The Pennsylvania State University

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THE EFFECTS OF OIL AND GAS DEVELOPMENT ON FOREST FRAGMENTATION AND BREEDING BIRD POPULATIONS IN THE ALLEGHENY NATIONAL FOREST

A Thesis in

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by

Margaret L. McGunegle

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The thesis of Margaret L. McGunegle was reviewed and approved* by the following:

Douglas A. Miller
Associate Professor of Geography
Thesis Advisor

Robert P. Brooks
Professor of Geography and Ecology

Erica A. H. Smithwick
Assistant Professor of Geography

Karl S. Zimmerer
Professor of Geography
Head of the Department of Geography

*Signatures are on file in the Graduate School.

ABSTRACT

Privately owned subsurface mineral rights underlie 93% of the Allegheny National Forest (ANF) and create challenges for wildlife management. The construction of well pads and road networks for the oil and gas industry fragments the forest landscape and dissects wildlife habitat. Bird species that nest, breed, and forage in a specific area are indicators of the habitat's health and biodiversity. This study examined how the oil and gas industry affected forest fragmentation in the ANF and impacted the breeding bird population from three specific habitat response guilds: edge forest, forest generalist, and forest interior obligate. The research focused on oil and gas development, but other causes of fragmentation such as road expansion were also examined.

Geospatial technology was applied to aerial imagery to measure landscape fragmentation from four time periods over the last 50 years. The landscape metrics indicated an increase in fragmentation since the late 1950s and 60s. Annual rates of change were calculated for each metric and nearly all trends also indicated an increase of fragmentation. Regression analysis was used to examine the relationship between oil and gas development and landscape fragmentation. The analysis indicated that oil and gas development could explain 42.3% of the variability of total edge in the study area. Multiple regression analysis was used to determine how much variability could be explained with a combination of fragmentation drivers. The results were able to predict at least 75% of the variability of total edge, core forest, number of patches, edge forest, and number of core patches.

The landscape metrics and the annual rates of change were compared with population demographics of the habitat guilds. The mini-routes from the 2nd Pennsylvania Breeding Bird Atlas provided data for the avian habitat guilds. The mini-routes had to be separated into full and partial routes resulting in two small sample sizes that limited the statistical significance. However, the full mini-routes proved to be much better indicators of avian response with both the landscape metrics and the annual rates of change.

Regression analysis indicated that there were not any significant relationships between the avian guilds and oil and gas development. However, some of the other landscape metrics did suggest connections between fragmentation and avian response. Forest generalist appeared to be the guild most affected by current measures of fragmentation, and edge forest appeared to be the guild most affected by annual rates of change. Overall, the guilds seemed to be more affected by annual rates of fragmentation than by current measures of fragmentation, but more testing is needed with a larger sample size of the full mini-routes.

The Allegheny National Forest offered a unique opportunity to study the effects of oil and gas development on fragmentation and breeding birds. Understanding the long term effects of fragmentation will help to inform wildlife management practices and contribute to the development of environmentally sensitive policies for natural resource extraction.

Key Words: forest fragmentation, oil and gas development, avian habitat guilds, Pennsylvania Breeding Bird Atlas, Allegheny National Forest

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Chapter 1 - Introduction

1.1 The Oil and Gas Industry of Pennsylvania

The commercial oil and gas industry traces its origins to Pennsylvania. In Titusville, Edwin Drake drilled the first commercial oil well in 1859. Murrysville, Pennsylvania claims the title as home of the world's first commercial gas well dating back to 1878. Since the mid-19th century, the industry has drilled over 350,000 wells in the Commonwealth. From 1986 to 2006, the number of reported active wells in Pennsylvania grew from 6,582 to 63,566 (*Pennsylvania Bureau of Topographic and Geologic Survey* 2008). As of July 2008, Pennsylvania had over 77,000 active oil and gas wells with 8,214 located in the Allegheny National Forest, Figure 1 (ANF GIS Data 2007; *Oil and Gas Locations* 2008). Improved access to deep gas fields through technological advancement, growing energy demands, and the expansion of mineral leases on public lands indicate a continued increase in well construction.

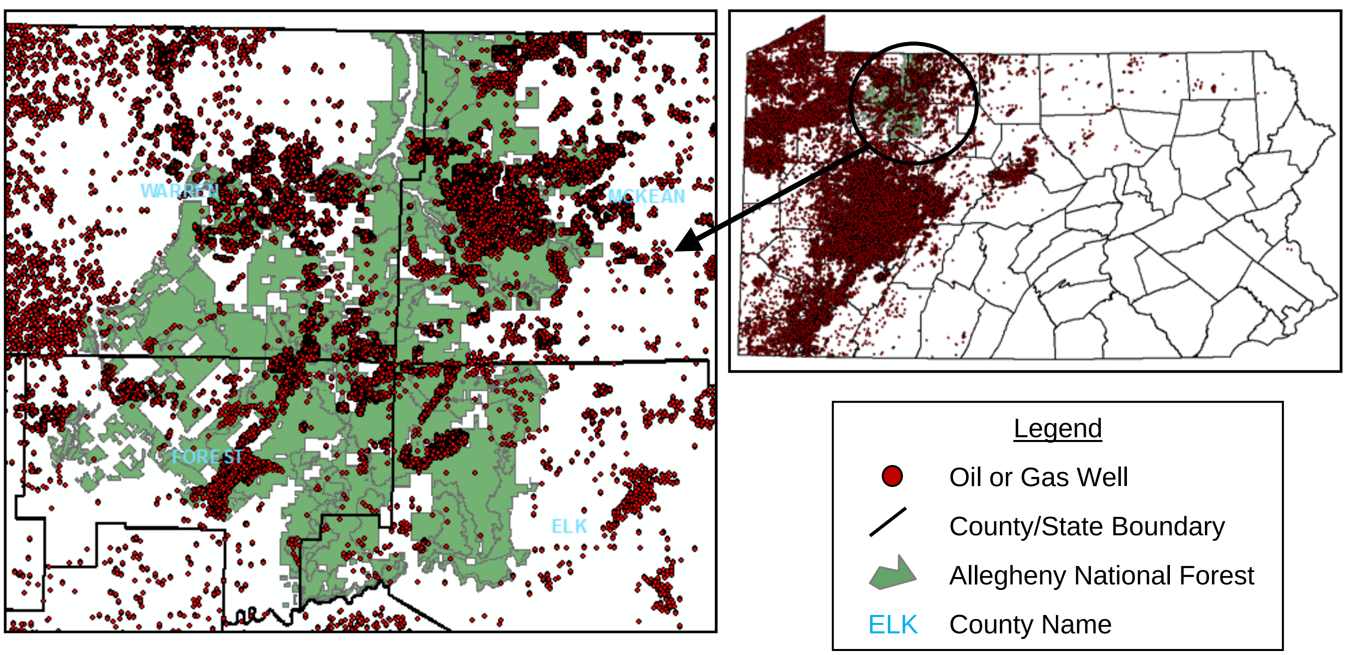


Figure 1 – Oil and Gas Wells in Pennsylvania and the Allegheny National Forest

Oil and gas development causes extensive forest fragmentation through the construction of drilling pads, road networks, and pipelines. The current regulatory guidance of the oil and gas industry in Pennsylvania does not directly address the impacts of forest fragmentation or deforestation on local ecosystems. The Oil and Gas Operators Manual of 2001, published by the Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management, does not mention planting trees or native vegetation in any of its 164 pages. Two possible reasons for not addressing fragmentation and reforestation are: (1) the Pennsylvania Oil and Gas Act of 1984 specifically addressed clean air and water standards, not wildlife habitat, and (2) wells in Pennsylvania can produce oil and gas for over 100 years making reclamation efforts impractical (*Land and Resource Management Plan (LRMP)* 2007).

To further complicate the issue of forest fragmentation, landowners in Pennsylvania do not always own the mineral rights to their land. Large timber companies were the major landowners during the oil boom of the 1860s. Without an economic interest in the subsurface, they would often sell or lease their mineral rights. Some of the current leases in Pennsylvania back date to the 1880s (*LRMP* 2007). By law, landowners must provide access to these mineral right owners and lease holders (*Landowners* 2007).

An excellent example of the split ownership between surface and mineral rights is the Allegheny National Forest (ANF), Figure 1. When the forest was established in September of 1923, it had suffered from over 100 years of unregulated logging. Few large trees were left and some of the locals called it the “Allegheny brush patch”. However, the U.S. Forest Service (USFS) decided that it could still accomplish its national forest objectives while keeping mineral and surface ownership separated. By the early 1940s, the ANF began to resemble a healthy forest (*LRMP* 2007).

Figure 2 - Fragmentation from Oil and Gas Development in the Allegheny National Forest
(photo source: PAMAP Imagery)

Only 7% or 34,973 acres of the forest's 513,256 acres of mineral rights are federally owned. The ANF leases a small portion of its subsurface rights, 6,297 acres, but only 870 acres are currently under contract. Conversely, the ANF does not own the surface rights to 4,297 acres of its mineral estate (*LRMP* 2007). Oil and gas development in the Allegheny National Forest has raised concern from conservation and wildlife organizations, and the resulting fragmentation is evident in aerial photographs as seen in Figure 2. From 1986 to 2005, 4,493 new wells were constructed in the ANF and 985 were drilled in 2006 (*LRMP 2007*).

1.2 Overview of Research

The split ownership between surface and mineral rights in the Allegheny National Forest is unique among national forests and hinders the implementation of the forest's planning and goals. The ANF must allow access to mineral right owners, but is under pressure to meet the conservation and recreation objectives expected of a national forest. To further complicate forest management, the Pennsylvania Department of Environmental Protection (PA-DEP), not the USFS, is the regulatory authority for road construction, soil erosion, sedimentation, and water quality (*LRMP* 2007). The USFS reviews development proposals and recommends mitigation measures, but rarely is able to stop or dramatically change oil and gas construction plans (Nelson 2008). Predictions for new well and road construction in the Allegheny National Forest are speculative due to the constant fluctuating oil and gas markets. Historic averages predict 3,375 wells and 1,368 kilometers (850 miles) of road added by the year 2020, but estimates based on highest yearly quarters predict 7,680 wells and 3,090 kilometers (1,920 miles) of road (*LRMP* 2007).

Fragmentation caused by oil and gas development is one of the biggest management challenges for the Allegheny National Forest. The oil and gas industry has been impacting the landscape since the forest's inception. According to McGarigal and Cushman (2002), wildlife communities may take years or decades to react to "fragmentation-induced changes in the physical landscape". However, most research about fragmentation only examines the effects over a few seasons or fails to look at a particular driver. This study examined fragmentation over the past five decades and quantified the expansion of oil and gas development.

1.3 Research Objectives

This study primarily addressed the effects oil and gas development on the Allegheny National Forest, the forest's leading contributor to fragmentation. Because the land surface is federally owned and protected, it has few other causes of fragmentation. The timber harvest is managed directly by the USFS and is practiced to maintain wildlife habitat levels. Timber production causes some deforestation, but the primary methods of harvest, thinning or single and group tree selection, cause little fragmentation. The USFS does employ some clearcutting to sustain shade-intolerant hardwood species such as black cherry, white ash, and yellow poplar. However, clearcutting contributes little to fragmentation because the USFS strictly limits its use and the openings are kept small at only 2 to 3 acres (*LRMP* 2007).

This study had two objectives. First, I examined how land cover changes in the Allegheny National Forest have affected forest fragmentation. To accomplish this, I used aerial photography and ArcGIS 9.2 (ESRI 2006) to classify the landscape from four different time periods. I measured characteristics of the landscape associated with fragmentation such as total edge and number of patches and calculated annual rates of change for each fragmentation metric. I compared the fragmentation metrics with the expansion of the oil and gas industry to determine how much fragmentation could be attributed to oil and gas development. I analyzed three other fragmentation drivers (roads, utility corridors, and transitional areas) to examine how they also contributed to forest fragmentation in the ANF.

The second objective was the comparison of current fragmentation and annual fragmentation rates with data from the 2nd Pennsylvania Breeding Bird Atlas (2nd PBBA). Annual rates of landscape metrics will capture dynamic change over a long period as opposed to current measures of fragmentation which are snapshots in time. The information from the 2nd PBBA was organized into three avian habitat guilds: edge, forest generalist, and interior forest obligate. I analyzed the avian data to determine if variations in the guild demographics were related to oil and gas development. I hypothesized that annual fragmentation rates are more indicative of variations in guild populations across the Allegheny National than current snapshot measurements of fragmentation.

Chapter 2 – Literature Review

2.1 Forest Fragmentation

The publication of *The Theory of Island Biogeography* advanced the scientific study of landscapes and habitat fragmentation (MacArthur and Wilson1967). From this book came the “island effect” theory that attributes an island’s ecological diversity primarily to size and isolation. Although the theory was originally developed for oceanic islands, ecologists soon applied it to isolated patches of habitat. Whitcomb et al. (1981) applied the theory to patches of forest in central Maryland to examine the effects of forest fragmentation on bird populations. Before this study, most research on terrestrial patches focused on uniquely isolated communities such as caves or alpine environments. Whitcomb’s work on eastern deciduous forests was one of the first to address the role of humans on fragmentation and their impacts on the natural landscape.

The 1980s and 90s saw an expansion of habitat fragmentation studies (McGarigal and Cushman 2002). With this increase in research came a broad application of fragmentation terminology, and many ecologists fear the term has became a euphemism for any landscape alteration (Fahrig 2003; Lindenmayer and Fischer 2006). For this study, I used the McGarigal and Cushman (2002) definition that defines habitat fragmentation as “a landscape-level process in which a specific habitat is progressively subdivided into smaller and more isolated fragments”. This definition separates habitat fragmentation from habitat loss. Although loss and fragmentation are linked, they are two different ecological processes and should be differentiated and measured separately (Fahrig 2003).

2.2 Challenges for Wildlife Management

The study of habitat fragmentation is a recent addition to the field of ecology and presents some distinct challenges for wildlife management (Villard 2002). It is difficult to correlate fragmentation with biodiversity because it has a much weaker negative effect than habitat loss (Fahrig 2003). Recent research suggests that patterns of landscape fragmentation have a much stronger impact on wildlife than the overall amount of landscape change (Fahrig 2002; Turner 2005). Higher rates of fragmentation can actually increase patch connectivity and thus wildlife range and territory. For example, large patches of isolated forest have a lower rate of fragmentation, but are not as well connected as a collection of small closely, spaced patches. However, each species perceives patch connectivity at different scales based on individual range and habitat requirements (Tischendorf and Fahrig 2000).

Establishing management guidelines for fragmentation is problematic because the effects are very dependent on scale, type of species, and ecological condition (Villard 2002). Also, long term effects of fragmentation are not well known or often studied. Turner (2005) gives examples of landscapes showing effects of disturbances dating back 2,000 years. Despite the complexity of habitat fragmentation, there is a need to quantify and establish relationships between pattern and process for conservation planning (Tischendorf and Fahrig 2000; Turner 2005).

2.3 The Effects of Oil and Gas Development

Few studies have been published on the effects of oil and gas development on habitat fragmentation. There has been some research on the oil and gas industry in the

American West (Lyon and Anderson 2003; *Habitat Fragmentation from Roads* 2006), but arid grasslands are a much different habitat than the temperate forests of Pennsylvania. Most of the literature linking oil and gas expansion to forest fragmentation is based in the western boreal forests of Alberta, Canada.

Alberta has extensive oil and gas reserves. The annual land cleared for development is twice that of timber production (*The Boreal Forest Natural Region of Alberta* 1998). Two recent studies examined the effects of habitat edge on Alberta's forest bird species and produced results inconsistent with predictions (Machtans 2006, Villard et al 2007). In both studies, the avian communities showed a relatively neutral response to the creation of forest edge. The major limitation of both studies and the probable cause of the neutral response was the short, two to three year, duration of the study period. The birds did not respond to the effects of forest disturbance over the study's course of just a few years. An avian community can take decades to adjust to habitat changes (McGarigal and Cushman 2002; Turner 2005).

2.4 Indicator Species and Avian Habitat Guilds

Wildlife experts are concerned about the effects of forest fragmentation on the health of local ecosystems. To assess the ecological condition of an area, ecologists often monitor a specific set of wildlife known as indicator species (O'Connell et al. 2000). A population change in an indicator species often relates to an alteration or adjustment in a particular habitat. For example, the Allegheny National Forest uses four specific species (timber rattlesnake, cerulean warbler, mourning warbler, and northern goshawk) and aquatic invertebrates as management indicator species to provide habitat data about the effects of forest management decisions (*LRMP* 2007).

Breeding birds are used as indicators because they can be easily identified and sampled and are especially sensitive to habitat change (O'Connell et al. 2000). A common approach to assess habitat health using birds is to categorize avian species into specific habitat response guilds. Root (1967) initiated the modern use of the avian guild concept in his study of the Blue-Gray Gnatcatcher and defined a habitat guild as "a group of species that exploit the same class of environmental resources in a similar way". Whitcomb et al. (1981) did not specifically use the term, "guild", but did categorize bird species into one of four major forest habitats: forest-interior specialists, interior-edge generalists, edge species, and field-edge species.

Avian habitat guilds are used as ecological indicators because a guild will exhibit a population response to the disturbance of a resource such as food or nesting location (Croonquist and Brooks 1991; O'Connell et al 1998; 2000). The strength of a guild's composition is often indicative of the ecological health and abundance of its respective habitat. O'Connell et al. (1998) expanded the guild concept by developing a Bird Community Index (BCI). The BCI represented a response guild designed to respond to selected stressors. They conducted the research with the EPA's Environmental Monitoring and Assessment Program (EMAP) to study the ecology of the Mid-Atlantic Highlands. The BCI ranked bird communities using a combination of behavioral and physiological response guilds. The research successfully linked response guild presence to an independent ranking of landscape disturbance.

Ecological research supports the use of existing bird data to assess the ecological condition of a landscape. Pidgeon et al (2007), O'Connell et al. (2007), and Bishop (2008) all used data from the North American Breeding Bird Survey (NABBS). Pidgeon et al. examined data from 3,420 NABBS routes to successfully link the diversity of eight avian forest guilds with housing patterns across the USA. The research demonstrated how residential land cover and housing density could be used to predict the richness of bird species. The O'Connell et al. study concluded that the NABBS was a suitable data source to evaluate broad scale ecological regions. Bishop used three NABBS routes from western Pennsylvania to link avian guild response with fragmentation change. Bishop and Myers (2005) and Bishop (2000) applied data from the 1st Pennsylvania Breeding Bird Atlas to explore the relationship between avian habitat guild selection and spatial landscape patterns. Both studies indicated a significant relationship between avian habitat selection and landscape properties.

2.5 Measuring Landscape Fragmentation

FRAGSTATS is one of the most common software packages used to quantify landscape pattern. Myers and Bishop (2005), Bishop (2000, 2008), Pidgeon et al. (2007) all used the program to analyze landscape patterns. FRAGSTATS was originally developed by McGarigal and Marks (1995) for the United States Department of Agriculture. The software calculates a broad range of landscape metrics from categorical map patterns. McGarigal et al. (2002) define landscape metrics as "algorithms that quantify specific spatial characteristics of patches, classes of patches and entire landscape mosaics". FRAGSTATS can analyze the landscape at the patch, class, or landscape level and calculate over 100 different metrics. Because of the large number of landscape measurements available, it was beneficial to identify metrics used in similar studies to help focus my research efforts.

O'Connell et al. (2000), Myers and Bishop (2005), and Bishop (2008) used the statistical software package, Minitab (2003), to narrow their FRAGSTATS calculations to a set of 6 to 9 metrics to represent each avian response guild. Many FRAGSTATS metrics are highly correlated which allows for the selection of a much smaller set of metrics to represent the properties of the landscape (Riitters et al. 1995). For the purposes of my study, I analyzed the 6 to 9 metrics for each guild along with additional variables identified in habitat edge and landscape connectivity literature (Tishendorf and Fahrig 2000; Ries et al. 2004). I eliminated metrics that were of little relevance to oil and gas development in the Allegheny National Forest such as mean elevation and percentage of urban land. Table 1 is a summary of the remaining 11 metrics and their associated guilds. I used this table as a guideline along with Minitab to narrow the FRAGSTATS' metrics into a set that was relevant to my research. Metric selection is further discussed in section 3.8.2.

Table 1 – Landscape Metrics Representing Avian Habitat Guilds from Previous Research

Avian Guild	% Forest	Mean Patch Size	% Core Forest	Patch Area Range	# of Patches	Patch Cohesion Index	Patch Density	# of Core Patches	Average Depth Index	Total Edge	Edge Density
Forest Interior	X (2, 4)	X (1)	X (1, 3)	X (5)	X (2)	X (5)	X (5)	X (3)	X (3)	-	-
Edge Habitat	X (2)	-	-	-	X (2)	-	-	-	-	X (3)	X (3)
Forest Generalist	X (2, 4)	-	-	-	-	-	-	X (3)	X (3)	X (3, 4)	-

(1 = Bishop 2008; 2 = Bishop and Meyers 2005; 3 = Ries et al. 2004; 4 = O'Connell et al. 2000; 5 = Tischendorf and Fahrig, 2000)

2.6 Limitations of Previous Research

There are three major limitations found in previous studies linking avian response to landscape change or fragmentation. First, there is the issue of spatial scale. Myers and Bishop (2005), Bishop (2000, 2008), and Pidgeon et al. (2007) used land cover based on the 30m x 30m pixels of the Landsat imagery. The coarse resolution of Landsat imagery combines land cover into one dominant classification and eliminates small forest patches and distorts edges. Landsat imagery is applicable to specific drivers of fragmentation that can be depicted in 30m x 30m pixels such as in Pidgeon's analysis of housing density. However, the fine network of oil and gas development would be lost in Landsat imagery. My research addressed this limitation by using aerial photography with a much smaller pixel size ranging from 0.3 to 3 meters.

The next limitation of previous research was the use of semi-automated image classification (Bishop 2000; Myers and Bishop 2005) or existing land cover classifications such as the National Land Cover Datasets (Bishop 2008, Pidgeon et al. 2007). When using existing land covers, the classification often has to be reinterpreted to define the land cover of interest. In all of the aforementioned studies, the classification used a combination of supervised and unsupervised approaches for classifying coarse resolution imagery. These techniques produce a higher rate of error in land cover classification. I addressed this limitation by conducting on screen digitizing on all of the imagery in my study area. This allowed me to minimize error and also tailor the classification scheme to the scope of my research.

The last major limitation was the analysis of landscape change and avian response over the course of just a few years. Studies that specifically examined the effects of oil and gas development on forested landscapes were short-term and only examined data from a two to three year time period (Machtans 2006, Villard et al 2007). My research used historic aerial imagery to examine fragmentation over the last 50 years, and examined how both current fragmentation and long term trends of fragmentation affected the current density and distribution of breeding birds.

Chapter 3 - Methods

3.1 Overview of Methods

The following section comprises a description of the methodological approach of the research. I used existing data sources and did not conduct fieldwork for data collection. Therefore, the sources of information and their acquisition will be explained. I also describe how I narrowed my focus to specific areas of the Allegheny National Forest. I detail how I used historic aerial imagery to analyze fragmentation change through time and applied the results to avian habitat guilds. The goals of this section are to present an understanding of the methodology and provide enough detail to allow the approach to be adapted to similar studies in other locations.

3.2 Site Selection in the Allegheny National Forest

The Pennsylvania Breeding Bird Atlas is divided into a grid of 4,937 blocks. Each atlas block is approximately 24 square kilometers (9.27 square miles). There are 157 atlas blocks that contain some part of the Allegheny National Forest (Figure 3). However, because of the forest's numerous private inholdings, many blocks only contain a fraction of the ANF.

This study will only include atlas blocks with a minimum surface coverage of 85% federal land (Figure 3). I made this decision for three reasons: (1) examining the entire forest of over 202, 300 hectares (500,000 acres) exceeds the scope and resources of my project, (2) selecting blocks with a high percentage of federal land highlights the ANF's unique split ownership of surface and mineral rights, and (3) blocks with 85% coverage were well dispersed spatially and across various densities of current oil and gas development. Based on the above criteria, 29 atlas blocks were selected yielding 94% federal land coverage, and an area of 65,648 hectares (162,219 acres) or about 30% of the Allegheny National Forest.

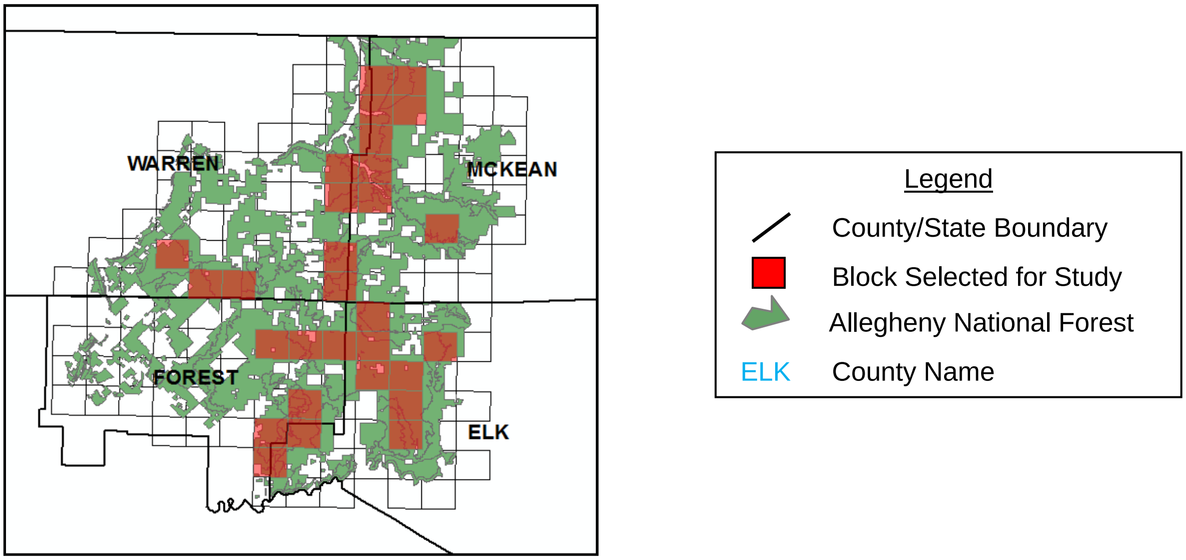


Figure 3 – Atlas Block Selection of the 2nd Pennsylvania Breeding Bird Atlas in the Allegheny National Forest

3.3 Habitat Guild Selection

To examine the effects of forest fragmentation on wildlife habitat, I originally selected the four avian habitat guilds developed by O'Connell et al (1998) during the EMAP study: edge forest, grassland, forest generalist, and forest interior obligate. I selected these guilds because I thought they represented the primary habitats of the Allegheny National Forest and correlated well with the forest's land cover. However, after receiving the mini-route data from the 2nd Pennsylvania Breeding Bird Atlas, I discovered that none of the 2026 records was a grassland species. Therefore, I eliminated the grassland guild and focused on the three forest guilds, Table 2. The list of species for the forest generalist and the interior forest obligate guilds were taken from the EMAP study (O'Connell et al. 1998). The lists of species for the edge and grassland guilds were not included in the EMAP study and were taken from Goodrich et al. (2002). The lists of species for each guild (including grassland) are found in Appendix A.

Table 2 – Breeding Bird Habitat Guild Selection
(source: O'Connell et al. 1998)

Habitat Guild	Brief Description
Edge Forest	Prefers shrub dominated or transitional areas at forest margins, commonly found in urban areas
Forest Generalist	Uses interior or edge forest and does not prefer one over the other
Interior Forest Obligate	Avoids forest edge and prefers interior forest or core areas of larger forest patches

3.4 Avian Data Sources

The 1st Pennsylvania Breeding Bird Atlas was compiled from 1983 to 1989 by more than 2,000 volunteers. The use of volunteers created inconsistencies and inaccuracies in the first atlas and contributed to the addition of the mini-routes to the second atlas. The mini-routes were the data source for the avian habitat guilds. The purpose of the mini-routes was to accurately sample the avian species in each atlas block using a consistent method and scale (2nd PBBA).

The mini-routes originally consisted of eight geospatially referenced and randomly selected points per atlas block. To complete a mini-route, a trained participant compiled a list of species over five successive time periods of 1.25 minutes at each point. The points were spaced at least 0.80 kilometers (0.5 miles) apart and were located far enough from the edge to eliminate overlap with adjacent blocks (2nd PBBA). Because most birds were identified by sound and not observed in an exact location, each bird cannot be given a specific geographic coordinate. Instead, the cumulative result of each mini-route represents the bird species of that block. For this reason, the mini-routes should not be subdivided. They should only be analyzed in their entirety to represent the avian demographics of their respective atlas block.

I grouped the mini-route data from the 2nd Pennsylvania Breeding Bird Atlas into the three avian habitat response guilds using the lists of bird species found in Appendix A. For each block, eight avian population metrics were created. This included the overall number of birds and species for each block and the number of birds and species from each habitat guild: edge forest, interior forest, and forest generalist.

The collection of data was spread over the five years of the 2nd PBBA, 2004 to 2008. During the summer of 2007, the protocol for the mini-routes was changed to collect data as accurately as possible with remaining time and resources. The discovery of this change of protocol caused me to alter my methodology. Instead of comparing all of the mini-routes and the fragmentation of their respective blocks together, I separated the routes based on the quantity of recorded data.

All of the routes with less than four roadside points were labeled incomplete and were not used in any further analysis. Routes with four to six points were labeled as partial and routes with seven or eight points were considered complete. I then analyzed the partial and full routes separately. The roadside points for each breeding bird atlas block are shown in Figure 4. The complete mini-route data and each route's status can be found in Appendix B.

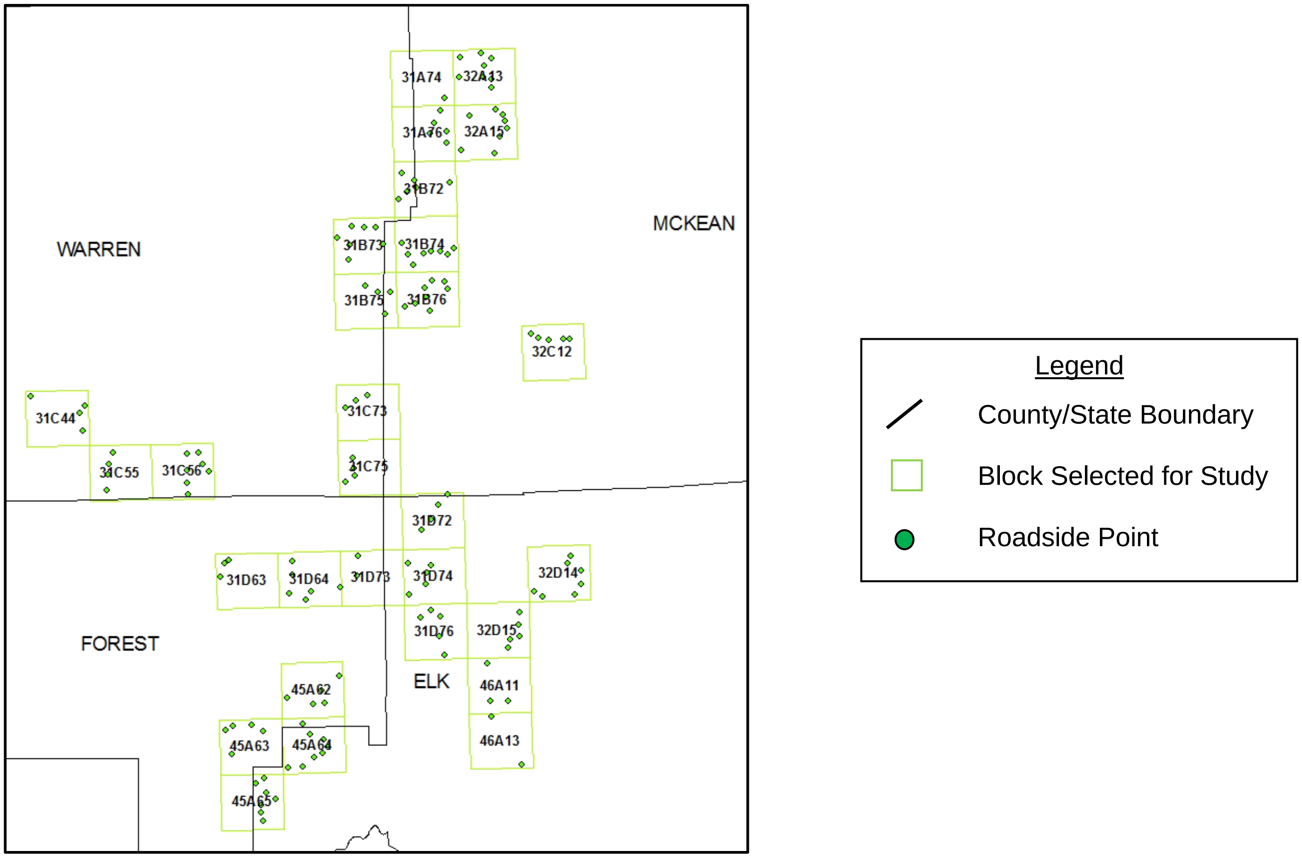


Figure 4 – Breeding Bird Atlas Blocks and Mini-Route Roadside Points

3.5 Database of Oil and Gas Wells

The Pennsylvania Bureau of Oil and Gas Management publishes a spatially-referenced data layer of oil and gas wells every 90 days (*Oil and Gas Locations* 2008). This data is available for free download from the Pennsylvania Spatial Data Access (PASDA). This file is an excellent source of georeferenced information, but has two shortcomings. The data layer only lists active and recently inactive wells and does not include well drill dates. The Pennsylvania Bureau of Topographic and Geologic Survey (PA-BTGS) maintains a georeferenced archive of all wells drilled in the Commonwealth since the late 1880s complete with known drill dates. However, this reference does not always list the most recently drilled wells.

Upon request, I received a report of all the oil and gas wells drilled in Elk, Forest, McKean, and Warren counties from PA-BTGS (Imbrogno 2008). To compile a complete database of all wells with drill dates, I made the archive from the PA-BTGS into an ArcGIS shapefile. I merged the PA-BTGS shapefile with the layer from the Oil and Gas Bureau. I clipped the merged layer with the boundary of the 29 selected atlas blocks plus a 0.40 kilometer (0.25 mile) buffer to ensure the effects of wells close to the edge were included. PA-BTGS wells were given precedence in the case of duplicates because they plotted more accurately on the imagery. To remove duplicates, I exported the merged database file to Microsoft Excel 2007. I added a column in Excel called "Keep" and each well was labeled "yes" if it was a duplicate or "no" if it was not. Next, I joined the Excel "Keep" column with the original merged file using the well number to match the data. I then selected all wells that had "yes" in the keep column and saved them as a separate shapefile.

The next step was to locate missing well drill dates. First, I deleted all wells identified as "proposed" in the attribute table. Wells that had dates were saved as a shapefile called "Wells_Dates_Only" and wells without dates were saved in a separate shapefile. I used the Bureau's monthly well reports, available back to 1998, to locate missing well drill dates (*Rig Activity Report* 2008). To do this, I downloaded all of the monthly well reports and combined them into one Excel file. I then exported the database file from the shapefile of the wells without dates. I opened the database file and the file of monthly well reports in Microsoft Access 2007 and used the query tools to match well numbers and locate missing dates. The wells with located dates were merged with "Wells_Dates_Only". Based on the attributes of the remaining wells without dates, I separated them into one of two shapefiles, "No_Dates_Active_Unknown" or "No_Dates_Inactive_Abandoned."

The goal was to obtain drill dates for at least 90% of the wells in the ANF study area (including the 0.25 mile buffer). After completing the above steps, I was able to identify 4,493 drilled wells; 3,882 with dates; 449 classified as active or unknown; and 162 classified as inactive or abandoned. The percentage with dates was below the goal at 86.40%. However, not all of the wells without dates were included in the land cover classification. They were separately analyzed for each time period during the classification process and will be discussed further in section 3.7.2.

3.6 Imagery Database

3.6.1 Imagery Acquisition

The Agricultural Adjustment Act of 1933 created farm programs to help stabilize prices and balance production. The United States Department of Agriculture established the Agricultural Stabilization and Conservation Service (now the Farm Service Agency) to accurately measure and track agricultural fields. By the 1940s, rectified aerial photography had replaced bulky survey equipment and hand drawn maps once used to calculate farm acreage (*History of APFO* 2006). Except for PAMAP, the official digital map of Pennsylvania, all of the imagery used in this research originated with the Farm Service Agency (FSA).

The Allegheny National Forest is located in Elk, Forest, McKean, and Warren counties. My search for available imagery from the four counties located datasets for seven time periods: 1937 – 1942, 1948 – 1951, 1958 –1959, 1968 – 1969, 1981 & 1983, 1993, and 2005 – 2006. I decided to analyze the four most recent datasets starting from late 1960s, see Table 3. I did not include the two earliest sets of imagery because the ANF was still mostly shrubs and small trees in its first couple of decades (*LRMP* 2007) and adding two imagery sets would greatly extend the timeline of the research. An exception is Forest County which lacks the 1968 - 1969 imagery. Forest County is heavily forested with few agricultural lands for the FSA to track which may explain its omission. The 1958 -1959 imagery was used in its place.

Table 3 – Imagery Data Sets and Represented Time Periods

Image Source	Counties			
	Elk	Forest	McKean	Warren
PAMAP (2005-2006)	2006	2006	2005	2005
DOQQs/NAPP2 (1993)	1993	1993	1993	1993
NHAP1 (1981 & 1983)	1983	1981	1983	1981
PennPilot FSA (1968-1969)	1969	1958*	1968	1968

*Imagery was not taken during 1968-1969; 1958 will be used instead.

The PennPilot program and Pennsylvania Spatial Data Access (PASDA) allowed simple and free of charge access to online imagery. PennPilot is a free download site of Pennsylvania's historical aerial FSA photos dating back to the 1930s (PennPilot 2008). The imagery from the 1950s and 1960s has a scale of 1:20,000 or about 1 meter / pixel. PASDA is the Commonwealth's official geospatial data clearinghouse. Both the PAMAP and the Digital Orthophoto Quarter Quadrangle (DOQQs) images were available through PASDA. The PAMAP has the highest resolution with 0.3 meter / pixel. The DOQQs originated with the imagery of the second cycle of the FSA's National Aerial Photography Program (NAPP) and were later made into DOQQs. They have a scale of 1:40,600 or about 2 meters / pixel. Hard copies of the National High Altitude Photography 1 (NHAP1) images were available at the main campus library of

The Pennsylvania State University. The scale of the NHAP1 imagery is 1:60,000 or about 3 meters / pixel.

3.6.2 Imagery Orthorectification

The PennPilot and NAPP2 datasets were already orthorectified and ready for land cover classification. The NHAP1 and PennPilot images had to be sorted into atlas blocks and orthorectified using Orthomapper, a commercial software package designed to process aerial images (Image Processing Software Inc. 2008). Before deciding on Orthomapper, I tried simpler georeferencing techniques such as stitching images together with RasterStitch 1.91 (VextraSoft 2008) and then using the georeferencing tools in ArcMap 9.2. Combining these techniques allowed me to get an acceptable visual product, but the geometric registration of the imagery was not precise enough to compare with other time periods.

Orthomapper is unique because it orthorectifies photos using visual orientation to select control points. Visual points such as buildings and road intersections are selected on the image and the reference photo. Orthomapper logs the coordinates and rectifies the image based on the visual control points. The georeferencing tools in ArcMap are similar, but Orthomapper also drapes the image over a digital elevation model (DEM) to correct for elevation. I downloaded and used 10 meter DEMs at from the United States Geological Survey (USGS 2008). I decided to use the PAMAP imagery as the reference photos. However, the PAMAP files were too large and in a format, MrSid, that was incompatible with Orthomapper. I downloaded the MrSid Viewer from the Library of Congress website and used it to clip and convert the PAMAP files into 11 smaller TIFF (tagged image file format) images of the study area. Figure 5 is an example of a PennPilot photo before and after orthorectification.

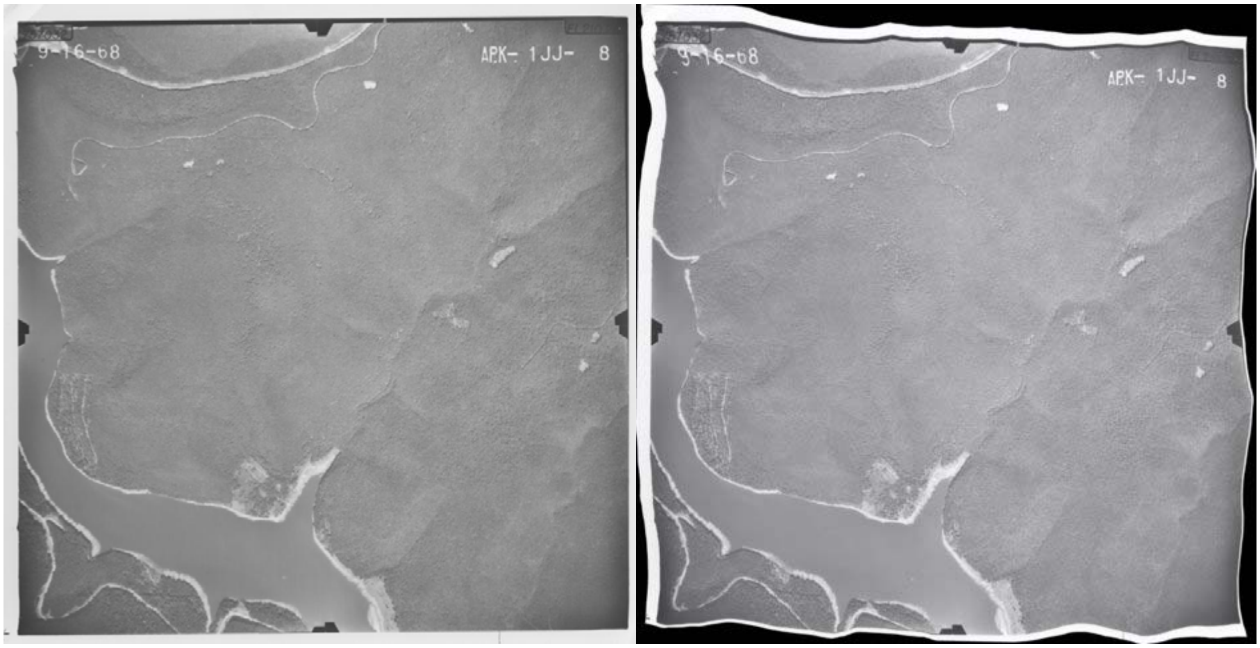


Figure 5 – A PennPilot Image Before and After Orthorectification
(source: right - PennPilot Imagery, Left – created using Orthomapper)

I started with the NHAP1 imagery and used a rudimentary photo corner map from the Penn State Library to locate all possible photos that included my study area. I scanned each photo at 1200 dpi resolution. The NHAP1 files are a relatively coarse resolution and I only needed to orthorectify 29 photos to create a complete image set of all 29 atlas blocks.

I used an existing shapefile of photo corner coordinates to locate the exact photos needed for the 1968 - 1969 PennPilot images. I downloaded the photos and placed them in separate files for each of the 29 atlas blocks. Each atlas block required between four and 16 PennPilot images depending on how the block boundaries coincided with the images. I needed to orthorectify a total of 186 photos for the 1968 –

1969 images. The 1958 Forest county images did not have a photocorner shapefile and I had to create one using a crude composite of the FSA images. I identified the 44 photos needed to complete the six remaining blocks of the PennPilot dataset and placed them in separate files.

I decided to create orthophoto mosaics at the atlas block scale instead of the entire study area for two reasons. First, orthophoto mosaics take time to correctly initialize and process. It was faster to process atlas block sized mosaics and also reprocess them if I needed to correct for small alignment errors. Second, and most importantly, not all of the images were taken on the same day for each data set. The images needed to be grouped into flight dates to facilitate land cover classification and oil and gas database queries. However, the blocks themselves could not be divided because it would prevent later comparisons with fragmentation trends and avian data. If there were different photo dates within an atlas block, the most common date was used. Blocks with dates that differed by more than a few days were checked to ensure that oil and gas development was not omitted by using the most common date.

Once the atlas block orthophoto mosaics were created, they were combined with other atlas blocks with the same flight date. The PAMAP imagery was subdivided because half of the area was flown in 2005 and half was flown in 2006. The NAPP2 was all flown in 1993 and could be stored under one date. The exact flight dates were printed on the images themselves for the PennPilot and NHAP1 images. I located flight dates in the metadata file for the PAMAP and NAPP2 imagery. Table 4 details the subsets under each time period and their exact flight dates. The PennPilot and NHAP1 orthomosaics were opened in ArcMAP 9.2 for land cover classification. The coordinate system used to project the final imagery sets was the Pennsylvania (North) State Plane Coordinate System which uses North American Datum 1983 (NAD83).

Table 4 – Time Period Subsets and Exact Flight Dates

Image Source	Exact Flight Dates	Imagery Location
PAMAP (2005-2006)	27-Apr-06	Warren and McKean Counties
	13-Apr-05	Elk and Forest Counties
DOQQs/NAPP2 (1993)	7-May-93	Complete Study Area
NHAP1 (1981 & 1983)	10-May-83	Elk, McKean, and Eastern Warren Counties
	8-May-81	Forest and Southern Warren Counties
PennPilot FSA (1958, 1968-1969)	15-May-69	Elk County
	16-Sep-68	Warren and McKean Counties
	23-Sep-58	Forest County

3.7 Land Cover Classification

3.7.1 Classification Scheme

The next part of the research process was the classification of the land cover for each time period. Most of the Allegheny National Forest is covered in forest which eliminated most urban and agricultural classes. However, 26 of the 29 atlas blocks contain private inholdings. The inholdings account for only 6% of the study area, but residential and cropland and pasture classes were included to accurately account for all land cover. The overall land cover classification scheme included nine classes. The classes were derived from *A Land Use and Land-Cover Classification for Use with Remote Sensor Data* (Anderson et al.1976).

The Anderson et al (1976) classification is a multi-level system that can be tailored for specific applications. Level I divides land use and land cover into nine general classes. Level II further breaks each class into two to seven subclasses. A brief description of Levels I and II can be found in Appendix C. The researcher defines

Level III to best describe the land use and land cover of their specific study area. Table 5 summarizes the nine classes selected for the classification of the Allegheny National Forest and also includes the precedence ranking of each land cover which will be discussed in the next section. Levels I and II are directly from Anderson et al (1976). Five of the classes were refined by adding a Level III. The Transitional Areas, Residential, and Cropland and Pasture classes were sufficient at Levels II, while the Water class remained at Level I.

Table 5 – Land Cover Classification of the Allegheny National Forest
(derived from Anderson et al. 1976)

Class	Class #	Description	Precedence
Residential	1.1	Rural residential subdivisions and housing areas	5
Oil and Gas Development	1.3.1	Oil and gas well pads, road networks, and related sites such as storage tanks	4
Roads	1.4.1	Roads except for those primarily used by the oil and gas industry	3
Utility Corridors	1.4.2	Linear corridors such as power lines	2
Cropland and Pasture	2.1	Land used for grazing or rotational non-permanent crops	6
Edge Forest	4.3.1	Forest within 100m of any other land class, except water	8
Core Forest	4.3.2	Forest at least 100m from any other land class, except water	9
Water	5	River, streams, ponds, and lakes	1
Transitional Areas	7.6	Open areas that do not fit into any other class (example: recently cleared forest)	7

3.7.2 Land Cover Classes

I used ArcMap 9.2 to create the land cover classes (ESRI 2006). I extended the area of classification to a 0.40 kilometer (0.25 mile) buffer around each atlas block to ensure the inclusion of features close to the block boundaries. I started classification with the 2006 PAMAP imagery. The imagery was flown leaf-off and it was sometimes challenging to identify forested areas. Therefore, I used the full color 2005 National Agriculture Imagery Program (NAIP) imagery to help distinguish between bare trees and open areas.

The first two land cover types classified were oil and gas and roads. First, the shapefile, "Wells_Dates_Only" from the oil and gas database was queried to identify oil and gas wells drilled before April 27th, 2006. They were saved as a separate shapefile called, "Wells_2006". Next, the attribute table of "Wells_2006" was opened to identify the most recent well number for each county. The wells numbers are assigned sequentially and wells are generally also drilled in the same order. By identifying the most recent well numbers, I could open the two well files without dates, "No_Dates_Active_Unknown" and "No_Dates_Inactive_Abandoned", and select the wells with numbers less than the most recent well numbers. It was assumed that all other wells were drilled after the imagery was taken. The selections from the two files without dates were saved as separate files. The wells in these files were all compared with the imagery to determine if they still contributed to fragmentation. If there was no evidence of the well, it was deleted. The remaining wells were added to "Wells_2006". Next, the well point data of "Wells_2006" was buffered 19.7 meters (64.5 feet) to create well pads of 0.12 hectare (0.3 acre) and saved as "Wells_2006_B" (*LRMP* 2007).

The Allegheny National Forest produced a road shapefile in 2001, ANF Travel Routes, which was used as the starting point of the road classification (ANF GIS Data 2007). I clipped ANF Travel Routes to only include the blocks associated with the 2006 PAMAP imagery and their respective 0.40 kilometer (0.25 mile) buffer. I analyzed the attributes of the data to remove recreational trails such as hiking and horseback riding. I had to add some roads because the PAMAP imagery is four to five years newer than ANF Travel Routes. Conversely, roads were deleted from ANF Travel Routes during the analysis of the three later time periods. The routes were created as line data and were buffered 5.33 meters (17.5 feet) to approximate their actual size (*LRMP* 2007). Using PAMAP imagery and the oil and gas database, I identified roads that primarily serviced the oil and gas pads and saved them in a separate file called, “OG_Roads_06”. I merged the oil and gas roads with the well pads to create the Oil and Gas Development class, “OG_06”. The buffers for all of the remaining roads were saved as “Roads_06”.

Residential and cropland pasture were the next areas that I classified. I drew polygons around the residential and cropland and pasture areas and saved the areas as “Residential_06” and “Cropland_and_Pasture_06” respectively. Any remaining open lands such as recently cleared forest or rocky areas were outlined with polygons, saved into a layer, and given the classification of “Transitional_Areas_06”. I created the water class by clipping the ANF Major Stream file and the ANF Water Bodies with a 0.25 buffer of the 2006 PAMAP blocks (ANF GIS Data 2007). I then buffered the rivers to approximate their widths and merged the buffer with the clip of the ANF Water Bodies to create, “Water_06”. The water class changed little over the periods examined in the study. However, an occasional dam or water level change would require minor edits to the shapefile. The last class created with heads up digitizing was Utility Corridors. To create the class, I drew lines along the center of each corridor and buffered each one individually to the appropriate width. The buffers were merged together to create, “Utility_Corridors_06”. I dissolved the features of each land cover class and saved each dissolved layer as a shapefile.

The next class created was the Edge Forest. In this study the edge forest was defined as forest that is within 100 meters of another class, excluding water. Previous studies demonstrated the extension of edge effects a distance of 100 meters into forested areas (Robbins et al. 1989, Goodrich et al. 2002, Bishop 2008). The individual dissolved layers except for the water class were merged together to create "SixClasses_06". I buffered the merged class 100 meters and saved it as "SixClasses_06_B". I then dissolved the features of the buffer to create "SixClasses_06_B_D". The edge forest was created by erasing "SixClasses_06" from "SixClasses_06_B_D". The remaining land cover comprised the Core Forest Class. For this study, I defined core forest as forest covered lands that are at least 100 meters from any other class except water. To create the Core Forest Class, I erased "SixClasses_B_D" from the buffer of the atlas blocks and saved it as "Core_Forest_06".

The last step of the land cover classification process was to combine the individual classes into one land cover data layer. I merged all nine classes together to create "NineClasses_06." To eliminate any overlap between land cover classes, I erased each class and merged it back with "Nine_Classes_06" in reverse order of precedence, see Table 5. Next, I clipped the final merged shapefile with the boundaries of the relevant atlas blocks, added a field to label each class, and saved the file as "Land_Cover_06". The combined land cover file was added to a map topolopy in ArcGIS 9.2 to correct any remaining gaps or overlap between polygons. To remove sliver patches, I used the eliminate function in ArcMap 9.2. I removed slivers less than 0.1 acres (4,356 square feet) and or any patch of core forest less than 1 acre (43,560 square feet). A summary of the classification workflow can be found in Figure 6.

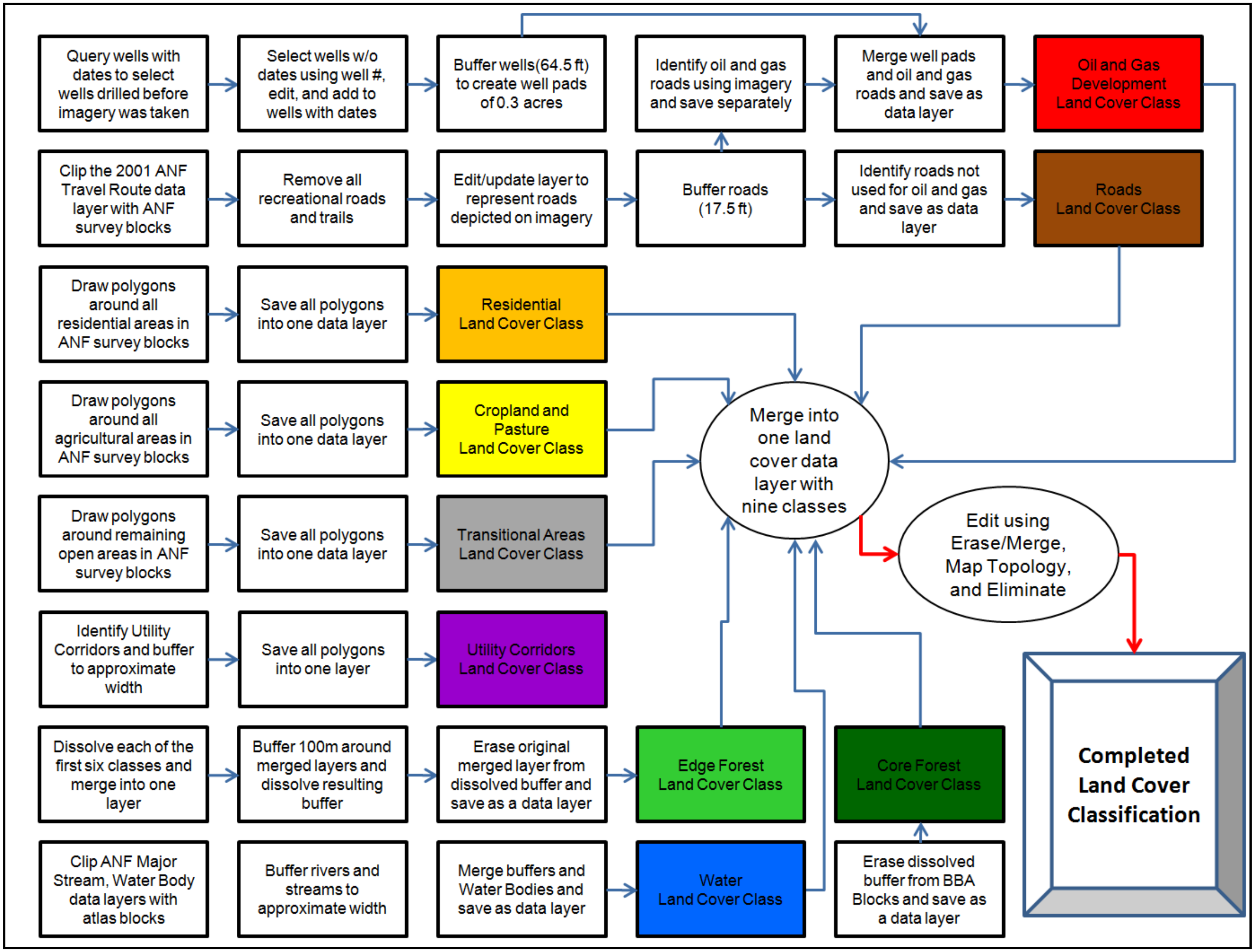


Figure 6 – Summary of Land Cover Classification Workflow

The land cover classification process was repeated for the imagery of each flight date, see Table 4. I created the land cover in order from newest to oldest. When I edited a subsequent set of imagery, I used the last set of land cover classes as a guide and edited any changes. This was faster than recreating all of the land cover classes and also maintained continuity of classification between the imagery sets. Figure 7 is an example of an aerial image and its resulting land cover classification.

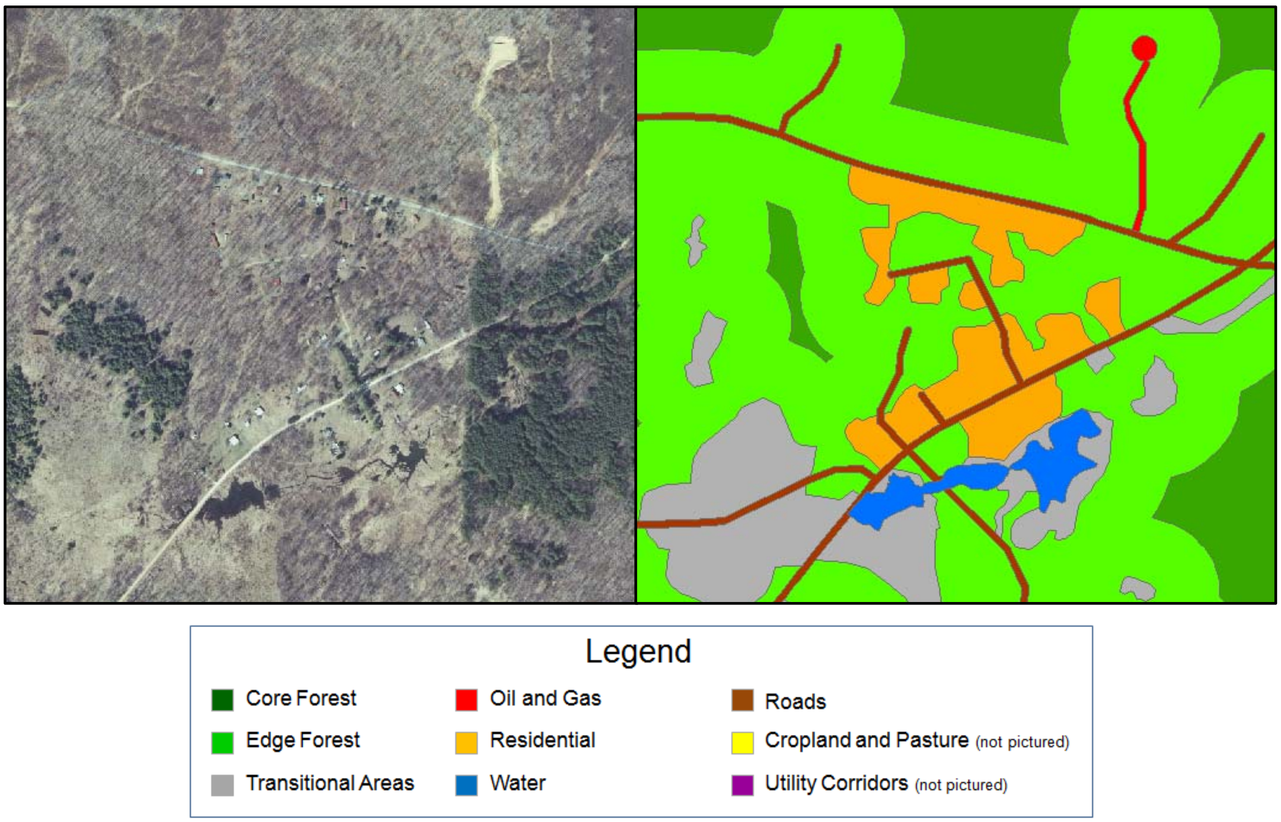


Figure 7 – Aerial Imagery and Resulting Land Cover Classification
(source: left – PAMAP imagery, right – classification created in ArcMap 9.2)

3.8 Measuring Landscape Fragmentation

3.8.1 ArcGrid Production

I used FRAGSTATS 3.3 to measure and quantify the landscape. The software is compatible with a number of image processing software packages including IDRISI, ERDAS IMAGINE, and ArcGIS. However, it will only accept ArcGIS files in the raster

ArcGrid format with a projection that uses metric units instead of U.S standard. All of the land cover classification files were created as vector files with the Pennsylvania State Plane Coordinate system which uses U.S. standard units. To convert the land cover to the correct format, the first step was to use the ArcMap Clip function to break the land cover files into individual atlas blocks. Each atlas block was then reprojected to NAD83 with Universal Transverse Mercator projection, 17 North using the batch Project feature available in ArcCatalog.

The next step was to convert the reprojected blocks into raster ArcGrids. I used the batch Feature to Raster function in ArcCatalog. I kept the field of class and chose an output cell size of 2 meters. After some preliminary tests with cell sizes and FRAGSTATS 3.3, an ArcGrid with 2 meter cells processed quickly and preserved the appearance of the original vector land cover data. An ArcGrid of 1 meter cells took 10 to 15 times longer to process and added little additional detail to the landscape metrics.

The last part of the ArcGrid production process was to remove the artifacts created during the raster conversion process. A raster artifact is a small patch sometimes only 1 cell in size that is created when files are converted from vector to raster. They usually occur in areas of complex land cover where the raster format cannot define the sharp edges of a vector file.

It was a three step process to remove the artifacts from the ArcGrids. First, each ArcGrid was processed using the Region Group function with the eight-neighbor option. This created a unique identifier for each patch. Next, I used the Extract by Attribute tool to create rasters comprised of just artifact patches. I chose 0.1 acres (4,356 square feet) as the maximum size of artifact patches to stay consistent with the patch size eliminated during the land cover editing process. Lastly, the Nibble function was used to reclassify the artifacts to the adjacent surrounding land cover. Figure 8 is a visual depiction of an original vector, and a raster before and after artifact removal. The removal of artifact patches is important to ensure accurate calculation of landscape metrics. Artifacts will affect metrics that use patch number in the calculations such as number of patches, mean patch size, or nearest neighbor.

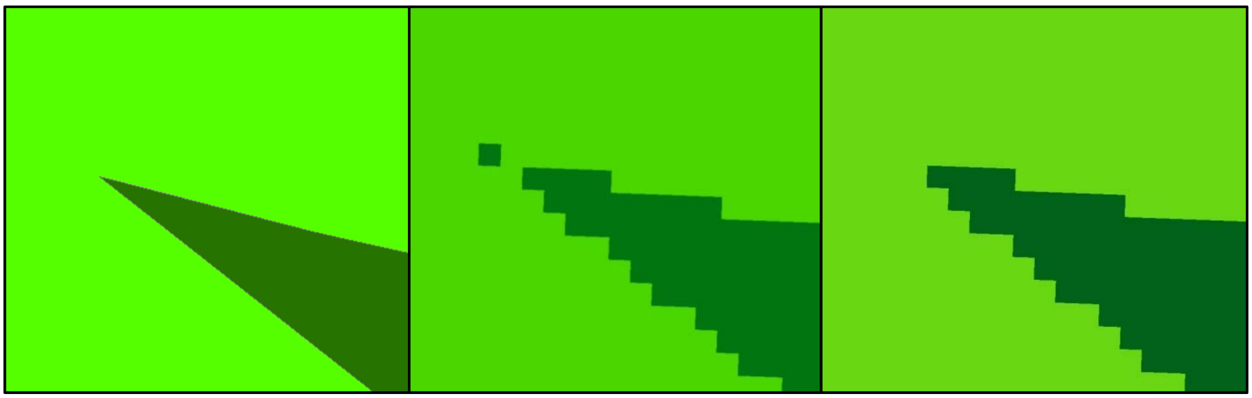


Figure 8 – Comparison of a Land Cover Vector and Land Cover Rasters Before and After Artifact Removal (light green = edge forest, dark green = core forest)

3.8.2 FRAGSTATS and Metric Selection

FRAGSTATS analyzes land cover and calculates landscape metrics within boundaries established by the user (McGarigal et al. 2002). For this study, the atlas blocks were used as the boundaries and served as the landscape level unit to measure fragmentation. This technique had two advantages. First, fragmentation was consistently measured across areas of the same size making comparisons much easier and more accurate. Second, the mini-route data remained intact allowing fragmentation in each block to be directly compared to the avian guild data.

I selected a wide range of FRAGSTATS metrics at the landscape, class, and patch level. Patch metrics are used to analyze change of a particular landscape feature such as water levels in a lake. This level of detail is outside the scope of my study, and I did not use any of the patch metrics. However, I did process them for possible use in future studies. I created a correlation matrix of FRAGSTATS' metrics in Minitab and narrowed the selection to 21 metrics (Minitab Inc. 2003). Some of the remaining 21 metrics were correlated, but were retained because of possible relationships between predictor and response metrics. Also, some of the correlated metrics could exhibit different linkages with avian demographics. Many of the original 11 metrics found in Table 1 were collinear or not relevant, and I only retained five. The atlas blocks all had the same area which allowed me to delete redundant metrics. For example, total edge and edge density had a correlation of one. Table 6 lists the selected metrics. An explanation of each can be found in Appendix D.

Table 6 – Selected Landscape Metrics for the Study of Fragmentation in the ANF

Metric	Full Name	Units	Metric Category
NP	Number of Patches	none	Response
PR	Patch Richness	none	Response
TE	Total Edge	m	Response
SHDI	Shannon's Diversity Index	none	Response
CONTAG	Contagion	%	Response
ENN_MN	Mean Euclidean Nearest Neighbor (ENN)	m	Response
AREA_MN	Mean Size of Patch Areas	m^2	Response
SHAPE_MN	Mean of Shape Index	none	Response
PLAND_EDGE	Percentage of Edge Forest Land Cover	%	Response
NP_CORE	Number of Core Patches	none	Response
PLAND_CORE	Percentage of Core Forest Land Cover	%	Response
AREA_MN_CORE	Mean Size of Core Forest Land Cover Patches	m^2	Response
SHAPE_MN_CORE	Mean of the Core Forest Land Cover Shape Index	none	Response
ENN_MN_CORE	Mean ENN of the Core Forest Land Cover	m	Response
ROAD_LENGTH	Road Length	km	Predictor
PLAND_TA	Percentage of Transitional Areas Land Cover	%	Predictor
TE_TA	Total Edge of the Transitional Areas Land Cover	m	Predictor
PLAND_UTILITY	Percentage of the Utility Corridors Land Cover	%	Predictor
TE_UTILITY	Total Edge of Utility Corridors Land Cover	m	Predictor
TE_OG	Total Edge of the Oil and Gas Land Cover	m	Predictor
PLAND_OG	Percentage of Oil and Gas Land Cover	%	Predictor

3.9 Analyzing Fragmentation Metrics

3.9.1 Reponses and Predictors

The 21 selected metrics fall into one of two categories, response or predictor, as depicted in Table 6. A predictor metric is an input into the system such as road length and a response is an output such as total edge. A predictor generates a response such as creating more edge or dividing patches. The predictors are the drivers of fragmentation. For my research I identified four drivers: roads, utility corridors, transitional areas, and oil and gas development. I measured roads in length, but the other three drivers were measured in both percentage of area and total edge. These two measurements are generally strongly correlated with each other, but one is sometimes more strongly correlated to a response metric. From the selected metrics, there were a total of seven predictor metrics and 14 response metrics.

3.9.2 Fragmentation Trends

FRAGSTATS 3.3 processed the selected list of landscape metrics for each atlas block for each time period; 21 metrics x 29 blocks x 4 time periods = 2436 metric calculations. I calculated the mean for the metrics from each time period to get a general idea of the change in each measurement over time. Because the metrics were based on land cover analysis with known dates, I was able to plot and calculate the trend of each landscape metric. The trend or slope of the regression line was given in unit change per day. I converted each trend to an annual rate of change by multiplying by 365.25 days. I excluded patch richness, Shannon's Diversity Index, contagion, and the shape indices because none of these metrics translated well into annual rates of change. The percentage of land metrics were converted to annual change in hectares. Plots of the trends and annual rates of change were examined to determine if the study area was becoming more or less fragmented over time.

3.9.3 Oil and Gas Development and Fragmentation

To determine if oil and gas development was a significant contributor to fragmentation, I created a correlation matrix using all of the landscape measurements. I defined a strong correlation as between 0.7 and 1.0 (positive correlation) or between -0.7 and -1.0 (negative correlation). I defined a moderate correlation as between 0.4 and 0.7 (positive correlation) or between -0.4 and -0.7 (negative correlation) (Salkind 2006). Moderate or strong correlations with any of the response metrics and the oil and gas metrics required regression analysis to test the strength of the relationship. If both the edge and percentage of area oil and gas metrics were correlated with the same response metric, only the one with the higher correlation was analyzed.

3.9.4 The Relationship between Predictor and Response Variables

After the oil and gas correlations were tested, I tested any strong correlations between any other predictors and response variables using regression analysis. I also used multiple regression analysis to test how well the four fragmentation drivers could predict a response variable. To conduct this test, I used either total edge or percentage of land, for utility corridors, oil and gas, and transitional areas. A p-value of 0.05 was used to determine if any of the regressions produced results that were statistically significant.

3.10 Linking Landscape Metrics with Avian Guild Data

3.10.1 Avian Guild Data and Oil and Gas Development

The correlations between the oil and gas metrics and avian guild data were examined to determine if there was a relationship between the data sets. The oil and gas metrics from the 2005 – 2006 PAMAP imagery were used because they closely represented the landscape at the time the mini-routes were completed. The correlations between oil and gas trends and guild data were also analyzed to determine if the annual changes in development had a different effect on the breeding birds. I analyzed the partial and full routes separately because the inconsistent levels of data between them could create spurious results. Moderate or strong correlations with any of the 2^{nd} PBBA demographics and the oil and gas metrics required regression analysis to test the strength of the relationship. If both the edge and percentage of area oil and gas metrics were correlated with the same demographic, I only tested the one with the higher correlation.

3.10.2 Fragmentation and Avian Guild Demographics

The relationships between current levels of fragmentation (2005 – 2006 metrics) and avian guilds were examined by testing any moderate and strong correlations with regression analysis. Moderate and strong correlations between annual rates of change and avian guilds were also tested to see if breeding birds responded more strongly to current levels of fragmentation or trends of fragmentation. The partial and full routes were analyzed separately to minimize error. A p-value of 0.05 was used to determine if any of the regressions produced results that were statistically significant.

Chapter 4 – Fragmentation in the Allegheny National Forest

4.1 Fragmentation Metric Means

To get a general sense of the change in landscape fragmentation, I calculated the mean of each metric for each time period as shown in Table 7. I included overall change for the metrics with consistent trends. Overall, the landscape level metrics showed little change. The only exception is total edge which increased over 50,000 meters (50 kilometers) per block over the time periods studied. The explanation for this can be found in the class level metrics.

Table 7 – Landscape Metric Means for the Four Time Periods of the Study

Mean of Landscape Level Metrics (Response)								
Time Period	**NP**	**PR**	**TE**	**AREA_MN**	**SHAPE_MN**	**ENN_MN**	**CONTAG**	**SHDI**
1958, 68 -69	217.55	7.38	242278.07	18.07	2.34	147.52	75.54	0.92
1981, 1983	210.24	7.21	261522.28	16.12	2.47	146.67	74.96	0.92
1993	226.34	7.28	280794.48	16.27	2.53	143.64	75.44	0.91
2005-2006	221.00	7.21	292452.21	16.88	2.65	147.18	74.59	0.93
Change			+50,174 m		-0.31			

Mean of Class Level Metrics (Response)						
Time Period	**PLAND_EDGE**	**NP_CORE**	**PLAND_CORE**	**AREA_MN_CORE**	**SHAPE_MN_CORE**	**ENN_MN_CORE**
1958, 68 -69	37.69	20.72	52.98	120.04	1.95	184.60
1981, 1983	40.77	23.69	51.77	105.95	1.93	182.05
1993	43.13	23.90	49.89	98.88	1.94	182.33
2005-2006	44.18	25.52	48.27	90.52	1.90	184.97
Change	+6.49%	+4.80	-4.71%	+29.52 HA		

Mean of Class Level Metrics (Predictor)							
Time Period	**ROAD_LENGTH**	**PLAND_TA**	**TE_TA**	**PLAND_UT**	**TE_UTILITY**	**PLAND_OG**	**TE_OG**
1958, 68 -69	28.37	5.29	61659.93	0.39	16520.69	0.25	11962.69
1981, 1983	33.29	2.91	46542.07	0.37	14389.86	0.56	25527.79
1993	35.84	1.85	37067.24	0.36	14768.48	1.02	46157.10
2005-2006	36.50	1.99	33914.14	0.35	13834.00	1.40	60931.52
Change	+8.13 km	-3.33%	-27,2745 m	-0.04%		+1.15%	48,969 m

The percentage of edge forest increased 6.49% while the percentage of core forest decreased 4.71%. The mean size of core forest patches also decreased by nearly 30 hectares. Edge forest by definition has much more edge per kilometer than core forest. Core forest tends to be more square and compact with less edge than other land cover classes. This is apparent in the comparison between the core forest shape index and the overall shape index. Core forest has a shape index closer to one.

The number of patches did not increase significantly and actually decreased since 1993. Therefore, the patch structure and landscape pattern is changing. The large compact patches of core forest are being replaced by long sinuous patches of other land covers. The significant changes in total edge coupled with only small changes in the number of patches suggests that number of patches may not be the best metric to measure fragmentation.

The probable causes for the increase in total edge can be found in the predictor class level metrics. Interestingly, the percentage of land and total edge of the transitional areas decreased significantly until 1993. Since 1993, there has been a small decrease in edge and a slight increase in the percentage of land covered by transitional areas. The decrease is likely attributed to afforestation. An example of a change in forest cover from 1969 to 1993 is shown in Figure 9. Until the 1940s, the

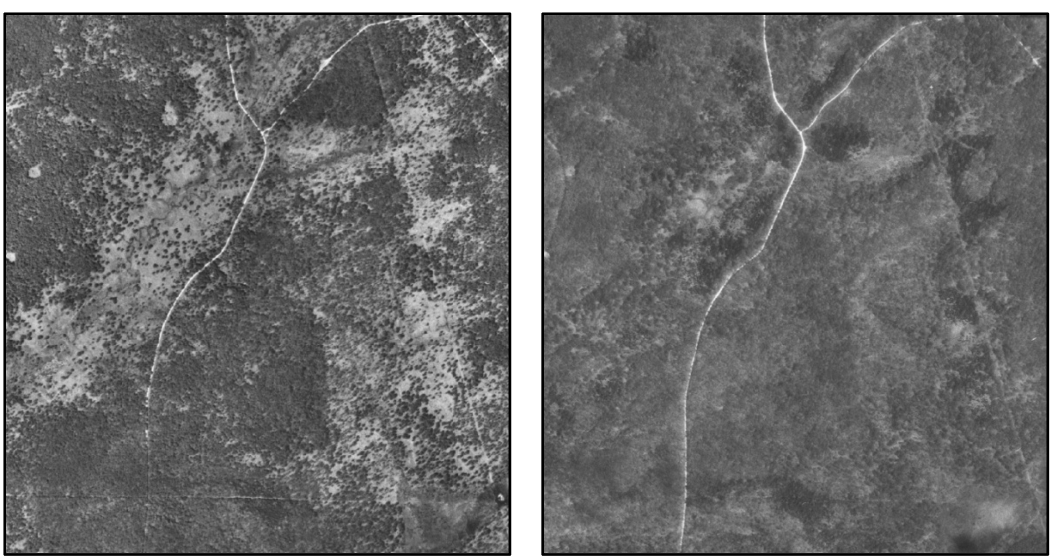


Figure 9 – Change in Forest Cover from 1969 to 1993

ANF was more shrub than forest (*LRMP* 2007). Based on the landscape metrics in Table 7, most of the deforested areas had grown back by the late 1990s. Edge attributed to utility corridors also decreased slightly. A possible explanation for this is the consolidation of small power lines into larger utility corridors.

The landscape metrics indicate that oil and gas development is the largest contributor to total edge. There are other contributors to edge such as residential and cropland pasture, but these land covers cannot expand beyond their small inholdings and comprise less than 0.35% of the current landscape. Residential and cropland and pasture land cover types were classified, but were not further analyzed.

Oil and gas development is a spider web network of roads and pads, which subdivides patches and creates edge forest. The change in mean oil and gas edge over the course of the study was 48,969 meters per block. This number is very close to the overall change in edge, 50,174 meters. However, not all of the change in edge can be directly attributed to oil and gas. Roads not related to oil and gas also contributed an overall change of 16,265.48 meters per blocks, equal to 8.13 kilometers of road. A combination of oil and gas development, utility corridors, roads, and transitional areas contributed to changes in fragmentation and will be further discussed in section 4.4.

4.2 Annual Rates of Change of Fragmentation Metrics

I calculated trends for each fragmentation metric using the flight dates of the images and converted the trends into annual rates of change. The complete list of annual rates of change can be found in Appendix E. The percentage of area metrics were converted to annual change of the respective class's total areas. Graphs of each metric over time and the resulting trend line were created to give a visual depiction of change of the landscape measurements. The data points are very close to the trend line for most of the metrics in the BBA blocks. An example of the graphs is shown in Figure 10 and the complete set of graphs can be found in Appendix G.

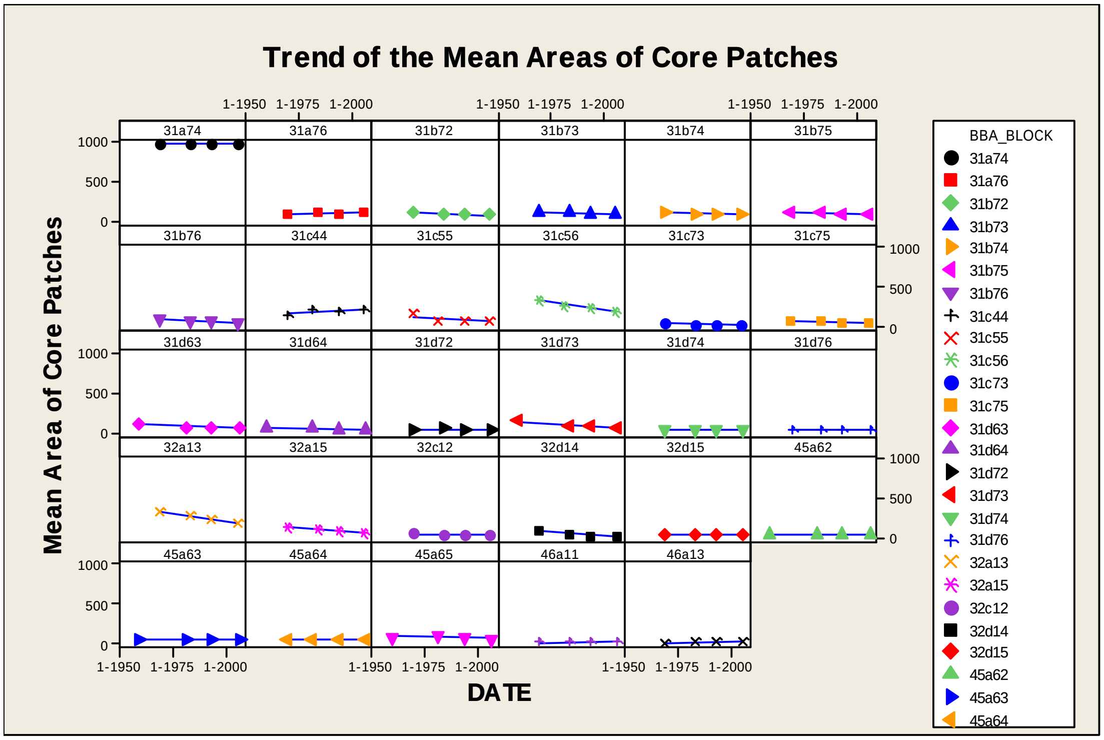


Figure 10 –Trend of Mean Core Patch Area from 1958 to 2006

To represent how the annual change in each block is contributing to fragmentation, the trend of each block was graphed with an individual value plot. An example is shown in Figure 11 and the complete set can be found in Appendix G.

In general, increasing fragmentation follows a positive or a negative trend, see Appendix F. However, there are some metrics such as Euclidean nearest neighbor (ENN) and number of core patches that do not show a clear trend with increasing fragmentation. The ENN of core patches, or the distance between patches of core forest, will decrease at the beginning of a fragmentation process as patches of forest are subdivided by road construction. As the process continues the core forest patches begin to shrink and the ENN begins to increase (Leitão et al. 2006). For this reason, both ENN metrics and the number of core patches are labeled as neutral. The relationship between predictor and response metrics and its effect on fragmentation will be discussed in the next two sections.

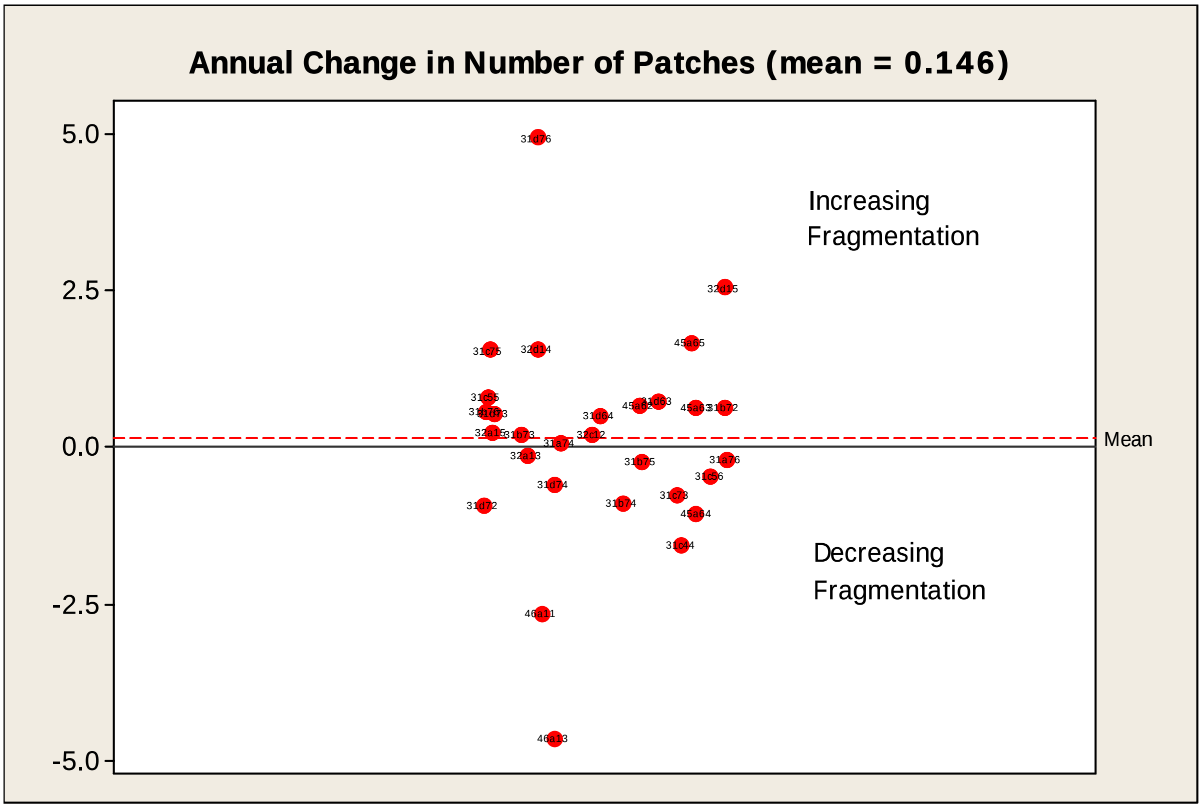


Figure 11 – Annual Change in Number of Patches per Atlas Block in the Allegheny National Forest from 1958 to 2006

4.3 The Effects of Oil and Gas Development on Forest Fragmentation

The fragmentation trends and metric means indicate that oil and gas contributes to the fragmentation of the Allegheny National Forest. I developed a correlation matrix using the metrics from all four time periods to identify the response metrics most affected by oil and gas development. Oil and gas did not have a strong correlation with any of the response metrics. However, the industry did have positive moderate correlations with three metrics: number of patches, total edge, and percentage of land in the edge forest. There was also a negative moderate correlation between oil and gas and the percentage of land in the core forest. The correlations all reflect the pattern of oil and gas development which dissects the landscape creating more patches, edge, and edge forest. Table 8 summarizes the correlations, and the complete correlation matrix can be found in Appendix J.

Table 8 – Correlations between Oil and Gas Development and Response Metrics
(the upper number is the Pearson correlation coefficient, the lower number is the p-value)

Metric	Number of Patches	Total Edge	Percentage of Edge Forest	Percentage of Core Forest
Percentage of Oil and Gas	+0.541	+0.642	+0.486	-0.506
	0.000	0.000	0.000	0.000
Total Edge of Oil and Gas	+0.540	+0.651	+0.500	-0.516
	0.000	0.000	0.000	0.000

I conducted linear regression analysis to test the strength of the relationship between oil and gas development and the response metrics. Because percentage of land and edge of oil and gas are highly correlated, I only used the predictor metric with the higher correlation. Table 9 lists the results of the regression analysis. The low p-values indicate that the results are statistically significant at a confidence level of 95%. The R^2, coefficient of determination, explains between 25% and 42.3% of the variation of each respective response metric. For example, 42.3% of the variation in total edge of the study area in the Allegheny National Forest can be explained using the edge of oil and gas development. Oil and gas development had the highest correlation of the predictor metrics with total edge.

Table 9 – Results of Linear Regression Analysis between Oil and Gas Development and Response Metrics

Response Metric	R^2	Adjusted R^2	p-value
Number of Patches	29.3%	28.7%	0.000
Total Edge	42.3%	41.8%	0.000
Percentage of Edge Forest	25.0%	24.3%	0.000
Percentage of Core Forest	26.6%	25.9%	0.000

It is not surprising that this particular set of four response metrics all correlated with oil and gas development because the four metrics are also highly correlated with each other. However, the explanation of over 40% of total edge by oil and gas edge is significant. It indicates that oil and gas development is a major contributor to fragmentation in the Allegheny National Forest.

4.4 The Relationship between Predictor and Response Metrics

4.4.1 Correlations and Simple Linear Regression

There are other relationships between predictor and response metrics other than those with oil and gas development. The complete correlation matrix can be found in Appendix I. The only strong correlation between a predictor and response metric was edge of utility corridors and number of core patches with a coefficient of 0.729. A linear regression analysis of these two metrics produced an R^2 of 53.2% and an adjusted R^2 of 52.8% with a p-value of 0.00. About 53.2% of the variation of the number of core patches can be predicted with the edge of utility corridors. This relationship is explained by utility corridors cutting long paths through the forest creating edge and subdividing core patches.

The four drivers of fragmentation (oil and gas development, utility corridors, transitional areas, and roads) all had positive moderate correlations with these metrics: number of patches, total edge, and percentage of edge forest. They also all had a negative moderate correlation with the percentage of core forest. Overall, the percentage of area and edge decreased for transitional areas. However, the transitional areas' metrics still correlate with the response metrics because they help explain the overall change in landscape pattern and fragmentation.

4.4.2 Multiple Linear Regression

The large number of moderate correlations between predictor and response metrics indicated that multiple regression analysis could be used to further understand the variation of the response metrics. I used the correlation matrix and the Best Subsets function in Minitab 14 to select predictor metrics with the highest correlations and p-values below 0.05. The Best Subsets function identified the best model with as few metrics as possible. I used it in conjunction with the correlation matrix because Best Subsets would often identify both metrics of a driver in a model. Only edge or percentage of area could be used for each regression model to avoid collinearity. There was not a problem with collinearity between the drivers. Only the oil and gas metrics and the percentage of utility corridors had a moderate correlation.

I used a combination of one to four predictor metrics for each regression model with the goal of attaining the highest R^2 with a p-value below 0.05. The results are summarized in Table 10 and the complete regression output can be found in Appendix I.

Table 10 – Results of Multiple Linear Regression Analysis between Predictor and Response Metrics

Response Metric	# of Predictor Metrics	Predictor Metrics	R^2	Adjusted R^2
Total Edge	4	Road Length, Edge of Transitional Areas, Edge of Utility Corridors, Edge of Oil and Gas	94.8%	94.6%
Percentage of Core Forest	4	Road Length, Edge of Transitional Areas, Edge of Utility Corridors, Edge of Oil and Gas	93.4%	93.1%
Number of Patches	4	Road Length, Edge of Transitional Areas, Edge of Utility Corridors, Percentage of Oil and Gas	90.2%	89.9%
Percentage of Edge Forest	4	Road Length, Edge of Transitional Areas, Edge of Utility Corridors, Edge of Oil and Gas	86.0%	85.5%
Number of Core Patches	3	Road Length, Edge of Transitional Areas, Edge of Utility Corridors	77.3%	76.7%
Mean ENN	3	Road Length, Edge of Transitional Areas, Edge of Oil and Gas	50.8%	49.4%
Mean Core Patch Area	3	Road Length, Edge of Transitional Areas, Edge of Oil and Gas	40.6%	39.0%
Mean Patch Area	3	Road Length, Edge of Transitional Areas, Edge of Oil and Gas	38.8%	37.2%
Mean Shape Index	1	Edge of Transitional Areas	36.2%	35.7%
Shannon's Diversity Index	2	Road Length, Edge of Transitional Areas	31.6%	30.4%
Contagion	2	Road Length, Edge of Transitional Areas	27.9%	26.6%
Patch Richness	2	Edge of Transitional Areas, Edge of Utility Corridors	13.9%	12.4%

Five of the models produced excellent results by explaining over 75% of the variation of their respective response metric. Four of the five metrics that I retained from Table 1 are among the models with high R^2 values. These metrics are percentage of core area, number of patches, number of core patches, and total edge. They are all commonly used as measures of fragmentation. The metric from Table 1 that is not in the top five is mean patch area which still had a statistically significant R^2 value at 38.8%. Percentage of edge forest was not used in the previous studies from Table 1, but it is an important metric in the examination of forest fragmentation.

In general, models with a higher number of predictor metrics produced a higher R^2 value as shown in Table 10. The mean shape index only needed one input variable, edge of transitional areas, to produce the highest possible R^2 with a p-value less than 0.05. The core patch mean shape index and the core patch mean Euclidean nearest neighbor (ENN) metrics were both omitted because none of the predictor metrics could reliably explain any of the metrics' variations. The most commonly used predictor metric was edge of transitional areas which proved explanatory in all 12 models. Road length was ranked second with 10 occurrences; followed by edge of utility corridors and edge of oil and gas at a tie for third with six occurrences each. Percentage of oil and gas ranked a distant fourth with one occurrence.

The explanatory power of edge of transitional areas in every model indicated that afforestation has helped to balance the fragmentation of the forest. The metric means from Table 7 show a steadying decrease in the loss of edge from transitional areas over the time period of the study. Between the NAPP2 (1993) and PAMAP (2005-2006) imagery, the average decrease of edge from transitional areas was only 3,153 meters as opposed to a 14,774 average increase of edge from oil and gas development. The decreases and increases of edge from these two drivers nearly balanced each other between earlier time periods. The effect of oil and gas development on forest fragmentation may escalate in the future because there are few areas left to afforest and offset the creation of more forest edge.

Chapter 5 – Breeding Bird Populations in the Allegheny National Forest

5.1 Mini-Routes of 2nd Pennsylvania Breeding Bird Atlas

The mini-routes of the 2nd PBBA provided the data for the avian habitat response guilds. Using the habitat lists found in Appendix A, the point count data of the mini-routes was grouped into avian guild demographics for each atlas block. The protocol for the mini-routes was changed in 2007. To incorporate this change into my research, I separated the routes for the 29 atlas blocks into full and partial based on each route's number of road side points, see section 3.4. This produced nine full routes and 14 partial routes. Six of the 29 routes did not have enough data or road side points and were removed from the analysis. The guild demographics for each of the 29 atlas blocks can be found in Appendix B. Table 11 summarizes the count and species means for each guild: edge forest, forest interior, and forest generalist. Overall, the majority of records came from the forest interior guild which is indicative of the Allegheny National Forest landscape.

Table 11 – Mean Values of the Avian Demographics of the Mini-Routes

Route Type	Total Count	Total Species	Edge Count	Edge Species	Interior Count	Interior Species	Generalist Count	Generalist Species
Full Routes	98.0	30.9	21.8	8.6	38.6	12.4	37.7	9.9
Partial Routes	65.7	24.4	15.4	7.8	29.3	9.4	21.1	7.1

The data between the full and partial routes was relatively consistent. The full and partial routes yielded nearly the same proportion of each demographic. For example, the edge count for the full routes was 22% of the total count and the edge count for the partial routes was 23.4% of the total count. The largest variation was the forest generalist count where full routes returned 38.5% of the total count and the partial routes returned 32.1%. The proportions were consistent, but the difference of magnitude between the point counts themselves required the full and partial routes to be analyzed separately.

5.2 The Effects of Oil and Gas Development on Breeding Birds

The results of Chapter 4 indicated that the oil and gas industry affects the fragmentation of the Allegheny National Forest. This suggests that breeding bird populations may also be affected by oil and gas development. However, an analysis of avian guild data and current fragmentation did not produce any strong or even moderate correlations.

An analysis of guild data and fragmentation trends produced two moderate correlations: the annual change of oil and gas edge and the generalist count of the full routes had a correlation of 0.417 and the annual change of oil and gas area and the generalist count at 0.42. However, both correlations had p-values well above 0.05, 0.264 and 0.261 respectively, and the relationships proved statistically insignificant using linear regression. The regression produced low R^2 values of 17.4% and 17.6% that were not significant at the 95% confidence level. The small sample size of the full and partial routes may account for the lack of correlation between the breeding bird data and the oil and gas metrics. The complete correlation matrices can be found in Appendix H and the regression analyses in Appendix I.

5.3 The Effects of Fragmentation on Breeding Bird Populations

5.3.1 Current Fragmentation and Guild Demographics

I examined the correlations between all of the guild demographics and the current fragmentation metrics and conducted simple linear regression on moderate and strong correlations. Forest generalist species had two strong correlations with patch richness and Shannon's Diversity Index thus allowing me to conduct multiple regression analysis. However, the two landscape metrics had a high correlation at 0.66 and the multiple regression proved statistically insignificant with the p-values above 0.05. Table 12 features the correlations and linear regressions with a confidence level of at least 95%. The complete results can be found in Appendices I and J.

Table 12 – Correlations and Linear Regressions between Guild Demographics and Current Fragmentation

Guild Demographic	Route Type	Metric	Correlation	R2	Adjusted R2	p-value
Forest Generalist Species	Full	Patch Richness	+0.815	64.8%	59.7%	0.009
Forest Generalist Species	Full	Shannon's Diversity Index	+0.750	56.3%	50.0%	0.020
Forest Generalist Count	Full	Shannon's Diversity Index	+0.718	51.6%	44.7%	0.029
Total Count	Full	Core Shape Index Mean	+0.681	46.4%	38.8%	0.043
Forest Generalist Count	Partial	Edge of Transitional Areas	+0.595	35.4%	30.0%	0.025
Forest Generalist Count	Partial	Percentage of Transitional Areas	+0.543	29.5%	23.6%	0.045

The avian demographics became the response variables and any of the landscape metrics were predictor variables when performing regression analysis between the guilds and landscape metrics. This was different than the use of the predictor and response metrics in Chapter 4 because I was now looking at how breeding birds respond to landscape fragmentation instead of the causes of forest fragmentation.

The results of the linear regression analysis suggested that the full routes are better indicators of the overall habitat than the shorter partial routes. The full routes had twice as many statistically significant relationships than the partial routes and also had higher R^2 values. The partial and full routes also did not have any of the same relationships between avian demographics and current fragmentation metrics. The analysis indicated that the total count of birds increased as patches became more compact or square.

The most commonly represented guild was forest generalist with three relationships of the count data and two of the species data. The forest generalist species appeared to respond to patch richness and diversity with both overall number and variety of species increasing as the landscape became more diverse. The overall number of forest generalist birds was also positively correlated with the transitional area metrics, and the population increased with an expansion of transitional area land cover. However, both these relationships came from the partial routes and had the lowest of the six R^2 values.

Overall, the linear regression analysis indicated that the forest generalist species are most sensitive to current fragmentation metrics. These birds have more options for nesting and breeding because they do not have a preference over edge or interior habitat. Based on the analysis, the forest generalists may be quicker to move into new areas of habitat than the other two guilds. The sample size of the routes was not large enough to produce strong evidence, but did provide enough to warrant further research.

5.3.2 Annual Rates of Fragmentation and Guild Demographics

I examined the correlations between the guild demographics and the annual rates of fragmentation to determine if the trends of change had a larger impact than current measures of fragmentation. Table 13 highlights the correlations and linear regressions with a confidence level of at least 95%. The complete results can be found in Appendices I and J. The majority of the correlations between the guild demographics and the annual rates of change were negative; 13 out of 17. All of the avian demographics were represented at least once except for interior forest count.

Table 13 – Correlations and Linear Regressions between Guild Demographics and Annual Rates of Fragmentation Change

Guild Demographic	Route Type	Annual Rate of Change	Correlation	R^2	Adjusted R^2	p-value
Edge Forest Species	Full	Road Length	-0.794	63.0%	57.7%	0.011
Edge Forest Count	Full	Number of Core Patches	-0.772	59.6%	53.8%	0.015
Total Species	Full	Edge of Utility Corridors	-0.717	51.4%	44.5%	0.030
Edge Forest Species	Full	Number of Patches	-0.713	50.9%	43.9%	0.031
Edge Forest Species	Full	Mean Patch Area	+0.708	50.1%	43.0%	0.033
Edge Forest Species	Full	Number of Core Patches	-0.704	49.6%	42.4%	0.034
Total Species	Full	Area of Utility Corridors	-0.701	49.1%	41.9%	0.035
Edge Forest Count	Full	Road Length	-0.698	48.8%	41.5%	0.036
Forest Generalist Count	Full	Edge of Utility Corridors	-0.689	47.5%	40.0%	0.040
Forest Generalist Count	Full	Area of Utility Corridors	-0.679	46.2%	38.5%	0.044
Edge Forest Species	Full	Mean ENN	+0.672	45.1%	37.2%	0.048
Total Count	Full	Edge of Utility Corridors	-0.571	45.0%	37.1%	0.048
Edge Forest Species	Full	Edge of Utility Corridors	-0.671	45.0%	37.2%	0.048
Total Count	Full	Road Length	-0.667	44.5%	33.6%	0.050
Forest Generalist Species	Partial	Mean of Core Patch Area	+0.578	33.4%	27.9%	0.030
Forest Generalist Species	Partial	Total Edge	-0.568	32.2%	26.6%	0.034
Interior Forest Species	Partial	Mean of Core Patch Area	+0.554	30.7%	24.9%	0.040

The annual rates of change produced more statistically significant relationships with the avian guild demographics than the current levels of fragmentation. The full routes once again proved to be better indicators of habitat and guild strength than the partial routes. 14 out of the 17 relationships came from the full routes. I examined the regressions and correlations to determine if multiple regressions could be used to predict a larger amount of the variability of the guild demographic. However, the annual rates of change were too collinear to produce valid multiple regressions and nearly the same amount of variability could be explained with just one correlated metric.

The most commonly represented guild was edge forest with six edge species relationships and two edge count relationships. Of these eight correlations, five were contrary to initial perceptions of fragmentation and guild strength. Both edge species and edge count showed a negative correlation with road length trends. Also, edge species indicated a negative response with a positive rate of patch number and utility corridor edge and a positive response with a positive rate of mean patch area. These relationships suggest that the edge guild is decreasing in diversity and somewhat in size in the blocks that show high annual rates of an increase in fragmentation.

Three possible explanations for this contrary result are: (1) the sample sizes are too small to produce valid correlations and R^2 values, (2) some edge species are more sensitive to changes than others causing the counts to remain relatively stable, but the guild diversity to decrease, and (3) even edge preferring species have limits to the amount of fragmentation that they will tolerate. According to the regression and correlation data, the last explanation is supported by a decrease of total count and total species with an increase in utility corridor edge, a decrease of total count with an increase in road length, and a decrease in total species with an increase in the area of utility corridors.

I explored combining current fragmentation metrics and fragmentation rates to conduct multiple regression analysis. Only the forest generalist count and the total count had enough relationships to attempt multiple regression. However, there was too much collinearity between the metrics of the forest generalist count to produce valid results. For the total count, the metrics of core shape mean index and annual change of utility corridors produced an R^2 of 70.4%, but the p-values of the predictor metrics were just above 0.05 at 0.064 and 0.070. A larger sample size of full BBA mini-routes would probably produce results that were statistically significant at the 95% confidence level.

The sample sizes of the bird data were small with only 9 blocks with full routes and 14 blocks with partial routes. However, the correlation and regression statistics between the avian guilds and fragmentation rates suggested that bird populations are lower in blocks with high rates of annual fragmentation metrics. There is enough evidence to justify further research into this relationship using a larger sample of BBA blocks with full mini-routes.

Chapter 6 – Conclusions

6.1 Summary of Key Methods

6.1.1 Application of Oil and Gas Information

The analysis of oil and gas development would not have been possible without the creation of the oil and gas database. Using a variety of data sources and ArcGIS 9.2, I was able to develop a date-based archive of well expansion. The context of development and expansion is just as important as the current state of oil and gas in the Allegheny National Forest. The industry has always been a part of the Allegheny National Forest and has challenged the U.S. Forest Service to meet its conservation goals. Without the oil and gas database, it would not have been possible to show how the oil and gas edge per BBA block has increased nearly 50 kilometers in length since the late 1960s.

6.1.2 Historic Imagery

The historic imagery was the principal component of the land cover classification. My successful use of Farm Service Agency photos from the 1950s, 60s, and 80s proved their importance in the study of landscapes. Orthorectifying the photos with Orthomapper allowed me to create an accurate depiction of land cover and easily compare different time periods. This study demonstrated that landscape fragmentation studies do not have to be conducted over a short two to three year time period. They can extend as far back as the imagery exists.

6.2 The Effects of Fragmentation

The landscape metrics from the four time periods depict an increase in fragmentation since the late 1950s and 60s. The trends for the metrics in nearly all of the blocks show annual changes of increasing forest fragmentation. Four relationships of statistical significance between oil and gas development and response metrics were found with regression analysis. The strongest relationship indicated that oil and gas development explained 42.3% of the variability of total edge in the study area.

Multiple regression analysis was used to determine if a combination of predictor metrics could be used to explain most of the variability of a response metric. Five of the multiple regressions were able to predict at least 75% of the variability with p-values of 0.000. Edge of transitional areas was used in every multiple regression model and has actually decreased since the late 1950s and 60s. The decrease in transitional area edge, while the overall edge increased, indicated that afforestation in the Allegheny National Forest has offset much of the edge created by the oil and gas industry. A quick examination of each time period shows that transitional areas reached their lowest percentage of land cover around the late 1990s. Most of the areas that could be afforested probably already have and the future effects of oil and gas development could be much more damaging to the environment.

6.3 Fragmentation and Breeding Bird Habitats

The mini-routes of the 2nd PBBA had to be separated into full and partial routes which created two small sample sizes and limited the statistical significance of my findings. I was not able to find any significant relationships between the guild demographics and any of the oil and gas metrics. I also was not able to produce any meaningful connections using multiple regression analysis because the predictor variables were collinear or the sample size was too small. Simple linear regression did provide some results with high R^2 values and p-values below 0.05. The full mini-routes proved to be much better indicators of guild strength using both the current metrics and the annual rates of change. The annual rates of change produced 17 statistically significant relationships with the avian guilds and the current metrics produced only six.

Forest generalist appeared to be the avian guild most affected by current levels of fragmentation and edge forest appeared to be the guild most affected by annual rates of change. The avian guilds had mostly negative correlations with increasing rates of fragmentation indicating that the total avian population would decrease as fragmentation increased. Overall, the guilds seemed to be more affected by fragmentation trends than by current levels of fragmentation, but more testing is needed with a larger sample size using full BBA mini-routes.

6.4 Limitations of the Study

The major limitations of this study centered on the lack of avian census data. There was not reliable historic bird survey data to correspond with all of the time periods of the historic imagery. Strong comparisons could not be made between fluctuations in bird populations and fragmentation over time. The only complete data sets were the 1st and 2nd Pennsylvania Breeding Bird Atlases, completed from 1983 to 1989 and 2004 to 2008 respectively. Inconsistencies in the 1st PBBA, necessitated the inclusion of the mini-routes in the 2nd PBBA to provide a reliable set of avian demographics across the

Commonwealth. Unfortunately, the protocol for the mini-routes was not kept consistent. The change to shorter routes in 2007 compromised the usability of the routes and the results of my research.

6.5 Recommendations for Future Research

The results of this study could be strengthened by using a sample of about 30 BBA blocks that have the full mini-routes. The volunteer data for the 2nd PBBA could also be tested against the landscape metrics once it is available later this year. The volunteer data does not follow a strict collection protocol, but the volume of additional data could offer some interesting results. A comparison could also be made using the data from both atlases with the land cover of NAPP2 (1993) and PAMAP (2005-2006). This would allow a direct comparison between land cover and guild demographics.

The successful conversion of historic imagery into land cover and ultimately landscape metrics, creates many opportunities for future landscape research. To expand on my research, I would orthorectify the imagery of the three other time periods (1937 – 1942, 1948 – 1951, the rest of 1958 – 1959) and classify the land cover. I could then calculate the landscape metrics and examine landscape change and fragmentation over the complete time coverage of the available imagery. I would also be interested in the landscape metrics for the next set of imagery, currently scheduled for 2010 in the PAMAP program. This would allow me to further test the balance between afforestation of transitional areas and oil and gas development.

6.6 Significance of the Study

A growing demand for energy continues to expand the oil and gas industry in Pennsylvania and necessitates an improved understanding of its effects on the landscape. My research is relevant to the current proliferation of oil and gas development in Pennsylvania. In 2007, the gas industry started drilling operations to tap the deep gas fields of the Trenton-Black River (3,000 meters) and the Marcellus Shale (1,800 to 2,400 meters) Formations (*Whopping Gas Field* 2008). On April 1st, 2008, the Commonwealth government ended a five year moratorium on shallow well drilling in state forests and opened up 30,350 hectares (75,000 acres) for lease to private companies (Levy 2008). A week later, the New York Times ran a story about Pennsylvania farmers leasing mineral rights to drillers wanting access to the gas rich Marcellus Shale (Krauss 2008). Increasing world energy consumption and escalating oil prices will further drive the demand for Pennsylvania's natural gas and oil.

The expansion of drilling in Pennsylvania's oil and gas fields will help meet domestic energy demands. Natural gas is also a much cleaner burning alternative to coal. This research was not intended to inhibit oil and gas development, but to improve the balance between energy demands and conservation goals. Little research has been done on the long term effects of fragmentation in Pennsylvania's deciduous forests. The Allegheny National Forest offered a unique opportunity to study fragmentation and its impact on wildlife. Hopefully, this study will help improve our understanding of the causes and effects of forest fragmentation and help influence regulatory guidance to minimize fragmentation through better land management and restoration practices.

LITERATURE CITED

2nd Pennsylvania Breeding Bird Atlas (2nd PBBA). 5 May 2008 <http://www.carnegiemnh.org/atlas/home.htm>.

Allegheny National Forest (ANF) GIS Data. Jan 2007. U.S. Forest Service. 12 Jun 2008. <http://www.fs.fed.us/r9/forests/allegheny/maps/gis/>

Anderson, J. R., E.E. Hardy, J.T. Roach, and R.E. Whitmer. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*. Geological Survey Professional Paper 964. United States Government Printing Office, Washington D.C.: 1976.

Bishop, J. A. *Temporal Dynamics of Forest Patch Size Distribution and Fragmentation of Habitat Types in Pennsylvania*. Doctoral Dissertation. The Pennsylvania State University, University Park, Pennsylvania, 2008.

Bishop, J. A., and W. L. Myers. *Associations Between Avian Functional Guild Response and Regional Landscape Properties for Conservation Planning*. Ecological Indicators 5.1 (2005): 33-48.

The Boreal Forest Natural Region of Alberta. Alberta Environmental Protection. Edmonton, Alberta, 1998.

Croonquist, M.J. and R.P. Brooks. *Use of Avian and Mammalian Guilds as Indicators Cumulative Impacts in Riparian-Wetland Areas*. Environmental Management 15.5 (1991): 701-714.

Environmental Systems Research Institute (ESRI). ArcGIS ver. 9.2. 380 New York Street Redlands, CA 92373-8100. 2006.

Fahrig, L. *Effect of Habitat Fragmentation on the Extinction Threshold: A Synthesis*. Ecological Applications 12.2 (2002): 346-353.

Fahrig, L. *Effects of Habitat Fragmentation on Biodiversity*. Annual Review of Ecology, Evolutionary, and Systematics 34 (2003): 487-515.

Goodrich, L., M. Brittingham, J.A. Bishop, and P. Barber. *Wildlife Habitat in Pennsylvania: Past, Present, and Future*. 2002. Pennsylvania Department of Conservation and Natural Resources. 5 May 2008. <http://www.fish.state.pa.us/promo/grants/swg/nongame_plan/pa_wap_sections/appx2habitat_pt2.pdf>.

Habitat Fragmentation from Roads: Travel Planning Methods to Safeguard Bureau of Land Management Lands. The Wilderness Society: Ecology and Economics Research Department. Volume 2, *May 2006.*

History of the APFO. 16 Sep 2006. United States Department of Agriculture - Farm Service Agency. 14 Aug 2008. <http://www.fsa.usda.gov/FSA/apfoapp?area=about&subject=landing&topic=his>

Image Processing Software, Inc. Orthomapper ver. 4.8.4S. 6409 Appalachian Way, Madison, WI 54705. 2008.

Imbrogno, K. *Archive of Oil and Gas Wells: Elk, Forest, McKean, and Warren Counties*. Pennsylvania Geological Survey. 27 Jun 2008.

Krauss, C. *There's Gas in Those Hills*. The New York Times 8 Apr 2008. 5 May 2008<http://www.nytimes.com/2008/04/08/business/08gas.html?em&ex=1207800000&en=0d5847258741198f&ei=5087>.

Land and Resource Management Plan (LRMP) 1986 – Allegheny National Forest. United States Department of Agriculture – U.S. Forest Service. 2007.

Land and Resource Management Plan (LRMP) 2007– Allegheny National Forest. United States Department of Agriculture – U.S. Forest Service. 2007.

Landowners and Oil and Gas Leases in Pennsylvania. Department of Environmental Protection, 2007. 5 May 2008 <http://164.156.71.80/VWRQ.asp?docid=0442d740780d000000000d2500000d25&context=2&backlink=WXOD.aspx%3ffs%3d0442d740780d000080000349000000349%26ft%3d1>.

Leitão, A. B., J. Miller, J. Ahern, and K. McGarigal. Measuring Landscapes: A Planner's Handbook. Washington D.C.: Island Press, 2006.

Levy, M. *Pa. to Let Gas Grilling to Resume in State Forests*. 1 Apr 2008. 5 May 2008 <http://www.phillyburbs.com/pb-dyn/news/281-04022008-1512288.html>.

Lindenmayer, D.B. and J. Fischer. *Tackling the Habitat Fragmentation Panchreston.* Trends in Ecology and Evolution 22.3 (2007): 127-132.

LizardTech Inc. MrSid Viewer Ver 2.0. 1008 Western Avenue, Seattle, WA 98104. 1998. <http://lcweb2.loc.gov/ammem/help/download_sid.html>

Lyon, A.G. and S. H. Anderson. *Potential Gas Development Impacts on Sage Grouse Nest Initiation and Movement.* Wildlife Society Bulletin 31.2 (2003): 486-491.

MacArthur, R.H. and E. O. Wilson. The Theory of Island Biogeography. 2nd ed. Princeton: Princeton University Press, 2001.

Machtans, C. S. *Songbird Response to Seismic Lines in the Western Forest: A manipulative experiment*. Canadian Journal of Zoology 84.10 (2006): 1421-1430.

McGarigal, K. and B. Marks. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure*. United States Department of Agriculture: General Technical Report PNW-GTR-351. August 1995.

McGarigal, K. and S.A. Cushman. *Comparative Evaluation of Experimental Approaches to the Study of Habitat Fragmentation Effects*. Ecological Applications 12.2 (2002): 335-345.

McGarigal, K., S. A. Cushman, M. C. Neel, and E. Ene. *FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps*. 2002. University of Massachusetts, Amherst. 2 May 2008. <http://www.umass.edu/landeco/research/fragstats/fragstats.html>

Microsoft Corporation. Microsoft Office 2007 Enterprise Edition. Redmond, Washington.

Minitab Inc. Minitab ver. 14. 3081 Enterprise Drive, State College, PA 16801-3008. 2004.

National Agriculture Imagery Program (NAIP). 2005. <http://datagateway.nrcs.usda.gov/>

Nelson, B. Meeting with Allegheny National Forest. Warren, Pennsylvania. 11 Jun 2008.

O'Connell, T.J., L. E. Jackson, and R. P. Brooks. *A Bird Community Index: A tool for assessing biotic integrity for the Mid-Atlantic Highlands.* Report No. 98-4 of the Penn State Cooperative Wetlands Center, The Pennsylvania State University, University Park, Pennsylvania. 1998.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. *Bird Guilds as Indicators of Ecological Condition in the Central Appalachians*. Ecological Applications 10.6 (2000): 1706-1721.

O'Connell, T. J., J. A. Bishop, and R. P. Brooks. *Sub-Sampling from the North American Breeding Bird Survey for Application to the Bird Community Index, an Indicator of Ecological Condition.* Ecological Indicators 7 (2007): 679-691.

Oil and Gas Locations. Jul 2008. Pennsylvania Spatial Data Access. 7 Jul 2008 <http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=OilGasLocations2008_07.xml&dataset=283>

Oil and Gas Well Operators Manual. Department of Environmental Protection – Bureau of Oil and Gas Management, 2001. 5 May 2008 <http://164.156.71.80/WXOD.aspx?fs=2087d8407c0e00008000027300000273&ft=1>

PASDA Aerial Photography. 2008. Penn State Institutes of Energy and the Environment. 16 Jun 2008. <http://www.pasda.psu.edu/uci/SearchResults.aspx?shortcutKeyword=aerial&searchType=shortcut&sessionID=2649685762008823114653>.

Penn Pilot: Historical Aerial Photo Library. Penn State Center for Environmental Informatics. 5 May 2008. <http://www.pennpilot.psu.edu/>.

Pennsylvania Bureau of Topographic and Geologic Survey: Oil and Gas Production Summary, 1986 - 2006. Jan 2008. Department of Conservation and Natural Resources. 5 May 2008 <http://www.dcnr.state.pa.us/topogeo/oilandgas/prodreports.aspx>.

Pidgeon, A.M. et al. *Associations of Forest Bird Species Richness with Housing and Landscape Patterns Across the USA*. Ecological Applications 17.7 (2007): 1989-2010.

Ries, L., R. J. Fletcher Jr., J. Battin, and T.D. Sisk. *Ecological Response to Habitat Edges: Mechanisms, Models, and Variability Explained*. Annual Review of Ecology and Systematics 35 (2004): 491-522.

Rig Activity Report. Aug 2008. Pennsylvania Department of Environmental Protection - Bureau of Oil and Gas Management. 23 Aug 08. <http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/OILGAS/RIG08.htm>.

Riitters, K.H. et al. *A Factor Analysis of Landscape Pattern and Structure Metrics*. Landscape Ecology 10.1 (1995): 23-39.

Robbins, C.S., D.K. Dawson, and B.A. Dowell. *Habitat Area Requirements of Breeding Forest Birds of the Middle Atlantic States*. Supplement to the Journal of Wildlife Management 53.3 (1989).

Root, R.B. *The Niche Exploitation Pattern of the Blue-Gray Gnatcatcher.* Ecological Monographs 37.4 (1967): 317-350.

Salkind, Neil J. Statistics for People who (Think They) Hate Statistics. Thousand Oaks, California: Sage, 2006.

Tischendorf, and Fahrig. *How should we measure landscape connectivity*?. Landscape Ecology 15.7 (2000): 633-641.

Turner, M. G. *Landscape Ecology: What is the state of the science?* Annual Review of Ecology, Evolutionary, and Systematics 36 (2005): 319-344.

United States Geological Survey (USGS). 2008. The National Map Seamless Server. <http://seamless.usgs.gov/index.php>

VextraSoft. RasterStitch 1.9.1 Vladivostok, Russia. 2008.

Villard, M. Habitat Fragmentation: *Major Conservation Issue or Intellectual Attractor?* Ecological Applications 12.2 (2002): 319-320.
Villard, M., F.K.A. Schiemgelow, and M.K. Trzcinski. *Short-term Response of Forest Birds to Experimental Clearcut Edges*. The Auk 124.3 (2007): 828-840.

Whitcomb, R.F. et al. *Effects of Forest Fragmentation on Avifauna of the Eastern Deciduous Forest.* Forest Island Dynamics in Man-Dominated Landscapes. Ed. R. L. Burgess and D.M. Sharpe. New York: Springer-Verlag, 1981. 125-205.

Whopping Gas Field Teases Drillers - CNN.com. 4 Feb 2008. 5 May 2008 <http://www.cnn.com/2008/TECH/science/02/04/natural.gas.ap/index.html>.

APPENDICES

Appendix A

Bird Species of the Avian Habitat Guilds

Guild - Edge Habitat

Source: Goodrich et al. (2002)

Code	Common Name
ALFL	Alder flycatcher
AMCR	American crow
AMGO	American goldfinch
AMRO	American robin
BARS	Barn swallow
BLVU	Black vulture
BLGR	Blue grosbeak
BWWA	Blue-winged warbler
BRTH	Brown thrasher
CACH	Carolina chickadee
CSWA	Chestnut-sided warbler
CHSW	Chimney swift
CHSP	Chipping sparrow
CLSW	Cliff swallow
GOGR	Common grackle
EABL	Eastern bluebird
EAKI	Eastern kingbird
EUST	European starling
FISP	Field sparrow
FICR	Fish crow
GWWA	Golden-winged warbler
HOFI	House finch
HOSP	House sparrow
HOWR	House wren
INBU	Indigo bunting
LEFL	Least flycatcher
MODO	Mourning dove
MOWA	Mourning warbler
NAWA	Nashville warbler
NOMO	Northern mockingbird
NRWS	Northern rough-winged swallow
OROR	Orchard oriole
PUMA	Purple martin
RHWO	Red-headed woodpecker
RTHA	Red-tailed hawk
RWBL	Red-winged blackbird

RODO	Rock dove
RTHU	Ruby-throated hummingbird
SOSP	Song sparrow
SWTH	Swainson's thrush
SWSP	Swamp sparrow
TRSW	Tree swallow
TUVU	Turkey vulture
WAVI	Warbling vireo
WTSP	White-throated sparrow
WIFL	Willow flycatcher
YEWA	Yellow warbler
YBCH	Yellow-breasted chat

Guild - Forest Generalist

Source: O'Connell et al. (1998)

Code	Common Name
BBCU	Black-billed cuckoo
BCCH	Black-capped chickadee
BLJA	Blue jay
BGGN	Blue-gray gnatcatcher
CARW	Carolina wren
COYE	Common yellowthroat
DEJU	Dark-eyed junco
DOWO	Downy woodpecker
EAPH	Eastern phoebe
EATO	Eastern towhee
EWPE	Eastern wood-pewee
GRCA	Gray catbird
GCFL	Great crested flycatcher
NOCA	Northern cardinal
NOFL	Northern flicker
NOPA	Northern parula
PUFI	Purple finch
RBWO	Red-bellied woodpecker
REVI	Red-eyed vireo
RBGR	Rose-breasted grosbeak
SUTA	Summer tanager
TUTI	Tufted titmouse
WEVI	White-eyed vireo
WOTH	Wood thrush
YBSA	Yellow-bellied sapsucker

YBCU	Yellow-billed cuckoo
YTVI	Yellow-throated vireo

Guild - Grassland Habitat

Source: Goodrich et al. (2002)

Code	Common Name
AMKE	American kestrel
BANS	Bank swallow
BNOW	Barn owl
BOBO	Bobolink
CCSP	Clay-colored sparrow
CONI	Common nighthawk
DICK	Dickcissel
EAME	Eastern meadowlark
GRSP	Grasshopper sparrow
HESP	Henslow's sparrow
HOLA	Horned lark
KILL	Killdeer
LOSH	Loggerhead shrike
NOBO	Northern bobwhite
HOHA	Northern harrier
RNPH	Ring-necked pheasant
SASP	Savannah sparrow
SEOW	Short-eared owl
UPSA	Upland sandpiper
VESP	Vesper sparrow
WEME	Western meadowlark

Guild - Interior Forest Obligate

Source: O'Connell et al. (1998)

Code	Common Name
ACFL	Acadian flycatcher
AMRE	American redstart
BAWW	Black-and-white warbler
BNWA	Blackburnian warbler
BTBW	Black-throated blue warbler
BTNW	Black-throated green warbler
BHVI	Blue-headed vireo
BRCR	Brown creeper

CAWA	Canada warbler
CERW	Cerulean warbler
CORA	Common raven
GCKI	Golden-crowned kinglet
HAWO	Hairy woodpecker
HETH	Hermit thrush
HOWA	Hooded warbler
KEWA	Kentucky warbler
LOWA	Louisiana waterthrush
MAWA	Magnolia warbler
NOWA	Northern waterthrush
OVEN	Ovenbird
PIWO	Pileated woodpecker
PIWA	Pine warbler
RBNU	Red-breasted nuthatch
SCTA	Scarlet tanager
VEER	Veery
WBNU	White-breasted nuthatch
WIWR	Winter wren
WEWA	Worm-eating warbler
YRWA	Yellow-rumped warbler
YTWA	Yellow-throated warbler

Appendix B Point Count Data from the Mini-Routes of the 2nd Pennsylvania Breeding Bird Atlas

BBA Block	Route Type	Total Count	Total Species	Edge Forest Count	Edge Forest Species	Interior Forest Count	Interior Forest Species	Forest Generalist Count	Forest Generalist Species
31a74	incomplete	19	12	2	2	5	5	12	5
31a76	partial	84	31	34	11	23	10	27	10
31b72	partial	79	24	29	6	32	12	18	6
31b73	complete	89	29	14	6	38	12	37	11
31b74	complete	107	35	25	12	36	13	46	10
31b75	partial	53	19	4	3	29	9	20	7
31b76	complete	122	42	27	11	51	17	44	14
31c44	partial	47	27	13	10	13	8	21	9
31c55	partial	72	26	13	7	36	13	23	6
31c56	complete	98	29	21	8	43	13	34	8
31c73	incomplete	48	21	13	7	20	10	15	4
31c75	partial	49	20	15	7	23	9	11	4
31d63	incomplete	25	10	4	4	16	5	5	1
31d64	partial	58	24	11	7	31	10	16	7
31d72	partial	54	17	7	4	23	7	24	6
31d73	incomplete	40	14	4	2	28	11	8	1
31d74	partial	75	35	28	17	25	8	22	10
31d76	partial	71	26	15	8	37	11	19	7
32a13	complete	92	32	23	10	34	14	35	8
32a15	complete	88	26	25	8	30	10	33	8
32c12	partial	60	19	6	4	39	11	15	4
32d14	complete	74	24	5	4	37	11	32	9
32d15	partial	48	17	4	3	20	6	24	8
45a62	partial	89	32	18	11	42	11	29	10
45a63	partial	81	24	18	11	37	7	26	6
45a64	complete	113	31	34	11	38	9	41	11
45a65	complete	99	30	22	7	40	13	37	10
46a11	incomplete	59	24	16	6	21	9	22	9
46a13	incomplete	28	19	7	6	11	7	10	6
TOTALS		2021	719	457	213	858	291	706	215

Appendix C

USGS Land Use and Land Cover Classification

Source: Anderson et al. (1976)

Level I	Level II
1 Urban or Built-up Land	
	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	
	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	
	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	
	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	
	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	
	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	
	71 Dry Salt Flats.
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	
	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	
	91 Perennial Snowfields
	92 Glaciers

Appendix D Description of Selected Landscape Metrics

Metric	Full Name	Units	Category	Metric Description
NP	Number of Patches	none	Response	Number of Patches
PR	Patch Richness	none	Response	Number of land cover types
TE	Total Edge	m	Response	Total edge
SHDI	Shannon's Diversity Index	none	Response	Measure of diversity of landscape; value is 0 if landscape consists of a single patch
CONTAG	Contagion	%	Response	Degree that land cover types are distributed in clumps; value is 100% if landscape consists of a single patch
ENN_MN	Mean of Euclidean Nearest Neighbor	m	Response	Average distance between a patch and its nearest neighbor of the same land cover
AREA_MN	Mean Size of Patch Areas	m^2	Response	Average size of a patch
SHAPE_MN	Mean of Shape Index	none	Response	Average of patch perimeter to minimum patch perimeter ratio; values close to 1 indicate a square compact shape
PLAND_EDGE	Percentage of Edge Forest Land Cover	%	Response	Percentage of landscape covered by edge forest
NP_CORE	Number of Core Patches	none	Response	Number of core patches
PLAND_CORE	Percentage of Core Forest Land Cover	%	Response	Percentage of landscape covered by core forest
AREA_MN_CORE	Mean Size of Core Forest Land Cover Patches	m^2	Response	Average size of a core forest patch
SHAPE_MN_CORE	Mean of the Core Forest Land Cover Shape Index	none	Response	Average of patch perimeter to minimum patch perimeter ratio of core forest patches
ENN_MN_CORE	Mean of Euclidean Nearest Neighbor of the Core Forest	m	Response	Average of distance between a core patch and the next nearest core forest patch
ROAD_LENGTH	Road Length	km	Predictor	Total distance of roads
PLAND_TA	Percentage of Transitional Areas Land Cover	%	Predictor	Percentage of landscape covered by transitional areas
TE_TA	Edge of the Transitional Areas Land Cover	m	Predictor	Total edge of transitional area patches
PLAND_UTILITY	Percentage of the Utility Corridors Land Cover	%	Predictor	Percentage of land covered by utility corridors
TE_UTILITY	Edge of Utility Corridors Land Cover	m	Predictor	Total edge created by the construction of utility corridors
TE_OG	Edge of the Oil and Gas Land Cover	m	Predictor	Total edge created by oil and gas development
PLAND_OG	Percentage of Oil and Gas Land Cover	%	Predictor	Percentage of landscape covered by oil and gas development

Appendix E

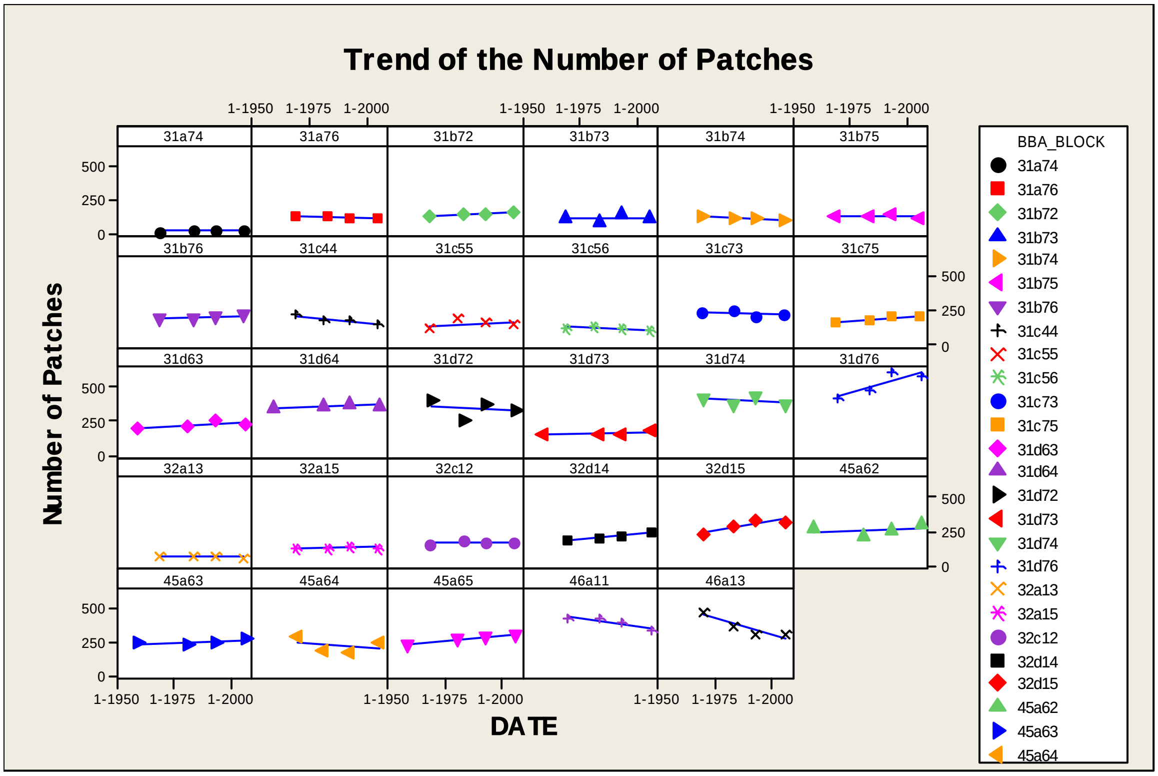
Annual Change of Landscape Fragmentation Metrics per Breeding Bird Atlas Block

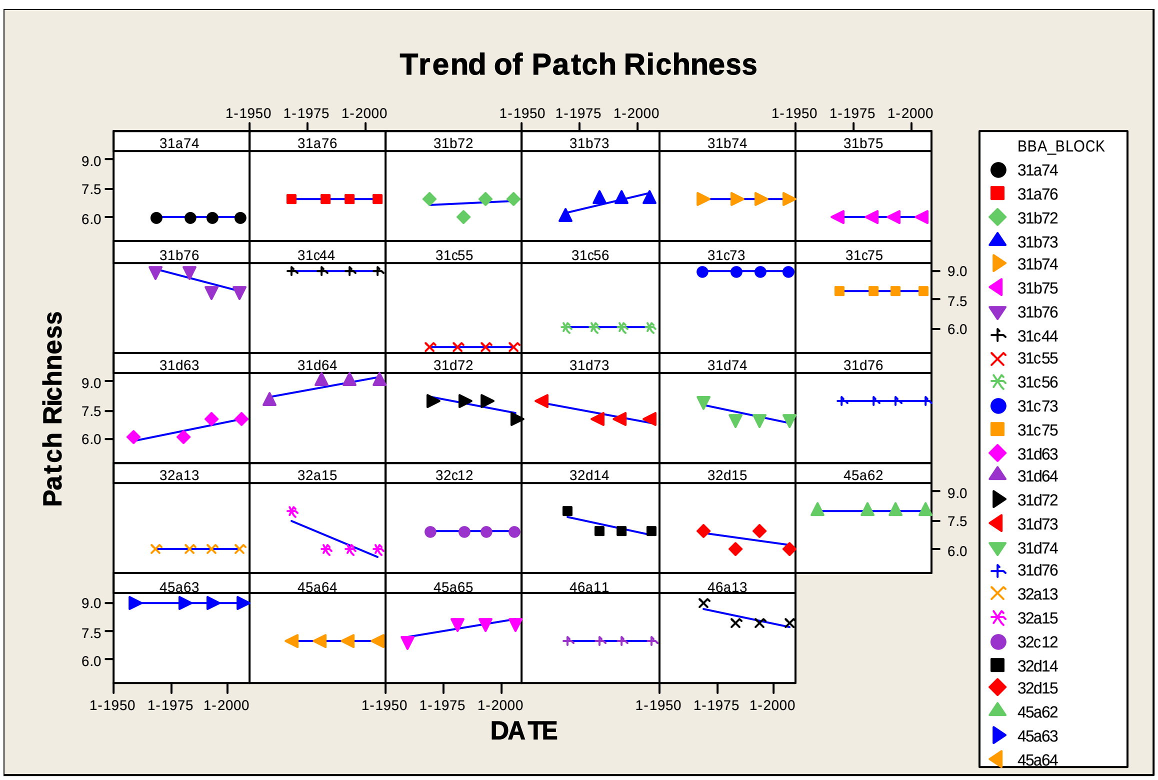
BBA_BLOCK	NP	TE (m)	AREA_MN (HA)	ENN_MN (m)	EDGE_AREA (HA)	NP_CORE	CORE_AREA (HA)	AREA_MN_CORE_(HA)
31a74	0.090	154.978	-0.685	-4.562	-0.011	0.000	-0.040	-0.020
31a76	-0.172	170.112	0.028	-0.054	-0.269	-0.031	0.263	0.146
31b72	0.634	1495.936	-0.079	-0.872	5.452	0.145	-6.097	-0.858
31b73	0.220	835.919	-0.043	0.131	3.991	0.125	-3.859	-0.867
31b74	-0.881	1152.598	0.170	1.850	4.847	0.026	-5.210	-0.418
31b75	-0.205	890.026	0.032	2.342	3.191	0.085	-2.715	-0.586
31b76	0.580	2011.263	-0.033	-0.207	7.578	0.177	-9.179	-1.170
31c44	-1.561	-1053.151	0.114	1.715	-4.587	-0.042	5.228	1.203
31c55	0.798	1737.872	-0.128	0.307	6.466	0.151	-7.374	-1.813
31c56	-0.447	415.832	0.086	1.788	0.720	0.107	-1.734	-4.219
31c73	-0.739	828.044	0.034	0.523	4.641	0.303	-4.391	-0.317
31c75	1.553	3368.430	-0.117	-1.739	10.581	0.285	-12.320	-1.197
31d63	0.742	1436.011	-0.039	0.968	4.981	0.246	-4.670	-1.096
31d64	0.521	928.405	-0.010	0.680	3.667	0.162	-2.728	-0.302
31d72	-0.913	2731.725	0.012	-0.298	4.814	0.180	-6.264	-0.297
31d73	0.528	2100.484	-0.052	1.320	7.776	0.271	-8.144	-1.972
31d74	-0.597	1877.396	0.010	-0.233	3.586	0.143	-4.745	-0.124
31d76	4.939	7106.946	-0.048	-1.781	10.603	-0.600	-14.341	-0.155
32a13	-0.127	997.980	0.079	-0.612	4.309	0.108	-4.230	-4.029
32a15	0.250	2784.095	-0.035	-0.531	10.717	0.187	-12.921	-1.940
32c12	0.211	1353.301	-0.021	-0.392	5.074	0.157	-4.843	-0.439
32d14	1.584	3069.047	-0.086	-2.923	11.445	0.742	-11.868	-1.912
32d15	2.549	2604.805	-0.080	-0.637	4.131	-0.123	-2.847	0.103
45a62	0.673	768.370	-0.021	-0.559	3.781	0.074	-1.458	-0.169
45a63	0.654	772.636	-0.024	-0.188	2.039	0.060	2.331	-0.020
45a64	-1.065	-324.705	0.036	1.209	-2.577	0.067	5.240	0.102
45a65	1.672	1911.420	-0.058	-0.637	3.764	0.121	-1.522	-0.517
46a11	-2.639	-1505.743	0.042	0.924	-0.465	0.032	13.365	0.291
46a13	-4.617	-1983.916	0.076	1.283	-0.213	0.157	19.325	0.455
Mean	0.146	1332.280	-0.029	-0.041	4.139	0.114	-3.026	-0.763
Trend of Increasing Fragmentation	positive	positive	negative	neutral	positive	neutral	negative	negative

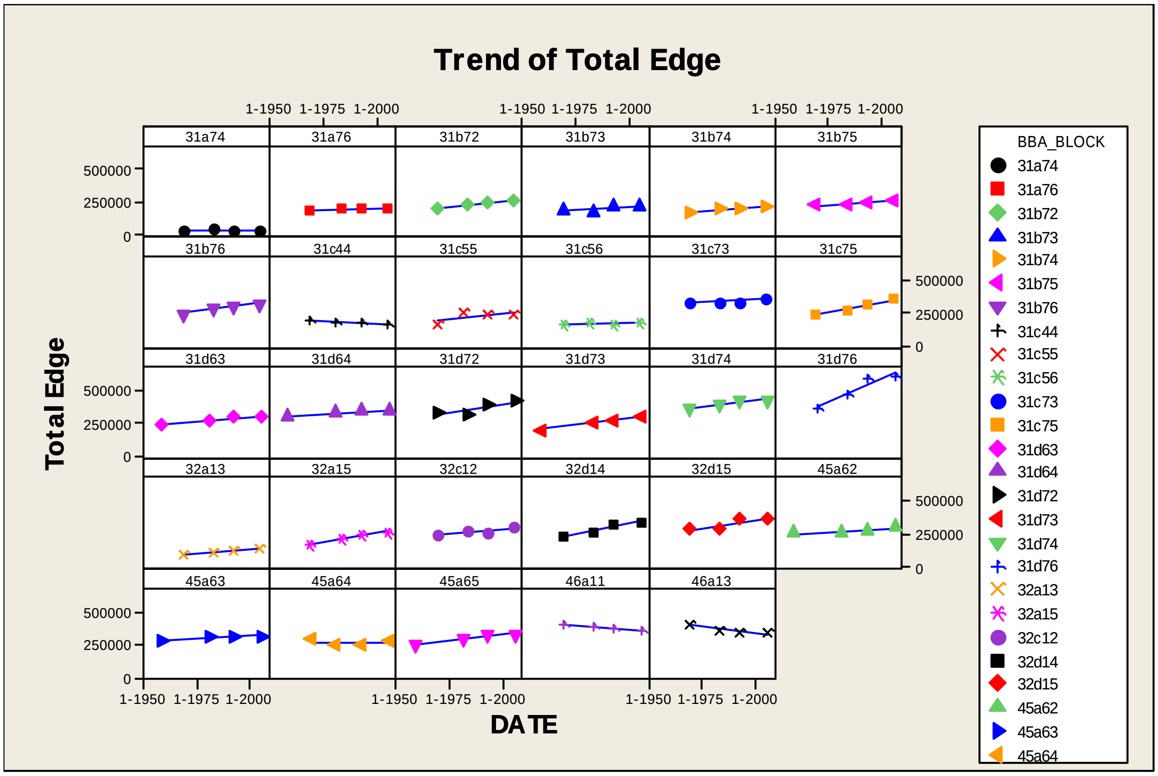
Appendix E - continued

BBA_BLOCK	ENN_MN_CORE (m)	ROAD_LENGTH (km)	TA_AREA (HA)	TE_TA (m)	UT_AREA (HA)	TE_UTILITY (m)	OG_AREA (HA)	TE_OG (m)
31a74	0.000	0.134	-0.083	-84.879	0.000	0.000	-0.009	-20.792
31a76	0.134	-0.060	-0.199	-85.614	0.000	0.000	0.269	512.578
31b72	0.230	0.141	-0.240	-158.877	-0.069	-232.591	0.790	1563.344
31b73	-0.312	0.509	-0.693	-756.516	-0.028	-118.429	0.046	101.241
31b74	-0.388	0.103	-0.177	-399.725	-0.050	-207.871	0.480	910.882
31b75	0.830	0.524	-1.051	-528.187	-0.036	-156.111	0.052	74.912
31b76	0.194	0.248	0.872	-42.038	-0.038	-177.723	0.430	865.640
31c44	-0.610	0.035	-0.557	-871.568	0.000	-0.199	0.020	47.882
31c55	-0.229	0.310	0.364	70.788	0.000	0.000	0.212	426.866
31c56	-0.822	0.116	0.658	-117.979	0.000	0.000	0.227	454.856
31c73	0.123	-0.195	-0.664	-505.165	0.045	158.239	0.589	1221.428
31c75	0.135	-0.408	-0.449	-329.421	0.000	0.597	2.576	4696.729
31d63	0.172	0.432	-1.137	-730.794	0.068	179.463	0.297	535.231
31d64	-0.172	0.373	-1.408	-831.552	-0.003	-6.185	0.424	626.039
31d72	-0.038	-0.035	-0.858	-1127.839	0.029	79.680	2.352	4145.334
31d73	0.480	0.543	-0.468	-252.073	0.016	25.439	0.240	385.921
31d74	0.690	0.260	-0.238	-318.119	-0.026	-144.860	1.285	2296.047
31d76	0.801	-0.359	-3.256	-1421.525	-0.204	-554.812	7.513	12179.210
32a13	-0.721	0.317	-0.433	-238.743	0.000	0.000	-0.017	-44.276
32a15	0.960	0.362	1.446	288.468	0.000	0.000	0.465	914.536
32c12	0.413	0.321	-0.776	-343.809	0.001	0.295	0.201	401.766
32d14	0.364	0.846	-0.743	-393.209	0.089	402.403	0.187	378.111
32d15	0.021	-0.127	-3.553	-1168.495	-0.230	-1.781	2.672	4686.522
45a62	-0.792	0.282	-2.893	-567.218	-0.095	-271.756	0.108	240.330
45a63	0.061	0.376	-5.289	-684.167	-0.057	-203.991	0.205	453.335
45a64	1.005	0.375	-3.662	-1546.822	0.018	59.336	0.141	306.694
45a65	0.746	0.460	-3.087	313.479	0.000	0.000	0.151	334.769
46a11	-1.343	0.018	-12.835	-3462.883	-0.167	-438.642	0.092	174.680
46a13	-1.912	-0.019	-19.057	-5204.767	-0.087	-235.567	0.093	190.038
Mean	0.001	0.203	-2.085	-741.353	-0.028	-63.623	0.762	1346.891
Trend of Increasing Fragmentation	neutral	positive	positive	positive	positive	positive	positive	positive

Appendix F – Graphs of Landscape Trends



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31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
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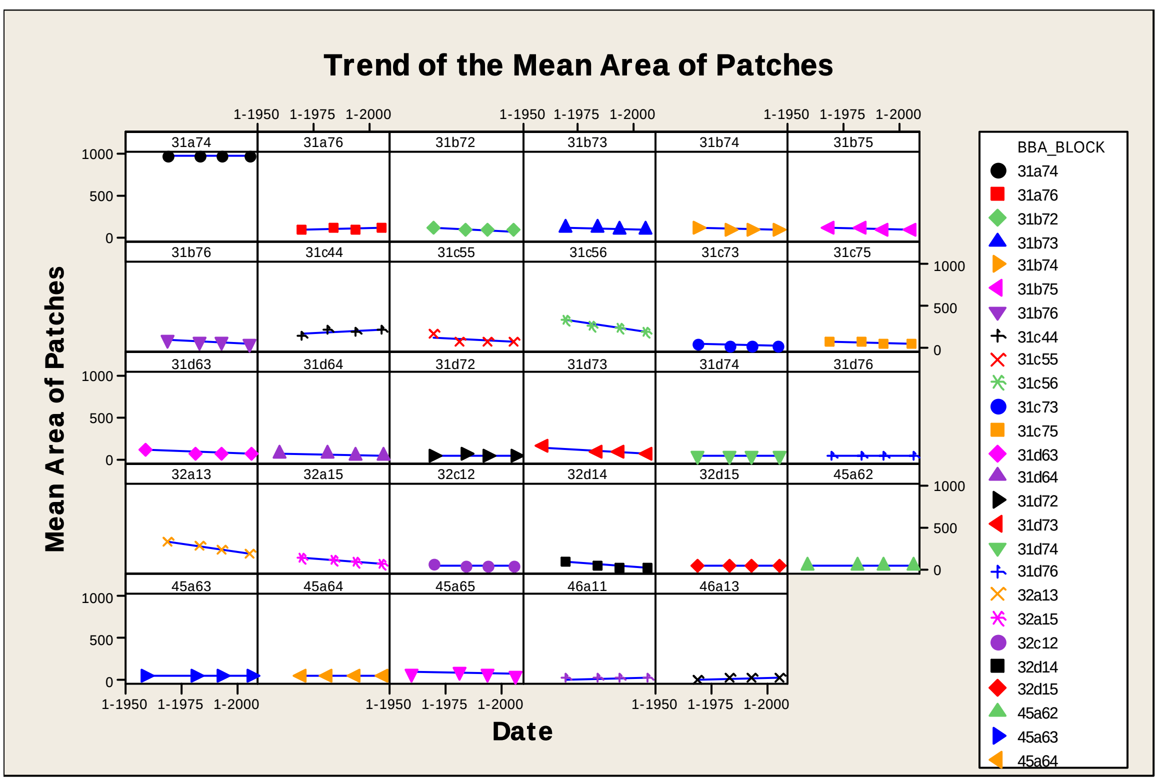
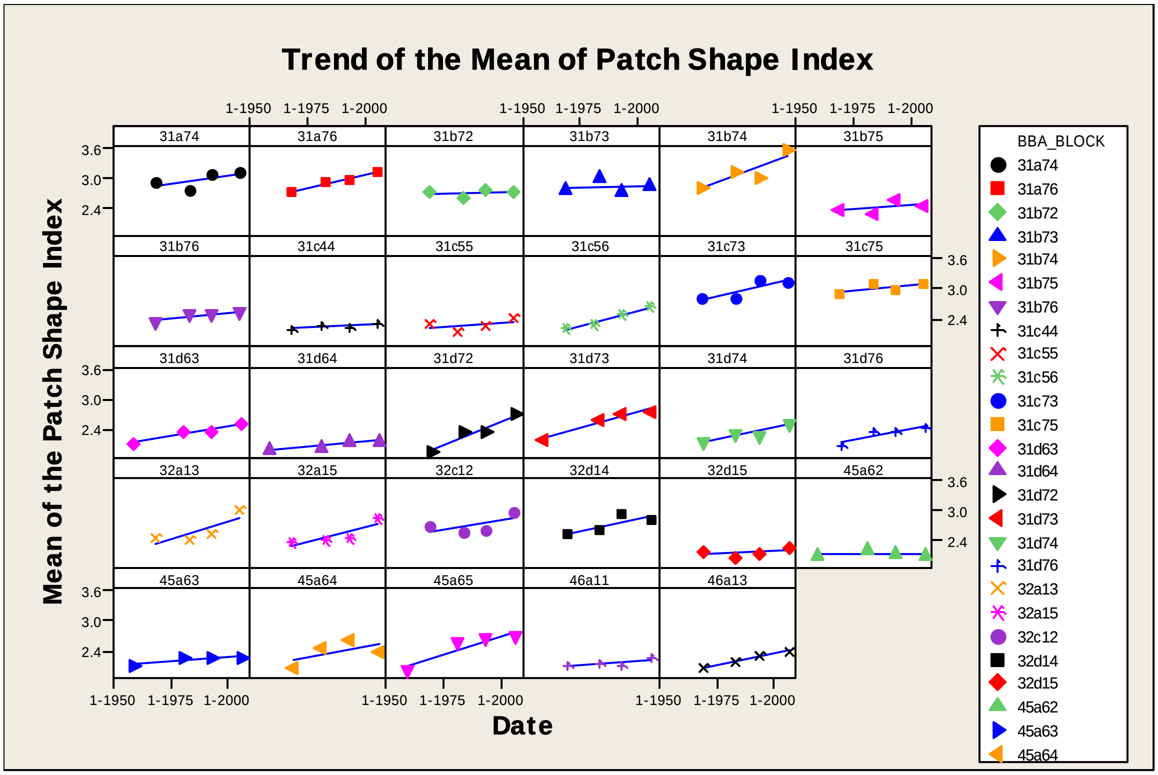
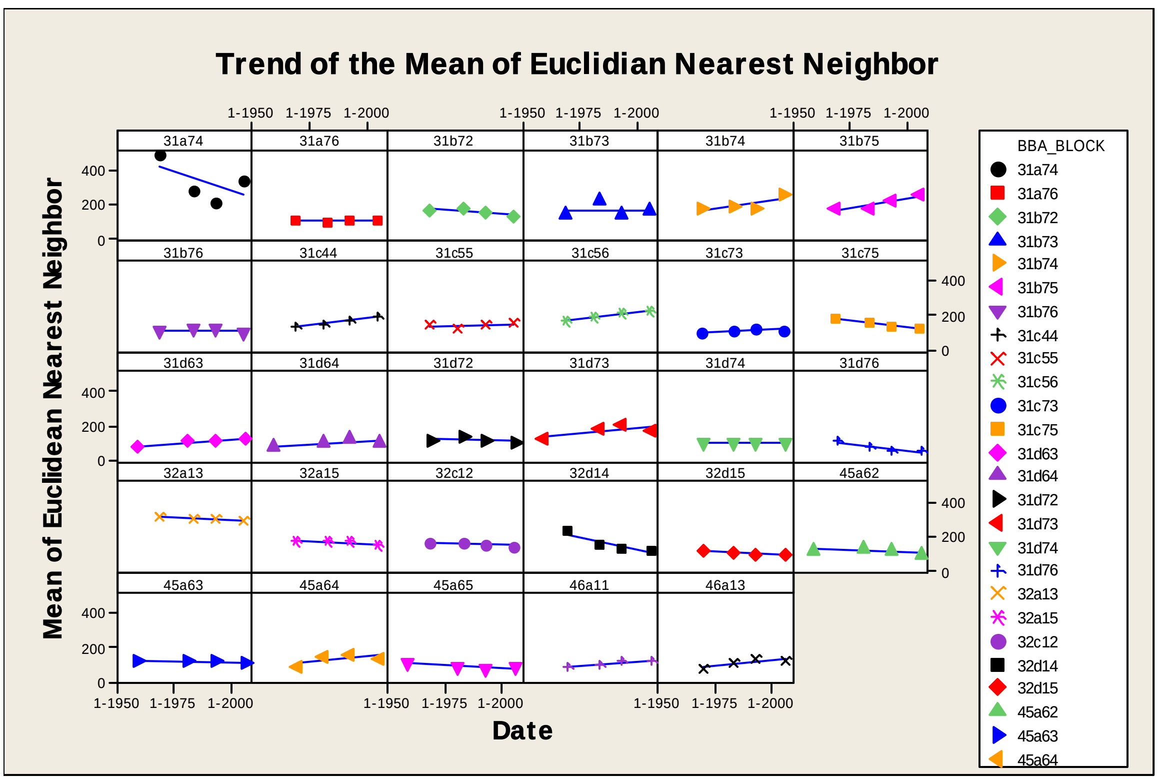
45a64
45a65
46a11
46a13
500000
250000
0
1-1950
1-1975
1-2000


Trend of the Mean Area of Patches
Mean Area of Patches
Date
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1000
500
0
1-1950
1-1975
1-2000


Trend of the Mean of Patch Shape Index
Mean of the Patch Shape Index
Date
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
2.4
3.0
3.6


Trend of the Mean of Euclidian Nearest Neighbor
Mean of Euclidean Nearest Neighbor
Date
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
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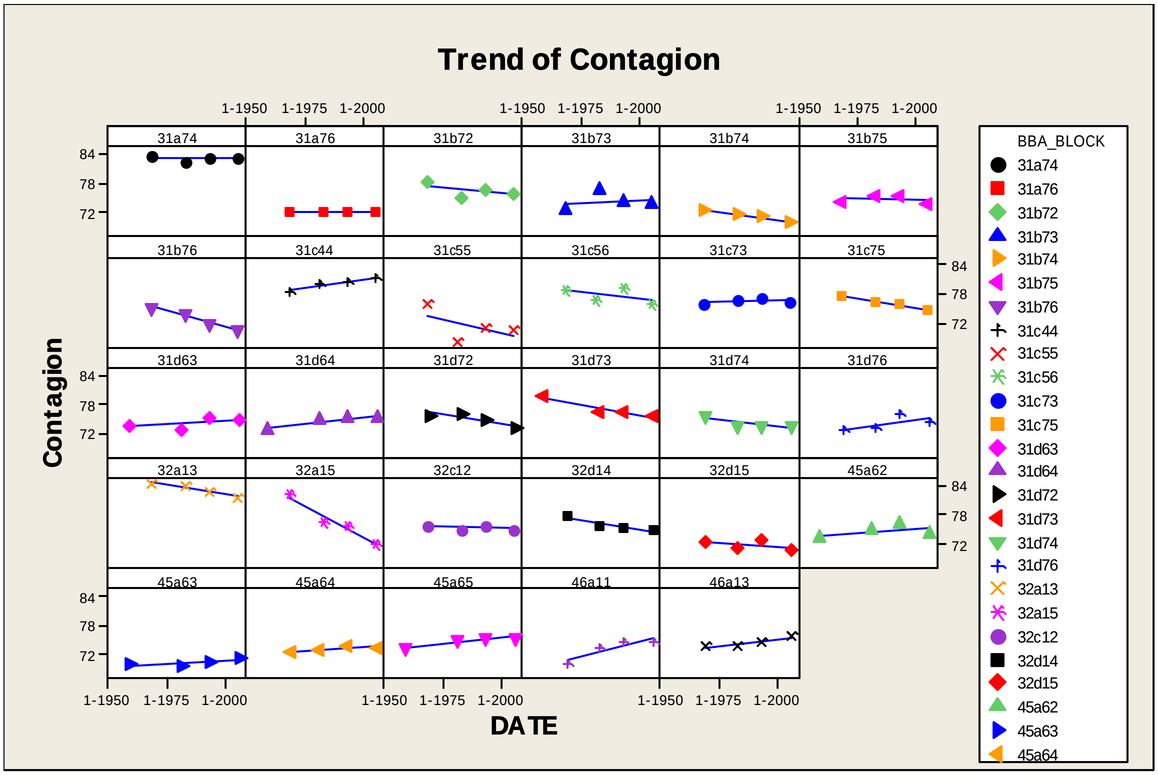
46a13
1-1950
1-1975
1-2000
0
200
400


Trend of Contagion
Contagion
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
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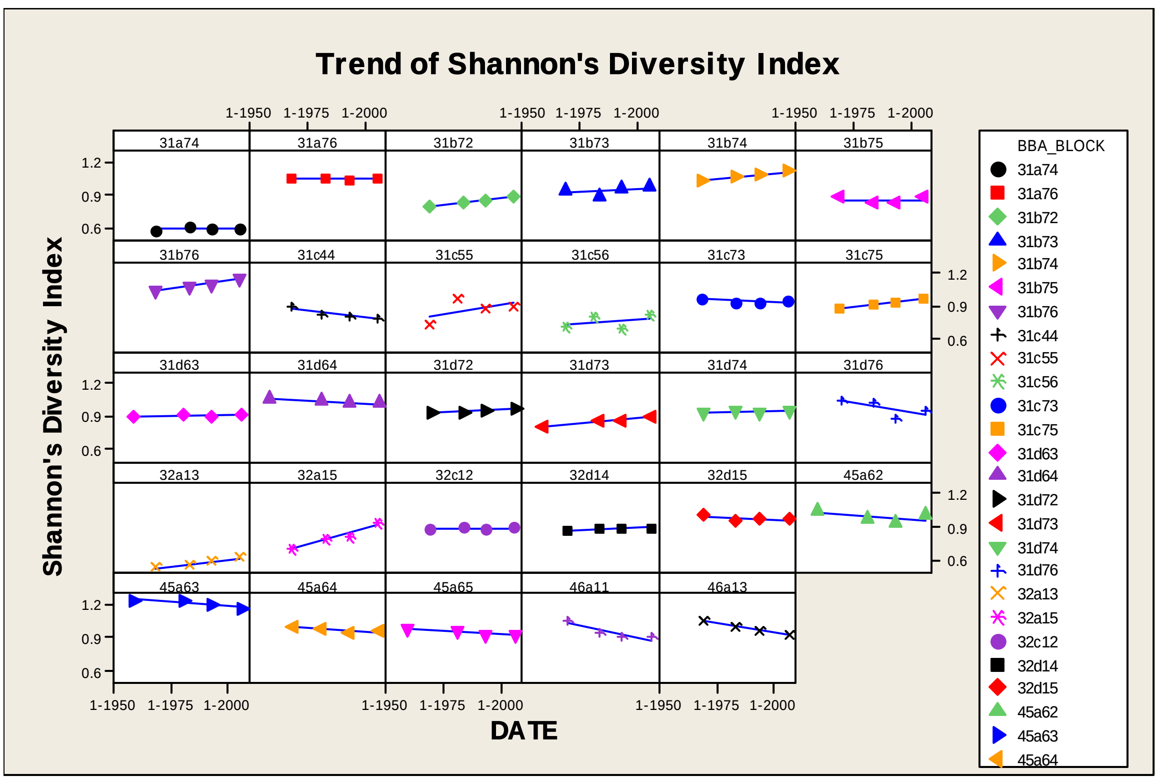
45a65
46a11
46a13


Trend of Shannon's Diversity Index
Shannon's Diversity Index
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
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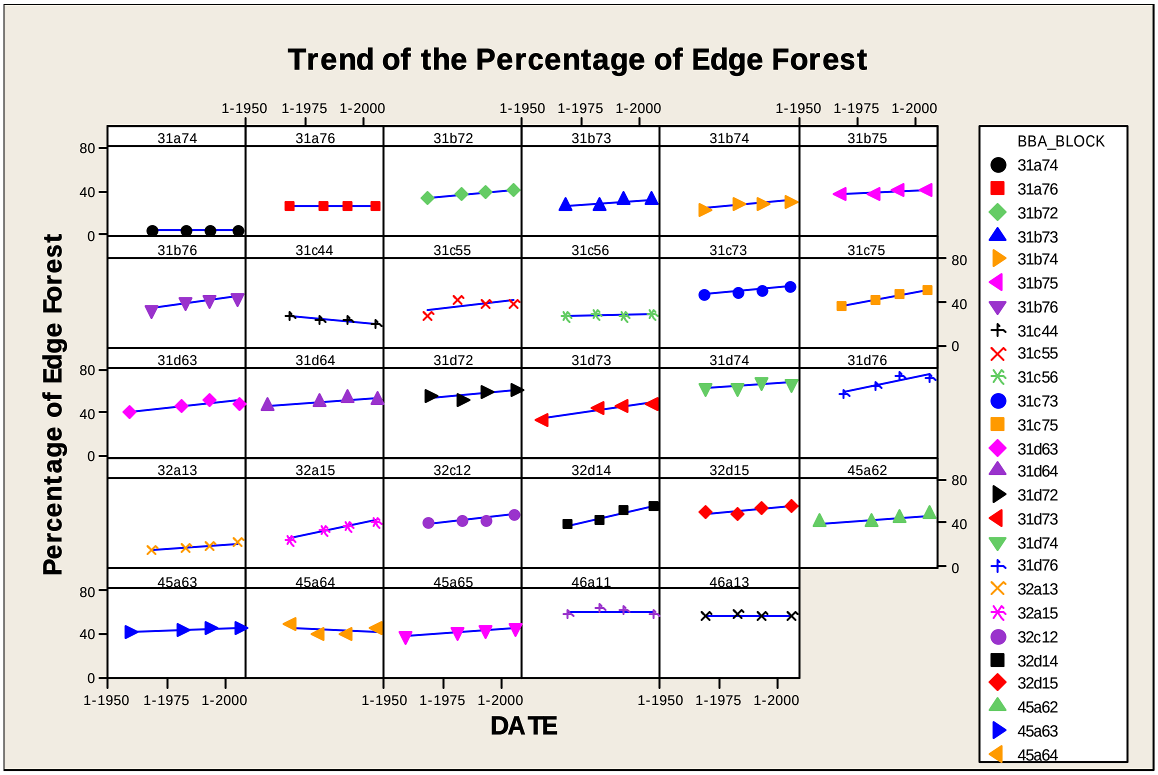
45a65
46a11
46a13


Trend of the Percentage of Edge Forest
Percentage of Edge Forest
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
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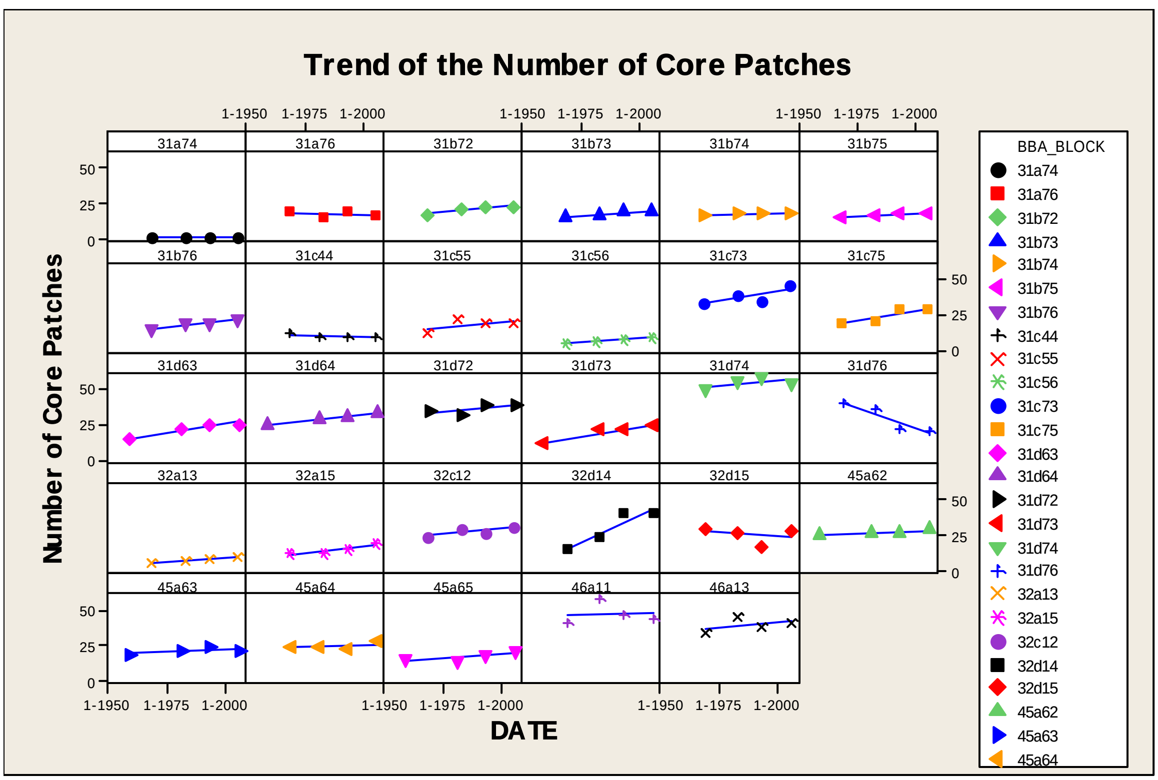
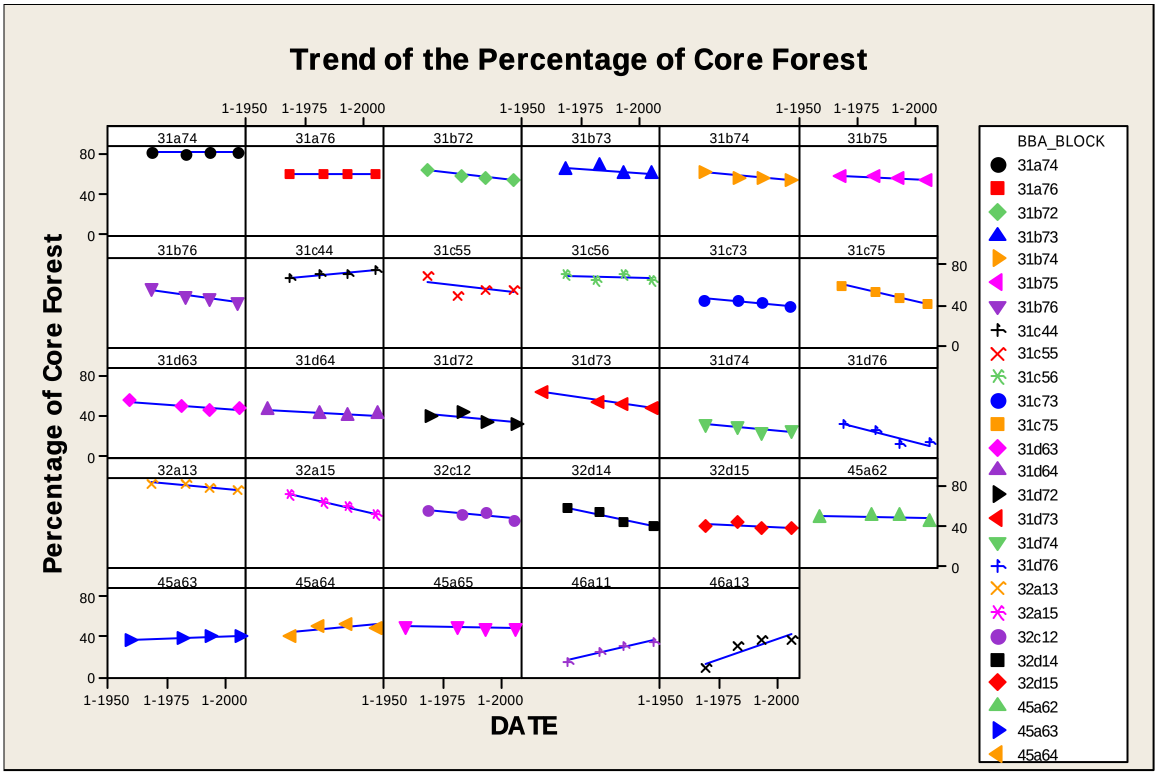
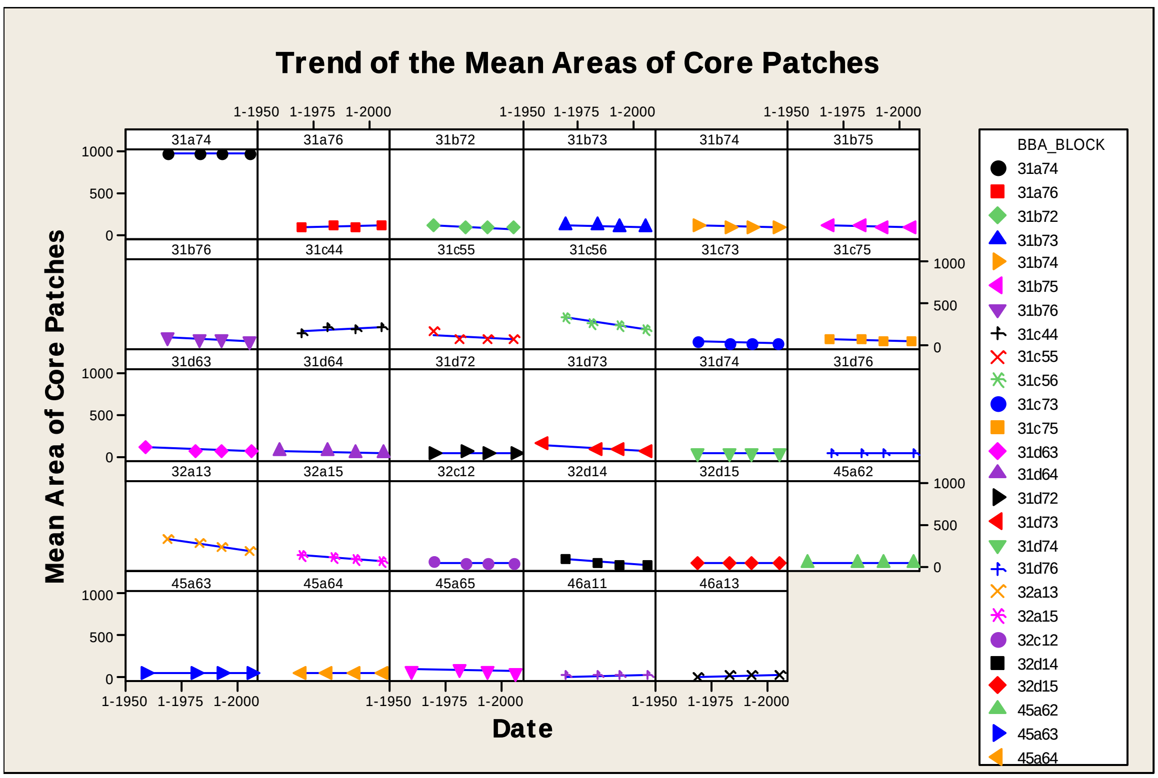
1-1950
1-1975
1-2000
0
40
80

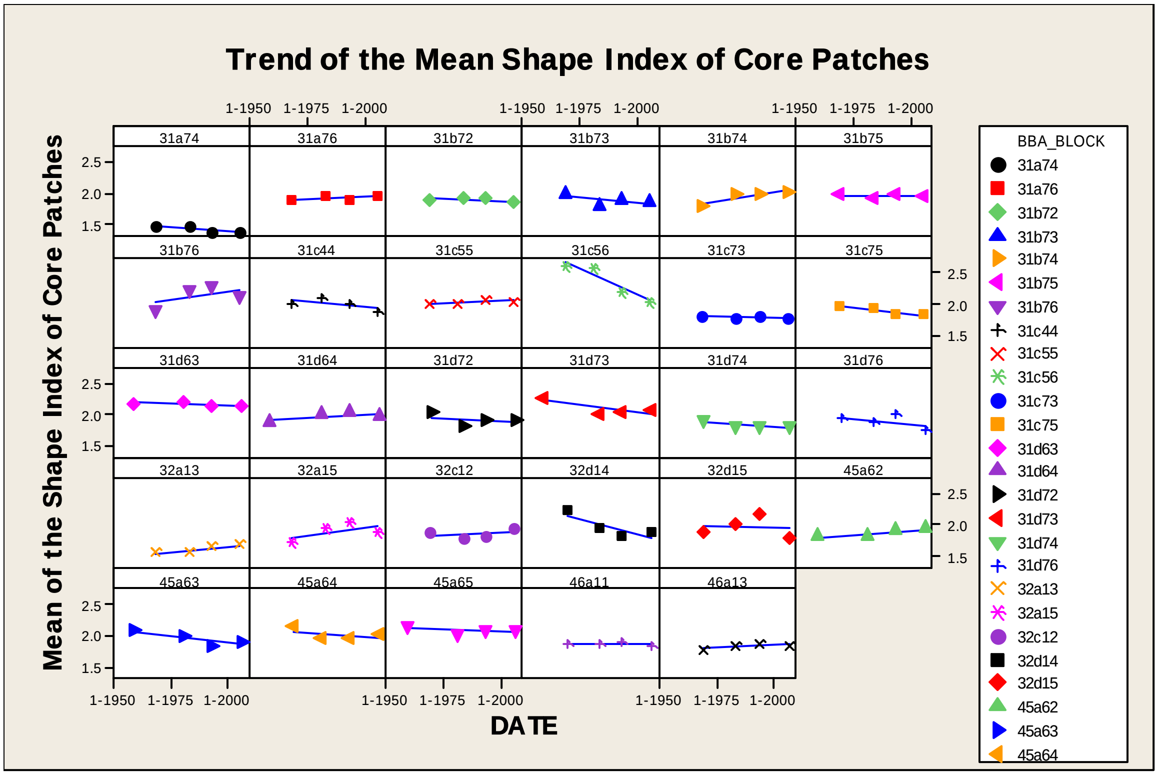

Trend of the Number of Core Patches
Number of Core Patches
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
0
25
50



Trend of the Percentage of Core Forest
Percentage of Core Forest
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000



Trend of the Mean Areas of Core Patches
Mean Area of Core Patches
Date
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000


Trend of the Mean Shape Index of Core Patches
Mean of the Shape Index of Core Patches
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
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45a65
46a11
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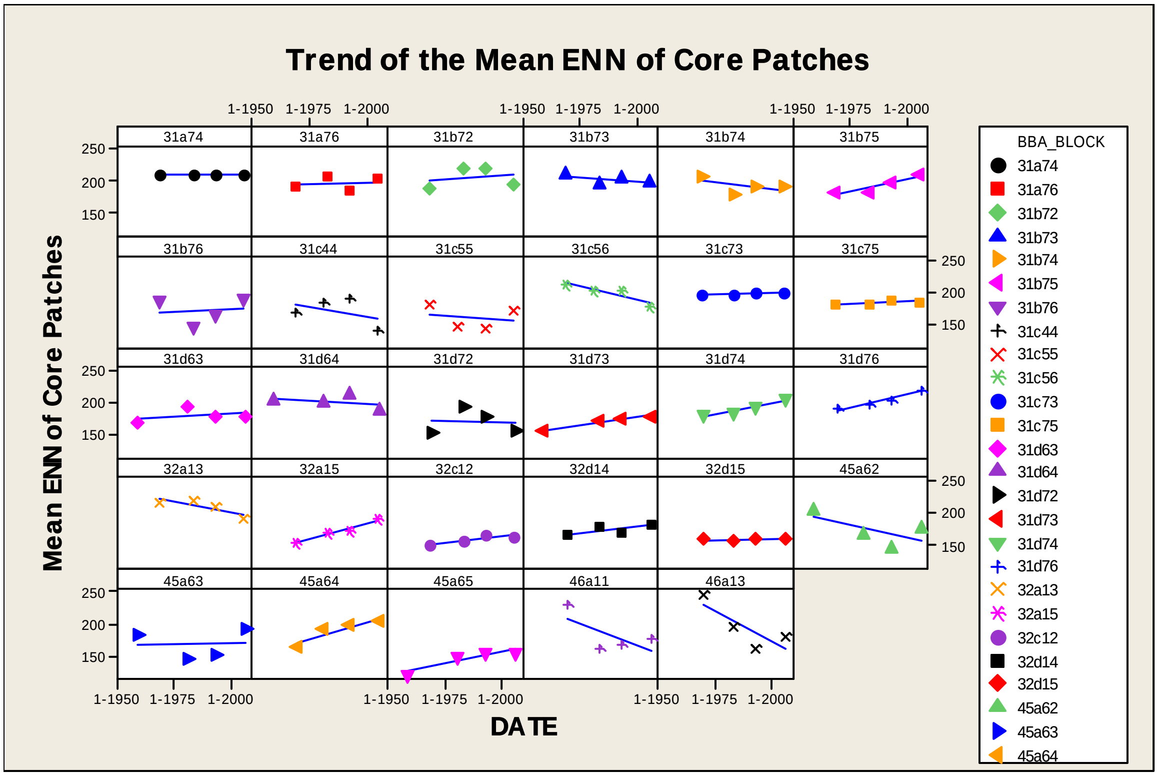
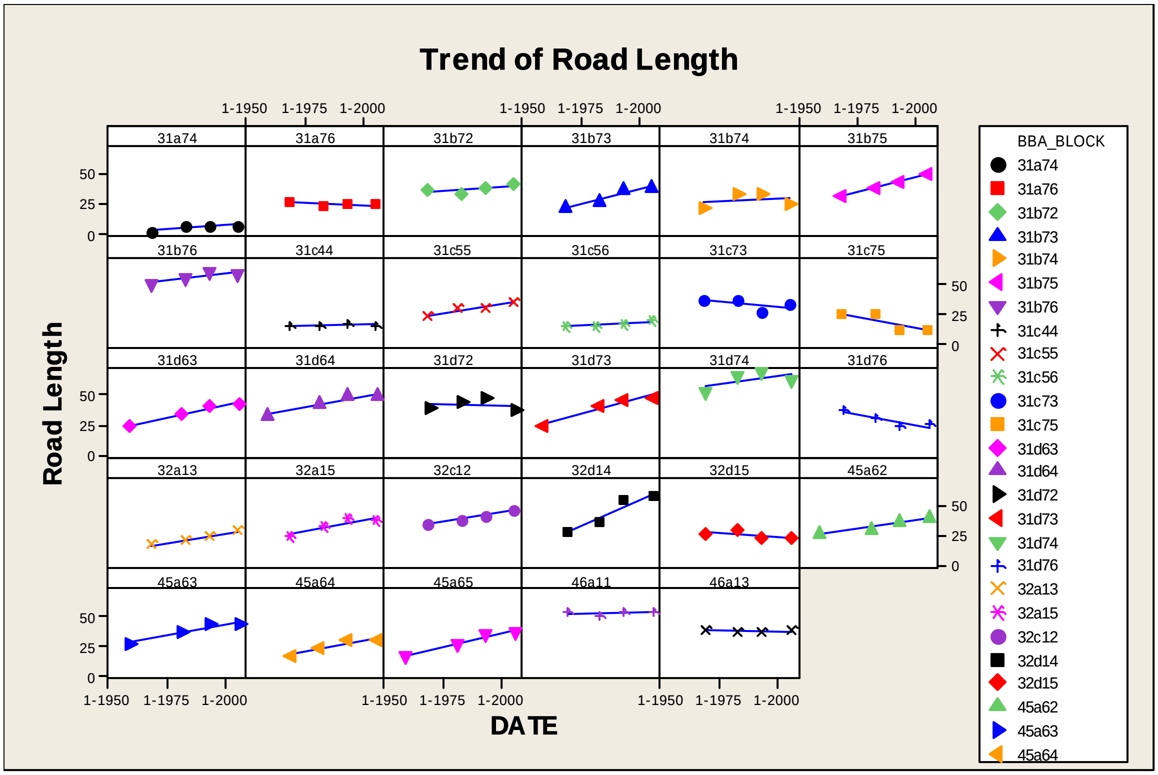
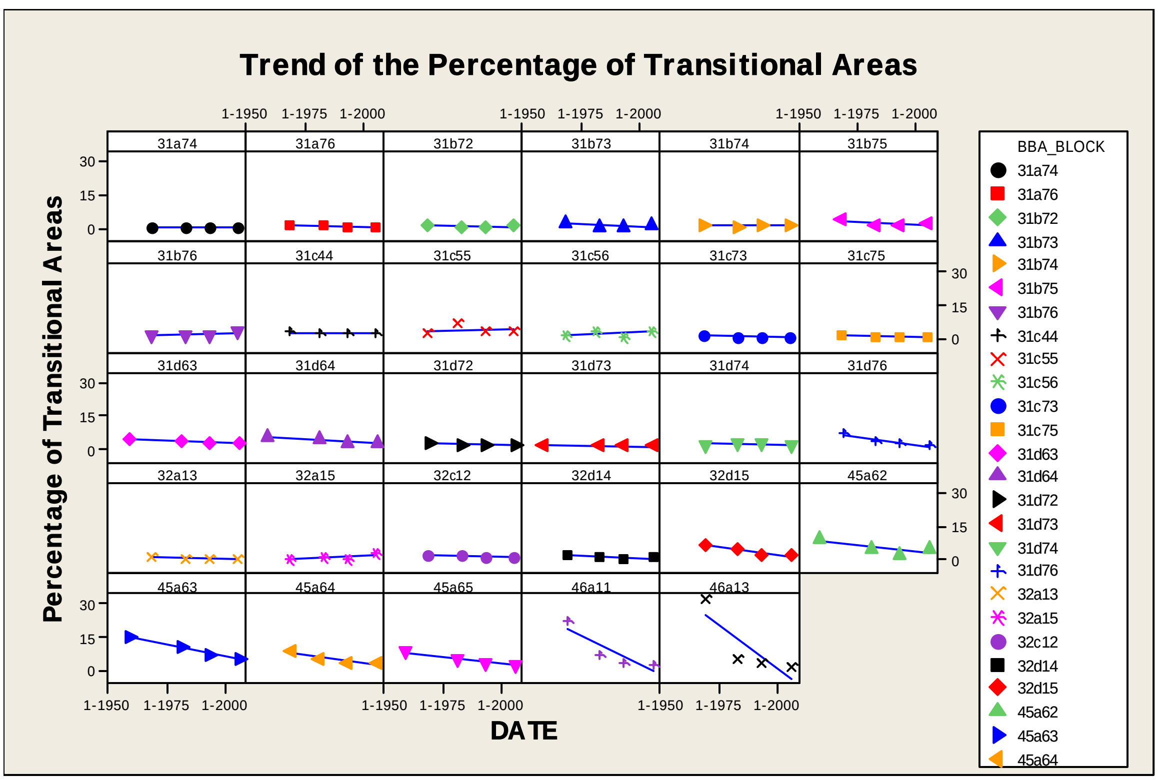
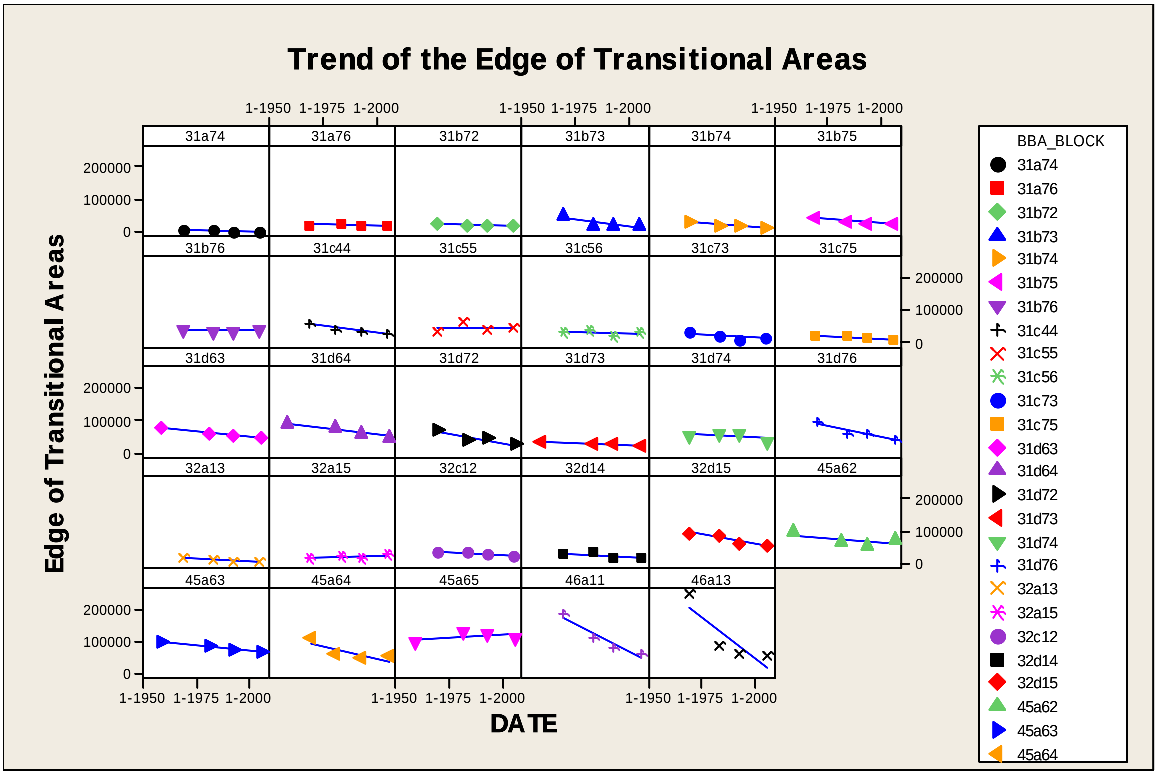
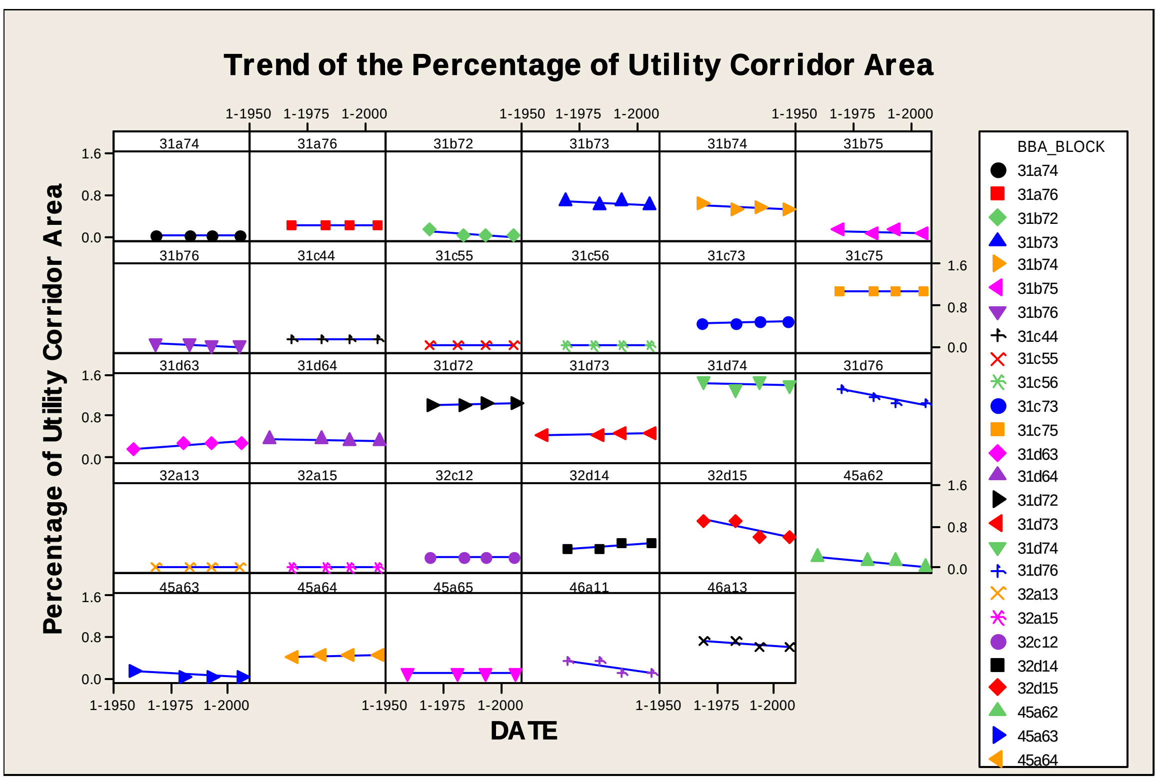
1-1950
1-1975
1-2000
1.5
2.0
2.5

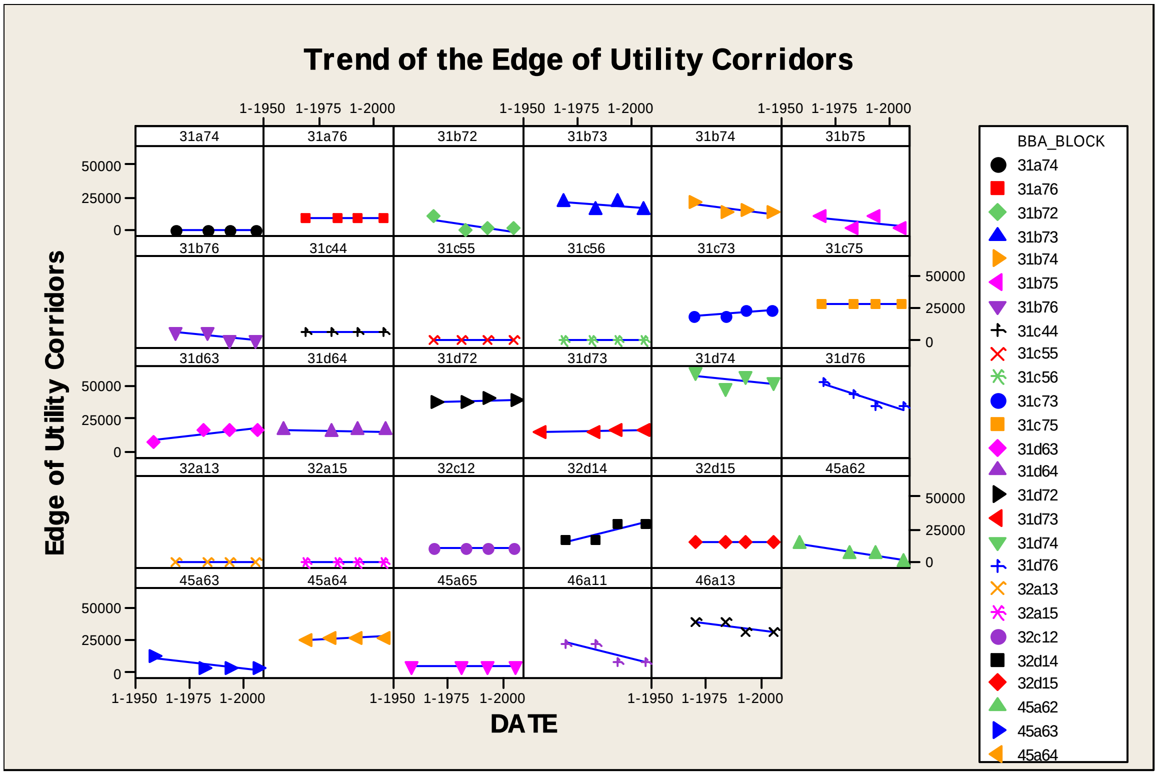

Trend of the Mean ENN of Core Patches
Mean ENN of Core Patches
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
150
200
250

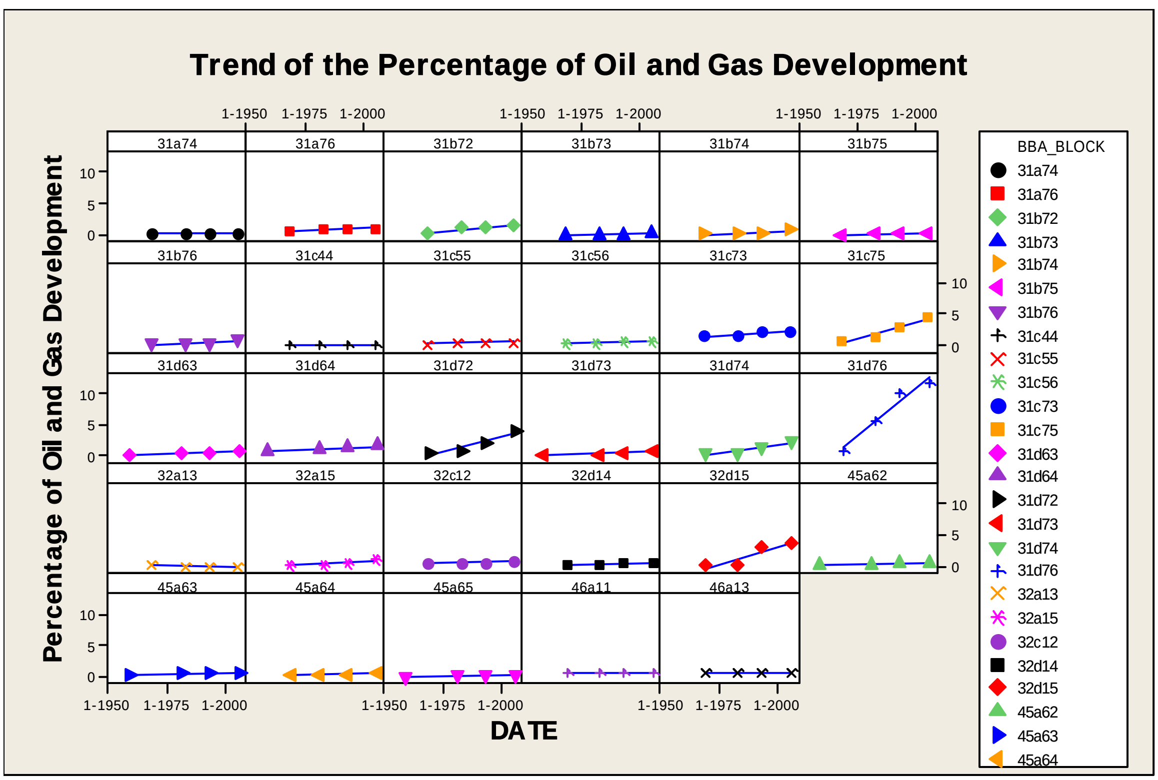

Trend of Road Length
Road Length
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
0
25
50

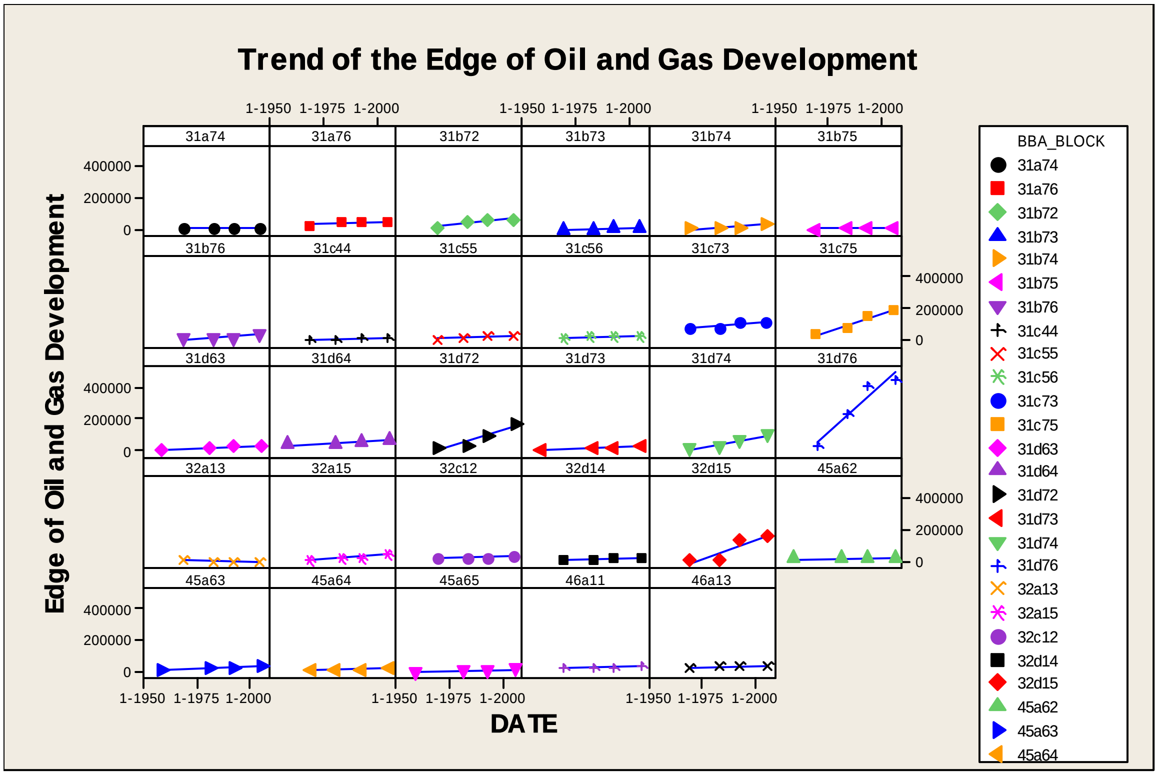

Trend of the Percentage of Transitional Areas
Percentage of Transitional Areas
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
0
15
30


Trend of the Edge of Transitional Areas
Edge of Transitional Areas
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
0
100000
200000
1-1950
1-1975
1-2000


Trend of the Percentage of Utility Corridor Area
Percentage of Utility Corridor Area
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
0.0
0.8
1.6
1-1950
1-1975
1-2000

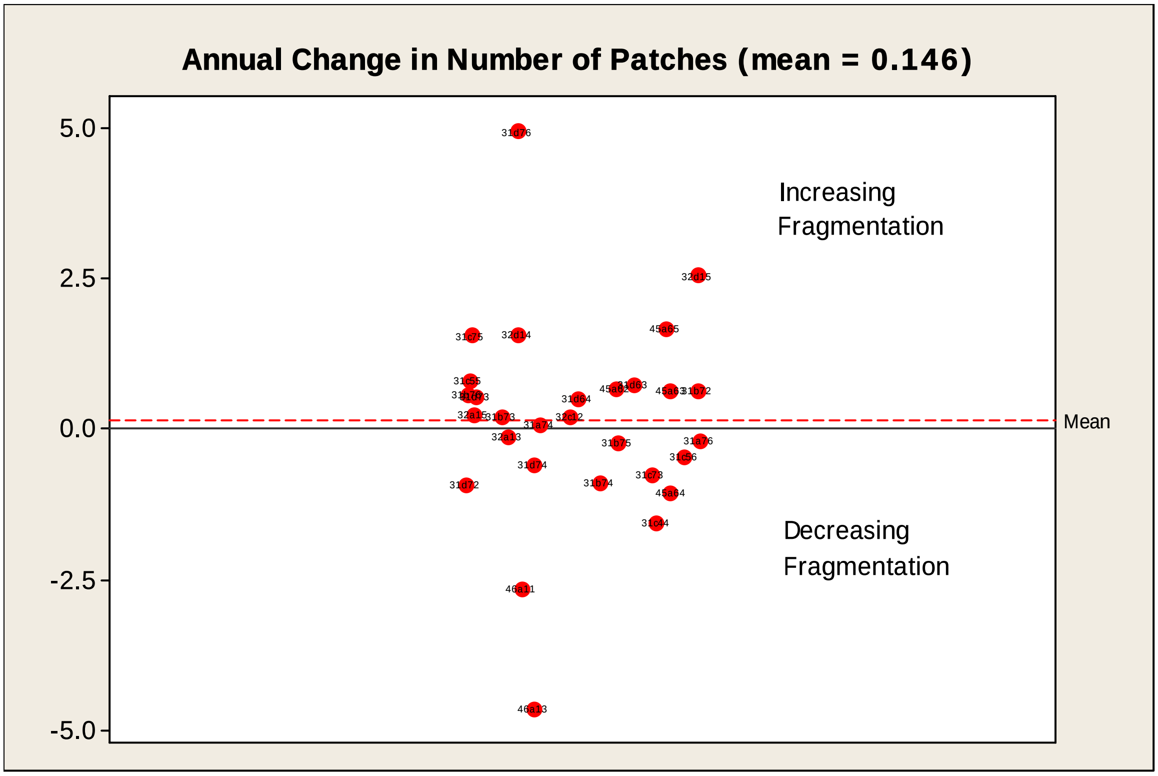

Trend of the Edge of Utility Corridors
Edge of Utility Corridors
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
0
25000
50000

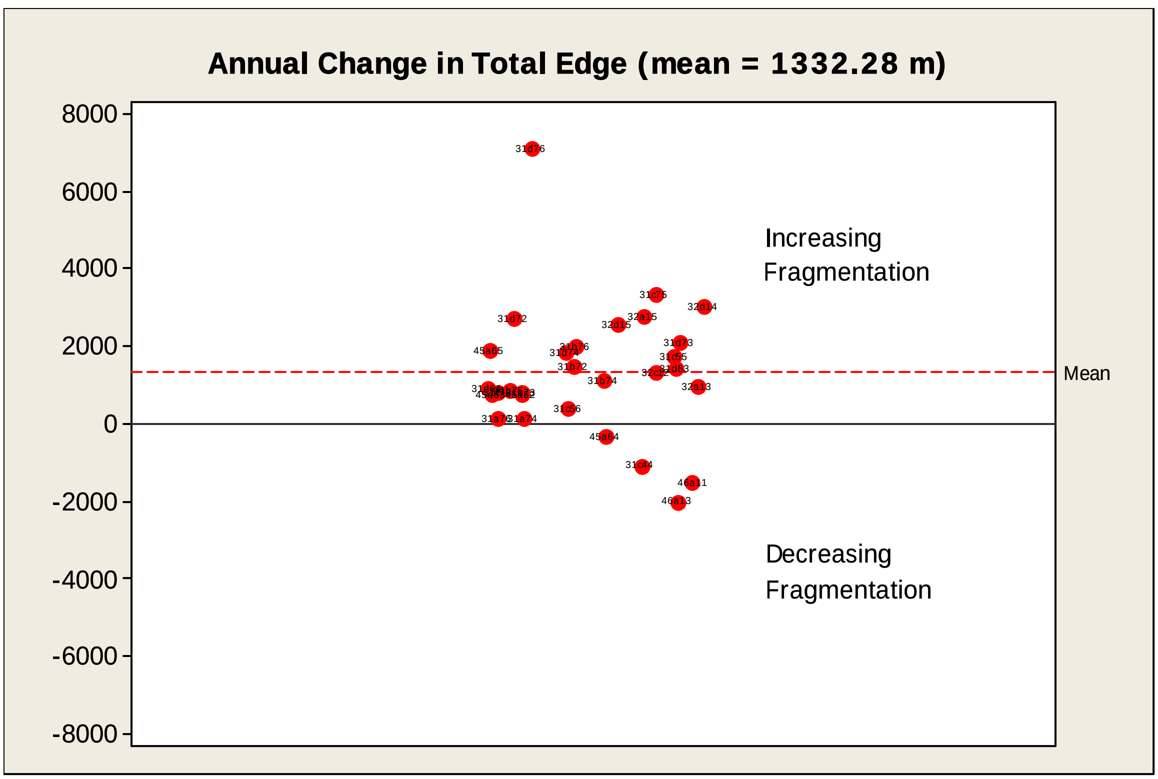

Trend of the Percentage of Oil and Gas Development
Percentage of Oil and Gas Development
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
1-1950
1-1975
1-2000
0
5
10

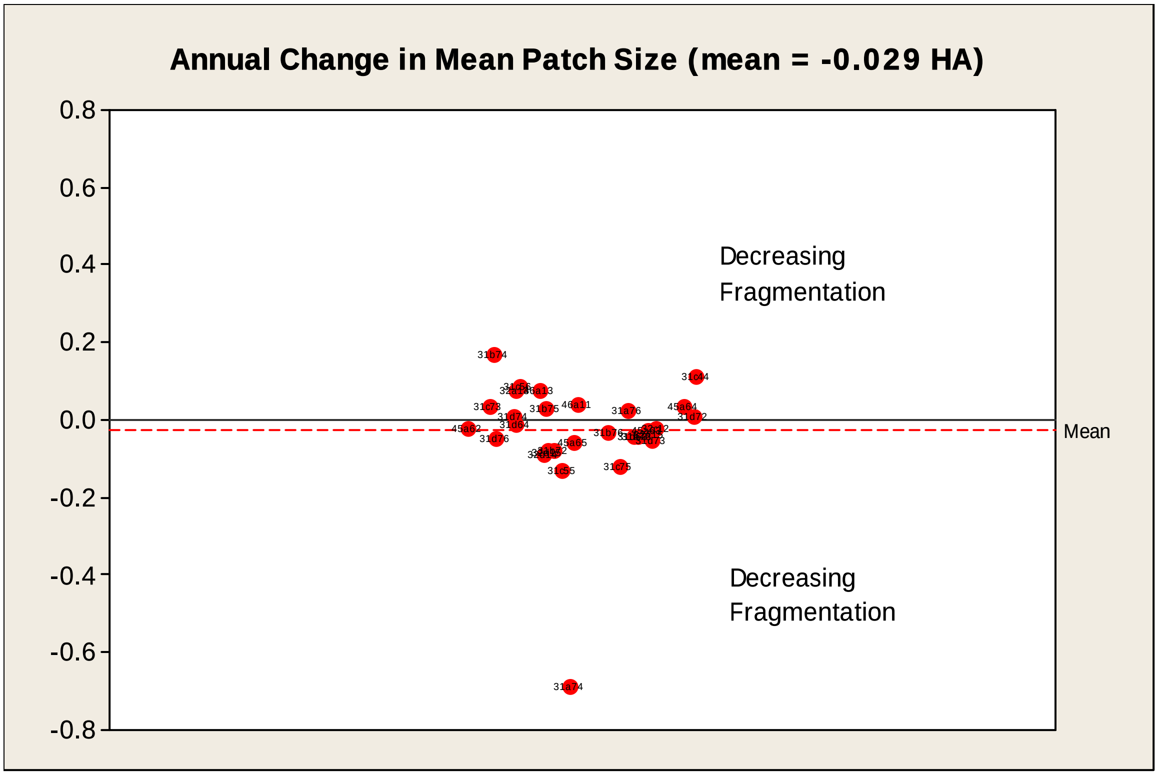


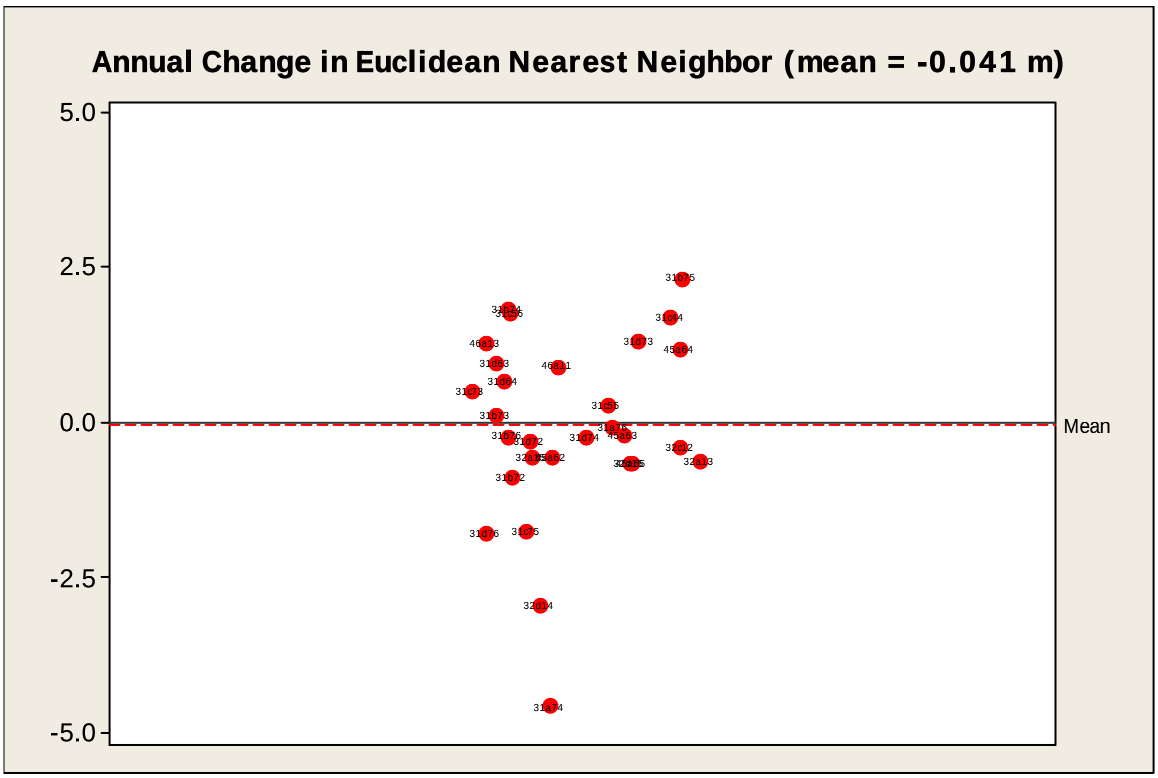
Trend of the Edge of Oil and Gas Development
Edge of Oil and Gas Development
DATE
BBA_BLOCK
31a74
31a76
31b72
31b73
31b74
31b75
31b76
31c44
31c55
31c56
31c73
31c75
31d63
31d64
31d72
31d73
31d74
31d76
32a13
32a15
32c12
32d14
32d15
45a62
45a63
45a64
45a65
46a11
46a13
400000
200000
0
1-1950
1-1975
1-2000

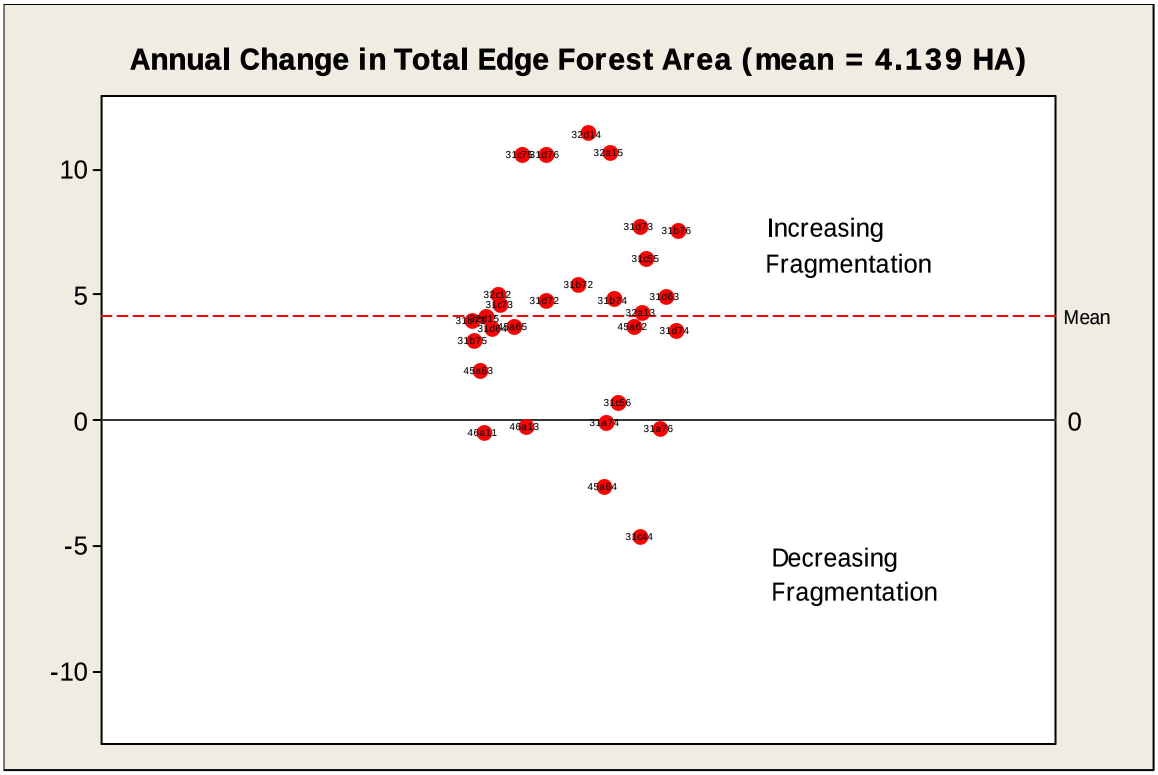
Appendix G – Value Plots of Fragmentation Trends

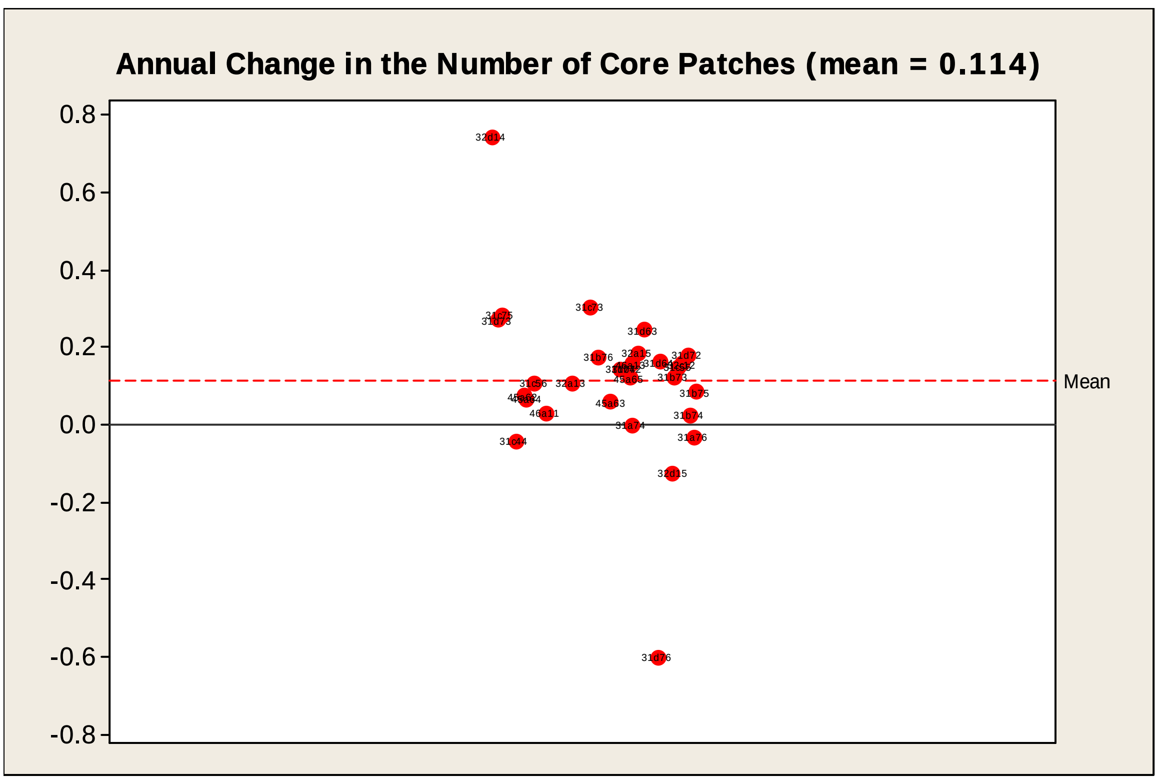


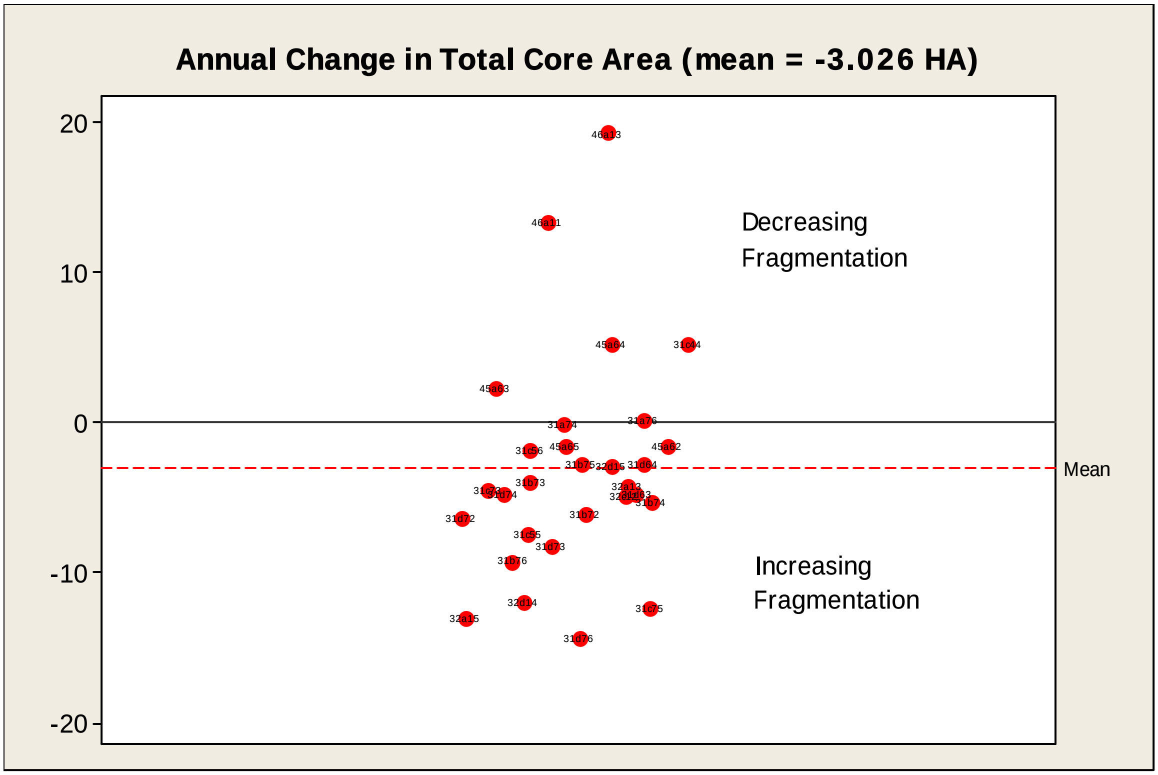


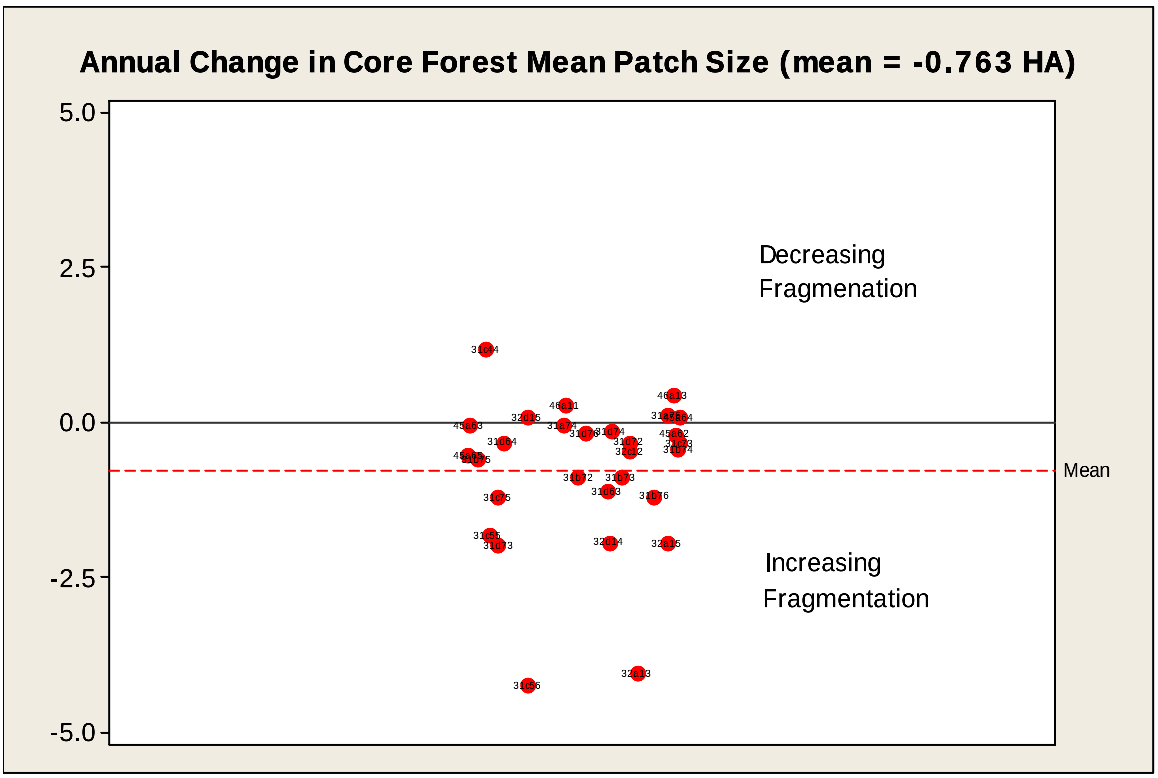

Annual Change in Mean Patch Size (mean = -0.029 HA)
Decreasing
Fragmentation
Decreasing
Fragmentation
Mean
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8

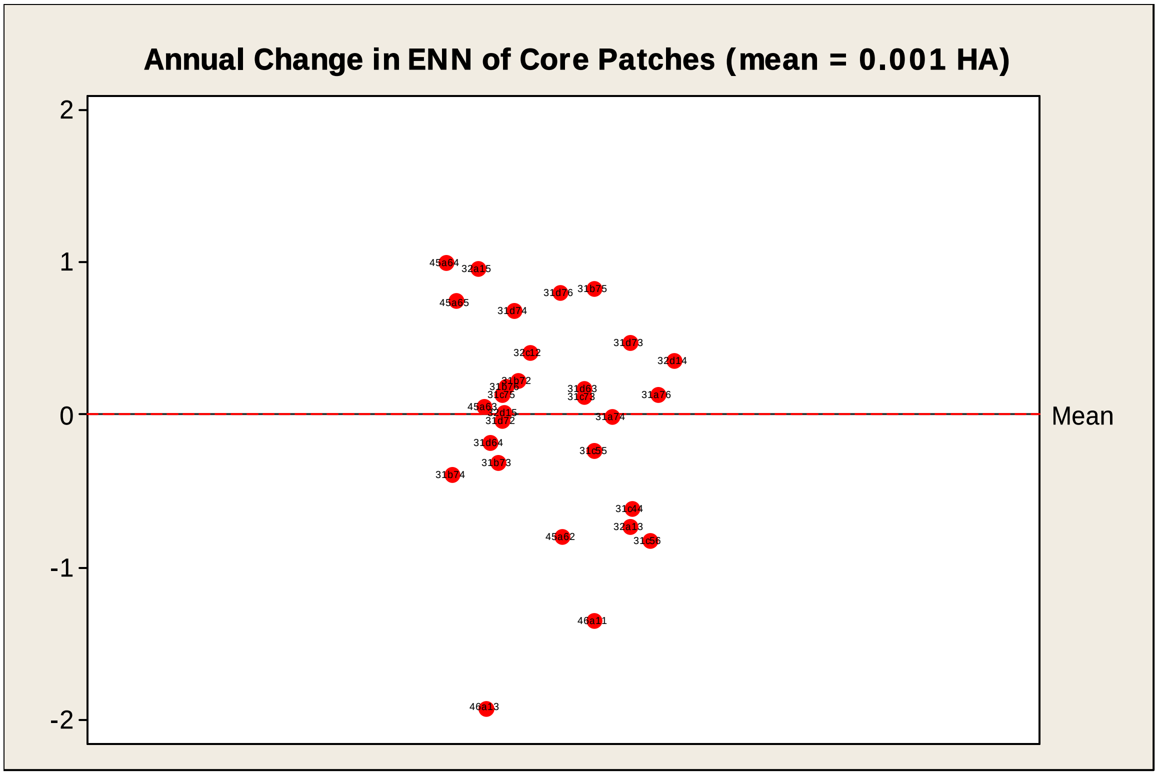

Annual Change in Euclidean Nearest Neighbor (mean = -0.041 m)
Mean
5.0
2.5
0.0
-2.5
-5.0

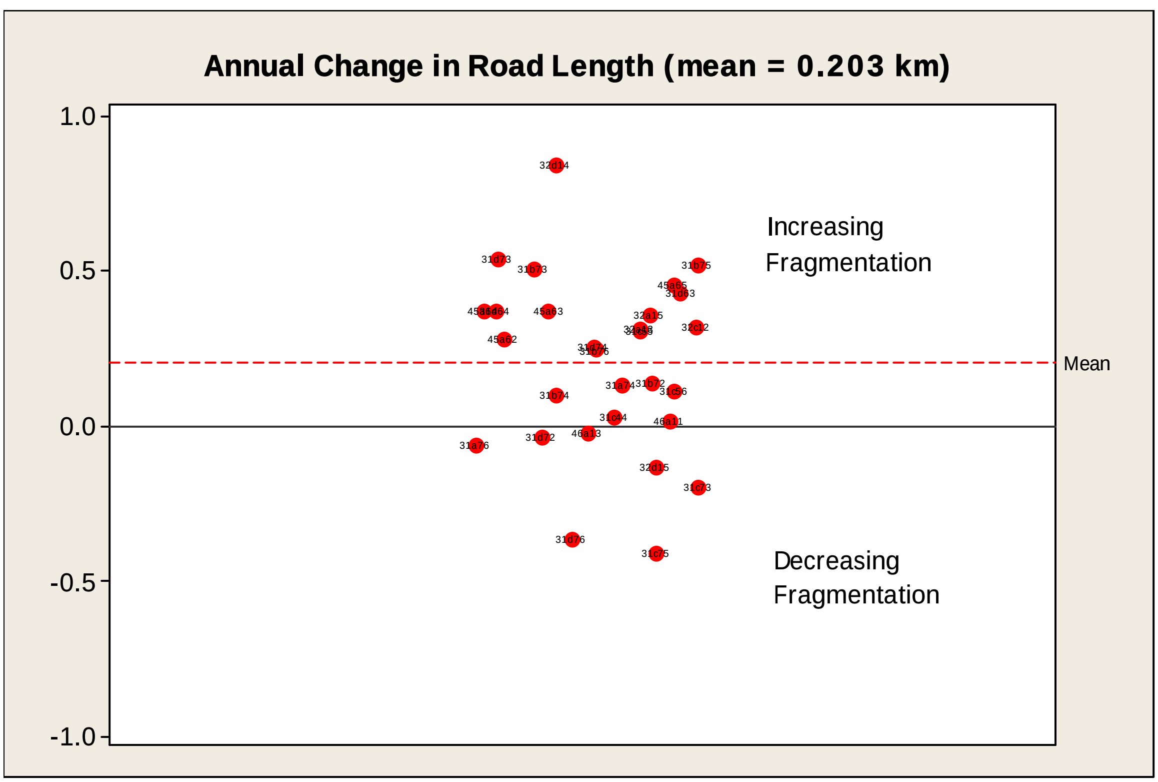

Annual Change in Total Edge Forest Area (mean = 4.139 HA)
10
5
0
-5
-10
Increasing
Fragmentation
Mean
0
Decreasing
Fragmentation

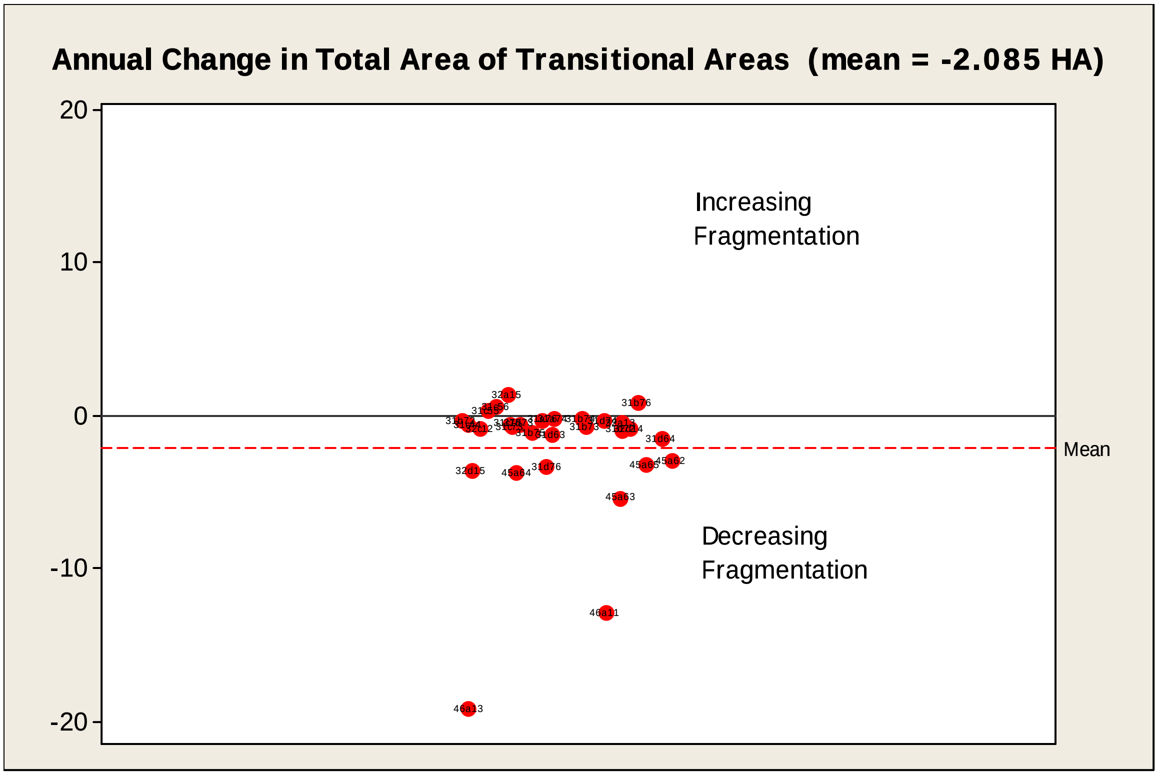

Annual Change in the Number of Core Patches (mean = 0.114)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Mean

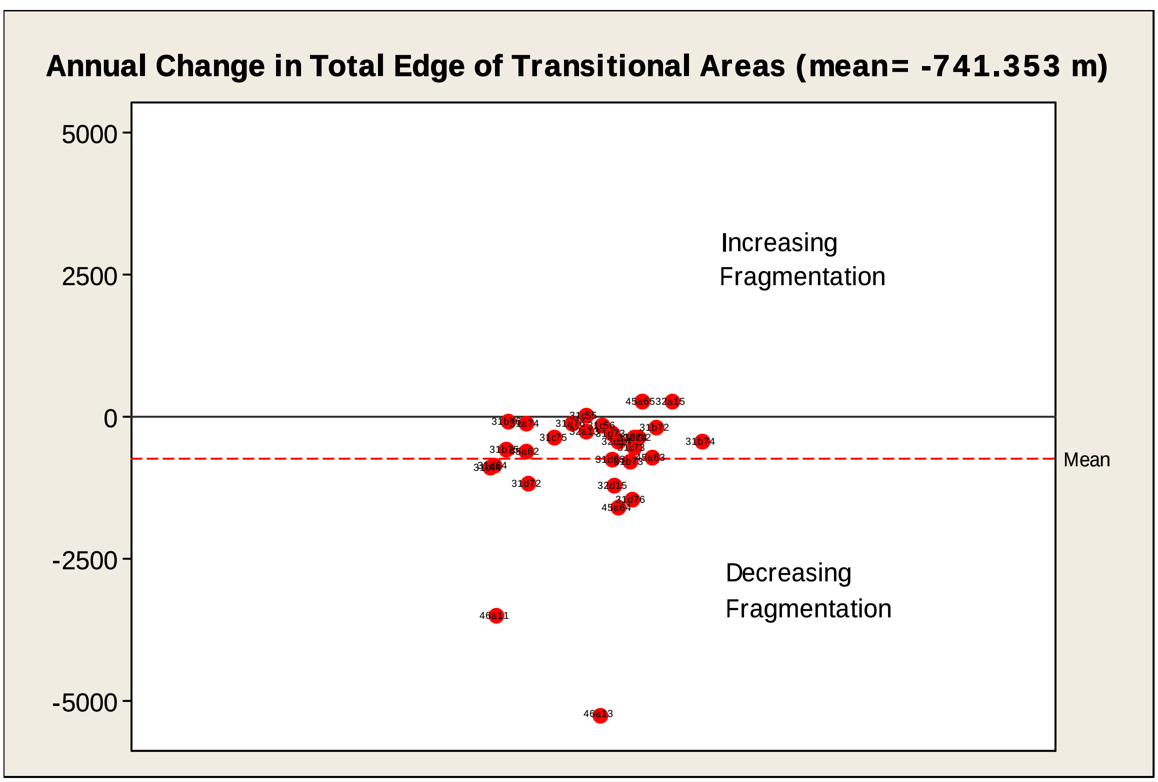

Annual Change in Total Core Area (mean = -3.026 HA)
20
10
0
-10
-20
Decreasing
Fragmentation
Increasing
Fragmentation
Mean

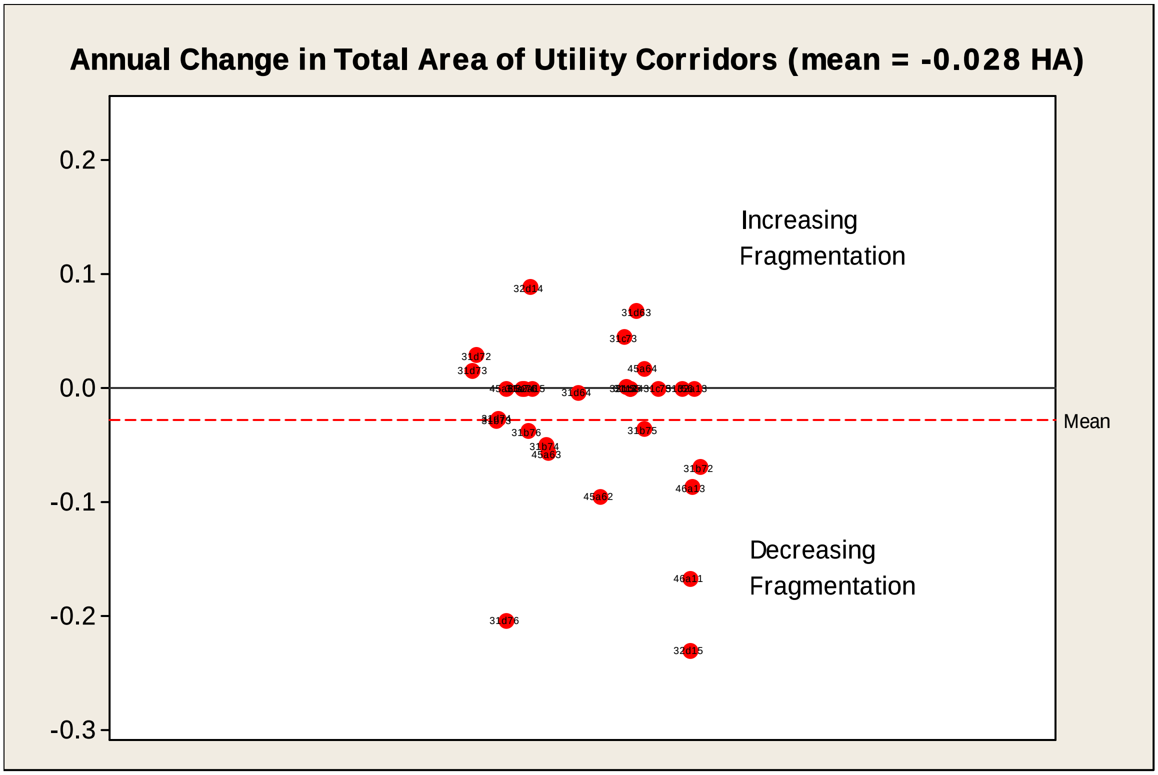

Annual Change in Core Forest Mean Patch Size (mean = -0.763 HA)
5.0
2.5
0.0
-2.5
-5.0
Decreasing
Fragmenation
Increasing
Fragmentation
Mean

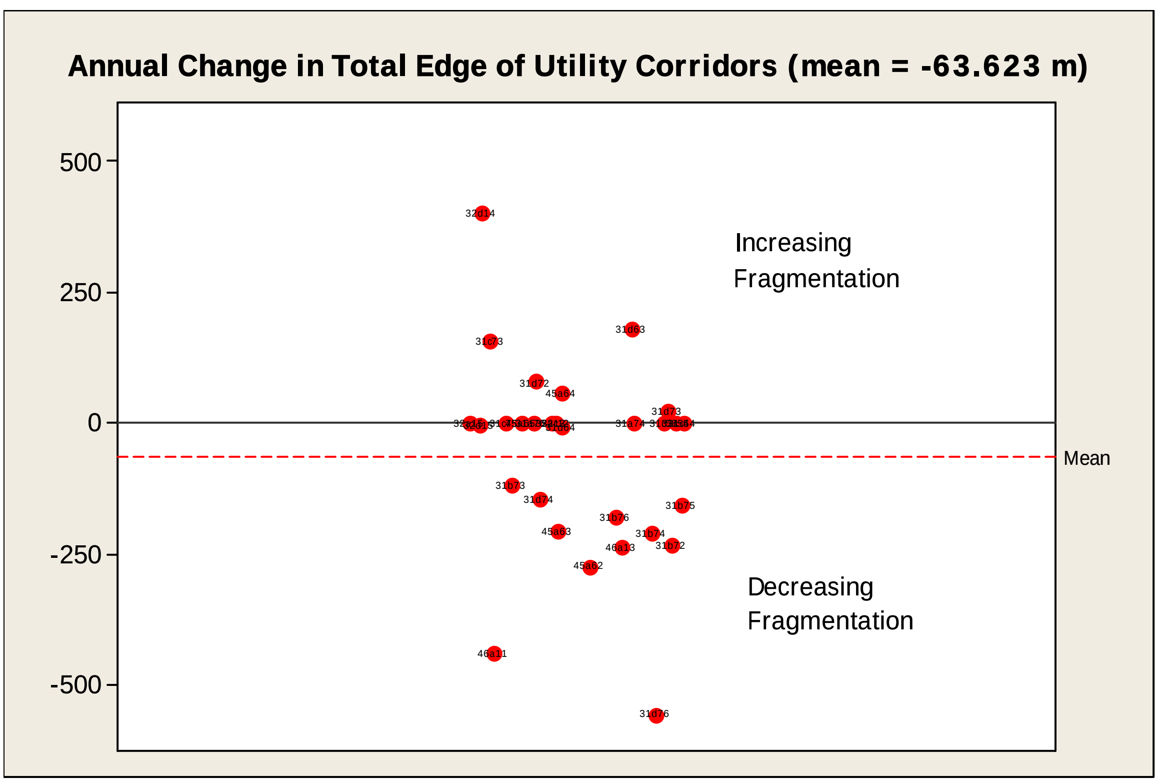

Annual Change in ENN of Core Patches (mean = 0.001 HA)
2
1
0
-1
-2
Mean

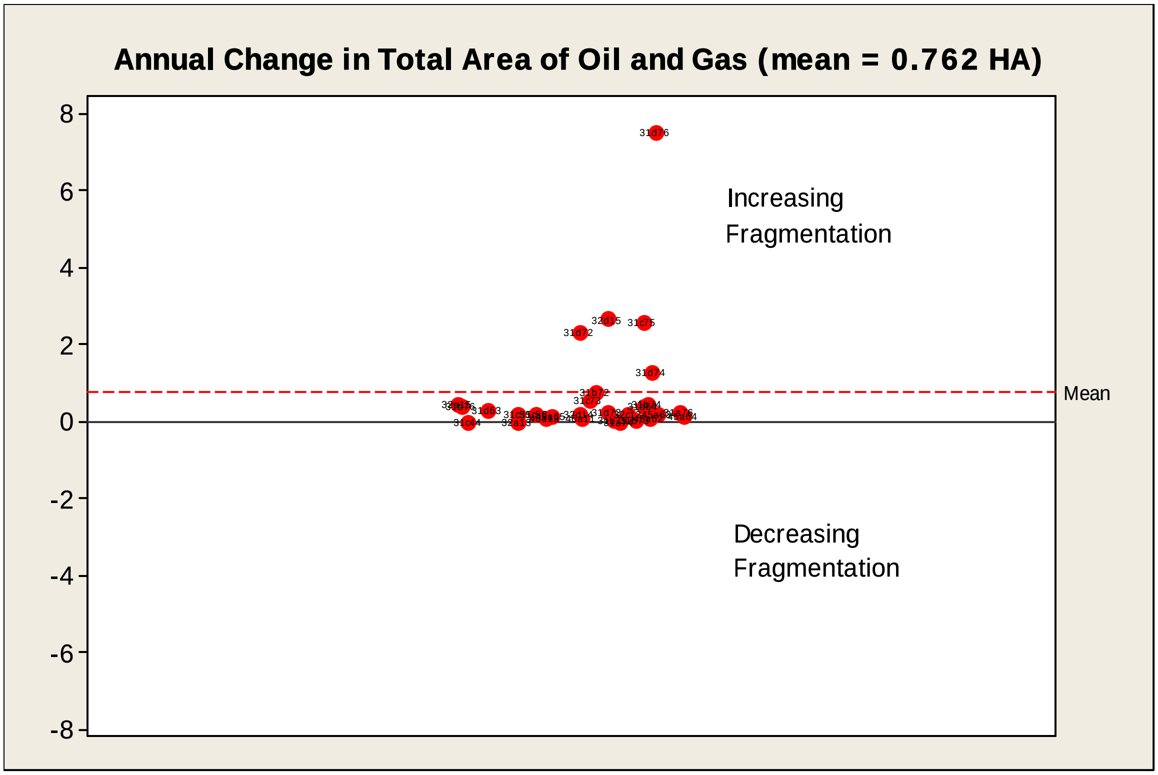

Annual Change in Road Length (mean = 0.203 km)
1.0
0.5
0.0
-0.5
-1.0
Increasing
Fragmentation
Mean
Decreasing
Fragmentation

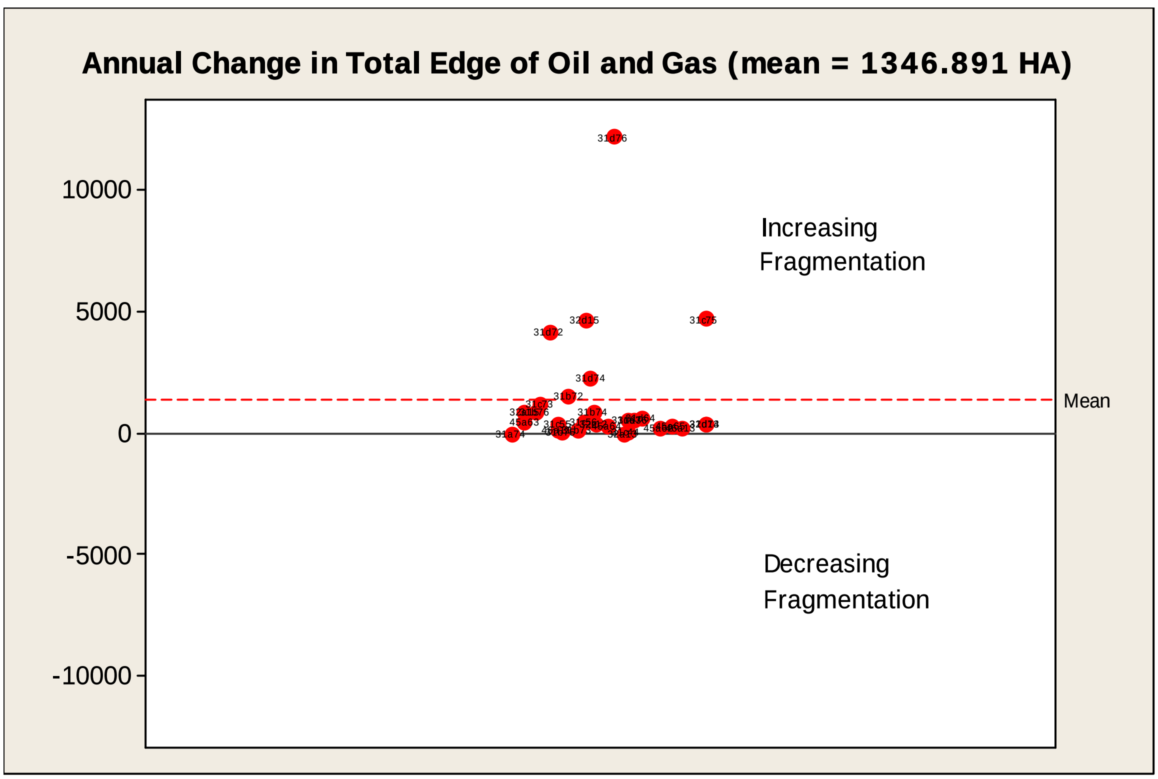

Annual Change in Total Area of Transitional Areas (mean = -2.085 HA)
20
10
0
-10
-20
Increasing
Fragmentation
Decreasing
Fragmentation
Mean


Annual Change in Total Edge of Transitional Areas (mean= -741.353 m)
5000
2500
0
-2500
-5000
Increasing
Fragmentation
Decreasing
Fragmentation
Mean


Annual Change in Total Area of Utility Corridors (mean = -0.028 HA)
0.2
0.1
0.0
-0.1
-0.2
-0.3
Increasing
Fragmentation
Decreasing
Fragmentation
Mean


Annual Change in Total Edge of Utility Corridors (mean = -63.623 m)
500
250
0
-250
-500
Increasing
Fragmentation
Decreasing
Fragmentation
Mean


Annual Change in Total Area of Oil and Gas (mean = 0.762 HA)
8
6
4
2
0
-2
-4
-6
-8
Increasing
Fragmentation
Decreasing
Fragmentation
Mean
31d76
32d15
31c75
31d72
31d74


Annual Change in Total Edge of Oil and Gas (mean = 1346.891 HA)
10000
5000
0
-5000
-10000
Increasing
Fragmentation
Decreasing
Fragmentation
Mean
31d76
32d15
31c75
31d72
31d74
31b72

Appendix H – Correlation Matrices

Correlation Matrix of Response Metrics

	# of Patches	Patch Richness	Total Edge	Mean Patch Size	Mean Shape Index	Mean ENN	Contagion	Shannon's Diversity Index	% of Edge Forest	# of Core Patches	% of Core Forest	Mean Core Patch Size	Mean Core Shape Index
Patch Richness	0.456												
	0												
Total Edge	0.911	0.419											
	0	0											
Mean Patch Size	-0.571	-0.374	-0.67										
	0	0	0										
Mean Shape Index	-0.53	-0.137	-0.296	0.396									
	0	0.144	0.001	0									
Mean ENN	-0.711	-0.442	-0.744	0.778	0.378								
	0	0	0	0	0								
Contagion	-0.391	-0.035	-0.512	0.56	0.175	0.618							
	0	0.708	0	0	0.06	0							
Shannon's Diversity Index	0.476	0.51	0.557	-0.595	-0.17	-0.684	-0.864						
	0	0	0	0	0.069	0	0						
%of Edge Forest	0.876	0.331	0.964	-0.704	-0.358	-0.721	-0.521	0.518					
	0	0	0	0	0	0	0	0					
# of Core Patches	0.714	0.3	0.757	-0.521	-0.196	-0.557	-0.418	0.442	0.844				
	0	0.001	0	0	0.035	0	0	0	0				
% of Core Forest	-0.91	-0.389	-0.956	0.61	0.343	0.727	0.609	-0.643	-0.945	-0.807			
	0	0	0	0	0	0	0	0	0	0			
Mean Core Patch Size	-0.509	-0.316	-0.666	0.947	0.249	0.699	0.632	-0.637	-0.708	-0.562	0.619		
	0	0.001	0	0	0.007	0	0	0	0	0	0		
Mean Core Shape Index	0.078	0.025	0.122	-0.500	-0.299	-0.358	-0.354	0.298	0.17	-0.116	-0.095	-0.404	
	0.406	0.791	0.192	0	0.001	0	0	0.001	0.067	0.215	0.311	0	
Mean Core Patch ENN	-0.06	-0.085	-0.097	0.288	0.23	0.253	0.209	-0.193	-0.166	-0.077	0.06	0.268	-0.326
	0.525	0.362	0.301	0.002	0.013	0.006	0.024	0.038	0.075	0.412	0.523	0.004	0

Legend

Moderate Correlation
Negative: -0.7 to -0.4
Positive: 0.4 to 0.7

Strong Correlation
Negative: -1.0 to -0.7
Positive: 0.7 to 1.0

- Top Number: Pearson Correlation Coefficient
- Bottom Number: p-value

Correlation Matrix of Predictor and Response Landscape Metrics – page 1

	Number of Patches	Patch Richness	Total Edge	Mean Patch Areas	Mean Shape Index	Mean ENN	Contagion	Mean Core Patch ENN
Road Length	0.444	0.196	0.557	-0.489	-0.195	-0.404	-0.412	-0.11
	0	0.035	0	0	0.036	0	0	0.241
Percentage of Transitional Area	0.412	0.209	0.281	-0.242	-0.475	-0.308	-0.371	0.086
	0	0.024	0.002	0.009	0	0.001	0	0.36
Edge of Transitional Areas	0.621	0.269	0.443	-0.383	-0.602	-0.501	-0.404	-0.098
	0	0.003	0	0	0	0	0	0.296
Percentage of Utility Corridors Area	0.56	0.236	0.579	-0.306	0.012	-0.353	-0.224	0.082
	0	0.011	0	0.001	0.895	0	0.016	0.382
Edge of Utility Corridors	0.652	0.308	0.641	-0.358	-0.081	-0.415	-0.232	0.124
	0	0.001	0	0	0.385	0	0.012	0.186
Percentage of Oil and Gas Area	0.541	0.18	0.642	-0.195	0.055	-0.341	-0.118	0.16
	0	0.053	0	0.036	0.555	0	0.207	0.086
Edge of Oil and Gas	0.54	0.199	0.651	-0.205	0.078	-0.351	-0.121	0.162
	0	0.032	0	0.027	0.404	0	0.194	0.082

Correlation Matrix of Landscape Metrics – page 2

	Shannon's Diversity Index	Percentage of Edge Forest	Number of Core Patches	Percentage of Core Forest	Mean Core Patch Size	Mean Core Patch Shape Index	Mean Core Patch ENN
Road Length	0.415	0.628	0.685	-0.575	-0.548	0.094	-0.11
	0	0	0	0	0	0.314	0.241
Percentage of Transitional Area	0.415	0.266	0.2	-0.463	-0.207	0.08	0.086
	0	0.004	0.031	0	0.026	0.394	0.36
Edge of Transitional Areas	0.453	0.44	0.335	-0.575	-0.316	0.178	-0.098
	0	0	0	0	0.001	0.056	0.296
Percentage of Utility Corridors Area	0.26	0.58	0.604	-0.58	-0.331	-0.116	0.082
	0.005	0	0	0	0	0.213	0.382
Edge of Utility Corridors	0.298	0.659	0.729	-0.668	-0.372	-0.119	0.124
	0.001	0	0	0	0	0.204	0.186
Percentage of Oil and Gas Area	0.122	0.486	0.191	-0.506	-0.187	-0.104	0.16
	0.191	0	0.04	0	0.045	0.267	0.086
Edge of Oil and Gas	0.134	0.5	0.217	-0.516	-0.199	-0.11	0.162
	0.153	0	0.02	0	0.032	0.242	0.082

Correlation Matrix of Current Landscape Metrics and Full Mini-Routes – page 1

	Number of Patches	Patch Richness	Total Edge	Mean Patch Size	Mean Shape Index	Mean ENN	Contagion	Shannon's Diversity Index	Percentage of Edge Forest	Number of Core Patches	Percentage of Core Forest
Total Count	0.178	0.453	0.054	-0.177	-0.238	-0.113	-0.434	0.545	-0.064	-0.241	-0.154
	0.647	0.221	0.891	0.649	0.537	0.772	0.243	0.129	0.869	0.533	0.692
Total Species	-0.016	0.484	-0.034	0.05	0.006	0.02	-0.341	0.501	-0.196	-0.29	-0.059
	0.967	0.187	0.932	0.898	0.988	0.959	0.369	0.169	0.613	0.45	0.88
Edge Forest Count	0.023	0.035	-0.137	0.02	-0.213	0.069	-0.219	0.215	-0.191	-0.375	0.086
	0.953	0.93	0.725	0.959	0.582	0.86	0.572	0.578	0.622	0.32	0.826
Edge Forest Species	-0.228	0.034	-0.307	0.273	0.154	0.349	-0.257	0.283	-0.375	-0.418	0.161
	0.556	0.932	0.421	0.477	0.693	0.357	0.505	0.461	0.321	0.263	0.678
Interior Forest Count	0.345	0.609	0.278	-0.377	-0.461	-0.369	-0.26	0.433	0.17	-0.012	-0.291
	0.363	0.081	0.469	0.317	0.212	0.329	0.499	0.244	0.662	0.975	0.447
Interior Forest Species	-0.14	0.37	-0.103	0.216	0.103	0.099	0.001	0.174	-0.283	-0.392	0.129
	0.72	0.327	0.792	0.576	0.793	0.801	0.999	0.654	0.46	0.296	0.741
Forest Generalist Count	0.068	0.538	0.053	-0.099	0.209	-0.005	-0.595	0.718	-0.074	-0.066	-0.246
	0.861	0.135	0.893	0.799	0.589	0.991	0.091	0.029	0.851	0.866	0.524
Forest Generalist Species	0.43	0.805	0.449	-0.493	-0.314	-0.535	-0.567	0.75	0.32	0.259	-0.53
	0.248	0.009	0.226	0.178	0.41	0.138	0.111	0.02	0.401	0.5	0.142

Correlation Matrix of Current Landscape Metrics and Full Mini-Routes – page 2

	Mean Core Patch Size	Mean Core Patch Shape Index	Mean Core Patch ENN	Road Length	Percentage of Transitional Areas	Edge of Transitional Areas	Percentage of Utility Corridors	Edge of Utility Corridors	Percentage of Oil and Gas	Edge of Oil and Gas
Total Count	-0.081	0.681	0.173	-0.078	0.468	0.263	-0.172	-0.22	0.291	0.309
	0.836	0.043	0.656	0.842	0.204	0.494	0.658	0.569	0.448	0.418
Total Species	0.009	0.44	0.152	0.14	0.122	0.019	-0.199	-0.349	0.198	0.191
	0.981	0.236	0.695	0.719	0.754	0.962	0.608	0.358	0.61	0.623
Edge Forest Count	0.076	0.396	0.276	-0.391	0.522	0.246	-0.315	-0.295	0.32	0.338
	0.847	0.291	0.473	0.299	0.149	0.523	0.409	0.441	0.401	0.373
Edge Forest Species	0.168	0.285	0.377	-0.346	0.165	-0.091	-0.161	-0.258	0.323	0.311
	0.666	0.457	0.317	0.362	0.672	0.816	0.678	0.503	0.396	0.415
Interior Forest Count	-0.076	0.657	-0.181	0.366	0.389	0.256	-0.203	-0.173	0.02	0.046
	0.846	0.054	0.642	0.333	0.301	0.507	0.6	0.656	0.96	0.907
Interior Forest Species	0.276	0.198	-0.266	0.253	-0.066	-0.029	-0.423	-0.591	-0.02	-0.039
	0.473	0.61	0.488	0.512	0.867	0.941	0.256	0.094	0.959	0.922
Forest Generalist Count	-0.272	0.548	0.264	-0.017	0.035	0.054	0.264	0.054	0.295	0.287
	0.479	0.127	0.492	0.966	0.929	0.89	0.493	0.891	0.441	0.453
Forest Generalist Species	-0.531	0.554	0.218	0.539	0.184	0.208	0.192	0.123	0.117	0.136
	0.141	0.122	0.574	0.134	0.636	0.592	0.62	0.753	0.765	0.726

Correlation Matrix of Current Landscape Metrics and Partial Mini-Routes – page 1

	Number of Patches	Patch Richness	Total Edge	Mean Patch Size	Mean Shape Index	Mean ENN	Contagion	Shannon's Diversity Index	Percentage of Edge Forest	Number of Core Patches	Percentage of Core Forest
Total Count	0.078	0.032	-0.007	-0.02	-0.05	-0.383	-0.312	0.453	-0.011	0.037	-0.089
	0.79	0.913	0.982	0.947	0.865	0.177	0.278	0.104	0.969	0.901	0.762
Total Species	0.127	0.204	-0.084	-0.049	-0.156	-0.263	0.09	0.102	-0.125	0.122	0.033
	0.666	0.483	0.776	0.868	0.594	0.365	0.759	0.729	0.67	0.678	0.912
Edge Forest Count	-0.082	0.143	-0.139	0.151	0.302	-0.317	0	0.227	-0.19	0.059	0.087
	0.78	0.627	0.635	0.606	0.293	0.27	1	0.436	0.515	0.842	0.767
Edge Forest Species	0.203	0.372	0.021	-0.209	-0.106	-0.327	0.074	0.271	-0.011	0.276	-0.085
	0.486	0.19	0.944	0.473	0.718	0.254	0.803	0.349	0.971	0.34	0.772
Interior Forest Count	0.204	-0.026	0.239	-0.177	-0.194	-0.22	-0.303	0.317	0.298	0.039	-0.3
	0.484	0.93	0.411	0.545	0.507	0.449	0.292	0.269	0.301	0.896	0.297
Interior Forest Species	-0.177	-0.219	-0.133	0.315	0.141	0.032	0.065	-0.273	-0.142	-0.255	0.156
	0.545	0.452	0.65	0.272	0.63	0.913	0.826	0.346	0.628	0.379	0.594
Forest Generalist Count	0.04	-0.131	-0.159	-0.044	-0.391	-0.152	-0.402	0.364	-0.177	-0.068	0.08
	0.891	0.654	0.587	0.88	0.166	0.603	0.155	0.2	0.545	0.816	0.786
Forest Generalist Species	0.139	0.071	-0.137	-0.052	-0.372	-0.129	0.042	0.035	-0.182	0.065	0.096
	0.635	0.809	0.641	0.859	0.191	0.66	0.886	0.904	0.533	0.826	0.744

Correlation Matrix of Current Landscape Metrics and Partial Mini-Routes – page 2

	Mean Core Patch Size	Mean Core Patch Shape Index	Mean Core Patch ENN	Road Length	Percentage of Transitional Areas	Edge of Transitional Areas	Percentage of Utility Corridors	Edge of Utility Corridors	Percentage of Oil and Gas	Edge of Oil and Gas
Total Count	-0.212	0.162	0.469	0.328	0.407	0.394	-0.255	-0.193	-0.108	-0.114
	0.466	0.581	0.091	0.253	0.148	0.163	0.379	0.509	0.713	0.697
Total Species	0.134	-0.035	0.321	0.194	0.207	0.257	0.007	0.085	-0.124	-0.138
	0.649	0.905	0.263	0.507	0.478	0.375	0.981	0.773	0.673	0.638
Edge Forest Count	0.046	-0.135	0.449	0.057	-0.129	-0.118	0.026	0.069	-0.079	-0.073
	0.875	0.646	0.108	0.847	0.66	0.689	0.929	0.814	0.788	0.805
Edge Forest Species	0.068	-0.184	0.272	0.196	0.213	0.246	0.213	0.289	-0.09	-0.092
	0.817	0.53	0.346	0.501	0.465	0.397	0.465	0.317	0.76	0.756
Interior Forest Count	-0.478	0.303	0.36	0.449	0.53	0.464	-0.321	-0.294	0.043	0.029
	0.084	0.292	0.206	0.107	0.051	0.094	0.263	0.307	0.885	0.921
Interior Forest Species	-0.002	0.364	0.265	0.091	0.016	-0.11	-0.383	-0.372	-0.027	-0.046
	0.993	0.201	0.36	0.758	0.958	0.707	0.177	0.19	0.927	0.876
Forest Generalist Count	0.097	0.217	-0.081	0.095	0.543	0.595	-0.255	-0.2	-0.24	-0.247
	0.742	0.457	0.784	0.746	0.045	0.025	0.379	0.494	0.408	0.394
Forest Generalist Species	0.242	-0.113	0.096	0.067	0.148	0.35	-0.003	0.056	-0.143	-0.159
	0.405	0.701	0.743	0.821	0.614	0.22	0.993	0.848	0.627	0.586

Correlation Matrix of Annual Change of Landscape Metrics and Full Mini-Routes – page 1

	Number of Patches	Total Edge (m)	Mean Patch Size (HA)	Mean ENN (m)	Edge Forest (HA)	Number of Core Patches	Core Forest (HA)	Mean Core Patch Size (HA)
Total Count	-0.446	-0.463	0.362	0.621	-0.489	-0.637	0.433	0.371
	0.229	0.21	0.338	0.074	0.181	0.065	0.245	0.326
Total Species	-0.261	-0.229	0.326	0.39	-0.186	-0.484	0.123	0.208
	0.498	0.554	0.393	0.299	0.633	0.187	0.752	0.591
Edge Forest Count	-0.623	-0.514	0.448	0.65	-0.542	-0.772	0.49	0.242
	0.073	0.157	0.226	0.058	0.132	0.015	0.181	0.531
Edge Forest Species	-0.713	-0.483	0.708	0.672	-0.416	-0.704	0.339	0.161
	0.031	0.188	0.033	0.048	0.266	0.034	0.372	0.679
Interior Forest Count	0.138	-0.128	-0.117	0.154	-0.186	-0.056	0.137	0.073
	0.723	0.742	0.764	0.693	0.632	0.887	0.726	0.851
Interior Forest Species	0.181	0.104	0.118	0.038	0.128	-0.173	-0.194	-0.238
	0.641	0.791	0.763	0.922	0.742	0.656	0.617	0.537
Forest Generalist Count	-0.433	-0.345	0.454	0.553	-0.307	-0.513	0.288	0.596
	0.244	0.363	0.22	0.123	0.421	0.158	0.452	0.091
Forest Generalist Species	0.048	-0.085	-0.226	0.092	-0.089	-0.137	0.104	0.625
	0.902	0.828	0.559	0.814	0.82	0.726	0.79	0.072

Correlation Matrix of Annual Change of Landscape Metrics and Full Mini-Routes – page 2

	Mean Core ENN (m)	Road Length (km)	Transitional Areas (HA)	Edge of Transitional Areas (m)	Utility Corridors (HA)	Edge of Utility Corridors (m)	Oil and Gas (HA)	Edge of Oil and Gas (m)
Total Count	0.071	-0.667	-0.133	-0.192	-0.638	-0.671	0.352	0.367
	0.856	0.05	0.733	0.62	0.064	0.048	0.354	0.331
Total Species	-0.197	-0.592	0.123	0.005	-0.701	-0.717	0.329	0.331
	0.611	0.093	0.752	0.989	0.035	0.03	0.387	0.384
Edge Forest Count	0.245	-0.698	-0.176	-0.19	-0.534	-0.571	0.278	0.287
	0.525	0.036	0.65	0.624	0.139	0.108	0.468	0.454
Edge Forest Species	-0.103	-0.794	0.02	-0.204	-0.65	-0.671	0.37	0.356
	0.792	0.011	0.959	0.599	0.058	0.048	0.328	0.346
Interior Forest Count	-0.151	-0.219	0.036	0.035	-0.251	-0.269	0.122	0.15
	0.698	0.57	0.926	0.929	0.515	0.483	0.755	0.7
Interior Forest Species	-0.504	-0.383	0.38	0.452	-0.501	-0.495	0.144	0.141
	0.166	0.309	0.313	0.222	0.17	0.176	0.712	0.718
Forest Generalist Count	-0.02	-0.528	-0.138	-0.288	-0.679	-0.689	0.42	0.417
	0.96	0.144	0.723	0.452	0.044	0.04	0.261	0.264
Forest Generalist Species	0.215	-0.053	-0.152	-0.252	-0.398	-0.42	0.21	0.236
	0.579	0.892	0.696	0.512	0.288	0.26	0.588	0.542

Correlation Matrix of Annual Change of Landscape Metrics and Partial Mini-Routes – page 1

	Number of Patches	Total Edge (m)	Mean Patch Size (HA)	Mean ENN (m)	Edge Forest (HA)	Number of Core Patches	Core Forest (HA)	Mean Core Patch Size (HA)
Total Count	0.075	-0.062	-0.12	-0.274	-0.002	-0.099	0.075	-0.113
	0.8	0.834	0.682	0.343	0.994	0.736	0.798	0.701
Total Species	-0.141	-0.204	0.241	-0.01	-0.279	-0.131	0.214	0.213
	0.631	0.485	0.407	0.972	0.333	0.655	0.462	0.464
Edge Forest Count	-0.114	-0.143	0.029	-0.27	-0.146	0.007	0.081	0.05
	0.698	0.627	0.922	0.351	0.619	0.982	0.784	0.865
Edge Forest Species	-0.197	-0.182	0.27	-0.081	-0.282	-0.036	0.247	0.299
	0.499	0.534	0.351	0.783	0.329	0.902	0.395	0.3
Interior Forest Count	0.361	0.223	-0.398	-0.272	0.438	-0.067	-0.266	-0.45
	0.205	0.444	0.158	0.347	0.118	0.821	0.358	0.106
Interior Forest Species	0.191	0.093	-0.364	-0.134	0.332	-0.01	-0.363	-0.554
	0.512	0.752	0.2	0.647	0.246	0.973	0.202	0.04
Forest Generalist Count	-0.174	-0.288	0.264	0.165	-0.47	-0.191	0.517	0.333
	0.551	0.319	0.361	0.573	0.09	0.513	0.058	0.244
Forest Generalist Species	-0.204	-0.309	0.518	0.265	-0.568	-0.284	0.487	0.578
	0.485	0.283	0.058	0.361	0.034	0.325	0.078	0.03

Correlation Matrix of Annual Change of Landscape Metrics and Partial Mini-Routes – page 2

	Mean Core ENN (m)	Road Length (km)	Transitional Areas (HA)	Edge of Transitional Areas (m)	Utility Corridors (HA)	Edge of Utility Corridors (m)	Oil and Gas (HA)	Edge of Oil and Gas (m)
Total Count	-0.057	0.241	-0.169	0.398	-0.074	-0.49	-0.128	-0.139
	0.848	0.406	0.564	0.159	0.801	0.076	0.663	0.635
Total Species	-0.161	0.128	0.12	0.333	0.065	-0.333	-0.141	-0.158
	0.583	0.663	0.682	0.245	0.825	0.245	0.63	0.59
Edge Forest Count	0.027	-0.102	0.214	0.498	0.123	-0.238	-0.103	-0.1
	0.926	0.728	0.463	0.07	0.675	0.413	0.726	0.734
Edge Forest Species	-0.099	0.06	-0.015	0.238	0.128	-0.245	-0.109	-0.115
	0.736	0.839	0.96	0.413	0.663	0.398	0.711	0.695
Interior Forest Count	0.085	0.401	-0.323	0.167	-0.155	-0.53	0.017	-0.001
	0.772	0.155	0.26	0.568	0.598	0.051	0.953	0.997
Interior Forest Species	-0.019	0.153	0.403	0.516	0.124	-0.291	-0.053	-0.07
	0.949	0.601	0.153	0.059	0.673	0.313	0.857	0.811
Forest Generalist Count	-0.361	0.224	-0.353	-0.055	-0.189	-0.093	-0.21	-0.218
	0.204	0.442	0.215	0.852	0.517	0.753	0.471	0.453
Forest Generalist Species	-0.235	0.083	-0.047	-0.061	-0.193	-0.154	-0.128	-0.143
	0.419	0.777	0.873	0.837	0.509	0.6	0.663	0.625

Appendix I – Regression Analysis

4.3 The Effects of Oil and Gas Development on Forest Fragmentation

Regression Analysis: Number of Patches vs. Percentage of Oil and Gas

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The regression equation is
NP = 187 + 38.9 PLAND_OG


Predictor    Coef  SE Coef      T      P
Constant   187.44    10.19  18.39  0.000
PLAND_OG   38.909    5.661   6.87  0.000


S = 98.1509   R-Sq = 29.3%   R-Sq(adj) = 28.7%


Analysis of Variance

Source           DF       SS      MS      F      P
Regression        1   455107  455107  47.24  0.000
Residual Error  114  1098231    9634
Total           115  1553338


Unusual Observations

Obs  PLAND_OG      NP     Fit  SE Fit  Residual  St Resid
 22       0.3  396.00  199.51    9.53    196.49     2.01R
 23       0.3  415.00  197.64    9.62    217.36     2.23R
 24       0.5  419.00  206.00    9.30    213.00     2.18R
 28       0.4  437.00  203.50    9.38    233.50     2.39R
 29       0.5  479.00  206.92    9.28    272.08     2.78R
 51       5.5  471.00  403.34   28.36     67.66     0.72 X
 57       0.5  430.00  206.05    9.30    223.95     2.29R
 75       1.3  436.00  236.60    9.47    199.40     2.04R
 76       9.9  607.00  572.80   52.31     34.20     0.41 X
108      11.6  577.00  638.32   61.72    -61.32    -0.80 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.
```

Regression Analysis: Total Edge vs. Edge of Oil and Gas

```
The regression equation is
TE = 234785 + 0.954 TE_OG


Predictor    Coef  SE Coef      T      P
Constant   234785     7851  29.90  0.000
TE_OG      0.9538   0.1043   9.15  0.000


S = 74172.6   R-Sq = 42.3%   R-Sq(adj) = 41.8%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4.60111E+11	4.60111E+11	83.63	0.000
Residual Error	114	6.27179E+11	5501569122		
Total	115	1.08729E+12			

Unusual Observations

Obs	TE_OG	TE	Fit	SE Fit	Residual	St Resid
7	3198	30900	237836	7696	-206936	-2.81R
28	21616	407608	255404	7052	152204	2.06R
29	25480	409722	259089	6976	150633	2.04R
39	2408	41786	237082	7734	-195296	-2.65R
51	224436	474652	448862	20811	25790	0.36 X
59	2408	37658	237082	7734	-199424	-2.70R
76	409444	586226	625331	39540	-39105	-0.62 X
88	2408	37734	237082	7734	-199348	-2.70R
99	191740	353520	417675	17630	-64155	-0.89 X
108	451832	613526	665762	43900	-52236	-0.87 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Edge of Oil and Gas vs. Percentage of Edge Forest

The regression equation is
PLAND_EDGE = 37.5 + 0.000109 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	37.494	1.335	28.09	0.000
TE_OG	0.00010927	0.00001773	6.16	0.000

S = 12.6112   R-Sq = 25.0%   R-Sq(adj) = 24.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6038.0	6038.0	37.97	0.000
Residual Error	114	18130.8	159.0		
Total	115	24168.9			

Unusual Observations

Obs	TE_OG	PLAND_EDGE	Fit	SE Fit	Residual	St Resid
7	3198	3.47	37.84	1.31	-34.38	-2.74R
39	2408	4.24	37.76	1.31	-33.52	-2.67R
51	224436	64.65	62.02	3.54	2.63	0.22 X
59	2408	3.61	37.76	1.31	-34.14	-2.72R
76	409444	74.92	82.23	6.72	-7.31	-0.68 X
88	2408	3.59	37.76	1.31	-34.17	-2.72R
99	191740	51.40	58.44	3.00	-7.05	-0.58 X
108	451832	72.04	86.86	7.46	-14.82	-1.46 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Edge of Oil and Gas vs. Percentage of Core Forest

The regression equation is
PLAND_CORE = 55.1 - 0.000121 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	55.113	1.421	38.78	0.000
TE_OG	-0.00012134	0.00001888	-6.43	0.000

S = 13.4281   R-Sq = 26.6%   R-Sq(adj) = 25.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	7446.1	7446.1	41.30	0.000
Residual Error	114	20555.8	180.3		
Total	115	28001.9			

Unusual Observations

Obs	TE_OG	PLAND_CORE	Fit	SE Fit	Residual	St Resid
7	3198	81.72	54.73	1.39	27.00	2.02R
19	2110	82.75	54.86	1.40	27.90	2.09R
28	21616	15.34	52.49	1.28	-37.15	-2.78R
29	25480	7.75	52.02	1.26	-44.28	-3.31R
51	224436	23.92	27.88	3.77	-3.96	-0.31 X
76	409444	10.53	5.43	7.16	5.10	0.45 X
99	191740	41.76	31.85	3.19	9.92	0.76 X
108	451832	11.73	0.29	7.95	11.44	1.06 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

4.4.1 Correlation and Simple Linear Regression

Regression Analysis: Edge of Utility Corridors vs. Number of Core Patches

The regression equation is
NP_CORE = 14.2 + 0.000624 TE_UTILITY

Predictor	Coef	SE Coef	T	P
Constant	14.174	1.132	12.53	0.000
TE_UTILITY	0.00062393	0.00005483	11.38	0.000

S = 8.44792   R-Sq = 53.2%   R-Sq(adj) = 52.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	9242.9	9242.9	129.51	0.000
Residual Error	114	8135.9	71.4		
Total	115	17378.8			

Unusual Observations

Obs	TE_UTILITY	NP_CORE	Fit	SE Fit	Residual	St Resid
23	61270	50.000	52.402	2.662	-2.402	-0.30 X
24	53538	40.000	47.578	2.260	-7.578	-0.93 X
50	48310	56.000	44.316	1.994	11.684	1.42 X
57	22428	58.000	28.167	0.887	29.833	3.55R
75	58106	58.000	50.428	2.496	7.572	0.94 X
86	8174	47.000	19.274	0.866	27.726	3.30R
98	23862	46.000	29.062	0.926	16.938	2.02R
107	52982	55.000	47.231	2.231	7.769	0.95 X
115	8174	45.000	19.274	0.866	25.726	3.06R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

4.4.2 Multiple Linear Regression

Regression Analysis: Number of Patches vs. Road Length, Edge of Transitional Areas, Edge of Utility Corridors, and Percentage of Oil and Gas

The regression equation is
NP = 0.43 + 2.46 ROAD_LENGTH + 0.00166 TE_TA + 0.00221 TE_UTILITY
+ 35.3 PLAND_OG

Predictor	Coef	SE Coef	T	P
Constant	0.428	9.954	0.04	0.966
ROAD_LENGTH	2.4639	0.2808	8.77	0.000
TE_TA	0.00166223	0.00009573	17.36	0.000
TE_UTILITY	0.0022135	0.0002820	7.85	0.000
PLAND_OG	35.282	2.351	15.01	0.000

S = 36.9986   R-Sq = 90.2%   R-Sq(adj) = 89.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	1401390	350348	255.93	0.000
Residual Error	111	151947	1369		
Total	115	1553338			

Source	DF	Seq SS
ROAD_LENGTH	1	305658
TE_TA	1	461014
TE_UTILITY	1	326470
PLAND_OG	1	308248

Unusual Observations

Obs	ROAD_LENGTH	NP	Fit	SE Fit	Residual	St Resid
22	39.7	396.00	300.84	7.17	95.16	2.62R
28	53.6	437.00	512.25	14.30	-75.25	-2.21RX
29	39.0	479.00	619.04	19.70	-140.04	-4.47RX
72	49.6	371.00	291.40	5.87	79.60	2.18R

76	23.6	607.00	571.70	20.04	35.30	1.13 X
86	54.2	399.00	306.38	8.05	92.62	2.56R
104	49.1	358.00	281.65	6.00	76.35	2.09R
108	24.5	577.00	607.22	23.63	-30.22	-1.06 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Patch Richness vs. Edge of Transitional Areas and Edge of Utility Corridors

The regression equation is
PR = 6.70 + 0.000006 TE_TA + 0.000020 TE_UTILITY

Predictor	Coef	SE Coef	T	P
Constant	6.6983	0.1643	40.77	0.000
TE_TA	0.00000616	0.00000256	2.41	0.018
TE_UTILITY	0.00001969	0.00000667	2.95	0.004

S = 1.00562   R-Sq = 13.9%   R-Sq(adj) = 12.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	18.443	9.221	9.12	0.000
Residual Error	113	114.273	1.011		
Total	115	132.716			

Source	DF	Seq SS
TE_TA	1	9.629
TE_UTILITY	1	8.814

Unusual Observations

Obs	TE_TA	PR	Fit	SE Fit	Residual	St Resid
23	47168	8.0000	8.1955	0.3221	-0.1955	-0.21 X
28	190786	7.0000	8.3015	0.3786	-1.3015	-1.40 X
29	251452	9.0000	9.0201	0.5284	-0.0201	-0.02 X
31	60012	5.0000	7.0680	0.1473	-2.0680	-2.08R
75	57154	7.0000	8.1947	0.2985	-1.1947	-1.24 X
95	26190	9.0000	6.9940	0.1132	2.0060	2.01R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Total Edge vs. Road Length, Edge of Transitional Areas, Edge of Utility Corridors, and Edge of Oil and Gas

The regression equation is
TE = 61640 + 3423 ROAD_LENGTH + 0.911 TE_TA + 1.25 TE_UTILITY + 0.930 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	61640	6127	10.06	0.000

ROAD_LENGTH	3422.7	172.1	19.89	0.000
TE_TA	0.91116	0.05870	15.52	0.000
TE_UTILITY	1.2460	0.1737	7.17	0.000
TE_OG	0.92976	0.03531	26.33	0.000

S = 22663.6   R-Sq = 94.8%   R-Sq(adj) = 94.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	1.03028E+12	2.57569E+11	501.46	0.000
Residual Error	111	57013776311	513637624		
Total	115	1.08729E+12			

Source	DF	Seq SS
ROAD_LENGTH	1	3.36960E+11
TE_TA	1	1.26332E+11
TE_UTILITY	1	2.10808E+11
TE_OG	1	3.56176E+11

Unusual Observations

Obs	ROAD_LENGTH	TE	Fit	SE Fit	Residual	St Resid
7	2.1	30900	75610	5754	-44710	-2.04R
23	52.3	362154	371442	8177	-9288	-0.44 X
28	53.6	407608	466065	8768	-58457	-2.80RX
29	39.0	409722	496875	12064	-87153	-4.54RX
39	7.2	41786	91363	5126	-49577	-2.25R
59	7.2	37658	89690	5160	-52032	-2.36R
75	68.7	428096	470743	7863	-42647	-2.01R
76	23.6	586226	613851	12306	-27625	-1.45 X
88	7.2	37734	89803	5158	-52069	-2.36R
108	24.5	613526	642196	13620	-28670	-1.58 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Mean Patch Size vs. Road Length, Edge of Transitional Areas, and Edge of Oil and Gas

The regression equation is
AREA_MN = 48.3 - 0.645 ROAD_LENGTH - 0.000161 TE_TA - 0.000074 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	48.310	4.140	11.67	0.000
ROAD_LENGTH	-0.6449	0.1095	-5.89	0.000
TE_TA	-0.00016091	0.00003901	-4.12	0.000
TE_OG	-0.00007368	0.00002166	-3.40	0.001

S = 15.3506   R-Sq = 38.8%   R-Sq(adj) = 37.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	16743.6	5581.2	23.69	0.000
Residual Error	112	26391.8	235.6		
Total	115	43135.3			

Source	DF	Seq SS
ROAD_LENGTH	1	10310.5
TE_TA	1	3705.1
TE_OG	1	2727.9

Unusual Observations

Obs	ROAD_LENGTH	AREA_MN	Fit	SE Fit	Residual	St Resid
7	2.1	140.88	46.05	3.89	94.83	6.39R
28	53.6	5.53	-18.54	5.86	24.07	1.70 X
29	39.0	5.04	-19.19	8.09	24.23	1.86 X
39	7.2	82.59	42.99	3.47	39.60	2.65R
59	7.2	108.86	43.28	3.49	65.58	4.39R
76	23.6	3.98	-5.56	8.25	9.54	0.74 X
88	7.2	108.86	43.26	3.49	65.60	4.39R
108	24.5	4.19	-6.77	9.10	10.96	0.89 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Mean Shape Index vs. Edge of Transitional Areas

The regression equation is
SHAPE_MN = 2.74 - 0.000005 TE_TA

Predictor	Coef	SE Coef	T	P
Constant	2.73865	0.03893	70.35	0.000
TE_TA	-0.00000538	0.00000067	-8.05	0.000

S = 0.268269   R-Sq = 36.2%   R-Sq(adj) = 35.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4.6650	4.6650	64.82	0.000
Residual Error	114	8.2044	0.0720		
Total	115	12.8693			

Unusual Observations

Obs	TE_TA	SHAPE_MN	Fit	SE Fit	Residual	St Resid
28	190786	2.1123	1.7127	0.1006	0.3996	1.61 X
29	251452	2.0450	1.3865	0.1403	0.6585	2.88RX
38	132684	2.5826	2.0252	0.0638	0.5574	2.14RX
85	123828	2.6555	2.0728	0.0584	0.5827	2.23R
92	12916	3.5491	2.6692	0.0328	0.8799	3.30R
114	112136	2.7033	2.1357	0.0514	0.5676	2.16R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Mean of Euclidean Nearest Neighbor vs. Road Length, Edge of Transitional Areas, and Edge of Oil and Gas

The regression equation is
ENN_MN = 251 - 1.65 ROAD_LENGTH - 0.000792 TE_TA - 0.000391 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	251.21	12.42	20.23	0.000
ROAD_LENGTH	-1.6513	0.3286	-5.03	0.000
TE_TA	-0.0007922	0.0001170	-6.77	0.000
TE_OG	-0.00039137	0.00006496	-6.02	0.000

S = 46.0466   R-Sq = 50.8%   R-Sq(adj) = 49.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	244886	81629	38.50	0.000
Residual Error	112	237473	2120		
Total	115	482359			

Source	DF	Seq SS
ROAD_LENGTH	1	78706
TE_TA	1	89221
TE_OG	1	76960

Unusual Observations

Obs	ROAD_LENGTH	ENN_MN	Fit	SE Fit	Residual	St Resid
7	2.1	489.32	243.15	11.68	246.17	5.53R
19	17.4	314.16	209.06	7.60	105.11	2.31R
28	53.6	85.84	3.12	17.58	82.72	1.94 X
29	39.0	75.61	-22.39	24.26	98.00	2.50RX
52	21.2	306.50	208.75	7.27	97.75	2.15R
76	23.6	52.74	10.15	24.75	42.59	1.10 X
77	24.8	298.59	204.21	6.92	94.38	2.07R
88	7.2	341.19	237.25	10.48	103.94	2.32R
93	49.8	256.78	149.17	7.87	107.60	2.37R
100	28.9	292.25	197.56	6.64	94.70	2.08R
108	24.5	44.83	4.48	27.29	40.35	1.09 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Contagion vs. Road Length and Edge of Transitional Areas

The regression equation is
CONTAG = 79.4 - 0.0862 ROAD_LENGTH - 0.000030 TE_TA

Predictor	Coef	SE Coef	T	P
Constant	79.3508	0.7409	107.11	0.000
ROAD_LENGTH	-0.08621	0.02026	-4.26	0.000
TE_TA	-0.00002977	0.00000722	-4.12	0.000

S = 2.84280   R-Sq = 27.9%   R-Sq(adj) = 26.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	352.81	176.41	21.83	0.000
Residual Error	113	913.21	8.08		
Total	115	1266.02			

Source	DF	Seq SS
ROAD_LENGTH	1	215.33
TE_TA	1	137.48

Unusual Observations

Obs	ROAD_LENGTH	CONTAG	Fit	SE Fit	Residual	St Resid
19	17.4	84.316	77.378	0.439	6.938	2.47R
28	53.6	70.061	69.052	1.085	1.009	0.38 X
29	39.0	73.807	68.502	1.497	5.304	2.19RX
31	31.2	68.098	74.876	0.293	-6.779	-2.40R
52	21.2	83.902	77.251	0.416	6.651	2.37R
77	24.8	82.822	76.994	0.394	5.828	2.07R
92	25.3	70.030	76.786	0.368	-6.756	-2.40R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Shannon’s Diversity Index vs. Road Length and Edge of Transitional Areas

The regression equation is
SHDI = 0.739 + 0.00345 ROAD_LENGTH + 0.000001 TE_TA

Predictor	Coef	SE Coef	T	P
Constant	0.73939	0.02953	25.04	0.000
ROAD_LENGTH	0.0034489	0.0008074	4.27	0.000
TE_TA	0.00000140	0.00000029	4.88	0.000

S = 0.113317   R-Sq = 31.6%   R-Sq(adj) = 30.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.67009	0.33505	26.09	0.000
Residual Error	113	1.45101	0.01284		
Total	115	2.12110			

Source	DF	Seq SS
ROAD_LENGTH	1	0.36450
TE_TA	1	0.30559

Unusual Observations

Obs	ROAD_LENGTH	SHDI	Fit	SE Fit	Residual	St Resid
5	27.4	1.2422	0.9697	0.0197	0.2725	2.44R
19	17.4	0.5373	0.8217	0.0175	-0.2844	-2.54R
28	53.6	1.0692	1.1920	0.0433	-0.1228	-1.17 X
29	39.0	1.0531	1.2268	0.0597	-0.1737	-1.80 X
36	37.5	1.2510	0.9922	0.0161	0.2588	2.31R
52	21.2	0.5512	0.8254	0.0166	-0.2742	-2.45R
77	24.8	0.5866	0.8353	0.0157	-0.2487	-2.22R
92	25.3	1.1144	0.8447	0.0147	0.2697	2.40R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Percentage of Edge Forest vs. Road Length, Edge of Transitional Areas, Edge of Utility Corridors, and Edge of Oil and Gas

The regression equation is
PLAND_EDGE = 9.85 + 0.556 ROAD_LENGTH + 0.000121 TE_TA + 0.000265 TE_UTILITY
+ 0.000099 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	9.845	1.492	6.60	0.000
ROAD_LENGTH	0.55636	0.04191	13.27	0.000
TE_TA	0.00012109	0.00001430	8.47	0.000
TE_UTILITY	0.00026477	0.00004230	6.26	0.000
TE_OG	0.00009949	0.00000860	11.57	0.000

S = 5.52016   R-Sq = 86.0%   R-Sq(adj) = 85.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	20786.5	5196.6	170.54	0.000
Residual Error	111	3382.4	30.5		
Total	115	24168.9			

Source	DF	Seq SS
ROAD_LENGTH	1	9544.1
TE_TA	1	2530.7
TE_UTILITY	1	4633.7
TE_OG	1	4078.0

Unusual Observations

Obs	ROAD_LENGTH	PLAND_EDGE	Fit	SE Fit	Residual	St Resid
13	51.1	32.503	44.611	1.043	-12.108	-2.23R
23	52.3	61.932	62.107	1.992	-0.176	-0.03 X
28	53.6	58.998	70.666	2.136	-11.668	-2.29RX
29	39.0	56.535	74.925	2.938	-18.391	-3.94RX
76	23.6	74.925	79.163	2.997	-4.239	-0.91 X
108	24.5	72.042	82.009	3.318	-9.968	-2.26RX

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Number of Core Patches vs. Road Length, Edge of Transitional Areas, and Edge of Utility Corridors

The regression equation is
NP_CORE = - 0.30 + 0.445 ROAD_LENGTH + 0.000042 TE_TA + 0.000468 TE_UTILITY

Predictor	Coef	SE Coef	T	P
Constant	-0.297	1.550	-0.19	0.848
ROAD_LENGTH	0.44540	0.04427	10.06	0.000
TE_TA	0.00004166	0.00001526	2.73	0.007
TE_UTILITY	0.00046826	0.00004122	11.36	0.000

S = 5.93989   R-Sq = 77.3%   R-Sq(adj) = 76.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	13427.2	4475.7	126.85	0.000
Residual Error	112	3951.6	35.3		
Total	115	17378.8			

Source	DF	Seq SS
ROAD_LENGTH	1	8143.2
TE_TA	1	730.2
TE_UTILITY	1	4553.8

Unusual Observations

Obs	ROAD_LENGTH	NP_CORE	Fit	SE Fit	Residual	St Resid
23	52.3	50.000	53.658	1.921	-3.658	-0.65 X
28	53.6	41.000	41.694	2.291	-0.694	-0.13 X
29	39.0	34.000	45.931	3.159	-11.931	-2.37RX
46	37.1	38.000	25.981	0.716	12.019	2.04R
57	51.2	58.000	37.565	1.239	20.435	3.52R
69	27.1	35.000	23.268	0.960	11.732	2.00R
75	68.7	58.000	59.880	2.031	-1.880	-0.34 X
86	54.2	47.000	31.138	1.270	15.862	2.73R
98	33.2	46.000	26.184	0.862	19.816	3.37R
115	53.5	45.000	29.919	1.154	15.081	2.59R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Percentage of Core Forest vs. Road Length, Edge of Transitional Areas, Edge of Utility Corridors, and Edge of Oil and Gas

The regression equation is
PLAND_CORE = 84.5 - 0.505 ROAD_LENGTH - 0.000194 TE_TA - 0.000280 TE_UTILITY
- 0.000112 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	84.540	1.107	76.38	0.000
ROAD_LENGTH	-0.50478	0.03109	-16.24	0.000
TE_TA	-0.00019397	0.00001060	-18.29	0.000
TE_UTILITY	-0.00027955	0.00003137	-8.91	0.000
TE_OG	-0.00011217	0.00000638	-17.59	0.000

S = 4.09410   R-Sq = 93.4%   R-Sq(adj) = 93.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	26141.4	6535.3	389.90	0.000
Residual Error	111	1860.5	16.8		
Total	115	28001.9			

Source	DF	Seq SS
ROAD_LENGTH	1	9251.6
TE_TA	1	6227.6
TE_UTILITY	1	5478.3
TE_OG	1	5183.9

Unusual Observations

Obs	ROAD_LENGTH	PLAND_CORE	Fit	SE Fit	Residual	St Resid
5	27.4	37.388	47.353	0.727	-9.965	-2.47R
19	17.4	82.753	72.439	0.691	10.314	2.56R
23	52.3	31.483	30.477	1.477	1.005	0.26 X
28	53.6	15.339	11.985	1.584	3.354	0.89 X
29	39.0	7.745	2.244	2.179	5.501	1.59 X
38	27.5	51.115	43.147	1.108	7.968	2.02R
52	21.2	81.320	72.009	0.667	9.311	2.31R
76	23.6	10.532	6.882	2.223	3.650	1.06 X
77	24.8	78.814	70.539	0.647	8.275	2.05R
85	36.0	49.776	40.559	1.006	9.217	2.32R
108	24.5	11.729	4.702	2.460	7.027	2.15RX

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Mean Core Patch Size vs. Road Length, Edge of Transitional Areas, and Edge of Oil and Gas

The regression equation is
AREA_MN_CORE = 408 - 6.91 ROAD_LENGTH - 0.00109 TE_TA - 0.000659 TE_OG

Predictor	Coef	SE Coef	T	P
Constant	407.76	37.38	10.91	0.000
ROAD_LENGTH	-6.9072	0.9890	-6.98	0.000
TE_TA	-0.0010873	0.0003522	-3.09	0.003
TE_OG	-0.0006589	0.0001955	-3.37	0.001

S = 138.593   R-Sq = 40.6%   R-Sq(adj) = 39.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1471878	490626	25.54	0.000
Residual Error	112	2151291	19208		
Total	115	3623169			

Source	DF	Seq SS
ROAD_LENGTH	1	1089053
TE_TA	1	164688
TE_OG	1	218137

Unusual Observations

Obs	ROAD_LENGTH	AREA_MN_CORE	Fit	SE Fit	Residual	St Resid
7	2.1	978.7	386.7	35.2	592.0	4.42R
28	53.6	9.0	-184.1	52.9	193.1	1.51 X
29	39.0	5.5	-151.9	73.0	157.4	1.34 X
39	7.2	967.5	353.1	31.3	614.4	4.55R
59	7.2	975.8	355.1	31.6	620.7	4.60R
76	23.6	11.6	-82.3	74.5	93.8	0.80 X
88	7.2	976.0	354.9	31.5	621.1	4.60R
108	24.5	14.2	-99.7	82.2	113.9	1.02 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

5.2 The Effects of Oil and Gas Development on Breeding Bird Populations

Regression Analysis: Forest Generalist Count vs. Annual Rate of Oil and Gas Edge

The regression equation is
COUNT_GENERAL = 34.9 + 0.00583 TE_OG_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	34.932	2.766	12.63	0.000
TE_OG_TREND(m)	0.005829	0.004803	1.21	0.264

S = 4.80967   R-Sq = 17.4%   R-Sq(adj) = 5.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	34.07	34.07	1.47	0.264
Residual Error	7	161.93	23.13		
Total	8	196.00			

Regression Analysis: Forest Generalist Count vs. Annual Rate of Oil and Gas Area

The regression equation is
COUNT_GENERAL = 35.0 + 11.3 OG_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	35.007	2.699	12.97	0.000
OG_TREND(HA)	11.345	9.269	1.22	0.261

S = 4.80254   R-Sq = 17.6%   R-Sq(adj) = 5.9%
Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	34.55	34.55	1.50	0.261
Residual Error	7	161.45	23.06		
Total	8	196.00			

5.3.1 Current Fragmentation Metrics and Guild Demographics – full routes

Regression Analysis: Total Count vs. Mean Core Shape Index

The regression equation is
COUNT = - 37.6 + 69.0 SHAPE_MN_CORE

Predictor	Coef	SE Coef	T	P
Constant	-37.57	55.18	-0.68	0.518
SHAPE_MN_CORE	69.02	28.03	2.46	0.043

S = 11.3266   R-Sq = 46.4%   R-Sq(adj) = 38.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	778.0	778.0	6.06	0.043
Residual Error	7	898.0	128.3		
Total	8	1676.0			

Regression Analysis: Forest Generalist Count vs. Shannon's Diversity Index

The regression equation is
COUNT_GENERAL = 16.4 + 22.7 SHDI

Predictor	Coef	SE Coef	T	P
Constant	16.390	7.888	2.08	0.076
SHDI	22.748	8.331	2.73	0.029

S = 3.68208   R-Sq = 51.6%   R-Sq(adj) = 44.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	101.10	101.10	7.46	0.029
Residual Error	7	94.90	13.56		
Total	8	196.00			

Regression Analysis: Forest Generalist Species vs. Patch Richness

The regression equation is
SPECIES_GENERAL = - 4.05 + 2.02 PR

Predictor	Coef	SE Coef	T	P
Constant	-4.045	3.908	-1.04	0.335
PR	2.0227	0.5640	3.59	0.009

S = 1.24707   R-Sq = 64.8%   R-Sq(adj) = 59.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	20.003	20.003	12.86	0.009
Residual Error	7	10.886	1.555		
Total	8	30.889			

Unusual Observations

Obs	PR	SPECIES_GENERAL	Fit	SE Fit	Residual	St Resid
9	8.00	10.000	12.136	0.752	-2.136	-2.15R

R denotes an observation with a large standardized residual.

Regression Analysis: Forest Generalist Species vs. Shannon's Diversity Index

The regression equation is
SPECIES_GENERAL = 1.07 + 9.43 SHDI

Predictor	Coef	SE Coef	T	P
Constant	1.068	2.976	0.36	0.730
SHDI	9.431	3.144	3.00	0.020

S = 1.38943   R-Sq = 56.3%   R-Sq(adj) = 50.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	17.375	17.375	9.00	0.020
Residual Error	7	13.514	1.931		
Total	8	30.889			

5.3.1 Current Fragmentation Metrics and Guild Demographics – partial routes

Regression Analysis: Forest Generalist Count vs. Percentage of Transitional Areas

The regression equation is
COUNT_GENERAL = 17.2 + 1.81 PLAND_TA

Predictor	Coef	SE Coef	T	P
Constant	17.221	2.077	8.29	0.000
PLAND_TA	1.8125	0.8093	2.24	0.045

S = 4.35650   R-Sq = 29.5%   R-Sq(adj) = 23.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	95.18	95.18	5.02	0.045
Residual Error	12	227.75	18.98		
Total	13	322.93			

Unusual Observations

Obs	PLAND_TA	COUNT_GENERAL	Fit	SE Fit	Residual	St Resid
1	0.72	27.00	18.52	1.63	8.48	2.10R
14	5.47	26.00	27.14	2.95	-1.14	-0.35 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Forest Generalist Count vs. Edge of Transitional Areas

The regression equation is
COUNT_GENERAL = 15.9 + 0.000151 TE_TA

Predictor	Coef	SE Coef	T	P
Constant	15.879	2.311	6.87	0.000
TE_TA	0.00015118	0.00005894	2.56	0.025

S = 4.16911   R-Sq = 35.4%   R-Sq(adj) = 30.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	114.35	114.35	6.58	0.025
Residual Error	12	208.58	17.38		
Total	13	322.93			

Unusual Observations

Obs	TE_TA	COUNT_GENERAL	Fit	SE Fit	Residual	St Resid
1	16756	27.00	18.41	1.52	8.59	2.21R

R denotes an observation with a large standardized residual.

5.3.2 Annual Rates of Fragmentation and Guild Demographics – full routes

Regression Analysis: Total Count vs. Annual Rate of Road Length

The regression equation is
COUNT = 114 - 42.8 ROAD_LENGTH_TREND (km)

Predictor	Coef	SE Coef	T	P
Constant	113.863	7.715	14.76	0.000
ROAD_LENGTH_TREND (km)	-42.80	18.05	-2.37	0.050

S = 11.5233   R-Sq = 44.5%   R-Sq(adj) = 36.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	746.5	746.5	5.62	0.050
Residual Error	7	929.5	132.8		
Total	8	1676.0			

Regression Analysis: Total Count vs. Annual Rate of Utility Corridor Edge

The regression equation is
COUNT = 97.7 - 0.0545 TE_UTILITY_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	97.744	3.828	25.54	0.000
TE_UTILITY_TREND(m)	-0.05446	0.02277	-2.39	0.048

S = 11.4787   R-Sq = 45.0%   R-Sq(adj) = 37.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	753.7	753.7	5.72	0.048
Residual Error	7	922.3	131.8		
Total	8	1676.0			

Unusual Observations

Obs	TE_UTILITY_TREND(m)	COUNT	Fit	SE Fit	Residual	St Resid
7	402	74.00	75.83	10.03	-1.83	-0.33 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Total Species vs. Annual Rate of Utility Corridor Area

The regression equation is
SPECIES = 30.8 - 91.5 UT_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	30.797	1.336	23.05	0.000
UT_TREND(HA)	-91.48	35.19	-2.60	0.035

S = 4.00694   R-Sq = 49.1%   R-Sq(adj) = 41.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	108.50	108.50	6.76	0.035
Residual Error	7	112.39	16.06		
Total	8	220.89			

Unusual Observations

Obs	UT_TREND(HA)	SPECIES	Fit	SE Fit	Residual	St Resid
3	-0.0380	42.00	34.27	1.87	7.73	2.18R
7	0.0890	24.00	22.66	3.44	1.34	0.65 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Total Species vs. Annual Rate of Utility Corridor Edge

The regression equation is
SPECIES = 30.8 - 0.0211 TE_UTILITY_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	30.790	1.306	23.58	0.000
TE_UTILITY_TREND(m)	-0.021140	0.007769	-2.72	0.030

S = 3.91596   R-Sq = 51.4%   R-Sq(adj) = 44.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	113.55	113.55	7.40	0.030
Residual Error	7	107.34	15.33		
Total	8	220.89			

Unusual Observations

Obs	TE_UTILITY_TREND(m)	SPECIES	Fit	SE Fit	Residual	St Resid
3	-178	42.00	34.55	1.87	7.45	2.17R
7	402	24.00	22.28	3.42	1.72	0.90 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: Edge Forest Count vs. Annual Rate of Number of Core Patches

The regression equation is
COUNT_EDGE = 27.2 - 29.6 NP_CORE_TREND

Predictor	Coef	SE Coef	T	P
Constant	27.231	2.521	10.80	0.000
NP_CORE_TREND	-29.565	9.201	-3.21	0.015

S = 5.59112   R-Sq = 59.6%   R-Sq(adj) = 53.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	322.73	322.73	10.32	0.015
Residual Error	7	218.82	31.26		
Total	8	541.56			

Unusual Observations

Obs	NP_CORE_TREND	COUNT_EDGE	Fit	SE Fit	Residual	St Resid
7	0.742	5.00	5.29	5.46	-0.29	-0.24 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Edge Forest Count vs. Annual Rate of Road Length

The regression equation is
COUNT_EDGE = 31.2 - 25.5 ROAD_LENGTH_TREND (km)

Predictor	Coef	SE Coef	T	P
Constant	31.215	4.214	7.41	0.000
ROAD_LENGTH_TREND (km)	-25.459	9.860	-2.58	0.036

S = 6.29483   R-Sq = 48.8%   R-Sq(adj) = 41.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	264.18	264.18	6.67	0.036
Residual Error	7	277.37	39.62		
Total	8	541.56			

Unusual Observations

Obs	ROAD_LENGTH_TREND (km)	COUNT_EDGE	Fit	SE Fit	Residual	St Resid
8	0.375	34.00	21.67	2.10	12.33	2.08R

R denotes an observation with a large standardized residual.

Regression Analysis: Edge Forest Species vs. Annual Rate of Number of Patches

The regression equation is
SPECIES_EDGE = 8.94 - 1.95 NP_TREND

Predictor	Coef	SE Coef	T	P
Constant	8.9426	0.6774	13.20	0.000
NP_TREND	-1.9502	0.7240	-2.69	0.031

S = 1.98588   R-Sq = 50.9%   R-Sq(adj) = 43.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	28.616	28.616	7.26	0.031
Residual Error	7	27.606	3.944		
Total	8	56.222			

Regression Analysis: Edge Forest Species vs. Annual Rate of Mean Patch Size

The regression equation is
SPECIES_EDGE = 8.27 + 22.2 AREA_MN_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	8.2696	0.6757	12.24	0.000
AREA_MN_TREND(HA)	22.189	8.362	2.65	0.033

S = 2.00107   R-Sq = 50.1%   R-Sq(adj) = 43.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	28.192	28.192	7.04	0.033
Residual Error	7	28.030	4.004		
Total	8	56.222			

Regression Analysis: Edge Forest Species vs. Annual Rate of Euclidean Nearest Neighbor

The regression equation is
SPECIES_EDGE = 8.55 + 1.20 ENN_MN_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	8.5465	0.7000	12.21	0.000
ENN_MN_TREND(m)	1.1952	0.4985	2.40	0.048

S = 2.10001   R-Sq = 45.1%   R-Sq(adj) = 37.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	25.352	25.352	5.75	0.048
Residual Error	7	30.870	4.410		
Total	8	56.222			

Regression Analysis: Edge Forest Species vs. Annual Rate of Number of Core Patches

The regression equation is
SPECIES_EDGE = 10.2 - 8.69 NP_CORE_TREND

Predictor	Coef	SE Coef	T	P
Constant	10.1587	0.9069	11.20	0.000
NP_CORE_TREND	-8.692	3.311	-2.63	0.034

S = 2.01170   R-Sq = 49.6%   R-Sq(adj) = 42.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	27.894	27.894	6.89	0.034
Residual Error	7	28.329	4.047		
Total	8	56.222			

Unusual Observations

Obs	NP_CORE_TREND	SPECIES_EDGE	Fit	SE Fit	Residual	St Resid
7	0.742	4.000	3.709	1.964	0.291	0.67 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Edge Forest Species vs. Annual Rate of Road Length

The regression equation is
SPECIES_EDGE = 12.0 - 9.32 ROAD_LENGTH_TREND (km)

Predictor	Coef	SE Coef	T	P
Constant	12.012	1.154	10.41	0.000
ROAD_LENGTH_TREND (km)	-9.324	2.699	-3.45	0.011

S = 1.72326   R-Sq = 63.0%   R-Sq(adj) = 57.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	35.435	35.435	11.93	0.011
Residual Error	7	20.787	2.970		
Total	8	56.222			

Regression Analysis: Edge Forest Species vs. Annual Rate of Utility Corridor Edge

The regression equation is
SPECIES_EDGE = 8.51 - 0.00998 TE_UTILITY_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	8.5087	0.7007	12.14	0.000
TE_UTILITY_TREND(m)	-0.009981	0.004169	-2.39	0.048

S = 2.10140   R-Sq = 45.0%   R-Sq(adj) = 37.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	25.311	25.311	5.73	0.048
Residual Error	7	30.911	4.416		
Total	8	56.222			

Unusual Observations

Obs	TE_UTILITY_TREND(m)	SPECIES_EDGE	Fit	SE Fit	Residual	St Resid
7	402	4.000	4.492	1.836	-0.492	-0.48 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Forest Generalist Count vs. Annual Rate of Utility Corridor Area

The regression equation is
COUNT_GENERAL = 37.6 - 83.5 UT_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	37.583	1.295	29.03	0.000
UT_TREND(HA)	-83.54	34.10	-2.45	0.044

```
S = 3.88269   R-Sq = 46.2%   R-Sq(adj) = 38.5%


Analysis of Variance

Source          DF      SS     MS     F      P
Regression       1   90.47  90.47  6.00  0.044
Residual Error   7  105.53  15.08
Total            8  196.00


Unusual Observations

Obs  UT_TREND(HA)  COUNT_GENERAL    Fit  SE Fit  Residual  St Resid
  7        0.0890          32.00  30.15    3.33      1.85      0.93 X

X denotes an observation whose X value gives it large influence.
```

Regression Analysis: Forest Generalist Count vs. Annual Rate of Utility Corridor Edge

```
The regression equation is
COUNT_GENERAL = 37.6 - 0.0191 TE_UTILITY_TREND(m)


Predictor                 Coef   SE Coef      T      P
Constant                37.577     1.279  29.38  0.000
TE_UTILITY_TREND(m)  -0.019134  0.007609  -2.51  0.040


S = 3.83560   R-Sq = 47.5%   R-Sq(adj) = 40.0%


Analysis of Variance

Source          DF      SS     MS     F      P
Regression       1   93.02  93.02  6.32  0.040
Residual Error   7  102.98  14.71
Total            8  196.00


Unusual Observations

Obs  TE_UTILITY_TREND(m)  COUNT_GENERAL    Fit  SE Fit  Residual  St Resid
  7                  402          32.00  29.88    3.35      2.12      1.14 X

X denotes an observation whose X value gives it large influence.
```

5.3.2 Annual Rates of Fragmentation and Guild Demographics – partial routes

Regression Analysis: Interior Forest Species vs. Annual Rate of Core Patch Size

```
The regression equation is
SPECIES_INTERIOR = 8.90 - 1.65 AREA_MN_CORE_TREND(HA)


Predictor                  Coef  SE Coef      T      P
Constant                 8.8978   0.5306  16.77  0.000
AREA_MN_CORE_TREND(HA)  -1.6482   0.7146  -2.31  0.040
```

S = 1.78891   R-Sq = 30.7%   R-Sq(adj) = 24.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	17.026	17.026	5.32	0.040
Residual Error	12	38.403	3.200		
Total	13	55.429			

Unusual Observations

Obs	AREA_MN_CORE_TREND(HA)	SPECIES_INTERIOR	Fit	SE Fit	Residual
4	1.20	8.000	6.915	1.190	1.085

Obs	St Resid
4	0.81 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Forest Generalist Species vs. Annual Rate of Total Edge

The regression equation is
SPECIES_GENERAL = 8.39 - 0.299 EDGE_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	8.3942	0.7007	11.98	0.000
EDGE_TREND(HA)	-0.2993	0.1253	-2.39	0.034

S = 1.74166   R-Sq = 32.2%   R-Sq(adj) = 26.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	17.314	17.314	5.71	0.034
Residual Error	12	36.400	3.033		
Total	13	53.714			

Unusual Observations

Obs	EDGE_TREND(HA)	SPECIES_GENERAL	Fit	SE Fit	Residual	St Resid
4	-4.6	9.000	9.767	1.193	-0.767	-0.60 X

X denotes an observation whose X value gives it large influence.

Regression Analysis: Forest Generalist Species vs. Annual Rate of Core Mean Patch Size

The regression equation is
SPECIES_GENERAL = 7.69 + 1.69 AREA_MN_CORE_TREND(HA)

Predictor	Coef	SE Coef	T	P
Constant	7.6879	0.5120	15.02	0.000
AREA_MN_CORE_TREND(HA)	1.6926	0.6895	2.45	0.030

S = 1.72626   R-Sq = 33.4%   R-Sq(adj) = 27.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	17.955	17.955	6.03	0.030
Residual Error	12	35.760	2.980		
Total	13	53.714			

Unusual Observations

Obs	AREA_MN_CORE_TREND(HA)	SPECIES_GENERAL	Fit	SE Fit	Residual
4	1.20	9.000	9.724	1.148	-0.724

Obs	St Resid
4	-0.56 X

X denotes an observation whose X value gives it large influence.

5.3.2 Annual Rates of Fragmentation and Guild Demographics – multiple regression

Regression Analysis: Total Count vs. Mean Core Shape Index and Annual Rate of Utility Corridor Edge

The regression equation is
COUNT = - 7.3 + 53.5 SHAPE_MN_CORE - 0.0416 TE_UTILITY_TREND(m)

Predictor	Coef	SE Coef	T	P
Constant	-7.25	46.43	-0.16	0.881
SHAPE_MN_CORE	53.48	23.60	2.27	0.064
TE_UTILITY_TREND(m)	-0.04164	0.01892	-2.20	0.070

S = 9.10050   R-Sq = 70.4%   R-Sq(adj) = 60.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	1179.09	589.54	7.12	0.026
Residual Error	6	496.91	82.82		
Total	8	1676.00			

Source	DF	Seq SS
SHAPE_MN_CORE	1	777.96
TE_UTILITY_TREND(m)	1	401.13