

Assessing Avian Diversity in Minnesota Through the Utilization of Spatial and Statistical Analysis

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Abstract

Improving the methods for determining which areas should be prioritized for conservation efforts may be accomplished by using indicators such as biodiversity. The data provided by the United States Geological Survey's Breeding Bird Survey (BBS) has made calculating changes in biodiversity over a specified time frame possible. By using bird survey data available for the state of Minnesota, analysis was performed to determine the levels of biodiversity in each area of the state during various time periods. Along with spatial analysis, statistical analysis was performed on the data by using the Statistical Package for Social Sciences (SPSS). Results of the analysis indicated there was a significant ($P < 0.05$) correlation between the proportion of natural land cover and the amount of avian diversity. Future studies may be able to develop predictive models using this and other correlatives. By predicting richness levels, priority may be placed on specific areas within the state for conservation efforts.

Introduction

To improve the conservation decision-making process as well as learn more about our environment, there has been a recent increase in attempts to assess the world's biodiversity (Bowker, 2000). In "Mapping Biodiversity," Bowker also writes that these attempts have been made both for the purpose of decision-making as well as to gain knowledge about our environment. On a smaller scale, this study attempts to assess the biodiversity of avian species within the defined geographic region of Minnesota.

In order to produce accurate assessments of avian biodiversity, a number of datasets were needed. To attain information about the distribution of species throughout Minnesota

landscapes, data from bird surveys were of an utmost importance. Additionally, these bird surveys needed to have both been uniformly conducted as well as cover a number of years in order to determine changes in biodiversity over time.

Such bird surveys have been conducted through the North American Breeding Bird Survey (BBS) between 1967 and 2008. Each year, the BBS collects data on over 90 routes in Minnesota alone. Figure 1 shows the exact locations of BBS routes within the state. For each route, dozens of bird species have been observed and recorded. This bird survey data were chosen over others because of the consistency of the survey methods as well as the extensive time frame over

which the surveys were conducted. Also, the routes used for surveying are available online to the public in a shapefile format, allowing for more extensive analysis to be performed on the survey data.

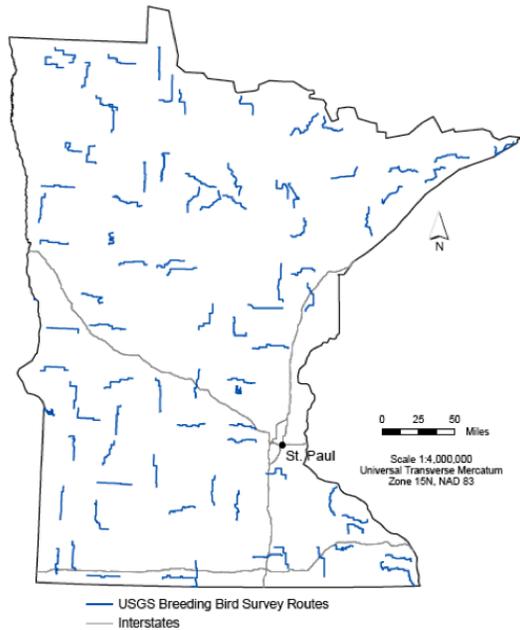


Figure 1. Distribution of all active USGS Breeding Bird Survey routes within Minnesota along with their relative proximity to major interstates and lakes within the state. Data for the map were obtained from the USGS website in 2009.

Since the United States Geological Survey's (USGS) Breeding Bird Survey has tracked the abundance of species over the course of several decades and the data is available to the public, the data can be used to conduct a limitless amount of statistical analysis. Examples include the analysis of single species abundance in selective areas over the course of several years or as in this study, changes in the entire biodiversity of a particular geographic region.

By calculating the richness of various routes using Simpson's Index of Diversity, the wellbeing of numerous

landscapes within Minnesota can be assessed. Using accurate and reliable data allows for any resulting statistical analysis to be used by conservation professionals to make informed decisions. Bustamante and Seoane (2004) believe that such individuals must be aware of the preferences of species.

In terms of Geographic Information Systems (GIS), it is Salem's (2003) belief that a GIS is the most suitable technology for estimating the world's biodiversity. Salem also states a GIS can be used to create data for important decision-makers in the environmental sector. For this reason, Salem urges GIS professionals to gather together and create a universal database that could be used by these decision-makers.

Foody (2008) adds that those hoping to determine any links between species distribution and land cover types have utilized GIS. This is for good reason since GIS gives users the opportunity to manage otherwise complex relationships between species and their environment (Tucker, Rushton, Sanderson, Martin, and Blaiklock, 1997). Once these complex relationships have been established, they can be utilized for further analysis.

There are several areas within Minnesota landscapes that may indicate the need for more conservation due to decreased levels in diversity. Such areas may include "intensively cultivated fine sediment plains (that) are usually rather poor in predicted species richness" (Bustamante and Seoane, 2004). On the other hand, Bustamante and Seoane also found areas "along river courses, in grid squares with a high habitat diversity and steep topography" to be the areas with the greatest biodiversity. With obvious

areas of greater diversity, decisions can be made easier for those who are key players in the work of conservation (Bustamante and Seoane).

In regard to the relation between avian biodiversity and landscape, Debinski, Kindscher, and Jakubauskas (1999) found that a portion of the avian species surveyed had a clear attachment to one specific type of land cover. Within these species, Debinski *et al.* also found that there was an attachment to land cover types that were predominantly woodland as opposed to grassland. Even more, there were clear differences in the denseness of the woodland and the preferences of specific species (Debinski *et al.*).

In this study, additional spatial datasets were used to determine correlates with avian biodiversity. Datasets including canopy cover (Figure 2) and land cover type (Figure 3) were derived to produce a set of correlatives. Using the National Land Cover Dataset available from the USGS, the percentage

of tree canopy cover as well as the type of land cover within a given region was used to determine whether significant correlations existed.

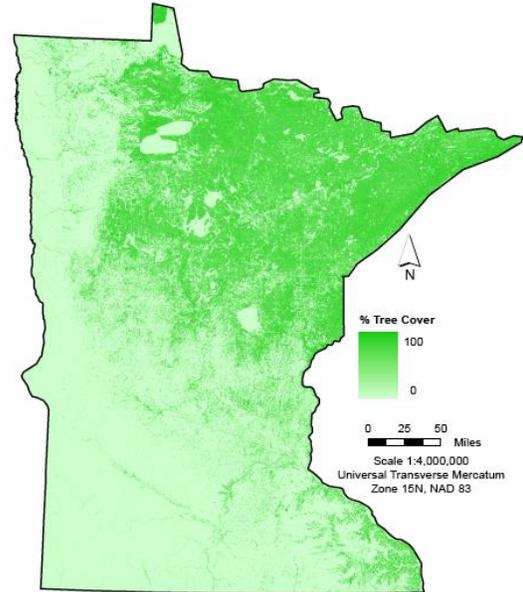


Figure 2. Overview of tree canopy cover for the state of Minnesota. Data is based on the 2001 National Land Cover Database and was obtained from the Minnesota DNR Data Deli in 2009.

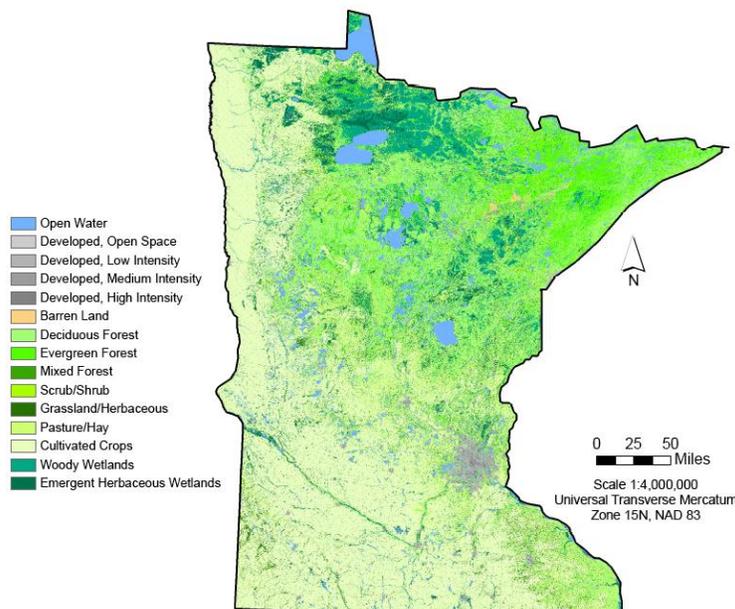


Figure 3. Land cover classification for the state of Minnesota as determined by the 2001 National Land Cover Database. Data for the map was obtained from the DNR Data Deli in 2009.

If specific correlatives are found as a result of this study, the information can be used in future studies to prioritize conservation efforts. Further, the information regarding the present richness levels within Minnesota will provide conservationists and researchers a resource with which to make further prioritizations. If the datasets used in this study are not found to produce correlatives, an assumption may be made that further studies are needed to determine what factors lead to dynamic levels of avian richness.

Methods

Since several gaps existed in the original BBS data, analysis was performed to determine the years and routes that would be selected for the study. The analysis included the creation of a spreadsheet covering the data for all

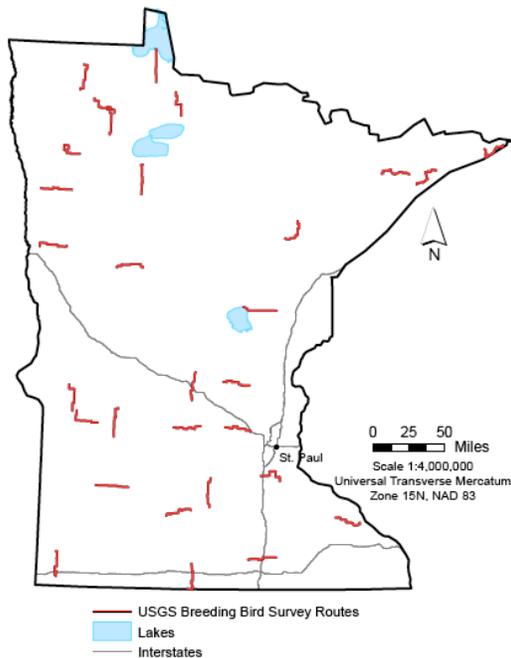


Figure 4. Distribution of the routes used for the year-to-year comparison between 1978 and 2008. Each of the 31 routes pictured above was surveyed in both 1978 and 2008, making analysis possible. Data for the map were obtained from the USGS website in 2009.

routes from 1967 to 2008. For the year-to-year comparison, two of the years with the most corresponding data available (31 routes) were used. The locations of these routes are shown in Figure 4.

Survey data were then used to choose the two routes that were most frequently surveyed between 1967 and 2008. The routes surveyed most, a total of 42 times were the Hartland (3) and Knapp (17) routes which, as displayed in Figure 5, are both located in the southern half of the state. Using this data along with the spatial locations of the routes, statistical analysis was performed to determine whether there was a significant difference between the two routes' respective levels of richness. The last set of BBS data that was queried was data for 2001. The year 2001 was chosen since it was the most recent year covered by the USGS National Land Cover Database. After choosing

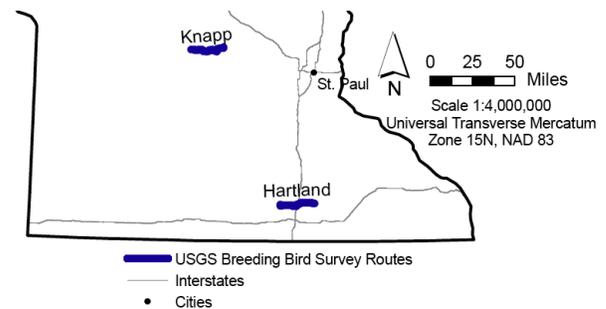


Figure 5. Distribution of the two routes used for route-to-route analysis between the years of 1967 and 2008. Data from the map was obtained from the USGS website in 2009.

the above routes, the next step involved performing queries on the USGS Breeding Bird Survey server. The raw data were acquired using the Online Retrieval System made available to the public by the USGS. After entering the site, a query for Species Totals Report for Route By Year (Figure 6) was

performed for each route and year of interest.



Figure 6. Image of the USGS online retrieval system used for acquiring specific Breeding Bird Survey data. The image was acquired from the USGS website.

After the data was acquired and entered into a Microsoft Excel spreadsheet, the Simpson’s Index of Diversity was calculated for each set of data. Calculations for this were performed in Excel by applying the following equation to the collected data:

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

Where:

- D = Index of Diversity
- N = Total number of organisms of all species
- n = Total number of organisms of a particular species

The possible values of D ranged from 0 to 1 where 1 indicated the highest possible level of richness. By calculating this number, each route was ranked in order from highest to lowest diversity. Further analysis was performed to determine if significant differences in diversity existed between the chosen routes and years.

To evaluate the land cover of the routes, a GZ file containing route

information for the continental United States was downloaded from the United States Geological Survey’s (USGS) Breeding Bird Survey (BBS) home page. After extracting the file using the open-sourced 7-Zip program, the route shapefile was imported into a new ArcMap session. Since the original file contained information for the continental U.S., steps were taken to select only the routes that were within Minnesota boundaries.

To perform these steps, a shapefile from the DNR Data Deli containing the political boundaries for the state of Minnesota was added to the ArcMap session. Also, with the BBS shapefile’s projection being undefined, the Define Projection tool in ArcToolbox was used to set the coordinate system equal to that of the shapefile from the DNR Data Deli, which was the 1983 North American Geographic Coordinate System. Both shapefiles were then projected to the 1983 North American Data Universal Transverse Mercator for Zone 15N using the Project tool in ArcToolbox. Next, the Select tool within ArcToolbox was used to create a new shapefile containing only the areas within Minnesota. This was accomplished by using the following SQL statement:

”STATE_ABBR” = ‘MN’

After completing the Select, the Intersect tool within ArcToolbox was used to create a shapefile containing all the routes within Minnesota. Since the goal of the BBS is to observe all species within a ¼ mile radius of each route, a buffer was created around each route that made up the new shapefile. This was accomplished by using the Buffer tool in ArcToolbox and setting the linear unit to

Table 1. Reclassification scheme used for route-level analysis of landscapes. The original National Land Cover Database was extracted from the USGS website in 2009.

Reclassification Category	Original NLCD Classification
1 – Natural Landscapes	11 – Open Water
	31 – Barren Land
	41 – Deciduous Forest
	42 – Evergreen Forest
	43 – Mixed Forest
	52 – Scrub/Shrub
	71 – Grassland/Herbaceous
	90 – Woody Wetlands
	95 – Emergent Herbaceous Wetland
2 – Human-influenced Landscapes	21 – Developed Open Space
	22 – Developed Low Intensity
	23 – Developed Medium Intensity
	24 – Developed High Intensity
	81 – Pasture/Hay
	82 – Cultivated Crops

.25 miles. The resulting shapefile contained information that would be used for all future analysis within this study.

To determine the types of landscapes existing along each Minnesota route, the 2001 National Land Cover Dataset was downloaded in a zipfile from the DNR Data Deli. After being unzipped, the ASC file was converted to a raster using the ASCII to Raster tool in ArcToolbox. The new raster still contained areas outside of Minnesota, so the Extract by Mask tool in ArcToolbox was used to extract only the areas within Minnesota. In order to simplify analysis, the Reclassify tool in ArcToolbox was used to reclassify the original land cover raster into two categories, human-influenced landscapes and natural landscapes (Table 1).

Performing route-level analysis required that a raster be created for each individual route in Minnesota. Doing so required the use of a model created with

ModelBuilder (Figure 7) where each route was selected from the existing shapefile using the Select tool then used as a mask in the Extract by Mask tool to create a raster for each route. Without performing this for each model, the process of calculating the raster cells for each classification would not have been possible.

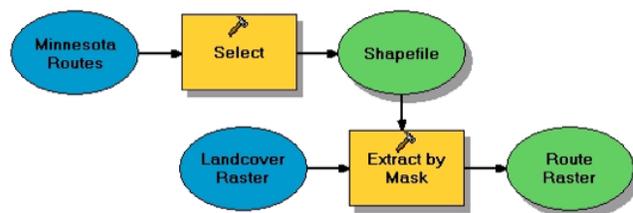


Figure 7. Raster processing model used within ModelBuilder in ArcGIS. The model created individual rasters for each of the routes used for land cover analysis.

After a raster for each route had been created, the proportion of natural-to-human-influenced land was found by dividing the total number of raster cells

by the total number of raster cells that could be classified as natural. After completing these calculations, the areas with the highest levels of natural land cover were ranked in ascending order and displayed spatially using ArcMap. To complete the necessary calculations, the route numbers of each of the surveyed routes from 2001 were added to a new spreadsheet. The percentage of the natural landscape for each route was added to the spreadsheet and then sorted in ascending order. After sorting, the spreadsheet was added to ArcMap and a Spatial Join was performed to add the data to the BBS route shapefile. A two and a half mile buffer was also added to the BBS routes to enhance visualization. The symbology was then changed to show the highest ranked (natural) to the lowest ranked (human-influenced) routes based on land cover types.

Similar procedures were used to determine the average percentage of tree canopy along each Minnesota route. The tree canopy data were downloaded in a zipfile from the Minnesota DNR Data Deli and extracted. The extracted file was an ASC file and was converted using the ASCII to Raster tool in ArcToolbox. Next, the state of Minnesota was extracted using the Extract by Mask tool. In this instance, the newly created tree canopy raster was used as the input and the shapefile containing the Minnesota boundary was used as a mask. In contrast to the multiple classifications within the land cover layer, the tree canopy layer ranged from 0 to 100, where values of 0 represented no tree cover and 100 represented total tree cover. In light of this, the color ramp of the tree canopy layer was set to green, where the area became greener as the percentage of canopy increased.

Similar to the land cover raster, a model was used to extract a new raster for each BBS route by using the Extract by Mask tool in ArcMap. Each individual route shapefile that was created in the previous step was then used to extract individual rasters. After extracting each of the individual routes from the tree canopy raster, the average percentage of tree canopy cover for each was calculated using the attributes of each route and was entered into a spreadsheet. The equation used to calculate the average percentage of tree canopy cover was:

$$\frac{VC}{C} = T$$

Where:

V = Cell value (0 - 100),

C = Cell value count

T = Average percentage of tree canopy for each layer

Using the above equation, the routes were ranked from highest percentage of tree canopy to lowest using the sort function in Excel. The table that was created in Excel was added to an existing ArcMap session with a Join to the original BBS routes shapefile. Again, a two and a half mile buffer was added to the BBS routes to enhance visualization. The symbology was changed to illustrate the rankings of routes based on the average percentage of tree canopy.

SPSS was used to perform statistical analysis on the data collected from the steps above. An independent-samples Student's t -test was performed on the data from the Hartland and Knapp BBS routes to determine if significant differences existed between the two. The

same test was used to determine if significant differences existed between 1978 and 2008. Lastly, a Pearson Produce-Moment Correlation was performed on the 2001 BBS, land cover, and tree canopy data to determine what degree, if any, correlation existed between the three variables.

Results

1978 vs. 2008 Analysis

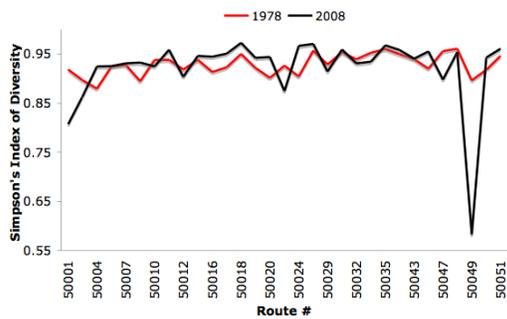


Figure 8. Results of Simpson’s Index of Diversity calculations for each route in 1978 and 2008. Data for the graph were obtained from the USGS website in 2009.

Figure 8 illustrates the overall trends of the 31 routes included in the 1978 vs. 2008 analysis. Within the results, the highest calculated Simpson’s Index of Diversity (0.97) occurred in 2008 within route 50018, located near the central Minnesota city of Brainerd (Figure 9). The lowest calculated Simpson’s Index of Diversity (0.58) occurred in 2008 within route 50049, just west of St. Cloud, Minnesota. In terms of changes over the course of 30 years, route 50049 also experienced the greatest decrease in diversity (-0.31) while route 50024, just southwest of Duluth, MN experienced the greatest increase (+0.06) over the course of 30 years.

The results for the *t*-test performed between the 1978 and 2008 survey data are shown in Figure 9. The SPSS output (Figure 10) indicates the

level of significance between the two sets of data

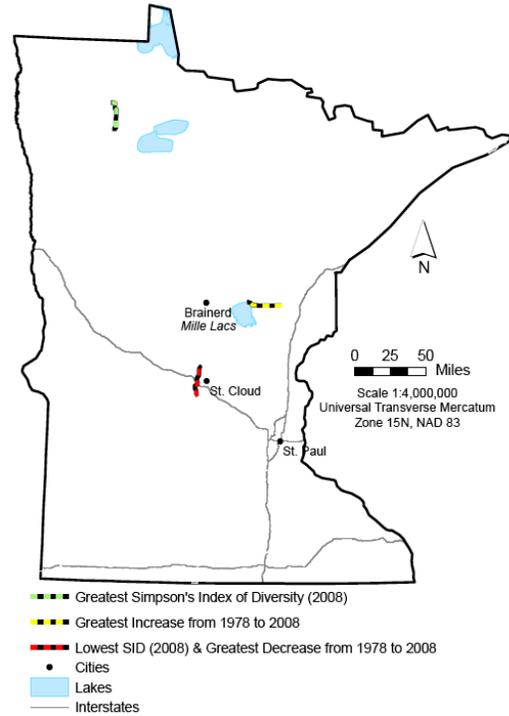


Figure 9. Results from analysis of survey data existing between 1978 and 2008. The data for the map were collected from the USGS website in 2009.

was 0.054. Since the value is not less than 0.05, overall there is almost but technically no statistically significant difference in the levels of richness between the 1978 and 2008 data.

		Levene's Test for Equality of Variances	
		F	Sig.
Simpson's Index of Diversity	Equal variances assumed	3.856	.054
	Equal variances not assumed		

Figure 10. SPSS output from *t*-tests performed on data from the 1978 and 2008. Data for the routes were obtained from the USGS in 2009.

Knapp vs. Hartland Analysis

The greatest diversity that occurred between the Knapp and Hartland routes was calculated to be in 2004 along the Knapp route. The value of Simpson’s

Index of Diversity (SID) in this case was 0.96 (Figure 11). The least diversity between the two routes occurred along the Hartland route in 2006. In 2006, the SID was equal to 0.84 (Figure 12). The year that exhibited the greatest difference between the two routes was 2004 when the SID of the Knapp route was 0.10 greater than that of Hartland.

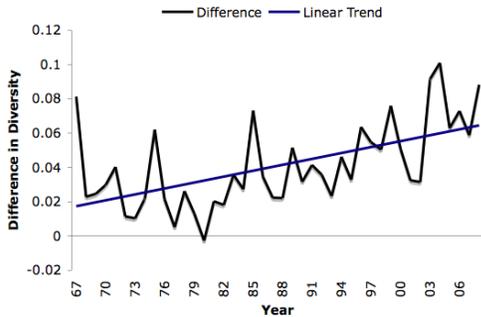


Figure 11. Results of Simpson's Index of Diversity calculations for Knapp and Hartland routes between 1967 and 2008. Data for the graph were obtained from the USGS website in 2009.

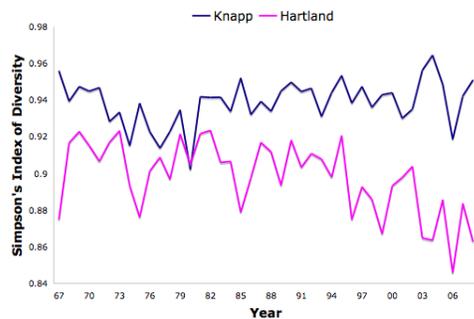


Figure 12. Calculated differences in diversity between Knapp and Hartland routes between 1967 and 2008. Data for the graph were obtained from the USGS website in 2009.

Of the 43 years surveyed, Hartland's calculated SID exceeded Knapp's once (1980) by a margin of 0.002. Also shown in Figure 11, the trendline created in Excel indicates there is a positive relationship between the difference in calculated diversity and the year. Results for the *t*-test used to determine whether a significant difference existed between the Hartland

and Knapp routes is shown in Figure 13. Since the level of significance (0.004) was less than 0.05, the *t*-test indicates that a significant difference between the two routes exists in terms of species richness.

		Levene's Test for Equality of Variances	
		F	Sig.
Simpson's Index of Diversity	Equal variances assumed	8.861	.004
	Equal variances not assumed		

Figure 13. SPSS output from *t*-tests performed on data from the Hartland and Knapp routes. Data for the routes was obtained from the USGS in 2009.

2001 Analysis

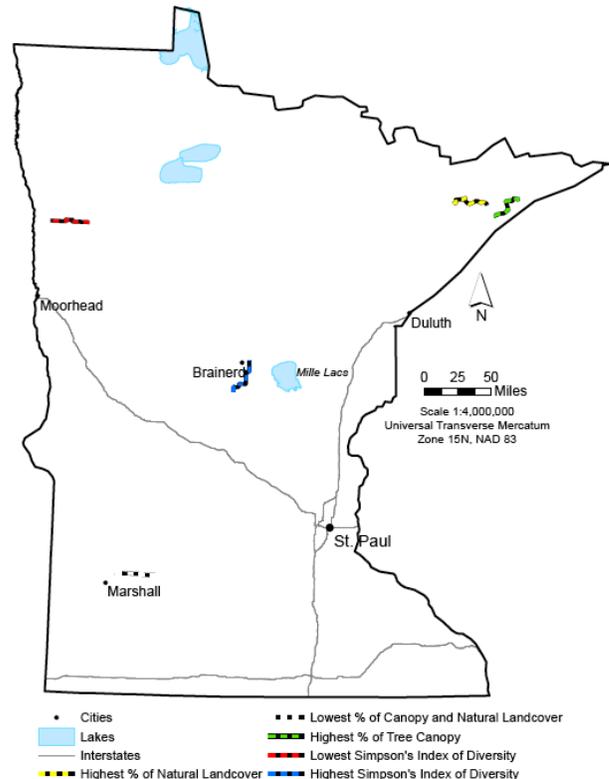


Figure 14. Results from analysis of National Land Cover Dataset data as well as BBS data from 2001. The data for the map were collected from the USGS website in 2009.

In 2001, the highest diversity occurred along route 50069 (0.97) while the lowest occurred along route 50043 (0.72). The route with the greatest

Correlations				
		Simpson's Index of Diversity	Landcover	Tree Canopy
Simpson's Index of Diversity	Pearson Correlation	1	.456**	.412**
	Sig. (2-tailed)		.001	.002
	N	52	52	52
Landcover	Pearson Correlation	.456**	1	.970**
	Sig. (2-tailed)	.001		.000
	N	52	52	52
Tree Canopy	Pearson Correlation	.412**	.970**	1
	Sig. (2-tailed)	.002	.000	
	N	52	52	52

** Correlation is significant at the 0.01 level (2-tailed).

Figure 15. SPSS output from the Pearson correlation tests performed on the land cover, tree canopy, and Simpson's Index of Diversity data. Data for the analysis were obtained from the USGS in 2009.

percentage of natural habitat was 50033 (99.74), which was located in the northeastern corner of the state. Situated within the southwestern area of Minnesota, route 50012 had the lowest percentage of natural habitat, at 2.70%. The same route, 50012, also experienced the lowest percentage (0.19) of tree canopy cover. In contrast, another northeastern route, 50032, saw the greatest percentage of tree canopy (85.44%). The locations of each of the above routes are shown in Figure 14.

Discussion

Interpretation of Results

The BBS route closest to Brainerd, Minnesota and just west of Lake Mille Lacs had the greatest calculated diversity on two occasions, once in the 1978 vs. 2008 study and in the 2001 study. This may be indicative of the natural landscape surrounding the area, the abundance of lakes, and the absence of a major interstate intersecting the area. Similarly, the route that experienced the greatest increase in diversity over the 30-year time period was located near Duluth, Minnesota. This area also lacks a major interstate, is nearby a large body of water (Lake Superior), and is home to an abundance of natural habitat.

In contrast, the route experiencing the lowest calculated

diversity in the 1978 vs. 2008 study was found near St. Cloud, Minnesota, where a major interstate runs through the middle of the route making a large section of the route uninhabitable by birds due to automobile traffic. This area of the state also experienced the largest decrease in avian diversity between 1978 and 2008.

In spite of an increased amount of human influence on landscapes across the state, the lack of a significant difference in richness between 1978 and 2008 indicates that avian diversity remains strong statewide. Although individual routes may have seen changes in diversity over this time period, none of the changes were drastic enough to indicate an alarming trend. Many of the routes that saw increases in biodiversity may have benefited from an increase in public awareness as well as improved conservation efforts.

In the study comparing the Hartland and Knapp routes, a significant difference in diversity existed between the two routes. The Knapp route located in central Minnesota consistently experienced higher calculations of diversity compared to the southern Hartland route. Much like the route near St. Cloud that experienced low diversity levels, the Hartland route is split by a major interstate.

Also, the trendline that shows the differences in diversity between

Hartland and Knapp increasing over the course of the study period indicates that the situation is getting worse. In other words, it appears by the results that the diversity of the Knapp route is remaining strong while the calculated diversity of the Hartland route has been decreasing for a number of years. Whether this is a result of increased development, increased traffic flow along the interstate, or a completely separate reason is unknown.

Canopy percentages studies suggest that the northeastern area of the state appears to be the least affected by human activity. This area, located near the shore of Lake Superior, had the highest calculated proportions of tree canopy cover and natural land cover. In contrast, a route located just north of Marshall, Minnesota, experienced both the lowest proportion of tree canopy cover and the lowest proportion of natural land cover. Located in the southwestern quarter of Minnesota, this route may be influenced by farming practices that cleared the land of trees and any other natural elements.

The significant correlation that exists between land cover, tree canopy percentage, and avian diversity indicates that areas greatly influenced by human development such as farming and the building of infrastructure will potentially have lower levels of avian diversity. In light of this, the routes located in northeastern Minnesota would be expected to have high levels of avian diversity while the routes in south central Minnesota, near Marshall would be expected to have lower levels of avian diversity.

Potential Study Problems

The major concern within this study is the Breeding Bird Survey data itself. Since this data is not consistently available for every year between 1967 and 2008, a thorough statewide analysis of avian diversity trends is nearly impossible. This hurdle was overcome by first determining what years and for what routes data was available and then choosing which data to analyze.

Another issue, also related to the limited amount of data, involved the lack of randomness involved with selecting the data used for this study. Ideally, a random selection of routes and years to study would have made for more sound analysis. Unfortunately randomization such as this would have led to the choosing of routes and years which had no data associated with them.

Future Implications

By using the results found in this and other studies, a determination can be made as to which areas of the state should be focused on with conservation efforts. Also, by using the correlatives found in this study, there is the potential for developing a predictive model to determine what trends will be like in the future. To create such predictive models or to discover potential indicators, several correlates to diversity must be considered. For instance, consider the possible correlation that exists between land cover and biodiversity. Bustamante and Seoane (2004) found diversity to be greatest in the areas where the landscape offered greater sustenance and protection than other areas. In addition, they discovered that the sites with the lowest diversity tended to exist arbitrarily in relation to the landscape (Bustamante and Seoane).

In order to build effective predictive models, species and habitats being studied must be abundant in order for strong connections to be found and used for predictive modeling (Debinski *et al.*, 1999). Fortunately, the National Land Cover Dataset makes all the data necessary for analysis available to the public. This analysis involves the use of vegetation classifications created by remote sensing for predicting species distributions (Bowker, 2000). By comparing the results of a predictive model and the current distribution of species, gaps in conservation can be found (Debinski *et al.*, 1999).

Tucker *et al.* (1997) cite the constant movement of avian species as the reason for making the creation of effective predictive models difficult. Despite such difficulties, there has been a precedence set by several groups of researchers. For instance, Osborne, Alonso, and Bryant (2001) successfully applied predictive models to great bustard populations within a Spanish province. In order to create the most accurate model, they applied several environmental predictors to their model, including land cover type and elevation (Osborne *et al.*). Dettmers and Bart (1999) also overcame the obstacles present in predictive modeling by using a combination of GIS and land use data. The studies conducted by Dettmers and Bart, as well as the study by Osborne *et al.*, are both useful examples of precedence for those wishing to create predictive models for avian communities.

Conclusion

According to Gottschalk, Huettmann, and Ehlers (2005), there are hurdles that must be overcome in order to maintain

biodiversity, namely the vanishing of species and the deterioration of the land used by its inhabitants. In order to overcome these hurdles, organizations around the world must work together in order to create one large storage space for the placement of biodiversity information (Bowker, 2000). The storage space for this information may be a GIS in which all the world's biodiversity information could be stored, managed, and spatially referenced.

Gottschalk, Huettmann, and Ehlers (2005) note that an effort to maintain biodiversity must include methods to stop the disappearance of species and prevent the destruction of the landscapes they prefer. By providing a means of storage and analysis, GIS is capable of providing a medium for the storage and analysis of such information. Further, the advances in GIS technology over the last decade have allowed for an increased ability to create accurate prediction models pertaining to the allocation of species in their environment (Salem, 2003). Salem also notes that these models are able to account for alterations in the environment over time. By combining these models with images of land cover, for instance, the areas with the greatest richness could be found and sought out as the most important to safeguard (Salem).

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