ASSESSING DEER-VEHICLE COLLISION RISK: A RISK INDEX FOR TEXAS

MICHELLE L. SHUEY, Department of Geography, Southwest Texas State University, San Marcos, TX 78666, USA, email: MS56641@swt.edu

NEIL CADLE, FIVCO Area Development District, Catlettsburg, KY 41129, USA

ABSTRACT: Deer -vehicle collisions have become a problem in many areas of the United States. The causes of collisions are complex, and relationships between factors affecting collisions remain unclear. It is possible that the inconsistencies between studies reflect a problem of scale. We argue that the causes of deer-vehicle collisions are relevant to their locational hot spots and cannot be generalized over regions (e.g., an entire state). In this study we created a white-tailed deer (*Odocoileus virginianus*) -vehicle collision risk for counties in Texas to identify site-specific areas of high risk. Unfortunately, the available data was aggregated to the county level and locational analyses were unachievable. Locational black bear (*Ursus americanus*) collision data were obtained from Florida, allowing a comparison of site-specific versus aggregated data for animal collisions. Results showed the deer-vehicle collision risk index was only about 50% accurate when measured against actual collision numbers. The spatial analysis of the bear collision data showed that site-specific data was better able to identify areas of greater risk.

Key words: white-tailed deer, deer-vehicle collisions, Texas, animal collisions, spatial analysis

2001 TRANSACTIONS OF THE WESTERN SECTION OF THE WILDLIFE SOCIETY 37:47-54

Within the last 30-40 years, deer-vehicle collisions have become a problem in the United States, as well as in many European countries and Japan (e.g., Bruinderink and Hazebroek 1996, Kaji 1996, Danielson and Hubbard 1998). Unfortunately, research has shown that the causes of deer-vehicle collisions are more complex than previously thought. While a number of studies have been conducted, such as the effects of deer population size in Wisconsin (McCaffery 1973) and the Netherlands (Bruinderink and Hazebroek 1996), and the effect of vegetation cover in Pennsylvania (Bashore et al. 1985) and Michigan (Allen and McCullough 1976) on the occurrence of deer-vehicle collisions, very little has been revealed about the factors affecting deer-vehicle collisions.

The risk of a deer-vehicle collision has increased since the mid 1900s as humans spread into undeveloped areas and deer populations increased. Over 20 million deer roam North America today, a more than two-fold increase from the estimated 10 million in the 1980s, and a marked increase from the estimated 500,000 deer in the early 1900s (Cook and Daggett 1995 in Hubbard et al. 2000, Walsh 1997). Deer population growth has been associated with the creation and increase of deer habitat (Waller and Alverson 1997), wildlife control measures that significantly reduced or extirpated large predators, and an increase in "deer friendly" environments created by urban and suburbanized development (Adler 1999). Lush, non-native landscaping and restrictive hunting laws in suburbanized developments support much larger deer herds, placing them in closer contact with humans (Baker and Fritsch 1997, Stout et al. 1997), and increasing the probability of collisions.

In the United States, numbers of reported deer-vehicle collisions increased from a little over 500,000 accidents in 1991 to 726,000 collisions in 1995 (Conover et al. 1995, Romin and Bissonette 1996). Furthermore, Romin and Bissonette (1996) argued that the actual collision rate is much higher, and suggested that 50% of deer-vehicle collisions go unreported. Conover et al. (1995) estimated the economic costs of damage from deer-vehicle collisions at over 1 billion dollars annually. Not only do deer-vehicle collisions cause economic loss, collisions also present risks to humans. Calculations indicate approximately 29,000 human injuries and 211 human deaths occur as a result of deer-vehicle collisions in the United States each year (Conover et al. 1995).

While deer-vehicle collisions are a problem over much of the United States, some states are suffering from a higher number of collisions than others. For example, Romin and Bissonette (1996) assessed deer-highway mortalities as a measure of collisions and found Wisconsin increased from 28,878 deer-roadway mortalities in 1982 to 76,626 in 1991, while both Michigan and Pennsylvania increased from approximately 20,000 deer mortalities in 1982 to over 40,000 in 1991. Within the same time frame, New Jersey had suffered a 2,206% increase in deer-highway mortalities, Illinois experienced a growth of 456%, and Indiana reported a deer mortality increase of 343% between 1982 and 1991 (Romin and Bissonette 1996). Wood and Wolfe (1988) estimated a 94% increase in Utah for deer-vehicle collisions from 1970 to 1986, and Danielson and Hubbard (1998) found an increase of more than 50% in five years for Iowa.

Despite previous research, factors influencing collisions are still unknown and the associations between variables remain unclear (Hubbard et al. 2000). Variables such as deer population size, land cover, traffic volume, lanes of traffic, and infrastructure (such as the number of bridges) have been assessed, but study results conflict (Bellis and Graves 1971, McCaffery 1973, Allen and McCullough 1976, Bashore et al. 1985, Feldhamer et al. 1986, Bruinderink and Hazebroek 1996, Putnam 1997, Hubbard et al. 2000). The lack of consensus on the factors influencing deer-vehicle collisions could reflect a problem of scale, such that previous research has attempted to find regional generalizations rather than localized patterns. For instance, Bashore et al. (1985) determined that deer-vehicle accidents were not random in time and space; therefore, they had a distinct spatial pattern, such that they aggregated around specific locational sites. This information points to the possibility that the factors affecting deer-related accidents, and characteristics of collisions are not generalizable across regions but are specific to their locational hot spots.

Because previous research conflicts with factors affecting deer-vehicle collisions, we believe collisions may be localized occurrences. We used data from Texas to assess factors affecting white-tailed deer-vehicle collisions in the state of Texas. Our objectives were to 1) create a risk map of white-tailed deer-related collisions for the state of Texas, and 2) compare aggregated to site-specific collision data to determine which type of data was more accurate and useful.

METHODS

Data Collection

Data used in this study were collected from multiple sources and only available by county for the years 1990 through 1998. We obtained deer population (Drpop) estimates, and the percentage of deer habitat (Hab) for each county to assess the occurrence and density of deer (Young and Richards 1995, Young and Traweek 1999). Lane miles (LM) and daily vehicle miles (DVM) for each county were gathered as a measure of traffic volume (Texas Department of Transportation 1990-1998), and we used animal collision (Coll) data per county (Accident Records Bureau 2000) to assess deer-vehicle collision numbers. We collected county land area (Area) and human population estimations for 1997 (Pop) available in the data provided with *ARCVIEW 3.2* Geographic Information System software.

There were a number of limitations with the Texas data. Data were incomplete for most years, which restricted our analyses to data from 1997, as it was the year with the most complete information. Estimates of deer population size were questionable as they were based on a myriad of collection methods and an incomplete vegetation classification. Additionally, the only collision data available included all animals colliding with vehicles, and it is very likely that not all white-tailed deer collisions made it to the Texas Department of Public Safety's database. All available data were aggregated to the county level, prohibiting site-specific analysis. To compare aggregated versus site-specific data, we obtained point data from an image of black bear-vehicle collision in Florida (Office of Environmental Services 1992).

Data Analysis

The analysis of our data occurred in two steps using two software packages. First, we ran a series of statistical methods using the *Statistical Package for the Social Sciences 9.0 (SPSS)*. To evaluate the appropriateness and significance of our variables, we ran a combination of three statistical procedures: a correlation, a principal components analysis, and a reverse stepwise multiple regression. The use of these three methods helped us determine which independent variables demonstrated the strongest relationships with the dependent variable (Coll97), yet did not have a significant correlation with other independent variables.

The second step in our analysis utilized the technology of *ARCVIEW 3.2* Geographic Information System (GIS) by Environmental Systems Research Institute (ESRI). Data entry first required the acquisition of a Texas county base map (available in the data provided with the software). Once we entered the data, we performed the necessary analysis at the county level. The mathematical nature of the database manipulation tools in a GIS allowed us to test replications of our index values until we found one that was the best possible fit. The cartographic quality of *ARCVIEW* made it possible to overlay the number of collisions map layer with our index values map layer. Overlays of this nature allow for the visual examination of quantitative spatial analyses.

For the Florida data, the process was similar: acquiring a county base map and creating a point map of bear-vehicle collisions based on our findings (Figure 1). Quantitative aggregation to the county level of these values was processed to produce the same level of information that was available for Texas. We then turned to the site-specific data that we acquired for Florida. The extraction of the kernel estimation (a point-pattern analytical procedure) required the use of ARCVIEW's Spatial Analyst extension-a modeling tool that uses raster-based operations to perform more advanced analyses (see Mitchell [1999] for a detailed explanation of raster analysis). Kernel estimation is a standard point-pattern method that runs a high number of Monte Carlo-based simulations at a specified radial distance (based on the scale of our study, which takes into consideration many spatial factors, we used the computer-generated distance of eleven miles). These simulations test for spatial patterns that vary against randomness. A significant find of clustering, ordering, or dispersion of data points give reason to suspect that a location may have factors affecting such a pattern. Because site-specific data is exact, not generalized, and easily manipulated in spatial analyses, results may be obtained much more easily and with a higher probability of accuracy than with aggregated data.

RESULTS

Texas Risk Index

The results of the statistical analyses left a limited range of significant data to use in creating the risk index for Texas. The final results of the regression analysis (Table 1) rejected Drpop97 and Area as insignificant contributions, leaving the other variables that gave an adjusted R^2 of 0.588.

Variables DVM97, LM97, and Pop97 all correlated significantly to Coll97, however, they were all also highly correlated among themselves (Table 2). These high correlation values suggest that the variables may explain similar functions of the collision phenomena. As the regression suggested, Drpop97 was not significantly correlated to Coll97. However, Hab97 was negatively correlated (-0.103) with Coll97 at the 0.05 significance level. Drpop97 and Area were dropped as a result of the regression, and LM97 and Pop97 were abandoned because they were both highly correlated with DVM97. The risk index was derived using the remaining variables: DVM97 and Hab97. The risk index is

$$\text{Risk Index} = Log_{10}DVM97*(0.5/Hab97)$$

where DVM97 is the average daily vehicle miles driven per county in 1997 and Hab97 is the percentage of each county that is classified as deer habitat in 1997.

We chose these two variables based on their correlations with the dependent variable: 0.614 and -0.103, respectively. The negative value of Hab97 suggests an inverse relationship to Coll97, and the 0.5 in the numerator is a weight assigned because of their different correlation strengths. The DVM97 variable exerts a parabolic curve when graphed against Coll97; thus, we applied a logarithmic scale to its values. We used a GIS software package to derive our index for each county and compare it against actual collision data (a spatial interpretation of the regression of our index and collision data).

Once the risk index equation was derived, the risk for each county for the year 1997 was calculated, and a choropleth map was created using *ARCVIEW 3.2* (Figure 2). Darker colors denote areas of higher probability of a deer-vehicle collision. The index identified the urban areas of Abilene, Brownsville, Corpus Christi, Dallas/Fort Worth, Houston/Galveston, San Antonio, and Wichita Falls, as well as the eastern section of the panhandle as having the highest risk. The three counties with "no data" were two counties in the Dallas/Fort Worth region and a Gulf county in the Galveston area. The risk index was unable to calculate deer-vehicle collision risk for these counties because there was no reported white-tailed

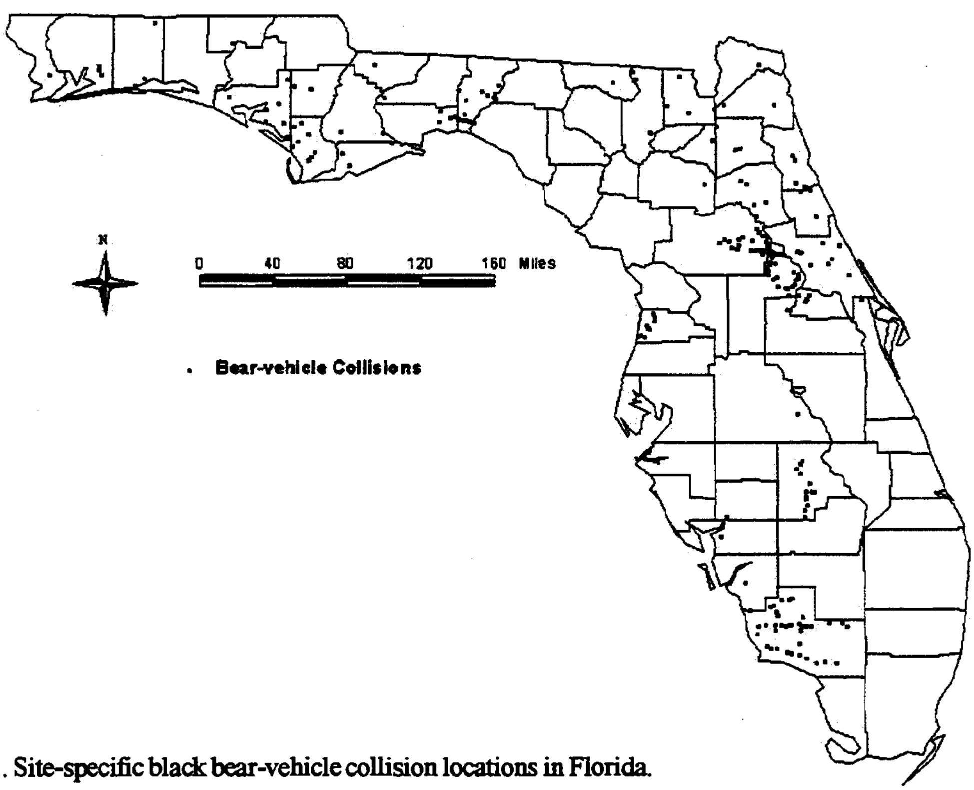

Figure 1. Site-specific black bear-vehicle collision locations in Florida.

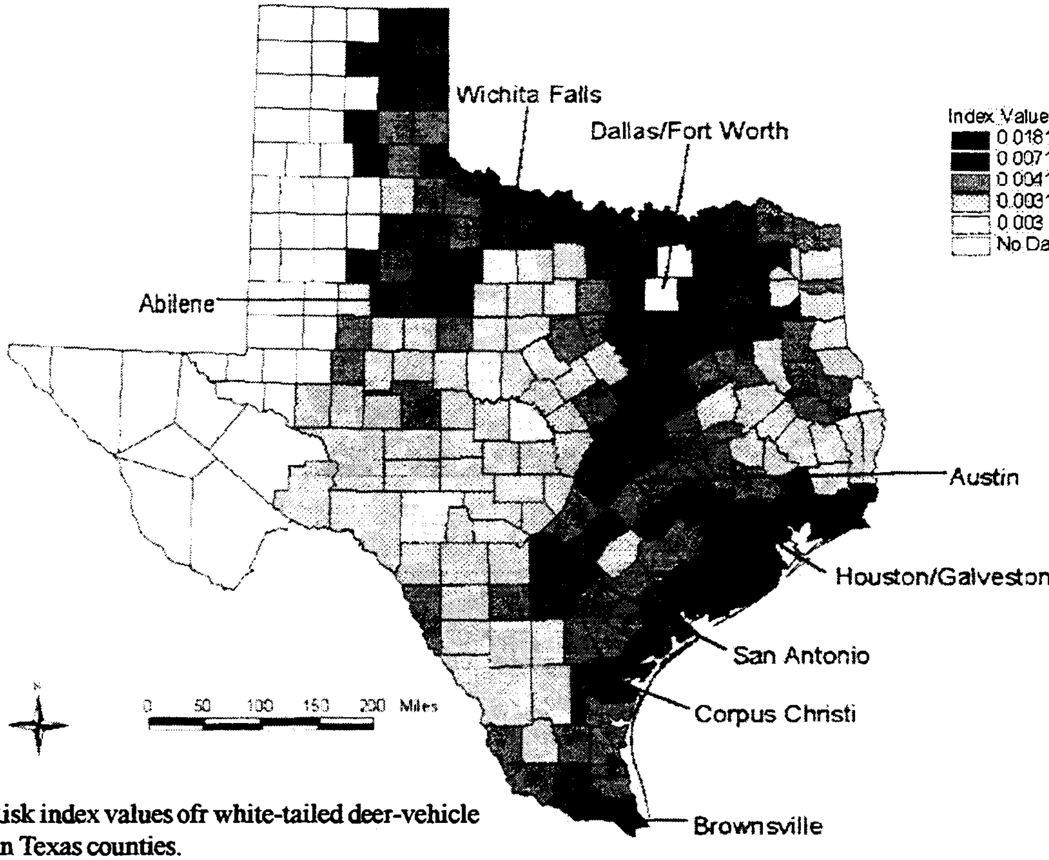

Figure 2. Risk index values ofr white-tailed deer-vehicle collisions in Texas counties.

Table 1. Reverse stepwise multiple regression results for variables of deer-vehicle collisions in Texas.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.773 (a)	0.598	0.588	7.3585
2	.773 (b)	0.598	0.59	7.3437
3	.771 (c)	0.595	0.588	7.3581

a Predictors: (Constant), AREA, HAB97, DVM97, LM97, DRPOP97, POP97
b Predictors: (Constant), AREA, HAB97, DVM97, LM97, POP97
c Predictors: (Constant), HAB, DVM97, LM97, POP97

Table 2. Pearson correlation of all variables where Coll97 was the dependent variable for deer-vehicle collisions in Texas.

	POP97	DRPOP97	AREA	DVM97	LM97	COLL97	HAB97
POP97	1	-0.104	0.039	.992 (**)	.688 (**)	.571 (**)	-.196 (**)
DRPOP97	-0.104	1	.245 (**)	-0.111	-.188 (**)	-0.07	.705 (**)
AREA	0.039	.245 (**)	1	0.033	0.087	-0.014	-0.004
DVM97	.992 (**)	-0.111	0.033	1	.715 (**)	.614 (**)	-.197 (**)
LM97	.688 (**)	-.188 (**)	0.087	.715 (**)	1	.717 (**)	-.320 (**)
COLL97	.571 (**)	-0.07	-0.014	.614 (**)	.717 (**)	1	-0.103
HAB97	-.196 (**)	.705 (**)	-0.004	-.197 (**)	-.320 (**)	-0.103	1

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

deer habitat based on the data collected from Texas Parks and Wildlife. County data for west Texas was discarded because white-tailed deer populations are almost nonexistent in the drier habitat (Young and Richards 1995, Young and Traweek 1999).

Based on the risk index values, we used the choropleth map of the index and overlaid it with a dot density map of the Coll97 (Figure 3). The dot density map does not show actual collision locations; rather it is another way of displaying data. The risk index shows fairly good fit with actual collision numbers in central Texas and the urban areas of Brownsville, Houston/Galveston, and San Antonio. However, the index over-predicts in the eastern panhandle, north central Texas, the northeastern section and the Wichita Falls area. Areas of under-prediction include the urban area of Austin, the region between Austin and Houston/Galveston and extreme east Texas. The dot density map shows collisions in the western section of the state; these collisions could be with mule deer, which have stable populations in west Texas. The dot density map also shows deer-vehicle collisions in each of the three counties in which the index was unable to calculate risk. We ran a simple regression between the risk index values against the Coll97 values for each county. The regression yielded an R^2 of 0.410 and an adjusted R^2 of 0.374.

Florida Location Analysis on Site-Specific Data

The spatial analysis of the site-specific Florida bear-vehicle collision data provided more accurate results than the aggregated county level from both the Florida and Texas examples. As with the Texas risk index, the Florida aggregated collision map (Figure 4) clearly shows counties with higher numbers of collisions, but assumes that collisions are arranged homogeneously within the borders of each county. For example, Marion, Lake and Volusa counties have very high collision numbers that seem to be distributed uniformly within each county, and as a result, it is assumed that the collision number changes immediately at each county border. This assumption was shown to be inaccurate by the kernel estimation analysis (Figure 5), which identified significant clusters of bear-

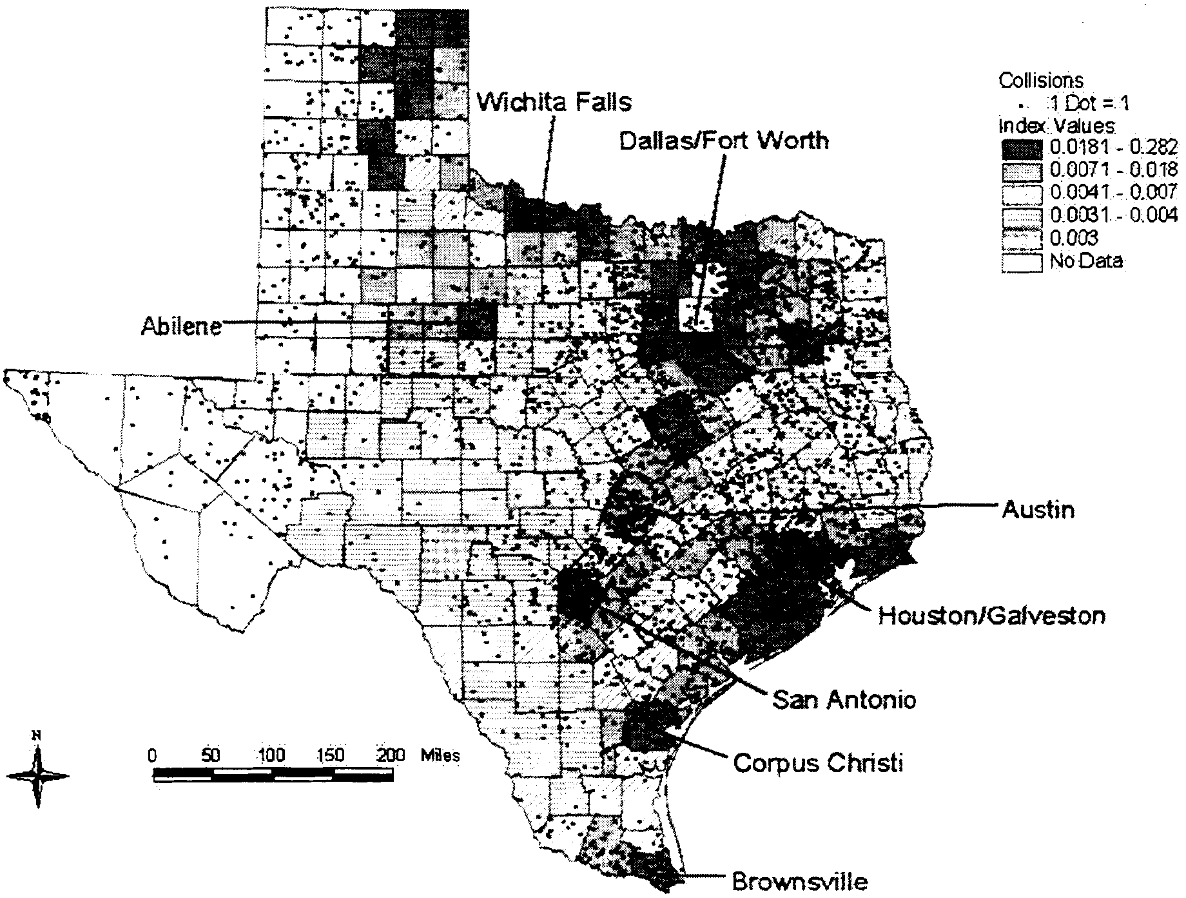

Figure 3. Risk index of white-tailed deer-vehicle collisions overlaid with raw collision dot density map.

vehicle collisions in localized hot spots. Additionally, the most noticeable cluster is not evenly distributed within Marion, Lake or Volusa counties, but overlapped the corners of each county.

DISCUSSION

Research on the causes of deer-vehicle collisions has presented conflicting results and relationships between variables affecting collisions remain ambiguous. In this study, we argue that one problem with research on deer-vehicle collisions is generalizing results to large regions. Previous studies imply that the results found in one area hold true for the entire regions (e.g., county, state). As found in the spatial analysis of the bear-vehicle collision data, collisions were clustered in hot spots. Further, point-pattern analyses could prove that characteristics of these site-specific occurrences differ from place to place, even within the same region.

The inconsistencies in past studies could also be one of inaccurate data, as was the case in this study. We incurred many obstacles with the Texas data that prohibited site-specific analysis and restricted our analyses to the year 1997. First, site-specific collision data were unavailable. Collision data were recorded at the county level without specific locations within each county; thus, the analyses were confined to the county level. In an effort to compare aggregate versus site-specific data, we were forced to search for other data. Place-specific data proved to be difficult to obtain elsewhere. Data on white-tailed deer collision exist in some states, but even for these, the data suffer from generalization or other inadequacies. For instance, collision data from Jackson County, West Virginia showed that records are kept for individual accidents, but locations are not specific. Rather, they only report many rural cases by the road on which they occur.

Second, the animal-vehicle collision data involved vehicle collisions with all animals, including other animals besides white-tailed deer, such as mule deer and livestock. We used the collision data because it was the only data available and it is believed that 98% of the animal collisions in white-tailed habitat were accidents involving white-tailed deer (B. Young, Deer Overpopulation Program Coordinator for Texas Parks and Wildlife, personal communication).

Third, the accuracy of deer population estimates was questionable. Deer population estimates were calculated using surveys of deer number and percentage of deer

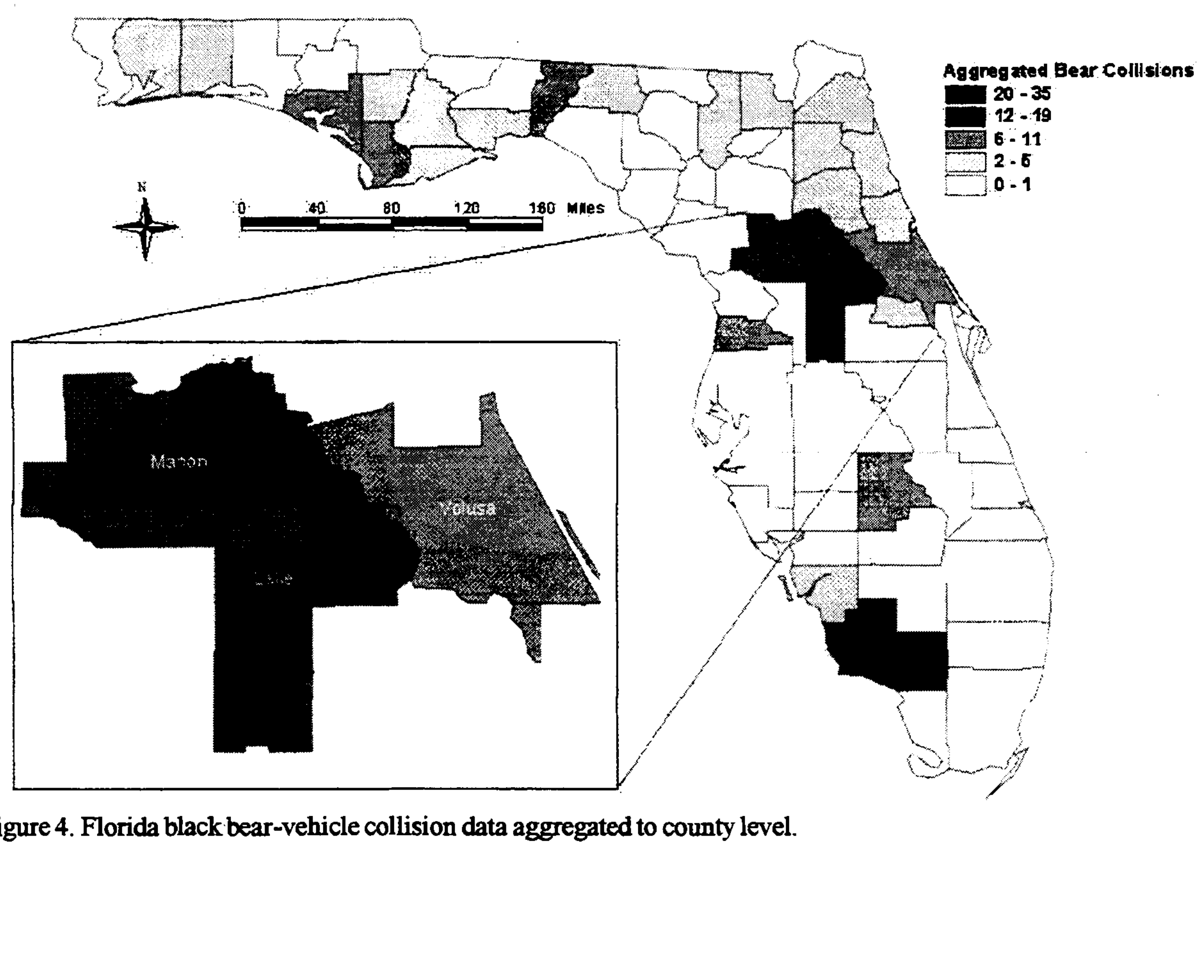

Figure 4. Florida black bear-vehicle collision data aggregated to county level.

habitat within each county. However, different people using different methods performed deer surveys over the 1990 - 1998 period. White-tailed deer surveys were not conducted in many of the western and urban counties because white-tailed deer populations and habitat were believed to be either extremely low or absent. There were also a number of counties, in what was considered to be white-tailed deer habitat, that were not surveyed consistently over the 8 year time period. As a result, the deer population estimates were not comparable from county to county, nor were they comparable from year to year for the same county. Additionally, the estimated percentage of deer habitat for each county was based on Gould's 1969 vegetation classifications for Texas, which was not entirely complete (Young and Richards 1995, Young and Traweek 1999). We could not find data suggesting there has been an update to Gould's classification, thus, the habitat classification could possibly be inaccurate, skewing deer population estimates either higher or lower than the actual number.

If the problems associated with data collected in this study are common for most or all of the previous studies of deer-vehicle collisions, it is understandable how so many studies have generated inconclusive results. Research on deer-related vehicle accidents would improve if standards for submitting and recording such events were created, and comprehensive records were kept. A statewide database might remove the inadequacies of dealing with regional data, however a national database would allow the comparison of data and study results between states. Wood and Wolfe (1988) suggest such a database keep statistics on place, time, date, species, sex, age, and weather in relation to productivity and population trends, as well as the spatial distribution of the species involved. In addition, we argue that statistics on all possible variables such as traffic volume, road characteristics, vegetation type, roadside vegetation, and amount and type of infrastructure also be included in the database. Only when agencies begin to keep such detailed records can there be hope of understanding and managing the spatial aspects of deer-vehicle collisions.

In conclusion, aggregation is not an appropriate way to deal with deer-vehicle accidents. The aggregation of data in the Texas example suggests the risk value is uniform within the boundaries of each county, however, the Florida bear analysis showed this to be incorrect. Animal distributions do not follow man-made boundaries, and important information is lost when animal data is aggregated to social and political boundaries. More specific data on deer-vehicle collisions can provide the location-specific answers needed to understand the relationships that affect the occurrence of accidents, and can therefore

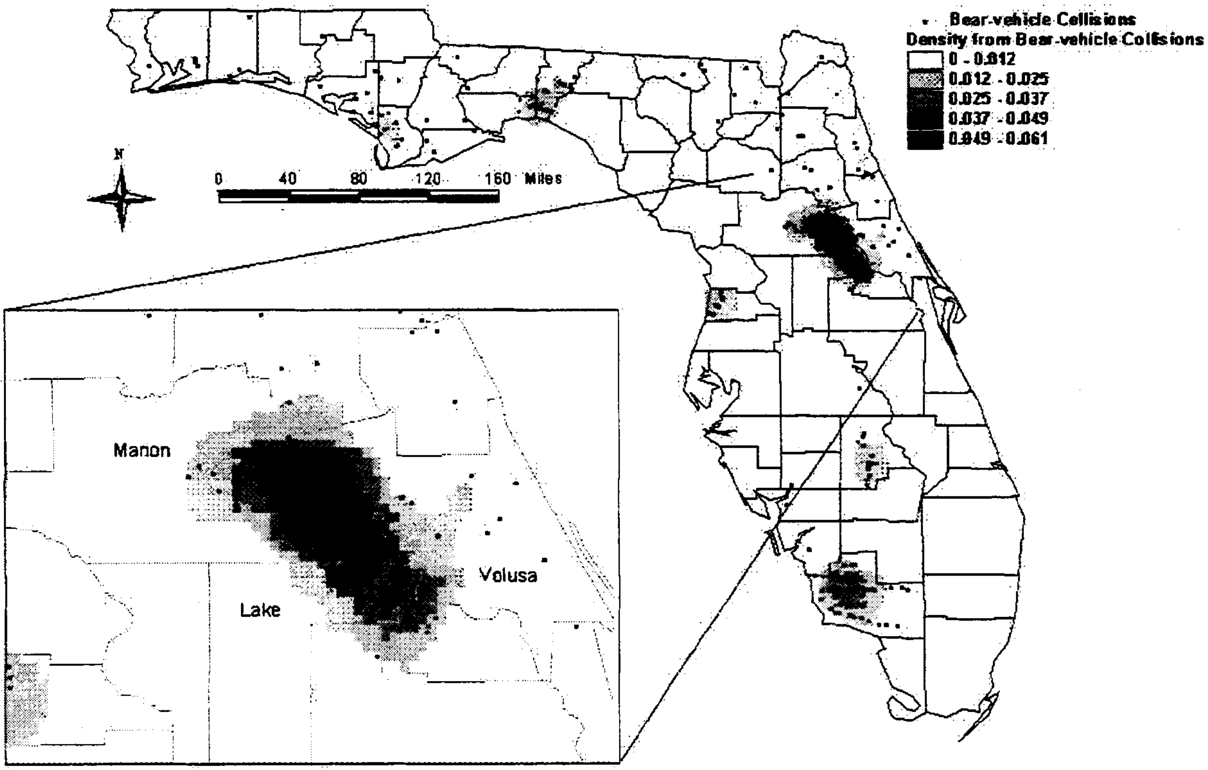

Figure 5. Kernel estimation of black bear-vehicle collision data to identify clustering of collisions.

increase the ability to determine spatial patterns. Management of deer-vehicle accidents can then be focused only on those areas where collisions are clustered, thereby investing less money and time in areas where it is not needed.

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