer, 2013). In other words, landscape ecology focuses on the relationship between landscape structure and function and the ways landscapes change over time. Landscape fragmentation can be quantified using landscape metrics. These landscape metrics enable comparison of landscape patterns across landscapes and different periods of time (Hermosilla et al., 2019). Landscape ecology focuses on three aspects of landscape (Forman and Godron, 1986; Gökyer, 2013). Structure defines the spatial relationships between specific ecosystems or elements, while function expresses interactions between spatial properties.

Landscape structure examines the relationship between ecosystems as a measure, number, size, and shape (Gökyer, 2013). Landscape structure contains the study of composition and configuration of ecosystems at the landscape level (Gökyer, 2013; Tolessa et al., 2016). The composition refers the amount and types of habitats present in landscape whereas the configuration implies to the structure and arrangement of those habitats (Tolessa et al., 2016). According to Ritchie et al. (2009), landscape composition also describes the amount and type of landscape elements, and landscape configuration describes spatial arrangements. Organisms can only be affected by both landscape composition and configuration to varying degrees (Ritchie et al. 2009; Echeverria et al., 2008; Shannon and Weaver, 1949; Simpson, 1949).

Landscape ecologists use four basic terms to define spatial structure (FISGRW, 1998; as cited by Gökyer, 2013). A patch is described as a relatively homogeneous nonlinear area different from its surroundings (Rutledge, 2003). Patches offer a variety of functions, including wildlife habitat, aquifer charging sites, or resources and sinks for species or nutrients. Agricultural fields, wood lots or village, are examples of the kinds of the patches.
Corridor is a special kind of patch that connects the other patches in the matrix. Typically, a corridor is linear or elongated, such as a stream corridor (Gökyer, 2013). Corridors serve for many functions within the landscape, including the natural habitat, roads or channels for the movement of plants, animals, nutrients and wind, or obstacles to such movements. There are many types of corridors, from riparian or river corridors to interstate highway systems, to canals in farmland. Matrix is the land cover, which is dominant and connected to each other in most of

the land surface (Gökyer, 2013). Usually the matrix is forest or agriculture, but theoretically, it can be any type of ground cover. Examples of the matrix include a city with parking patches and a forest with patches produced by timber harvesting. Mosaic specifies to a collection of patches, none of which are dominant adequately to be connected together throughout the landscape.

2. 3. 2. Road-Based Metrics

Road Density

Road density (RD) measurements represent an existing methodology for measuring the amount of habitat fragmentation (Loraamm, 2011). RD is calculated as the ratio of the total road network length to the total land area (m / m^2) of a working area. Although RD is a practical measure of fragmentation, it is only applied at the landscape level. RD explains how much of a particular patch or patch type is affected by road networks. In general, as the RD increases, the mean patch size decreases, and the total edge increases. In some cases, patch shape complexity either increases (Loraamm, 2011) or becomes more simplified (Saunders et al., 2002), with the exact effect of roads depending on their spatial pattern (Gökyer, 2013). RD is a useful indicator because it combines the many ecological effects of roads and vehicles. RD varies, and some ecosystems are more fragmented by roads than others (Saunders et al., 2002).

Road Length.

The road length is considered to be any part of the road between two adjacent intersections or among the intersection and the end of the length of road. The length of the road is the road and related areas.

Distance to Roads

Distance to Roads (DR) is a new metric for calculating road-based habitat fragmentation. At the patch level, DR is measured as the Euclidean distance from a patch edge to the nearest road edge in meters. Higher values for DR demonstrate less fragmented landscapes, since it indicates habitats are located further from roads (Loraamm, 2011).

2. 3. 3. Other Metrics

Patch Number

The Patch number identifies the degree of subdivision for a particular class or landscape explicitly, calculating the total number of patches for a given region (Loraamm, 2011). Patch number must be interpreted in conjunction with patch size and landscape area to be a useful measure.

Patch Density (PD)

The simplest evaluation of landscape configuration is patch density, the total number of patches divided by the total reference area (McGarigal and Marks 1995, cited in Loraamm, 2011). In general, patch density is considered in association with other metrics, as it is affected by both the size of patches and size of the reference area.

Patch Size

Patch Size is used to measure subsections of habitats in a landscape Patch size is one of the most beneficial measurements to characterize a landscape as larger patches often show less fragmentation (McGarigal and Marks 1995; as cited by Loraamm, 2011). The size of the habitat patches can also illustrate the number of species that a region can support.

Edge Density (ED)

Edge Density (ED) is sum of length of all edge segments for the class, divided by total landscape area. ED is an indicator for level of interaction among all classes (Biodiversity Indicators Partnership, 2010). Higher values for ED indicate patches with relatively more edge than interior.

Area-Weighted Mean Shape Index (SHAPE_AM)

It measures the complexity of patch shape of a particular LULC class compared to a standard shape (square), by weighting patches according to their size (Tolessa, 2016). This index may be more appropriate than the weighted average shape index when it plays a dominant role in landscape function (Mcgarigal and Marks, 1995).

Mean Euclidian Nearest Neighbour Distance (ENN-MN)

Mean Euclidian Nearest Neighbour Distance (ENN-MN) is mean of Euclidean geometry as the shortest straight-line distance between the focal patch and its nearest neighbour of the same class (Biodiversity Indicators Partnership, 2010). ENN_MN measures the distance to the nearest neighbor patch of the same type. (Posada Posada, 2012). ENN_MN provides useful information about landscape composition and texture.

Largest-Patch Index (LPI)

Largest-Patch Index (LPI) is area of the largest patch in each class, described as a percentage of total landscape area (Biodiversity Indicators Partnership, 2010). The largest patch index is used to characterize the dominance of the landscape. The landscape shape index can be a useful index, in particular when comparing between landscapes of different sizes.

Mean Patch Size (AREA_MN)

Mean Patch Size (AREA_MN) equals total area divided by the total number of patches (Biodiversity Indicators Partnership, 2010). The mean patch size indicates a function of the field and the status of the patch numbers (Posada Posada, 2012).

CHAPTER THREE

GOALS AND OBJECTTIVES

The major goal of this study is to analyze changes in forest area, forest fragmentation, and forest road impacts using GIS for St. Johns County, Florida, between the years of 2000 and 2014. In this study, we research the landscape composition and configuration and its implications on the landscape structure in St Johns County, in order to reveal the spatial and temporal integrity of ecological processes. This assessment aims to describe how land use has changed over time and, in particular, how some dynamics of forests have been fragmentated by roads. We compare LULC changes and fragmentation processes at temporal scales in the study area. The general objectives in this study:

(1) To measure and map changes in forest composition in St. Johns County from 2000 to 2014.

(2) To measure changes in forest configuration from 2000 to 2014.

(3) To measure changes in road impacts to forests from 2000 to 2014.

This paper seeks to address the following research questions: How have land use and land cover changed in the study region between 2000 and 2014 the years? How has fragmentation changed over time? How has road-based fragmentation changed over time?

CHAPTER FOUR

STUDY AREA

St. Johns County, the oldest county in the state, is on the Atlantic coast in the northeastern part of Florida (Figure 1). The total area of the county is 389,760 acres, or 609 square miles, including approximately 1,610 acres of water (Readle, n.d). St Johns County has a subtropical maritime climate. It is characterized by long, warm, humid summers and mild, dry winters. St. Johns County has three incorporated cities: St. Augustine, St. Augustine Beach, and Hastings (County Quick Facts, n.d). According to the US Census, the population of St Johns County was 123,223 in 2000 and 217,865 in 2014 (City Population, n.d). It was estimated to be 254,261 in 2018 (World Population Review, n.d). Agriculture, forestry, and tourism are the main businesses. Water and soil are essential resources in St. Johns County. The Atlantic on the east and the St. Johns River on the west provide excellent fishing and water sports. The brackish St. Johns River is one of the few rivers in the northern hemisphere which flow in a northerly direction (Readle, n.d).

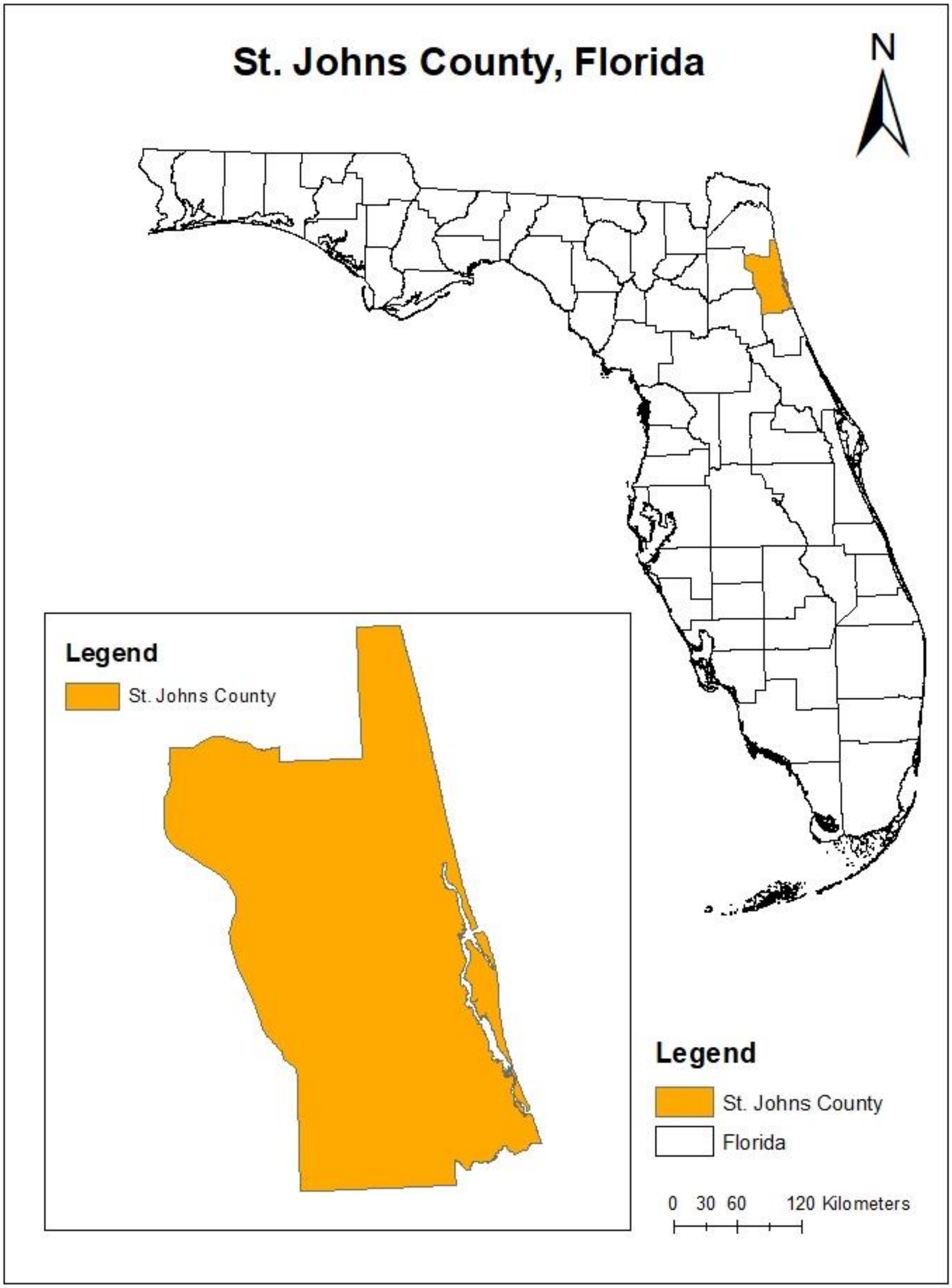

Figure 1. Location of study area.

CHAPTER FIVE

METHODS

5.1 Data Collection

2000 and 2014 land use and land cover data were used for this research layers (FDGL Metadata Explorer, 2000-2014). These datasets were used because they were created using the same classification techniques and are therefore comparable. Also, 2000 and 2014 road data were used as these data indicated a change in road networks in the study area (US Census Tiger Line Shape File, 2000,2006 and from 2010 to 2014). Additionally, satellite images from Google Earth Pro were used to illustrate forest fragmentation.

5.2 Methodology

Land Use / Land Cover (LULC) refers to the classification of human activities and natural elements at a given time, based on scientific and statistical analysis methods commonly used in the analysis of appropriate source materials (Singh & Satpalda, 2002). Land cover and land use (LULC), geospatial applications that helps to detect the extent of human influence on the natural environment. Remote sensing (RS) and Geographic Information System (GIS) are two effective tools for detecting and analyzing land cover and changes over a period of time by integrating spatial and temporal windows of the study area (Chowdhury et al., 2018). To identify changes over time, land cover maps are needed over several different years, and the result analysis helps the relevant manager understand the current landscape, along with the changing landscape. In most cases, land use and land cover change are the results of different anthropogenic activities, i.e. cutting down trees and conversion of forest land into agricultural land or human settlements which cause disturbance of biodiversity, water and radiation budgets, affects trace gas emissions and other processes that cumulatively affect climate and biosphere (Rawat and Kumar, 2015; Chowdhury et al., 2018). Hence, information about LULC is increasingly needed to manage the environment as well as living conditions effectively. LULC maps also assist us to study the changes that are happening in our ecosystem and environment. In this study, we research the landscape composition and configuration and its implication on the landscape structure in St Johns County as it has been to reveal the spatial and temporal integrity of ecological processes. This assessment describes how land use changes and, in particular, how some dynamics of forest have been torn fragmentation by roads. We compare land use and land cover changes and fragmentation processes at temporal scales in the study area. Landscape composition work together with landscape configuration to effectively measure changes in habitat loss and fragmentation over time.

LULC classification

In this study, thirteen LULC classes were defined: agriculture, herbaceous and shrubby vegetation, barren land, water, upland coniferous forest, upland hardwood forest, wetland coniferous forest, wetland hardwood forest, tree plantations, vegetated non-forested wetlands, non-vegetated wetlands, settlements(urban), and others (Table 1). These classes were created by combining sum of the Level 2 LULC classifications in the original layers. These classes were selected to present both broad LULC types, such as water and agricultural and specific forest classes. Five forest types are: upland coniferous, upland hardwood, wetland coniferous, wetland hardwood forest and tree plantations. Tree plantations consist of with only one or two types of forest trees of the same age. As they are generally commercially valuable, they are cut at certain time intervals and then re-planted (Sustaining Biodiversity, n.d) Wetland coniferous forest is defined swamp area, usually dominant by cypress trees. Wetlands coniferous and hardwood forest contain an ecosystem that is important for the nesting of birds, turtles and fish. Wetland hardwood forests are home to various species of ash, maple, oak and willow. Upland coniferous forests are very rich for biodiversity such as longleaf pine, slash pine and juniper. They have more function for sustainable environmental.

Table 1. Demonstration of land use/land cover supervised classification scheme.

Class Name	Description
Agriculture	Areas designated as cropland and pastureland, other open lands-rural, tree crops, nurseries and vineyards, specialty farms and feeding operations.
Barren Land	Disturbed land and sand other than beaches.
Water	Reservoirs, lakes and streams and waterways.
Herbaceous and Shrubby Vegetation	Areas covered by mixed rangeland, upland shrub and bushland and herbaceous.
Settlements (Urban)	Areas displayed as residential, commercial, industrial, transportation, extractive, institutional, utilizes, recreational and open land.
Tree Plantations	Forest regeneration areas and coniferous plantations.
Upland Coniferous Forests	Pine flatwoods, Longleaf Pine-Xeric oak.
Upland Hardwood Forests	Upland hardwood forests
Wetland Coniferous Forests	Cypress, Hydric pine flatwoods
Wetland Hardwood Forests	Mixed wetland hardwoods, Willow and Elderberry, Mangrove swamps and Bay swamps.
Vegetated Non-Forested Wetlands	Freshwater marshes, Saltwater marshes, Wet prairies and Treeless hydric savanna
Non-Vegetated Wetlands	Non-vegetated wetlands
Others	Special and missing classification

(1) LULC change

First, the percent change in area for each LULC type from 2000 to 2014 was calculated using the following formula: $\% \; Change = \left(\frac{CAP_{2014} - CAP_{2000}}{CAP_{2000}}\right) * 100$, where CAP refers to the class area proportion for that cover type and the subscript denotes the year. The resulting values measure the percent change in area over the time period, where positive values indicate a gain and negative numbers reflect a loss. Second, binary raster analysis was used to map changes in the distribution of individual forest types and all forest types combined from 2000 to 2014. First, each forest type and all forest types combined were converted to binary rasters. Then, the 2014 raster was subtracted from the corresponding 2000 raster in order to generate a change map that shows areas of no change as zero, areas of gain as 1, and areas of loss as -1.

(2) Changes in forest configuration

Landscape metrics were applied to both the 2000 and 2014 LULC data in order to evaluate changes in forest configuration. The following class-level metrics were selected: number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch size (AREA_MN), area- weighted mean shape (SHAPE_AM), mean Euclidean nearest neighbor distance (ENN_MN) and mean patch shape index (SHAPE_MN). These particular metrics were selected in order to provide measures of different aspects of habitat fragmentation including quantity, size, shape, and edginess of patches, because they are the most useful and also the most widely preferred metric for understanding changes in landscape.

These selected metrics are very important for analyzing forest fragmentation and can be interpreted as follows. Number of patches and mean patch size are reflected change in patch density. Two shape metrics are affected by LPI and ED change in landscape. An increase in number of patches (NP) and decrease in mean patch size (AREA_ MN) would mean that the habitat was fragmented into a larger number of smaller patches, while an increase in AREA_MIN would indicate reforestation with either a larger number or smaller number of patches (NP). A decrease in NP and decline in mean patch size would indicate that the habitat was reduced into a fewer number of smaller patches. An increase in LPI would show either that the largest patch in the county grew in size, or another larger patch was converted to forest elsewhere. A decrease in LPI would indicate that the largest patch in the county was transformed, at least in part, to another type. A decline in ENN_MN would explain how patches became closer to one another and more isolated, while an increase would suggest that reforestation results in less isolation. An increase in ED describes how there are more edges relative to interior in forest patches, meaning increased levels of fragmentation. The shape index (SHAPE) measures the complexity of the patch shape compared to a standard shape. The shape index examines the average patch shape for a particular patch type in the landscape.

Calculation of the landscape metrics was performed using the software package FRAGSTATS, because of its accuracy for calculating fragmentation metrics and the ease of the use of the program on raster datasets (Tolessa et al., 2016). Then, the percent change from 2000 to 2014 was calculated for each landscape metric, similar to the LULC percent change described above.

This study was looked at how fragmentation rates changed relative to changes in forest loss. Are the rates of forest fragmentation similar to rates of forest loss? In other words, is the effect of fragmentation larger than expected for a given amount of forest loss? We computed a ratio for each forest type with this formula.

$$\text{A ratio for each forest type} = \left(\frac{\%\ \text{change in fragmentation metrics}}{\%\ \text{change in forest}}\right)$$

A large ratio would indicate that % changes in fragmentation were happening at a greater rate than habitat loss. A value of 1 would indicate the changes were equal. Values less than 1 indicate the percent of fragmentation change was less than the percent of change in habitat. This ratio is intended to increase our understanding of the magnitude of fragmentation changes.

(3) Changes in road-based fragmentation

Road-based landscape metrics were used to evaluate changes in road impacts to forests from 2000 to 2014. The following metrics were calculated for each year: road length, road density, and distance to nearest road. Road lengths were calculated using standard tools in ArcGIS. Road lengths were calculated for each forest type and all forests types combined. Road density was calculated by dividing those lengths by the area of the relevant forest type(s). The average Euclidean distance to the nearest road was calculated for each forest type and all forest types combined. The average was calculated based on the distances between each raster cell in the forest layer to the nearest road. Over time, in a similar manner to that computed for changes in LULC and fragmentation metrics.

In this study, we looked at comparing the metrics to our change in roads with this formula. Additionally, a ratio for $\text{change in roads} = \left(\frac{\text{\% change in metrics}}{\text{\% change in road density}}\right)$ was calculated. A large ratio would indicate that fragmentation is happening at a greater rate than loss. Anything about 1 would indicate they're about the same. Rate bigger than 1 -fragmentation is occurring at a much larger than loss. That means fragmentation has a much strong effect than forest loss. That would allow us to examine how the changes in fragmentation relate to changes in road density. That comparing these rates will help us figure out how much of the fragmentation might be related to roads. Finally, a comparison of the fragmentation ratio between habitat loss and road density will help us understand if changes in fragmentation are driven more by habitat loss or road density.

CHAPTER SIX

RESULTS

6.1 LULC change

Land cover classification was made according to thirteen land use types for two periods. In 2000, tree plantations, wetland hardwood forest, and settlements (urban) were the dominant land use/land covers 45141 ha (26.3%), 29795 ha (17.4%) and 21863 ha (12.7%), respectively in St. Johns County. In 2014, 42135 ha (24.5%), 30104 ha (17.5%) and 28346 ha (16.5%) of land under tree plantations, settlements and wetland hardwood forest, respectively were the dominant land use/land cover types. Tree plantations and wetland hardwood forests declined considerably, while settlements have increased dramatically from 12.7 to 17.5 percent with a change rate of 37.8%. From 2000 to 2014, wetland coniferous forests declined from 8141 to 4651 hectares, a reduction of almost half. Likewise, there has been a reduction in the amount of upland coniferous forests and wetland hardwood forests by -14.9% and -5.2% between 2000 and 2014, respectively (Table 2). Figure 2 shows the overall LULC type changes from 2000 to 2014.

Generally, there was a loss in the rate of overall forest types, but only a slight increase in upland hardwood forests. Change of tree plantation was - 6.8% (Table 2). The losses were mostly in the northwest, northeast and west central. Losses were mostly in the form of large patches (Figure 3). Upland coniferous forest of change was -14.9% (Table 2). The losses were mostly in the northwest and southeast (Figure 4). Upland hardwood forest of change was 2.6% (Table 2). Losses and gains were mostly in the form of small patches (Figure 5). Wetland coniferous forest of change was -42.6% (Table 2). The losses were often in the form of small, scattered patches. The losses in general were in the southeast and central areas (Figure 6). Wetland hardwood forest of change was-5.2% (Table 2). Losses were mostly in the form of large patches, generally in the south, north and central regions (Figure 7). Overall forest types losses were mostly in the form of large patches, with a widespread spatial distribution. Losses were usually found in all areas of St. Johns County, but the northwest and central regions loss (Figure 8). Overall, LULC results show that there is a large change in the proportion of forests in general.

Table 2. Category land use distribution and land use change of St. Johns County from 2000 to 2014.

Land Use Category	Land use in 2000 Area (Hectare)	Percentage (%)	Land use in 2014 Area (Hectare)	Percentage (%)	Land use change (%) from 2000 to 2014
Agriculture	15522	9.0	13604	7.9	-12.2
Herbaceous and Shrubby Vegetation	5644	3.3	4543	2.6	-21.2
Tree Plantations	45141	26.3	42135	24.5	-6.8
Water	15113	8.8	16924	9.9	12.5
Barren Land	555	0.3	542	0.3	0.0
Vegetated Non-Forested Wetlands	11647	6.8	13641	7.9	16.2
Settlements (Urban)	21863	12.7	30104	17.5	37.8
Upland Coniferous Forests	11451	6.7	9816	5.7	-14.9
Upland Hardwood Forest	6641	3.9	6894	4.0	2.6
Wetland Coniferous Forests	8141	4.7	4651	2.7	-42.6

Table2. (continued)

Wetland Hardwood Forests	29795	17.4	28346	16.5	-5.2
Non-Vegetated Wetlands	98	0.1	445	0.3	200.0
Others	101	0.1	67	0.0	-100.0
Total	171712	100	171712	100	0.00

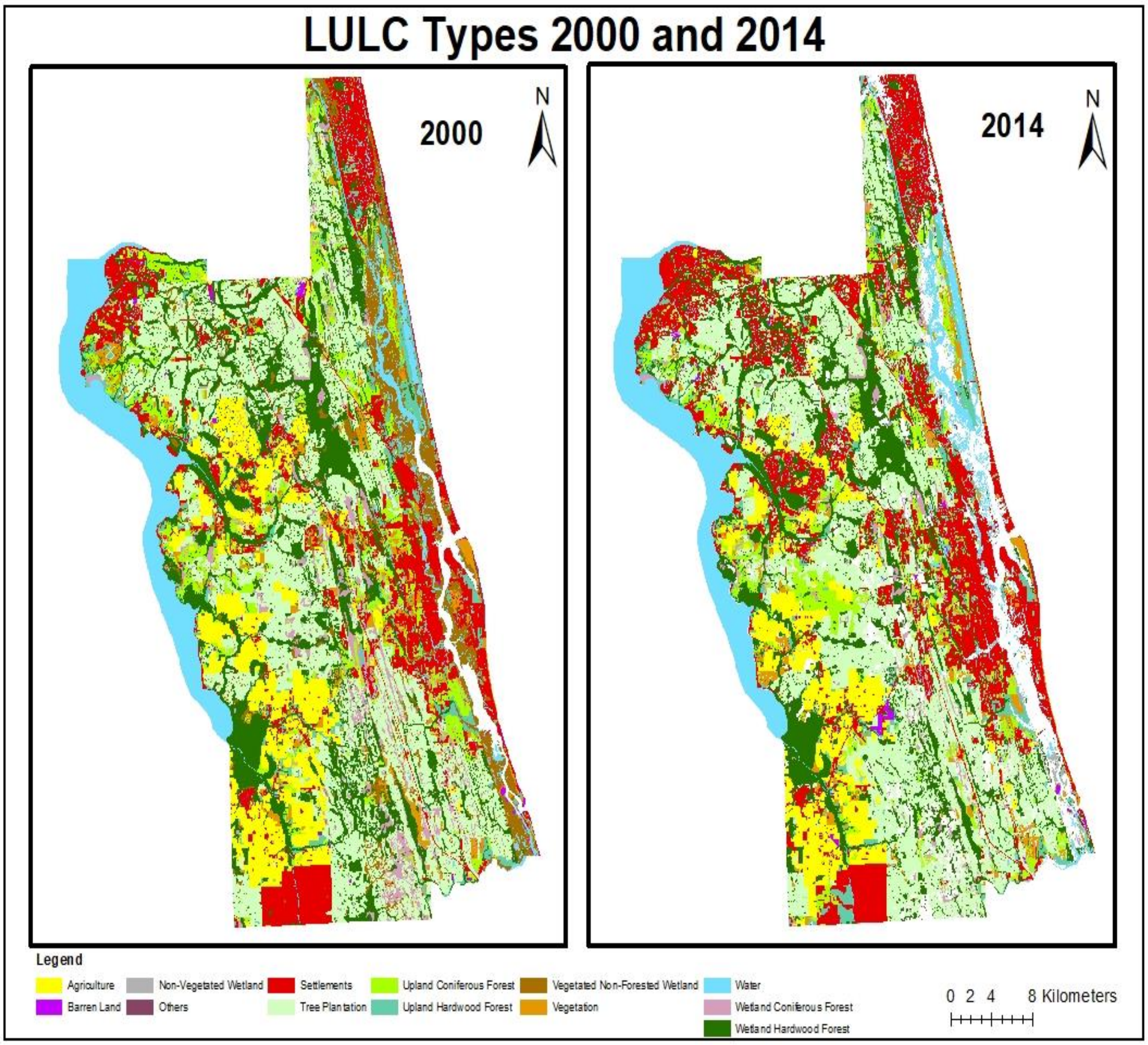

Figure 2. LULC types between 2000 and 2014 in St. Johns County.

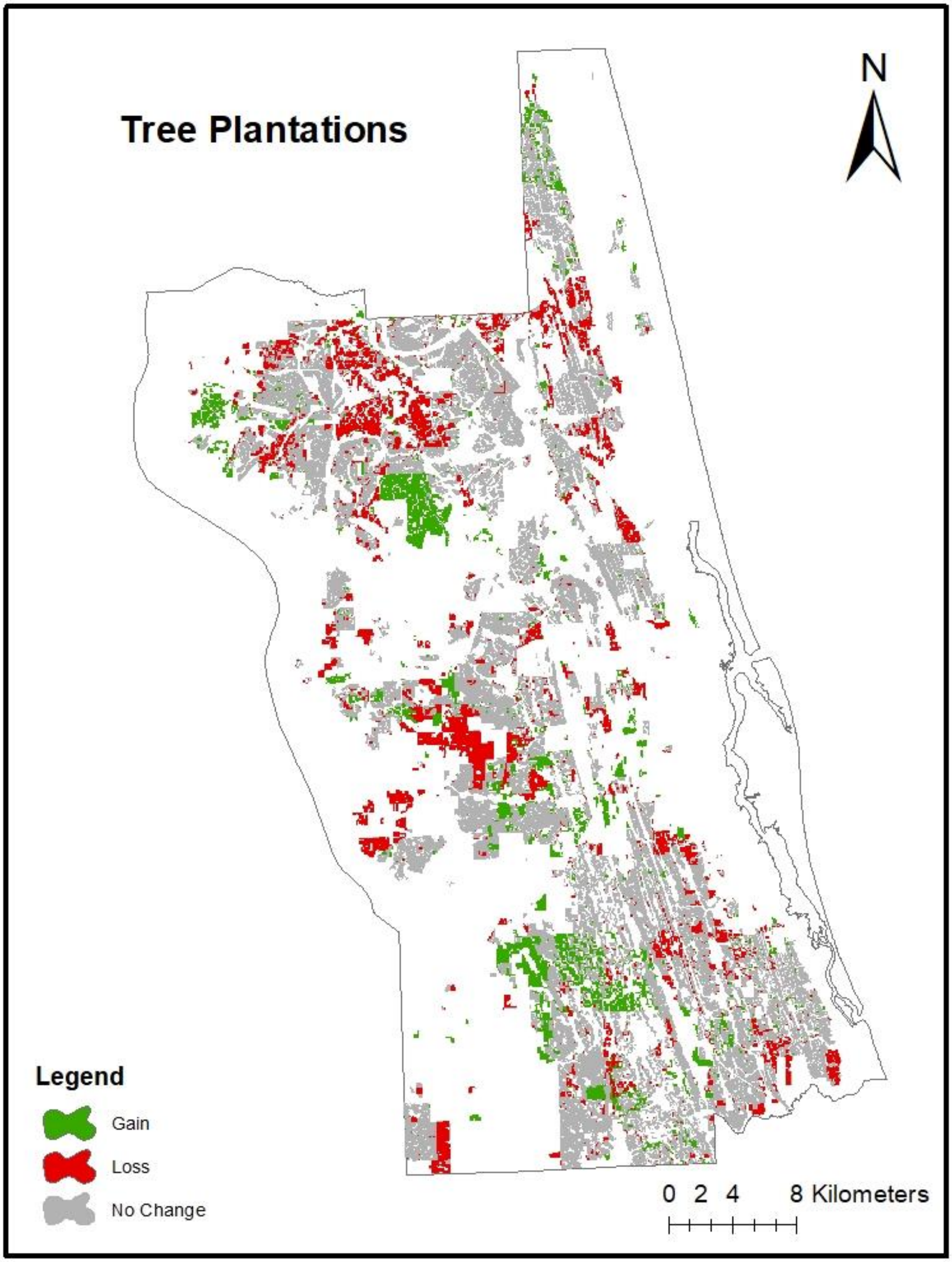

Figure 3. Indication of change in tree plantation.

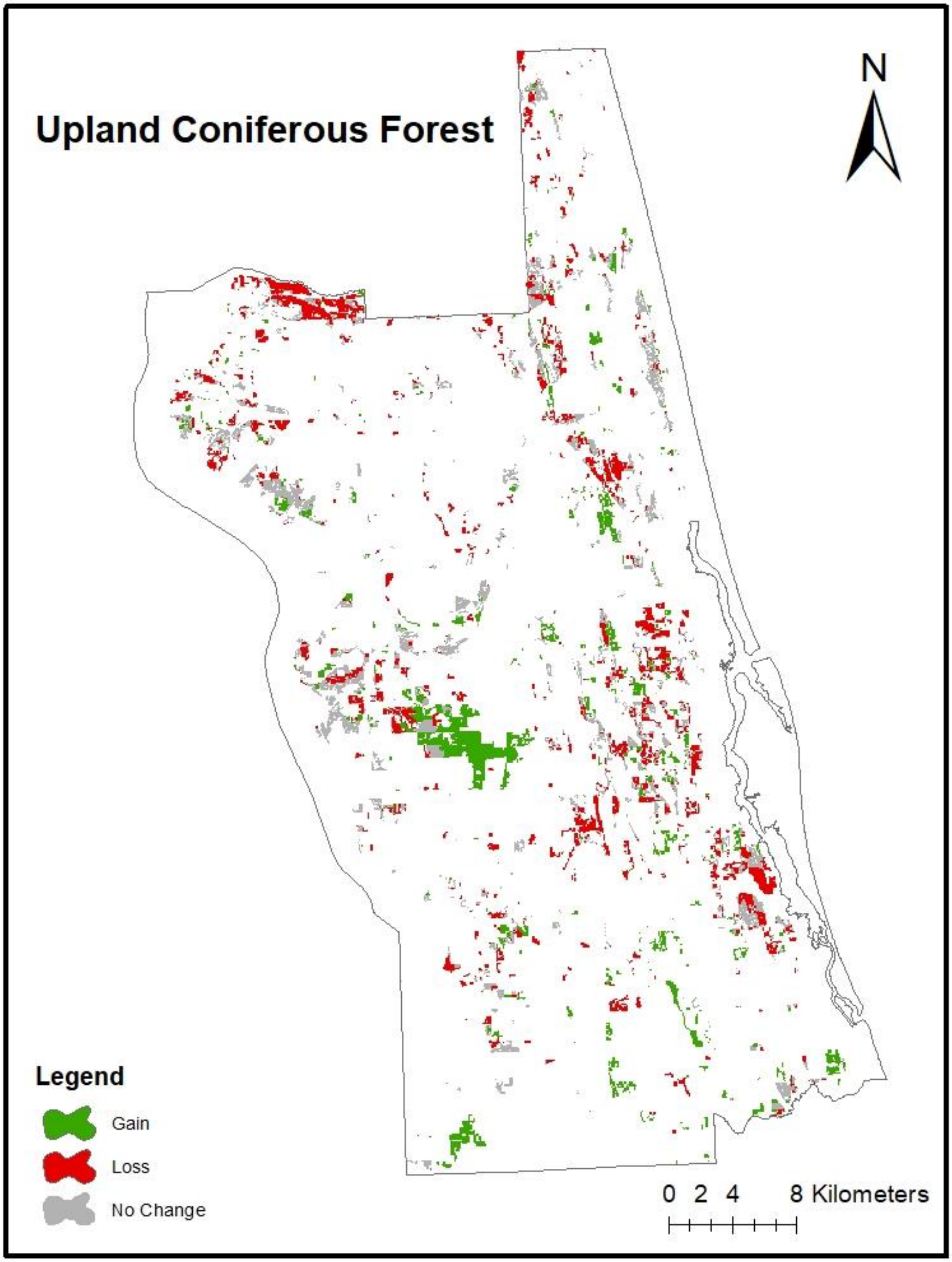

Figure 4. Indication of change in upland coniferous forest.

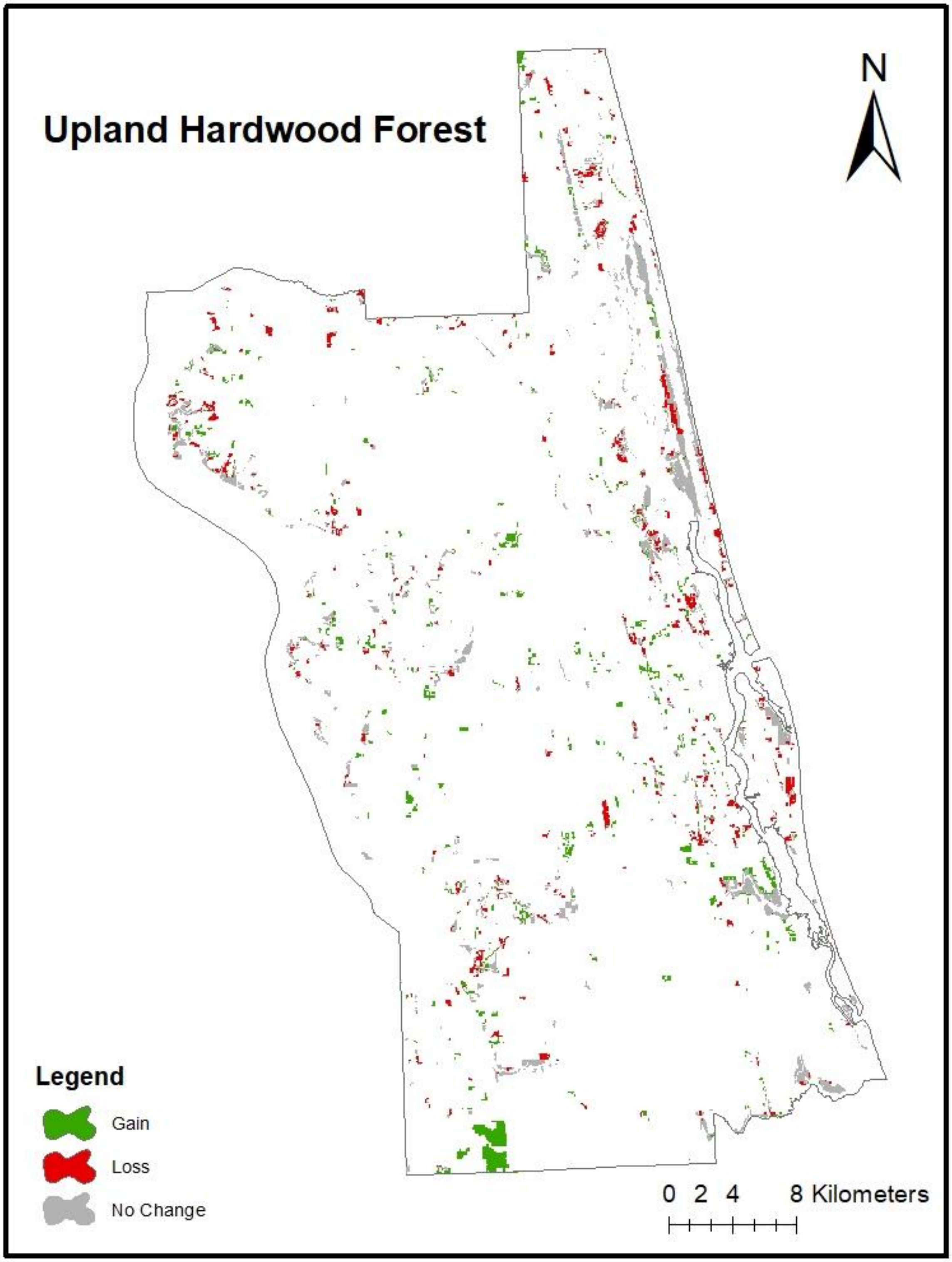

Figure 5. Indication of change in upland hardwood forest.

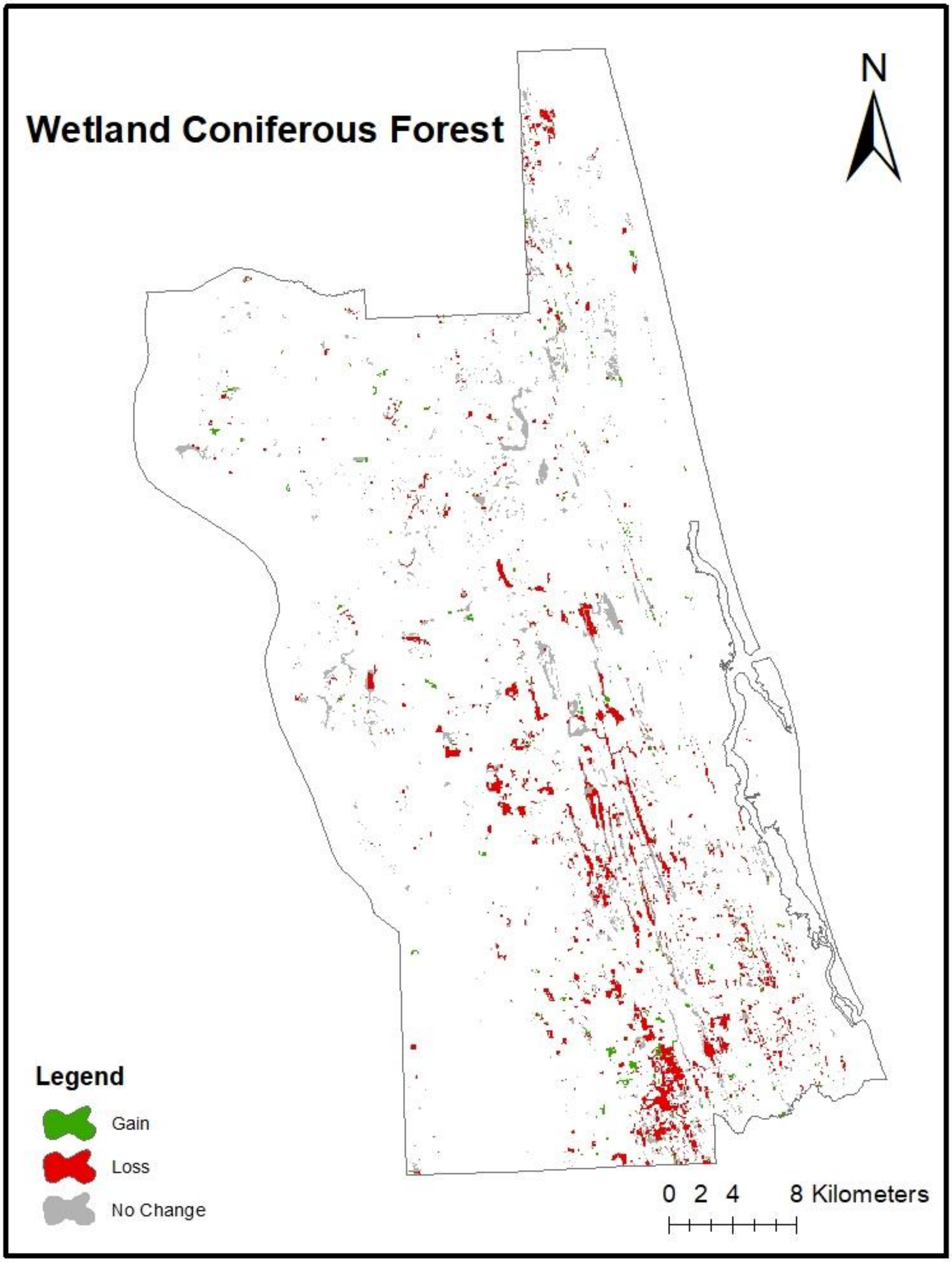

Figure 6. Indication of change in wetland coniferous forest.

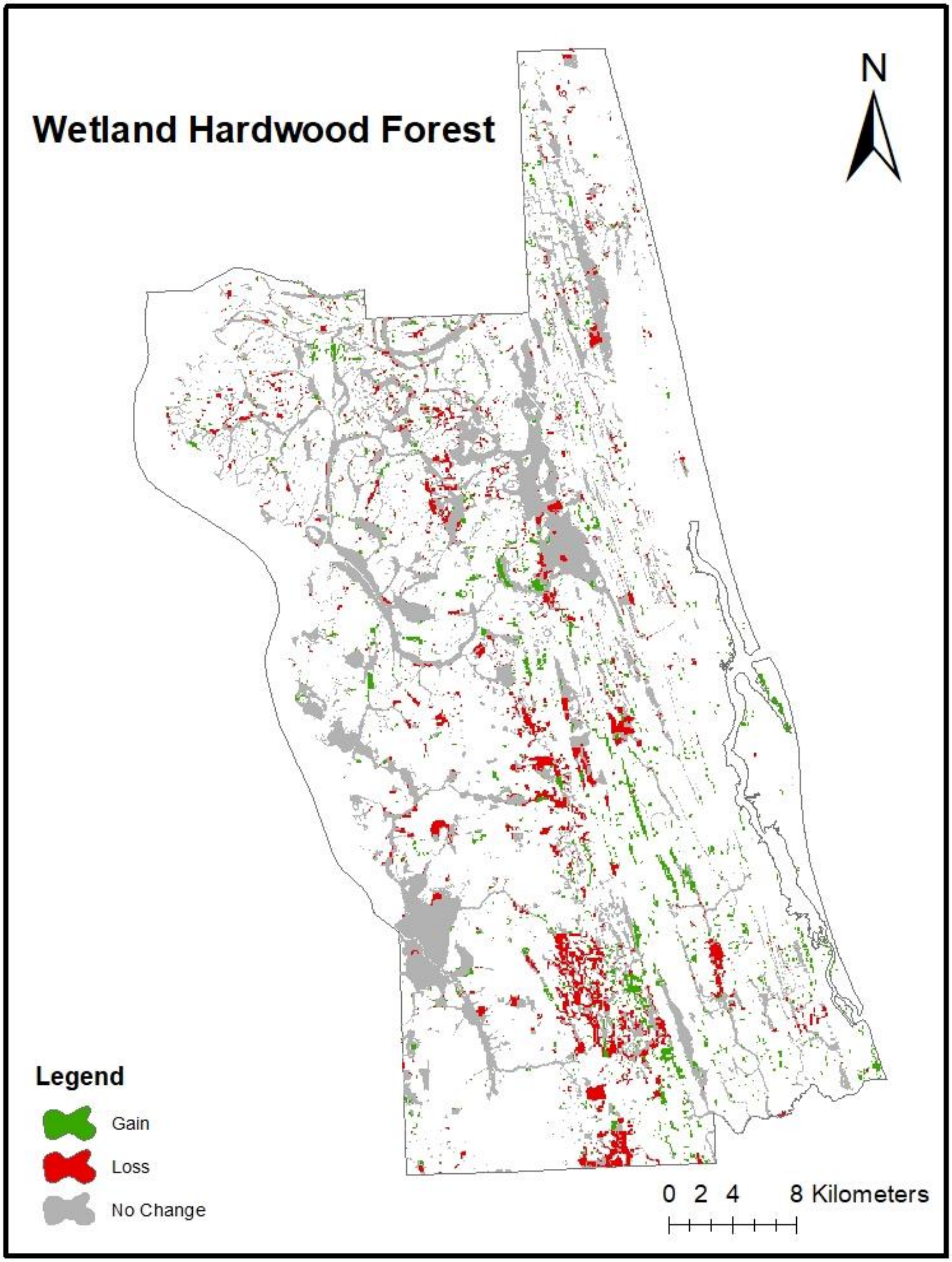

Figure 7. Indication of change in wetland hardwood forest.

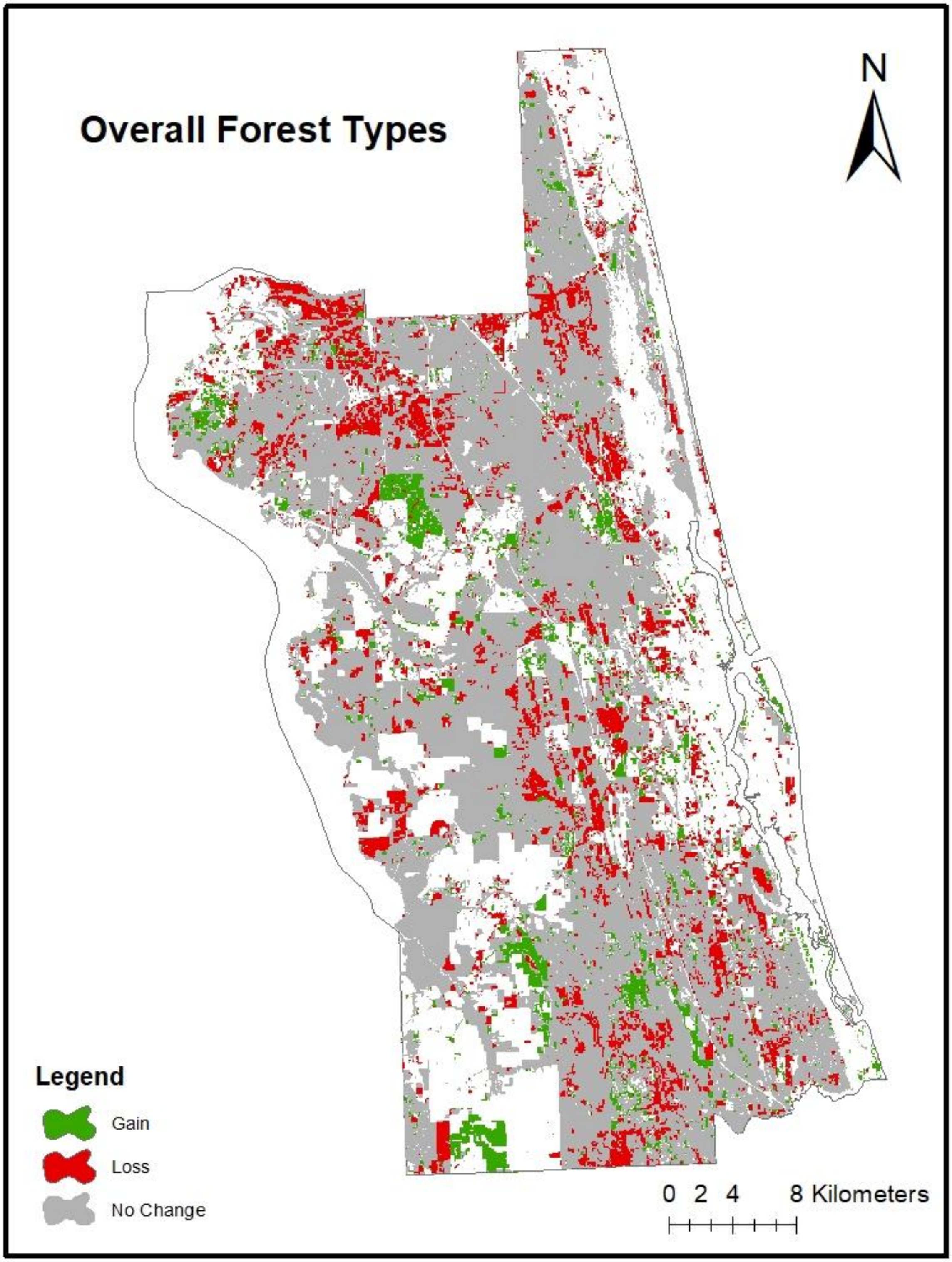

Figure 8. Indication of change in overall forest types.

Tree plantations, upland coniferous forest, upland hardwood forest and overall forest types losses have been transformed into settlements, wetland coniferous, wetland hardwood forests and vegetated non-forested wetlands. Thirty two percent of tree plantations, 41% of upland coniferous forest, and 60% of upland hardwood forest have been converted to settlements. Overall forest has turned into 42% settlements, followed by 32% vegetated non-forested wetlands, and 16% herbaceous and shrubby vegetation. A vast amount of forest types were converted to settlement (Table 3).

Table 3. Representation of other LULC conversion percentage of forest types losses.

Loss %		**Land Use Categories**										
		Agriculture	Herbaceous and Shrubby Vegetation	Tree Plantations	Water	Barren Land	Vegetated Non-Forested Wetlands	Settlements (Urban)	Upland Coniferous Forests	Upland Hardwood Forest	Wetland Coniferous Forests	Wetland Hardwood Forests
Forest Types	Tree Plantations	6	16	0	5	1	7	32	23	3	2	5
	Upland Coniferous Forests	3	16	20	3	1	2	41	0	10	1	4
	Upland Hardwood Forest	3	10	12	3	0	1	60	5	0	0	5
	Wetland Coniferous Forest	0	1	19	0	0	42	2	3	0	0	31
	Wetland Hardwood Forest	1	1	25	1	0	54	9	2	2	4	0
	Overall Forest	5	16	0	4	1	32	42	0	0	0	0

6. 2 Changes in forest configuration

Eight landscape metrics were used to measure changes in the configuration of LULC types in St. Johns County between 2000 and 2014: Number of patches (NP), Large patch index (LPI), Edge density (ED), Patch density (PD), Mean patch size (AREA_MN), Area-weighted mean shape index (SHAPE_AM), mean patch shape index (SHAPE_MN), and Mean Euclidean nearest neighbor distance (ENN_MN) (Table 4). The main findings are described by LULC type below:

Upland Coniferous Forest

The decline in upland coniferous forest area was associated with an increase in the number of patches (701 to 750), and decline in mean patch size (16.4 ha to 13.1 ha), changes of 7% and -19.6% respectively. These changes are reflected in the 7.3% change in patch density. LPI increased significantly during the time frame while the two space-shape metrics declined by about 4% and 7%. Additionally, the mean Euclidean nearest neighbor increased from 367 m to 377.2 m, and change was 2.8% (Table 4).

Tree Plantations

The decline in tree plantations area was associated with an increase in the number of patches (327 to 539), and decline in mean patch size (138.3 ha to 78.4 ha), change of 64.8% and -43.3%` respectively. These changes are reflected in the 50% change in patch density. LPI and ED remained fairly similar during the time frame, while two shape metrics declined by about 5% and 17%. Furthermore, the mean nearest neighbor distance (ENN_MN) of tree plantations decreased from 326.2 m in 2000 to 295 m in 2014, a change of -9.6% (Table 4).

Wetland Coniferous Forest

The large decline in wetland coniferous forest area was associated with decrease in the number of patches (1517 to 1299), and decline in mean patch size (5.3 ha to 3.6 ha), change of -14.4% and -22.9 respectively. These changes are reflected in the 11.1% change in patch density. LPI and ED declined remarkably during the time frame from 0.3% to 0.1% and from 9.7% to 6.5% respectively, while the mean nearest neighbor distance (ENN_MN) increased from 336 m to 3380 m, and change was 13.1% (Table 4).

Wetland Hardwood Forest

The decline in wetland hardwood forest area was associated with an increase in the number of patches (1953 to 2403), and decline in mean patch size (15.3 ha to 11.8 ha), change of 23% and -19.6% respectively. These changes are reflected in the 7.3% change in patch density. For upland hardwood forest, ED increased 22.4 m to 23.4 m, and change was 4.5% (Table 4).

Upland Hardwood Forest

NP of upland hardwood forest increased from 647 in 2000 to 827 in 2014, and change was 27.8%, while LPI of upland hardwood forest decreased from 0.4 to 0.2, and change was -50 percent. ED increased from 6.4% to 8.5%, and change was 6.2%. PD in upland hardwood forest went up from 0.4 to 0.5, and change was 25% (Table 4).

Settlements

The increase in settlements area was associated with increase in mean patch size (AREA_MN) (29 ha to 40.2 ha) and decline in mean nearest neighbor distance (ENN_MN) (323.7 m to 298.6 m) and change of 38.6 % and -7.8 % respectively. As LPI and ED increased considerably, two shape increased by about 41 % and 7 % From 2000 to 2014, ED in settlements increased from 12.7 m to 18 m, and change was by about 42%, while NP of settlements declines from 754 to 747, and change was around at 1% (Table 4).

Herbaceous and Shrubby Vegetation

The decrease in herbaceous shrubby vegetation area was associated with decline in mean patch size (8.8 ha to 8.3 ha), change of by about -6%. NP of herbaceous and shrubby vegetation decreased from 638 to 554, and change was by about -13%, while ED of herbaceous shrubby vegetation decreased from 5.4 to 4.3, and change was by around -20%. Additionally, the mean Euclidean nearest neighbor went up from 469 m to 526.7 m (Table 4).

Vegetated Non-Forest Wetlands

The increase in vegetated non-forest wetland area was associated decline in mean nearest neighbor distance (ENN_MN) (376.6 m to 350.1 m) and change of -7 % NP of vegetated non-forest wetland increased from1429 to 1676, and change was by about 17%. ED in vegetated non-forest wetland went up (10.2 to 13.5), and change was approximately 32% (Table 4).

Agriculture

The decline in agriculture area was associated with an increase in the number of patches (143 to 241) and decline in mean patch size (108.7 ha to 56.3 ha), changes of 68.5% and -48.2% respectively. These changes are reflected in the 75% change in patch density. LPI increased during the time frame while the two space-shape metrics declined by about -11% and -13. Furthermore, the mean nearest neighbor distance (ENN_MN) of agriculture declined from 723 m in 2000 to 624.6m in 2014, a change of -13.6% (Table 4).

Table 4. Representation of spatial pattern at class level between 2000 and 2014, based on nine class metrics for St. Johns County: number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch area (AREA_MN), area- weighted mean shape (SHAPE_AM), mean patch shape index (SHAPE_MN), and mean Euclidean nearest neighbor distance (ENN_MN).

Year	NP	LPI	ED	PD	AREA-MN	SHAPE-AM	SHAPE-MN	ENN-MN
2000								
Agriculture	143.0	1.46	4.9	0.08	108.7	3.6	1.5	723.0
Herbaceous and Shrubby Vegetation	638.0	0.1	5.4	0.4	8.8	2.0	1.2	469.0
Tree Plantation	327.0	8.1	23.2	0.2	138.3	14.3	1.8	326.2
Water	947.0	6.4	5.4	0.6	15.9	4.0	1.1	398.3
Barren Land	181.0	0.04	0.7	0.1	3.2	1.3	1.1	781.8
Vegetated Non-Forest Wetlands	1,429.0	0.7	10.2	0.8	8.1	3.9	1.2	376.6
Settlements (Urban)	754.0	1.8	12.7	0.439	29.0	5.4	1.4	323.7
Upland Coniferous Forest	701.0	0.4	9.5	0.41	16.3	2.9	1.4	367.0
Upland Hardwood Forest	647.0	0.4	6.4	0.4	10.3	2.4	1.31	441.6
Wetland Coniferous Forest	1,517.0	0.3	9.7	0.9	5.3	2.3	1.2	336.0
Wetland Hardwood Forest	1,953.0	2.7	22.4	1.1	15.3	6.5	1.27	264.6
Non-Vegetated Forest	30.0	0.01	0.1	0.02	3.2	1.5	1.2	895.6
Others	22.0	0.04	0.1	0.01	4.8	2.2	1.1	1,889.9
2014								
Agriculture	241.0	1.5	5.0	0.14	56.3	3.2	1.3	624.6
Herbaceous and Shrubby Vegetation	554.0	0.1	4.3	0.3	8.3	2.0	1.2	526.7
Tree Plantation	539.0	8.9	22.3	0.3	78.4	13.6	1.5	295.0
Water	1,533.0	6.3	7.8	0.9	11.0	4.0	1.1	346.4
Barren Land	69.0	0.1	0.5	0.04	7.9	1.8	1.2	1,310.5
Vegetated Non-Forest Wetlands	1,676.0	0.3	13.5	1.0	8.1	3.2	1.2	350.1
Settlements (Urban)	747.0	3.1	18.0	0.435	40.2	7.6	1.5	298.6

Table 4. (continued)

Upland Coniferous Forest	750.0	0.9	8.5	0.44	13.1	2.8	1.3	377.2
Upland Hardwood Forest	827.0	0.2	6.8	0.5	8.3	2.1	1.25	400.4
Wetland Coniferous Forest	1,299.0	0.1	6.5	0.8	3.6	1.7	1.1	380.0
Wetland Hardwood Forest	2,403.0	2.2	23.4	1.4	11.8	5.8	1.26	269.7
Non-Vegetated Forest	97.0	0.04	0.5	0.1	4.6	1.9	1.2	422.6
Others	33.0	0.02	0.1	0.02	2.1	1.8	1.1	730.3
% Change								
Agriculture	68.5	2.7	2.0	75	-48.2	-11.1	-13.3	-13.6
Herbaceous and Shrubby Vegetation	-13.2	0.0	-20.4	-25	-5.7	0.0	0.0	12.3
Tree Plantation	64.8	9.9	-3.9	50	-43.3	-4.9	-16.7	-9.6
Water	61.9	-1.6	44.4	50	-30.8	0.0	0.0	-13
Barren Land	-61.9	150	-28.6	-60	146.9	38.5	9.1	67.6
Vegetated Non-Forest Wetlands	17.3	-57.1	32.4	25	0.0	-17.9	0.0	-7.0
Settlements (Urban)	-0.9	72.2	41.7	-1	38.6	40.7	7.1	-7.8
Upland Coniferous Forest	7.0	125	-10.5	7.3	-19.6	-3.4	-7.1	2.8
Upland Hardwood Forest	27.8	-50	6.2	25	-19.4	-12.5	-4.6	-9.3
Wetland Coniferous Forest	-14.4	-66.7	-33.0	-11.1	-32.1	-26.1	-8.3	13.1
Wetland Hardwood Forest	23.0	-18.5	4.5	27.3	-22.9	-10.8	-0.8	1.9
Non-Vegetated Forest	223.3	300	400	400	43.8	26.7	0.0	-52.8
Others	50	-50	0.0	100	-56.3	-18.2	0.0	-61.4

Landscape metrics for St. Johns County

For the entire county with all LULC types combined, between 2000 and 2014, number of patch (NP) increased from 9289 to 10768, and change was 15.9%, while AREA-MN and SHAPE-MN declined, and change of -1.4% and -3.6%, respectively. LPI and ED increased remarkably during the time frame, while PD decreased from 18.5 m to 15.9 m, and change was -14.1%. Furthermore, ED went up from 55.4 m to 58.6 m (Table 5).

Table 5. Representation of spatial pattern between 2000 and 2014, based on eight landscape metrics for St. Johns County: number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch area (AREA_MN), area- weighted mean shape (SHAPE_AM), mean patch shape index (SHAPE_MN), and mean Euclidean nearest neighbor distance (ENN_MN).

Landscape scale metrics								
Year	NP	LPI	ED	PD	AREA-MN	SHAPE-AM	SHAPE-MN	ENN-MN
2000	9,289.0	8.1	55.4	18.5	7.0	1.3	371.2	5.4
2014	10,768.0	8.9	58.6	15.9	6.9	1.3	357.9	6.3
% Change	15.9	9.9	5.8	-14.1	-1.4	0.0	-3.6	16.7

6. 3 Changes in road-based fragmentation

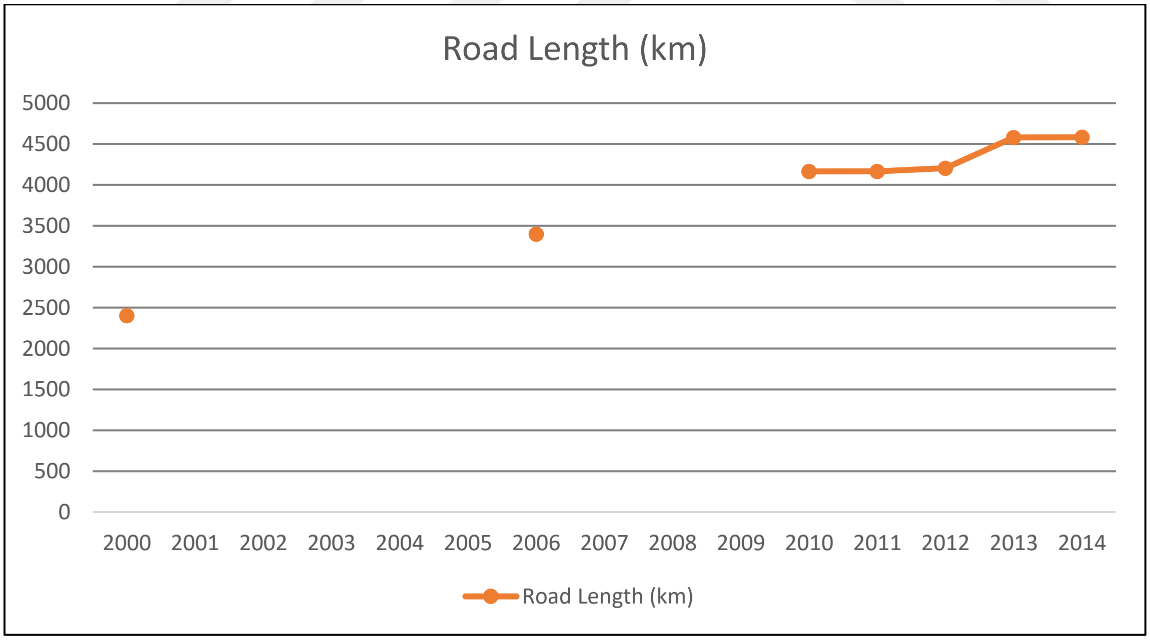

Figure 9. Road length in different years St. Johns County.

From 2000 to 2010, the road length has increased significantly, and this increase has continuously increased until 2014 in St Johns County. In 2010 and 2012, road length continued to increase steadily. In 2000 the length of the road was 2404 kilometers (km), and in 2014 the length of the road was 4583 km. Road length in St. Johns County has increased by approximately 90 percent from 2000 to 2014 years (Figure 9). The length of the road has increased between 2000 and 2014 years and especially in the central and northwest of region (Figure 10).

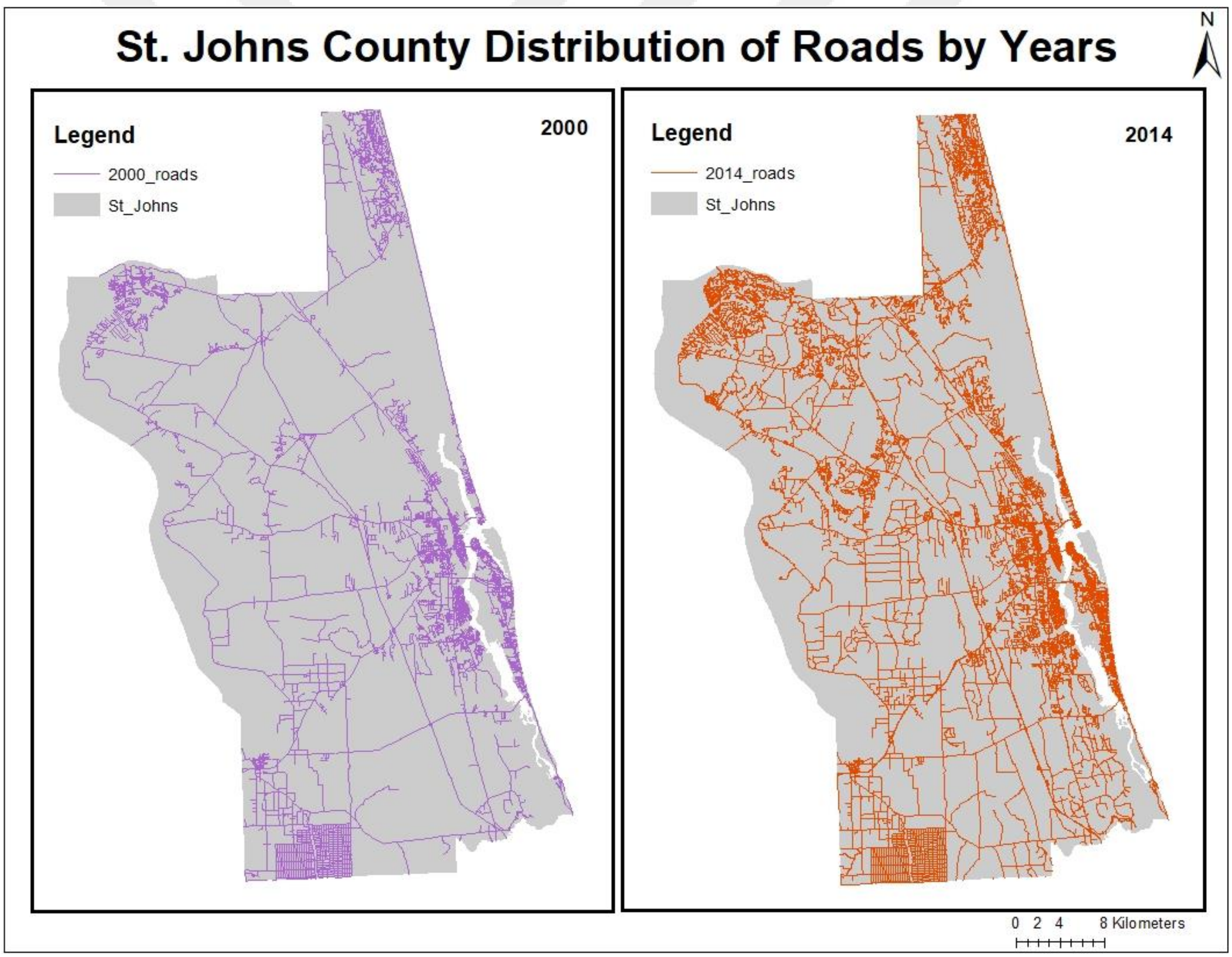

Figure 10. Distribution of roads by years in St. Johns County.

The change in road density increased in all forest types, but in particular the change in the upland coniferous forest was enormous. Upland coniferous forest in road density dramatically increased 0.0019 km/ha to 0.0121 km/ha, and the change was by approximately 537%. For tree plantations in RD increased from significantly from 0.0044 km/ha to 0.0134 km/ha, and change by about 205%. Between 2000 and 2014, RD in wetland coniferous and hardwood forest increased from 0.0027 km/ha to 0.0029 and from 0.0037 km/ha to 0.0040 km/ha, respectively and both changes were by almost 8%. In addition, overall forest types in RD increased from 0.0055 to 0.0104 km/ha, and the change was by about 90% (Table 6).

Table 6. Calculation of road density (RD) for each forest and overall forest types.

	Forest Types	Road Length (km)	Area (ha)	Road Density (km/ha)
2000	Tree plantation	199.8	45141	0.0044
	Upland coniferous forest	22.0	11451	0.0019
	Upland hardwood forest	105.4	6641	0.0159
	Wetland coniferous forest	22.0	8141	0.0027
	Wetland hardwood forest	111.1	29795	0.0037
	Overall forest types	559.6	101170	0.0055
2014	Tree plantation	564.9	42135	0.0134
	Upland coniferous forest	118.8	9816	0.0121
	Upland hardwood forest	141.2	6894	0.0205
	Wetland coniferous forest	13.3	4651	0.0029
	Wetland hardwood forest	114.6	28346	0.0040
	Overall forest types	952.7	91841	0.0104
% Change				
	Tree plantation	182.7	-6.7	204.5
	Upland coniferous forest	440	-14.3	536.8
	Upland hardwood forest	34.0	3.8	85.5
	Wetland coniferous forest	-39.5	-42.9	7.4
	Wetland hardwood forest	3.2	-4.9	8.1
	Overall forest types	70.2	-9.2	89.1

DR shows how dominant roads were in the landscape. For tree plantations, mean DR decreased from 0.008 m to 0.003 m between 2000 and 2014, a change of about -63% (Table 7).

The effect of DR was more severe in the northwest, south, and central regions (Figure 11). For upland coniferous forest mean distance to nearest roads declined from 0.005 m to 0.003 m, and change was by about -40% (Table 7). In upland coniferous forest, where DR was low in 2000, DR increased its impact in 2014. DR increased most in the central region. With the increasing DR, upland coniferous forest has been divided into small patches (Figure 12). Like upland coniferous forest, upland hardwood forest (Figure 13), and wetland coniferous forest (Figure 14) DR also increased. From 2000 to 2014, the dominance of DR over wetland hardwood forest increased significantly (Figure 15). Specifically, in 2014, DR had a heavy impact on all part regions (Figure 16).

For overall forest maximum DR decreased from 0.036 m to 0.032 m from 2000 to 2014. DRs dominance over general forest types went up negatively (Table 7). Where the ecological impact of DR was low in the year 2000, the negative effects increased considerably in 2014. There is also a reduction in distance to roads in all forest types (Figure 16). For wetland hardwood forest in mean RD decreased exactly by half. Between 2000 and 2014, overall forest in mean DR decline from 0.007 m to 0.003 m, and change was by about -57% (Table 7).

Table 7. Result of Euclidean distance forest class types.

Forest Classes	2000			2014			% Change Mean
	Max (m)	Mean (m)	Std dev. (m)	Max (m)	Mean (m)	Std dev. (m)	
Tree plantations	0.035	0.008	0.006	0.021	0.003	0.003	-62.5
Upland Coniferous	0.029	0.005	0.005	0.021	0.003	0.004	-40
Upland Hardwood	0.028	0.004	0.005	0.024	0.003	0.004	-25
Wetland Coniferous	0.036	0.008	0.007	0.020	0.003	0.003	-62.5
Wetland Hardwood	0.036	0.008	0.007	0.032	0.004	0.004	-50
Overall Forest	0.036	0.007	0.006	0.032	0.003	0.004	-57.1

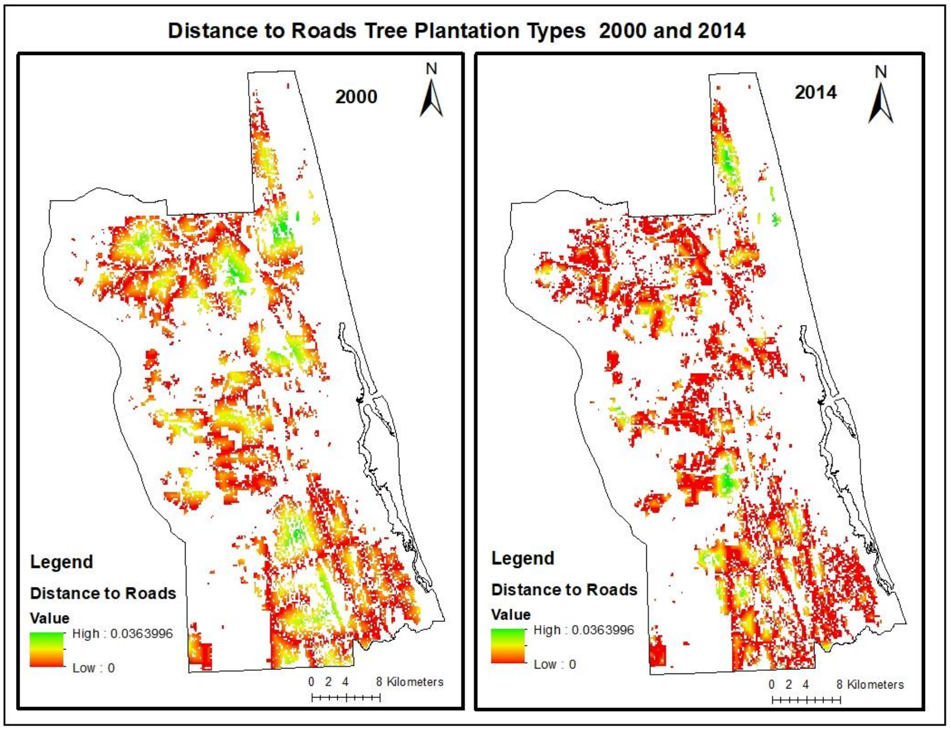

Figure 11. Euclidean distance to the nearest road tree plantations.

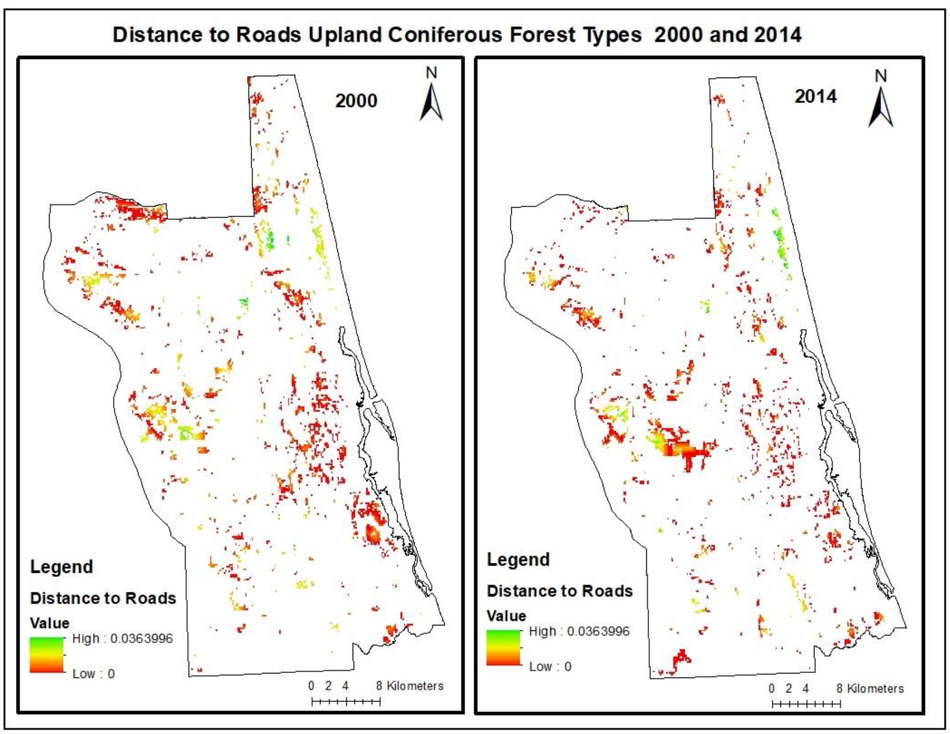

Figure 12. Euclidean distance to the nearest road upland coniferous forest.

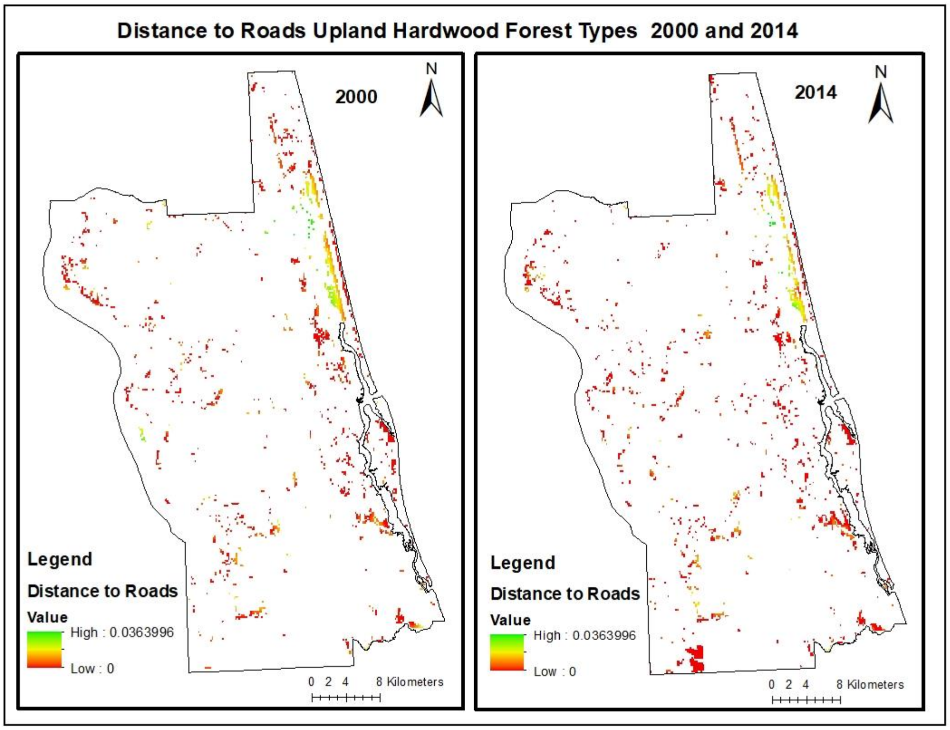

Figure 13. Euclidean distance to the nearest road upland hardwood forest.

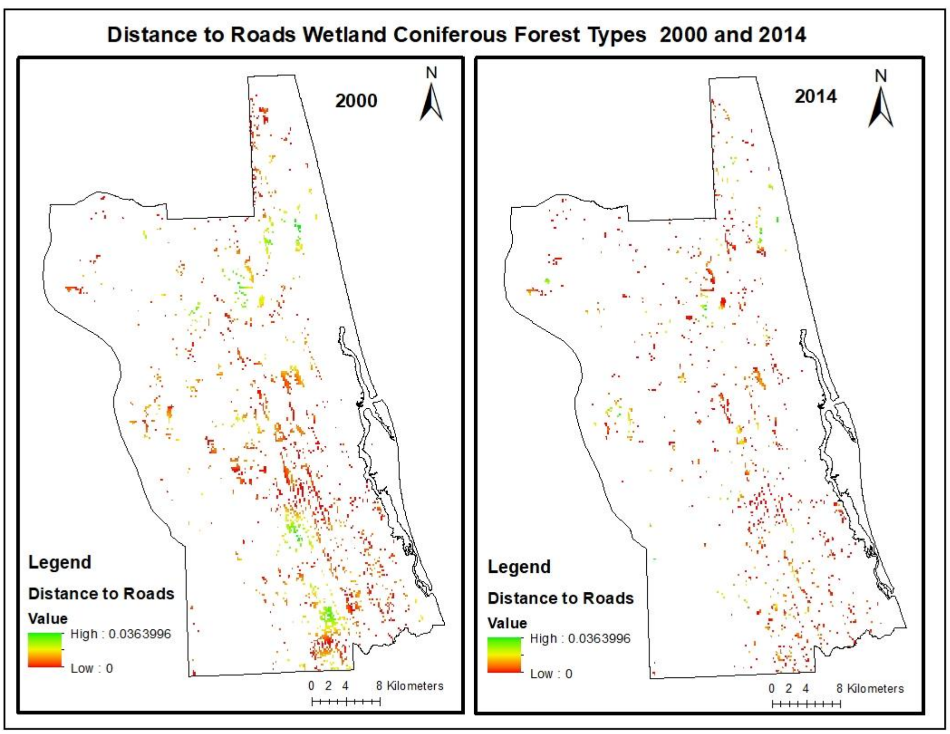

Figure 14. Euclidean distance to the nearest road wetland coniferous.

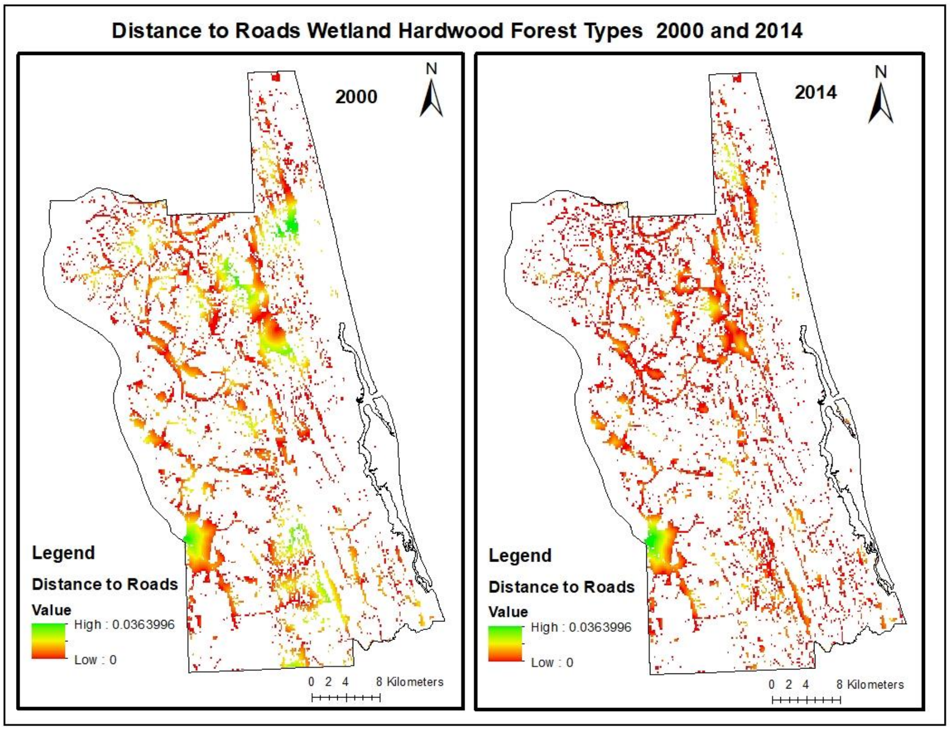

Figure 15. Euclidean distance to the nearest road wetland hardwood forest.

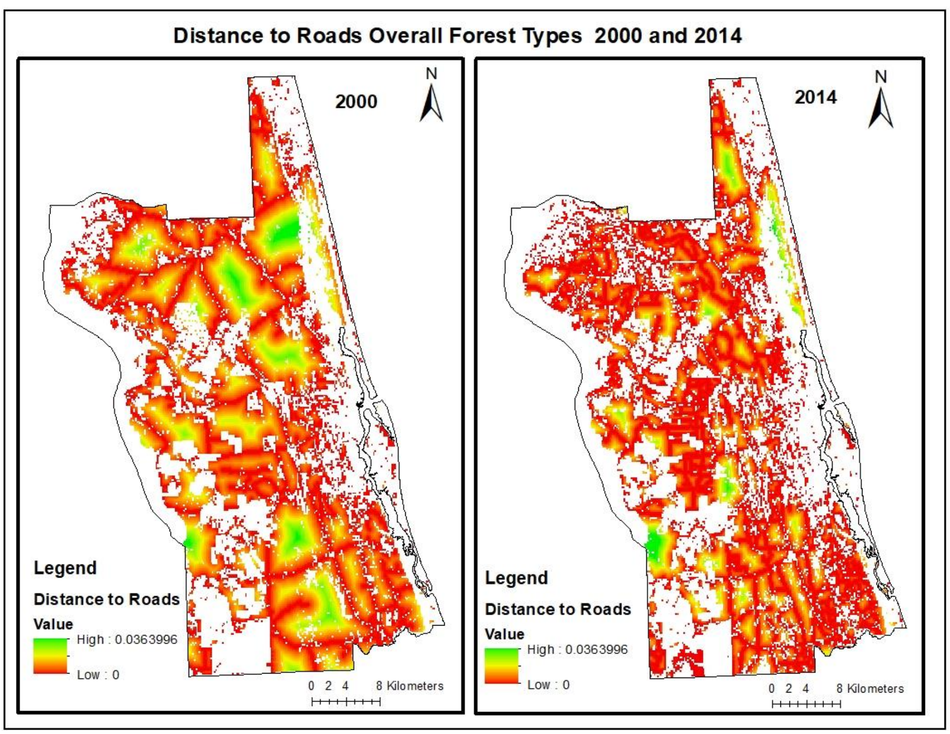

Figure 16. Euclidean distance to the nearest road overall forest types.

6.4 Assessing Relative Rates of Forest Loss and Fragmentation

Table 8 shows the ratios between the percent changes in fragmentation metrics to the percent change in habitat loss for each forest type. For tree plantations and upland hardwood forest, the number of patches changed by about 10 times the rate of habitat loss. For tree plantations and wetland coniferous forest, LPI changed by approximately 1.5 times the rate of habitat loss. However, for upland hardwood forest, LPI has changed dramatically by about 19 times the rate of habitat loss. For upland hardwood forest, edge density changed by almost 2.5 time the rate of habitat loss. For upland hardwood forest, tree plantations and wetland hardwood forest, patch density changed by about 10 times, 7 times and 5 times the rate of habitat loss, respectively. For tree plantations, upland hardwood forest and wetland hardwood forest, AREA_MN changed by about 6 times, 8 times and 4 times respectively the rate of habitat loss. For tree plantations and upland hardwood forest, SHAPE_AM changed by about 5 times and 2 times the rate of habitat loss. For tree plantations and upland hardwood forest, SHAPE_MN changed by around 2.5 times and 2 times, respectively the rate of habitat loss.

Table 8. Calculation of each forest type fragmentation / loss: number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch area (AREA_MN), area-weighted mean shape (SHAPE_AM), mean patch shape index (SHAPE_MN), and mean Euclidean nearest neighbor distance (ENN_MN)

Forest types	NP	LPI	ED	PD	AREA_MN	SHAPE_AM	SHAPE_MN	ENN_MN
Tree plantations	9.5	1.5	0.6	7.4	6.4	0.7	2.5	1.4
Upland coniferous forest	0.5	8.39	0.7	0.5	1.32	0.2	0.5	0.2
Upland hardwood forest	10.7	19.2	2.4	9.6	7.6	4.8	1.8	3.6
Wetland coniferous forest	0.3	1.57	0.8	0.3	0.8	0.6	0.2	0.3
Wetland hardwood forest	4.4	3.6	0.9	5.3	4.4	2.1	0.5	0.4

Table 9 illustrates the ratios between the percent changes in metrics to percent in road density. For wetland coniferous and hardwood forest, NP changed by about 2 times and 3 times, respectively the rate of habitat loss. For tree plantations and upland coniferous, LPI has changed by the same rate of habitat loss. However, for wetland coniferous forest, LPI changed by about 9 times of rate of habitat loss. For wetland coniferous forest, ED changed by around 4.5 times of rate of habitat loss. For wetland coniferous forest, AREA_MN, AREA_AM AND ENN_MN changed by 4 times, 3.5 times and 2 times, respectively of rate of habitat loss. In addition, for wetland hardwood, PD and AREA_MN changed by approximately 3 times of habitat loss.

Table 9. Calculation of each forest type fragmentation / loss based on road density: number of patches (NP), largest patch index (LPI), edge density (ED), patch density (PD), mean patch area (AREA_MN), area- weighted mean shape (SHAPE_AM), mean patch shape index (SHAPE_MN), and mean Euclidean nearest neighbor distance (ENN_MN)

Forest types	NP	LPI	ED	PD	AREA_MN	SHAPE_AM	SHAPE_MN	ENN_MN
Tree plantation	0.3	0.05	0.02	0.24	0.2	0.02	0.08	0.05
Upland coniferous forest	0.01	0.23	0.02	0.01	0.04	0.01	0.01	0.01
Upland hardwood forest	0.33	0.58	0.07	0.29	0.23	0.15	0.05	0.11
Wetland coniferous forest	1.9	9	4.5	1.5	4.3	3.5	1.1	1.8
Wetland hardwood forest	2.8	2.3	0.6	3.4	2.8	1.3	0.1	0.2

These two examples show habitat fragmentation between 2000 and 2014. This fragmentation increased over time and the habitat was divided into smaller areas. As the length of the road and the density of the road increased, the human influence intensified (Figure 18; Figure 19).

Figure 17. Habitat fragmentation in N Durbin Pkwy, St. Johns County (Google Earth Pro)

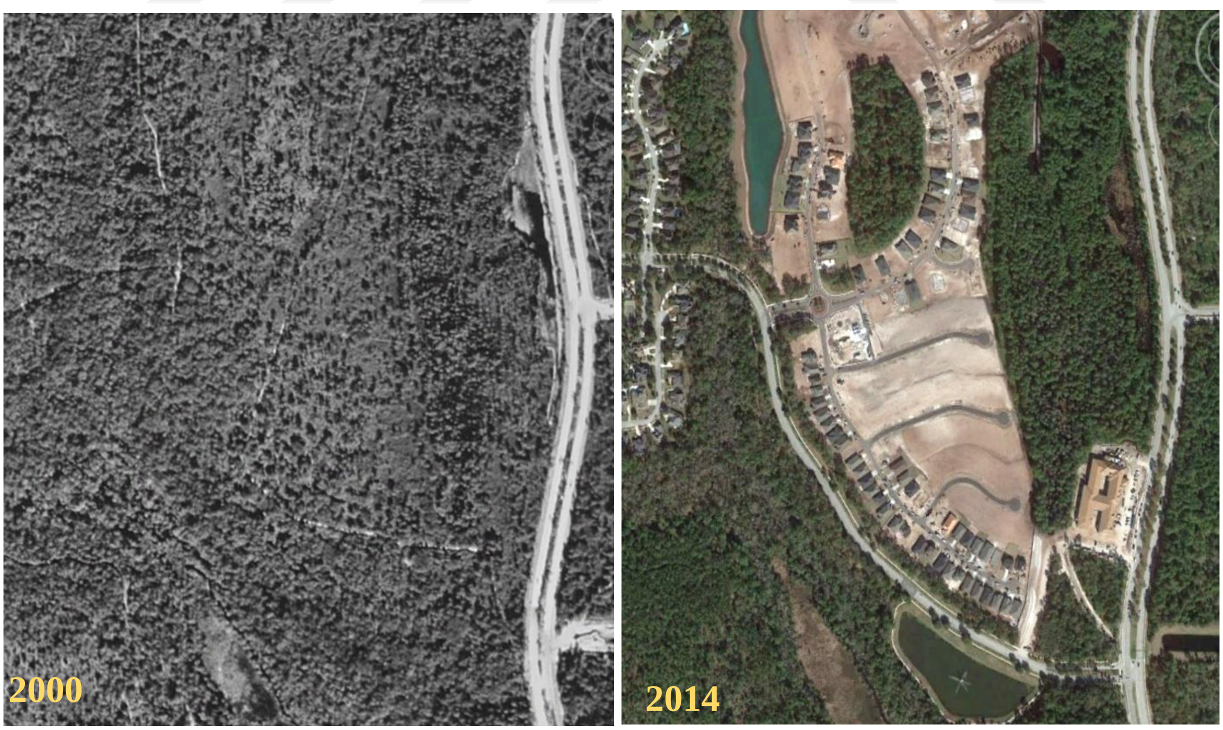

Figure 18. Habitat fragmentation in Crosswater Blvd & San Pablo Pkwy, St. Johns County (Google Earth Pro).

CHAPTER SEVEN

DISCUSSION

LULC Change

Human activities change land use patterns along a range of spatial and temporal scales. In this study, LULC, road-based metrics, and landscape metrics were combined to try to unravel forest composition and configuration. LULC dynamics is vital for fragmentation analysis to assess land use changes and the level of fragmentation in each land use over time. From 2000 to 2014 there was a decline in overall forest type areas. Forest type losses are mostly transformed into settlements. However, in LULC, especially settlements have increased and caused a change in the ecosystem due to the increase in human population in area. The population increased from 123,223 in 2000 to 217,865 in 2014, and change was 76.8 percent. Settlements are common east of Palm Valley, central of St. Augustine, south of Hastings and northwest of Fruit Cove. Wetland coniferous forests are more affected by the increase in settlements and losses are greater here. As fragmentation increased, the wetland coniferous forest became more vulnerable and biodiversity decreased. Changes in this LULC have led to a decrease in forests. Results show that forest loss and fragmentation are affected by the LULC change.

Configuration Change

The analysis of fragmentation at class level provided detailed information about the number of patches, the percentage of land use within the landscape, and other important variables that could be useful for understanding changes in fragmentation.

The increase in number of patches and decrease in mean patch size (AREA_MN) for tree plantations imply that the habitat was fragmented into a larger number of smaller patches. Decrease in LPI means that the largest patch in the county was converted, at least in part, to another type. Decline in ENN_MN shows how patches became closer to one another and more isolated.

For upland coniferous forest, increase in NP and decrease in mean patch size mean that the habitat was fragmented into a larger number of smaller patches. Increase in LPI means that the largest parch in the county was converted al least in part turn into forest patch. Increase in PD means that the habitat was fragmented and turn into smaller patches. Increased in the mean Euclidean nearest neighbor means that large sized forest patches tended to become more isolated.

For upland hardwood forest increase in number of patches and decrease in mean patch size (AREA_MN) refer that the habitat was fragmented into a larger number of smaller patches. Decrease in LPI means that the largest patch in the county was transformed, at least in part, to another type. Increase in ED refers that there are more edges and increased level of fragmentation. The decrease in ENN_MN explains how remaining patches are located further apart from one another.

For wetland coniferous forest decrease in NP and decline in mean patch size mean that the habitat was lost. Decrease in LPI means that the largest patch in the county was converted, at least in part, to another type. Increase in ENN_MN means that large sized forest patches tended to become far away and more isolated.

For wetland hardwood forest, the increase in number of patches and decline in mean patch size (AREA_MN) mean that the habitat was fragmented into a larger number of smaller patches. Decline in LPI means that the largest patch in the county was turn into, at least in part, to another type. Increase in ENN_MN means that large sized forest patches tended to become more isolated. Increase in PD implies that wetland hardwood forest converts into more smaller patches. Also, increase in ED refers that remaining patches have larger amount of edge. The increase at the edge of the forest has some effects, as the microclimatic conditions at the edge of the forest may be significantly different from these main forest areas and therefore may be favorable or unfavorable conditions for plant growth and consequently, animal populations.

Forest types are very important because some of forest trees are frost resistant, or some of them are erosion and flood resistant, and other forest trees have ability to enrich the soil. In addition, some trees have important functions especially for wildlife such as tree canopy and trunk. They find the opportunity to live on these parts of the trees. Because of these reasons, it is very important to develop different forest types and plan accordingly. In this study area, wetland coniferous and upland coniferous forest areas declined and there was easier to urbanization.

Road Change

The results of the analysis revealed substantial increases in road lengths and densities, in both forests the county overall. Increased human activity is associated with increased forest fragmentation, and where human activities are high, road density will be significantly higher and forest fragmentation will be higher in areas with high road density. At the patch level, as the road density for each forest landscape increased, patches approached the roads and more patches were intersected by roads. Roads promoted forest fragmentation by dividing large forest patches into smaller areas. Where the road density is high, access to forest areas has become faster, and more suitable for settlement. Likewise, distance to the nearest roads (DR) plays an important role in forest fragmentation. Higher values for distance to roads (DR) demonstrate less fragmented landscapes. From 2000 to 2014, the effect of (DR) on forest species increased and this increase resulted in forest fragmentation. Road density and road length directly affect the fragmentation of forest areas, and divide them into smaller areas. Generally, the length of the road increased and the Euclidean distance decreased in all forest varieties. The results of this study illustrated that areas with high road density in St. Johns County showed a significant change in forest fragmentation rates between 2000 and 2014.

For tree plantations upland coniferous and hardwood forest, wetland coniferous and hardwood forest and overall forest types, increase in road density and road length mean that on average road, forests are much closer to roads.

If people need a road, they should first make a risk assessment analysis of forest types. As can be seen in this study, wetland and upland forest types are in more danger because of their ecological aspects, because the natural forest habitat contains many different species. Given all this, the tree plantation area may be suitable for road construction. Because these areas are generally made for commercial and harvesting purposes, and the biodiversity is not very intense. Reduction in natural forest types causes many problems, such as fires, erosion and invasive species. Fragmentation affects the microclimate conditions of the forest, i.e. light, humidity, temperature and wind conditions. These changes damage wildlife animals and some trees in the forest.

Forest size and shape are important parameters in forest management. The change in size and shape mean that the area is reduced and fragmentation occurs. In St. Johns County, overall forest size and shape have decreased, and they turn into small patches. The reduction in shape and size limits the range of motion of animals and causes them to migrate from their natural environment. Increasing road density and road length have changed the size and shape of the forest, and divided the forest area into smaller parts in St Johns County.

Loss and Fragmentation

According to the resulting ratios comparing percent changes in habitat fragmentation to habitat loss, results changes in habitat fragmentation are much larger than expected based habitat loss. Increase in settlements and road construction either caused habitat loss or fragmentation. According to the results, habitat fragmentation is occurring at much larger rate than habitat loss based on the number of patches where tree plantations and upland hardwood forest were planted. In addition, habitat fragmentation is occurring at a much larger rate than habitat loss based on LPI where upland hardwood forest areas were cultivated. This shows that upland hardwood forest areas dramatically divided into smaller patches. For upland hardwood forest, habitat fragmentation was seen more greater than habitat loss based on patch density, and followed by tree plantations and wetland hardwood forest. For tree plantations, upland hardwood forest and wetland hardwood forest, habitat fragmentation is much larger than habitat loss based on AREA_MN rate.

According to the resulting ratios comparing percent changes in habitat fragmentation to road density, the fragmentation metrics are very similar to the road measures. This suggests changes in road density explain patterns of forest fragmentation. According to the results, habitat fragmentation is occurring at much larger rate than habitat loss based on the number of patches, LPI and mean patch size where wetland coniferous and hardwood forest were planted. This demonstrates that wetland coniferous and hardwood forest converted into small patches. Furthermore, habitat fragmentation is occurring at a much larger rate than habitat loss based on PD and ENN_MN where wetland coniferous and hardwood forest areas were grown.

Finally, forest harvesting likely has impacted the results. Some forest types, especially plantations, were converted to shrubby or herbaceous vegetation, which suggests they may have been harvested. In those cases, it is likely that the calculated losses are not habitat losses but rather changes in forest successional stages. Similarly, the results showed that some forest types were converted into other forest types. This could also be due to harvesting or other changes in forest succession. Because of that, this study probably overestimates the loss of particular types of forests.

Implications

Forest habitats have significant importance for the sustainable environment. Decreases in forest habitat will reveal environmental, social and economic problems. Biodiversity of habitat will reduce, and as a result of this, invasive species will take place in the forest. In addition, the ecosystem health will rapidly decrease and variety of animal species will replace to invasive species or the lost. Also, the quality of water will change negatively, and water scarcity will occur in many areas. Soil quality of field will reduce, and the drainage of soil will decrease, so soil erosion and land slide will occur in these environments. Moreover, forests play a very important role in the absorption of carbon gas, therefore forests play an important role in the fight against climate change. Forests help to manage micro climate conditions. Forest provide timber, firewood, and other forest products so people who have benefit from those will be affected economically. If the impact of roads on the forest increases, it causes habitat loss, fragmentation and isolation. Roads reduce habitat quality, damage the wildlife population, cause the roadkill and prevent accessibility to resources on the other side. Increasing fragmentation of remaining forest will cause losing recreation places and dramatically have many affects such as losing social activities, ecotourism, and educational tours opportunities.

This study will help raise awareness among people so that roads can be built while minimizing harm to the natural environment. With the increasing human populations, county officials will continue to build new roads, so this research will provide important guidelines about where to establish new roads and how to protect the environment. This research can help county authorities to make a plan such as calculate metrics for different scenarios and choose one with minimal impacts. This county may still have forests, but it is not difficult to predict what will happen after twenty years with increasing population and road density. This research could encourage county managers to make sustainable forestry planning for a healthier environment in the future. The study may provide an essential basis for holistic thinking on the need to protect the rapidly fragmenting forests.

Planners or government officials could come up with mitigation strategies in order to reduce effect on wild life. For instance, one way to effectively reduce roadkill is to build wildlife corridors, tunnels, and fence which will help animals to travel across roads. Besides, for protecting natural forests, they can plan zoning areas which will help to protection of specific forest areas. This can also support with policies such as most vulnerable areas can be under the government management, not private owners.

Limitations

Habitat fragmentation and loss occur because of several reasons, and this study only focuses mostly on land conversation and roads. First, the road data analyzed only for 2000, 2006, and from 2010 to 2014. The road data for other years were unavailable. This research was unable to properly analyze in which years road length was decreased in this area. Additionally, this study did not consider road types or traffic volumes which are important factors in understanding the impacts of roads on ecosystems.

Similarly, the LULC data were used only 2000 and 2014, between these years, the LULC data was not found. This research would be better if the other years and each LULC change was measured and mapped in order to understand when changes occurred. Also, there was no up to date LULC data for St. Johns County, so this research was unable to find when changes occurred in this area.

Moreover, the data classification is unknown, because the tree plantation classifications were not described clearly. Tree plantations might have been included both coniferous, or hardwood forests. Erroneous classifications might be occurred since they might have similar species. This can affect the measurement of habitat fragmentation and loss in forest area. The information about forest where habitat fragmentation and loss occurred were not identified as private and public. Also, misclassification of forest or changes in forest succession cause difficulty of analyzing habitat forest and loss. Some researchers might also have difficulty to understand forest fragmentation in this kind of areas because people may not know that each forest type has a separate function and structure, which provide balance to the environmental factors.

In addition, Modifiable Aerial Unit Problem (MAUP) have impacted this study. The result might change for different scales. The spatial analysis of forests and road might be affected by the grain, or resolution of the data, or might be affected by the extent of the area. The LULC data was converted polygon to raster, so this might cause some data value loss in St. Johns County as well.

Future Study

Future research might minimize forest fragmentation with developing GIS methods to better plan development of settlements and roads. Future research may investigate the abiotic effects of roads. Roads are not only cause habitat fragmentation, but also cause hydrology, air pollution, dust and sand, heavy metal, and gases. The further research may focus on these impacts and their effect on both human and ecological health. Future study can also analyze as a result of habitat fragmentation effects on human life.

This study was analyzed effect of roads on forest fragmentation, so future studies may also analyze roadkill animal and wildlife habitat in St. Johns County. Planners might improve structure of ecological tunnels, wildlife corridors, and fences based on this study. Future study may expand on larger areas such as other counties of Florida or other states.

Future researchers might consider other effects of forest fragmentation and loss. For example, future research might focus on quality of soil. In this study, some of landscape metrics and road-basic metrics were used, so further study might include other metric for analyzing road effects on forest.

Furthermore, planners or governments might focus on improving policies, or making new policies about reducing road effects on not only forest but also for all habitats. The policy makers may improve laws to prevent private forest owners to sell their land without knowledge of forest conditions.

CHAPTER EIGHT

CONCLUSIONS

LULC change detection and road-based metrics analysis are beneficial tools for addressing the amount and location of change, and also using ArcGIS and FRAGSTATS to compare changes in matrices over the specified run time. In this research, we first analyzed LULC dynamics over two periods and found that settlements increased over time. Settlements remarkably went up in the research period, while forest types illustrated a decrease. The results from the analysis provide a clear definition and are therefore useful for measuring forest fragmentation. The results of the analysis show significant differences in forest fragmentation in St. Johns County from 2000 to 2014 with trends indicating increasing forest fragmentation and connectivity. This information is useful in developing appropriate forest management strategies to mitigate the negative effects of land use changes, particularly those caused by human activities.

We also found that fragmentation of forest was evident, indicating the partitioning of each landscape into smaller patches. One interesting finding we observed in our analysis is the fact that the number of patches for forest types dramatically increase, except wetland coniferous forest. This is mainly because isolated forest patches are slowly converted into settlement or other forest types which is a typical case in our study area. Moreover, the results also show that road length, road density and distance to roads significantly contribute to the degree of forest fragmentation in that area. Because the existence of road density accelerates people's access to natural environments and thus transforms into the settlement area. Forest fragmentation has mostly occurred in areas with high transportation routes and rapid urbanization. Given all this, forest fragmentation is affected by LULC changes and road-based metrics. Changes in the amount of these accelerate fragmentation. These changes affect the biodiversity in the natural forest area and other living organisms in the landscape. If urbanization continues to increase, there will be more fragmentation in the coming years and the county will be deprived of forests, it may face various environmental problems, and the loss of many forest types will increase further with climate change.

REFERENCES

Biodiversity Indicators Partnership. (2010). Forest Fragmentation: Identifying a biodiversity-relevant indicator. Retrieved from https://biofrag.files.wordpress.com/2012/04/bip-forest-fragmentation-report.pdf

Boston, K. (2016). The potential effects of forest roads on the environment and mitigating their impacts. *Current Forestry Reports*, *2*(4), 215-222.

Chowdhury, M., Hasan, M. E., & Abdullah-Al-Mamun, M. M. (2018). Land use/land cover change assessment of Halda watershed using remote sensing and GIS. *The Egyptian Journal of Remote Sensing and Space Science*.

City Population (n.d). ST. JOHNS County in Florida (USA). Retrieved from https://citypopulation.de/en/usa/admin/florida/12109__st_johns/

Coffin, A. W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. *Journal of transport Geography*, *15*(5), 396-406.

Daigle, P. (2010). A summary of the environmental impacts of roads, management responses, and research gaps: A literature review. *Journal of Ecosystems and Management*, *10*(3).

D'Amico, M., Ascensão, F., Fabrizio, M., Barrientos, R., & Gortázar, C. (2018). Twenty years of Road Ecology: a Topical Collection looking forward for new perspectives. *European Journal of Wildlife Research*, *64*(3), 26.

Echeverria, C., Coomes, D. A., Hall, M., & Newton, A. C. (2008). Spatially explicit models to Analyze forest loss and fragmentation between 1976 and 2020 in southern Chile. *ecological modelling*, *212*(3-4), 439-449.

Eker, M., Acar, H. H., & Çoban, H. O. (2010). Orman yollarının potansiyel ekolojik etkileri. SDÜ Orman Fakültesi Dergisi, A (1), 109-125.

European Commission Directorate General Transport (n.d). Habitat Fragmentation due to Transportation Infrastructure. Retrieved from http://www.iene.info/wp-content/uploads/COST341_final_report.pdf.

FGDL Metadata Explorer. (n.d) Search & Download Data. Retrieved from https://fgdl.org/metadataexplorer/explorer.jsp

Forman, R. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual review of ecology and systematics*, *29*(1), 207-231.

Forman, R. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., ... & Jones, J. (2003). *Road ecology: science and solutions*. Island press.

Frazier, A. E., & Kedron, P. (2017). Comparing forest fragmentation in Eastern US forests using patch-mosaic and gradient surface models. *Ecological informatics*, *41*, 108-115.

Freitas, S. R., Hawbaker, T. J., & Metzger, J. P. (2010). Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest. *Forest Ecology and Management*, *259*(3), 410-417.

Gonçalves, L. O., Alvares, D. J., Teixeira, F. Z., Schuck, G., Coelho, I. P., Esperandio, I. B., ... & Kindel, A. (2018). Reptile road-kills in Southern Brazil: Composition, hot moments and hotspots. *Science of the Total Environment*, *615*, 1438-1445.

Gökyer, E. (2013). Understanding landscape structure using landscape metrics. In *Advances in Landscape Architecture*. InTech.

Gucinski, H. (2001). *Forest roads: a synthesis of scientific information* (Vol. 509). DIANE Publishing.

Hanski, I. (2011). Habitat loss, the dynamics of biodiversity, and a perspective on conservation. *Ambio*, *40*(3), 248-255.

Hermosilla, T., Wulder, M. A., White, J. C., Coops, N. C., Pickell, P. D., & Bolton, D. K. (2019). Impact of time on interpretations of forest fragmentation: Three-decades of fragmentation dynamics over Canada. *Remote Sensing of Environment*, *222*, 65-77.

Jones, J. A., Swanson, F. J., Wemple, B. C., & Snyder, K. U. (2000). Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology*, *14*(1), 76-85.

Karlson, M. (2015). *Road ecology for environmental assessment* (Doctoral dissertation, KTH Royal Institute of Technology).

Loraamm, R. W. (2011). Road-based Landscape Metrics for Quantifying Habitat Fragmentation. Retrieved from https://scholarcommons.usf.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=4409&context=etd

Madadi, H., Moradi, H., Soffianian, A., Salmanmahiny, A., Senn, J., & Geneletti, D. (2017). Degradation of natural habitats by roads: Comparing land-take and noise effect zone. *Environmental Impact Assessment Review*, *65*, 147-155.

Mcgarigal, K., & Marks, B. J. (1995). Spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1-122.

Mech, S. G., & Chesh, A. (2014). Effects of roads on movement of displaced white-footed deermice (Peromyscus leucopus). *Journal of the Pennsylvania Academy of Science*, *88*(2), 89-94.

Newman, M. E., McLaren, K. P., & Wilson, B. S. (2014). Assessing deforestation and fragmentation in a tropical moist forest over 68 years; the impact of roads and legal protection in the Cockpit Country, Jamaica. *Forest Ecology and Management*, *315*, 138-152.

North East New South Wales (2004). Wildlife Corridors. Retrieved from https://www.environment.nsw.gov.au/resources/nature/landholderNotes15WildlifeCorridors.pdf

Ojoyi, M. M. (2014). *Analysis of vegetation fragmentation and impacts using remote sensing techniques in the Eastern Arc Mountains of Tanzania* (Doctoral dissertation).

Posada Posada, M. I. (2012). Using Landscape Pattern Metrics to Characterize Ecoregions. Retrieved from https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1059&context=natresdiss

Reading, A. Characterizing landscape patterns–conceptual foundation. Retrieved from https://pdfs.semanticscholar.org/87fe/401a94b282a1c3e1af6cd6629201fa238e89.pdf

Reddy, C. S., Sreelekshmi, S., Jha, C. S., & Dadhwal, V. K. (2013). National assessment of forest fragmentation in India: Landscape indices as measures of the effects of fragmentation and forest cover change. *Ecological Engineering*, *60*, 453-464.

Ritchie, L. E., Betts, M. G., Forbes, G., & Vernes, K. (2009). Effects of landscape composition and configuration on northern flying squirrels in a forest mosaic. *Forest Ecology and Management*, *257*(9), 1920-1929.

Roedenbeck, I. A., Fahrig, L., Findlay, C. S., Houlahan, J. E., Jaeger, J. A., Klar, N., ... & Van der Grift, E. A. (2007). The Rauischholzhausen agenda for road ecology. Ecology and society, 12(1).

Rutledge, D. T. (2003). Landscape indices as measures of the effects of fragmentation: can pattern reflect process? Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.214.5563&rep=rep1&type=pdf

Saunders, S. C., Mislivets, M. R., Chen, J., & Cleland, D. T. (2002). Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. Biological conservation, 103(2), 209-225.

Scanes, C. G. (2018). Human Activity and Habitat Loss: Destruction, Fragmentation, and Degradation. In *Animals and Human Society* (pp. 451-482).

Seiler, A. (2001). *Ecological effects of roads: a review*. Uppsala: Swedish University of Agricultural Sciences. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.556.1764&rep=rep1&type=pdf

Singh, Y. (2002). Significance of Land Use / Land Cover (LULC) Maps. Retrieved from https://www.satpalda.com/blogs/significance-of-land-use-land-cover-lulc-maps

Spellerberg, I. A. N. (1998). Ecological effects of roads and traffic: a literature review. *Global Ecology & Biogeography Letters*, *7*(5), 317-333.

St. Johns County Quick Government. (n.d). St. Johns County Quick Facts. Retrieved from http://www.co.st-johns.fl.us/County/QuickFacts.aspx

Sustaining Biodiversity. (n.d). An Ecosystem Approach. Retrieved from https://quizlet.com/15467559/ch-10-sustaining-biodiversity-an-ecosystem-approach-flash-cards/

The National Academies of SEM, (1996). Road Ecology and Road Density in Different Landscapes with International Planning and Mitigation Solutions. Retrieved from https://trid.trb.org/view/475846.

Tolessa, T., Senbeta, F., & Kidane, M. (2016). Landscape composition and configuration in the central highlands of Ethiopia. *Ecology and evolution*, *6*(20), 7409-7421.

van der Ree, R., Jaeger, J. A., van der Grift, E. A., & Clevenger, A. P. (2011). Effects of roads and traffic on wildlife populations and landscape function: road ecology is moving toward larger scales. *Ecology and society*, *16*(1).

United States Census. (n.d). Tiger / Line Shapefiles. Retrieved from https://www.census.gov/cgi-bin/geo/shapefiles/index.php

United States Census. (n.d). Parent Directory. Retrieved from https://www2.census.gov/geo/tiger/tiger2k/fl/

United States Department of Agriculture., & Readle, E.L. (n.d). Soil Survey of St. Johns County, Florida. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/florida/FL109/0/StJohns.pdf

Wójcicki, K. M., & Borowski, A. (2018). Effects of forest roads on oak trees via cervid habitat use and browsing. *Forest ecology and management*. Retrieved from https://ac.els-cdn.com/S037811271830118X/1-s2.0-S037811271830118X-main.pdf?_tid=0bdadd84-d605-467e-bf8d-c0d6c0cf30d7&acdnat=1546801333_739d939606f97c958cc4b8475d250f2b

World Population Review (n.d). St. Johns County, Florida Population 2019. Retrieved from http://worldpopulationreview.com/us-counties/fl/st-johns-county-population/.