THESIS

DETERMINING DIFFERENCES IN THE SPATIAL DISTRIBUTION OF FOREST STRUCTURE ON THE KAIBAB PLATEAU:

Implications for forest management and the northern goshawk.

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY RYAN S. MILLER ENTITLED "DETERMINING DIFFERENCES IN THE SPATIAL DISTRIBUTION OF FOREST STRUCTURE ON THE KAIBAB PLATEAU: IMPLICATIONS FOR FOREST MANAGEMENT AND THE NORTHERN GOSHAWK." BE ACCEPTED AS FULFILLING IN PART THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Abstract

The Kaibab Plateau, in North Central Arizona, has undergone extensive change in the last 100 years due to land management practices such as logging, road building, and fire suppression. The northern goshawk (*Accipiter gentilis*) has been a center of controversy, due to the potential effects of silvicultural practices on goshawk breeding habitat (Reynolds 1983, Bloom et al 1986, Kennedy 1989, Crocker-Bedford 1990). Current and past research efforts on the Kaibab Plateau have mapped Goshawk nesting territories and temporal change in nesting behavior and success. However, these research efforts have not determined how long-term spatial changes in land-use activities that have influenced forest structure, in turn affect goshawk nesting habitat. Researchers have proposed that differences in forest structure affect goshawk nesting success (Reynolds et al. 1992, Lang 1994), but no empirical evidence has been presented to support this proposition. Differences in forest structure on the North Kaibab Ranger District and the Grand Canyon National Park may affect goshawk use of each management area.

This study investigated possible forest structure differences between the North Kaibab Ranger District and the adjacent Grand Canyon National Park. Forest inventory data was collected for both the Grand Canyon National Park and North Kaibab Ranger District. Analysis was conducted at three scales biologically important to the northern goshawk: landscape, stand, and nest site.

Landscape analysis of the National Park and the National Forest found that there are significant differences in the size and spatial distribution of forest biomass between the two sites. Landscape metrics for the National Park and National Forest showed considerable differences with regard to forest cover type connectivity, size, shape, and distribution. The forests also demonstrated significant differences in tree-size class distributions, total basal area, and species composition. These differences were present at all three scales biologically important to the northern goshawk. The differences in spatial characteristics and composition of the forests could be the result of diverging management philosophies of the National Park and the National Forest. The effects of divergent management are not well understood and could have long lasting effects on the ecological integrity of the Kaibab Plateau and sensitive species such as the northern goshawk.

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Introduction and Literature Review

The Kaibab Plateau, in North Central Arizona, has undergone extensive change in the last 100 years due to land management practices such as logging, road building, and fire suppression. The northern goshawk (*Accipiter gentilis*), a sensitive species, has been a center of controversy, due to the potential effects of silvicultural practices on goshawk breeding habitat (Reynolds 1983, Herron et al. 1985, Bloom et al. 1986, Kennedy 1989, Crocker-Bedford 1990, Reiser 1991, Reynolds 1992, 1996). Consequently, landscape scale management plans have been proposed for goshawks in both the Pacific Northwest and Desert Southwest (U.S. Department of Agriculture 1994 and Reynolds et al. 1992, 1996).

In the Southwestern United States the northern goshawk relies primarily on the ponderosa pine forest type but is found in mixed conifer and spruce-fir forests as well. These forest types have changed considerably, in regards to structure and composition, over the past 100 years due in part to timber harvesting practices and fire suppression (Rasmussen 1941, Cooper 1960, Moir and Dieterich 1988, Covington and Moore 1991). Current silivicultural practices on many forests occur in small treatments, which are widely distributed throughout the landscape resulting in relatively slow rates of change (Reynolds and Joy 1998). Most temporal change studies to date have examined stand structural change and species composition but have not quantified landscape change on any large geographic extent (Cooper 1960, Weaver 1961, Ellenwood 1993).

Ellenwood (1993) compared forest inventory data for the Kaibab Plateau collected by Lang and Stewart (1910 and 1913) with inventory data collected by the North Kaibab Ranger District in 1955 and 1990. Comparisons determined that stand density on the Plateau increased 125% on 76.5% of the Plateau while only 11.4% of Plateau experienced declining stand density. Ellenwood concluded that the Plateau currently possesses more large tree biomass at higher stand densities than at the turn of the century. Stand structural characteristics, such as stand density, canopy closure, and tree size effect goshawk nesting and foraging behavior (Renyolds, 1992, 1996).

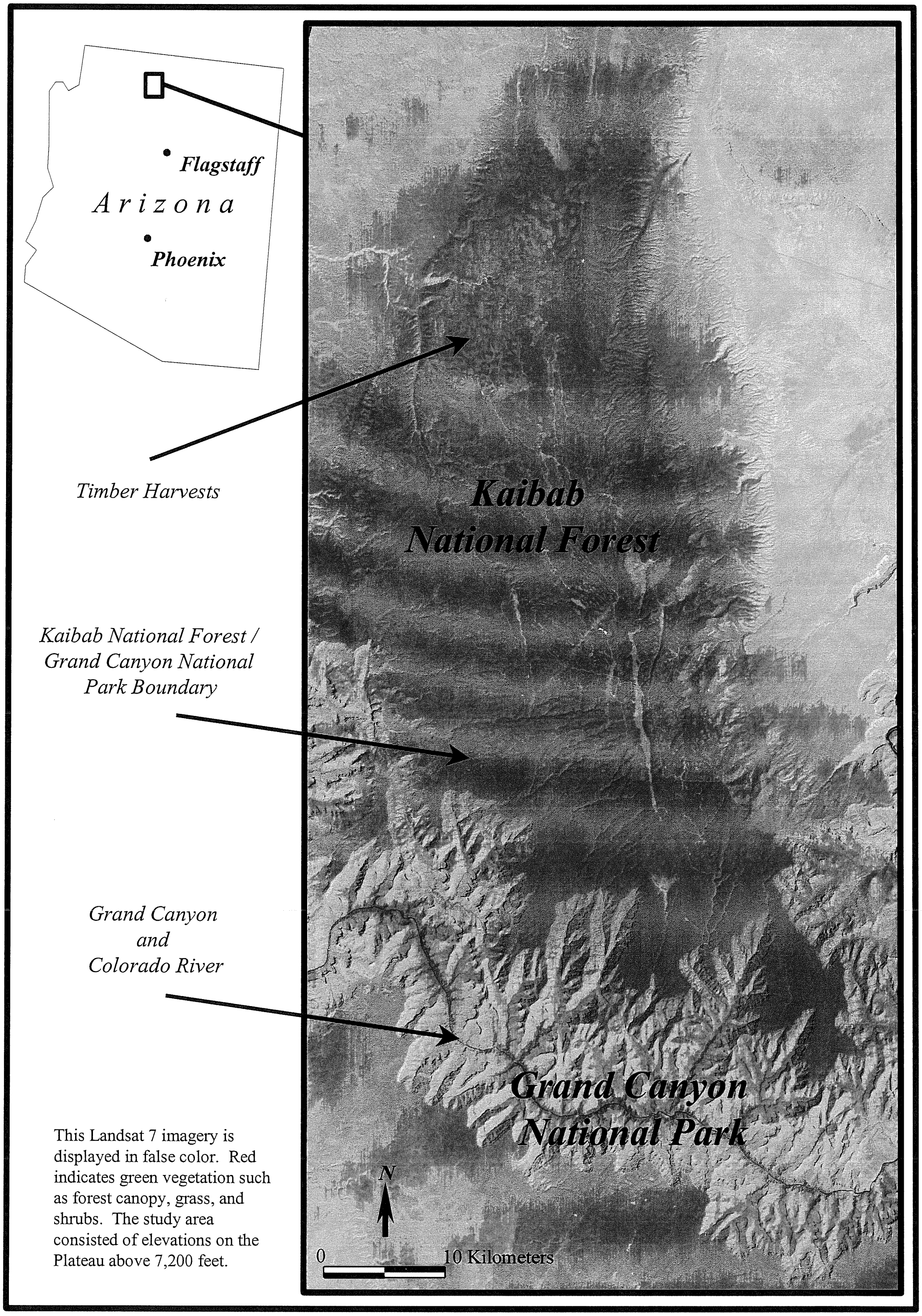
Researchers have determined three landscape scales that are important for goshawk breeding biology: the nest stand (12 ha), post-fledging area (168 ha), and foraging area (>2,160 ha) (Reynolds et al 1983, Reynolds et al. 1992, Kennedy 1989). Research suggests that dense late succession forest conditions, stands with relatively large trees of high density and dense canopy cover, are important for nesting habitat (Reynolds et al 1982, Moore Henny 1983, Crooker-Bedford and Chaney 1988, Reynolds 1992). Dense late succession vegetation provides protection of newly fledged young and creates stable microclimates that may be important to fledgling survival (Reynolds et al. 1982, Morre and Henny 1983). Goshawks use available habitats opportunistically for foraging. However, the goshawk's hunting strategy is adapted to dense forest conditions with an open understory, the raptor perches in the canopy and scans the understory and ground for prey. Open understory enhances prey detection and capture in dense late succession forests due to visual limitations (Reynolds, 1992).

Study Site:

The Kaibab Plateau is a limestone plateau located on the north rim of the Grand Canyon in north central Arizona (see figure 1). The Plateau is bounded on the south by the Grand Canyon, on the east by abrupt steep slopes and on the west and north by gentle slopes. The Plateau rises from a desert plane at 1,750 meters to an elevation of 2,800 meters. This elevational gradient encompasses shrub-steppe, pinyon-juniper, ponderosa pine, mixed-conifer, and spruce-fir forests. Ponderosa pine is the dominant forest type on the Plateau encompassing approximately 122,400 ha followed by mixed-conifer forests with 51,600 ha, and spruce-fir forests with 30,600 ha. The long-term average annual precipitation on the Kaibab Plateau is 67.5 cm, with winter snow-packs of 2.5-3.0 meters (White and Vankat 1993, Reynolds and Joy 1998).

The Kaibab Plateau boosts large populations of the northern goshawk, mule deer, Kaibab squirrel (unique to the Plateau), and other species commonly associated with the ponderosa pine ecosystem. Researchers have identified in excess of 100 goshawk nest territories on the Plateau from 1990 through 1996 (Reynolds and Joy 1998). Both private industry and federal agencies have intensively studied the population of goshawks on the Plateau (Crocker-Bedford 1990, Zinn and Tibbitts 1990, Ellenwood 1993, Reynolds and Joy 1998, Dewhurst et al. 1995).

Figure 1. Satellite imagery for the Kaibab Plateau.



This Landsat 7 imagery is displayed in false color. Red indicates green vegetation such as forest canopy, grass, and shrubs. The study area consisted of elevations on the Plateau above 7,200 feet.

The Plateau is divided into two management areas, the North Kaibab Ranger District (NKRD) of the Kaibab National Forest and Grand Canyon National Park (GCNP) (Figure 1). Historically, the Kaibab Plateau experienced numerous natural and human induced disturbance regimes, such as frequent low severity surface fires, livestock grazing, enlarged deer herds, road building, intensive timber management, and fire suppression. Over the past century, the occurrence or lack of these change dynamics has altered the forest composition on the Plateau. Philosophical differences in agency missions between the United States Forest Service and National Park Service may have lead to different forest dynamics on the GCNP and on the NKRD resulting in different forest conditions.

Silivicultural practices on the NKRD have historically removed large tree biomass and reduced overall tree density resulting in a less dense forest condition (1992 Kaibab National Forest Timber Atlas). Timber harvests have also been distributed across the landscape effectively reducing the spatial variation of forest biomass. Timber harvesting did not begin on the Plateau until the early 1920's and was limited to harvest of dead and dying trees (sanitation cutting) until the 1960's (Burnett 1991). In the late 1960's clear-cut siliviculture was introduced, harvesting approximately 922 hectares over approximately a 5 year period and was discontinued in the early 1970's. Single tree selection cutting continued through the mid-1970's when more intensive management of the forest began. Starting in the mid-1970's the pine and mixed-conifer forests where converted to regulated even aged forests. This increased the total volume of wood removed from the forests by a factor of five, from 9,077 to 48,412 board feet per hectare between 1986 and 1990. Between 1970 and 1990 approximately 1.2 million board feet was harvested on the Plateau. Much of the early sanitation cutting occurred over the entire Plateau. Intensive stand-level management began in 1986 and reduced the total area harvested to 12,632 by 1991. Recommendations for forest management for the northern goshawk, referred to as the goshawk guidelines, were adopted in final form by the National Forest in 1992 (Reynolds et al. 1992). The goshawk guidelines outline silivicultural and management strategy to conserve the goshawk in the southwestern United States. In general, the guidelines instituted a silivicultural regime, which harvests groups of trees to increase horizontal structure within stands. Annual harvests after adoption of the guidelines reduced to approximately 8,000 to 17,000 board feet annually on the Plateau (1992 Kaibab National Forest Timber Atlas, Reynolds and Joy 1998, North Kaibab Ranger District historical timber sale records, 2000).

The ponderosa pine and mixed-conifer forests on the GCNP, have changed extensively over the past 100 years partly due to changing fire regimes (Mitchell and Freeman 1993, Fule et al. 2000). Historically, the ponderosa pine forests on the Kaibab Plateau experienced frequent, low severity surface fires with a return interval of 3 - 5 years (Cooper 1960, Madany and West 1980, Dieterich 1980, Covington and Moore 1991, Fule et al. 2000). However, the fire return interval on the Plateau and across much of the western United States has increased due to fire suppression and livestock grazing

(Weaver 1961, Dieterich 1980, Madany and West 1980, Fule et al. 2000). Frequent surface fires maintained ponderosa pine forests in a relatively open condition by destroying regeneration. The lack of frequent fires has resulted in increased Douglas-fir and true fir regeneration in ponderosa pine forests (Barrett et al. 1980, Reynolds 1992, Fule et al. 2000). The fire frequency on the Kaibab Plateau has lengthened due in part to livestock grazing, enlarged deer herds, road building, and fire suppression (Fule et al 2000).

Extensive livestock grazing began in 1885 and continued until the mid-1900's, except on the southern portion of the Plateau where it ceased in 1919 with the establishment of GCNP (Rasmussen 1941, Merkle 1962, Reynolds and Joy 1998, Mitchell and Freeman 1993). Livestock grazing along with an enlarged deer herd in the 1920's, 1930's and the 1950's reduced fine and small woody fuels (Rasmussen 1941, Merkle 1962, Reynolds and Joy 1998, Mitchell and Freeman 1993). Logging activities and road building on the NKRD may have reduced the continuity of fuels. These activities along with historic fire suppression practices of both the GCNP and NKRD resulted in the reduction of fire return rate on the Plateau. The increase in the return frequency of surface fires has increased sapling and pole-sized ponderosa pine by a factor of 8 and mixed-conifer by a factor of 11 (1992 Kaibab National Forest Timber Atlas, Reynolds and Joy 1998, Heinlein et al. 2000).

Problem Statement:

Current and past research efforts on the Kaibab Plateau have mapped Goshawk nesting territories and temporal change in nesting behavior and success. However, these research efforts have not determined how long-term temporal changes in land-use activities (i.e. logging, fire suppression, and resource development) have influenced forest structure, which in turn affects goshawk nesting habitat. Researchers have proposed that differences in forest structure affect goshawk nesting success (Reynolds et al. 1992, Lang 1994). Differences in forest structure on the North Kaibab Ranger District (NKRD) and the Grand Canyon National Park (GCNP), if such differences exist, may effect goshawk utilization of each area.

The overall objective of this study was to compare the spatial distributions of forest cover types on the Grand Canyon National Park to those on the North Kaibab Ranger District. This study tested two hypotheses concerning the composition of forest structure, which are:

H_o: There is no difference in the forest structure [1] between the Kaibab National Forest and the Grand Canyon National Park.

H_a: There is a difference in the forest structure between the Kaibab National Forest and the Grand Canyon National Park.

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[1] This study defined forest structure as the amount and organization of overstory and understory biomass as described by basal area, density of trees, saplings, and seedlings, average diameter at breast height, and canopy density.

H_o: There is no difference in the spatial distribution of forest structure between the Kaibab National Forest and the Grand Canyon National Park.

H_a: There is a difference in the spatial distribution of the forest structure between the Kaibab National Forest and the Grand Canyon National Park.

Methods

Two analysis processes were used to identify possible difference in landscape characteristics at broad and fine scales. In order to identify possible differences at a coarse scale, FRAGSTATS (version 2.0, 1995) landscape indices generated from Landsat TM imagery for the NKRD and the GCNP were qualitatively compared. Landscape indices are mathematical functions, which describe the shape, size, and spatial relationships among distinctive elements present on the landscape (McGarigal and Marks, 1995). Fine scale landscape characteristics such as stand and sub-stand forest structure (i.e. basal area, tree density, and others) were explored by statistically comparing forest inventory measures generated from ground survey data for both management areas.

Landscape Indices Analysis:

This analysis process was based on a single Landsat TM image collected in August of 1997 over north central Arizona (see figure 1). The image was geometrically corrected using nearest neighbor resampling. The Landsat data is of high quality possessing no clouds, smoke, or other atmospheric deformity. The data also lacks systematic errors such as striping and banding making the data very suitable for image processing. This data was provided as part of a research partnership with the United

States Forest Service Rocky Mountain Research Station (RMRS).

In order to effectively analyze the data, the image was first examined to determine the variability within each spectral band and to determine which features are best represented in each band. This is both a quantitative process (e.g., producing histograms for each band) and a qualitative process (e.g., noting in which band(s) certain features seem most apparent). In general, it is important to become very familiar with the data set in order conduct effective image classification.

The imagery was corrected for atmospheric attenuation. Atmospheric attenuation is the effect of water, dust, smoke or other media in the atmosphere that systematically alters the perceived spectral reflectance of an object. Water in the atmosphere (haze) is the most common result of altered spectral reflectance. This was accomplished by examining the bands to determine if any large differences in the distribution of spectral values existed. Variation in the data is a result of atmospheric attenuation and is most prevalent in the visible bands. This variation was removed using a histogram shift that involved subtracting the lowest spectral value obtained in each band from every value in the band.

Principal component analysis (PCA) was performed on the imagery to compress the information content of the data set. PCA transforms the data, evaluating all bands in the imagery and identifies unique combinations of the bands that account for the majority of the variability within the data set (Jensen et al. 1979, Chavez et al 1982, 1984). Past studies have shown that approximately 95% of the variability within an image is contained in the first three principal components (Jensen et al. 1979, Chavez et al 1982, 1984). Principal components often provide information in a way that identifies subtle changes in the data not obvious in the original spectral data. This information often aids in separating cover types that are spectrally similar.

Analysis determined that 99.74% of the variability within the image was contained in the first three principal components (Table 1). The first principal component (PC) contained ~86% of the variability in the imagery. Visual inspection of the PC's determined that the second and third PC's contained little information within the study area. The majority of the features identified by these PC's resided outside of the study area along the Grand Canyon and on the lower elevation plains surrounding the Plateau. For this reason, only the first PC was used in the classification analysis.

Table 1. Principle Component Analysis Results.

Band	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
1	0.10	0.29	-0.34	-0.08	0.08	-0.88
2	0.03	0.26	-0.37	-0.20	-0.86	0.17
3	0.10	0.47	-0.59	-0.03	0.49	0.43
4	0.50	-0.71	-0.49	0.12	-0.01	0.00
5	0.76	0.19	0.38	-0.50	0.04	0.05
6	0.40	0.32	0.15	0.83	-0.15	0.00
Eigen Value[2]	1345.04	181.30	24.94	3.26	0.62	0.11
Variability (%)[3]	86.48	11.66	1.60	0.21	0.04	0.01
Cumulative (%)[4]	86.48	98.14	99.74	99.95	99.99	100.00

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[2] The length of a principle component which measures the variance of a principle component band.
[3] Variability accounted for by principle component.
[4] Total cumulating variability described by principle components.

The first PC was masked to the extent of the Kaibab Plateau, which is considered all areas above 2,194 meters (7,200 feet) in elevation. This high elevation area was identified using USGS 1:24,000 scale digital elevation models (DEM). The first PC was filtered to reduce variability in the data set and to remove additional noise resulting from variability of forest types, which could affect classification and in turn FRAGSTATS analysis. A 3 x 3 majority filter was used to reduce inner patch variability and to define boundaries between patches. The resulting filtered image was classified into thematic maps in order to generate landscape indices. An unsupervised classification was deemed appropriate for this study due to the complexity of the data and the need to classify the imagery into many different thematic resolutions.

Landscape indices such as contagion, edge density, and patch size are greatly affected by spatial and thematic resolution. Spatial resolution is the physical scale at which the data can accurately represent landscape features such as patch shape, patch size, and patch arrangement. The term thematic resolution refers to the number of landscape features that can be identified. For example, 10 thematic categories represent the landscape at finer thematic resolution then 5 thematic categories. To investigate influences of thematic resolution the imagery was classified into 6 thematic maps containing 5, 15, 35, 40, 45, and 50 thematic classes. Thematic classes were not assigned to specific cover types. It was not possible to control for influences of spatial resolution, due to the fixed 30-meter resolution of the Landsat sensor system.

The six thematic maps where subsetted into two landscapes of interest, North Kaibab Ranger District and Grand Canyon National Park. The boundary data used in this subsetting was internally buffered by 400 meters to control for possible boundary affects along the National Forest / National Park boundary and to eliminate the affects of shear rock in the imagery along the Grand Canyon. The subsetting and multiple thematic classification procedure resulted in 12 images (6 unique thematic classifications for the GCNP and 6 additional classifications for the NKRD) which where used as inputs into the FRAGSTATS analysis. Landscape metrics were calculated at both the landscape and thematic class level. The analysis was limited to the following metrics:

1) Largest Patch Index (LPI)
2) Mean Patch Size (MPS)
3) Edge Density (ED)
4) Shannon's Evenness Index (SHEI)
5) Contagion
6) Mean Shape Index (MSI)
7) Landscape Shape Index (LSI)

The metrics for the two landscapes, NKRD and GCNP, were compiled for all thematic scales resulting in datasets that illustrated how the metrics changed as a function of thematic resolution. Performing the analysis in this fashion allowed the investigation of how different thematic resolutions effect the landscape metrics.

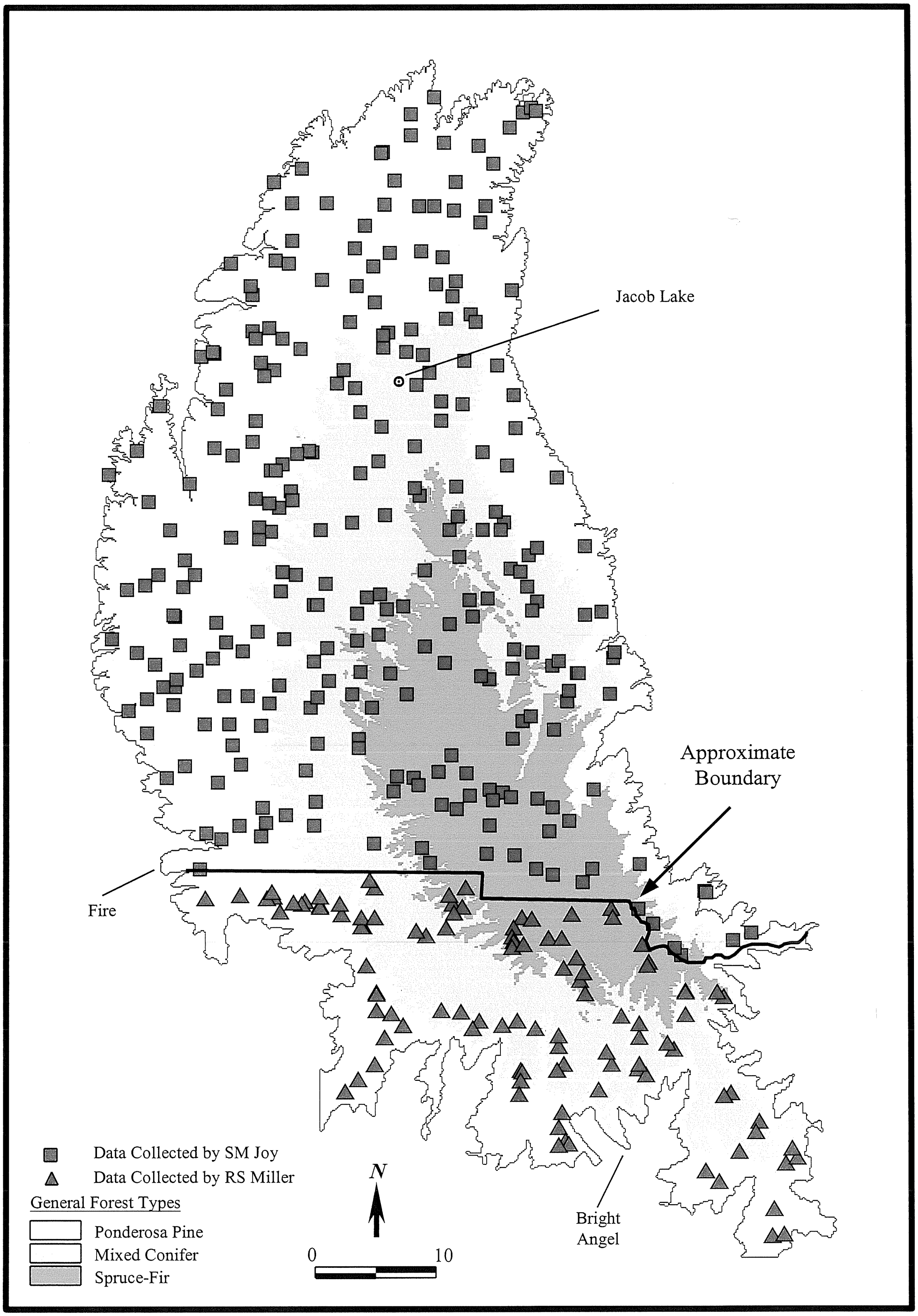
Forest Inventory Data Analysis:

The purpose of this analysis was to compare inventory measures collected by S.M. Joy (unpublished data) on the NKRD with similar inventory measures collected on the GCNP. Joy collected inventory measures for 184 random point locations and 88 historic goshawk nest sites on the NKRD (N = 272). Inventory measures describing forest structure where collected at 113 points on the GCNP during the summer of 1999 duplicating the methodology used by Joy (Figure 2).

The measures of basal area collected by Joy et al. were used to determine the target sample size required to accurately measure variation in basal area on the GCNP. The variance in the NKRD data was used to calculate the minimum sample size needed to estimate the mean and capture variation within the ponderosa pine, mixed conifer, and spruce-fir forest cover types (Appendix C). This analysis showed that 42 plots were required to capture the variation in the ponderosa pine forest type while approximately 127 sample plots were required to capture variation in the spruce-fir cover types. The mixed conifer forest type was highly variable and was assumed similar to either the ponderosa pine or spruce-fir type. A final sample size of 102 plots was chosen as a compromise between the number of plots needed to accurately represent the mean and the time required to perform the sampling. Additional plots (N = 11) were also located in each known goshawk territory on the GCNP. These 11 plots were placed at the base of a randomly selected historic nest tree within the territory. These plots provided information concerning forest characteristics for nesting areas on the GCNP.

The 113 points were located in the field using USGS 7.5 minute quadrangles and GCNP road maps. Point locations were verified using Global Positioning System (GPS). At each point location, square 30 x 30 meter plots (referred to as 30 meter plots), variable radial plots, and radial plots were established. Plots were laid out in a north-south, east-

Figure 2. Location of 30 meter sample



west fashion with the point assigned to the center of the plot. Vegetation data collected consisted of 18 measures of forest structure and species composition for the 30 meter plots, variable radial plots, and radial plots. Variable radial plots for basal area and radial plots for tree density, sapling density, and seedling density were located at the center point of the 30 meter plots. Canopy density was also measured at the center point of the 30 meter plot. The variables measured within the 30 meter plots included number of snags, dominant tree and sapling species and herbaceous variables. Vegetation characteristics and measurements collected at each plot corresponded with variables collected for the NKRD. The measures collected provide information characterizing overstory and understory density, biomass, and species composition. Table 2 explicitly lists the biometrics measured at each plot.

Statistical analysis of the data consisted of stratifying inventory measures respective to each management area. The data was stratified at two scales, data for the entire management area and data for historic nest sites. This resulted in four data sets: all Park measures, measures for nest sites on the Park, all Forest measures, and measures for nest sites on the Forest. The data was stratified at the nest level to explore trends in the forest characteristics of goshawk nesting areas within both management areas. Nest sites were classified as ponderosa pine, mixed conifer or spruce-fir by locating the nest sites geographically and examining the proportion of basal area by species at the nest plots. For example if the nest site resided at an elevation that possessed mixed conifer forests and if the nest plot possessed fir, spruce, and ponderosa pine then the nest plot was classified as mixed conifer.

Table 2. Forest inventory variables measured at 30 meter plots.

Biometrics	**Plot Type**
Qualitative Measures	
General site description	30 Meter
Slope	30 Meter
Aspect	30 Meter
Overstory Measures	
General forest type (e.g. ponderosa pine, spruce-fir, etc)	30 Meter
Basal area (ft^2 / acre)	Variable
Dominant tree species, DBH (cm) and height (m) [5]	30 Meter
Number of snags	30 Meter
Canopy closure (%) [6]	Center Point
Number of trees within 8.9 meters of center point	Radial
Understory Measures	
Dominant sapling species, DBH (cm) and height (m) [7]	30 Meter
Number of seedlings within 1.3 meters of center point	Radial
Number of saplings within 4 meters of center point	Radial
Understory herbaceous species, height, and overall percent cover [8]	30 Meter

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[5] Measures were taken for four characteristic trees in the overstory.
[6] Measures were taken for four characteristic trees in the understory.
[7] Canopy closure was measured using a spherical densiometer.
[8] Biometrics not used in statistical analysis.

The distribution of the data for management area was compared to determine if there was a statistically significant difference between the NKRD and the GCNP. Two-sampled T-tests were used to determine if any difference existed for the means of the forest measures at both the management area level and nest level. Differences in the population variance for all forest measures were also tested using an F test statistic.

Measures of understory herbaceous variables (species, height, and percent cover) were not used in the statistical analysis. It was determined that these measures were not comparable due to the seasonal differences between the data sets. The NKRD data was collected mid to late summer (July – August) while the GCNP data was collected during late spring early summer (May – June). This temporal difference in the timing of collection resulted in incomparable data.

Multivariate linear regression was used to generate predictive models, which described the difference in inventory data between each sample plot. The purpose of this analysis was to explore general trends in the data that may provide an understanding of the spatial distribution of forest structure. The analysis was restricted to variables found significant in the analysis of means and variables important to the biology of the goshawk. The independent variables analyzed included basal area of ponderosa pine, basal area of fir species, total basal area, conifer trees per acre, conifer saplings per acre, and canopy density. Forest structural attributes are influenced by site conditions such as aspect, slope, and elevation. In order to compensate for confounding influence of site conditions aspect, slope, and elevation were included in the analysis.

In order to generate these predictive models the absolute difference in the biometrics between each pair of sample plots was calculated. The euclidean distance and azimuth between each pair of sample plots was also calculated. This resulted in a paired dataset that contained a difference value for each biometric and variables describing the spatial orientation for each pair of sample plots. The paired data provided information concerning the spatial homogeneity and heterogeneity of the biometrics, which in turn describes the spatial distribution of the biometrics across the landscape. Multivariate linear regression models were created for each inventory measure using a forward selection procedure and a 5% level of significance. An example of the structural form of the models follows:

$$\Delta X = f\left(\text{Distance}_{AB}, \text{Azimuth}_{AB}, \Delta\ \text{Elevation}_{AB}, \Delta\ \text{Slope}_{AB}, \Delta\ \text{Aspect}_{AB}, \text{Coordinate}_{A}, \text{Coordinate}_{B}\right)$$

Where X is basal area, sapling density, tree density, or canopy density.

Due to the low predictive ability of these initial models (1.7% to 20.5%) the data was averaged to explore general trends in the difference data. The data was generalized by calculating the mean difference between each biometric for 25 value steps in three predictive variables that best described spatial arrangement of the biometrics: azimuth between plots, distance between plots, and change in elevation between plots. This provided information concerning the central tendency of the data across the distribution of values for each predictive variable.

In order to determine if there is a difference in general landscape trends for the NKRD and the GCNP, models for the averaged dataset were generated and qualitatively compared. Due to the reduction in the data, trends where easily determined through visual inspection by graphing the data. The non-linear or linear model deemed most appropriate for the trend was fit to the data. In most instances, the trend was clearly apparent, linear, quadratic, or cubic. For example, if the trend appeared linear in nature a linear model was used to represent the relationship between the independent and predictor variables.

Results

The NKRD landscape and GCNP landscape possessed differences in composition and structure in terms of patch size, patch shape and patch arrangement. In addition statistical comparisons of inventory measures identified significant difference between NKRD and GCNP at both the landscape extent and nest extent.

Landscape Indices Analysis:

The seven landscape metrics analyzed in this study displayed varying degrees of disagreement between the NKRD and the GCNP. Comparison of landscape metrics across all thematic resolutions is presented below. The relationship between the NKRD and GCNP metrics remained relatively constant across thematic resolutions.

Largest Patch Index (LPI):

Largest Patch Index (LPI) values can range from 0 to 100, with 100 indicating that the landscape consists of only a single patch. LPI approaches zero as the largest patch on the landscape decreases in size. The NKRD showed a significantly lower LPI than GCNP at all thematic resolutions. LPI values in NKRD were approximately 1 when greater then 5 classes were identified; while for GCNP, the LPI was approximately 8 (Table 3). This

Table 3. Comparison of selected landscape metrics for entire landscapes within the Grand Canyon National Park and the North Kaibab Ranger District.

Number of Thematic Classes	**Largest Patch Index (LPI)**			**Mean Patch Size (MPS)**			**Shannon's Evenness Index (SHEI)**			**Edge Density (ED)**		
	GCNP	NKRD	Difference (%)[9]	GCNP	NKRD	Difference (%)	GCNP	NKRD	Difference (%)	GCNP	NKRD	Difference (%)
5	12.25	5.00	59.18	2.21	1.51	31.67	0.74	0.94	21.28	161.00	225.65	28.65
15	8.11	0.96	88.16	0.64	0.37	42.19	0.73	0.96	23.96	236.23	356.39	33.72
35	8.09	0.84	89.62	0.44	0.25	43.18	0.69	0.94	26.60	271.68	407.50	33.33
40	8.09	0.84	89.62	0.42	0.24	42.86	0.68	0.93	26.88	274.46	413.16	33.57
45	8.09	0.84	89.62	0.41	0.23	43.90	0.68	0.93	26.88	278.23	416.36	33.18
50	8.09	0.87	89.25	0.41	0.23	43.90	0.66	0.93	29.03	277.48	418.25	33.66
Mean	8.79	1.56	82.25	0.76	0.47	38.16	0.70	0.94	25.53	249.85	372.89	33.00

Number of Thematic Classes	**Contagion**			**Landscape Shape Index (LSI)**			**Mean Shape Index (MSI)**		
	GCNP	NKRD	Difference (%)	GCNP	NKRD	Difference (%)	GCNP	NKRD	Difference (%)
5	40.44	22.68	43.92	77.23	121.61	36.49	1.35	1.36	0.74
15	39.39	17.94	54.46	111.95	191.09	41.42	1.16	1.16	0.00
35	42.05	18.27	56.55	128.31	218.26	41.21	1.10	1.09	0.91
40	42.61	18.36	56.91	129.59	221.27	41.43	1.10	1.09	0.91
45	42.82	18.63	56.49	131.33	222.97	41.10	1.09	1.08	0.92
50	43.59	18.82	56.82	130.98	223.98	41.52	1.09	1.08	0.92
Mean	41.82	19.12	54.28	118.23	199.86	40.84	1.15	1.14	0.87

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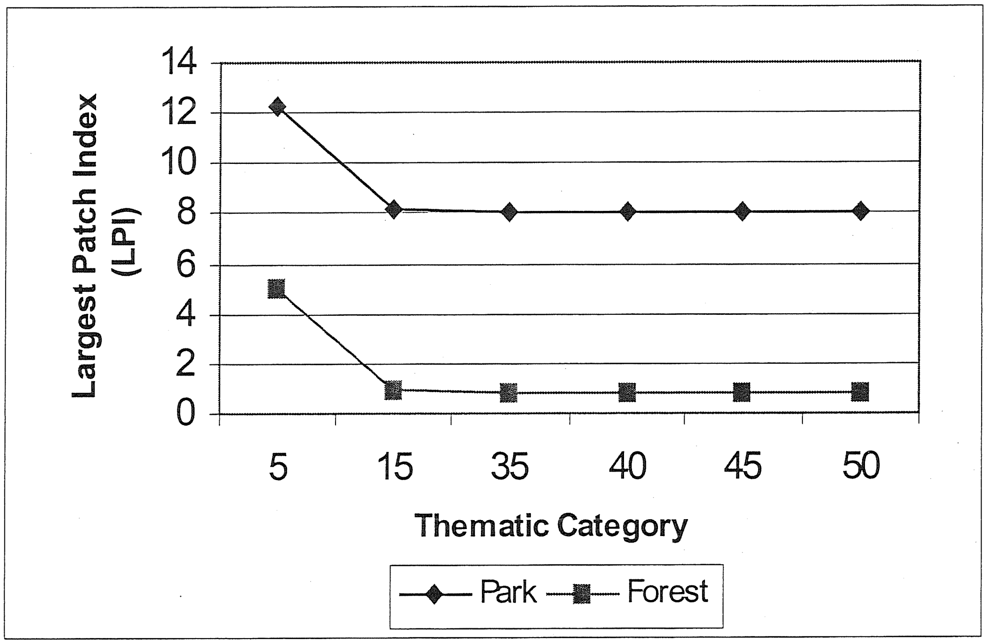
[9] Percent difference between landscape metrics.

indicates that patches in NKRD are significantly smaller than in GCNP and that there are essentially no large patches present on the NKRD landscape (Figure 3).

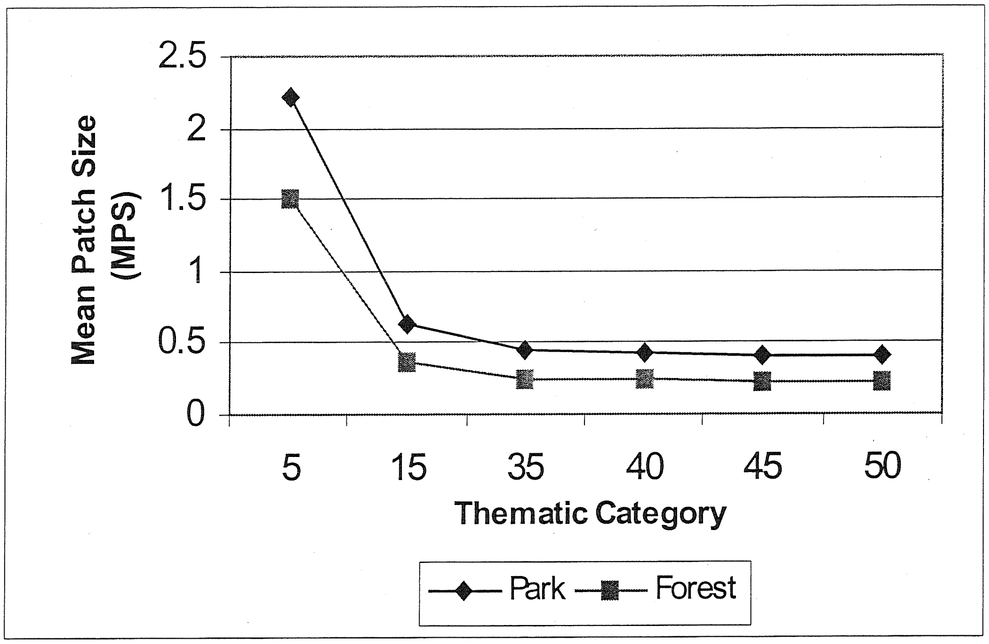
Figure 3. Comparison of the largest patch index (LPI).



Mean Patch Size (MPS):

The range in MPS is limited by the grain and extent of the data. MPS values are higher for GCNP than for NKRD, averaging approximately 0.76 ha in GCNP and 0.47 ha in NKRD (Table 3). This relationship is consistent across all thematic resolutions and further suggests that patches on the NKRD landscape are significantly smaller than those in GCNP (Figure 4).

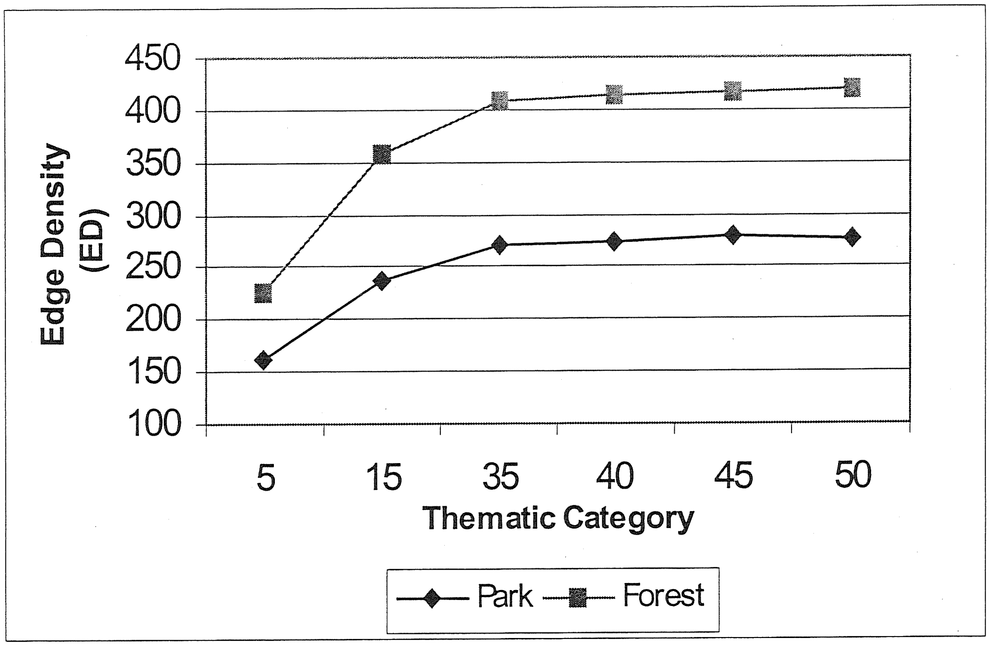
Figure 4. Comparison of mean patch size (MPI).



Edge Density (ED):

Edge density approaches zero when the entire landscape consists of a single patch. The NKRD possessed greater edge density then the GCNP across all thematic resolutions (Table 3). Edge density increased for both the NKRD and the GCNP as the number of thematic classes increased from 5 to 35 classes. The difference in edge density between the NKRD and GCNP also changed as a function of thematic category. The difference in edge density was smallest at 5 thematic categories but increased until 35 categories were it remained unchanged for both as the number of thematic classes increased until 50 categories (Figure 5).

Figure 5. Comparison of edge density (ED).

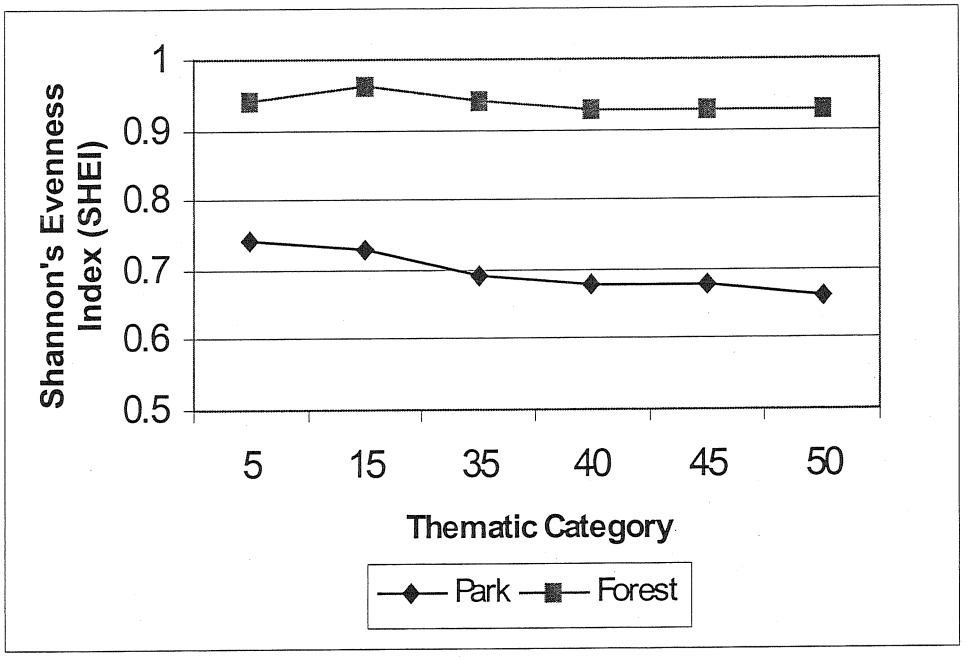


Shannon's Evenness Index (SHEI):

As SHEI values increase from 0 to 1, evenness in the distribution of area among patch types increases. A value of 1 indicates that the proportional abundance of all patch types is equal throughout the landscape. Analysis of the NKRD yields a SHEI value of approximately 0.9, while analysis of the GCNP yields a value of approximately 0.7 (Table 3). These values indicate that the NKRD landscape is composed of a fairly even distribution of cover types, while the GCNP is dominated to a greater extent by a few cover types (Figure 6). SHEI values generally remained constant across all thematic resolutions for both landscapes, except for a very slight tendency for the SHEI values of

GCNP to decrease as the number of thematic categories increased.

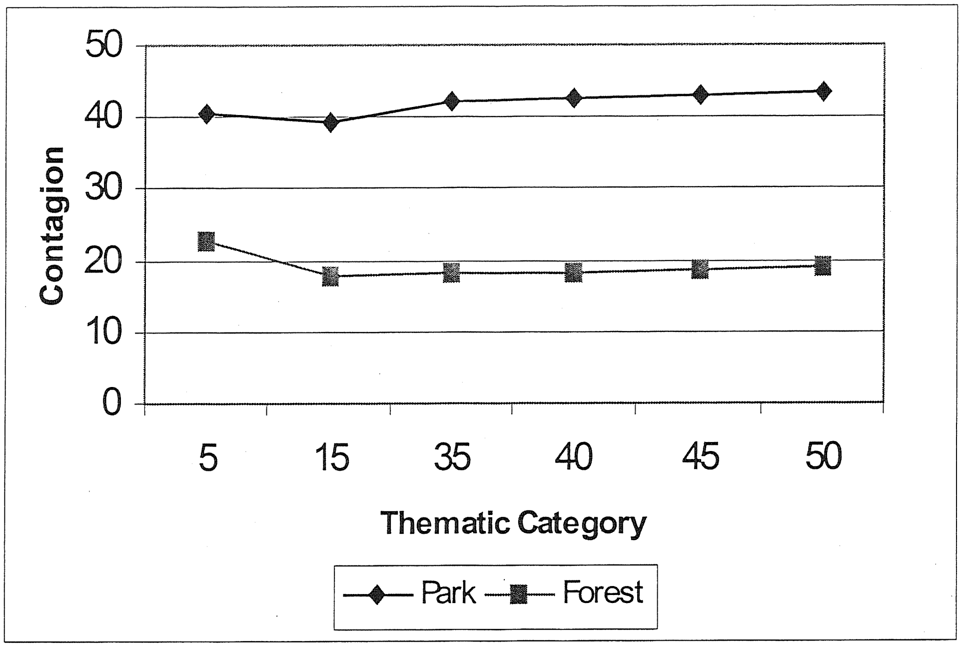
Figure 6. Comparison of Shannon's evenness index (SHEI).



Contagion:

Contagion approaches zero when the spatial distribution of adjacencies among patch types becomes increasingly uneven. Contagion reaches 100 when all patch types are equally adjacent to all other patch types. The GCNP possessed a mean contagion of 41.8 while the NKRD possessed a mean contagion of 19.1 (Table 3). Thus, certain thematic types tend to occur adjacent to each other more frequently on the GCNP then on the NKRD. Contagion remained unaffected by changes in thematic scale in both landscapes. Figure 7 depicts contagion values for all thematic resolutions for the NKRD and the GCNP.

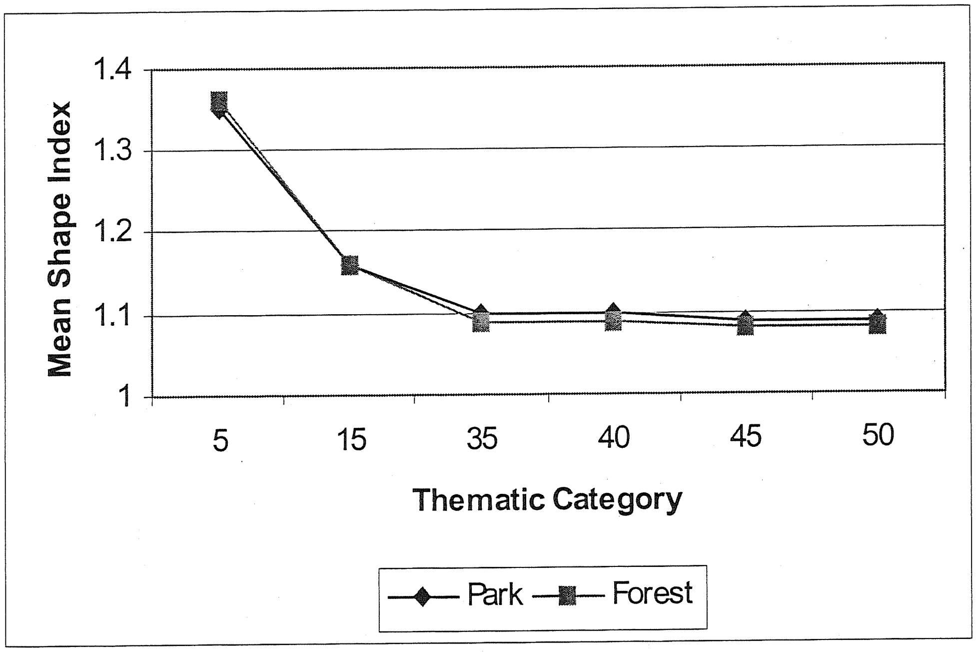
Figure 7. Comparison of contagion.



Mean Shape Index (MSI):

When all patches on the landscape are circular or square MSI equals one; MSI increases without limit as the patch shapes become more irregular. MSI values for the two regions are nearly identical over all thematic categories, indicating no difference, on average, in the complexity of patch shape. Values in both landscapes ranged from approximately 1.1 to 1.4 and averaged 1.2 (Table 3). MSI values changed as a function of thematic categories for both landscapes. MSI values were highest for 5 thematic categories and decreased until 35 thematic categories were it remained constant until 50 categories (Figure 8). Values for both landscapes were close to 1 which indicates that this index may have been effected greatly by the square input data of the classified Landsat data and may not provide information representative of the two landscapes.

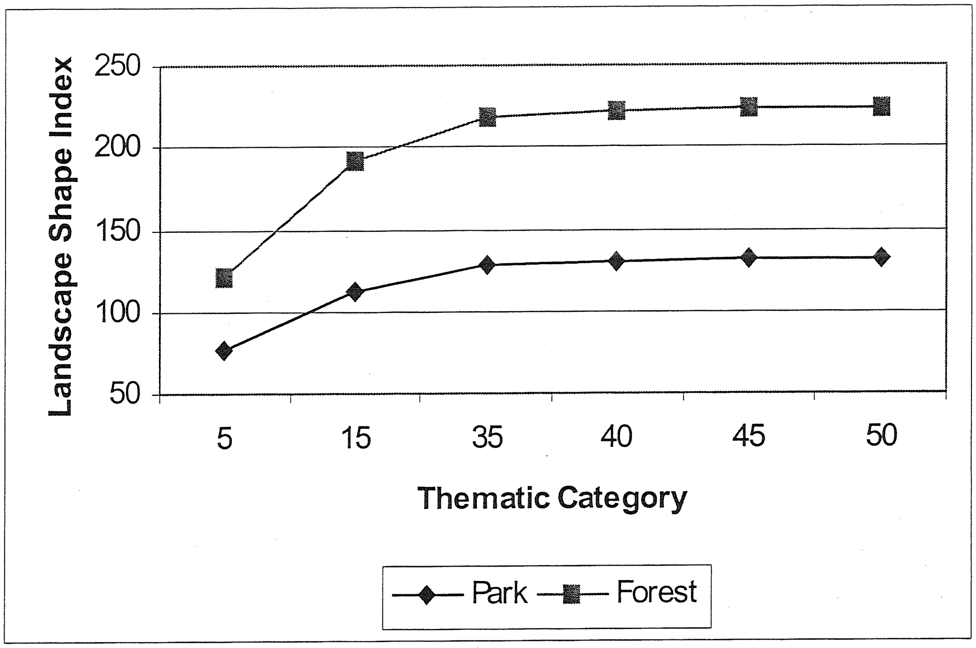
Figure 8. Comparison of mean shape index (MSI).



Landscape Shape Index (LSI):

LSI increases without limit as patch shape becomes more irregular or as the length of edge on the landscape increases. LSI equals one when the landscape consists of a single circular or square patch. LSI values were markedly higher on the NKRD. GCNP yielded an average value of 118.0, while NKRD yielded an average value of 200.0 (Table 3). This indicates that on a landscape level, patch shape in NKRD is significantly more complex than in GCNP. However, differences in LSI were not consistent between the landscapes. LSI was smallest at 5 thematic categories and increased as a function of thematic category until 35 categories (Figure 9).

Figure 9. Comparison of landscape shape index (LSI).



Forest Inventory Data Analysis:

Forest Wide Data:

Statistical comparisons of mean inventory measures identified significant difference between NKRD and GCNP for all but three of the metrics. The measures that were not significant different at the 5% level were: total basal area of aspen (Populus tremuloides), conifer seedlings per acre, and deciduous trees per acre (Table 4).

The NKRD is on average less dense possessing 50% less basal area, 75% fewer stems, and decreased canopy density. The NKRD is also characterized by trees that are on average slightly more then half the diameter of those found on the GCNP (National Forest 36.3 cm; National Park 63.2 cm). The forest also experiences greater deciduous

Table 4. Results of statistical comparison of the means and variance at stand scale.

Variable		N	Mean	StDev	Coefficient of Variation	T-statistic (H$_o$: Equal Means)	P-Value	F-statistic (H$_o$: Equal Var)	P-Value	DF
Basal Area (ft^2 / acre)										
Ponderosa Pine	Park	113	133.0	116.0	87.22	4.41	0.000	2.53	0.000	169
	Forest	174	79.3	72.9	91.93					
Aspen *	Park	113	26.2	45.5	173.66	1.91	0.058	1.31	0.104	215
	Forest	174	16.2	39.7	245.06					
Spruce	Park	113	29.7	59.9	201.68	2.97	0.003	3.53	0.000	153
	Forest	174	11.5	31.9	277.39					
Fir Species [10]	Park	113	85.5	91.0	106.43	8.03	0.000	7.12	0.000	132
	Forest	174	13.7	34.1	248.91					
All Trees	Park	113	274.7	84.7	30.83	15.14	0.000	1.01	0.943	238
	Forest	174	120.2	84.3	70.13					
Tree Counts (Circular Sub-Plots)										
Seedlings Conifer *	Park	113	1,638.5	1,969.2	120.19	-1.32	0.191	4.65	0.000	132
	Forest	98	2,253.8	4,246.1	188.40					
Seedlings Deciduous	Park	113	615.4	1,092.3	177.50	-3.45	0.001	38.58	0.000	101
	Forest	98	3,007.7	6,784.6	225.58					
Saplings Conifer	Park	113	257.3	400.8	155.80	3.18	0.002	3.06	0.000	182
	Forest	98	116.1	229.0	197.22					
Saplings Deciduous	Park	113	37.1	133.1	358.70	-2.50	0.014	46.90	0.000	100
	Forest	98	266.1	911.3	342.42					
Trees Conifer	Park	113	346.3	185.4	53.52	13.68	0.000	5.57	0.000	155
	Forest	98	83.4	78.5	94.15					
Trees Deciduous *	Park	113	51.2	84.1	164.13	1.20	0.231	1.22	0.310	197
	Forest	98	36.4	92.8	254.91					
Miscellaneous Measures										
Canopy Density (%)	Park	113	83.1	11.5	13.84	8.95	0.000	5.47	0.000	254
	Forest	175	62.5	26.9	43.04					
DBH (cm)	Park	453	63.2	20.3	32.12	19.25	0.000	1.33	0.002	975
	Forest	525	36.3	23.4	64.46					

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[10] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pseudotsuga menziesii).

* Comparison insignificant at the $\alpha = 0.05$ level.

regeneration, with aspen (Populous tremuloides) being the primary species. The GCNP possesses greater conifer regeneration, primarily englemann spruce (Picea engelmannii), fir (Abies concolor and Abies lasiocarpa), and Douglas-fir (Pseudotsuga menziesii).

Comparison of the variances for the biometrics found that all but three were significantly different: aspen basal area, total basal area, and total deciduous trees. The coefficient of variation indicated that the forest demonstrated a higher degree of variability for all but one inventory measure, total number of deciduous saplings. The NKRD possessed from 5% to 70% greater variability then the GCNP.

Statistical comparison of data for all historic nest sites identified significant differences in nest site composition for the NKRD and the GCNP (Table 5). The trends found at the management area scale are also present at the nest site scale. Nest sites on the GCNP possessed twice as much total basal area compared with the NKRD nest sites and twice as much basal area of ponderosa pine (Pinus ponderosa). Aspen and fir species composition was not significantly different for the management areas. Nest sites on the GCNP also possessed trees that on average possessed DBH 50% larger then trees found at nest sites on the NKRD. NKRD nest sites possessed greater variation in basal area, canopy density, and DBH. Circular sub-plots were not established at NKRD nest sites making a comparison of trees and saplings per acre impossible.

The majority of the nest sites on the GCNP are found in mixed conifer forests while the majority of the nest sites on the NKRD are located in pure stands of ponderosa pine. These forest types inherently possess differences in stocking levels and densities

Table 5. Results of statistical comparison of the means and variance at nest site scale for all nest sites.

Variable		N	Mean	StDev	Coefficient of Variation	T-statistic (H_o: Equal Means)	P-Value	F-statistic (H_o: Equal Var)	P-Value	DF
All Nest Sites										
Basal Area (ft^2 / acre)										
Ponderosa Pine	Park	11	224.0	125.0	55.8	-2.94	0.015	2.77	0.010	10
	Forest	88	110.0	75.1	68.3					
Aspen *	Park	11	10.9	36.2	332.1	0.32	0.757	1.17	0.645	12
	Forest	88	14.5	33.5	231.0					
Fir Species [11]	Park	11	60.0	100.0	166.7	-1.53	0.157	13.52	0.000	10
	Forest	88	13.6	27.2	200.0					
All Trees	Park	11	294.5	71.6	24.3	-6.34	0.000	1.13	0.701	12
	Forest	88	150.2	67.4	44.9					
Miscellaneous Measures										
Canopy Density (%)	Park	11	81.3	4.53	5.57	-1.58	0.123	9.28	0.001	38
	Forest	88	78.1	13.8	17.67					
DBH (cm)	Park	44	74.5	16.5	22.2	13.62	0.000	1.98	0.008	66
	Forest	344	36.6	23.2	63.4					

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[11] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pseudotsuga menziesii).

* Comparison insignificant at the α = 0.05 level.

due to the species composition of the forest types (i.e. mixed conifer is generally more dense then pure ponderosa pine forests). In order to control for possible bias due to different forest types, nest sites for the GCNP and NKRD were stratified into sites located in ponderosa pine forests and sites located in mixed conifer sites. The stratification was performed based on field classification of the general forest type at the time of sampling. The resulting nest sites where compared for differences using the same tests used in the previous analysis.

Statistical comparison of data for the historic nest sites located in mixed-conifer forests identified significant differences in nest site composition for the NKRD and the GCNP (Table 6). Stratification of the nest data for the GCNP resulted in 9 nests classified as mixed conifer and 2 classified as ponderosa pine. On the NKRD 26 nest sites were classified as mixed conifer, 56 as ponderosa pine, 6 as spruce-fir. Due to the relatively few nests located in ponderosa pine for the GCNP the comparison was only conducted between nest sites classified as mixed conifer. Mixed-conifer nest sites possessed significant differences in the basal area of ponderosa pine and total basal area but did not possess significant differences for other variables. Aspen and fir species composition was not significantly different for the management areas. Differences in variation were not analyzed due to the relatively small sample size.

Table 6. Results of statistical comparison of the means and variance at nest site scale for mixed conifer nest sites.

Variable		N	Mean	StDev	Coefficient of Variation	T-statistic (H$_o$: Equal Means)	P-Value	F-statistic (H$_o$: Equal Var)	P-Value	DF
Mixed-conifer Nest Sites										
Basal Area (ft^2 / acre)										
Ponderosa Pine	Park	9	209.0	131.0	-	-2.78	0.021	-	-	9
	Forest	26	83.1	61.9	-					
Fir Species [12] *	Park	9	69.0	109.0	-	-0.82	0.435	-	-	8
	Forest	26	38.5	34.8	-					
All Trees	Park	9	291.1	75.6	-	-4.19	0.002	-	-	11
	Forest	26	174.6	60.3	-					
Miscellaneous Measures										
Canopy Density (%) *	Park	9	82.22	3.96	-	-1.54	0.134	-	-	32
	Forest	26	77.7	13.3	-					
DBH (cm)	Park	36	73.0	16.4	-	-10.09	0.000	-	-	81
	Forest	127	38.1	23.9						

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[12] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pseudotsuga menziesii).

* Comparison insignificant at the $\alpha = 0.05$ level.

Regression Analysis:

Initial analysis found that linear models describing the spatial distribution of the inventory measures possessed low predictive ability. Models for the data possessed from 6 to 11 independent variables. Table 7 presents the independent variables that were significant in each predictive model in addition to the R^2 values, F-statistics, and P-values. Models for the NKRD described from 1.7% to 12.5% of the variability in the inventory measures while models for the GCNP explained from 1.9% to 20.5% of the variation. These models also included many confounding variables such as aspect, slope and elevation, which caused difficulty in interpretation. Due to the low predictive ability of the models, models for the NKRD and GCNP were not compared to assess statistical significance.

Table 7. Model results of initial forest inventory data.

Variable	**National Park**			**National Forest**		
	R^2	F-Statistic	P-Value	R^2	F-Statistic	P-Value
Basal Area						
Ponderosa Pine	20.5	165.74	0.000	1.7	33.20	0.000
Fir Species [13]	4.7	39.78	0.000	12.5	217.72	0.000
All Trees	1.9	41.29	0.000	3.2	45.43	0.000
Tree Counts (Circular Sub-Plots)						
Saplings Conifer	4.0	33.89	0.000	2.5	20.36	0.000
Trees Conifer	3.6	60.75	0.000	3.9	31.79	0.000
Miscellaneous Measures						
Canopy Density	3.8	31.63	0.000	2.1	54.24	0.000

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[13] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pusdotsuga menzesii).

Grand Canyon National Park:

Basal area demonstrated varying degrees of relationship with azimuth, distance, and elevation. In all cases, the relationship appeared non-linear in nature. The basal area of two species, ponderosa pine and spruce, were strongly correlated with all three predictor variables. Azimuth described 80.3% of the variation in basal area for Ponderosa pine and 61.9% of the variation for spruce species (Table 8). While distance and elevation, both described over 75% of the variation in basal area for these two species. The basal area of aspen, fir species, and all trees demonstrated varying degrees of association with the predictor variables. The basal area of aspen demonstrated the strongest relationship with distance between plots. Azimuth and elevation were correlated with aspen basal area but possessed low predictive ability. The basal area of fir species was also correlated with all three variables however, elevation described greater variation in fir basal area. Azimuth, distance between plots and change in elevation between plots possessed low predictive ability for total basal area of each plot.

Sapling and tree density was poorly predicted by the three variables: azimuth, distance, and elevation. Azimuth was not correlated with sapling density but did describe a positive non-linear trend in tree density (Table 8). Distance was only correlated with sapling density and possessed a linear association with distance between plots but only described approximately 45% of the variation. Sapling and tree density were both

Table 8. Model results of generalized forest inventory data for the Grand Canyon National Park (GCNP).

Variable	**Azimuth**				**Distance**				**Elevation**			
	Model Type[14]	R^2	F-Statistic	P-Value	Model Type	R^2	F-Statistic	P-Value	Model Type	R^2	F-Statistic	P-Value
Basal Area **(ft^2 / acre)**												
Ponderosa Pine	Cubic	80.3	28.49	0.000	Quad	89.4	92.92	0.000	Quad	88.8	87.44	0.000
Aspen	Quad	28.0	4.28	0.027	Quad	64.9	20.31	0.000	Quad	34.2	5.71	0.010
Spruce	Cubic	61.9	11.37	0.000	Quad	77.0	36.92	0.000	Quad	85.0	62.35	0.000
Fir Species[15]	Quad	33.7	5.59	0.011	Quad	29.7	4.65	0.021	Quad	65.1	20.53	0.000
All Trees	Cubic	6.6	1.61	0.216	Quad	21.7	3.05	0.067	Quad	2.5	0.28	0.760
Tree Counts - Circular Sub-Plots (stems / acre)												
Saplings Conifer	Linear	0.0	0.072	0.933	Linear	45.8	19.45	0.000	Quad	29.2	4.52	0.023
Trees Conifer	Cubic	43.4	5.37	0.007	Linear	13.6	3.63	0.069	Quad	51.3	11.61	0.000
Miscellaneous												
Canopy Density (%)	Quad	9.7	1.19	0.324	Linear	38.2	6.81	0.005	Linear	45.4	9.16	0.001

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[14] Indicates the linear or nonlinear model used to represent the trend – Quad = Quadratic.

[15] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pseudotsuga menziesii).

correlated with elevation. Elevation described approximately 51% of the variation in tree density and 30% of the variation in sapling density.

Canopy density possessed a linear correlation with both distance and elevation and was not correlated with azimuth. Distance possessed low predictive ability for canopy density, describing approximately 38% of the variation (Table 8). Elevation describing approximately 45% of the variation in canopy density. Azimuth did not demonstrate an association with canopy density.

North Kaibab Ranger District:

On the NKRD, basal area for all species was correlated with distance between plots and elevation but was not correlated with azimuth. Species such as aspen, spruce and fir showed the greatest response to elevation changes, with R^2 values of 91.8%, 93.1%, and 85.3% respectively when quadratic models were fit to the data (Table 9). Except for ponderosa pine all of the species possessed a quadratic relationship with elevation. The distance between plots possessed similar results. Distance between plots described from 55.1% to 89.1% of the variation in basal area when non-linear models were fit to the data (Appendix B). Azimuth between plots was not correlated with the basal area of any species.

Tree and sapling density exhibited linear trends with azimuth and distance but non-linear trends with elevation. Azimuth was significantly correlated with sapling density but not significantly correlated with tree density (Table 9). Despite the correlation, azimuth was not a good predictor of sapling density describing only 21% of

Table 9. Model results of generalized forest inventory data for the North Kaibab Ranger District (NKRD).

Variable	**Azimuth**				**Distance**				**Elevation**			
	Model Type [16]	R^2	F-Statistic	P-Value	Model Type	R^2	F-Statistic	P-Value	Model Type	R^2	F-Statistic	P-Value
Basal Area (**ft^2 / acre**)												
Ponderosa Pine	Linear	16.0	0.25	0.623	Quad	64.9	20.31	0.000	Linear	67.0	44.57	0.000
Aspen	Linear	16.0	4.38	0.048	Cubic	89.1	57.36	0.000	Quad	91.8	123.93	0.000
Spruce	Linear	2.1	0.50	0.488	Cubic	80.7	29.23	0.000	Quad	93.1	149.49	0.000
Fir Species [17]	Linear	0.7	0.17	0.681	Quad	55.1	13.52	0.000	Quad	85.3	63.80	0.000
All Trees	Linear	0.6	0.14	0.709	Linear	72.5	29.09	0.000	Quad	62.8	18.58	0.000
Tree Counts - Circular Sub-Plots (stems / acre)												
Saplings Conifer	Linear	20.9	6.33	0.019	Linear	33.0	11.79	0.002	Cubic	72.0	17.98	0.000
Trees Conifer	Linear	15.2	4.31	0.049	Linear	0.8	0.19	0.669	Cubic	72.3	18.25	0.000
Miscellaneous												
Canopy Density (%)	Linear	13.3	3.54	0.073	Linear	28.4	4.35	0.026	Linear	19.7	2.70	0.089

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[16] Indicates the linear or nonlinear model used to represent the trend – Quad = Quadratic.

[17] Fir species includes true firs (Abies lasiocarpa and Abies concolor) and Douglas-fir (Pseudotsuga menziesii).

the variation. Distance was correlated with sapling density but was again a poor predictor. Tree and sapling density possessed a strong non-linear relationship with elevation. Elevation described over 70% of the variation for both variables (Appendix B). Canopy density was only significantly correlated with one variable, distance between plots. However, distance between plots was a poor predictor of canopy density describing approximately 28% of the variation (Table 9).

Discussion

The Grand Canyon National Park and the North Kaibab Ranger District demonstrated distinct differences in landscape pattern, forest structure and the spatial distribution of forest structure. These differences were present at multiple scales important to the northern goshawk. These differences could be the result of philosophical differences in agency missions (i.e. preservation and multiple use) which have altered change dynamics on the Plateau over the past 100 years. Landscape scale differences in forest structure are likely the direct result of timber management on the NKRD; however, recent large fires on the GCNP may also contribute to this effect. Intrastand differences are likely the result of the two diverging management practices on the Plateau, timber management on the NKRD and fire suppression on the GCNP.

Landscape Scale Trends:

The size, shape and spatial distribution of patches differ greatly between the GCNP and NKRD. The NKRD landscape possessed greater fragmentation and smaller patches then the GCNP. These forests are also less dense and demonstrate a more even spatial distribution of forest structure. In contrast, the forests on the GCNP demonstrated greater continuity and larger overall patch size.

Timber harvesting may increase landscape variability in patch spatial distribution and size on the NKRD. Shannon's evenness index (SHEI) values for the NKRD indicate that the landscape possess a roughly even distribution of forest cover types which may result from variation in rotation age and cut frequency. Variation in rotation age and cut frequency result in distributing timber activities across the landscape increasing landscape variation in forest cover types (Figure 10). In addition, the NKRD possessed smaller patches that were dispersed with greater spatial constancy across the landscape when compared with the GCNP. Decreased mean patch size and largest patch size, as well as increased edge density all indicate greater levels of landscape heterogeneity and fragmentation on the NKRD.

Road density on the NKRD may indirectly contribute to the general pattern of greater patch heterogeneity (Figure 11). Edge density for the NKRD is 33% greater then that of the GCNP. Roads may have the indirect effect of creating isolated stands on the NKRD, which are in turn managed on different rotation ages and possibly with different silivicultural prescriptions. This would result in a more heterogeneous landscape with smaller patches increasing the edge density on the landscape.

Less continuity, smaller patches, and greater edge density on the NKRD may be the result of fragmentation due in part to stand scale silivicultural practices. Timber harvesting and road building change the spatial characteristics of forest structure at two fundamental scales. Timber harvesting directly altars stand level characteristics, which in turn alters landscape patch arrangement (Figure 10). Even-aged siliviculture removes

Figure 10. Location of historic silivicultural

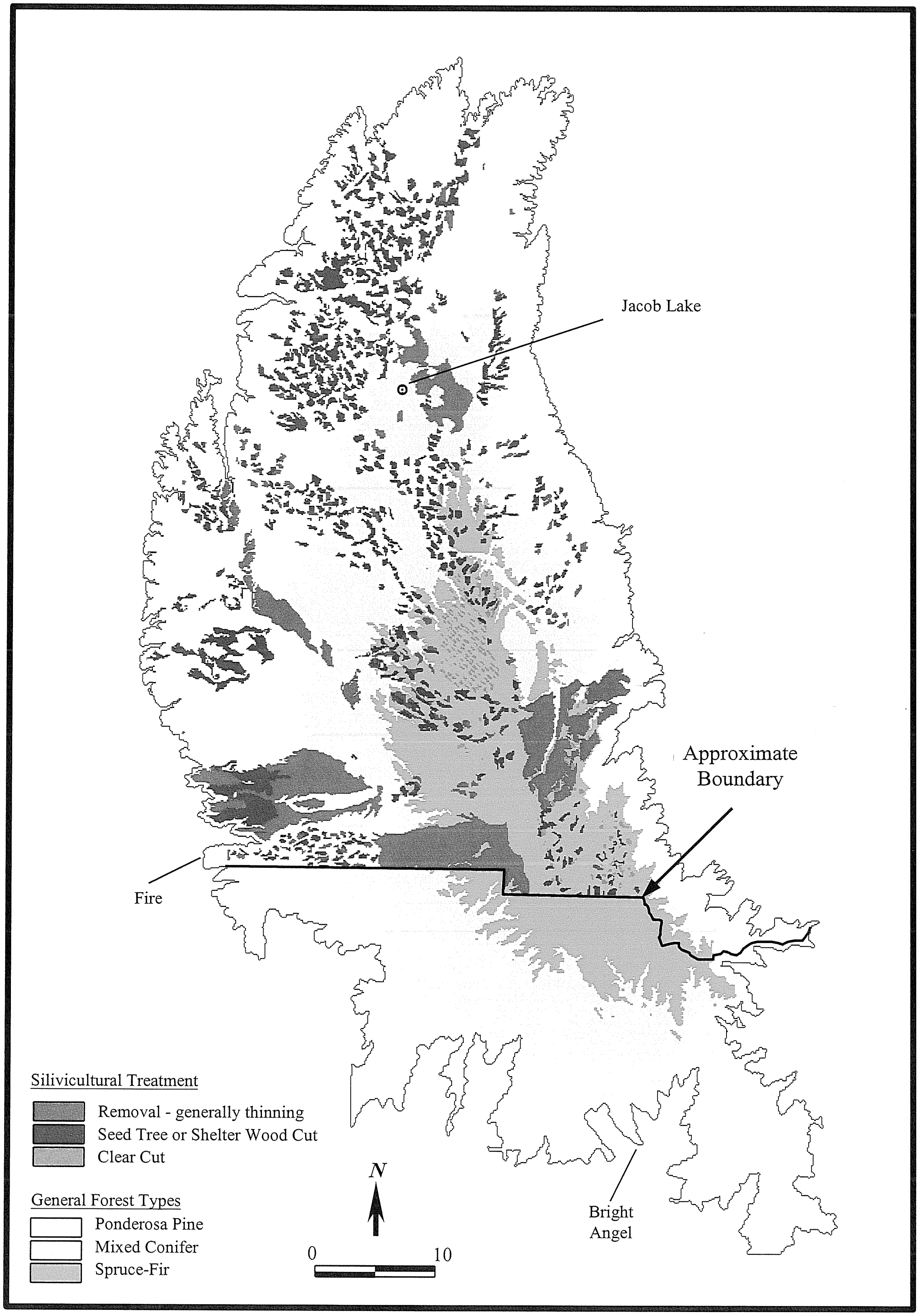
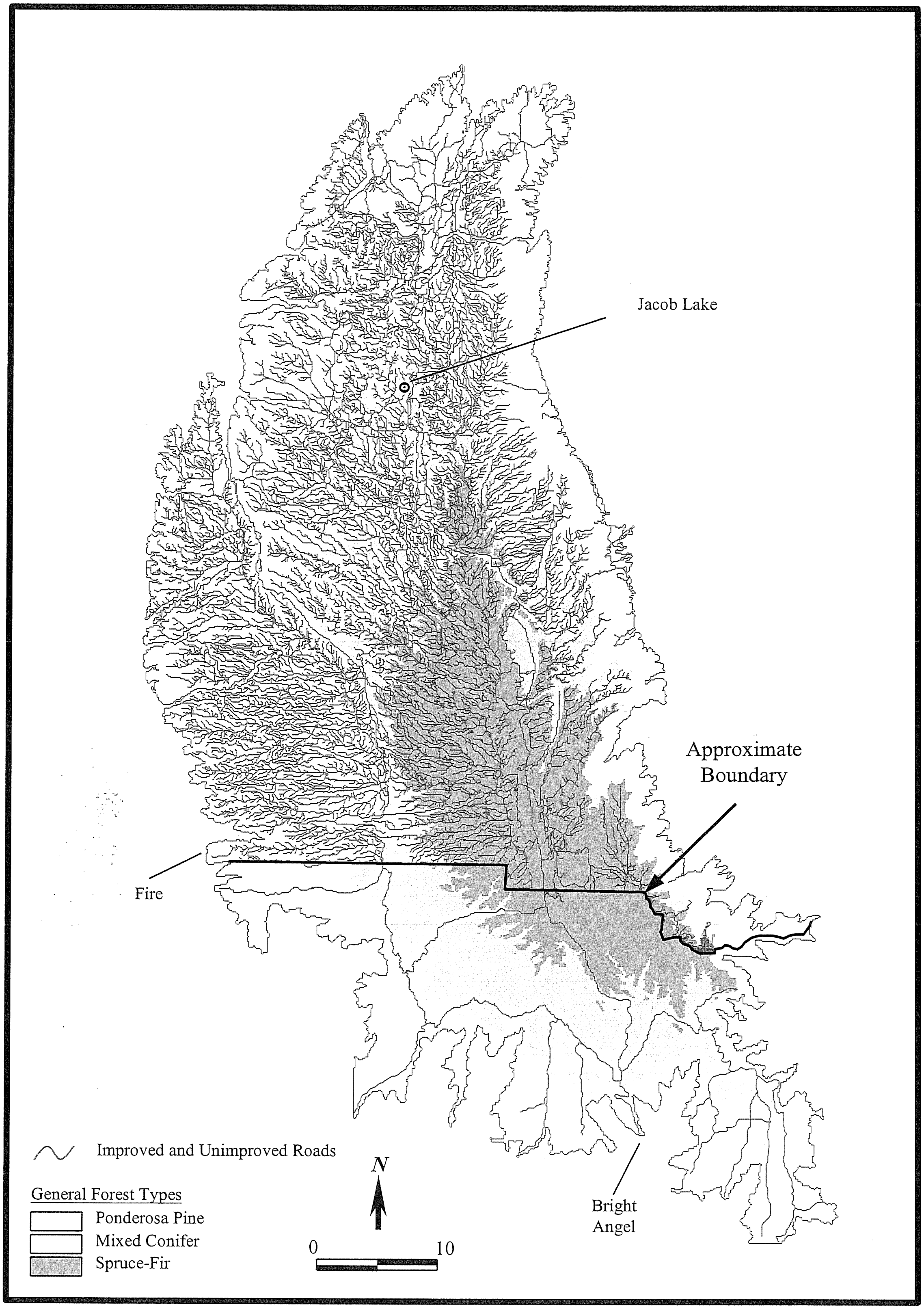


Figure 11. Improved and unimproved roads on the Kaibab

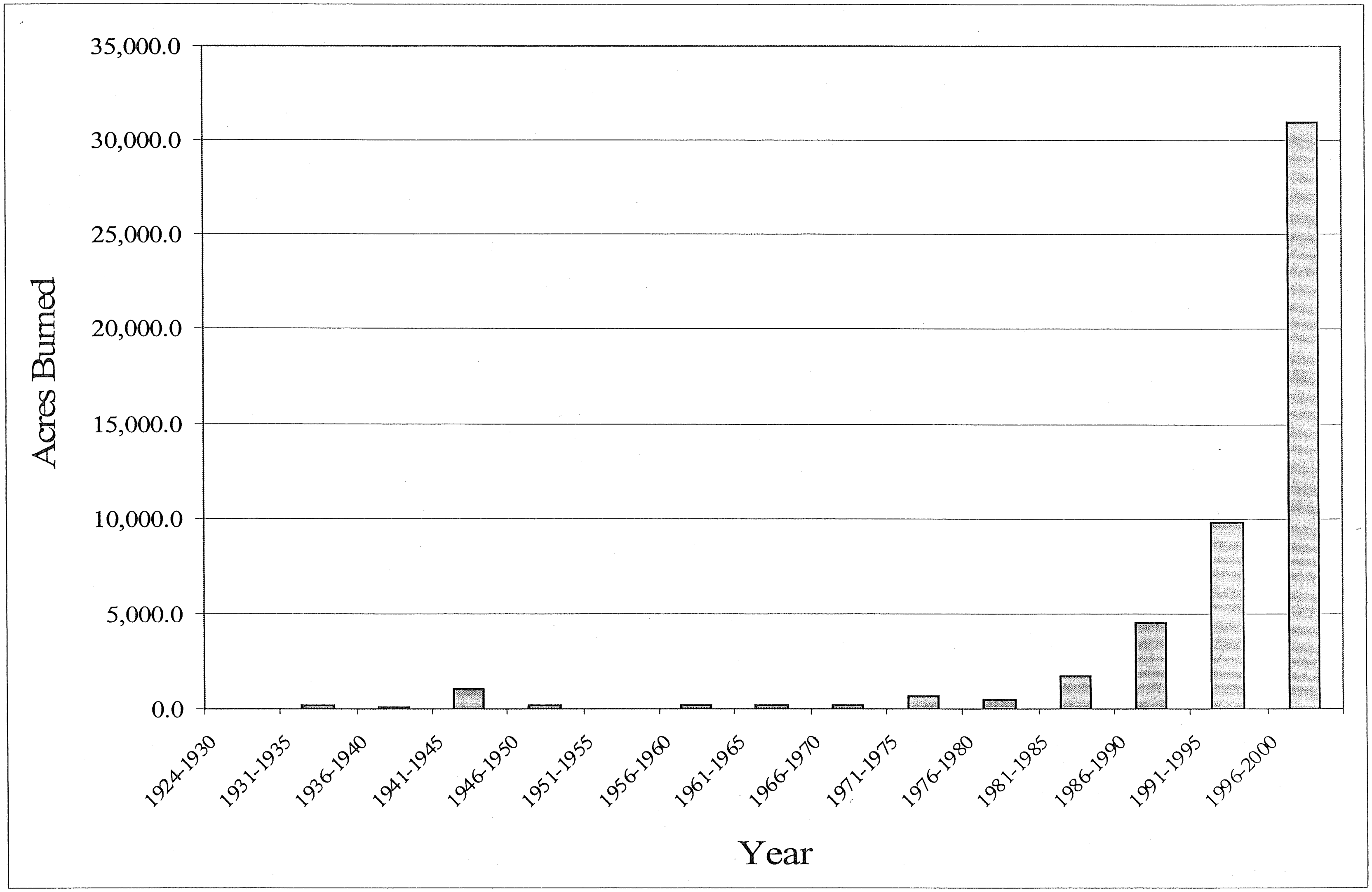


intrastand variability, creating more homogenous stand condition. A primary objective of even-aged siliviculture is to increase stand productivity through even tree diameter distributions and homogenous spacing between trees. This timber management philosophy was adopted by the NKRD and many other National Forests in the southwest in the 1970's and 1980's (Long and Smith, 2000; Edminster and Olsen, 1996). These silivicultural prescriptions have traditionally been applied at scales smaller then the landscape scale, typically 10 to 100 acre stands (Long and Smith, 2000). Thus, even-aged siliviculture results in a more heterogeneous landscape composed of homogenous 10 to 100 acre stands existing at different successional stages.

In contrast to the NKRD the GCNP possess greater continuity, larger patch size, and lower edge density which may result from two processes, the absence of timber harvesting and the occurrence of large stand replacement fires. The forests of the GCNP have not experienced timber harvest operations to the extent of those found on the NKRD. Any timber harvesting that may have occurred historically was probably limited to fuel wood harvesting of dead and dying trees (Heinlein et al. 2000, Fule et al. 2000). Fuel wood harvests would have removed comparatively small volumes having little effect on landscape scale composition (Heinlein et al. 2000). Continuity of patches and size of patches would have been effected little because relatively few roads would have been built to access stands. In addition, fuel wood harvests would not have resulted in changes in patch size, generally these harvests are not performed at the stand scale.

Additionally, larger patch size and greater continuity on the GCNP may result from stand replacement fires. Recently, catastrophic stand replacing fires have dramatically increased the annual acreage burned on the GCNP (Figure 12). In the past five years a total of 30,995 acres burned accounting for approximately 62% of the total acreage burned from 1924 to 2000 (Grand Canyon National Park Fire Report records, 2001). The dramatic increase in the acreage burned annually is attributed in part to an effort by the GCNP to begin prescribed burning of the forests. Several large fires, such as the Pointlet fire in 2000, were the result of prescribed burns that grew out of control (Grand Canyon National Park Fire Report records, 2001). The loss of prescribed burns is due in part to the current forest structure of the GCNP. The current forest condition possesses ladder fuels that enable a fire to burn through the forest canopy, promoting stand replacement fires (Heinlein et al. 2000). This is a fundamental shift from the historic fire regime of the ponderosa and mixed conifer forests on the Kaibab Plateau (Fule et al. 2000). Historically the fire regime was dominated be frequent low severity surface fires, which burned every 3 to 5 years (Cooper 1960, Madany and West 1980, Dieterich 1980, Covington and Moore 1991; Fule et al 2000, Heinlein et al. 2000). Research indicates that stand replacement fires have been historically rare in this forest type (Brawn and Balda 1988, Covington and Moore 1991).

Figure 12. Total acres burned on the Grand Canyon National Park (GCNP).



Landscape Scale Trends in Forest Inventory Data:

The forest inventory data possessed landscape scale trends similar to trends found with the landscape indices. The GCNP data possessed spatial trends indicating spatial autocorrelation and less small-scale heterogeneity then the NKRD. The GCNP demonstrated strong relationships between sample plot basal area and two variables, distance between plots and azimuth between plots, indicating that the biomass on the GCNP possesses stronger spatial relationships. The distribution of basal area on the GCNP is most probably an effect of the Grand Canyon and the elevational gradient on the Park. Ponderosa pine forests on the Park are, for the most part, located on low elevation peninsulas that extend into the Grand Canyon while spruce-fir forests are located at higher elevations in the center of the Park (see Figure 1). This results in a highly organized distribution of overstory biomass for these tree species.

On the NKRD, sample plot basal area was not highly correlated with distance between plots and azimuth between plots. This indicates less spatial autocorrelation between plots and greater fine scale heterogeneity on the landscape. This could be the result of silivicultural prescriptions, which reduce tree densities in relatively dense stands and maintain tree densities in relatively open stands. These affects result in a more homogenous distribution of basal area by removing stand spatial variation and in turn increasing landscape scale heterogeneity.

Intrastand Scale Trends:

The history of timber cutting on the NKRD indicates that the current stand composition may have been created during a 20 year period from 1970 to 1990 (Figure 13). This 20 year period accounts for approximately 67% of the wood volume harvested on the NKRD from 1950 until 2000. The majority of this harvesting used even aged siliviculture such as clear cuts, seed tree cuts, and shelter wood cuts to harvest the wood volume (Kaibab Ranger District historical timber sale records, 2000) Even aged and single tree selection cutting siliviculture has reduced over all tree size and stand density (stems per acre). NKRD possessed on average 60% less basal area and 20% fewer trees then the GCNP. These forests also possessed trees that were on average 50% smaller in diameter then those found in GCNP. Figure 14 graphically presents the differences in diameter at breast height (DBH) for characteristic trees (> 1.6 meters in height and > 10 cm DBH) and basal area for the two management areas.

The GCNP exhibits characteristics that would be expected with 100 years of fire suppression (Heinlein et al, 2000). However, the magnitude of the effect is quite surprising. The GCNP possesses significantly greater conifer regeneration primarily in the form of white fir (Abies concolor), sub-alpine fir (Abies lasiocarpa), and Douglas-fir (Pseudotsuga menziesii). Pine forests on the GCNP are characterized by mature ponderosa pine with an understory of fir. Dense regeneration has resulted in continuous ladder fuels which increases the occurrence of crown fires by altering the forest overstory thereby fundamentally changing the forest environment (Mitchell and Freeman 1993,

Figure 13. Total board feet of timber sold on the Kaibab Plateau, 1950 – 2000.

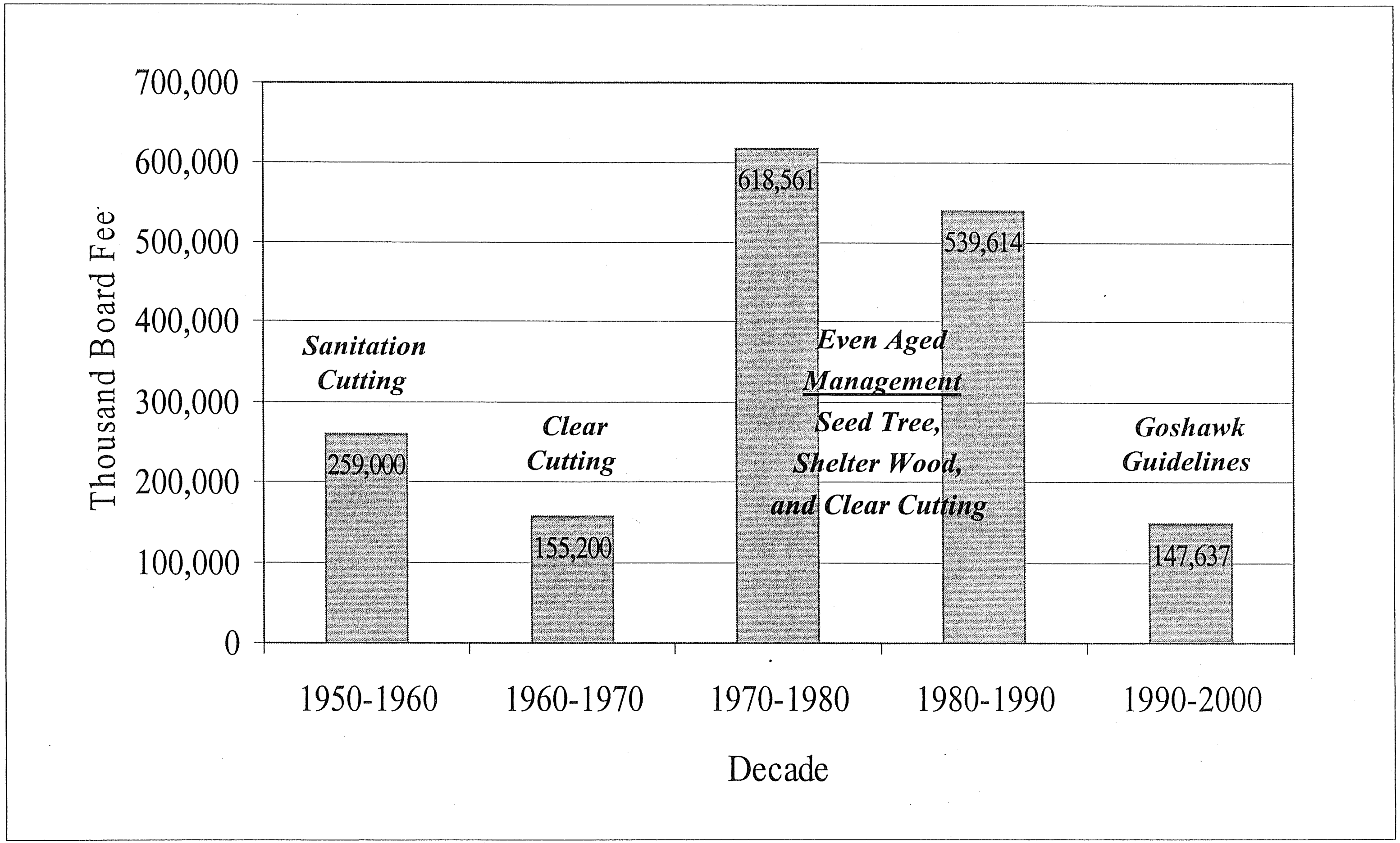
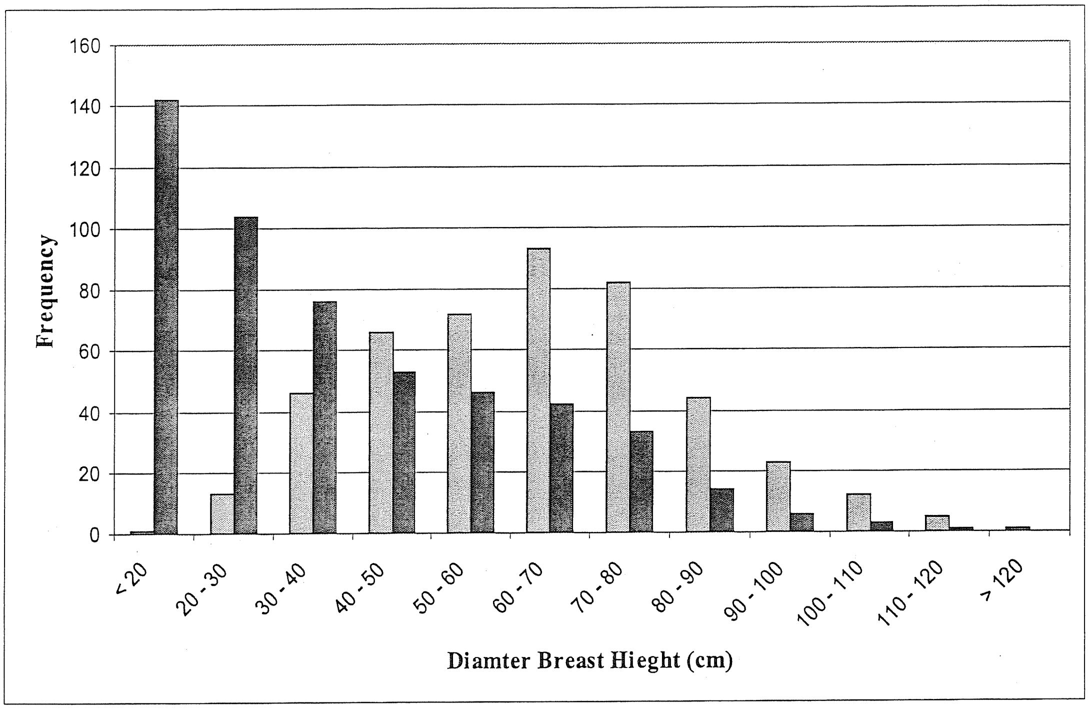
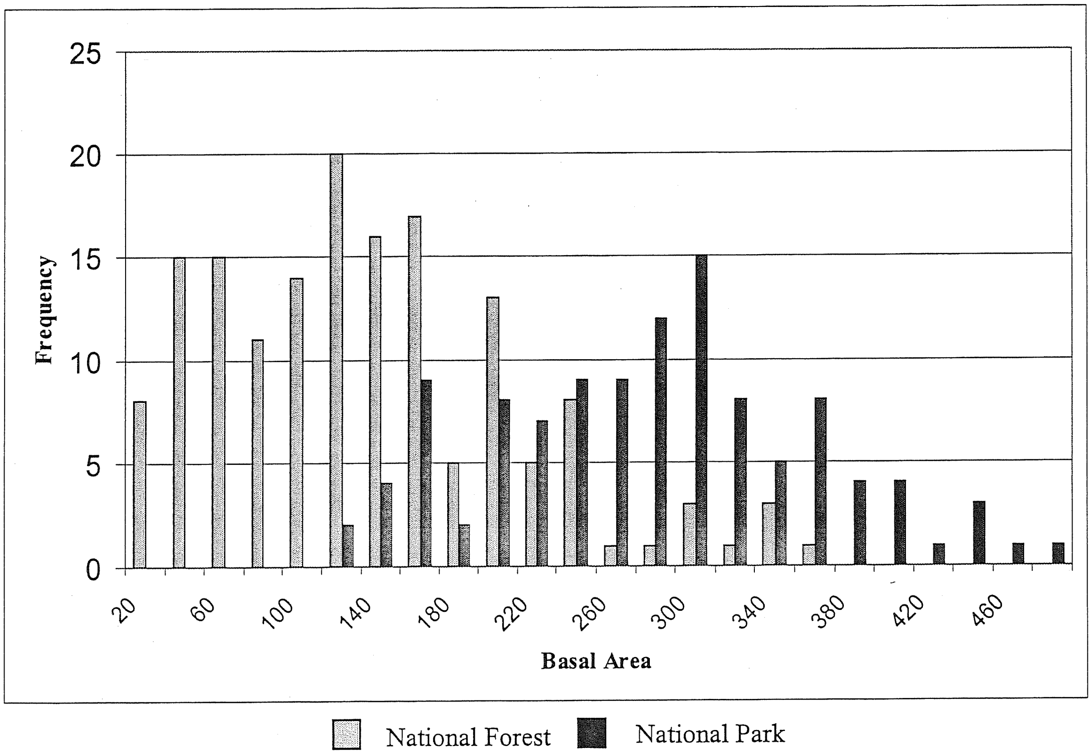


Figure 14. Comparison of diameter at breast height and basal area.

A) Diameter at breast height (DBH) for sample plots.



B) Total basal area for sample plots.



Fule et al. 2000). Figure 15a depicts a typical ponderosa pine stand on the GCNP contrasted with a ponderosa pine stand on the NKRD, Figure 15b. These photos visually illustrate the difference in the composition of ponderosa pine forests on the two management areas. The stand in Figure 15a depicts a classic example of fir invasion resulting from the past century of fire suppression on the Park (Heinlein et al, 2000). If the GCNP historically experienced low intensity ground fires similar to the surrounding ecosystems, the conifer understory would have been destroyed in frequent fire events. Thus, it is possible that the regeneration within these forests is outside the historic range of variability that these forests may have experienced (Fule et al. 2000, Heinlein et al, 2000).

Nest Site Scale:

Analysis of nest site data indicates that landscape and intrastand differences are mimicked at the nest site. Goshawks select nest sites that are on average twice as dense on the GCNP then those found on the NKRD. Management practices on the NKRD such as timber harvesting also appear to have effected goshawk nesting habitat by reducing overall basal area and DBH. Nest sites for the GCNP and NKRD possessed characteristics that varied greatly from the *minimum* structural attributes presented in the goshawk guidelines (Reynolds et al. 1992). Sample plots located at historic goshawk nest sites on the NKRD possessed trees that where on average smaller then the minimum DBH in the guidelines and only 48% of the nest sites located in ponderosa pine meet the

Figure 15 . Typical stands of pine on national park and forest.

A) Grand Canyon National

This photo illustrates a typical ponderosa pine stand on the Grand Canyon National Park. Understory is predominantly composed of fir while overstory is composed of mature ponderosa pine.

B) Kaibab National

This photo presents a typical managed stand of ponderosa pine on the Kaibab National Forest. There is evidence of timber cutting in mid-ground (stumps) and lower over all basal area.

Photos by: Ryan S. Miller **Note:** Scale bar in foreground is three meters in height.

guidelines minimum requirement. In addition, 27% of the NKRD nest sites did not meet the minimum basal area listed in the guidelines; assuming most nest sites were located on sites with high productivity (site index ≥ 55). These nest sites also, on average, did not meet the minimum structural attributes for sites with low productivity (site index < 55).

Nest sites located on the GCNP demonstrated the inverse of nest sites located on the NKRD. All nest sites analyzed on the GCNP exceeded the minimum basal area and DBH for nest site stands. Nest sites possessed trees that were on average 23- to 35-cm larger and possessed ~45% greater basal area when compared with the minimum attributes in the guidelines. Again, this comparison assumes nest sites were located on highly productive sites (site index ≥ 55). It might seem at first that the greater basal area at these nests sites is due to greater conifer regeneration on the GCNP. However, the majority of the conifer regeneration on the GCNP was sapling and small pole size material (see Figure 15 a and b), which would not account for differences in basal area when measured using a prism with a basal area factor of 20.

Analysis Caveats:

There are important caveats to consider with inferences for NKRD and GCNP comparative analysis of landscape indices and forest inventory data. First, sample plots for the NKRD and GCNP were located randomly and did not attempt to measure entire stands and sampled a small proportion of the entire landscape for the GCNP and NKRD. As a result, the sampling procedure may have missed some variation in forest structural characteristics for both landscapes. Larger sample plots that intensively measure many variables over a larger area, such as those used by Heinlein et al. (2000), may have provided a better measure of variability within the NKRD and GCNP.

In addition, diameter measures of characteristic trees provide at best fuzzy representation of stand diameter classes. Measurements were taken for four randomly selected trees that were deemed characteristic of the stand and are assumed to be representative of the diameter classes present at the site. However, the process was open to bias, which may have effected the results. Recording the DBH of all trees located on the plot would have provided a better understanding of the diameter class distribution on the GCNP. In addition, the diameter measures also possess dependence due to the correlation associated with within stand cluster of trees at each plot. This dependence could reduce the reliability of the statistical tests used to determine statistical differences in DBH for the NKRD and GCNP. Despite, this dependence the data does provide some understanding of general trends but should *not* be considered an absolute measure of DBH differences between the NKRD and GCNP.

Moreover, there are several important caveats with inferences for NKRD and GCNP nest sites analysis. Sample plots were located at the base of one randomly selected historic nest tree and may not accurately represent the entire nest site. Nest sites encompass a much larger area then that sampled in this study and could be at least 30 acres in size (Reynolds et al. 1992). Goshawk territories also possess several nest sites (Reynolds et al. 1992); sample plots could have been randomly located at the least suitable historic nest site within a given territory thereby skewing the results.

In addition, the sample size for the GCNP nest sites was relatively small (N = 11) and may not be representative of all goshawk territories on the GCNP. However, this data may indicate a general trend in differences between nest sites on the NKRD and GCNP, but should *not* be considered an absolute measure of differences in nest sites on the Kaibab Plateau.

Future Research Recommendations

Ecosystem Effects of Landscape Differences:

The Kaibab Plateau presents a unique opportunity for integrated cross agency ecosystem management. The Plateau is an unusual ecosystem; due to the surrounding geology (i.e. Grand Canyon and high deserts), the pine ecosystem on the Plateau exists as a relatively closed system with few outside perturbations. The Plateau also possesses a diverse and unique assemblage of species, some of which, such as the Kaibab squirrel, are unique to the Plateau. In addition, the GCNP possesses one of the few remnant old growth ponderosa pine forests that has not been degraded by timber harvesting (Fule et al, 2000). This creates a common but difficult forest management challenge. The National Forest and the National Park must manage in a cooperative manor for the integrity of the entire ecosystem. It also presents the opportunity to demonstrate management across political and agency boundaries solely to maintain the ecological integrity of the larger area. However, historic management of the National Park and National Forest have resulted in two landscapes that possess different landscape scale composition and different forest structural attributes. Despite these differences, it is not clear whether ecosystem function or population dynamics on the Plateau is effected. Research is needed to address whether current divergent management practices alter ecosystem function and population dynamics on the Plateau. Moreover, policies that encourage cooperative management between the National Park and National Forest are needed.

Intrastand and Landscape Scale Effects on the Northern Goshawk:

National Park management philosophy has resulted in forests that are generally unmodified at the landscape scale. These forests possess relatively little fragmentation due to few roads and no timber harvesting (Figure 10 and 11). However, these forests have undergone considerable change at the intrastand scale (Fule et al, 2000). Increased understory density of ponderosa pine forests, due to conifer regeneration, may affect goshawk nesting on the GCNP. Increased density of conifer regeneration may place herbaceous and woody species at a competitive disadvantage reducing overall presence of grasses, forbs, and shurbs. Conifer regeneration may also reduce cone production by reducing overall vigor of overstory pine. These two affects may influence overall prey abundance by reducing food source for prey species, which are either granivores or herbivores (Reynolds et al. 1992). Moreover, greater understory density may influence goshawk hunting success by limiting the ability to find and capture prey (Reynolds et al. 1992). The goshawk's hunting strategy is adapted to dense late succession forests with an open understory. Dense forest understory, such as spruce and fir regeneration, reduces detection and capture of prey by limiting vision (Reynolds et al 1992, 1996). Reduced prey density along with reduced hunting success may influence nesting success of goshawks on the GCNP.

However, the interactions between prey abundance, forest density, and hunting success are not well understood or documented. Studies that would aid in further understanding these dynamics are:

- Comparison of nesting success and nesting habitat selection for the Grand Canyon National Park and North Kaibab Ranger District.
- Comparison of prey abundance within the Grand Canyon National Park and North Kaibab Ranger District.
- Monitoring and comparison of base line goshawk population with current populations on the Grand Canyon National Park and North Kaibab Ranger District.

Studies that compare nesting success and vegetation characteristics of the National Park and the National Forest might be especially helpful in understanding the influence of altered forest structural attributes on hunting success. Studies of prey abundance within the National Park and National Forest may also aid in understanding hunting success on the two landscapes. In addition, goshawk nesting success in a unmodified forest that possess presettlement conditions has not been documented. The identification and monitoring of such a population would provide a base line with which to compare current populations of raptors.

Conclusion

The Grand Canyon National Park and the North Kaibab Ranger District demonstrated distinct and significant differences in landscape pattern, the spatial distribution of forest structure, and differences in forest composition (structure) on the Kaibab Plateau. These differences are likely the result of philosophical differences in agency missions (preservation verses multiple use and ecosystem management), which have altered dynamics on the Plateau over the past 100 years in turn altering the current forest composition.

Effective ecosystem management requires innovative cross agency cooperation that bridges political boundaries. However, attempts to manage entire ecosystems across agency boundaries have only been moderately successful (Lilieholm, 1990; Loomis 1993). The Kaibab Plateau provides the National Park Service and National Forest Service with a unique opportunity to implement management policies that would integrate management of the Plateau.

However, it is not clear how current differences in landscape composition effect ecosystem function or population dynamics of the northern goshawk. Future research on the Kaibab Plateau should explore differences in nesting habitat and nesting success differences on the National Park and National Forest lands. The long term effects of divergent management are not well understood, and could have long lasting effects on the ecological integrity of the Kaibab Plateau and in turn sensitive species such as the northern goshawk.

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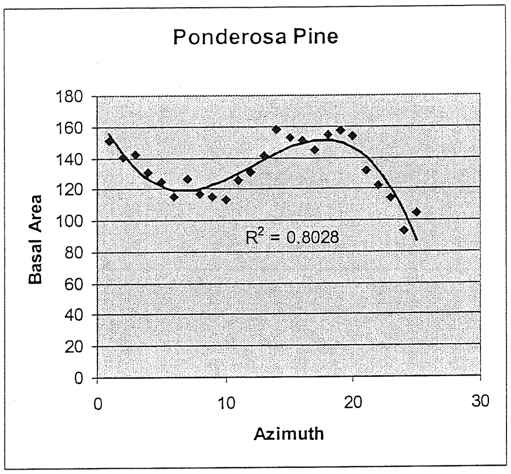
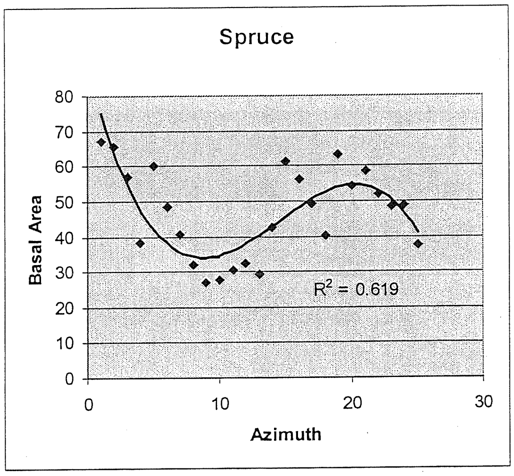
APPENDIX A

REGRESSION MODELS OF GENERALIZED FOREST INVENTORY DATA FOR THE GRAND CANYON NATIONAL PARK

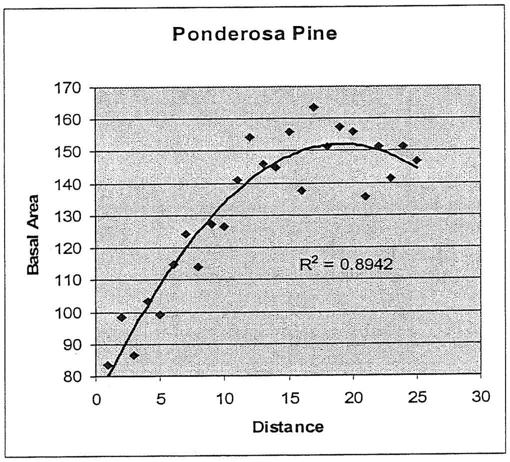
Regression models of generalized forest inventory data for the Grand Canyon National Park.

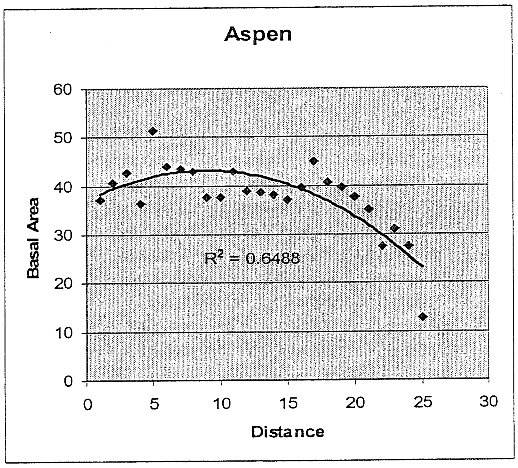
Basal Area Verses Azimuth National

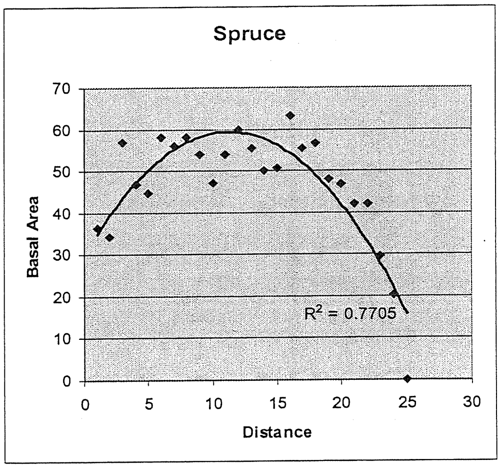




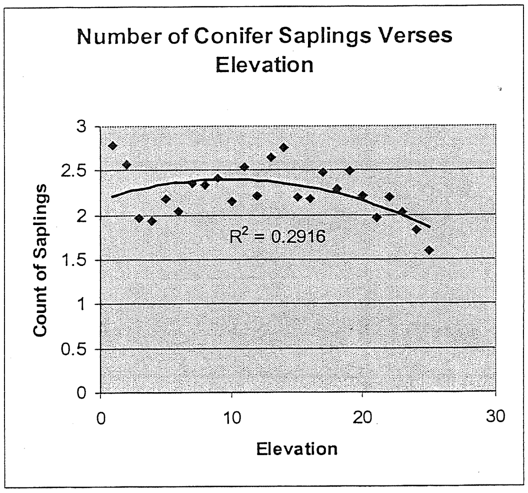
Basal Area Verses Distance Between Sample Plots National

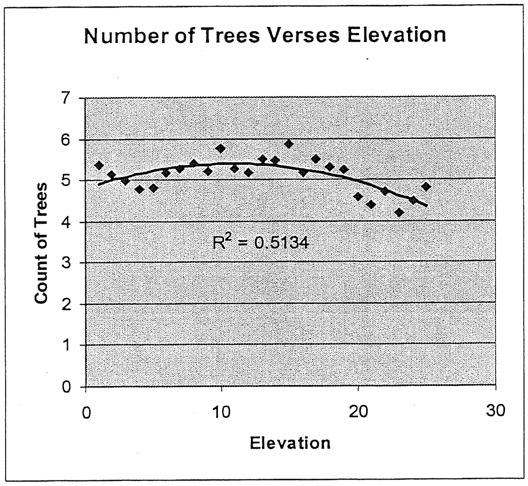






Number of Saplings and Trees Verses Elevation National Park

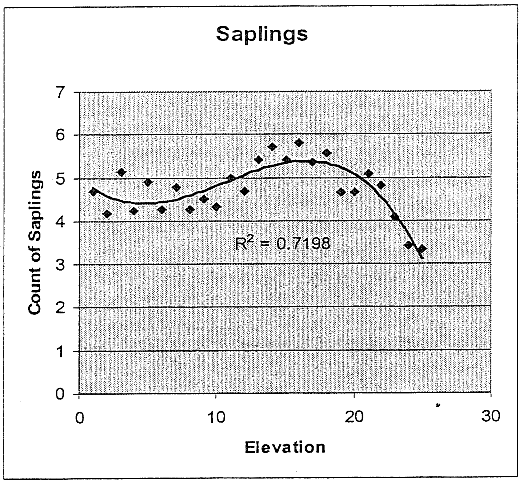


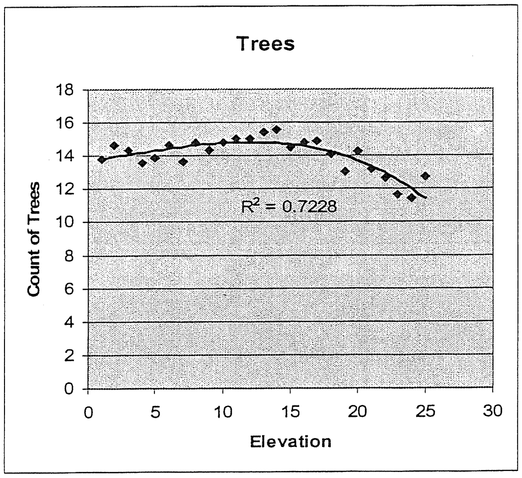


APPENDIX B

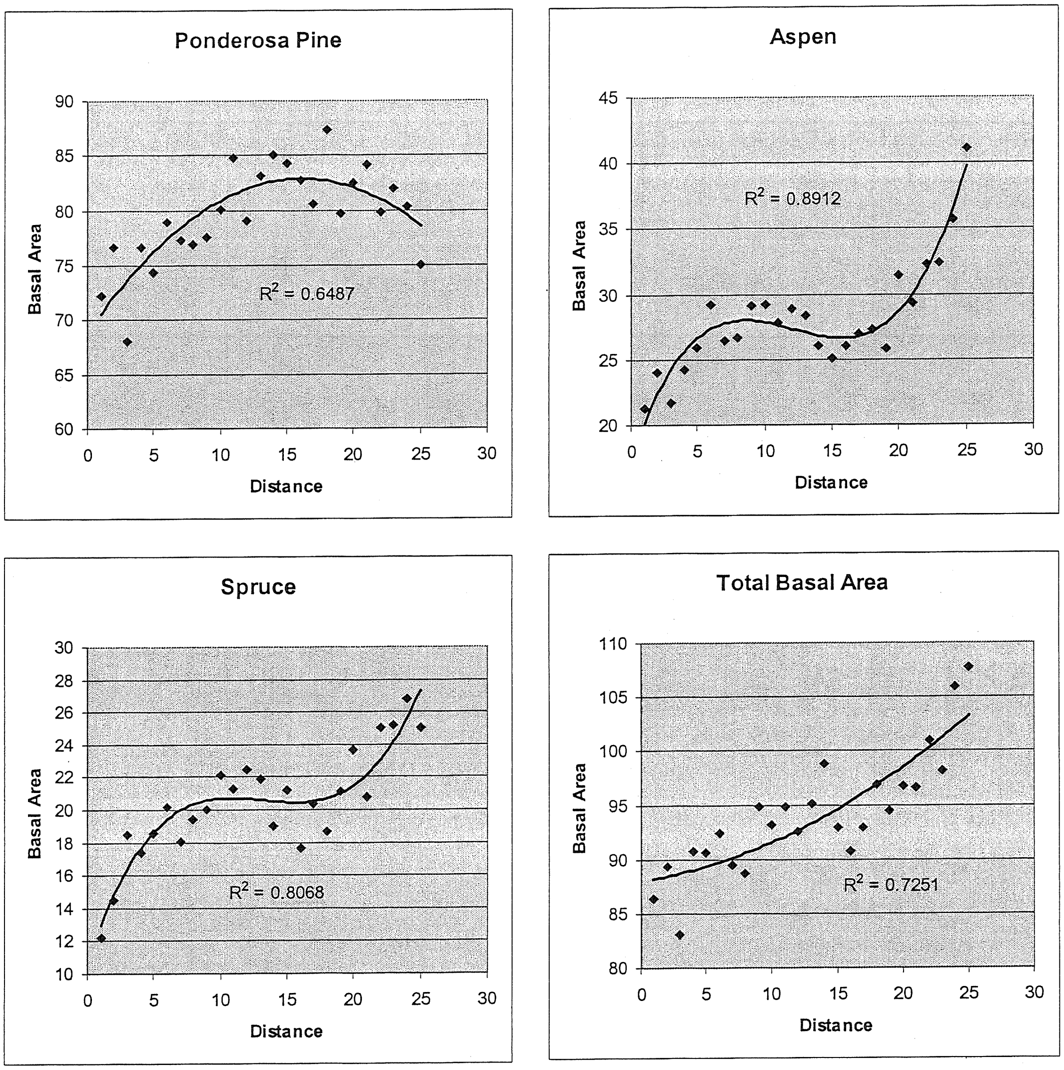
REGRESSION MODELS OF GENERALIZED FOREST INVENTORY DATA FOR THE KAIBAB NATIONAL FOREST

Number of Saplings and Trees Verses Elevation National Forest





Basal Area Verses Distance Between Sample Plots National Forest



APPENDIX C

CACLULATION OF SAMPLE SIZE

Calculation for Sample Size

The basal area measures collected by Joy et al. were used to determine the target sample size required to accurately measure variation in basal area on the GCNP. The variance in the NKRD data was used to calculate the minimum sample size needed to capture variation within the ponderosa pine, mixed conifer, and spruce-fir forest cover types. The following equation was used to calculate the minimum sample size needed (Kleinbaum et al. 1998; Scheaffer et al. 1996):

$$n \ge \frac{Z^2V^2}{\varepsilon^2}$$

$$Where: V \cong \frac{S_g}{\chi_g}$$

And:

Z is the confidence level, 95%
S_g is an approximation of the standard deviation in the population.
X_g is an approximation of the mean in the population.
ε is the percentage deviation from the true mean

DESCRIPTIVE STATISTICS OF BASAL AREA FOR THE KAIBAB NATIONAL

Forest Type	*Number of Plots*	*Ponderosa Pine*		*Aspen*		*Spruce Species*		*Fir Species*		*Total Plot*	
		Mean	*Stdev*	*Mean*	*Stdev*	*Mean*	*Stdev*	*Mean*	*Stdev*	*Mean*	*Stdev*
Ponderosa	92	91.74	75.49	4.13	22.49	0.43	4.17	2.83	12.07	99.57	81.04
Mixed Conifer	49	88.16	69.75	18.78	48.37	10.20	24.87	19.18	40.41	136.33	72.65
Spruce/Fir	34	30.59	47.54	44.71	46.98	42.94	55.08	34.71	49.80	152.94	94.69

Value of V

Forest Type	*Ponderosa Pine*	*Aspen*	*Spruce Species*	*Fir Species*	*Total Plot*
	V	V	V	V	V
Ponderosa	0.822826312	5.445102271	9.591653768	4.272194027	0.813899225
Mixed Conifer	0.79116564	2.57649209	2.43763535	2.106275581	0.532905044
Spruce/Fir	1.554260388	1.050955621	1.282622628	1.434965577	0.619149326

Sample Size Required to Estimate within 10% of the True Mean

Forest Type	*Ponderosa Pine*	*Aspen*	*Spruce Species*	*Fir Species*	*Total Plot*
	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size
Ponderosa	260	11,390	35,343	7,012	254
Mixed Conifer	240	2,550	2,283	1,704	109
Spruce/Fir	928	424	632	791	147

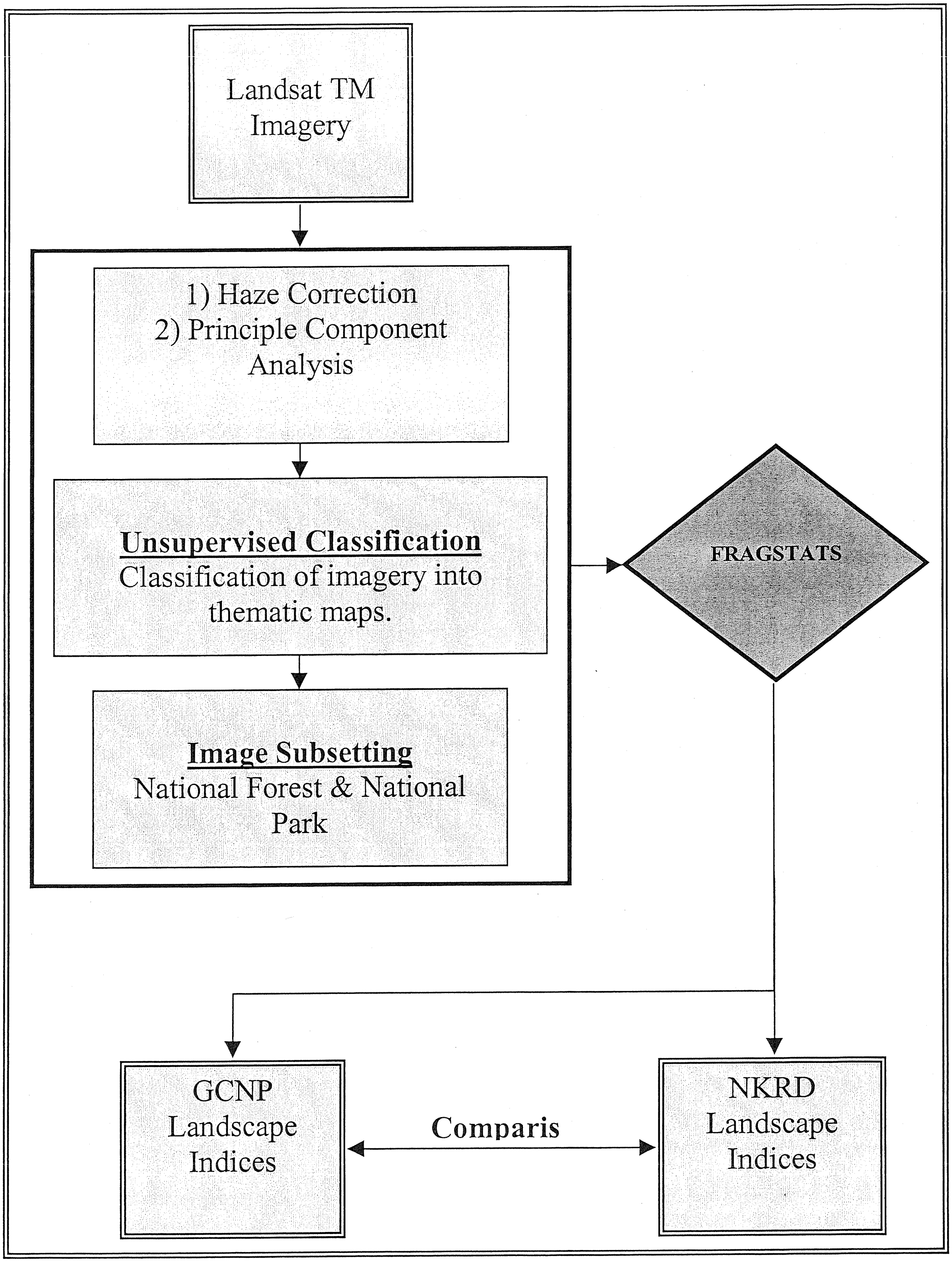
Sample Size Required to Estimate within 25% of the True Mean

Forest Type	*Ponderosa Pine*	*Aspen*	*Spruce Species*	*Fir Species*	*Total Plot*
	Sample Size	Sample Size	Sample Size	Sample Size	Sample Size
Ponderosa	42	1,822	5,655	1,122	41
Mixed Conifer	38	408	365	273	17
Spruce/Fir	148	68	101	127	24

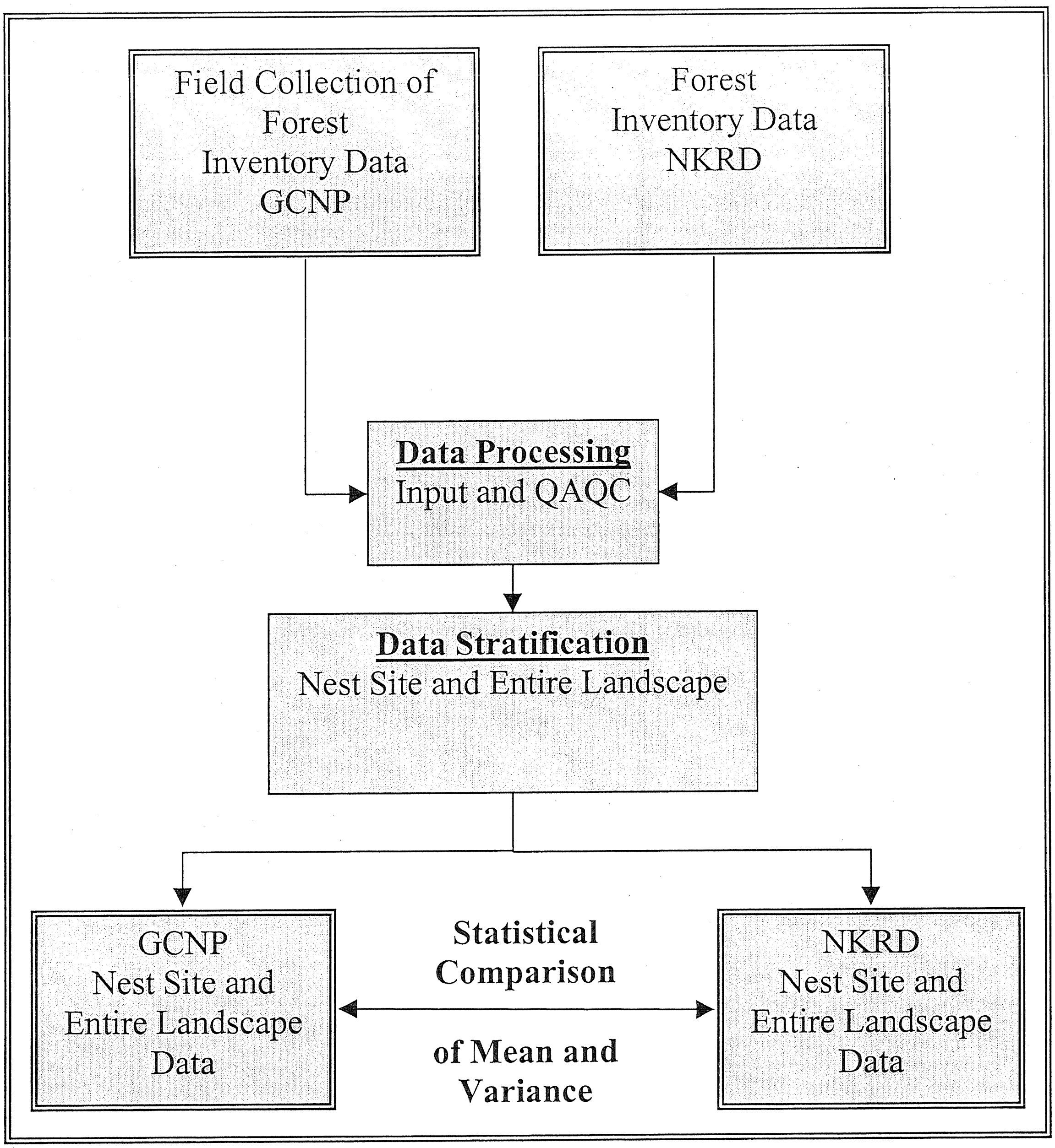
APPENDIX D

FLOW CHARTS OF ANALYSIS PROCEEDURE

Landscape Index Analysis



Forest Inventory Data Analysis



Creation of Models for the Forest Inventory