An Assessment of Traffic Safety in Urban Deer Herd Management Zones in Iowa

Center for Transportation Research and Education

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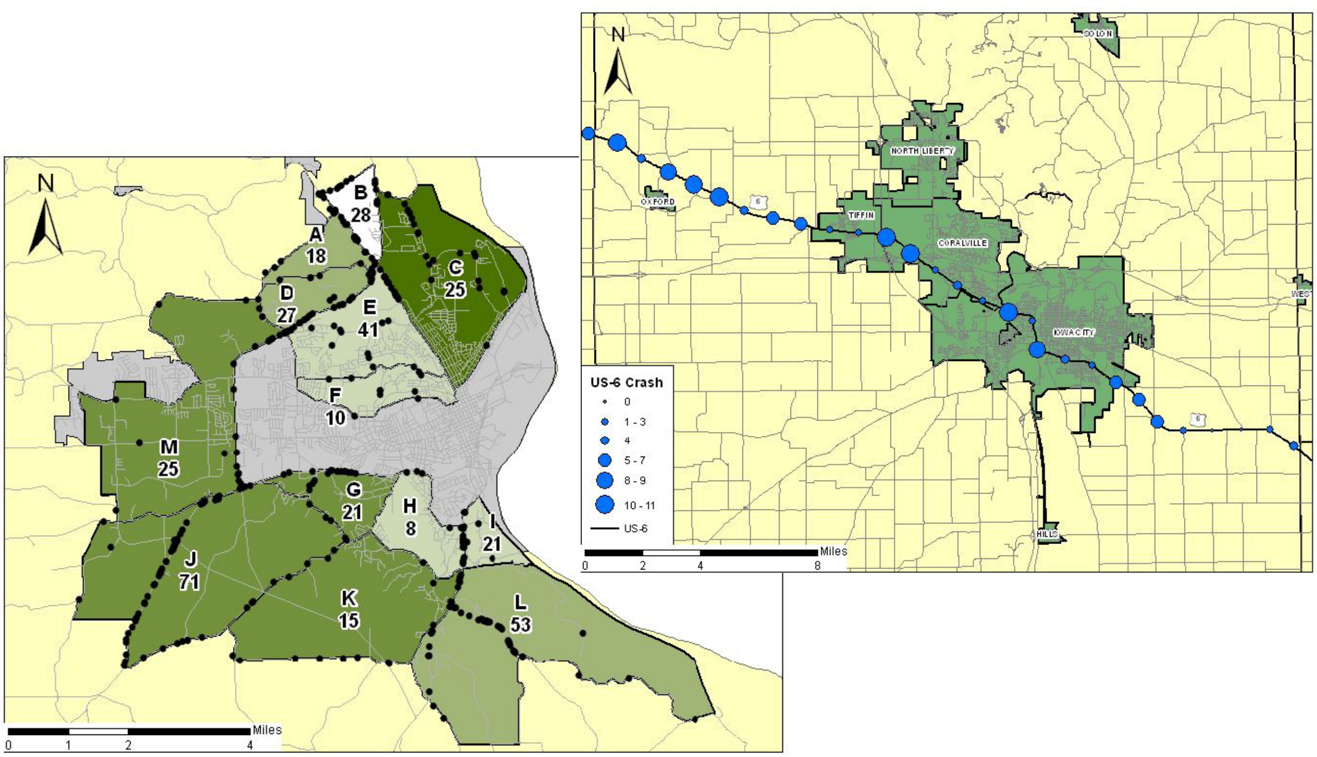

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16. Abstract

Many states are striving to keep their deer population to a sustainable and controllable level while maximizing public safety. In Iowa, measures to control the deer population include annual deer hunts and special deer herd management plans in urban areas. While these plans may reduce the deer population, traffic safety in these areas has not been fully assessed. Using deer population data from the Iowa Department of Natural Resources and data on deer-vehicle crashes and deer carcass removals from the Iowa Department of Transportation, the authors examined the relationship between deer-vehicle collisions, deer density, and land use in three urban areas in Iowa that have deer management plans in place (Cedar Rapids, Dubuque, and Iowa City) over the period 2002 to 2007. First, a comparison of deer-vehicle crash counts and deer carcass removal counts was conducted at the county level. Further, the authors estimated econometric models to investigate the factors that influence the frequency and severity of deer-vehicle crashes in these zones.

Overall, the number of deer carcasses removed on the primary roads in these counties was greater than the number of reported deer-vehicle crashes on those roads. These differences can be attributed to a number of reasons, including variability in data reporting and data collection practices. In addition, high rates of underreporting of crashes were found on major routes that carry high volumes of traffic. This study also showed that multiple factors affect deer-vehicle crashes and corresponding injury outcomes in urban management zones. The identified roadway and non-roadway factors could be useful for identifying locations on the transportation system that significantly impact deer species and safety and for determining appropriate countermeasures for mitigation.

Efforts to reduce deer density adjacent to roads and developed land and to provide wider shoulders on undivided roads are recommended. Improving the consistency and accuracy of deer carcass and deer-vehicle collision data collection methods and practices is also desirable.

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An Assessment of Traffic Safety in Urban Deer Herd Management Zones in Iowa

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EXECUTIVE SUMMARY

Iowa has been placed among the top five states where drivers are most likely to be involved in a deer-vehicle crash (probability of 1 in 104). The Iowa Department of Natural Resources (Iowa DNR) designates special deer population management zones around cities to manage the deer population within the cities' boundaries as a countermeasure to property damage and deer-vehicle crashes. While these plans may reduce the deer population in an area, traffic safety in these areas has not been fully assessed.

The main objective of this study was to investigate the relationship between deer-vehicle collisions, deer density, and land use in select urban deer management zones in Iowa over the period 2002 to 2007. Three urban areas in Iowa that have deer management plans in place were selected for this study: Cedar Rapids, Dubuque, and Iowa City. Three different databases were used in this study: first, deer population counts from 1997 to 2008 were acquired from the Iowa DNR; second, deer carcass removal locations on primary roads and corresponding carcass counts were provided by the Iowa Department of Transportation (Iowa DOT); and last, deer-vehicle crash data from 2002 to 2007 were gathered from the Iowa DOT. To begin, the deer-vehicle crash and deer carcass removal counts were compared at the county level. Further, the authors estimated econometric models to investigate the factors that influence the frequency and severity of deer-vehicle crashes in these zones. Results from this study can assist in a better assessment of traffic safety in urban deer herd management zones and could be of interest to transportation, ecology, and deer management communities.

Overall, the number of deer carcasses removed on the primary roads in the counties of the study was greater than the number of reported deer-vehicle crashes on those roads. These differences can be attributed to a number of reasons, including variability in data reporting and data collection practices. In addition, high rates of crash underreporting were found on major routes that carry high volumes of traffic.

This study also showed that multiple factors with corresponding outcomes affect deer-vehicle crashes in urban management zones. The authors found that deer density rather than deer herd size is a more significant predictor of the frequency of deer-vehicle crashes in urban deer management zones. Further, the frequency of deer-vehicle crashes was higher in zones with a higher percentage of residential and commercial acreage, which confirms the adverse safety impacts of human migration into deer habitats. While a reduction in deer density may not be attainable in all zones, the authors recommend efforts to reduce deer density adjacent to roads and developed land.

The severity outcomes and the number of injuries that resulted from a deer-vehicle collision were determined as a function of crash-, road-, and land-use–specific factors. Overall, the frequency of deer-vehicle injuries increased over the study period in the three urban deer management areas, which may be attributed to an increase in the vehicle miles traveled and a higher deer population. While the frequency of crashes is higher on roads with a posted speed limit below 55 miles per hour, these crashes are less likely to result in injury, probably because of lower impact speeds that result in a less severe outcome. Further, the expected frequency of

deer-vehicle injuries was lower on roads with wider shoulders. The fact that the expected frequency of crashes is higher on undivided roads may suggest the potential benefits of wider shoulders on these roads.

It is also interesting to note the significant predictive values of non-roadway factors (land use characteristics) in both the frequency of deer-vehicle crashes and corresponding injury outcome. The identified roadway and non-roadway factors could be useful for identifying locations on the transportation system that significantly impact deer species and safety and for determining appropriate mitigation countermeasures.

Additional recommendations to the Iowa DOT and Iowa DNR regarding the current herd reduction programs and traffic safety in these areas over time are summarized as follows:

Data collection: The lack of accurate and consistent reporting of deer carcass removals and deer-vehicle crashes as well as the absence of deer population counts for some zones in some years of the study period are important limitations of these data. In addition, deer carcasses are mainly collected on primary roadways, and very little carcass data are reported on the secondary roadways in Iowa. Not considering the secondary roadway system leaves many deer-vehicle crashes unaccounted for. It is desirable to improve the consistency and accuracy of deer carcass and deer-vehicle collision data collection methods and practices. Providing maintenance crews with global positioning system (GPS) units to record the location of deer carcasses could improve the accuracy of carcass reporting.

Countermeasures: The literature review showed that different countermeasures have been implemented over time to reduce the occurrence of deer-vehicle crashes. Many countermeasures, such as deer whistles and deer flagging models, have been proven ineffective. A few countermeasures, such as wildlife crossings and deer fencing, have been proven effective (but at a higher cost), while some countermeasures (including herd management) require more research to evaluate their effectiveness. The implementation of countermeasures should be considered in terms of effectiveness, level of investment, and maintenance costs. Countermeasure locations are critical to their effectiveness. These countermeasures must also be maintained properly to sustain their effectiveness. Moreover, continuous monitoring can detect changes in the effectiveness of countermeasures due to changes in driver behavior or animal adaptation. Last, findings should be properly documented for future reference.

Urban Planning and Management Implications: Results from this study illustrated the impact of urban development on deer habitat and densities and, subsequently, on deer-vehicle crashes. Urban planners and officials need to account for these interactions early during urban planning efforts, determine how to minimize impacts to wildlife during planning, and monitor future trends.

The effectiveness of special herd management hunts in urban areas cannot be fully assessed based solely on their effect on traffic safety. In order for an accurate assessment to be made, reductions in property and crop damage are other important measures of effectiveness that need to be taken into account. This could be achieved though a comprehensive, multidisciplinary study on all measures of effectiveness.

1. INTRODUCTION

1.1 Problem Statement and Background Summary

In the United States, 1.5 million deer-vehicle crashes occur every year that result in 150 fatalities and cost $1.1 billion (Hedlund et al. 2003). According to a study conducted by State Farm Insurance (2009), the nationwide average insurance claim for a deer-vehicle crash is $3,050. Specifically, Iowa has been placed among the top five states where drivers are most likely to be involved in a deer-vehicle crash (probability of 1 in 104) (State Farm Insurance 2009). In 2008, deer-vehicle crashes in Iowa accounted for approximately 12% of all the crashes that occurred and resulted in 9 fatalities and 451 injuries. During the period 2000–2007, the number of fatalities in deer-vehicle collisions in Iowa increased from 1 to 12 (Iowa Department of Transportation 2008). Further, there has been an increasing problem with crashes occurring in urban settings for reasons such as an increase in the vehicle miles traveled, a higher deer population, and human migration into deer habitats.

Different countermeasures with varied degrees of success have been implemented over time to reduce the number of deer-related vehicle crashes (Knapp 2005). These methods include driver-focused measures (driver education, deer warning signs, in-vehicle technologies, and speed limit reduction), animal-focused measures (herd reduction/hunting, vegetation management, deicing slat alternatives, intercept feeding, repellants, exclusionary fencing, wildlife crossings, deer flagging models, deer whistles, and reflectors), and driver- and animal-focused measures (roadway lighting and long-term roadway management).

One common thread in the effectiveness of the aforementioned measures is a controlled and manageable herd size. Many states are striving to keep their deer population to a sustainable and controllable level while maximizing public safety. In Iowa, deer population management and hunting regulations are handled by the Iowa Department of Natural Resources (Iowa DNR). According to the Iowa DNR (2006), the deer population grows 20 to 40 percent each year if no action is taken. The Iowa DNR conducts aerial surveys each year in order to obtain deer counts and estimate the deer population. Quotas are set for female deer, or does, which historically have not been harvested in great numbers without an incentive. The Iowa DNR may set a quota for antlerless licenses in specific counties where the population is not at a controllable level. In addition to the regular deer seasons with gun, muzzleloader, and bow, the state holds many special hunts for various groups, such as youth, disabled, residents, and nonresidents. These hunts are held in certain target areas to reduce the deer population to a sustainable level.

In addition, Iowa DNR designates special deer population management zones around cities to manage the deer population within the cities' boundaries as a countermeasure to property damage and deer-vehicle crashes. These areas can set their own criteria for how many deer per square mile is acceptable for the area and, further, decide the zones where hunting will be acceptable. These zones are restricted to the killing of antlerless deer and are limited to a season that falls between September 1 and February 28. Baiting the deer may be allowed in some cases, but not during regular deer hunts. In order to participate, the hunters in these zones generally have to be either professional or pass a proficiency test in the weapon being used. To assess the success of these hunts, aerial counts are conducted annually.

While the localized deer management plans may reduce the deer population in an area, traffic safety (measured as the number of deer-vehicle crashes) in the areas where they are implemented has not been fully assessed. Thus, there is a need for a focused study on urban hunting and deer-vehicle crashes. The ability to understand special deer hunts is critical for maintaining a sustainable deer population in the state while maximizing public safety.

The following section discusses the major research objectives to be accomplished and the anticipated benefits of the study.

1.2 Research Objectives and Tasks

The main objective of this study is to investigate the relationship between deer-vehicle collisions, deer density, and land use in select urban deer management zones in Iowa over the period 2002–2007. Results from this study can assist in a better assessment of traffic safety in urban deer herd management zones.

This research project included the following tasks:

Task 1: Selection of a Technical Advisory Committee (TAC) for the project.

TAC members were identified in consultation with representatives from the Iowa Department of Transportation (Iowa DOT) Office of Traffic and Safety and the Iowa DNR. A meeting of the TAC was convened every quarter of the project.

Task 2: Literature Review

The past research in the area of deer-vehicle crashes was critically reviewed and synthesized. Two major areas were examined. The first area included studies on the effectiveness of countermeasures that have been undertaken to reduce the number of deer-vehicle crashes that occur. In the second area, data collection and analysis techniques were discussed. This review included different techniques of collecting crash and carcass data, different techniques of finding high-crash areas or hot spots, techniques of comparing carcass and crash data, and injury analysis.

Task 3: Selection of Study Sites and Data Collection

The special deer management hunt sites in Iowa's urban areas for the focused study were identified in consultation with the TAC members. Three different databases were used in this study: first, deer population counts from 1997 to 2008 were acquired from the Iowa DNR; second, deer carcass removal locations and corresponding carcass counts were provided by the

Iowa DOT; and third, deer-vehicle crash data from 2002 to 2007 were gathered from the Iowa DOT.

Task 4: Descriptive Data Analysis

A descriptive data analysis was conducted to quantify the trends (increasing or decreasing) in deer population, deer-vehicle crashes, and the number of deer killed on Iowa's highways (deer carcasses) during the analysis period. In addition, the research team examined the magnitude of the problem of deer-vehicle collision underreporting by examining the Iowa DOT deer-vehicle crash data and carcass reports.

Task 5: Statistical Data Analysis

The authors conducted statistical tests to examine if rises and falls in deer population (as a result of deer hunts) are statistically related to rises and falls in deer-vehicle crashes. In addition, the authors estimated count data models to investigate additional factors (besides deer population) that influence the frequency of deer-vehicle crashes in deer management zones and the frequency of injuries in deer-vehicle collisions. Last, the authors estimated a binary probit model for crash severity outcomes (no injury and injury) as a function of crash, road, and land use characteristics. The results of this analysis can enhance understanding of the factors that affect the frequency of deer-vehicle crashes and corresponding severity outcomes.

Task 6: Conclusions and Recommendations

Based on the work conducted for the previous tasks, the research team made recommendations to the Iowa DOT and the Iowa DNR regarding the current herd reduction programs and traffic safety in these areas over time. Needs for additional research were identified as well.

1.3 Report Organization

Table 1.1 lists the tasks and corresponding chapters.

Table 1.1. Tasks and corresponding chapters

Task	Corresponding Chapter
1. Selection of TAC	1. Introduction
2. Literature Review	2. Literature Review
3. Data Collection	3. Data Collection
4. Descriptive Data Analysis	4. Descriptive Data Analysis
5. Statistical Data Analysis	5. Statistical Data Analysis
6. Conclusions and Recommendations	6. Conclusions and Recommendations

2. LITERATURE REVIEW

2.1 Overview

In this chapter, the past research in the area of deer-vehicle crashes is critically reviewed and synthesized. Two major areas of deer-vehicle interaction are examined. The first area includes studies on countermeasures that have been implemented to reduce the number of deer-vehicle crashes that occur. These studies have evaluated the effectiveness of these countermeasures and identified future research needs. The second area includes studies on improving data collection and analysis techniques. Different techniques of collecting crash and carcass data and comparing these data are presented. The review concludes with a discussion of different methods and tools for identifying high-crash areas or hot spots and for analyzing injuries.

2.2 Countermeasures

2.2.1 Categories

Various countermeasures have been implemented in order to reduce the growing number of deer-vehicle crashes throughout the world. These countermeasures have been applied to varying degrees of success. Following Knapp et al. (2004), deer-vehicle countermeasures can be grouped into three categories: (1) driver-focused, (2) animal-focused, and (3) driver- and animal-focused measures. This section discusses the different types of countermeasures, while Section 2.2.2 presents the findings of evaluation studies on the effectiveness of different countermeasures.

2.2.1.1 Driver-Focused Countermeasures

Some deer-vehicle crash countermeasures are targeted at drivers only. Driver education and public service campaigns are examples of driver-focused countermeasures. For example, the Iowa DOT issues newsletters that advise drivers of what they should do in case they encounter a deer or other animal on the roadway (Iowa Department of Transportation 2009). Similar advice is offered by the Iowa Department of Public Safety (2006) through the “Don’t Veer for Deer” campaign, whose main advice is to not to swerve if hitting a deer is imminent because hitting the deer head on is normally safer than swerving off the road or into oncoming traffic. The effectiveness of these campaigns depends on drivers’ perceived risk of a deer-vehicle collision and change in their driving behavior as a result of the information they receive.

The second countermeasure in this category is deer warning signs. These signs are common on many roads throughout the country. However, limited research has been conducted to evaluate the effectiveness of the regular sign in reducing crashes (Knapp 2004). Possible enhancements to the existing deer warning signs have been proposed. Adding temporary signs could be more effective in areas with migratory deer species; however, in Iowa, the white-tailed deer is the only species present. Since the white-tailed deer is not migratory species, this countermeasure may not be effective. Dynamic warning signs, where a beacon would turn on when an animal triggers a sensor, are a promising technology. However, these systems are expensive, and there are limited studies that have quantified the safety benefits of these systems that would enable a benefit-cost analysis.

The third countermeasure in this group is in-vehicle technologies. These technologies include night vision systems that enable a driver to see an animal on the road much sooner than with traditional headlights. However, these technologies are quite expensive and are only available on high-end vehicles, meaning that their effectiveness cannot be evaluated on a large-scale.

The final countermeasure in this group is speed limit reduction. This countermeasure is based on the concept that drivers who are traveling slower have more time to react to hazardous situations that may arise while driving. However, the effectiveness of a speed limit reduction measure is debatable. It is widely accepted that most drivers drive at a speed that they feel is reasonable and prudent for given conditions, which is the reason for using 85th percentile speed as the baseline for setting speed limits. However, drivers will not usually follow a speed limit they feel is unjustly set too low, as shown with the nationwide implementation of a 55 mph speed limit in the United States from 1973 to 1995. If this option is to be pursued, it has to be coupled with enforcement and public education campaigns that would explain the reasoning for implementing this measure.

2.2.1.2 Animal-Focused Countermeasures

A different set of countermeasures targets the deer population. Herd reduction is one such measure that is implemented mainly through deer hunting. A controllable deer population seems to be a common factor in most approaches for deer-vehicle crash reduction. While this correlation has been generally acknowledged on the large scale, to date, this correlation has not been fully examined to see if it holds true in a smaller area. A recent study (DeNicola and Williams 2008) examined the use of sharpshooting as a herd reduction measure and its effect on deer-vehicle collisions. Three sites were investigated: Iowa City, Iowa, from 2000 to 2002; Princeton, New Jersey, from 2001 to 2006; and Solon, Ohio, from 2005 to 2006. The annual number of deer-vehicle crashes decreased by 49% to 78% in the three study sites. It was also found that numbers did not rebound. While the study found sharpshooting to be an effective method of herd reduction in suburban areas, the study cautioned that sharpshooting can be a costly measure and, as such, the benefit/cost ratio needs to be estimated in order to establish its cost-effectiveness.

Vegetation management addresses one of the reasons that deer travel near the roadway—deer are looking for an easy, convenient food source. There are numerous guides available that explain which plants are more likely to attract deer to an area. Deer are also attracted to sources of salt, such as deicing agents used on the roads in the winter in colder climates. Deicing salt alternatives have been proposed as a possible countermeasure. While these measures have some merit, their effectiveness on a large scale is yet to be studied. Another countermeasure in this area is intercept feeding. This measure aims to keep deer from crossing the road to find food. A major drawback of this technique is that it can make the deer reliant on the feeding for a food source and could draw more deer to an area than those that are already present. In addition, there is the danger of chronic wasting disease (CWD). This disease is similar to mad cow disease and is spread by contact between deer. The disease has led states to ban feeding, such as the bordering state of Wisconsin where CWD has been found in the deer herd in the southwest part of the state. The proximity of CWD to Iowa can mean that this option might not be available in a bid to preserve the entire deer herd in Iowa. Another option for reducing the number of deer in a certain area is repellants. This measure involves applying a substance, normally a predator's urine, to make the deer move away from that area. However, when tested on the large scale, the results have been conflicting. Furthermore, there is no evidence that these measures keep deer from crossing the road.

Another measure in this category is exclusionary fencing. This involves putting up a fence around a roadway to keep the deer from attempting to cross it. These have been found to be effective in numerous studies; however, the cost can be very prohibitive, especially if fencing is installed along long stretches of road. Also, if fences are installed improperly, deer can become trapped inside the fence. Most studies rely on carcass count before and after, and the results cannot be easily transferred between test sites. However, these could be effective if used with other countermeasures, such as wildlife crossings. Wildlife crossings involve constructing either an overpass or underpass for animals, such as deer, to safely cross a roadway. These crossings have been found to be effective in numerous studies, but the cost can be very prohibitive. These projects rival many transportation projects in cost and can be perceived as a poor use of construction dollars. However, if these projects are well planned, the costs can be compensated with additional benefits from crash reduction.

Deer flagging models, deer whistles, and reflectors are three other countermeasures that target deer. A deer flagging model consists of a model of a white-tailed deer with the tail up, which is a signal deer use for danger. Deer whistles are installed on a car in hopes of making a noise audible to deer that will scare them away from the car. However, it is questionable if the sound they produce can be heard by deer. Also, drivers may fall into a false sense of security after installing these on their car and may compensate for it by driving more aggressively. The purpose of reflectors is to reflect a car's headlights to "freeze the deer in the headlights" off of the road. Reflectors have been installed in many places (such as Iowa City), but results of effectiveness have been conflicting. Multiple studies will be necessary in order to validate results.

2.2.1.3 Driver and Animal-Focused Countermeasures

There are a few countermeasures that target both drivers and the deer population. Roadway lighting attempts to change deer crossing patterns and vehicle speeds. There has only been one study done in this area (Reed et al. 1977, as cited in Knapp 2005), which did not find any reductions in vehicle speed but found a reduction in crashes. However, one study cannot provide a precedent; more research is needed to validate the results. The other countermeasure in this area is roadway maintenance, design, and planning procedures. The effectiveness of this countermeasure has not yet been fully examined. However, as we move into the future, engineers and planners should evaluate the effects that certain construction or maintenance practices can have on the surrounding environment and wildlife.

2.2.2 Studies on the Effectiveness of Countermeasures

The Insurance Institute for Highway Safety (Hedlund et al. 2003) discussed the effectiveness of various countermeasures that have been implemented. The report concluded that the effectiveness of fencing coupled with an overpass crossing has been scientifically proven. Some other measures that are promising but that need more data to fully evaluate their effectiveness are herd reduction, roadside clearing, temporary signage, at-grade crossings (for migratory deer), and infrared driver vision. Countermeasures with limited effectiveness are reflectors, roadside lighting, intercept feeding, and deer repellants. Based on available evidence, countermeasures that appear ineffective are education, passive signage, and speed limit reduction. Finally, methods that have not been claimed effective in scientific research are deer whistles and deer flagging.

A study (DeNicola et al. 2000) on urbanization and its effect on deer population was conducted throughout the United States. This study examined the effectiveness of many lethal and non-lethal countermeasures to combat the deer population problem, including deer-vehicle crashes. General effects rather than statistically proven effects of these countermeasures are reported. The authors concluded that deer population can be controlled with either lethal (hunts primarily) or non-lethal (trap and release deer elsewhere) management methods, and added that lethal methods (if administered properly) can provide better control than just moving the deer population elsewhere.

Danielson and Hubbard (1998) studied some countermeasures that can be used against deer-vehicle crashes in Iowa and explained the impacts of crashes on the economy of Iowa. It was concluded that fences were the best countermeasure to reducing crashes if they are properly maintained. It is also stated that overpasses could work well with fencing on high-speed facilities. The authors also identified driver education as an essential part of the solution to this growing problem.

Huijser and McGowen (2003) reviewed dynamic warning systems in North America and Europe. Numerous systems that were already in place at the time or that were planned for the future were evaluated. It was found that more research had to be done on these systems to prove their effectiveness. A follow-up study (Huijser et al. 2009a) on the effectiveness of dynamic warning systems was conducted on a roadway in Yellowstone National Park in Montana to examine if dynamic warning signs could detect elk more accurately and could be attached to the system. Small speed reductions were found as a result of these systems, but even a small reduction in speed can reduce the severity of a crash. These signs were also generally accepted by the public. However, Yellowstone National Park required the removal of the system at the end of the study, and it was not possible to collect addition data on the signs' effectiveness.

The effectiveness of different detection systems was evaluated in a pen using horses and llamas (Huijser et al. 2009b). Reliability standards were established using input from the stakeholder groups of employees of transportation agencies, employees of natural resource agencies, and the traveling public. It was found that direct comparison cannot be conducted due to the different ways of detecting large animals and diverse environmental conditions. While "false positives" were not an issue, "false negatives" were a problem for some systems. When comparing the systems to the reliability standards that were established, five of the nine systems met the standards. The author pointed out the integration of these systems with intelligent transportation systems (ITS) as an area for future work.

When the current federal highway authorization bill SAFETEA-LU was passed in 2005, a provision was included to conduct a national study on wildlife-vehicle crashes (Huijser et al. 2007a). It was found that about 5% of all crashes were animal-related. It was also found that while fatalities are low, the economic cost of these crashes is estimated to be \$8.4 billion per year. Turning to countermeasures, fences were found to be 80% to 99% effective, while wildlife crossings were almost 100% effective but at a higher cost. This study also outlined the need for better roadway planning to mitigate potential wildlife-vehicle crashes.

W. Brown et al. (2000) conducted a study in Alberta, Canada, on the use of repellants in road salt to prevent caribou from using it for a salt lick. The products were tested on 14 caribou during a five-day period. One repellant, Wolfin, was not effective at all. The second, Deer Away Big Game Repellent, was effective at first but, as the study moved on, the effectiveness tapered off. The third one, lithium chloride, was found to be effective. However, it was noted that lithium chloride could potentially be toxic to smaller animals, so further tests need to be carried out in order to evaluate the potential environmental impacts.

A study was conducted to investigate the future of hunting as a deer management program (T. Brown et al. 2000). At the time, the recreational hunt was being evaluated in terms of its effectiveness to control the white-tailed deer population. The authors argued that recreational hunting alone would not work because of a decrease in hunting and human intrusion into the deer habitat. It was suggested that while hunting will still be the major measure to control deer population in the near future, a combination of recreational deer hunting and other techniques, such as sharpshooting or culling, will be needed for good deer population control.

Kilpatrick and Walter (1999) led a study on the effectiveness of urban archery hunts. In the study, hunters in a residential community in Connecticut had to pass a rigorous proficiency test in order to hunt. During the first year of the hunts, the deer population decreased by 50%, no deer-vehicle crashes were recorded, and residents noticed a reduction in property damage caused by deer. In view of these findings, the authors concluded that bow hunts can be an effective tool for controlling urban deer populations.

Different deer population management programs in the Washington D.C. metropolitan area (including Maryland, Virginia, and the District of Columbia) are discussed in a report published by the Metro Washington Council of Governments (Bates et al. 2006). In Fairfax County, the City of Lynchburg, and the Town of Blacksburg in Virginia and Montgomery County in Maryland, the number of deer-vehicle crashes decreased after deer management programs were implemented. However, the authors cautioned that the effectiveness of these programs cannot be evaluated solely on the decreasing trends of deer-vehicle crashes. Scientific proof is needed.

2.3 Other Studies of Interest

2.3.1 Studies on Data Collection Techniques

A study, funded by the National Cooperative Highway Research Program (NCHRP), was conducted in 2007, documenting how data on animal-vehicle collisions was collected across the United States and Canada (Huijser et al. 2007b; Huijser et al. 2007c). To achieve this, the researchers sent out surveys to the states and Canadian provinces to gather information on the methods that were used to collect data on animal-vehicle collisions. It was found that, in most states and provinces, the departments of transportation and/or departments of natural resources (or similar agencies) keep track of these collisions. However, the data collection was found to be managed differently; little emphasis was put on the animal itself (species identification, etc.), and the spatial data were often found to be without specific geographic coordinates. These limitations of the data prohibit further analysis of animal-vehicle collisions. Another concern was that these agencies were collecting data for different reasons and had different methodologies and, for the benefit of both, methodologies and data collection should be done in a more coordinated manner—not just the collection, but the thresholds—and to create a more centralized database.

A study conducted in Virginia documented the need for better carcass data collection (Donaldson and Lafon 2009). In this study, maintenance workers were provided with GPS units to record the locations of deer carcasses. It was found that nine times as many carcasses were recorded compared to the number of deer-vehicle crashes reported to police. The authors recommended a broad implementation of this technology in Virginia and concluded that improving the accuracy of the carcass removal data can be valuable for determining where countermeasures should be implemented.

Knapp et al. (2007) investigated the differences between the deer carcass and deer-vehicle crash data in Iowa during the period 2001–2003. Geographic information systems were used to visualize and spatially compare the data on two selected corridors. Crashes were kept at the milepost assigned, while carcasses were assigned to the nearest milepost. Overall, the number of deer carcasses removed from those corridors was greater than the number of reported deer-vehicle crashes on those corridors. These differences can be attributed to a number of reasons, including variability in data reporting and data collection practices. The authors also developed negative binomial regression models to estimate the frequency of crashes and carcasses as a function of average annual daily traffic (AADT) and other roadway cross-section characteristics. The estimation results were compared, and it was determined that the model based on crash data had a better explanatory value than the model based on carcasses. In addition, the models as a function of AADT and other cross-sectional variables did not have a better statistical fit than the models as a function of AADT only. The authors noted that these models could be modified as appropriate and used in an empirical Bayes approach. Finally, it was concluded that, preferably, both the deer carcass and deer-vehicle crash data should be used to describe the deer-vehicle interaction problem, but caution should be exercised to avoid double counting.

2.3.2 Studies on High-Risk Locations (Hot Spots)

A study, funded by the NCHRP, was conducted to evaluate wildlife crossings (Bissonette and Cramer 2008). A software tool was developed to help agencies select the best locations for wildlife crossings. High-risk locations were identified with the estimation of safety performance functions, which were calibrated on crash data. The authors recommended using GPS units in the field for locating carcasses and using these data for hot spot modeling. In addition, it was concluded that wildlife crossings should be used on locations with high wildlife-vehicle crash rates, but they need to be properly spaced.

A wildlife and domestic animal accident toolkit was developed in Utah (West 2008). A wildlife animal collision hot spot was identified as a location with ten or more crashes in a three-year period, while a domestic animal collision hot spot was identified as one that has three or more such crashes in the three-year period. The author also reviewed previous literature on mitigation measures and their effectiveness and reiterated the importance of planning and designing roadways with animals in mind.

Using data on animal-vehicle collisions from 1986 to 2004, Crooks et al. (2008) identified animal-vehicle collision hot spots in Colorado. The authors used geographic information tools and spatial statistics (the Getis-Ord statistic in ArcMap) to determine the hot spot locations. These statistics were then used to rank sections based on both fatality/injury and property damage only crashes and identify the top 1% and 5% sections for further study.

2.3.3 Studies on Injury Severity

Perrin and Diesgni (2003) analyzed animal-vehicle collision data using the Utah Central Accident Record System and found that 7% of wild animal and 23% of domestic animal-vehicle crashes result in injury or fatality. This difference was attributed to the size of the animals. In addition, it was found that crashes involving motorcycles are much more likely to result in injury.

A study on deer-vehicle crash injury severity was conducted in Michigan (Savolainen and Ghosh 2008). The study estimated a multinomial logit model to determine the factors that contribute to injury severity in single-vehicle deer-vehicle crashes. It was found that younger drivers and females were more likely to experience injuries in a deer-vehicle crash. The presence of passengers in the vehicle increased the likelihood of an injury. Seat belts and air bags reduced the likelihood of severe injuries, but air bags increased the likelihood of minor injuries. One of the main findings of the study was that head-on collisions with deer significantly decreased the probability of moderate or severe injuries. The authors emphasized the need for additional research to confirm their study findings.

2.4 Summary/Conclusions

This chapter summarized the previous work in the area of animal-vehicle crashes, which included countermeasures and studies on their effectiveness, data collection, hot spot identification, and injury severity analysis. Many countermeasures, such as deer whistles and deer flagging models, have been proven ineffective; a few countermeasures, such as wildlife crossings and deer fencing, have been proven effective, but some countermeasures (including herd management) require more research to evaluate their effectiveness.

In addition, many studies have been conducted on data collection techniques and modeling. Many of these studies have led to the improvement of the data that is collected in the field, which can in turn lead to more accurate identification of problem areas and countermeasure effectiveness evaluation.

Past studies have also provided valuable insights into appropriate modeling techniques to describe the magnitude and severity of the deer-vehicle interaction problem. Although many studies have been conducted on the aftermath of deer management programs, very few have analyzed scientific data to support claims of success. Most of these studies found a reduction in crashes, but it was not determined whether this was statistically correlated to the action taken or whether it was due to the random nature of deer-vehicle crashes. In addition, very few of these studies have focused on deer management programs in urban areas, which represent areas of increasing problems and are in need of additional research to evaluate if the countermeasure is effective. With this past work in mind, this study will examine the relationship between deer density, land use, and deer-vehicle crashes in urban deer management areas in Iowa.

3. DATA COLLECTION

3.1 Selected Urban Areas with Special Deer Herd Management Plans

In consultation with the Iowa DNR, three urban areas in Iowa that have a deer management plan in place that includes hunting were selected for this study. The sites were selected based on the availability of deer population counts in a particular city so that the number of crashes could be compared to the population.

The first city is the City of Dubuque, the county seat of Dubuque County. According to the 2000 Census, the city has a population of 57,686 people, and is the eighth largest city in Iowa. The city has 13 designated deer management zones and has been conducting archery hunts since 1997.

The second city selected is Cedar Rapids, the county seat of Linn County. The city has a population of 120,758 people, according to the 2000 Census, and is the second largest city in Iowa. The city has seven designated deer management zones and has been conducting archery hunts since 2005 (deer management plans have been in place since 1996).

The third city is Iowa City, the county seat of Johnson County. According to the 2000 Census, the city has a population of 62,220 people, and is the sixth largest city in Iowa. The city also is the home of the University of Iowa, the largest public university in the state. Iowa City has nine designated deer management zones. The city hires sharpshooters to hunt the deer; the city's sharpshooting program started in 1999.

A table of all cities/counties with deer management plans in place in 2007 is shown in Table 3.1. This table shows whether the city/county has a task force that oversees the management, the initial year it was put into place, the population survey that is conducted, if the program is active, and the type of hunt that takes place.

Table 3.1. Cities in Iowa with deer management plans, 2007

Area	Task Force	Initial Year	Aerial Survey	Active Control	Activity
Amana Colonies	No	2006	Helicopter	Yes	Gun/Bow Hunt
Ames (City)	Yes	2006	Helicopter	Yes	Archery Hunt
Ames (Perimeter)	Yes	2006	Helicopter	Yes	Gun/Bow Hunt
Bettendorf & Riverdale (City)	No	2006	Helicopter	Yes	Archery Hunt
Cedar Rapids (City)	Yes	1996	Helicopter	Yes	Archery Hunt
Clinton (City)	No	2006	Helicopter	Yes	Archery Hunt
Coralville (City)	Yes	1998	Helicopter	Yes	Archery Hunt
Davenport (City)	No	2006	Helicopter	Yes	Archery Hunt
Denison	No	2005	Fixed	Yes	Archery Hunt
Dubuque (City)	Yes	1997	Helicopter	Yes	Archery Hunt
Dubuque (County)	Yes	1997	Helicopter	Yes	Gun/Bow Hunt
Iowa Falls	No	2005	Fixed	Yes	Archery Hunt
Jefferson County Park	No	2007	Helicopter	Yes	Archery Hunt
Johnson County	No	2000	Helicopter	Yes	Gun/Bow Hunt
Jones County Central Park	No	2007	Helicopter	Yes	Archery Hunt
Linn County	Yes	1996, 98	Helicopter	Yes	Gun/Bow Hunt
Muscatine	No	2005	Helicopter	Yes	Archery Hunt
Ottumwa (City)	No	2005	Fixed	Yes	Archery Hunt
Pikes Peak/McGregor (City)	No	2005	Fixed	Yes	Archery Hunt
Polk-Dallas County	Yes	1997, 98	Helicopter	Yes	Gun/Bow Hunt
Scott County Park	No	1995	Fixed	Yes	Firearm Hunt
Waterloo-Cedar Falls (City)	Yes	1994	Helicopter	Yes	Archery Hunt

3.2 Deer Population Data

Information on deer population and land use was obtained from the Iowa DNR. Each city is divided up into management zones. These zones may not include the whole city, while they may include surrounding land. Maps of these zones are shown in Figures 3.1 to 3.4, courtesy of the Iowa DNR.

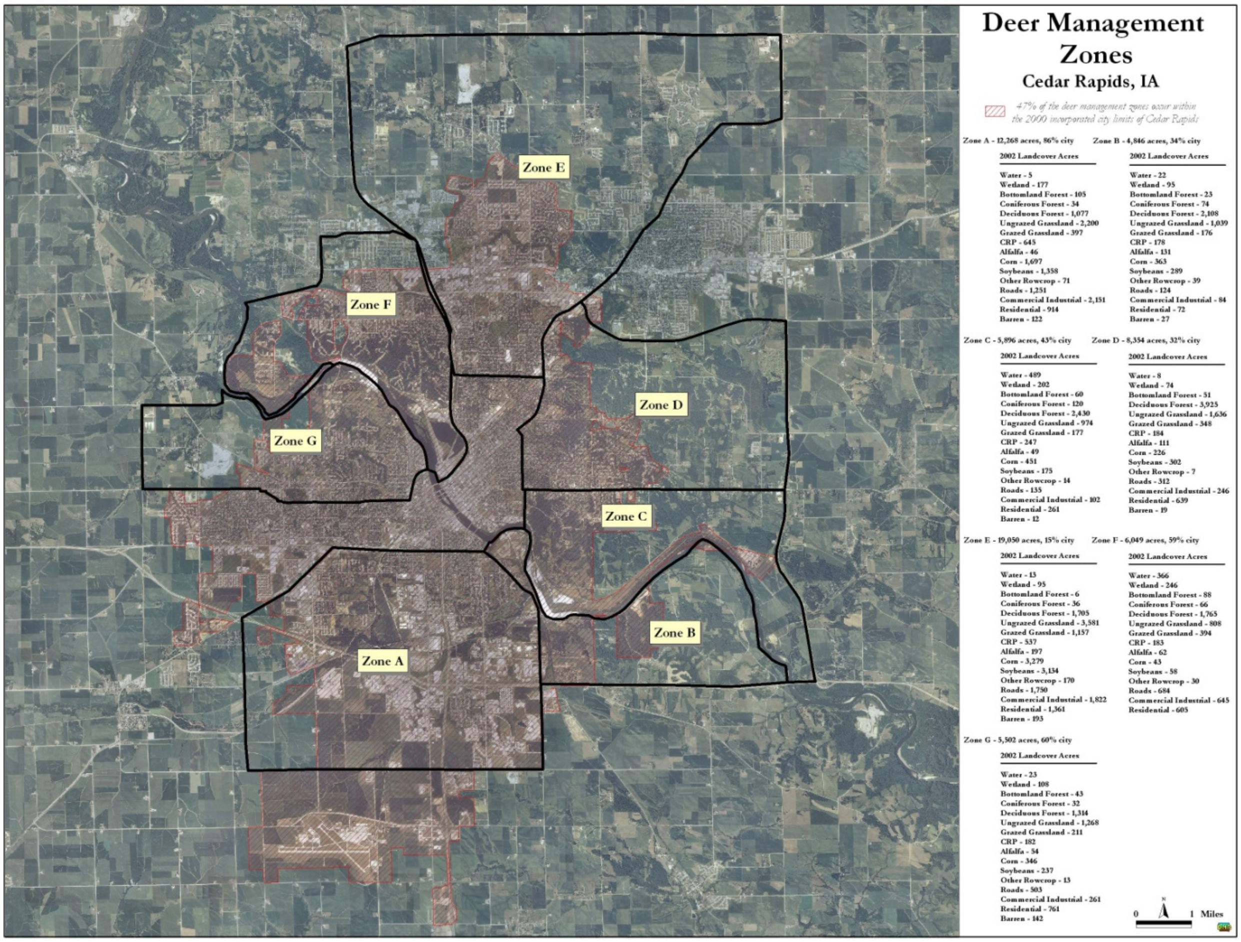

Figure 3.1. Map of Cedar Rapids deer management zones

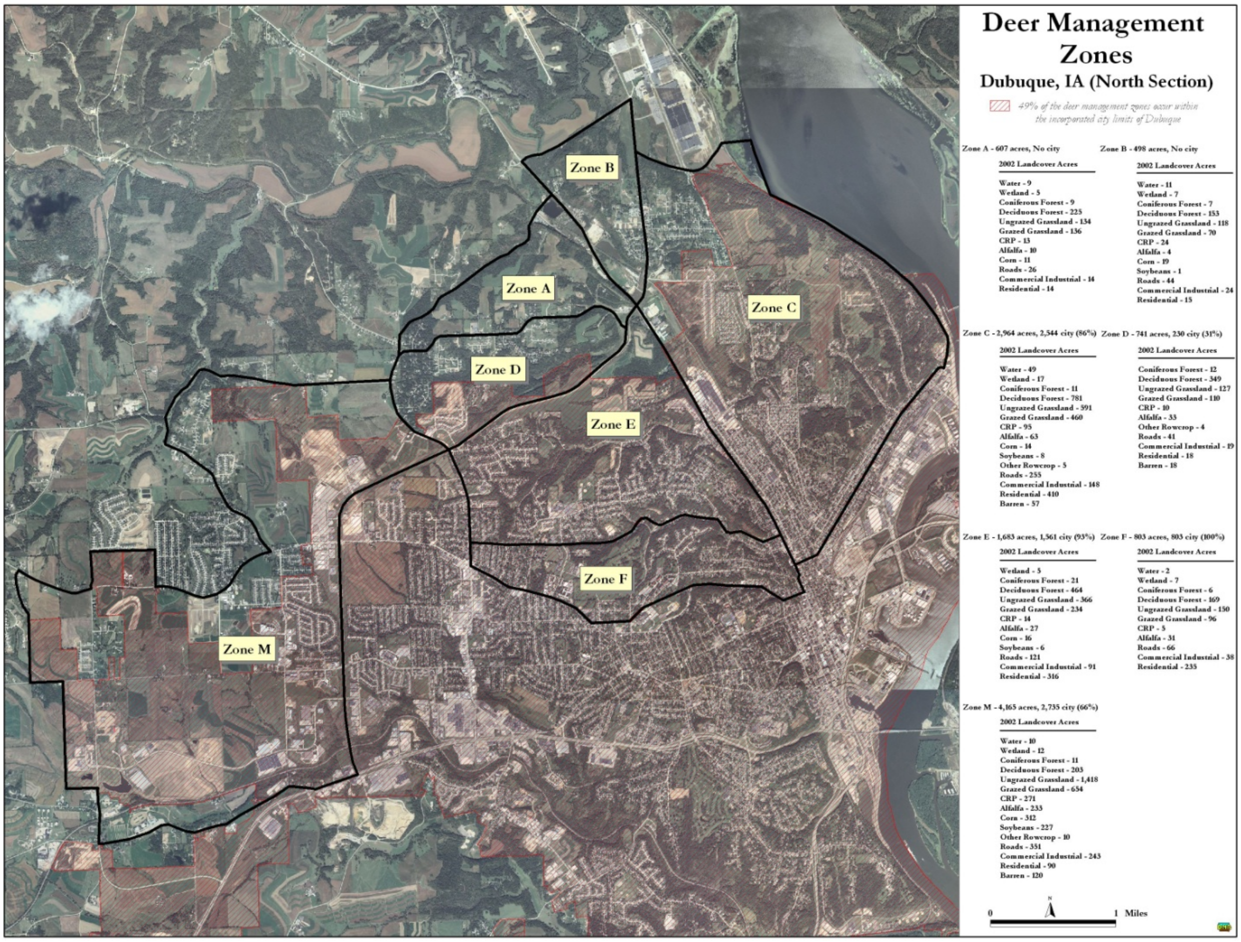

Figure 3.2. Map of Dubuque deer management zones—north section

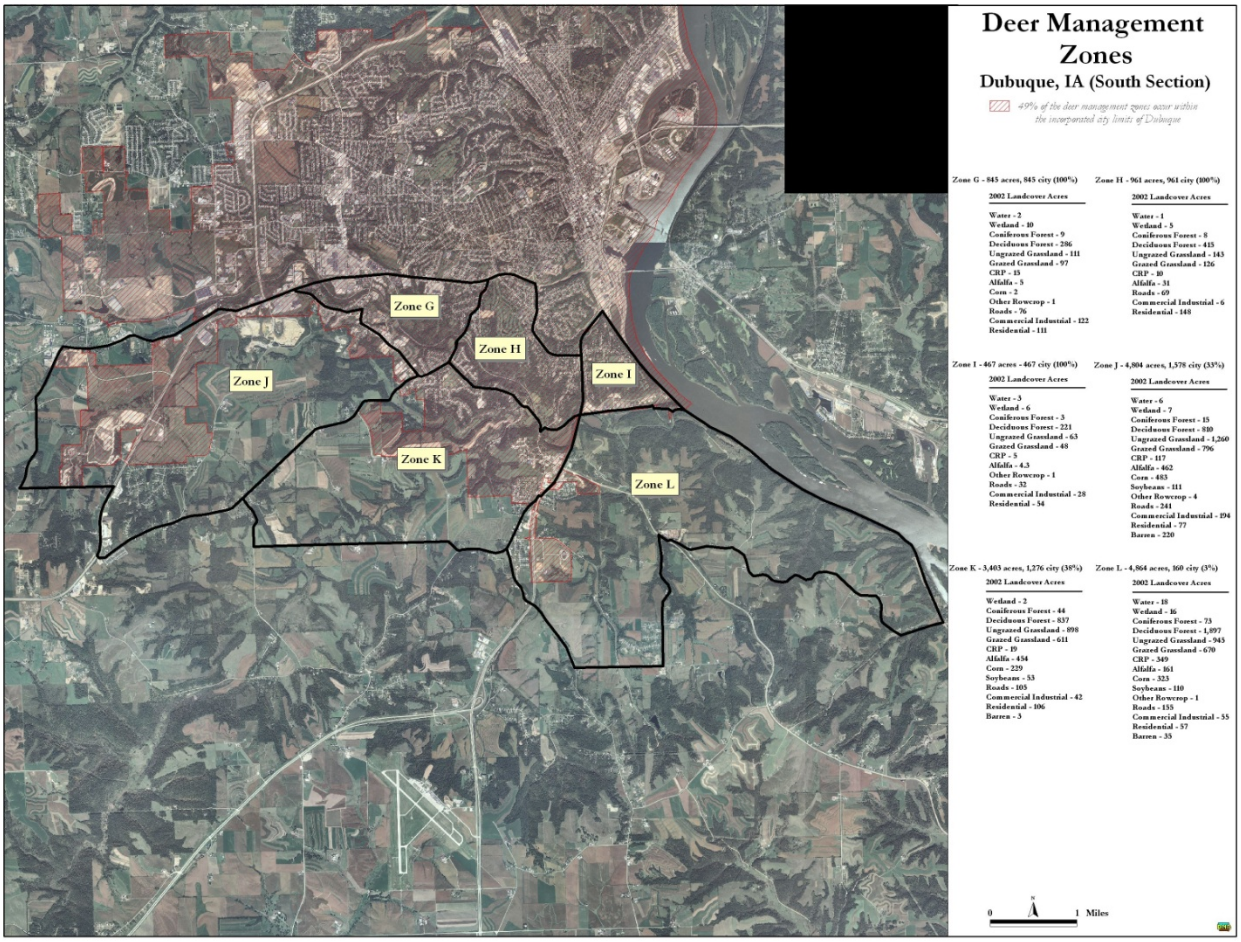

Figure 3.3. Map of Dubuque deer management zones—south section

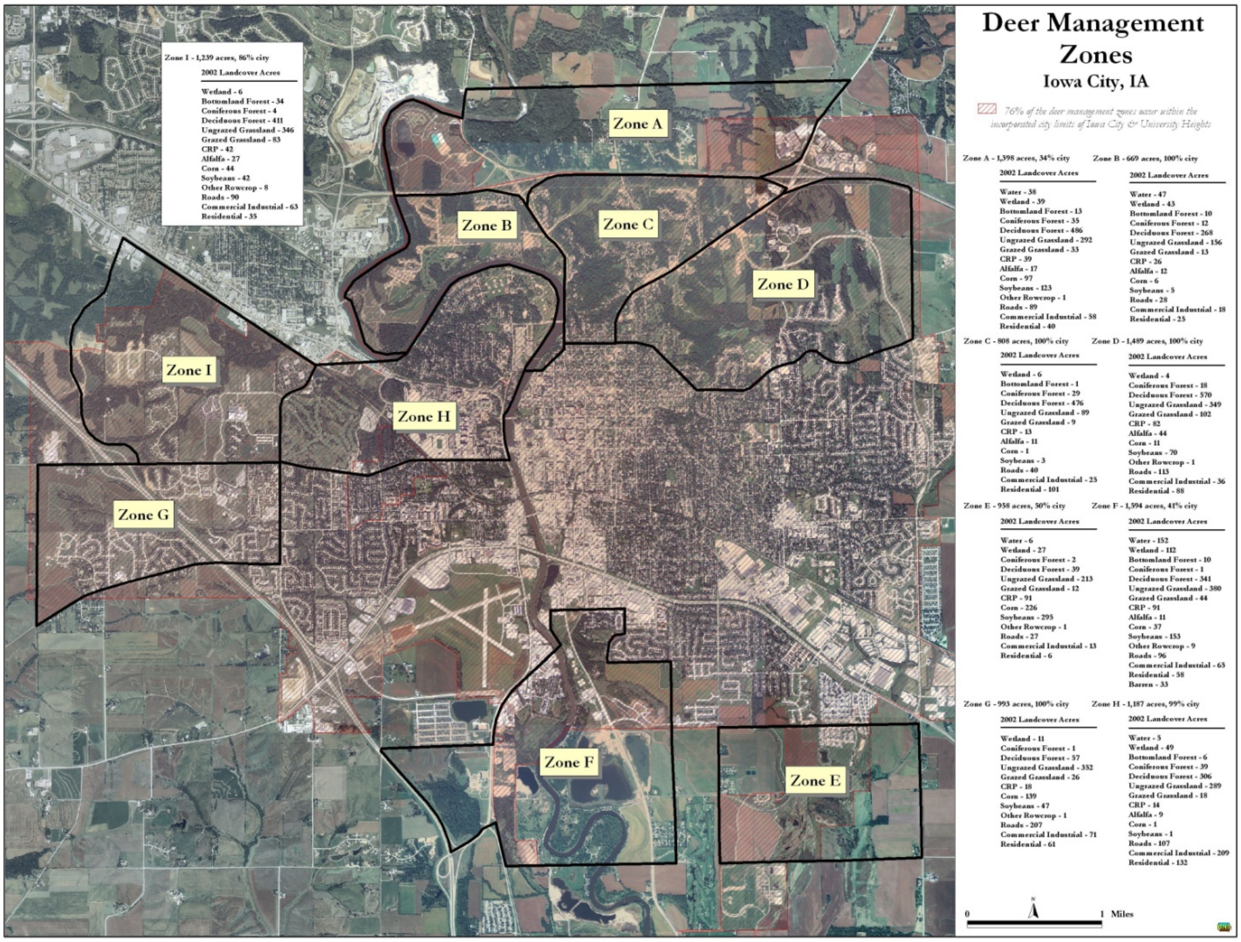

Figure 3.4. Map of Iowa City deer management zones

The deer population within each zone is counted through aerial surveys, which are typically conducted in January or February every year. Note that the accuracy of these counts are affected by the weather, and it may not be possible to conduct a survey each year. For instance, some zones in some survey years in Dubuque had no deer population data counted. There were partial surveys conducted in Cedar Rapids in 2002 and 2005, and there were no surveys in Cedar Rapids in 2001 and 2004 nor in Iowa City in 1998, 2004, and 2006. Figures 3.5 through 3.7 show the deer density in deer per acre per zone in each city. The limit line on each of these graphs corresponds to the limit that the city has set for its “optimal” deer population: 20 deer per square mile in Dubuque, 25 deer per square mile in Iowa City, and 30 deer per square mile in Cedar Rapids. In addition, a weighted average deer density per city was estimated to enable comparison of the three cities. This weighted average is shown in Figure 3.8.

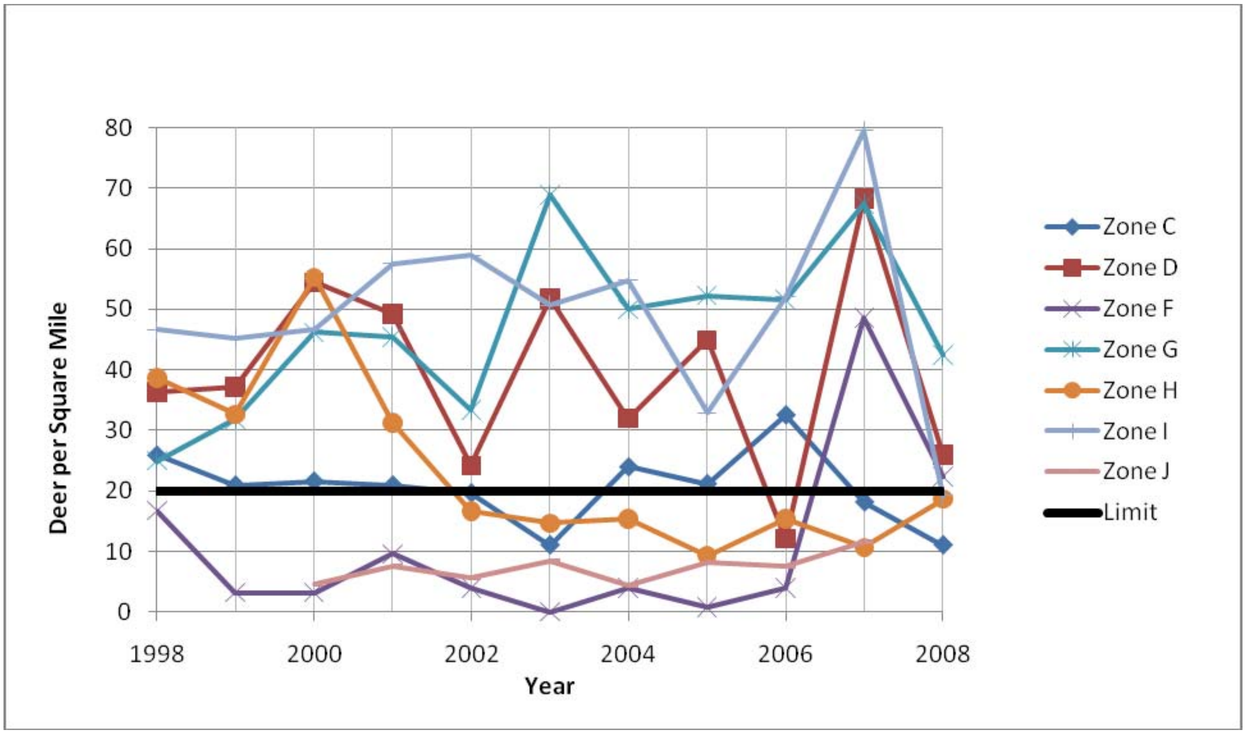

Figure 3.5. Deer density by zone in Dubuque, 1997 to 2008

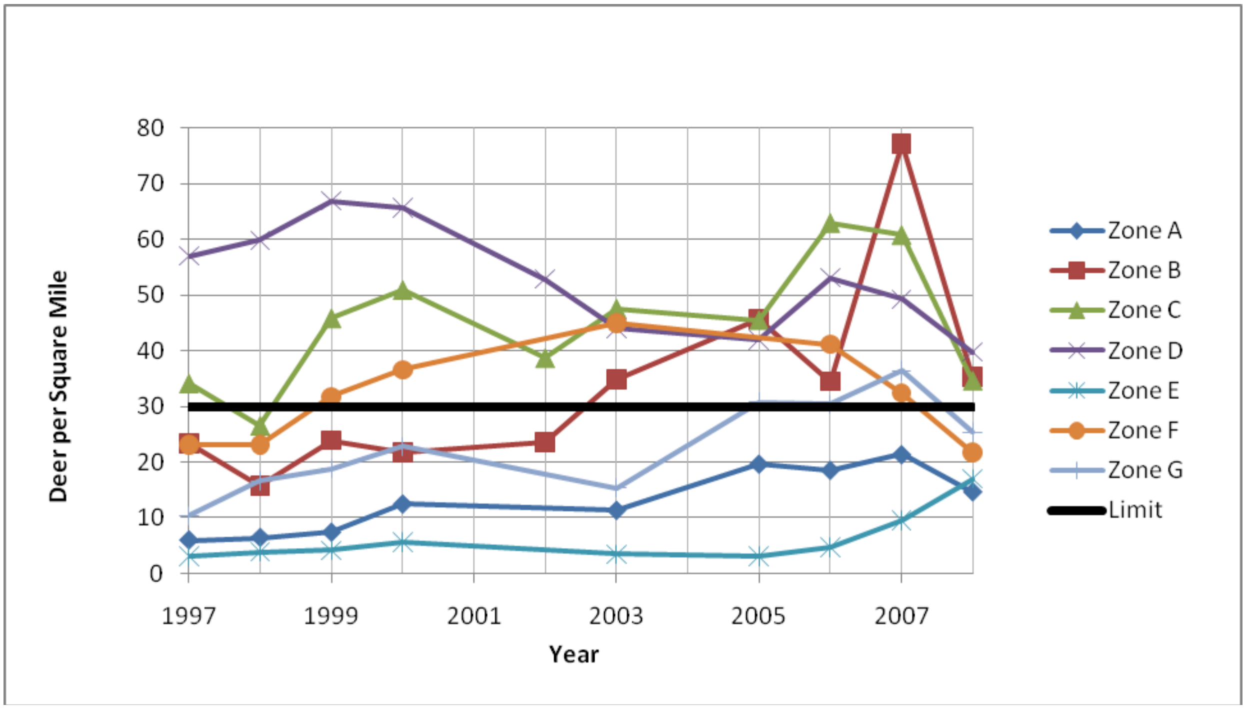

Figure 3.6. Deer density by zone in Cedar Rapids, 1997 to 2008

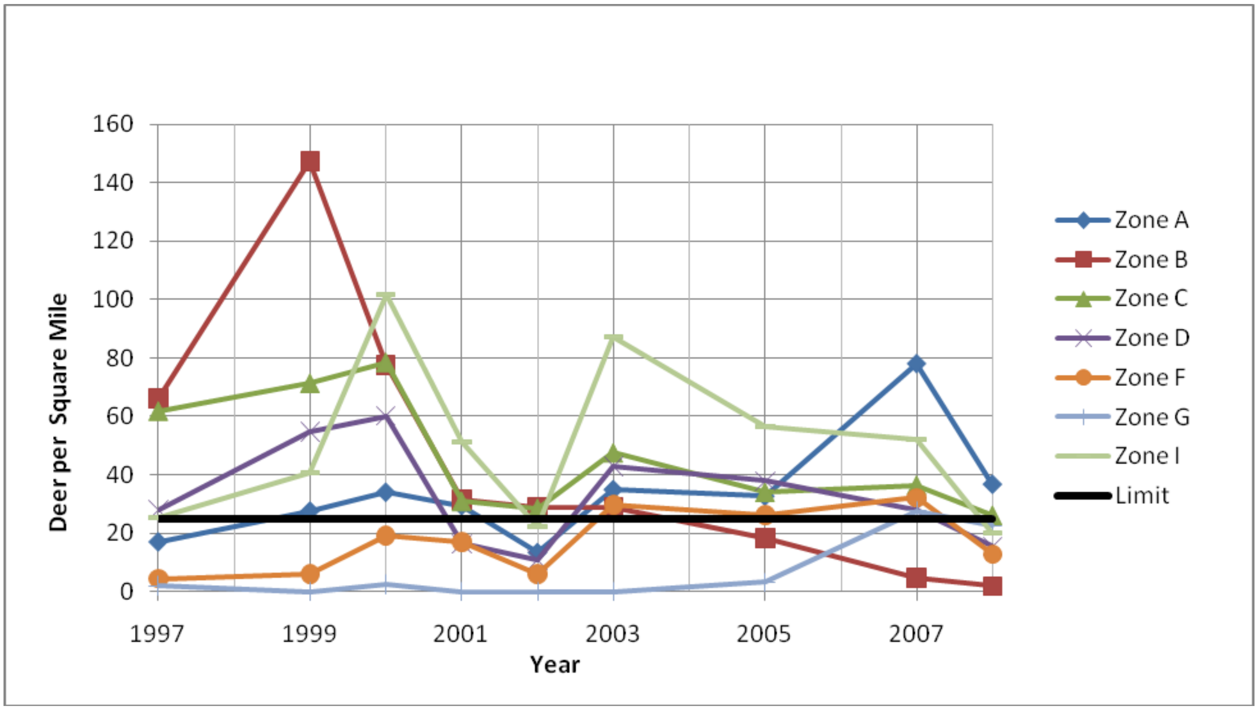

Figure 3.7. Deer density by zone in Iowa City, 1997 to 2008

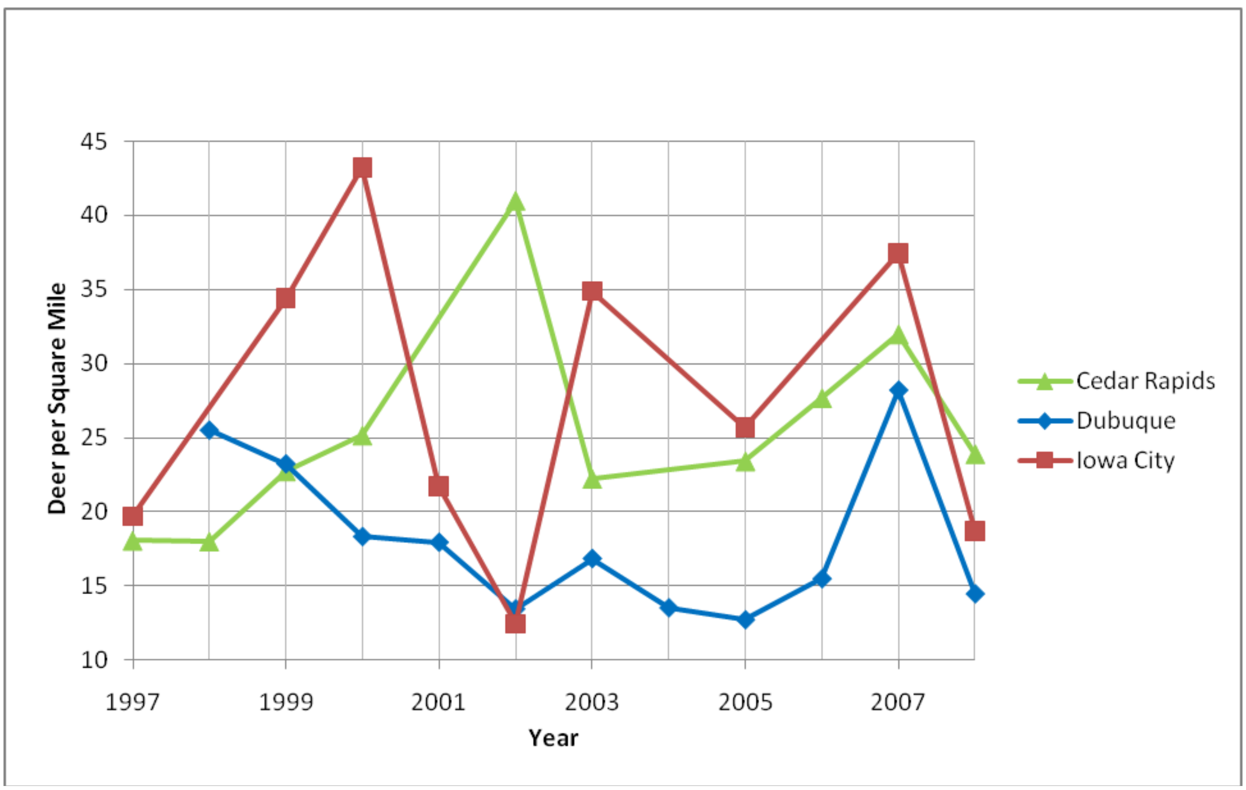

Figure 3.8. Average deer density for Cedar Rapids, Dubuque, and Iowa City, 1997 to 2008

As can be seen, deer population counts in a given zone have fluctuated from year to year due to a number of factors, such as the number of harvested deer, the weather, and the day of the survey. Deer density was above the predetermined limit in all three cities in 2007 but was lower and close to the limit in 2008. The comparison of deer density by city over the analysis period showed that there were no statistically significant differences in deer population and deer density in Dubuque and Iowa City ($p > 0.1$), despite the differences in the type of the deer management program that is administered (archery hunts versus sharpshooting program). However, the differences in deer population and deer density in Cedar Rapids compared to the other two cities were found to be statistically significant ($p < 0.01$) with, on average, higher values observed in Cedar Rapids. This might be also attributed to the year when the hunts started. Hunts in Cedar Rapids resumed in 2005, while Dubuque and Iowa City have been conducting the special deer hunts since 1996 and 1999, respectively.

3.3 Deer Carcass Removal Counts

Deer carcass removal locations and corresponding carcass counts that were picked up from state roadways in a given year by maintenance crews were provided by the Iowa DOT. These records were organized by state route and to the nearest 0.1 milepost. Because the Iowa DOT's linear referencing system currently doesn't support integration of fractional milepost data, the carcass records were assigned to the nearest geo-referenced milepost. The analysis of carcass data was conducted at the county level and only for primary roads because Iowa DOT maintenance personnel do not remove deer carcasses from secondary and local roads. Figure 3.9 shows the carcass counts on primary roads by county during the analysis period.

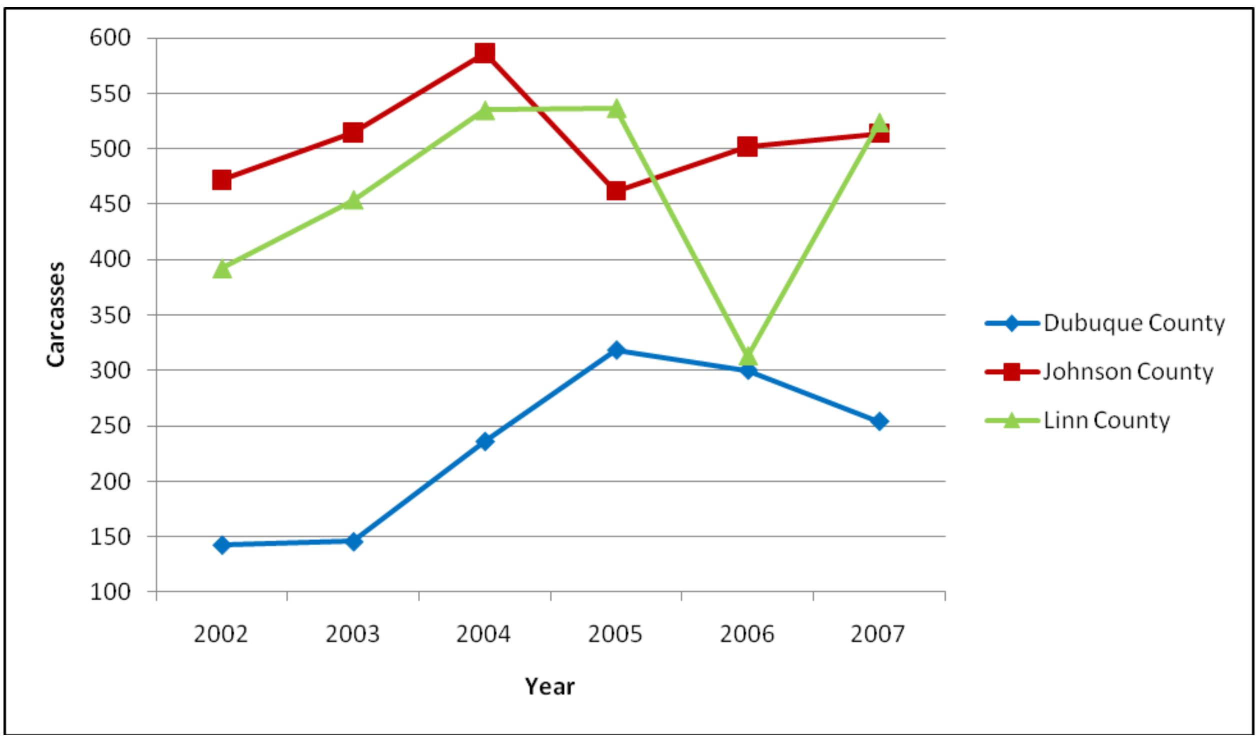

Figure 3.9. Deer carcass removal counts on primary roads by county, 2002 to 2007

On average, deer carcass removals in the three counties have increased since 2002. Interestingly, there was a drop of almost 200 counts in 2006 in Linn County, but this drop could be attributed to a new carcass reporting system that Iowa DOT implemented that year.

3.4 Deer-Vehicle Crash Data

The last piece of information gathered was the crash reports. These data were imported to ArcGIS for the three counties being studied. Any crash that had an animal as the major cause, first harmful event, major harmful event, or in the chain of events was selected from the dataset so that every possible crash involving deer was selected. These crashes are shown in Figures 3.10 through 3.12. These crashes are shown at the county, urban area, and city level.

Information on deer-vehicle crashes from 2002[1] to 2007 was gathered from the Iowa DOT in a GIS format for the three study counties. Any crash that had an animal reported as the major cause, first harmful event, major harmful event, or in the chain of events was included so that every possible crash involving deer would be examined. A total of 4,718 crashes were reported in the three counties from 2002 to 2007, which resulted in 6 fatalities and 649 injuries. The distribution of deer-vehicle crashes for each county over the study period is shown in Figure 3.10. Figures 3.11 and 3.12 show these trends at the urban area and city level.

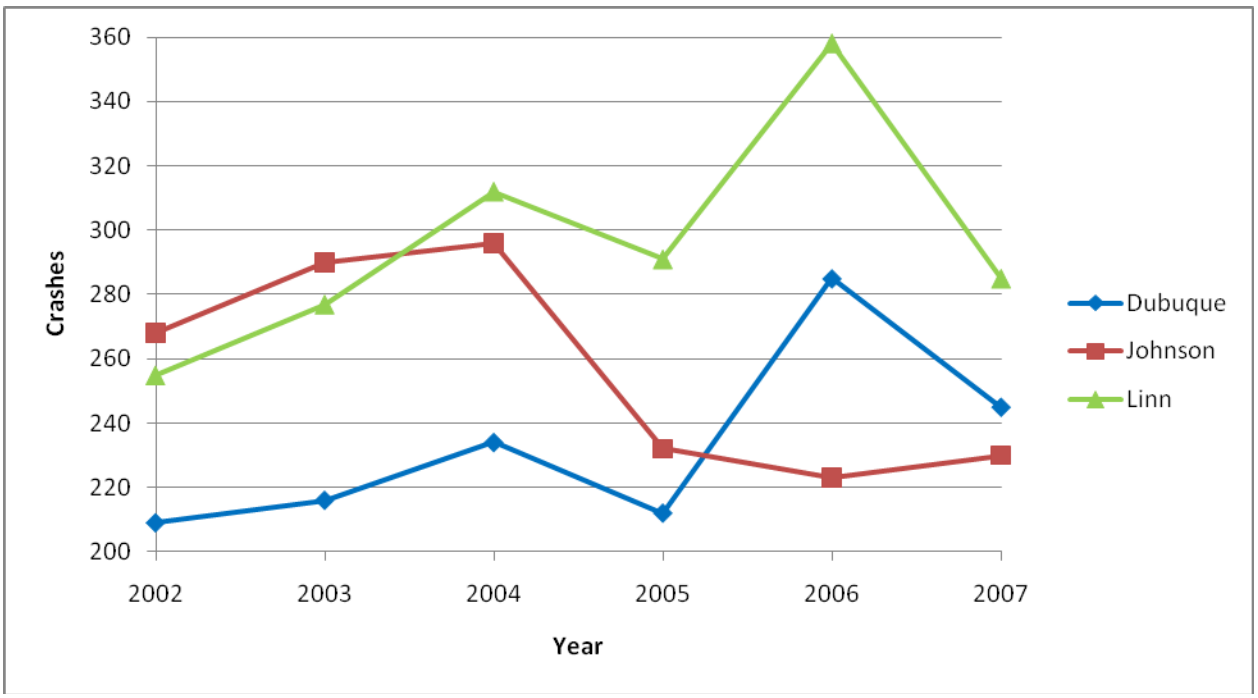

Figure 3.10. Frequency of deer-vehicle crashes by county, 2002 to 2007

[1] The year 2002 was the first full year that a police officer had the option to select animal or object in roadway on the crash reporting form as a cause or factor in the crash.

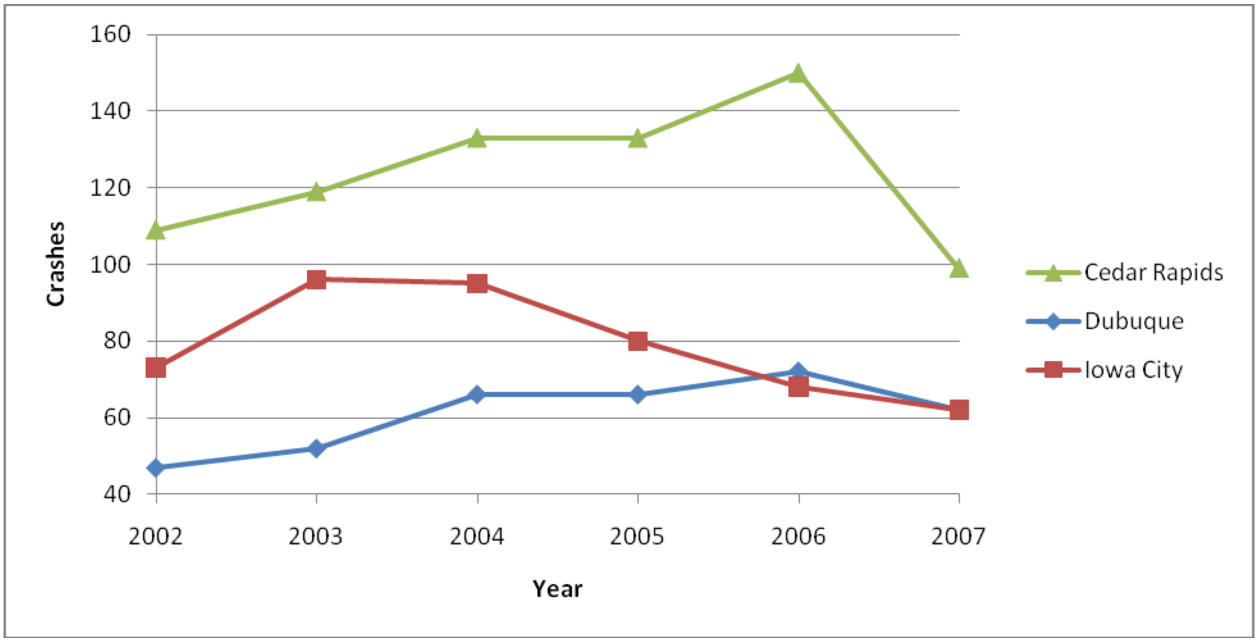

Figure 3.11. Frequency of deer-vehicle crashes by urban area, 2002 to 2007

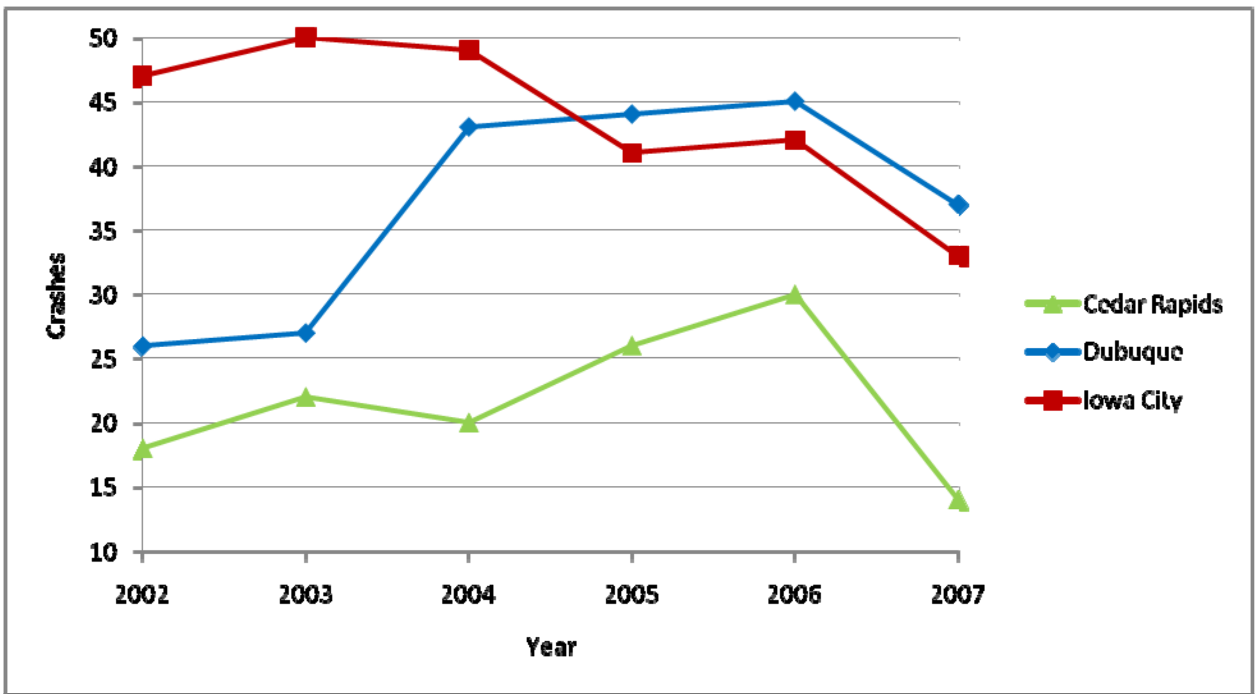

Figure 3.12. Frequency of deer-vehicle crashes by city, 2002 to 2007

As can be observed, the number of crashes occurring in a given area fluctuates from year to year. The distribution of crashes over time follows a similar trend in Dubuque and Linn Counties, while the frequency of crashes has been decreasing in Johnson County.

Interestingly, the number of crashes in Cedar Rapids was significantly lower over the analysis period compared to those in Iowa City and Dubuque ($p<0.001$). This may be attributed to a policy by the Cedar Rapids Police Department (Betz 2009) where police officers are not required to compile crash reports for property damage only crashes. As such, crashes that fall in this category may not be included in the crash database.

Last, it was of interest to examine the frequency of injuries resulting from a deer-vehicle collision. Figure 3.13 shows the total number of injuries in the three study cities and counties during the analysis period 2002 to 2007. The number of injuries as a result of a deer-vehicle collision at both the county and city levels in 2007 was almost six times higher than that in 2002. This issue is further examined with the estimation of a statistical model of the factors that affect the frequency of injuries in deer-vehicle collisions (presented in Chapter 5).

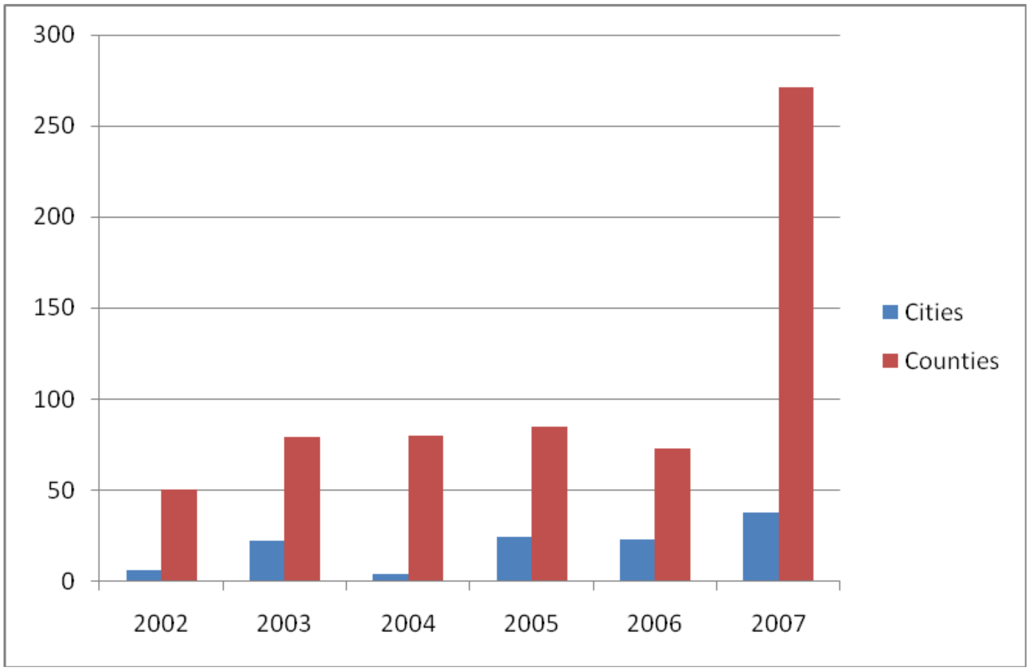

Figure 3.13. Frequency of injuries in deer-vehicle collisions, 2002 to 2007

3.5 Summary/Conclusions

In this chapter, the data on deer population, deer carcasses, and deer-vehicle crashes were summarized and interpreted using graphical representations. It has been shown that there is a great amount of data available to work with in the area of deer-vehicle crashes. Most of these data did not have many surprises, but there were inconsistencies. The lack of data in some aerial surveys may make it more difficult to come to any significant conclusions. In Chapter 4, we present the findings of a descriptive data analysis. Characteristics of the crashes are examined to see if there are any general trends between these characteristics and crashes. In addition, carcass and crash reports are compared to examine if the difference between crashes and carcasses is significant.

4. DESCRIPTIVE DATA ANALYSIS

4.1 Summary Statistics

This chapter presents the results of the descriptive analysis of the crash data that was conducted at the county and urban area levels.

A total of 4,718 crashes were reported in the three counties from 2002 to 2007, which resulted in 6 fatalities and 649 injuries. Table 4.1 shows the summary statistics for select crash- and road-specific variables in the three study counties. It was found that most crashes occur at night on unlit roadways during clear and dry weather. Most of the vehicles involved in these crashes are single vehicles with one to two occupants. These crashes occur the most in the months of October, November, and December on Fridays and Saturdays, with the day of the month being almost equally distributed. Most crashes also occurred on rural two- or four-lane roads with a speed limit of 55 or 65 mph. Table 4.1 shows the summary statistics for select crash-, road-, and land-use–specific variables in the three study counties.

Table 4.1. Summary statistics of select variables in the three study counties

Variables	Mean or Percentage (standard deviation)
Crash-Specific Variables	
Crash frequency Dubuque/Johnson/Linn Counties	29.7/32.6/37.7
Crash injury severity No injury/Possible, unknown injury/Minor injury/ Major injury or fatality	87.9/7.8/3.6/0.7
Number of injuries	0.14 (0.40)
Total number of vehicles involved in crash	1.0 (0.19)
Single-vehicle/Multiple-vehicle crash	97.6 / 2.4
Total number of occupants in all vehicles involved in crash	1.2 (0.8)
Single-occupant vehicle	69.8
Year of crash 2002/2003/2004/2005/2006/2007	15.5/16.6/17.8/15.6/18.4/ 16.1
Month of crash Jan/Feb/Mar/Apr/May/Jun/Jul/Aug/Sep/Oct/Nov/Dec	6.6/4.6/4.9/4.6/8.9/ 6.7/4.8/3.3/5.3/14.8/ 23.8/11.7
Day of crash Mon/Tue/Wed/Thu/Fri/Sat/Sun	13.2/13.3/13.2/12.4/17.0/ 16.0/15.0/

Table 4.1. Summary statistics of select variables in the three study counties (continued)

Variables	**Mean or Percentage (standard deviation)**
Light conditions Day/Dusk or dawn/Dark/Unknown/Not reported	8.3/4.6/29.6/23.8/33.7
Weather conditions Clear/Partly cloudy or cloudy/Unknown/Not reported	25.8/12.1/23.9/34.0
Road surface Dry/Wet or ice or snow or slush/Unknown/Not reported	35.3/4.4/23.7/34.9
Road-Specific Variables	
Functional classification Interstate/Other principal arterial/Minor arterial/ Collector/Local	11.7/43.9/12.3/21.6/10.5
Number of lanes	3.0 (1.2)
Two/Four/Other	50.2/37.0/12.8
Surface Type Asphalt/Concrete/Other	51.8/35.1/13.1
Median type No barrier/Raised Median/Grass without barrier/Barrier	55.2/7.5/36.0/1.3
Shoulder type—right No shoulder/Earth/Gravel/Paved	7.8/31.2/44.4/16.3
Shoulder type—left No shoulder/Earth/Gravel/Paved	10.3/31.2/39.0/19.4
Shoulder width—right (ft)	6.5 (3.7)
Shoulder width—left (ft)	4.8 (2.9)
Speed limit of road on which vehicle was traveling Below 55 mph/55 mph/Over 55 mph	24.8/46.3/28.9
Type of terrain Flat/Rolling/Hilly/Not applicable	25.4/39.6/14.0/21.1
Annual Average Daily Traffic (vehicles per day)	9,805 (10,937)
Natural logarithm of AADT	8.4 (1.7)

Turning to the study urban areas, a total of 921 crashes were reported from 2002 to 2007, which resulted in 2 fatalities and 117 injuries. Table 4.2 shows the summary statistics for select crash-, road-, and land-use–specific variables in the three study urban areas. It is shown that the majority of deer-vehicle crashes in urban deer management zones were single vehicle with one to two occupants. Further, the frequency of crashes was higher on undivided roads, roads with a posted speed limit below 55 miles per hour, on dry roads, and on roads with dark lighting conditions. Half of the deer-vehicle crashes reported during the analysis period occurred during the deer migration and mating season—in October, November, or December. These summary statistics are consistent with previous research on deer-vehicle collisions (Huijser et al. 2007a). A copy of the outputs can be found in Appendix A.

Table 4.2. Summary statistics of select variables in the study urban areas

Variables	Mean or Percentage (standard deviation)
Crash-Specific Variables	
Crash injury severity No injury/Possible, unknown injury/Minor injury/ Major injury or fatality	88.8/7.2/3.0/1.0
Number of injuries	0.13 (0.38)
Total number of vehicles involved in crash	1.0 (0.28)
Single-vehicle/Multiple-vehicle crash	96.6/3.4
Total number of occupants in all vehicles involved in crash	1.3 (1.0)
Single-occupant vehicle	69.4
Year of crash 2002/2003/2004/2005/2006/2007	13.2/21.2/6.7/20.0/22.5/ 16.4
Month of crash Jan/Feb/Mar/Apr/May/Jun/Jul/Aug/Sep/Oct/Nov/Dec	6.2/4.8/4.9/4.3/9.0/6.4/ 4.9/3.4/6.3/17.4/24.4/9.0
Day of crash Mon/Tue/Wed/Thu/Fri/Sat/Sun	14.7/13.1/11.9/12.1/18.0/ 15.3/14.9
Light conditions Day/Dusk or dawn/Dark/Unknown/Not reported	8.1/4.6/32.8/17.4/33.1
Weather conditions Clear/Partly cloudy or cloudy/Unknown/Not reported	28.9/15.3/34.1/17.4
Road surface Dry/Wet or ice or snow or slush/Unknown/Not reported	41.4/6.3/17.3/34.5
Road-Specific Variables	
Functional classification Interstate/Other principal arterial/Minor arterial/ Collector/Local	8.7/54.2/17.4/7.8/11.9
Number of lanes Two/Four/Other	3.4 (1.2) 34.2/50.0/15.8
Surface Type Asphalt/Concrete/Other	48.8/43.6/7.5
Median type No barrier/Raised Median/Grass without barrier/Barrier	42.6/14.0/39.2/4.2
Shoulder type–right No shoulder/Earth/Gravel/Paved	11.1/18.2/55.6/15. 1
Shoulder type–left No shoulder/Earth/Gravel/Paved	18.4/18.0/33.1/30.5
Shoulder width–right (ft)	6.9 (3.9)

Table 4.2. Summary statistics of select variables in the study urban areas (continued)

Variables	**Mean or Percentage (standard deviation)**
Shoulder width–left (ft)	4.2 (3.0)
Speed limit of road on which vehicle was traveling Below 55 mph/55 mph/Over 55 mph	50.6/20.7/28.7
Type of terrain Flat/Rolling/Hilly/Not applicable	26.0/16.2/9.5/48.3
Annual Average Daily Traffic (vehicles per day)	13,199 (11,040)
Natural logarithm of AADT	8.9 (1.4)
Land Use-Specific Variables	
Area (acres)	6,289.7 (5,474.4)
Commercial and residential land (% of area)	12.8
Forest/Grassland/Cropland (% of area)	33.6/29.4/10.5
Water and wetland (% of area)	3.0
Roads (% of area)	6.7
City (% of area within city limits)	59.6
Deer Population-Specific Variables	
Deer population per zone	133.4 (167.7)
Deer density per square mile	28.7 (20.0)
Interaction of Deer density and Land Use-Specific Variables	
Deer density * Commercial and residential land	3.7 (3.9)
Deer density *Forest/Grassland	11.1 (9.6)/7.8 (5.4)
Deer density * Cropland	2.3 (2.5)
Deer density *Water and wetland	1.0 (1.6)
Deer density *Roads	1.8 (1.5)
Deer density *City	17.7 (17.2)

4.2 Distribution of Deer-Vehicle Crashes by AADT in the Three Study Counties

The distribution of crashes by AADT is shown in Figure 4.1.

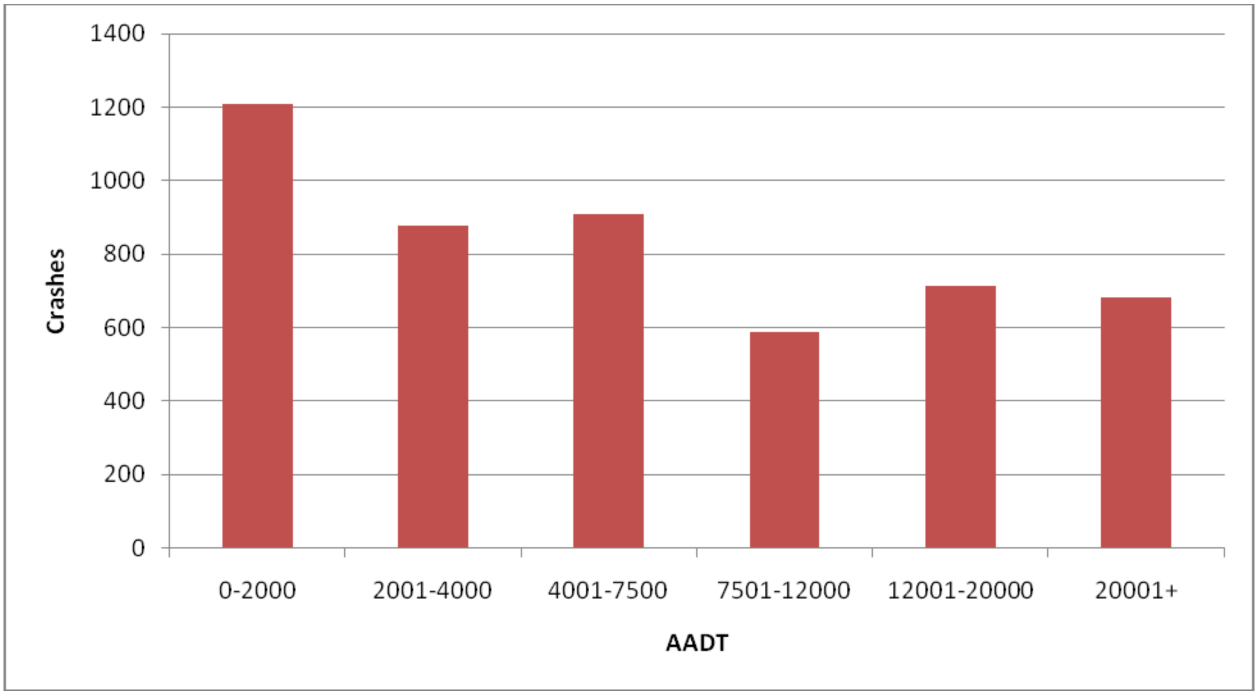

Figure 4.1. Deer-vehicle crashes by AADT

As can be seen in Figure 4.1, most crashes occurred on roads with an AADT of under 7,500 vehicles per day.

In addition, deer-vehicle crashes were analyzed by the posted speed limit in the three study counties, as shown in Figure 4.2.

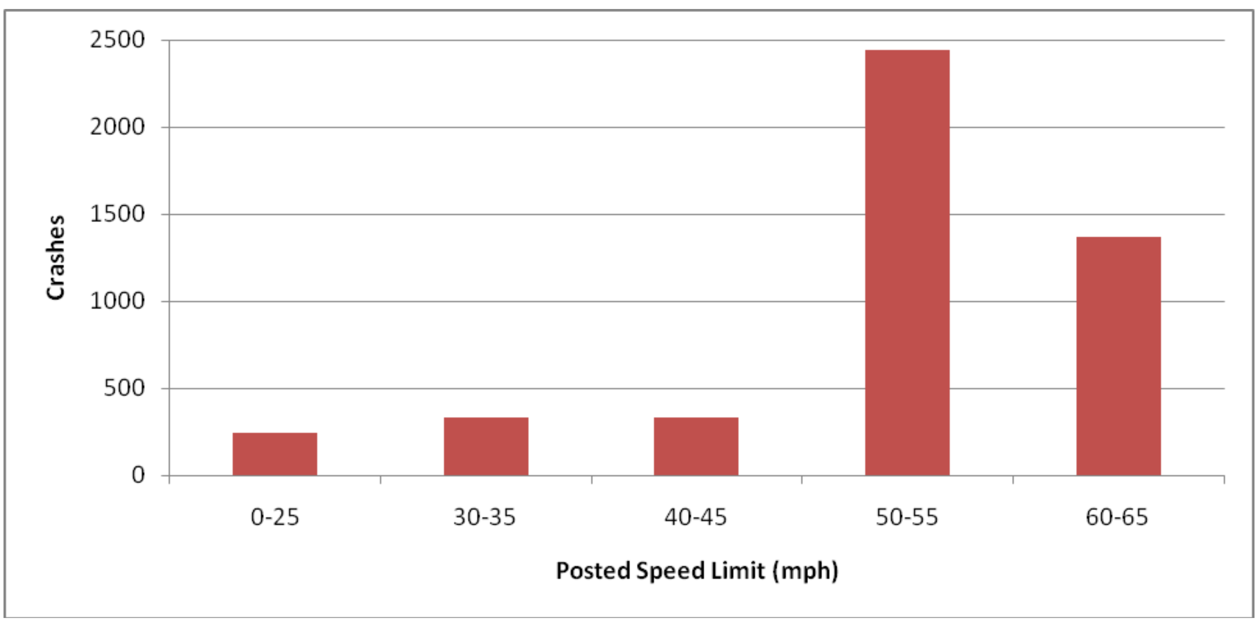

Figure 4.2. Deer-vehicle crashes by posted speed limit

As can be seen, most deer-vehicle crashes occur on roads with a posted speed limit of 50 mph or higher. This is not surprising due to the fact that most of the rural roads have a posted speed limit of 55 mph.

4.3 Deer-Vehicle Crash Rates by Vehicle Miles Traveled

Crashes were also analyzed by vehicle miles traveled (VMT) at both the county and urban area levels. The analysis was broken down by road classification: primary, secondary, and municipal. An average crash rate was then calculated for all road classifications, and this line is shown in Figures 4.3 through 4.5 as the "Total." The individual urban area charts are in Figures 4.3 through 4.5, and a comparison chart for all of the urban areas is shown in Figure 4.6. The individual county and county comparison charts can be found in Appendix B.

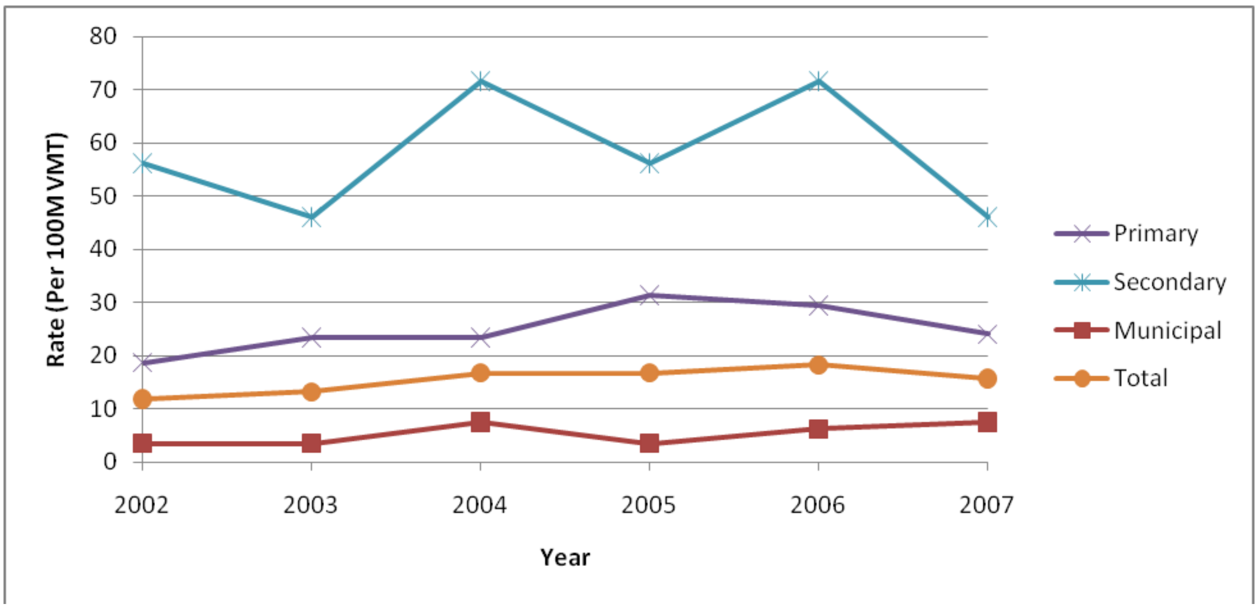

Figure 4.3. Deer-vehicle crash rate per 100 million VMT in Dubuque urban area

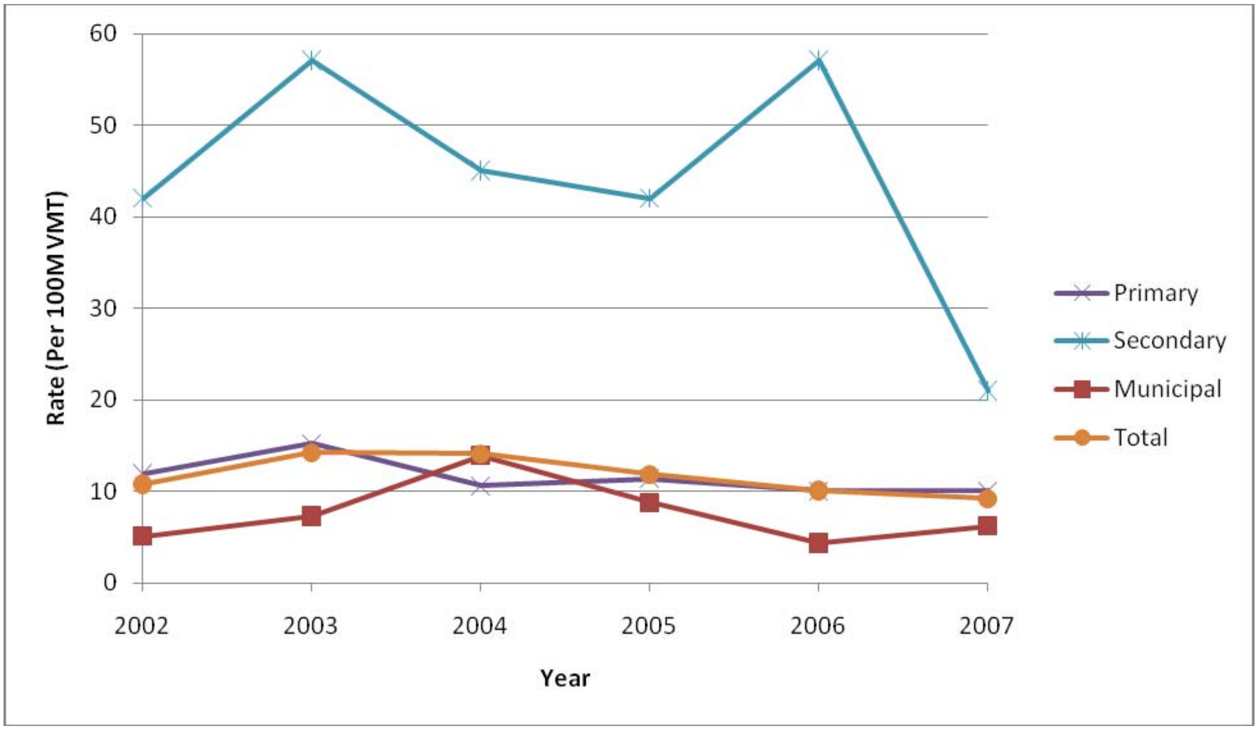

Figure 4.4. Deer-vehicle crash rate per 100 million VMT in Iowa City urban area

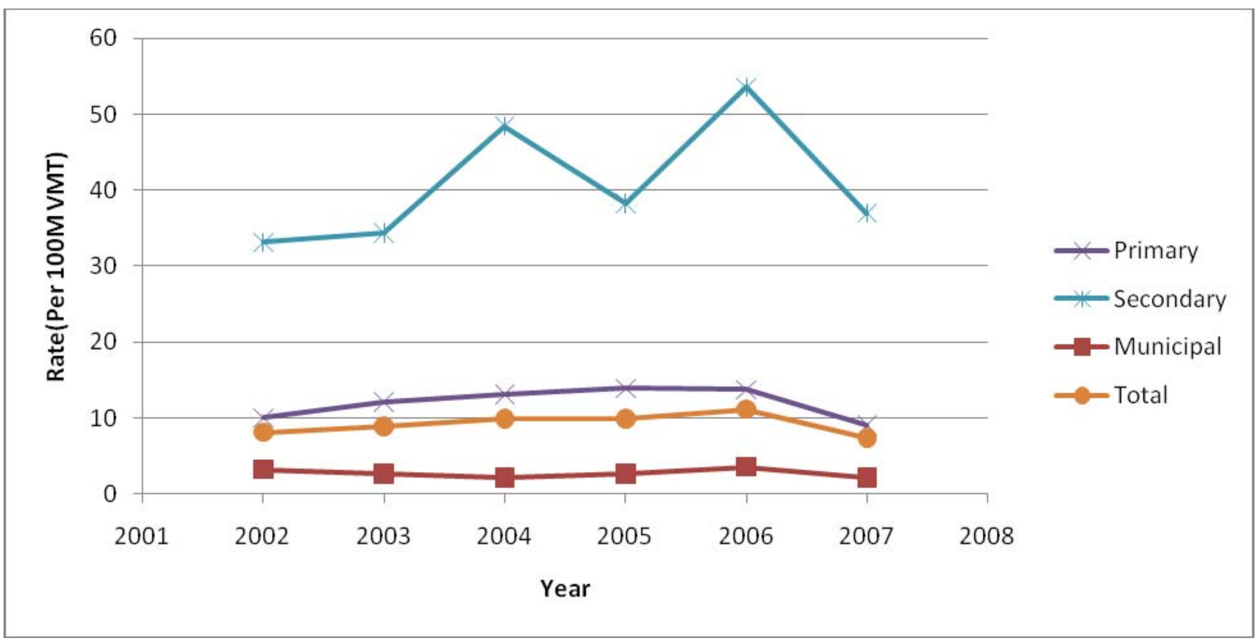

Figure 4.5. Deer-vehicle crash rate per 100 million VMT in Cedar Rapids urban area

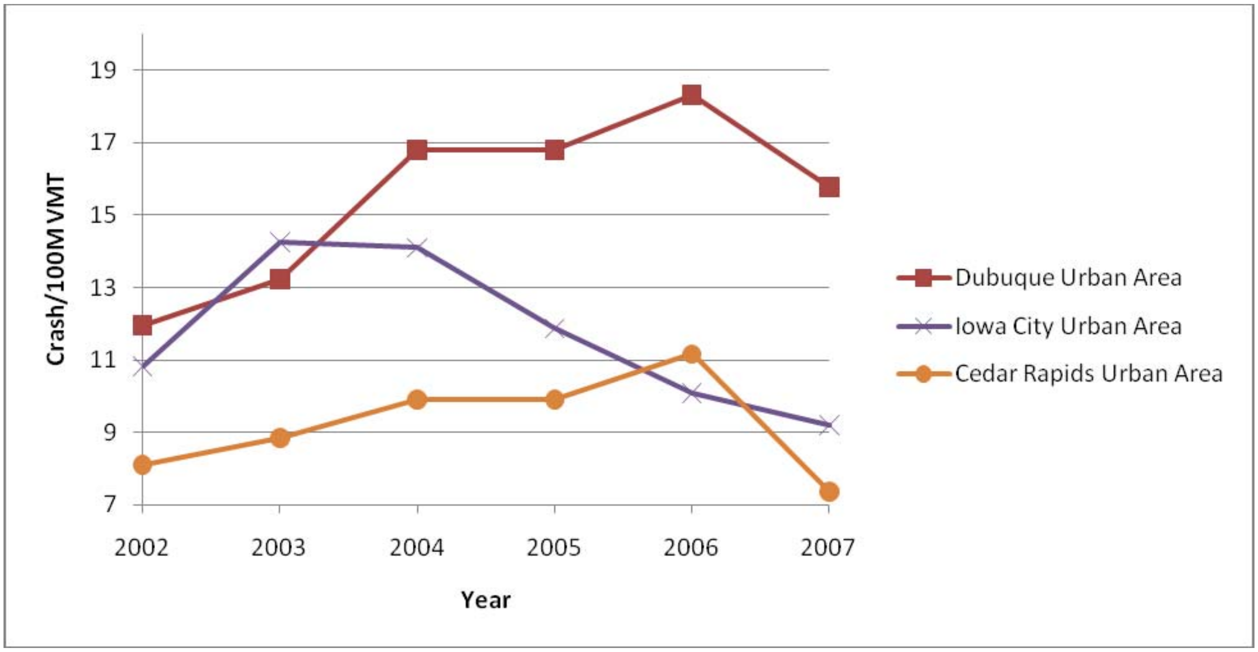

Figure 4.6. Comparison of crash rate per 100 million VMT—urban areas

In these graphs, it can be seen that in most of the urban areas secondary roads experience the highest deer-vehicle crash rates. It is also noted that deer-vehicle crash rates on secondary roads have sharp rises and falls. This might be attributed to the fact that larger cities in Iowa have low secondary roadway mileage within city limits. For the most part, the deer-vehicle crash rates on primary and municipal roads show no surprises, with the rates on primary roads being higher than the average crash rate (noted in the Figures 4.3 through 4.5 as "Total") and the rates on municipal roads being lower than the average crash rate. This could be due to the amount of traffic on different road facilities, with primary roads experiencing higher volumes of traffic than municipal roads. Figure 4.6 shows that deer-vehicle crash rates in most of the urban areas are between 10 and 20 crashes per 100 million VMT. It can be noted that Dubuque County has a rate that is higher than any of the other areas examined (see Appendix B).

4.4 Deer-Vehicle Crashes per Lane Mile

A similar analysis to what was presented in the previous section was conducted by lane mile and for each roadway classification. The individual urban area graphs are shown in Figures 4.7–4.9, and a summary graph is shown in Figure 4.10. County graphs can be found in Appendix B.

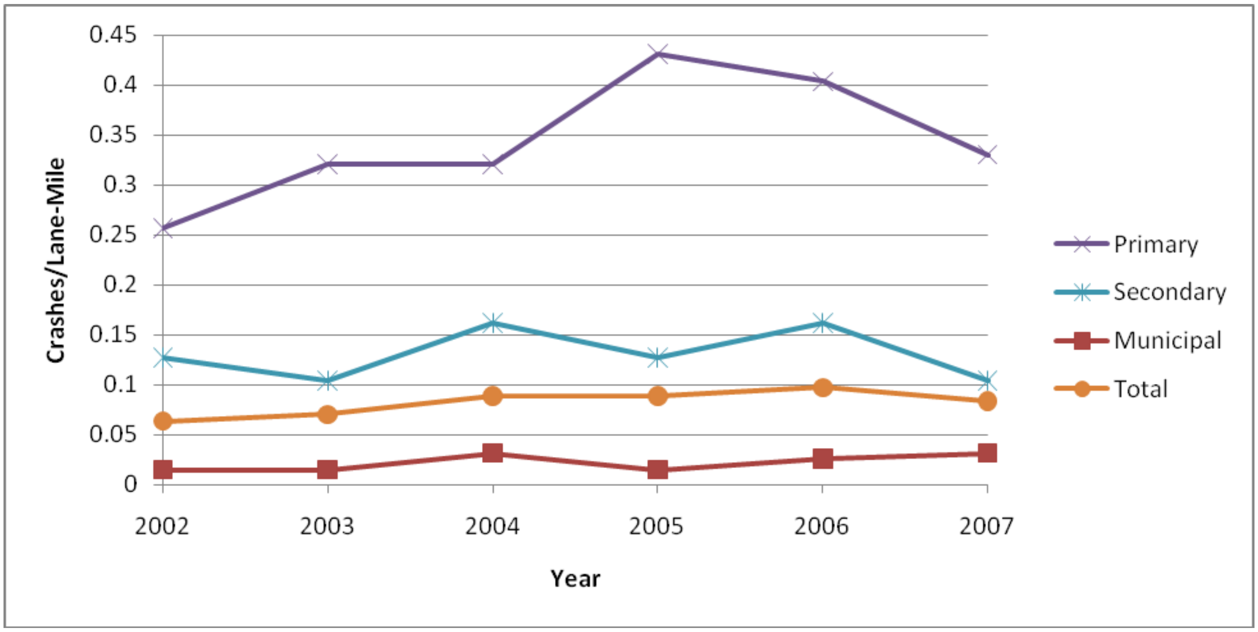

Figure 4.7. Deer-vehicle crashes per lane mile in Dubuque urban area

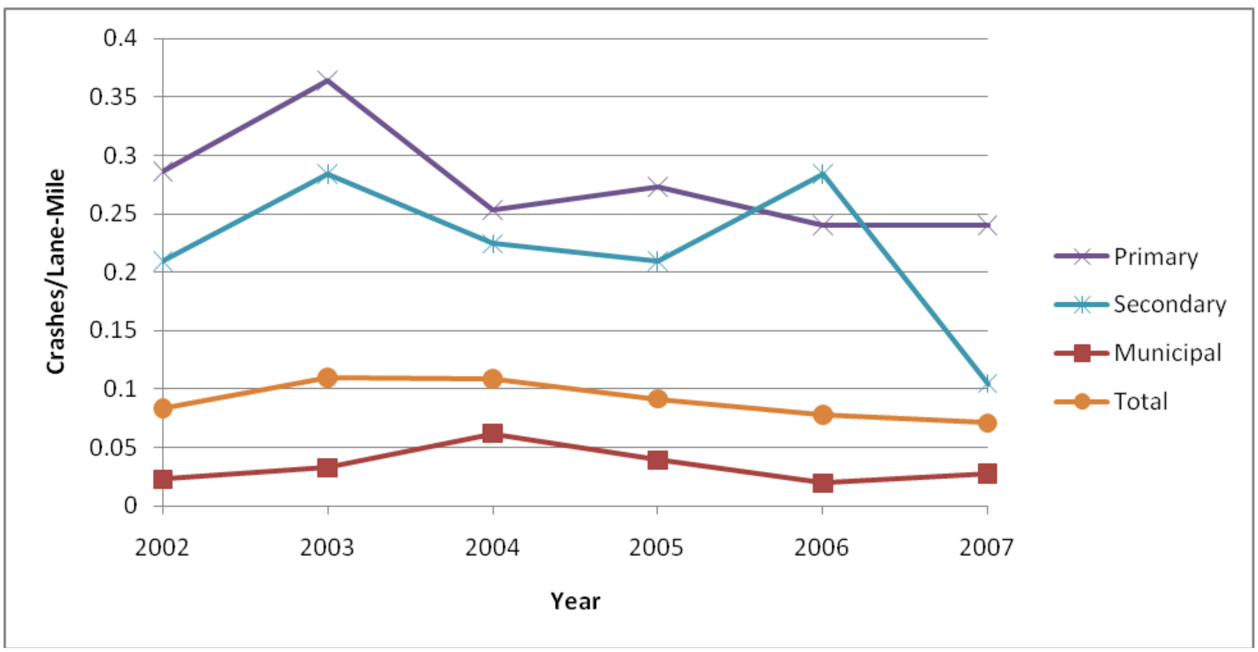

Figure 4.8. Deer-vehicle crashes per lane mile in Iowa City urban area

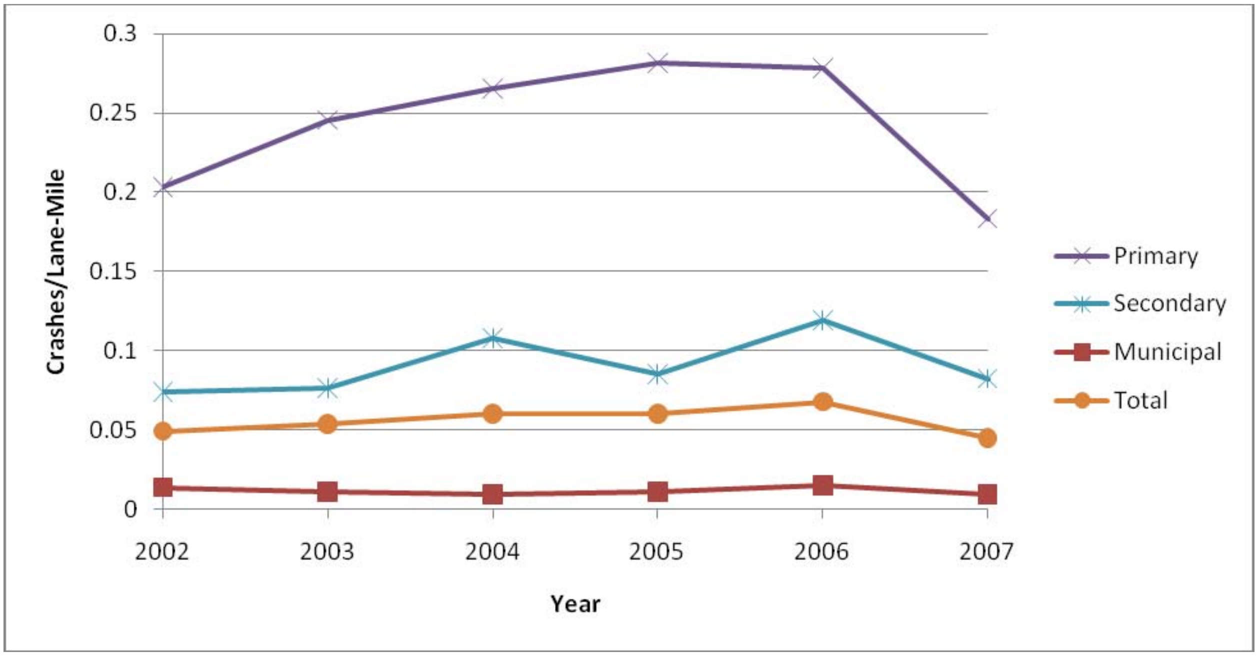

Figure 4.9. Deer-vehicle crashes per lane mile in Cedar Rapids urban area

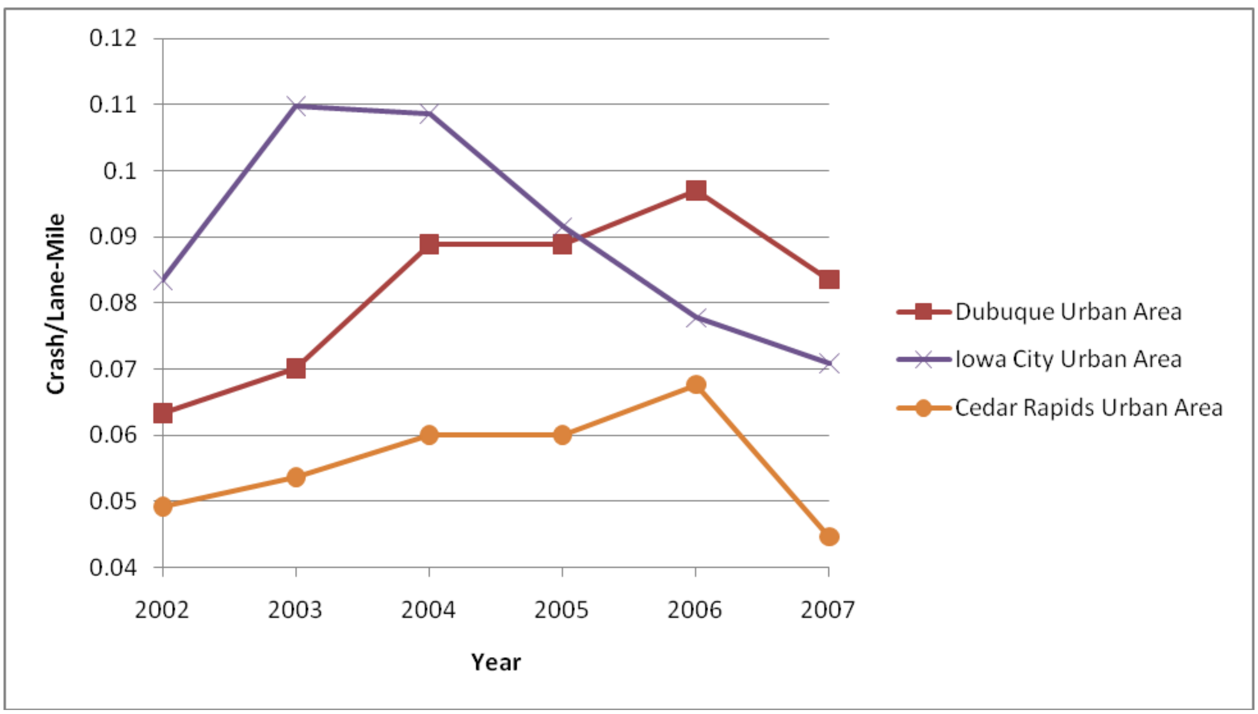

Figure 4.10. Comparison of crashes per lane mile—urban areas

In these graphs, it can be seen that in most of the counties and urban areas primary roads experience the most deer-vehicle crashes per lane mile. This trend may be attributed to the fact that primary roads have a higher volume for less mileage than secondary and municipal roadways. The deer-vehicle crashes per lane mile on secondary and municipal roads show no surprises, except for the Iowa City urban area. The rates on these roads are around the average line (designated as "Total"), except for secondary roads in the Iowa City urban area, which are quite a bit higher than the average. Figure 4.10 shows that deer-vehicle crashes per lane mile in most of the counties and urban areas are between 0.04 and 0.11 crashes per lane mile, with Linn County and the Cedar Rapids urban area always being the lowest values.

4.4 Comparison of Deer Carcass and Deer-Vehicle Crash Counts

Next, the total number of deer carcass counts was compared to deer-vehicle crashes on primary roads at the county level. Figures 4.11, 4.12, and 4.13 show the comparisons in Dubuque, Johnson, and Linn Counties, respectively.

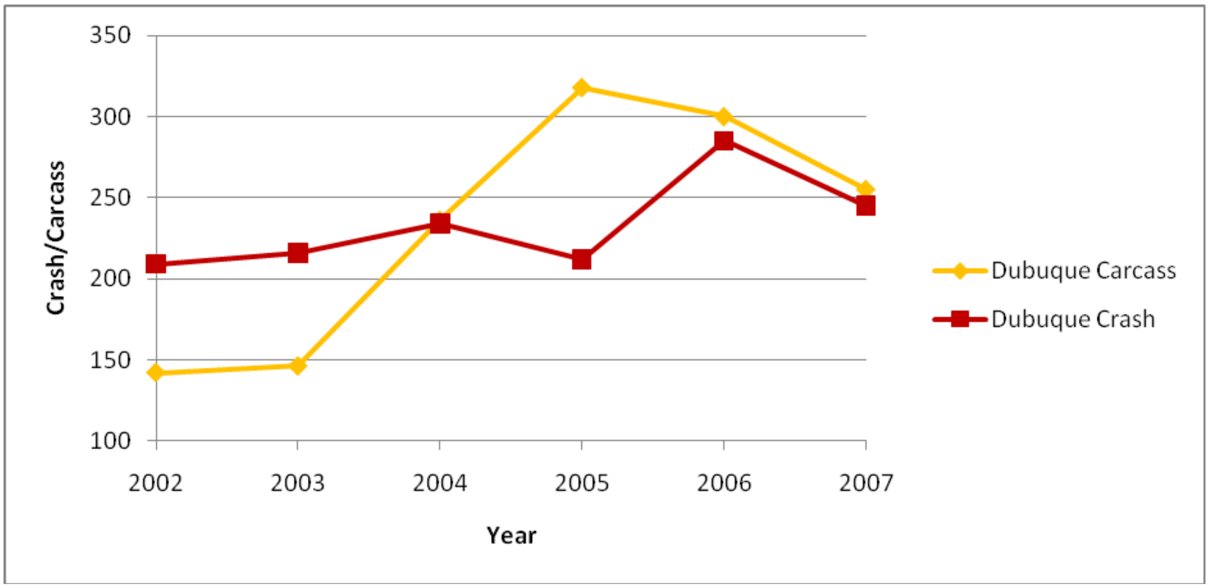

Figure 4.11. Comparison of deer carcass and deer-vehicle crash counts in Dubuque County

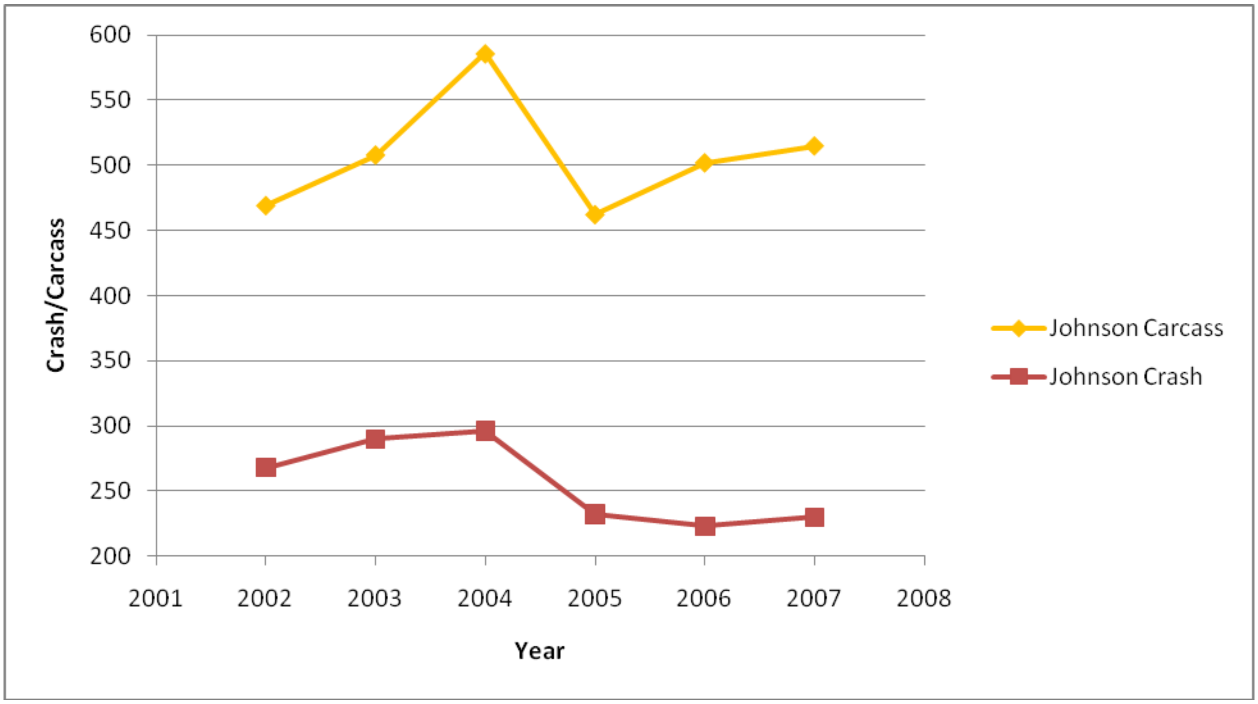

Figure 4.12. Comparison of deer carcass and deer-vehicle crash counts in Johnson County

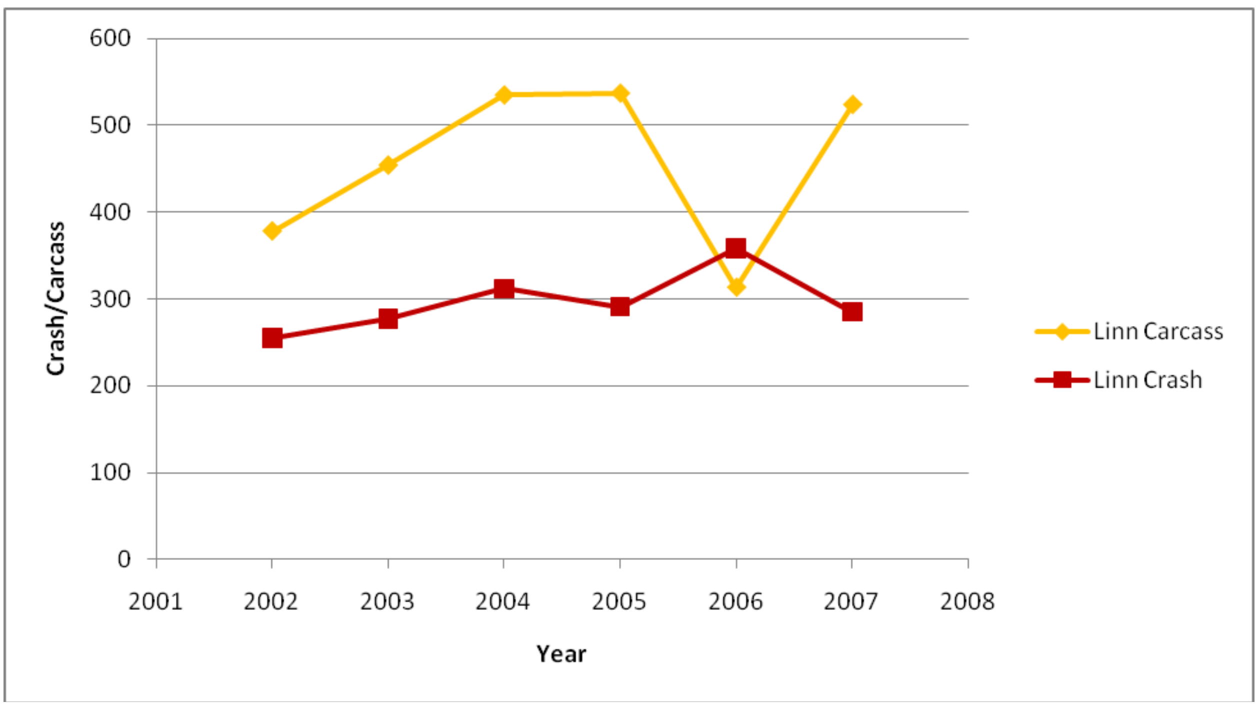

Figure 4.13. Comparison of deer carcass and deer-vehicle crash counts in Linn County

Overall, the number of deer carcasses removed on the primary roads in these counties was greater than the number of reported deer-vehicle crashes on those roads (except in Dubuque County in 2002 and 2003 and in Linn County in 2006). These differences can be attributed to a number of reasons, including variability in data reporting and data collection practices, as discussed in previous research (Knapp et al. 2007; Huijser et al. 2007b; Huijser et al. 2007c; Donaldson and Lafon 2009). There is no good explanation for the drop in the carcass counts in Linn County in 2006, but it could be due to a new reporting system being put into place. The authors expect carcass reports to be higher than crash reports, as the literature has indicated. However, not all of the statistics for the study areas, especially Dubuque County, reflect the estimate that 50 percent of deer-vehicle crashes are not reported.

Table 4.3 compares the total number of deer carcasses and deer-vehicle crashes on primary roads by county from 2002 to 2007. The two-factor analysis of variance showed that the deer carcass counts and the deer-vehicle crash counts differ significantly in Johnson and Linn Counties. However, the differences in the annual counts across the survey years were found to be marginally significant in Johnson County and insignificant in the other two counties.

Table 4.3. Comparison of deer carcass and deer-vehicle crash counts on primary roads by county and year

Year	Dubuque		Johnson		Linn	
	Carcass Count	Crash Count	Carcass Count	Crash Count	Carcass Count	Crash Count
2002	142	209	469	268	378	255
2003	146	216	508	290	454	277
2004	236	234	586	296	535	312
2005	318	212	462	232	537	291
2006	300	285	502	223	313	358
2007	255	245	515	230	524	285

Analysis of Variance Estimation Results

	Dubuque	Johnson	Linn
	p-value	p-value	p-value
Rows (year)	*ns**	0.125	*ns**
Columns (counts)	*ns**	< 0.0001	0.016

*Note: ns means no significant difference

4.5 Comparison of Deer Carcass and Deer-Vehicle Crash Counts by Primary Route

Finally, an analysis was conducted to compare the number of deer-vehicle crashes to deer carcasses on each primary route. A selection of routes is shown in Figure 4.14. This figure includes counts by routes in the study area rather than an individual county count.

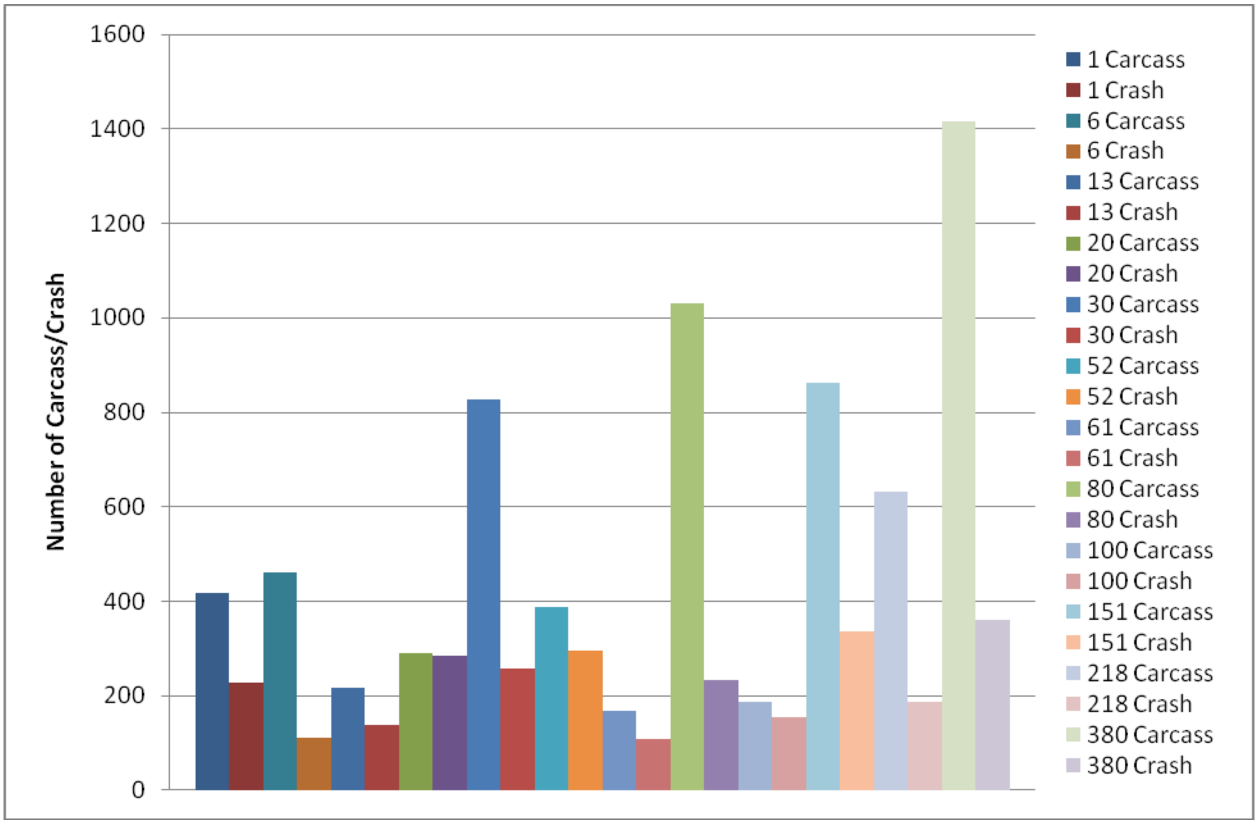

Figure 4.14. Comparison of deer-vehicle crash and carcass counts by primary route

The comparison of deer carcasses and crashes by primary route in each of the three counties suggested high rates of underreporting of crashes on major routes that carry high volumes of traffic, such as US 6, US 30, I-80, US 151, US 218, and I-380. These rates ranged from 158% (for US 151) to 341% (for I-80). However, the comparison of deer carcasses and crashes on other routes—like US 20, US 61, and Iowa 100—showed that the numbers are more closely in line, with only a few more carcasses being picked up than crashes reported.

Figures 4.15 through 4.18 illustrate the difference between deer crash and carcass data. The two routes that were analyzed were I-380 (multilane roadway) in Johnson and Linn Counties and US 6 (two-lane roadway) in Johnson County. Both crashes and carcasses were rounded to the nearest reference post for this comparison.

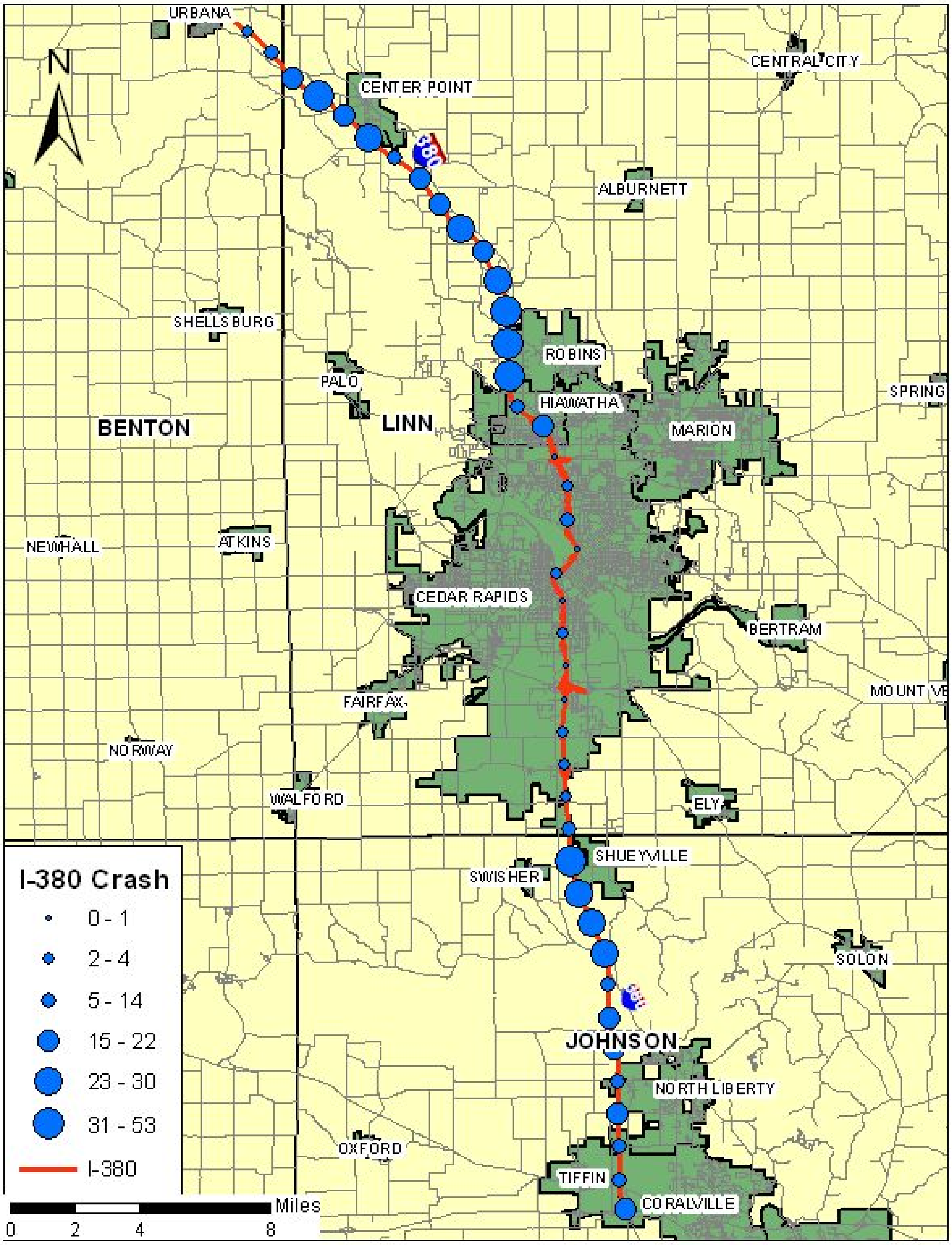

Figure 4.15. Deer-vehicle crashes on I-380

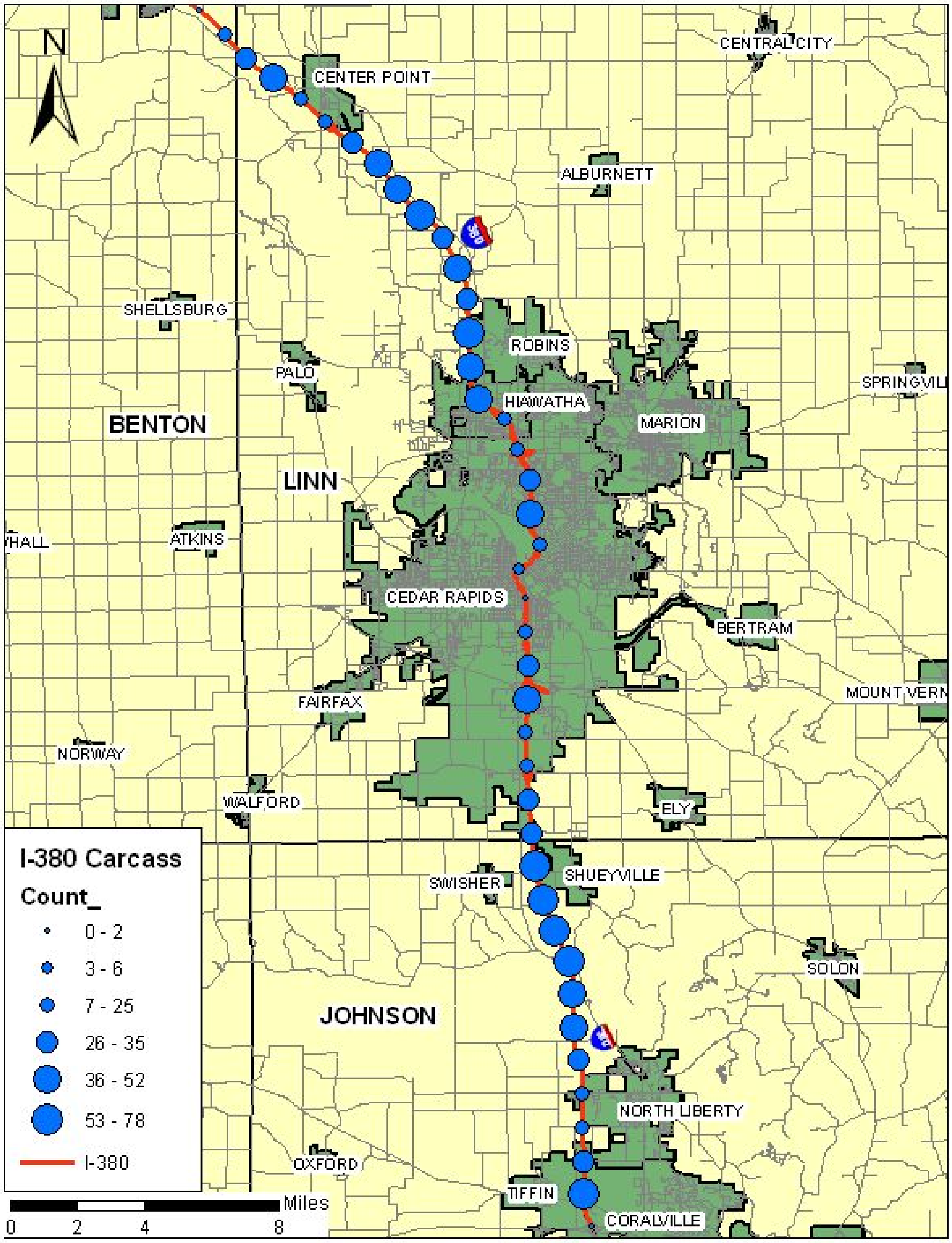

Figure 4.16. Deer carcasses on I-380

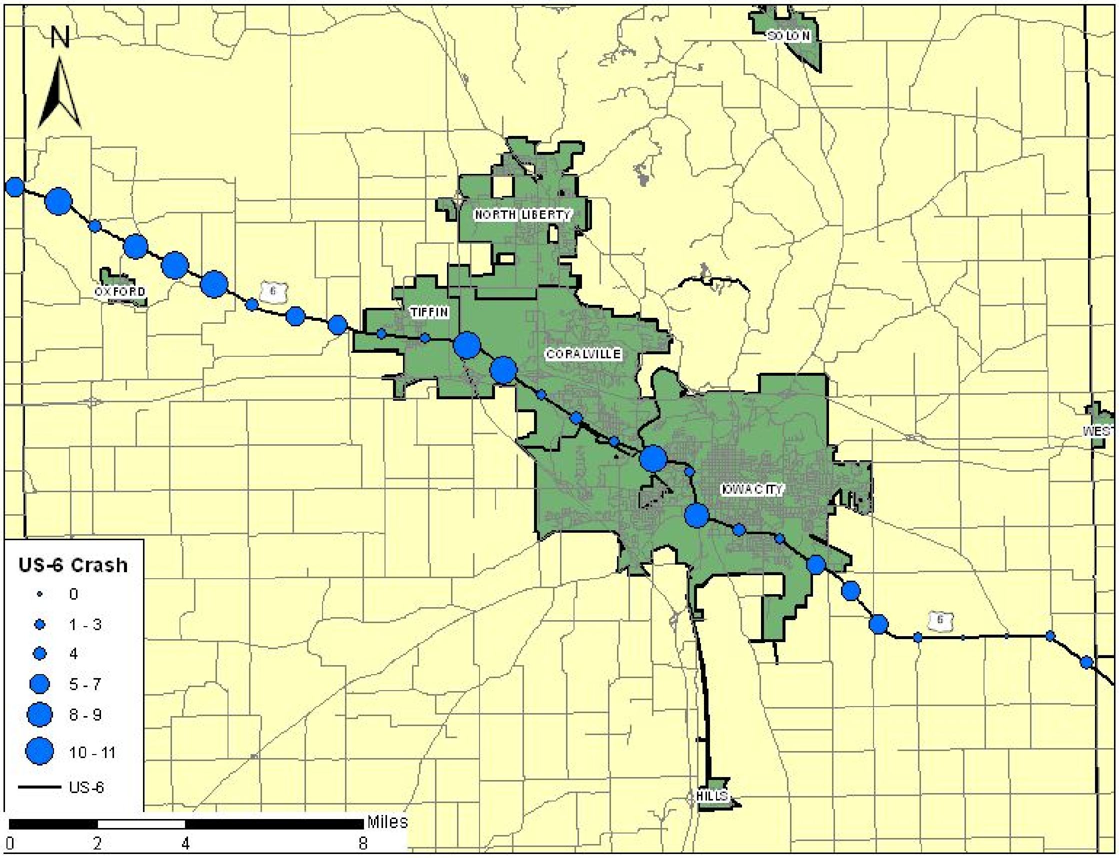

Figure 4.17. Deer-vehicle crashes on US 6

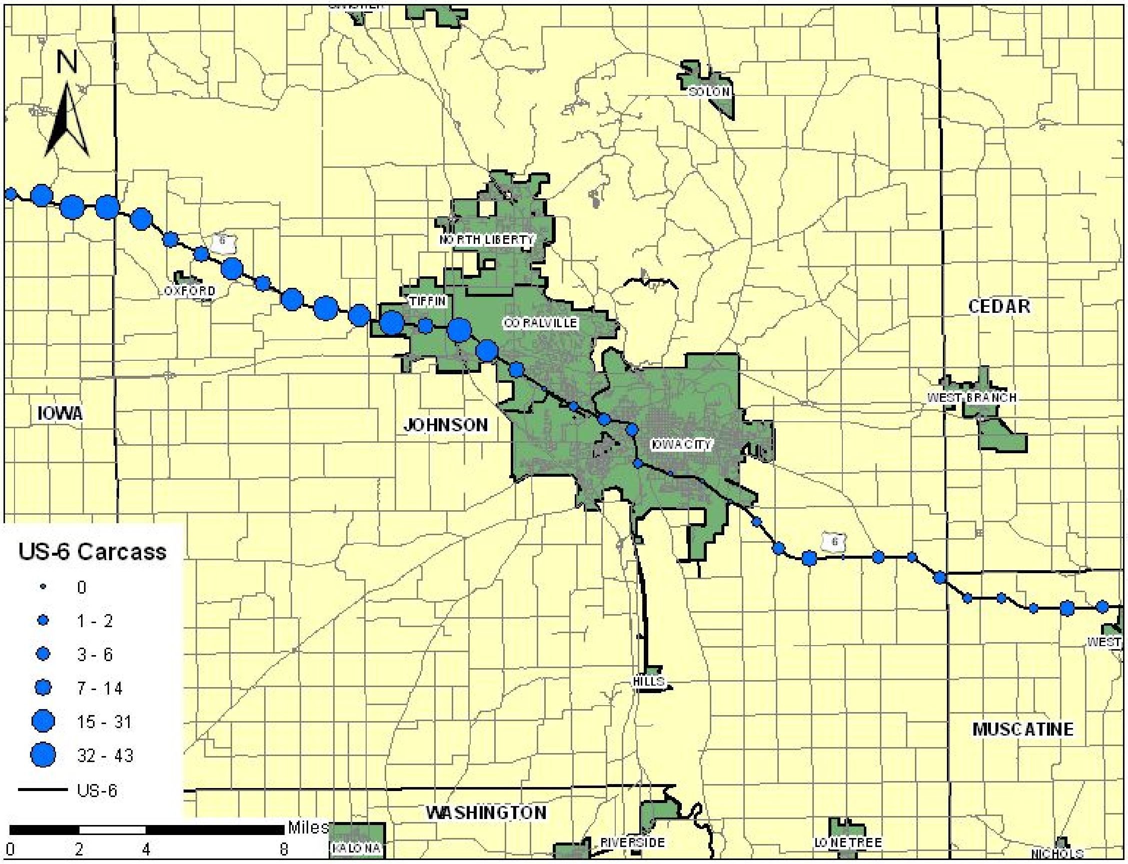

Figure 4.18. Deer carcasses on US 6

For most of the reference posts, the number of carcasses that were picked up by the maintenance crew was greater than the number of crashes reported. This trend was pronounced in the city of Cedar Rapids, especially within the city limits. This may be attributed to a policy by the Cedar Rapids Police Department (Betz 2009) that does not require police officers to compile crash reports for property damage only crashes. As such, crashes that fall in this category may not be included in the crash database.

4.6 Relationship between Deer Population and Deer-Vehicle Crash Frequency in Urban Deer Management Zones

Figure 4.19 shows the relationship between deer population and deer-vehicle crash frequency in the three urban deer management zones over the analysis period. The frequency of deer-vehicle crashes is a third-degree polynomial function of deer population. While deer population seems to be a good predictor of deer-vehicle crashes, it can only explain 50% of the variability in deer-vehicle crashes.

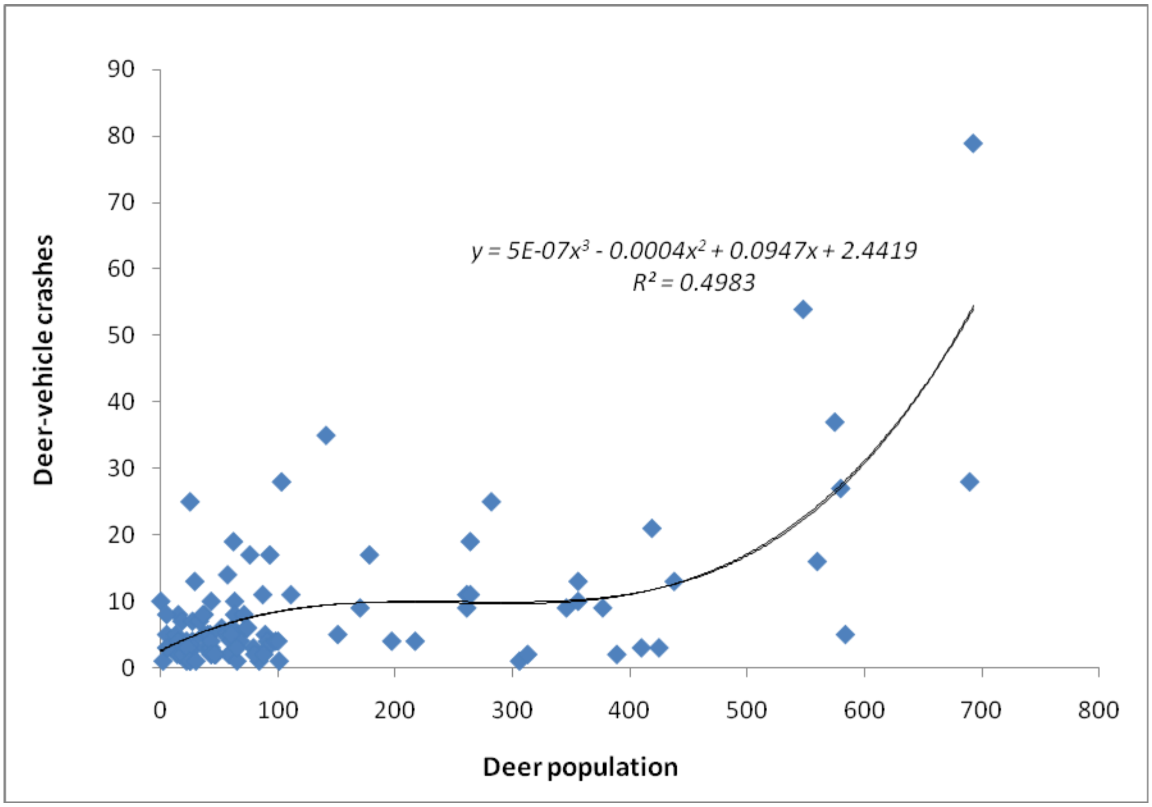

Figure 4.19. Comparison of deer-vehicle crash frequency and deer population in urban deer management zones

The fluctuations in deer population and deer-vehicle crashes by urban management zone and year are shown in Appendix C. The graphs suggest that, in most zones, rises and falls in deer population (as a result of deer hunts) seem to be similar to rises and falls in deer-vehicle crashes over the analysis period.

Maps were also created to show the relationship between deer population and deer-vehicle crash frequency. The crashes were assigned to each Iowa DNR-designated zone. Figures 4.20 to 4.22 show the average deer population and number of deer-vehicle crashes in each zone. Similar maps showing the relationship between deer density and deer-vehicle crash frequency can be found in Appendix D.

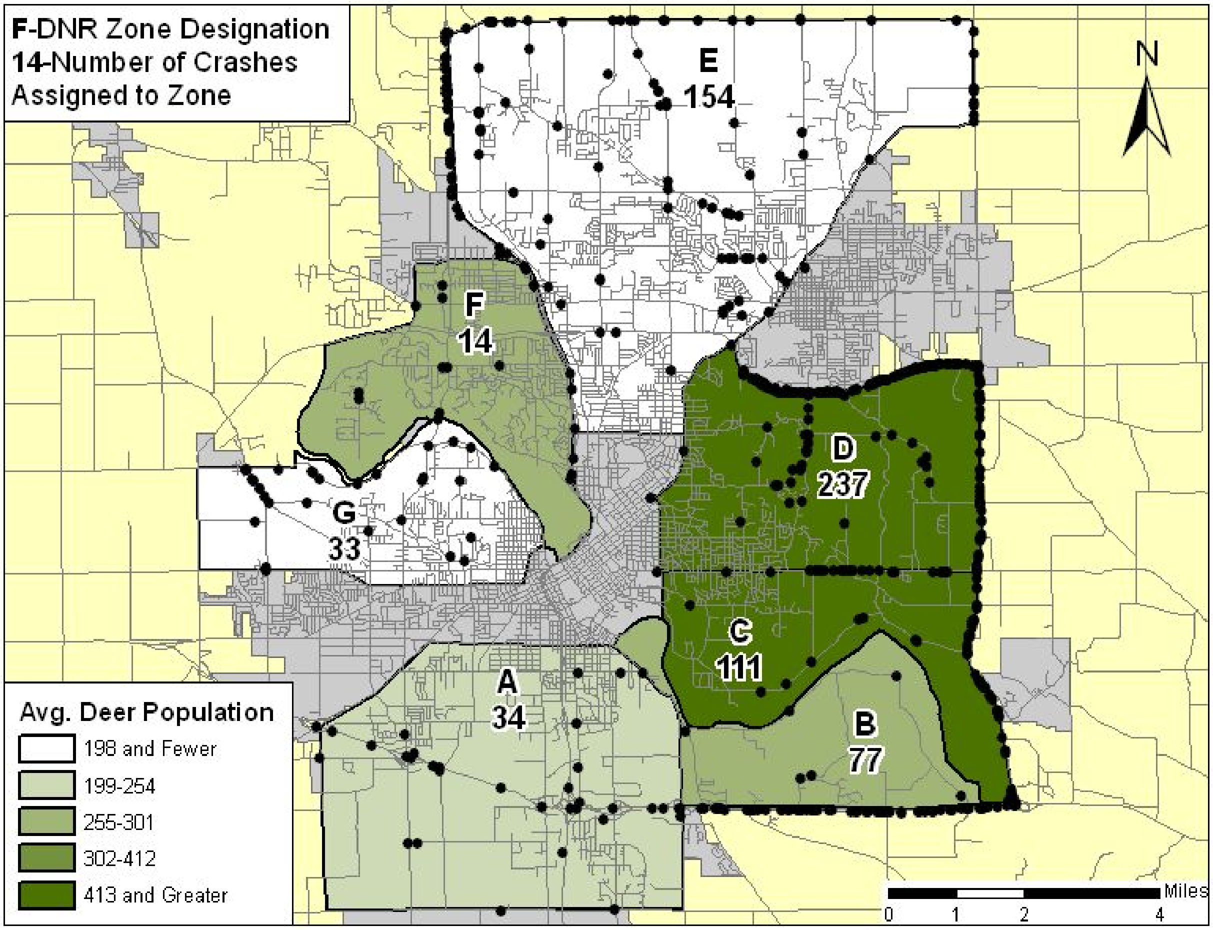

Figure 4.20. Average deer population and deer-vehicle crashes in Cedar Rapids

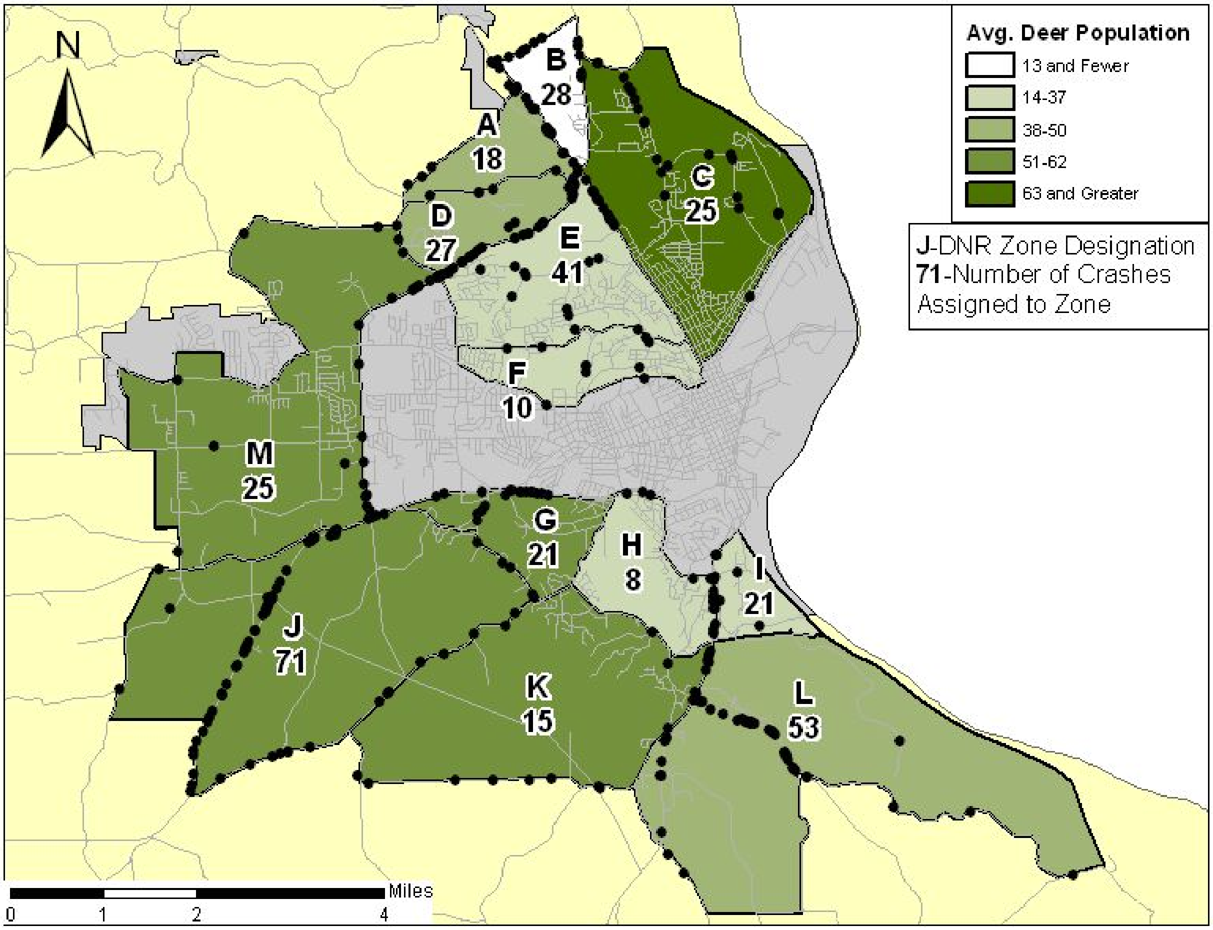

Figure 4.21. Average deer population and deer-vehicle crashes in Dubuque

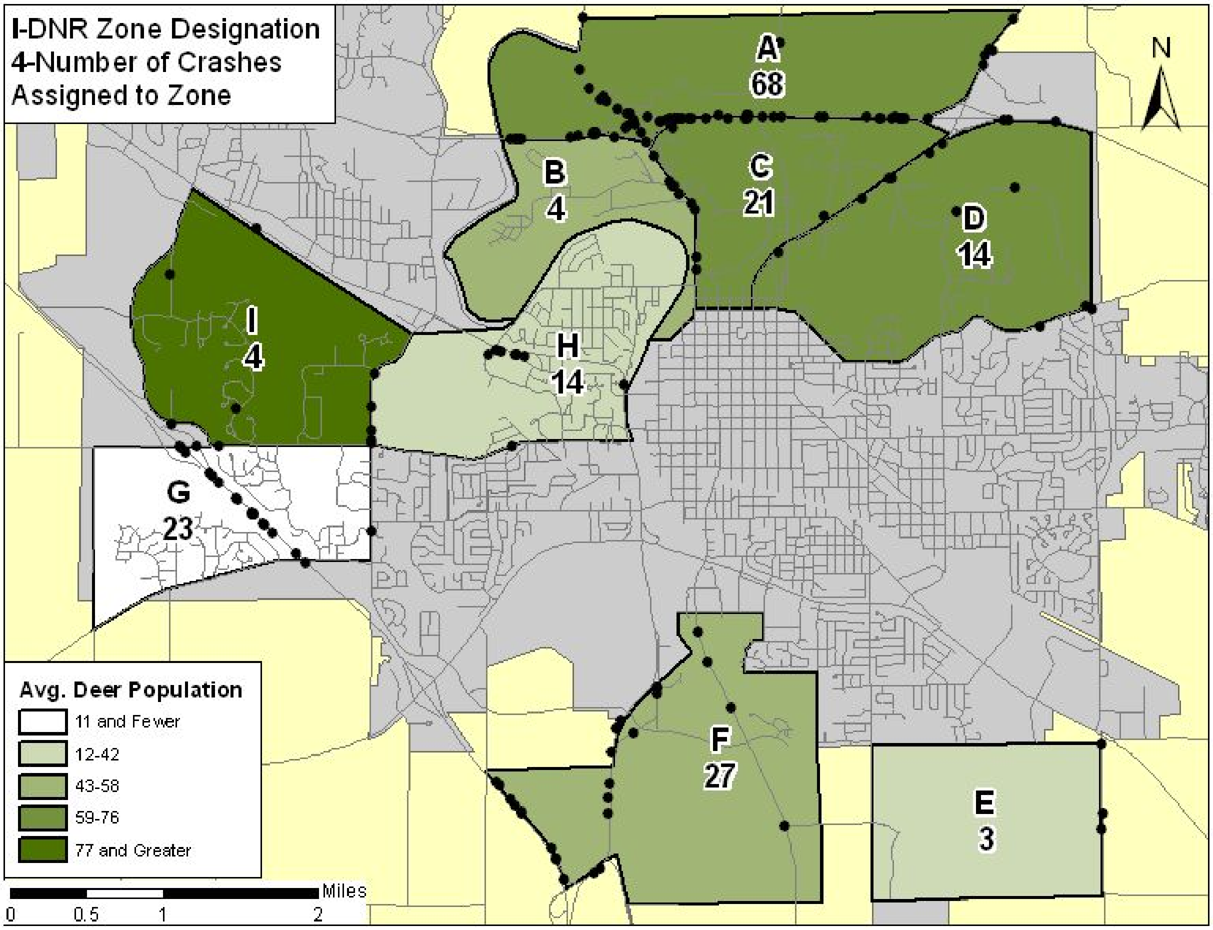

Figure 4.22. Average deer population and deer-vehicle crashes in Iowa City

4.7 Relationship between Deer-Vehicle Crash Frequency and Land Use in Urban Deer Management Zones

Figures 4.23 to 4.25 show the percentage of cropland, land developed, and roadways and the number of deer-vehicle crashes in each zone in Cedar Rapids, Dubuque, and Iowa City, respectively. Similar maps showing the relationship between deer-vehicle crash frequency and other types of land use (e.g., forestland, grassland, water) can be found in Appendix D.

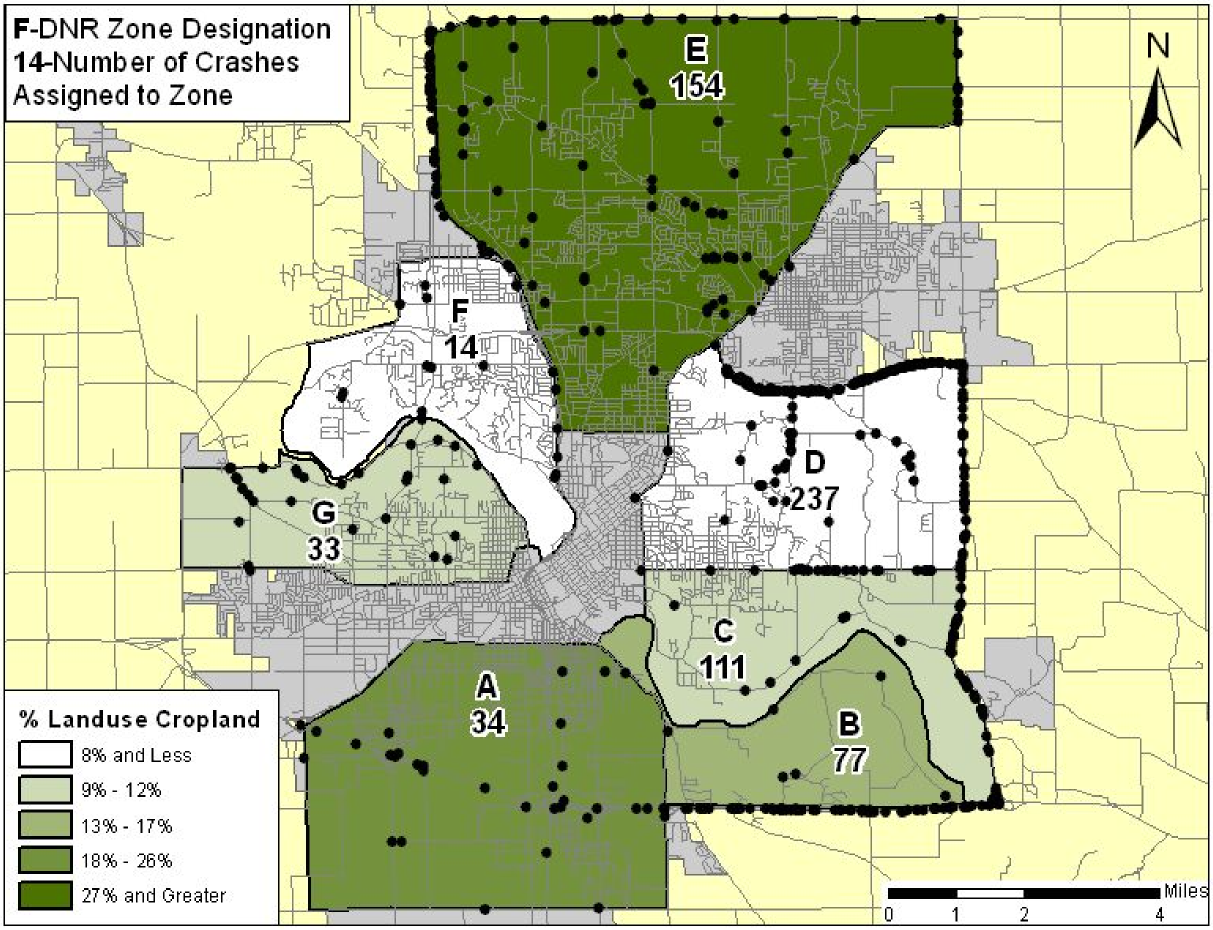

Figure 4.23. Percentage of cropland and deer-vehicle crashes in Cedar Rapids

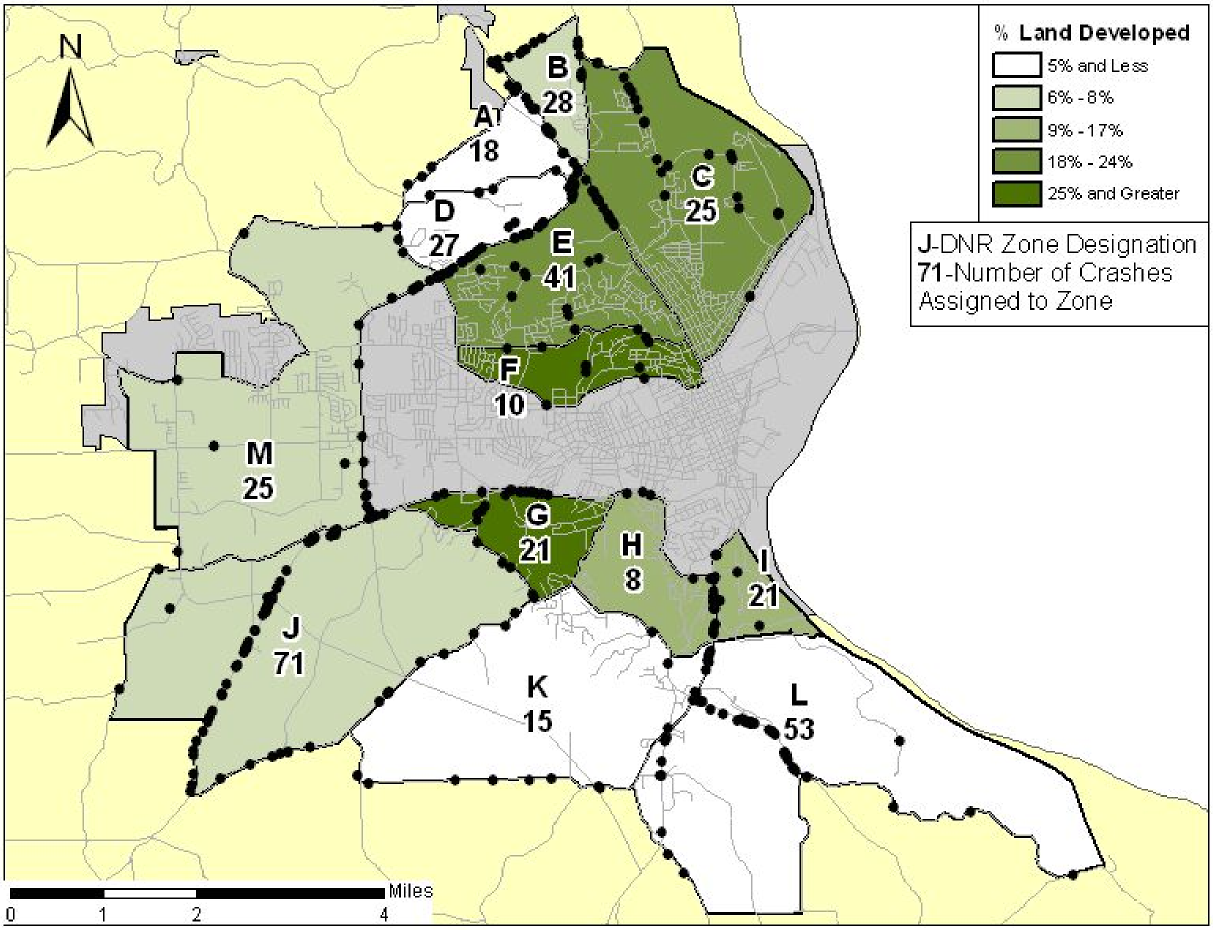

Figure 4.24. Percentage of land developed and deer-vehicle crashes in Dubuque

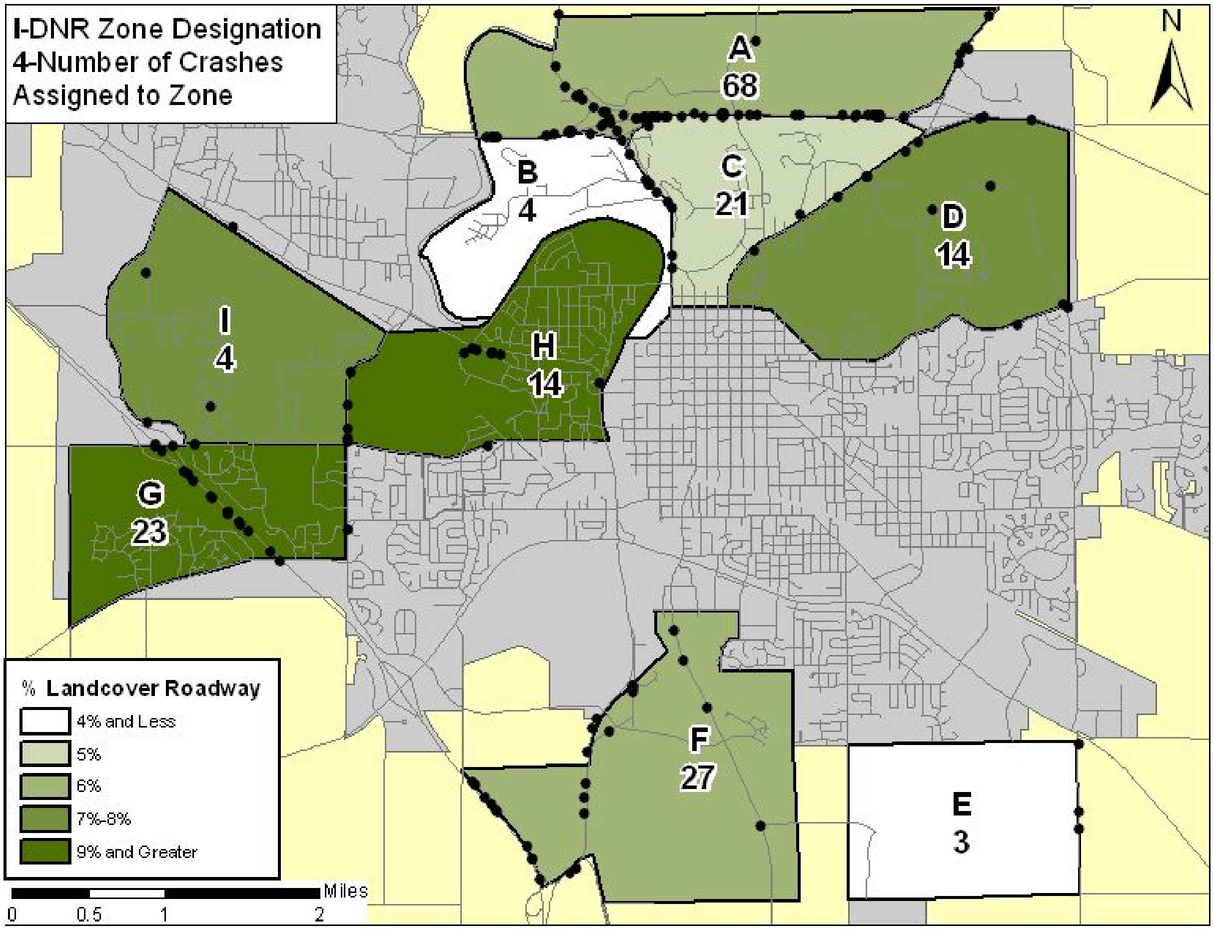

Figure 4.25. Percentage of roadways and deer-vehicle crashes in Iowa City

4.7 Summary/Conclusions

In this chapter, descriptive analysis techniques were applied to identify the major factors that contribute to deer-vehicle crashes in the three study counties and urban areas. In addition, the total number of deer carcasses and deer-vehicle crashes on primary roads were compared at the county level. Last, maps were created to show the relationships between deer population and deer-vehicle crash frequency and between land use and deer-vehicle crash frequency in urban deer management zones. Preliminary findings showed that the number of deer carcasses removed on the primary roads in the three counties was greater than the number of reported deer-vehicle crashes on those roads and, further, high rates of underreporting of crashes were found on major routes that carry high traffic volumes. Deer population was found to be a good predictor of deer-vehicle crashes, while the descriptive analysis identified the frequency of a number of crash-, road-, and land-use–specific factors in deer-vehicle crashes. In Chapter 5, the authors used statistical methods to investigate the effect of these factors on deer-vehicle crash frequency and injury severity.

5. STATISTICAL DATA ANALYSIS

5.1 Overview

In this chapter, the authors examine the relationship between deer-vehicle collisions, deer density, and land use in select urban deer management zones in Iowa. First, count data models are applied to investigate the factors that influence the frequency of deer-vehicle crashes in urban deer management zones and the frequency of injuries in deer-vehicle collisions. Then, the authors estimate a binary probit model for crash severity outcomes (no injury or injury) as a function of crash, road, and land use characteristics. Results from this study can assist in a better assessment of traffic safety in urban deer herd management zones.

5.2 Methodology

The frequency of deer-vehicle crashes in a deer management zone and the frequency of injuries in deer-vehicle crashes are properly modeled using count data models, the most popular of which are Poisson and negative binomial regression models. One requirement of the Poisson distribution is that the mean of the count process equals its variance. When the variance is significantly larger than the mean, the data are said to be overdispersed and can be properly modeled using a negative binomial model (Washington et al. 2003). In this study, the frequency of deer-vehicle crashes in a deer management zone was estimated using a negative binomial model (because overdispersion was present), while the frequency of injuries in deer-vehicle crashes was estimated using a Poisson regression model.

In modeling deer-vehicle crash severity, two possible discrete outcomes were considered when a vehicle was involved in a crash with a deer: no injury (property damage only), and injury (possible/ unknown, minor, or major injury or fatality). While it was of interest to examine the factors that influence injury severities, there were not enough observations to draw statistically significant conclusions about the factors that influence each injury severity outcome (possible/ unknown, minor, or major injury or fatality).

5.2.1 Poisson Regression

For a non-negative integer variable, Y, with observed frequencies, $y_i,\ i = 1, \dots, N$, the probability of y_i (in this case, deer-vehicle injuries) at i is given by

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!}, \tag{1}$$

where λ_i is the Poisson parameter for i, which is equal to the expected frequency of deer-vehicle injuries at i, $E[y_i]$.

The log-linear model form used in this study to predict the expected number of injuries in deer-vehicle crashes is shown in equation (2).

$$\ln(\lambda_i) = \beta_i \cdot x_i, \tag{2}$$

where x_i is a vector of explanatory variables, and β_i is a vector of estimable parameters by maximum likelihood estimation techniques. To assess the vector of estimated coefficients (β_i), the authors calculated elasticities, which measure the magnitude of the impact of specific variables on the expected frequency. The elasticity of frequency λ_i is defined as

$$E_{x_{ik}}^{\lambda_i} = \frac{\partial \lambda_i}{\partial x_{ik}} \times \frac{x_{ik}}{\lambda_i} = \beta_k \cdot x_{ik}, \tag{3}$$

where *E* represents the elasticity , x_{ik} is the value of the *k*th independent variable for observation i, and β_k is the estimated parameter for the *k*th independent variable. Elasticity values can be interpreted as the percent effect that a 1% change in x_{ki} has on the expected frequency λ_i.

Note that elasticities are not applicable to indicator variables that take on values of 0 or 1. The pseudoelasticity for indicator variables represents the percent change on the expected frequency λ_i when the variable is changed from zero to one and is computed as

$$E_{x_{ik}}^{\lambda_i} = \frac{EXP(\beta_k) - 1}{EXP(\beta_k)} \times 100. \tag{4}$$

5.2.2 Negative Binomial Regression

The negative binomial regression model is an extension of the Poisson regression model, which allows the variance of the process to differ from the mean. One way that the model arises is as a modification of the Poisson model in which λ_i is specified so that

$$\ln(\lambda_i) = \beta_i \cdot x_i + \varepsilon_i, \tag{5}$$

where $EXP(\varepsilon_i)$ follows a gamma distribution with mean 1.0 and variance α^2. This model has an additional parameter, α, which is often referred to as the overdispersion parameter, such that

$$VAR[y_i] = E[y_i] \cdot [1 + \alpha \cdot E[y_i]]. \tag{6}$$

5.2.3 Binary Probit Model

For two crash injury severity outcomes, the binary probit model defines a function that determines injury severity as

$$W_{in} = \beta_i x_{in} + \varepsilon_{in}, \tag{7}$$

where W_{in} is the function that determines the probability of discrete injury severity outcome i for crash n, x_{in} is a vector of measurable characteristics (crash, road, and land use characteristics) that determine the injury severity for crash n, β_i is a vector of estimable coefficients, and ε_{in} is an error term that accounts for unobserved effects that influence the injury severity outcome i for crash n.

It can be shown that if ε_{in} is assumed to be normally distributed (McFadden 1981), then a standard binary probit model results, and the probability $P_n(i)$ that crash n will result in no injury outcome i is given as

$$P_n(i) = \frac{EXP[\beta_i x_i]}{1+EXP(\beta_i x_i)}. \tag{8}$$

To assess the vector of estimated coefficients (β_i), the authors calculated elasticities, which measure the magnitude of the impact of specific variables on the outcome probabilities. The elasticity is computed for each crash n (n subscripting omitted) as

$$E_{x_{ki}}^{P(i)} = \frac{\partial P(i)}{\partial x_{ki}} \times \frac{x_{ki}}{P(i)}, \tag{9}$$

where $P(i)$ is the probability of no injury outcome I, and x_{ki} is the value of variable k for outcome i. Combining Equation (8) with Equation (9) gives

$$E_{x_{ki}}^{P(i)} = [1 - P(i)] \cdot \beta_{x_{ki}} \cdot x_{ki}., \tag{10}$$

where β_{ki} is the estimated coefficient associated with variable x_{ki}. Elasticity values can be roughly interpreted as the percent effect that a 1% change in x_{ki} has on the crash injury severity outcome probability $P(i)$.

The pseudoelasticity for indicator variables can be calculated as

$$E_{x_{ki}}^{P(i)} = \left[\frac{EXP(\beta_{ki})[1+EXP(\beta_i x_i)]}{1+EXP(\Delta\beta_i x_i)} - 1\right] \times 100, \tag{11}$$

where $\Delta(\beta_i x_i)$ is the value of the function (see Equation [7]) that determines the crash injury severity level after x_{ki} has been changed from zero to one, and $\beta_i x_i$ is the value when $x_{ki} = 0$. The pseudoelasticity of a variable with respect to a crash injury severity outcome category represents the percent change in the probability of that severity category when the variable is changed from zero to one.

5.3 Estimation Results

5.3.1 Frequency of Deer-Vehicle Crashes in Urban Deer Management Zones

A negative binomial regression model was estimated to investigate the factors that influence the frequency of deer-vehicle crashes in urban deer management zones. The dependent variable was the number of crashes/zone. A total of 29 zones within the 3 urban areas were considered, and the number of crashes, the deer population, and land cover per zone were recorded for each analysis year (2002 to 2007). As noted in Section 3.2, some zones in some survey years had no deer population data counted, leading to a final sample consisting of 108 observations (instead of 174 for 29 zones times 6 years). Table 5.1 shows the estimation results. The model output is provided in Appendix E.1.

Table 5.1. Negative binomial regression model for frequency of deer-vehicle crashes in urban deer management zones

Variable	Estimated Coefficient	Elasticity[a]	*t*-Statistic
Constant	1.764		4.42
Deer density	0.014	0.41	3.27
City	–1.684	–1.00	–4.04
Commercial and residential land	4.000	0.29	2.07
Cropland	2.745	0.51	1.73
Overdispersion parameter α	0.516		5.45
Number of observations		108	
Log-likelihood at zero		–519.95	
Log- likelihood at convergence		–320.95	

[a] Reported elasticities are estimated by sample enumeration

As expected, the frequency of deer-vehicle crashes in urban deer management zones is higher in zones with higher deer density.[2] A 1% increase in the zonal deer density increases the frequency of deer-vehicle crashes by 0.4%. Turning to the land-use–related variables, the frequency of deer-vehicle crashes is expected to be lower in zones with a higher percentage of land within the city limits (elasticity of –1.002) but higher in zones with higher percentages of crop acreage and residential and commercial acreage. A 1% increase in the ratio of cropland acreage increases the expected frequency by 0.5%, which is nearly twice as much as the effect of a 1% increase in the ratio of residential and commercial acreage. These findings are likely impacted by the level of human migration into deer habitats.

It was also of interest to examine the interaction effect of land use and deer density. Table 5.2 shows that the interaction effects of deer density with city, commercial/residential land, and cropland are highly significant. The model output is provided in Appendix E.1.

[2] Deer density was found to be a more significant predictor of deer-vehicle crashes in city zones, compared to deer population.

Table 5.2. Negative binomial regression model for frequency of deer-vehicle crashes in urban deer management zones—interaction effects

Variable	**Estimated Coefficient**	**Elasticity[a]**	***t*-Statistic**
Constant	1.852		12.60
Deer density * City	–0.047	–0.83	–3.67
Deer density * Commercial and residential land	0.157	0.66	2.93
Deer density * Cropland	0.180	0.36	5.25
Overdispersion parameter α	0.580		5.07
Number of observations		108	
Log-likelihood at zero		–567.56	
Log- likelihood at convergence		–326.47	

[a] Reported elasticities are estimated by sample enumeration

5.3.2 Frequency of Injuries in Deer-Vehicle Collisions in Urban Deer Management Zones

As discussed in Chapter 4, a total of 921 crashes were reported from 2002 to 2007, which resulted in 2 fatalities and 117 injuries. A Poisson regression model was estimated to investigate the factors that influence the frequency of injuries resulting from a deer-vehicle collision. Table 5.3 shows the estimation results. The model output is provided in Appendix E.2.

Table 5.3. Poisson regression model for frequency of injuries in deer-vehicle collisions

Variable	Estimated Coefficient	Elasticity[a]	*t*-Statistic
Constant	–1.942		–4.95
Crash-Specific Variables			
Light conditions—Dark	0.450	36.2	2.38
Month of crash—October, November or December	–0.303	–35.4	–1.61
Year of crash (1: 2002 to 6: 2007)	0.227	0.83	3.89
Road-Specific Variables			
Shoulder type–right: Gravel	–0.660	–93.5	–3.04
Shoulder width–left	–0.078	–0.33	–1.98
Speed limit of road on which vehicle was traveling—Below 55 mph	–0.508	–66.1	–2.42
Land Use-Specific Variables			
Cropland	1.002	0.15	1.96
Roads	–6.451	–0.39	–1.80
Number of observations		921	
Log-likelihood at zero		–369.20	
Log- likelihood at convergence		–344.57	

[a] Reported elasticities are estimated by sample enumeration. Elasticities for indicator variables (0, 1) represent the percent change on the expected frequency following a change in the variable from zero to one (see Equation [4]).

It was found that the frequency of deer-vehicle injuries increased from 2002 to 2007. Further, deer-vehicle crashes on dark roads were more likely to result in a higher number of injuries, while deer-vehicle crashes on roads with a posted speed limit below 55 mph, roads with a gravel right shoulder, and roads with a wider left shoulder[3] were less likely to result in a higher number of injuries. Elasticity estimation showed that a 1% increase in the width of the left shoulder decreases the expected injury frequency by 0.3%. Elasticity estimation also showed that a right gravel shoulder influences the expected frequency of deer-vehicle injuries at a higher degree (elasticity of –93.5%) compared to speed limit (elasticity of –66.1%) and light conditions (elasticity of –36.2%).

While a higher number of deer-vehicle crashes occurred in October, November, and December, the frequency of injuries resulting from these crashes was found to be lower. This could be attributed to higher driver awareness and perceived risk of the presence of deer on roadways during the mating season as a result of safety campaigns (Iowa Department of Public Safety 2006), which are typically organized during that season. For land-use–specific variables, the frequency of deer-vehicle injuries is higher in zones with a larger percentage of cropland (elasticity of 0.150%) and lower in zones with a higher percentage of roads (elasticity of –0.387%).

[3] Note that, generally, the left and right shoulders are the same width on undivided, two-lane roadways. As such, the presence of wider shoulders on this type of facility is recommended.

The interaction effect of cropland and deer density was found to be positive and significant on the frequency of injuries resulting from a deer-vehicle collision. However, that model specification resulted in a lower overall statistical fit than the one presented in Table 5.3 and, as such, it is presented in Appendix E.2. Interestingly, the AADT and deer population or deer density were not found to be significant determinants of the frequency of deer-vehicle injuries.

5.3.3 Severity of Deer-Vehicle Crashes in Urban Deer Management Zones

The estimation results for the binary probit model for crash severity outcomes (no injury and injury) in urban deer management zones in Iowa between 2002 and 2007 are presented in Table 5.4. The model output is provided in Appendix E.3.

Table 5.4. Binary probit model estimation results for deer-vehicle crash severity outcome [a]

Variable	Estimated Coefficient	Elasticity[b]	*t*-Statistic
Constant	0.366		0.81
Crash-Specific Variables			
Single-occupant vehicle	0.711	18.0	5.75
Year of crash (1: 2002 to 6: 2007)	–0.133	–0.07	–3.61
Day of crash—Friday	0.356	7.2	2.02
Road surface—Dry	–0.237	–5.0	–1.96
Road-Specific Variables			
Functional classification—Other principal arterial	–0.368	–7.5	–2.08
Shoulder type–right: Gravel	0.527	12.2	3.19
Speed limit of road on which vehicle was traveling—Over 55 mph	–0.469	–10.1	–3.15
Natural logarithm of Annual Average Daily Traffic	0.117	0.12	2.30
Land Use-Specific Variables			
Cropland	–0.911	–0.02	–2.51
Roads	3.125	0.02	1.52
Number of observations	921		
Log-likelihood at zero	–322.69		
Log- likelihood at convergence	–280.35		

[a] Results presented for the no-injury outcome
[b] Reported elasticities are estimated by sample enumeration. Elasticities for indicator variables (0, 1) represent the percent change in the probability following a change in the variable from zero to one (see Equation [11]).

For crash-specific variables, findings show that the outcome of deer-vehicle crashes involving single-occupant vehicles was more likely to be no injury, while over time (2002 to 2007) the outcome of crashes was more likely to be an injury. Crashes that occurred on Fridays were more likely to result in no injury, while crashes on dry road conditions were more likely to result in injury. The latter finding can relate more generally to risk perception and risk-compensating (or offsetting) behavior in which drivers adjust their driving behavior in response to situations that can be perceived as comparatively dangerous or safe (for example, dry road conditions can be perceived as comparatively safe). Elasticity estimation showed that vehicle occupancy influences the expected severity outcome at a higher degree (elasticity of 18%) compared to day of crash (elasticity of 7.2%) and road surface (elasticity of −5.0%).

For road-specific variables, the outcome of deer-vehicle crashes on principal arterials and on roads with a posted speed limit over 55 mph was more likely to be injury. These findings are likely picking up the effect of impact speed on the severity outcome of a crash, with higher speeds resulting in more severe outcomes. Crashes on roads with a gravel right shoulder and higher traffic volume were more likely to result in no injury. Elasticity estimation showed that a 1% increase in the natural logarithm of AADT increases the probability of a no-injury outcome by 0.12%.

For land-use–specific variables, the outcome of deer-vehicle crashes in zones with a larger percentage of cropland was more likely to be injury, while crashes in zones with a higher percentage of roads were more likely to result in no injury. These findings are consistent with the Poisson regression estimation results that suggested a higher frequency of deer-vehicle injuries in zones with a larger percentage of cropland and a lower frequency of deer-vehicle injuries in zones with a larger percentage of roads.

The interaction effect of cropland and deer density was found to be negative and significant on the outcome of deer-vehicle crashes (which is more likely to be an injury). However, that model specification resulted in a lower overall statistical fit than the one presented in Table 5.4. These results are presented in Appendix E.3.

5.4 Summary/Conclusions

The authors found that deer density is a more significant predictor of the frequency of deer-vehicle crashes in urban deer management zones than deer herd size. Further, the frequency of deer-vehicle crashes was higher in zones with a higher percentage of residential and commercial acreage, which confirms the adverse safety impacts of human migration into deer habitats. The interaction effects of deer density and some types of land use (cropland, city, commercial, and residential land) were also found to be significant. The severity outcomes and the number of injuries that resulted from a deer-vehicle collision were determined as a function of crash-, road-, and land-use–specific factors. Overall, the frequency of deer-vehicle injuries increased over the study period in the three urban deer management areas, which may be attributed to an increase in the VMT and a higher deer population.[4] While the frequency of crashes is higher on roads with a posted speed limit below 55 mph, these crashes are less likely to result in injury, probably because of lower impact speeds that result in a less severe outcome. Results also indicated that the severity outcome and corresponding number of injuries were lower on roads with a gravel right shoulder. Further, the expected frequency of deer-vehicle injuries was lower on roads with

[4] However, traffic volume and deer herd size were not significant explanatory variables in the Poisson regression model for frequency of injuries in deer-vehicle collisions.

a wider left shoulder. The fact that the expected frequency of crashes is higher on undivided roads may suggest the potential benefits of a wider left shoulder in the absence of a median barrier. It is also interesting to note the significant predictive values of non-roadway factors (land use characteristics) in both the frequency of deer-vehicle crashes and corresponding injury outcome.

6. CONCLUSIONS AND RECOMMENDATIONS

Special deer herd management plans are implemented in urban areas in Iowa to keep the deer population at a sustainable level. While these plans may reduce the deer population in an area, traffic safety in these areas has not been fully assessed. The main objective of this study was to investigate the relationship between deer-vehicle collisions, deer density, and land use in select urban deer management zones in Iowa over the period 2002–2007. Three urban areas in Iowa that have a deer management plan in place were selected for this study: Cedar Rapids, Dubuque, and Iowa City. Three different databases were used in this study: first, deer population counts from 1997 to 2008 were acquired from the Iowa DNR; second, deer carcass removal locations on primary roads and corresponding carcass counts were provided by the Iowa DOT; and third, deer-vehicle crash data from 2002 to 2007 were gathered from the Iowa DOT. Results from this study can assist in a better assessment of traffic safety in urban deer herd management zones and could be of interest to transportation, ecology, and deer management communities.

The comparison of deer-vehicle crash counts and deer carcass removal counts in the three counties confirmed the statewide trend that was documented in a study conducted by Knapp et al. (2007), which is that the number of deer carcasses removed in these counties was greater than the number of reported deer-vehicle crashes. These differences were statistically significant in two of the three counties we examined. While it was not possible to conduct this comparison at the city level, the authors compared these counts by route and found high rates of crash underreporting on major routes that carry high traffic volumes, such as I-380. Furthermore, the discrepancies in the number of reported crashes and carcasses were more pronounced in the city of Cedar Rapids, especially within the city limits. This may be attributed to a Cedar Rapids Police Department policy (Betz 2009) that does not require police officers to compile crash reports for property damage only crashes. As a result, an assessment of traffic safety in Cedar Rapids based only on deer-vehicle crashes would not be enlightening for the traffic safety problems.

This study also examined the factors that influence the frequency of deer-vehicle crashes in the three selected urban deer management zones. The majority of deer-vehicle crashes in urban deer management zones involved single vehicles with one to two occupants. Further, the frequency of crashes was higher on undivided roads, on roads with a posted speed limit below 55 mph, on dry roads, and on roads with dark lighting conditions. Half of the deer-vehicle crashes that were reported during the analysis period occurred during the deer mating season—in October, November, or December. These findings are consistent with previous research on deer-vehicle collisions (Huijser et al. 2007a). The statistical analysis showed that deer density is a more significant predictor of the frequency of deer-vehicle crashes in urban deer management zones than deer herd size. Further, the frequency of deer-vehicle crashes was higher in zones with a higher percentage of residential and commercial acreage, which confirms the adverse safety impacts of human migration into deer habitats. While a reduction in deer density may not be attainable in all zones, efforts are recommended to reduce deer density adjacent to roads and developed land. Interestingly, while previous work in Alabama (Hussain et al. 2007) showed that a high proportion of cropland reduced the frequency of deer-vehicle collisions, the authors found that the frequency of deer-vehicle crashes was higher in zones with a higher percentage of cropland. The authors speculate that this is attributed to the different types of crops that are grown in Iowa (corn) and Alabama (cotton), as well as differences in the study design and scale of analysis.

The severity outcomes and the number of injuries that resulted from a deer-vehicle collision were determined as a function of crash-, road-, and land-use–specific factors. Overall, the frequency of deer-vehicle injuries has increased over time in the three urban deer management areas, which may be attributed to an increase in the VMT and a higher deer population. However, traffic volume and deer herd size variables did not explain the frequency of injuries in deer-vehicle collisions. This is in line with past work (Bissonette and Kassar 2008) that showed no relationship between traffic volume and deer-vehicle collisions in Utah. While the frequency of crashes is higher on roads with a posted speed limit below 55 mph, these crashes are less likely to result in injury, probably because of lower impact speeds that result in a less severe outcome. Further, the expected frequency of deer-vehicle injuries was lower on roads with wider shoulders. The fact that the expected frequency of crashes is higher on undivided roads may suggest the potential benefits of the presence of wider shoulders on these roads.

This study showed that multiple factors affect deer-vehicle crashes and corresponding outcomes in urban management zones. Past work has reached similar conclusions at the county level (Farrell and Tappe 2007). It is also interesting to note the significant predictive values of non-roadway factors (land-use–related variables) in both the frequency of deer-vehicle crashes and corresponding injury outcomes. The identified roadway and non-roadway factors could be useful for identifying locations on the transportation system that significantly impact deer species and safety and for determining appropriate mitigation countermeasures.

Additional recommendations to the Iowa DOT and Iowa DNR regarding the current herd reduction programs and traffic safety in these areas over time are summarized as follows:

Data collection: The lack of accurate and consistent reporting of deer carcass removals and deer-vehicle crashes, as well as the absence of deer population counts for some zones in some years of the study period, are important limitations of these data. In addition, deer carcasses are mainly collected on primary roadways, and very little carcass data are reported on the secondary roadways in Iowa. Not considering the secondary roadway system leaves many deer-vehicle crashes unaccounted for. It is desirable to improve the consistency and accuracy of deer carcass and deer-vehicle collision data collection methods and practices. Providing maintenance crews with GPS units to record the location of deer carcasses could improve the accuracy of carcass reporting.

Countermeasures: The literature review showed that different countermeasures have been implemented over time to reduce the occurrence of deer-vehicle crashes. Many countermeasures, such as deer whistles and deer flagging models, have been proven ineffective. A few countermeasures, such as wildlife crossings and deer fencing, have been proven effective (but at a higher cost), but some countermeasures (including herd management) require more research to evaluate their effectiveness. In Iowa, some of these countermeasures that have been proven ineffective are still being implemented or maintained, such as reflectors in Iowa City (City of Iowa City 2008). The use of these countermeasures should be reconsidered in terms of effectiveness, level of investment, and maintenance costs. Countermeasure locations are critical to their effectiveness. These countermeasures must also be properly maintained to sustain their effectiveness. For the countermeasures that require more research to evaluate their effectiveness, caution should be exercised if implementing one of these countermeasures is pursued so that undue harm is not caused to the driving public or to the wildlife. Moreover, continuous monitoring can detect changes in the effectiveness of the countermeasures due to changes in driver behavior or animal adaptation. Last, findings should be properly documented for future reference.

Urban Planning and Management Implications: Results from this study illustrated the impact of urban development on deer habitat and densities and, subsequently, on deer-vehicle crashes. Urban planners and officials need to account for these interactions early during urban planning efforts, determine how to minimize impacts to wildlife during planning, and monitor future trends.

Special herd management hunts in urban areas cannot be fully assessed as effective based solely on their effect on traffic safety. In many cases, it appeared that the special hunts are not keeping pace with the growth in both the deer population and traffic volume. These aspects have made it difficult to assess the impacts that these hunts have on traffic safety. While this study was able to identify correlations between deer population, land use, and deer-vehicle crashes, the overall effectiveness of urban deer management plans was not examined. Reductions in property and crop damage are other important measures of effectiveness that need to be considered for an accurate assessment to be made. A comprehensive, multidisciplinary study on all measures of effectiveness could help assess the deer management plans.

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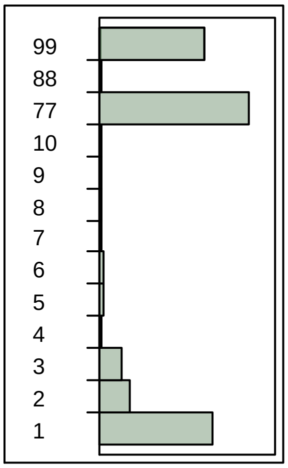
APPENDIX A. DEER-VEHICLE CRASH DATA

The following graphs and table are a descriptive analysis of deer-vehicle crash data for Dubuque, Johnson, and Linn Counties for the study period 2002 to 2007.

WEATHER1

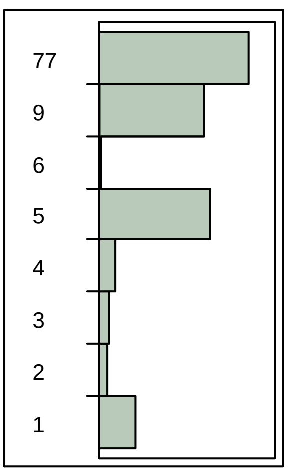


Frequencies

Level	Count	Prob	
1	1217	0.25795	Clear
2	327	0.06931	Partly Cloudy
3	245	0.05193	Cloudy
4	35	0.00742	Fog/smoke
5	47	0.00996	Mist
6	64	0.01357	Rain
7	8	0.00170	Sleet/hail/freezing rain
8	27	0.00572	Snow
9	9	0.00191	Severe winds
10	6	0.00127	Blowing sand/soil/dirt/snow
77	1605	0.34019	Not reported
88	2	0.00042	Other (explain in narrative)
99	1126	0.23866	Unknown
Total	4718	1.00000	

N Missing 0
13 Level

LIGHT

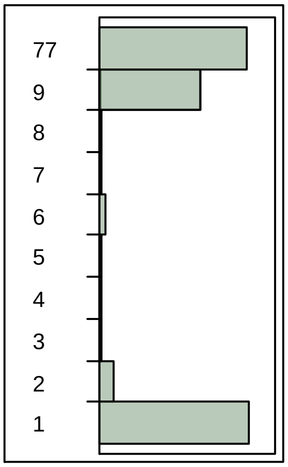


Frequencies

Level	Count	Prob	
1	392	0.08309	Daylight
2	100	0.02120	Dusk
3	116	0.02459	Dawn
4	175	0.03709	Dark - roadway lighted
5	1178	0.24968	Dark - roadway not lighted
6	41	0.00869	Dark - unknown roadway lighting
9	1124	0.23824	Unknown
77	1592	0.33743	Not reported
Total	4718	1.00000	

N Missing 0
8 Levels

CSURFCOND

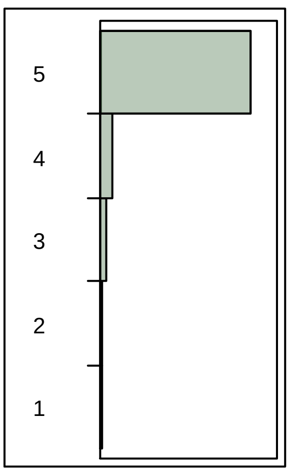


Frequencies

Level	Count	Prob	
1	1666	0.35312	Dry
2	171	0.03624	Wet
3	10	0.00212	Ice
4	23	0.00487	Snow
5	5	0.00106	Slush
6	72	0.01526	Sand/mud/dirt/oil/gravel
7	1	0.00021	Water (standing/moving)
8	3	0.00064	Other (explain in narrative)
9	1119	0.23718	Unknown
77	1648	0.34930	Not Reported
Total	4718	1.00000	

N Missing 0
10 Levels

CSEVERITY

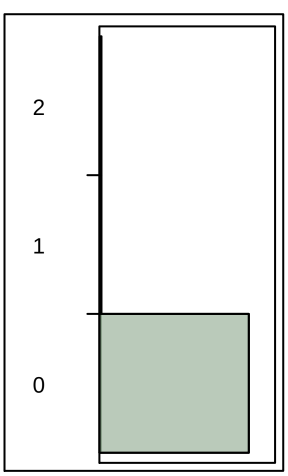


Frequencies

Level	Count	Prob	
1	5	0.00106	Fatal
2	27	0.00572	Major
3	172	0.03646	Minor
4	369	0.07821	Possible/unknown
5	4145	0.87855	PDO
Total	4718	1.00000	

N Missing 0
5 Levels

FATALITIES

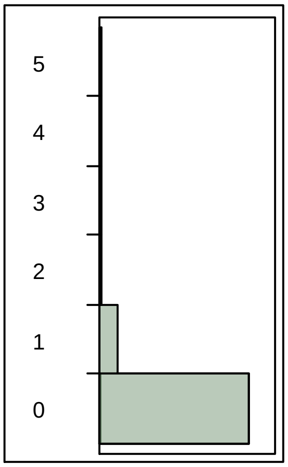


Frequencies

Level	Count	Prob
0	4713	0.99894
1	4	0.00085
2	1	0.00021
Total	4718	1.00000

N Missing 0
3 Levels

INJURIES

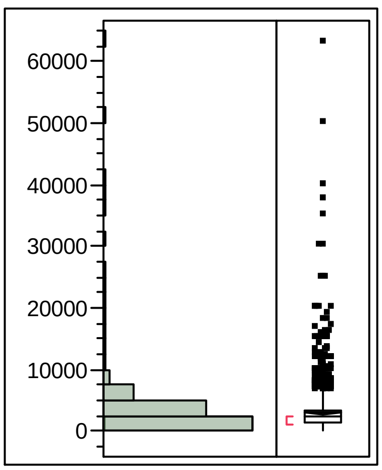


Frequencies

Level	Count	Prob
0	4149	0.87940
1	504	0.10682
2	55	0.01166
3	6	0.00127
4	3	0.00064
5	1	0.00021
Total	4718	1.00000

N Missing 0
6 Levels

PROPDMG



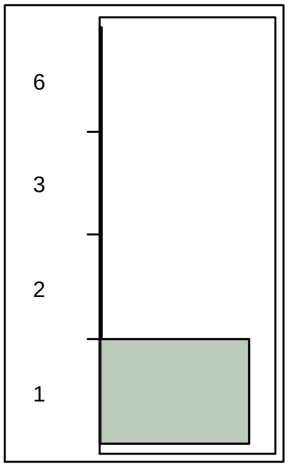
Quantiles

100.0%	maximum	63000
99.5%		15621
97.5%		8800
90.0%		5000
75.0%	quartile	3503
50.0%	median	2397
25.0%	quartile	1500
10.0%		1000
2.5%		1000
0.5%		0
0.0%	minimum	0

Moments

Mean	2954.9585
Std Dev	2718.7365
Std Err Mean	39.581126
upper 95% Mean	3032.5559
lower 95% Mean	2877.361
N	4718

VEHICLES



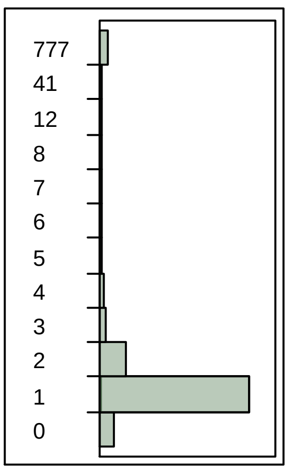
Frequencies

Level	Count	Prob
1	4607	0.97647
2	97	0.02056
3	13	0.00276
6	1	0.00021
Total	4718	1.00000

N Missing 0
4 Levels

Single-vehicle

TOCCUPANTS



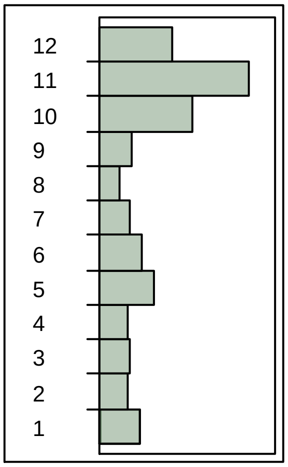
Frequencies

Level	Count	Prob
0	320	0.06783
1	3291	0.69754
2	601	0.12738
3	157	0.03328
4	92	0.01950
5	33	0.00699
6	8	0.00170
7	5	0.00106
8	2	0.00042
12	1	0.00021
41	1	0.00021
777	207	0.04387
Total	4718	1.00000

N Missing 0
12 Levels

1-2 occupants

MONTH

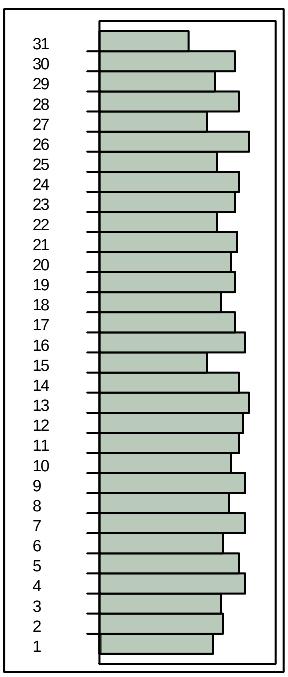


Frequencies

Level	Count	Prob
1	311	0.06592
2	219	0.04642
3	231	0.04896
4	217	0.04599
5	420	0.08902
6	318	0.06740
7	227	0.04811
8	154	0.03264
9	250	0.05299
10	700	0.14837
11	1121	0.23760
12	550	0.11657
Total	4718	1.00000

N Missing 0
12 Levels

DAYOFMONTH



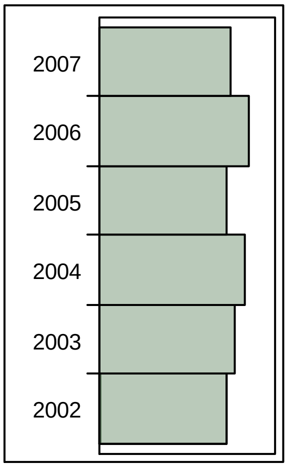
Frequencies

Level	Count	Prob
1	131	0.02777
2	143	0.03031
3	141	0.02989
4	170	0.03603
5	162	0.03434
6	143	0.03031
7	170	0.03603
8	151	0.03201
9	170	0.03603
10	152	0.03222
11	163	0.03455
12	167	0.03540
13	174	0.03688
14	162	0.03434
15	126	0.02671
16	170	0.03603
17	157	0.03328
18	142	0.03010
19	157	0.03328
20	153	0.03243
21	160	0.03391
22	137	0.02904
23	158	0.03349
24	162	0.03434
25	137	0.02904
26	173	0.03667
27	126	0.02671
28	163	0.03455
29	135	0.02861
30	158	0.03349
31	105	0.02226
Total	4718	1.00000

N Missing 0
31 Levels

Almost equally distributed

YEAR

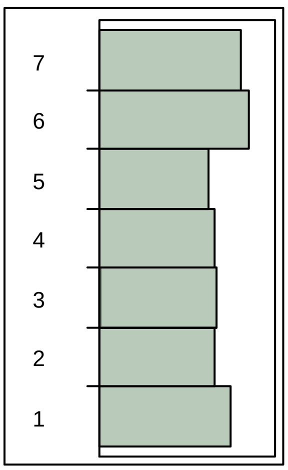


Frequencies

Level	Count	Prob
2002	732	0.15515
2003	783	0.16596
2004	842	0.17847
2005	735	0.15579
2006	866	0.18355
2007	760	0.16109
Total	4718	1.00000

N Missing 0
6 Levels

DAY

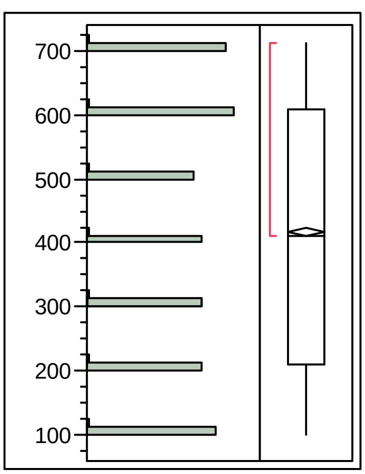


Frequencies

Level	Count	Prob
1	707	0.14985
2	621	0.13162
3	626	0.13268
4	622	0.13184
5	584	0.12378
6	803	0.17020
7	755	0.16003
Total	4718	1.00000

N Missing 0
7 Levels
1 is Sunday

TIMEDAY



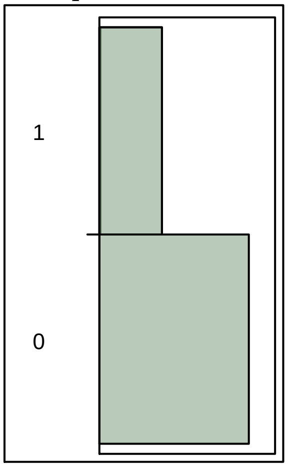
Quantiles

100.0%	maximum	713.00
99.5%		712.00
97.5%		711.00
90.0%		708.00
75.0%	quartile	610.00
50.0%	median	410.00
25.0%	quartile	211.00
10.0%		110.00
2.5%		103.00
0.5%		101.00
0.0%	minimum	101.00

Moments

Mean	417.81708
Std Dev	206.08787
Std Err Mean	3.0003606
upper 95% Mean	423.69919
lower 95% Mean	411.93498
N	4718

Dubuque

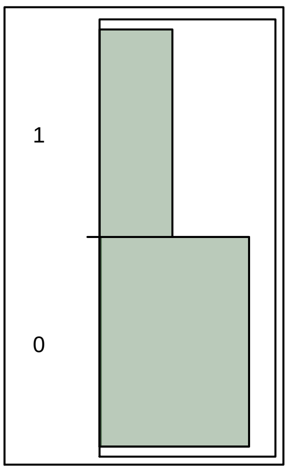


Frequencies

Level	Count	Prob
0	3317	0.70305
1	1401	0.29695
Total	4718	1.00000

N Missing 0
2 Levels

Johnson

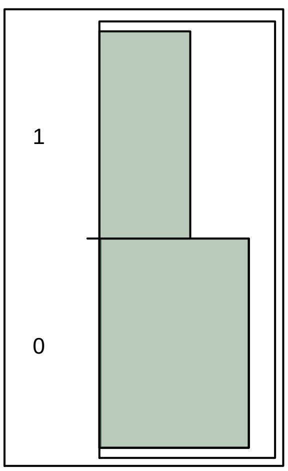


Frequencies

Level	Count	Prob
0	3179	0.67380
1	1539	0.32620
Total	4718	1.00000

N Missing 0
2 Levels

Linn

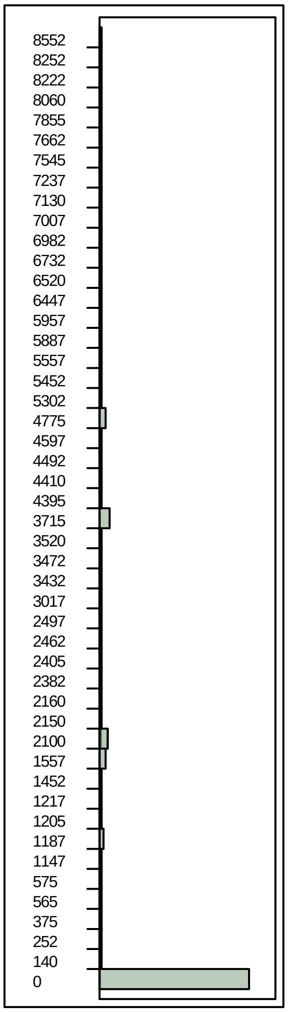


Frequencies

Level	Count	Prob
0	2940	0.62315
1	1778	0.37685
Total	4718	1.00000

N Missing 0
2 Levels

CITYBR

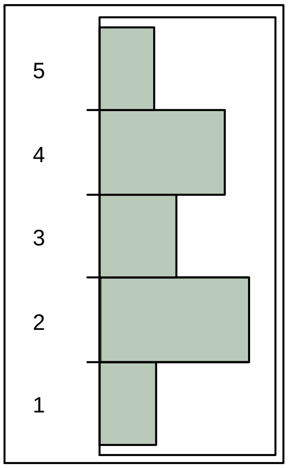


Frequencies

N Missing 0
48 Levels

Level	Count	Prob	
0	3503	0.74248	
140	1	0.00021	AMANA (Un-incorporated.)
252	3	0.00064	ASBURY
375	3	0.00064	BALLTOWN
565	1	0.00021	BERNARD
575	2	0.00042	BERTRAM
1147	3	0.00064	CASCADE(2)
1187	130	0.02755	CEDAR RAPIDS
1205	9	0.00191	CENTER POINT
1217	17	0.00360	CENTRAL CITY
1452	7	0.00148	COGGON
1557	144	0.03052	CORALVILLE
2100	222	0.04705	DUBUQUE
2150	3	0.00064	DURANGO
2160	69	0.01462	DYERSVILLE
2382	10	0.00212	ELY
2405	2	0.00042	EPWORTH
2462	2	0.00042	FAIRFAX
2497	3	0.00064	FARLEY
3017	1	0.00021	GRAF
3432	20	0.00424	HIAWATHA
3472	4	0.00085	HILLS
3520	2	0.00042	HOLY CROSS
3715	262	0.05553	IOWA CITY
4395	2	0.00042	LINN GROVE
4410	12	0.00254	LISBON
4492	2	0.00042	LONE TREE
4597	2	0.00042	LUXEMBURG
4775	182	0.03858	MARION
5302	14	0.00297	MOUNT VERNON
5452	1	0.00021	NEW VIENNA
5557	19	0.00403	NORTH LIBERTY
5887	3	0.00064	PALO
5957	5	0.00106	PEOSTA
6447	1	0.00021	RICKARDSVILLE
6520	11	0.00233	ROBINS
6732	5	0.00106	SAGEVILLE
6982	1	0.00021	SHERRILL
7007	4	0.00085	SHUEYVILLE
7130	7	0.00148	SOLON
7237	6	0.00127	SPRINGVILLE
7545	2	0.00042	SWISHER
7662	10	0.00212	TIFFIN
7855	1	0.00021	UNIVERSITY HEIGHTS
8060	1	0.00021	WALFORD(2)
8222	1	0.00021	WELLMAN
8252	2	0.00042	WEST BRANCH(2)
8552	1	0.00021	WORTHINGTON
Total	4718	1.00000	

SYSCODE



Frequencies

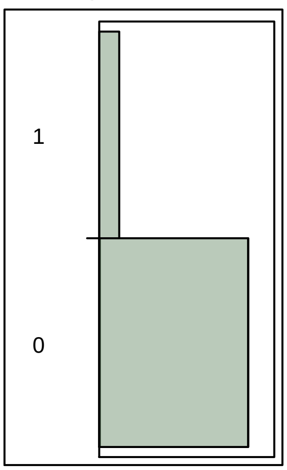
Level	Count	Prob	
1	574	0.12166	Interstate
2	1518	0.32175	US Route
3	794	0.16829	Iowa Route
4	1276	0.27045	Farm to Market Route
5	556	0.11785	Local Road
Total	4718	1.00000	

N Missing 0
5 Levels

Indicates the state assigned system for the road segment.
Also see FEDFUNC

Code	Description
1	Interstate
2	US Route
3	Iowa Route
4	Farm to Market Route
5	Local Road

INTERSTATE



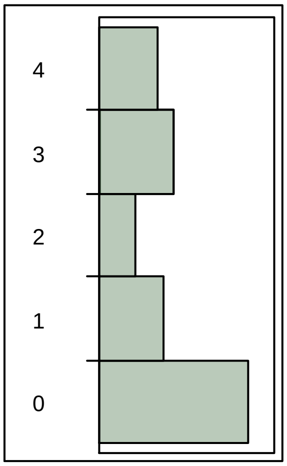
Frequencies

Level	Count	Prob
0	4144	0.87834
1	574	0.12166
Total	4718	1.00000

N Missing 0
2 Levels

This field indicates whether or not a road system is classified as an interstate traveled way.

ACCESSCNTL



Frequencies

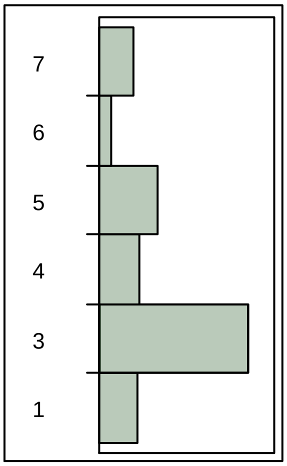
Level	Count	Prob	
0	1832	0.38830	No Access Control (not presently used)
1	793	0.16808	Interstate and Freeway
2	460	0.09750	Expressway
3	916	0.19415	Planned Access with through traffic given primary consideration
4	717	0.15197	Planned Access with through traffic and land services traffic given equal consideration
Total	4718	1.00000	

N Missing 0
5 Levels

This field indicates the type and number of points at which traffic is allowed to enter or exit a roadway. Access control is on primary roads only and is obtained from the color-coded map provided by the Office of Maintenance.

Code	Description
0	No Access Control (not presently used)
1	Interstate and Freeway
2	Expressway
3	Planned Access with through traffic given primary consideration
4	Planned Access with through traffic and land services traffic given equal consideration

FEDFUNC



Frequencies

Level	Count	Prob	
1	550	0.11657	Interstate
3	2073	0.43938	Other Principal Arterial
4	579	0.12272	Minor Arterial
5	826	0.17507	Major Collector
6	193	0.04091	Minor Collector (rural only)
7	497	0.10534	Local
Total	4718	1.00000	

N Missing 0

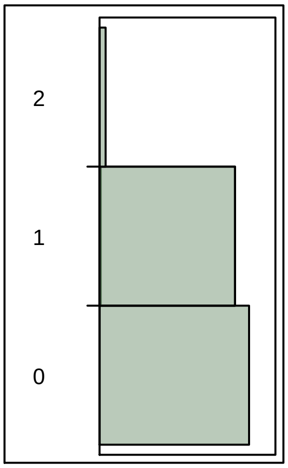
also see SYSCODE

6 Levels

This field indicates the federal functional classification of the road segment.

Code	Functional Classification
1	Interstate
3	Other Principal Arterial
4	Minor Arterial
5	Major Collector
6	Minor Collector (rural only)
7	Local

TRUCKRTE



Frequencies

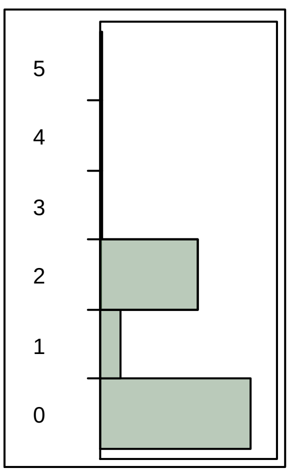
Level	Count	Prob	
0	2409	0.51060	Not on a Truck Route
1	2182	0.46248	Federal Truck Route
2	127	0.02692	State Truck Route
Total	4718	1.00000	

N Missing 0
3 Levels

This field indicates whether or not the road is on a truck route on the primary road system only.

Code	Description
0	Not on a Truck Route
1	Federal Truck Route
2	State Truck Route

MEDTYPE



Frequencies

Level	Count	Prob	
0	2605	0.55214	No barrier (< .152 meter curb)
1	354	0.07503	Hard surface without barrier (Raised Median) (PV)
2	1700	0.36032	Grass surface without barrier (SL)
3	15	0.00318	Hard surface with barrier (PV-BR)
4	35	0.00742	Grass surface with barrier (SL-BR)
5	9	0.00191	Barrier (> .152 meters) (Jersey barrier, center of road parking, etc.)
Total	4718	1.00000	

N Missing 0
6 Levels

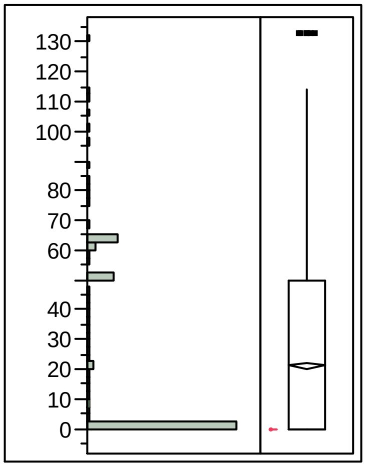
The characteristics of the median on all road sections are entered using the following criteria. If median has a curb, the curb is placed on the inside shoulder. A barrier is .152 meters or more. A painted median is not considered a median.

Code	Description
0	No barrier (< .152 meter curb)
1	Hard surface without barrier (Raised Median) (PV)
2	Grass surface without barrier (SL)
3	Hard surface with barrier (PV-BR)
4	Grass surface with barrier (SL-BR)
5	Barrier (> .152 meters) (Jersey barrier, center of road parking, etc.)

MEDWIDTH

This code indicates the width of the median between the edges of traffic lanes recorded to the nearest foot. This field is applicable for all road systems

Quantiles

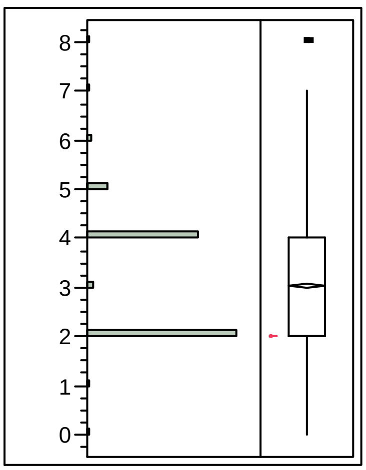


100.0%	maximum	132.00
99.5%		108.43
97.5%		68.00
90.0%		64.00
75.0%	quartile	50.00
50.0%	median	0.00
25.0%	quartile	0.00
10.0%		0.00
2.5%		0.00
0.5%		0.00
0.0%	minimum	0.00

Moments

Mean	21.166172
Std Dev	28.251287
Std Err Mean	0.4113005
upper 95% Mean	21.972513
lower 95% Mean	20.359831
N	4718

NUMLANES



Quantiles

100.0%	maximum	8.0000
99.5%		6.0000
97.5%		5.0000
90.0%		4.0000
75.0%	quartile	4.0000
50.0%	median	2.0000
25.0%	quartile	2.0000
10.0%		2.0000
2.5%		2.0000
0.5%		1.0000
0.0%	minimum	0.0000

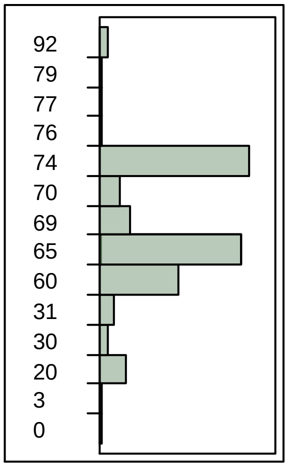
Moments

Mean	3.046206
Std Dev	1.1937516
Std Err Mean	0.0173794
upper 95% Mean	3.0802778
lower 95% Mean	3.0121343
N	4718

This field indicates the number of lanes for all road systems. This is the total number of lanes on both sides of the highway including those with a median.

Code	Description
1	1 Lane
4	4 Lane

SURFTYPE

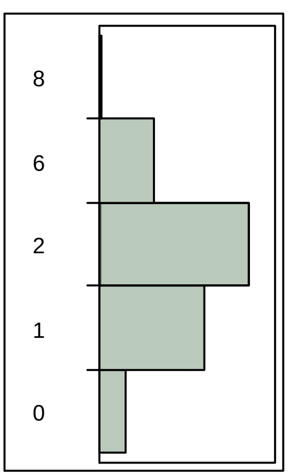


Frequencies

Level	Count	Prob	
0	12	0.00254	Unknown
3	3	0.00064	Grade and drained earth without borrow topping (No Shoulder)
20	260	0.05511	Gravel or stone without admixture
30	78	0.01653	Generic bituminous
31	153	0.03243	Bituminous on gravel or stone without admixture (Macadam-with choke stone overlay with seal coat.) Use code 63 after ACC resurfacing
60	760	0.16109	Generic asphalt
65	1377	0.29186	Asphalt on old portland cement concrete
69	307	0.06507	Asphalt on asphalt
70	207	0.04387	Generic concrete
74	1450	0.30733	New type portland cement concrete (not reinforced) (After 1960) Use code 66 after ACC resurfacing
76	2	0.00042	New type portland cement concrete (fully reinforced) Use code 67 after resurfacing
77	2	0.00042	Special portland cement concrete resurfacing (PCC over PCC)
79	12	0.00254	Portland cement concrete on asphalt
92	95	0.02014	Combination surface - asphalt and asphalt
Total	4718	1.00000	

N Missing 0
14 Levels

SHDTYPER: This field indicates the right side or outside shoulder type for all road systems using the following criteria

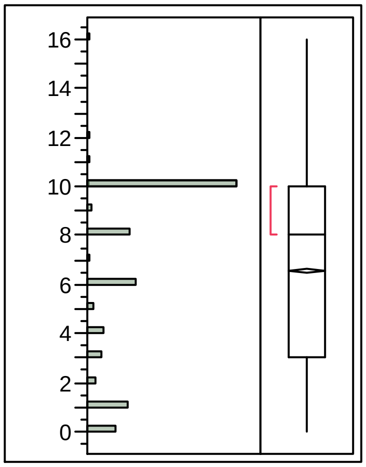


Frequencies

Level	Count	Prob	
0	366	0.07758	No shoulder
1	1470	0.31157	Earth
2	2096	0.44426	Gravel
6	770	0.16320	Paved
8	16	0.00339	Combination shoulder – paved and gravel
Total	4718	1.00000	

N Missing 0
5 Levels

SHDWIDTHR: This field indicates the width of the right side or outside shoulder to the nearest foot. It is used on all road systems.



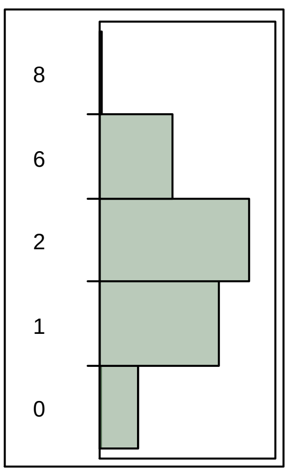
Quantiles

100.0%	maximum	16.000
99.5%		10.000
97.5%		10.000
90.0%		10.000
75.0%	quartile	10.000
50.0%	median	8.000
25.0%	quartile	3.000
10.0%		1.000
2.5%		0.000
0.5%		0.000
0.0%	minimum	0.000

Moments

Mean	6.5481136
Std Dev	3.6851546
Std Err Mean	0.0536509
upper 95% Mean	6.6532944
lower 95% Mean	6.4429329
N	4718

SHDTYPEL: This field indicates the left side or inside shoulder type for all road systems using the following criteria.

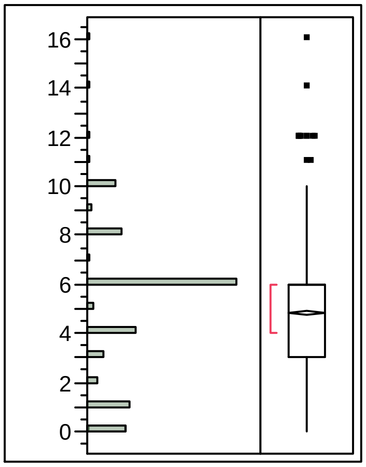


Frequencies

Level	Count	Prob	
0	486	0.10301	No shoulder
1	1474	0.31242	Earth
2	1842	0.39042	Graved
6	913	0.19351	Paved
8	3	0.00064	Combination shoulder – paved and gravel
Total	4718	1.00000	

N Missing 0
5 Levels

SHDWIDTHL



Quantiles

100.0%	maximum	16.000
99.5%		10.000
97.5%		10.000
90.0%		8.000
75.0%	quartile	6.000
50.0%	median	6.000
25.0%	quartile	3.000
10.0%		0.000
2.5%		0.000
0.5%		0.000
0.0%	minimum	0.000

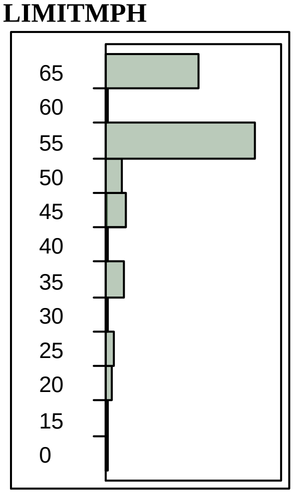
Moments

Mean	4.8416702
Std Dev	2.8927082
Std Err Mean	0.0421139
upper 95% Mean	4.9242331
lower 95% Mean	4.7591072
N	4718

LIMITMPH: This code indicates the lowest posted MPH excluding MPH for curves for a road segment. This is applicable for all road systems.

Code	Description
035	35 MPH
055	55 MPH

LIMITMPH

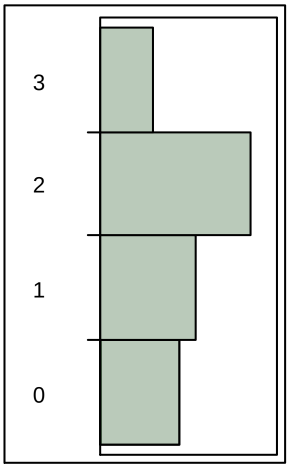


Frequencies

Level	Count	Prob
0	12	0.00254
15	1	0.00021
20	90	0.01908
25	138	0.02925
30	55	0.01166
35	277	0.05871
40	39	0.00827
45	296	0.06274
50	260	0.05511
55	2184	0.46291
60	8	0.00170
65	1358	0.28783
Total	4718	1.00000

N Missing 0
12 Levels

TERRAIN



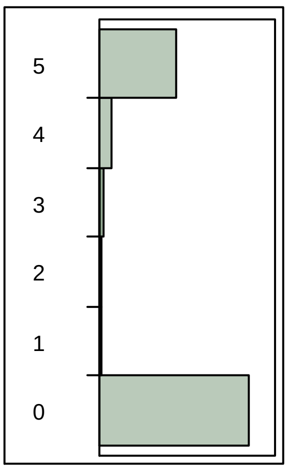
Frequencies

Level	Count	Prob	
0	994	0.21068	Not applicable
1	1198	0.25392	Flat
2	1866	0.39551	Rolling
3	660	0.13989	Hilly
Total	4718	1.00000	

N Missing 0
4 Levels

This field indicates the type of terrain located on both sides of the road segments on the primary, secondary and institutional roads.

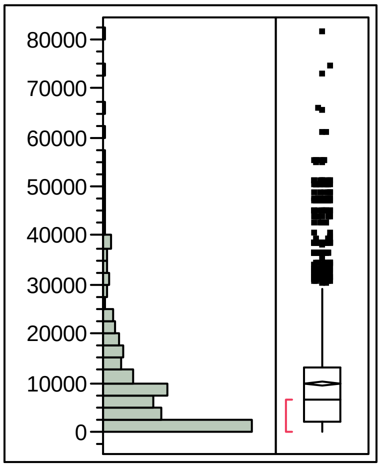
TYPEAREA



Frequencies

Level	Count	Prob	
0	2837	0.60131	Not Applicable
1	5	0.00106	Central business district
2	34	0.00721	Fringe business district
3	113	0.02395	Outlying business district
4	245	0.05193	Residential area
5	1484	0.31454	Rural area, the area which has agricultural or conservation usage
Total	4718	1.00000	

AADT



The average annual daily traffic crossing this track.

Quantiles

100.0%	maximum	81400
99.5%		50700
97.5%		38100
90.0%		23400
75.0%	quartile	13100
50.0%	median	6500
25.0%	quartile	1980
10.0%		480
2.5%		70
0.5%		13
0.0%	minimum	0

Moments

Mean	9804.7974
Std Dev	10937.206
Std Err Mean	159.23093
upper 95% Mean	10116.964
lower 95% Mean	9492.6304
N	4718

APPENDIX B. COUNTY-LEVEL CRASH ANALYSIS GRAPHS

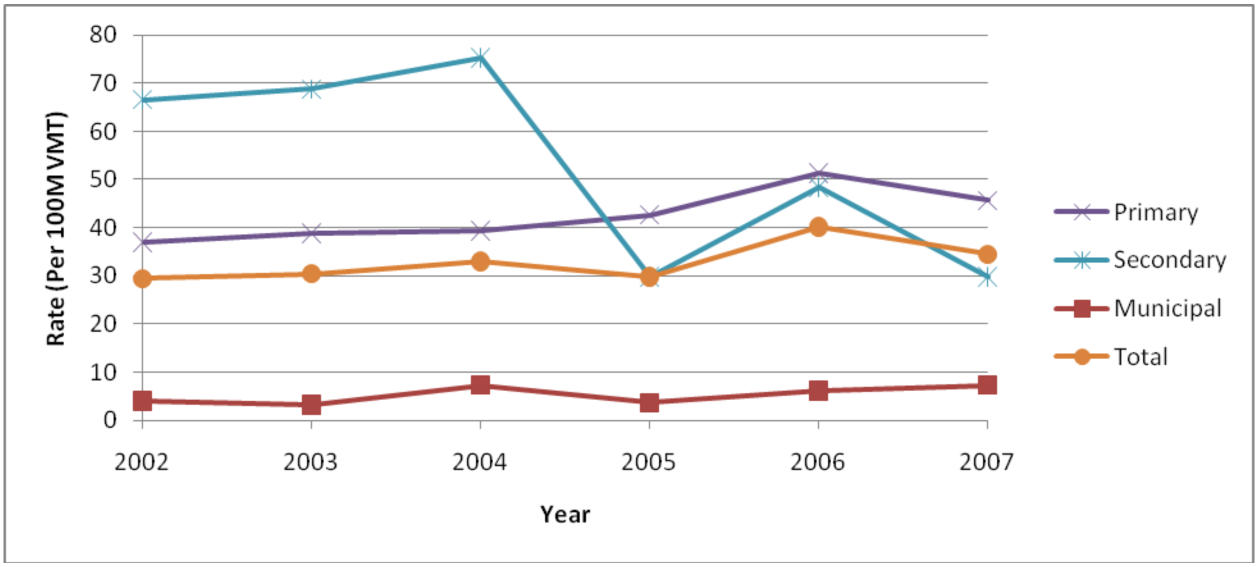


Figure B.1. Deer-vehicle crash rate per 100 million VMT in Dubuque County

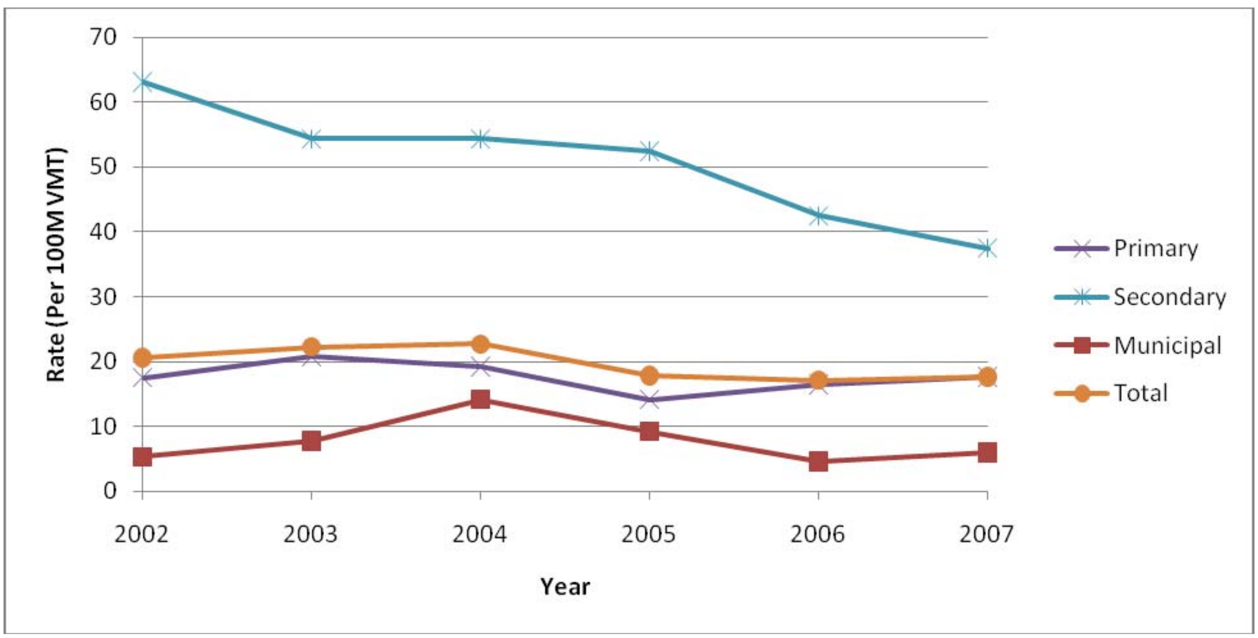


Figure B.2. Deer-vehicle crash rate per 100 million VMT in Johnson County

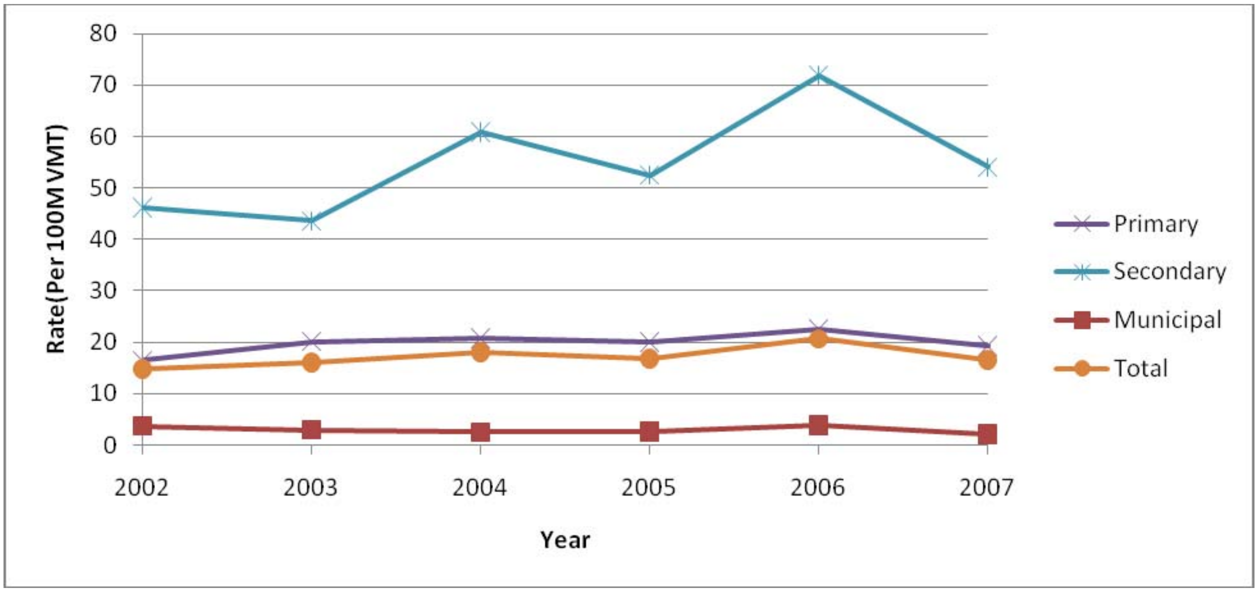


Figure B.3. Deer-vehicle crash rate per 100 million VMT in Linn County

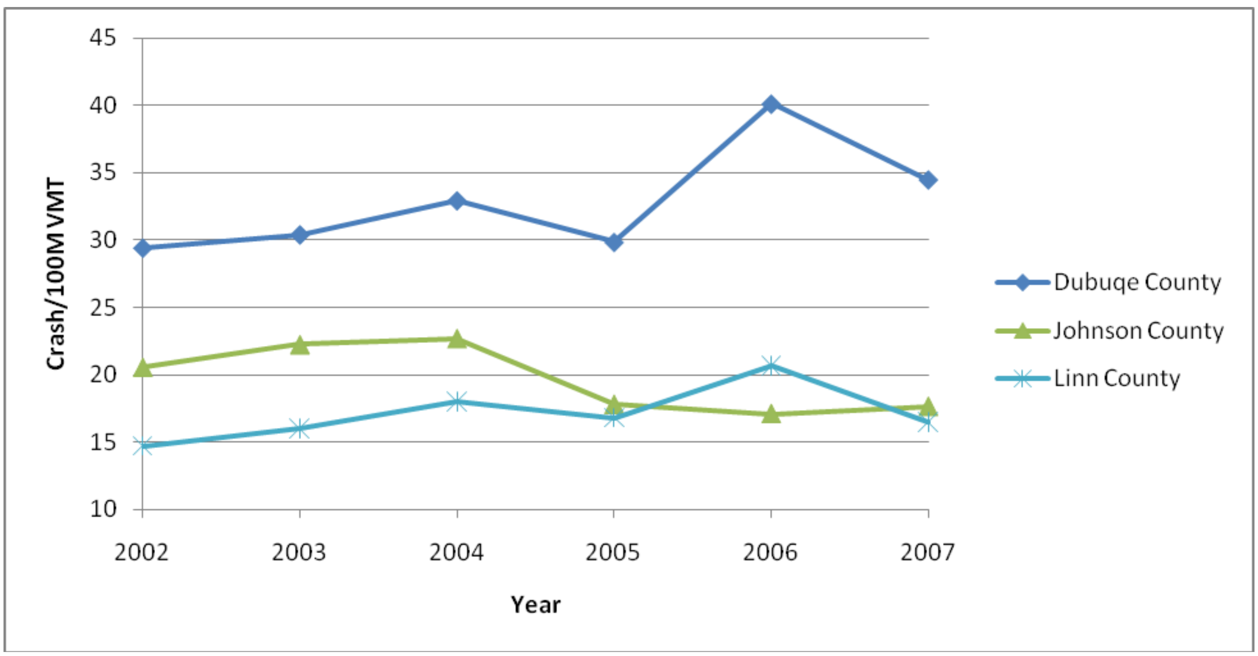


Figure B.4. Comparison of crash rate per 100 million VMT—county

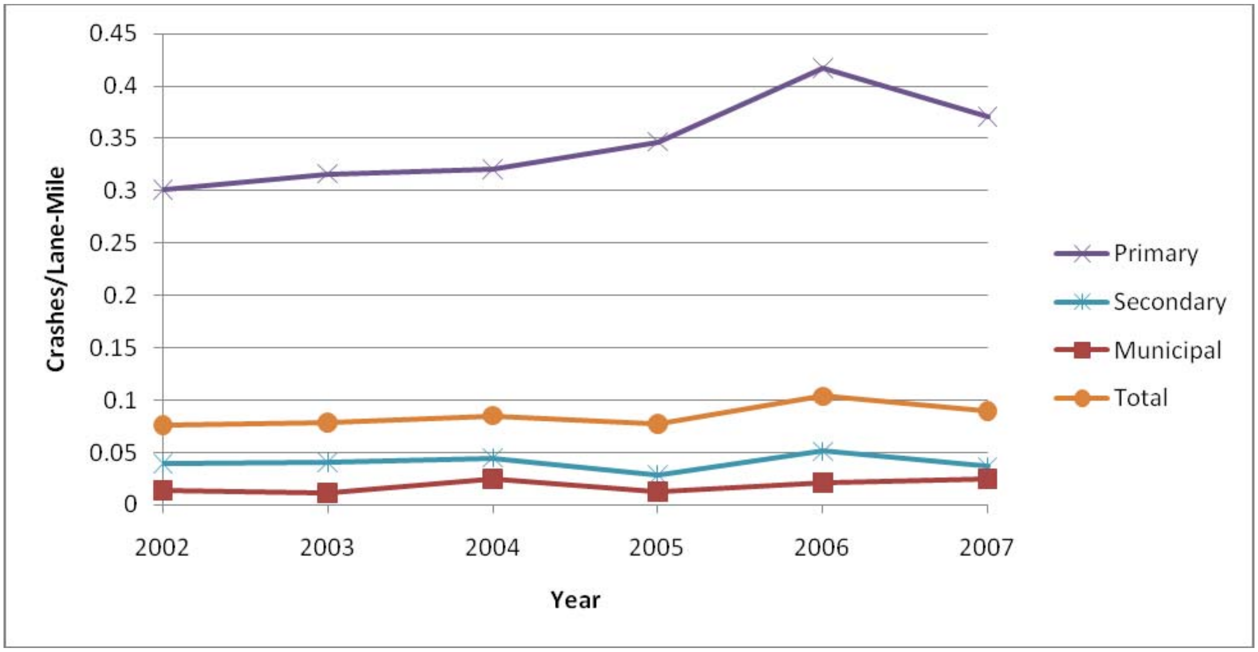


Figure B.5. Deer-vehicle crashes per lane mile in Dubuque County

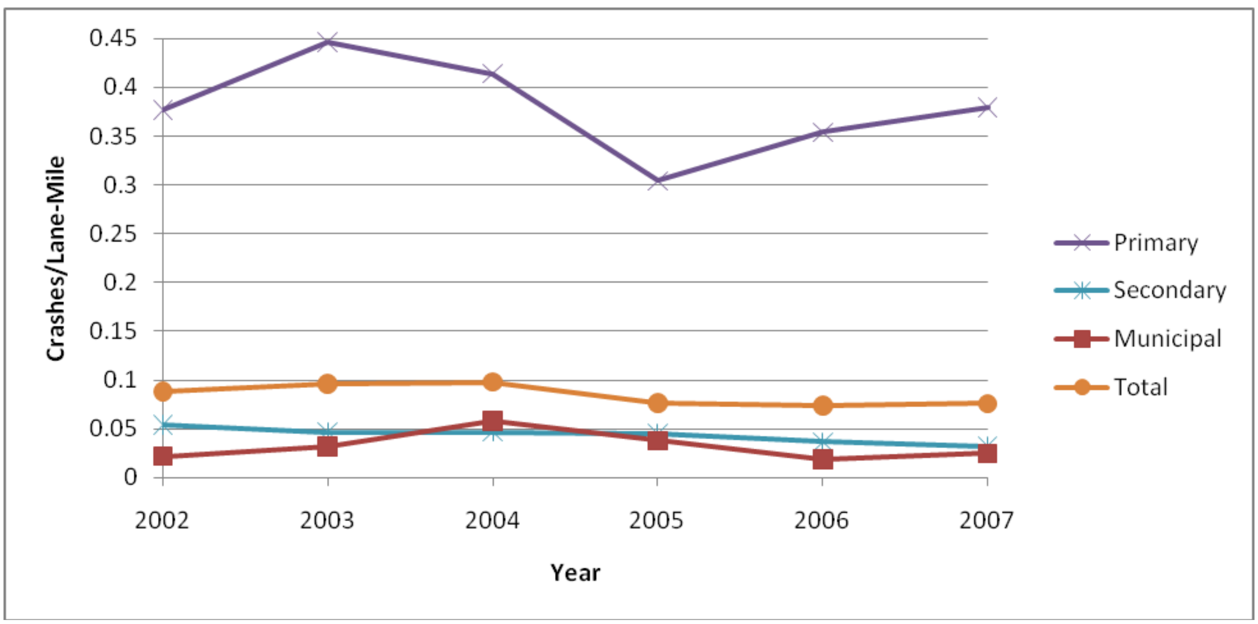


Figure B.6. Deer-vehicle crashes per lane mile in Johnson County

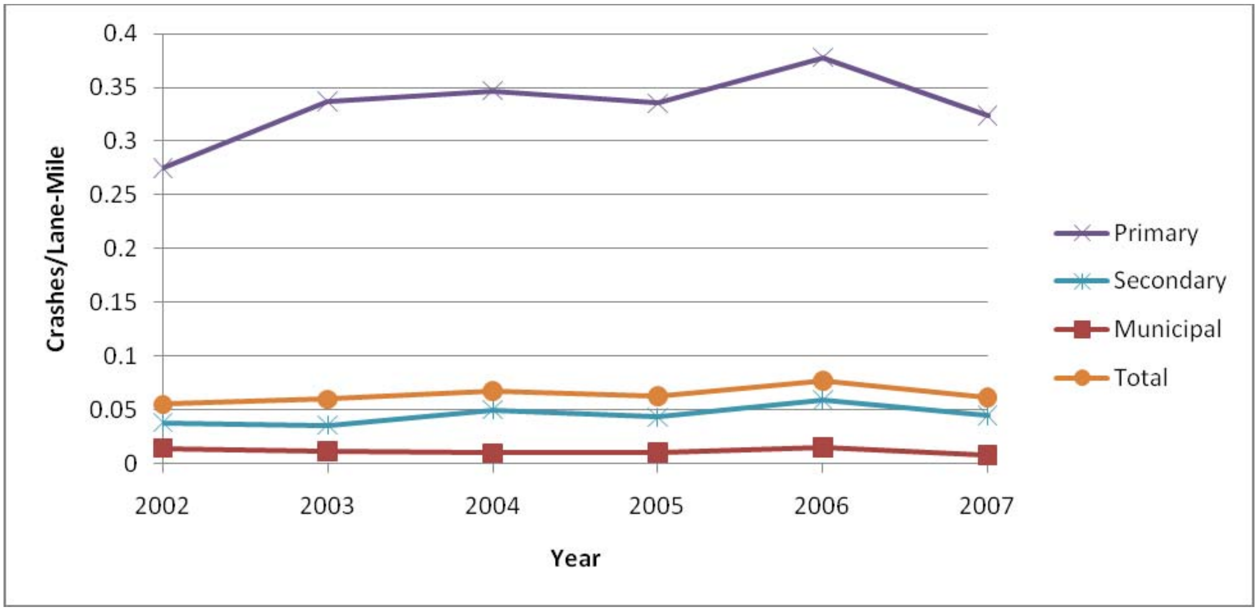


Figure B.7. Deer-vehicle crashes per lane mile in Linn County

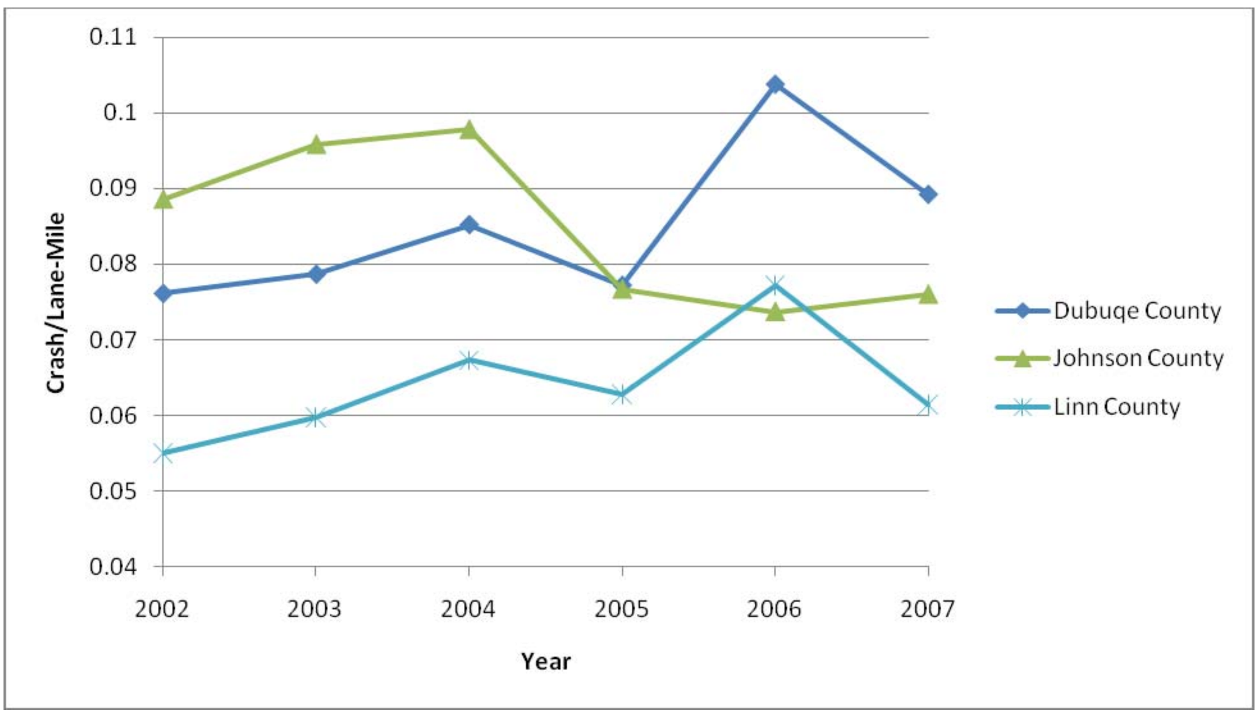
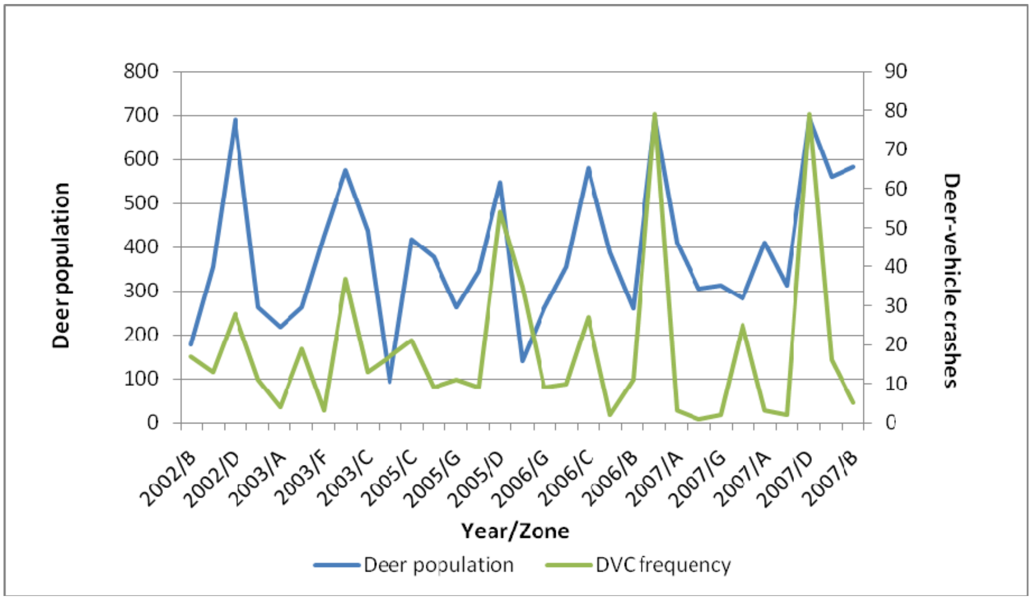


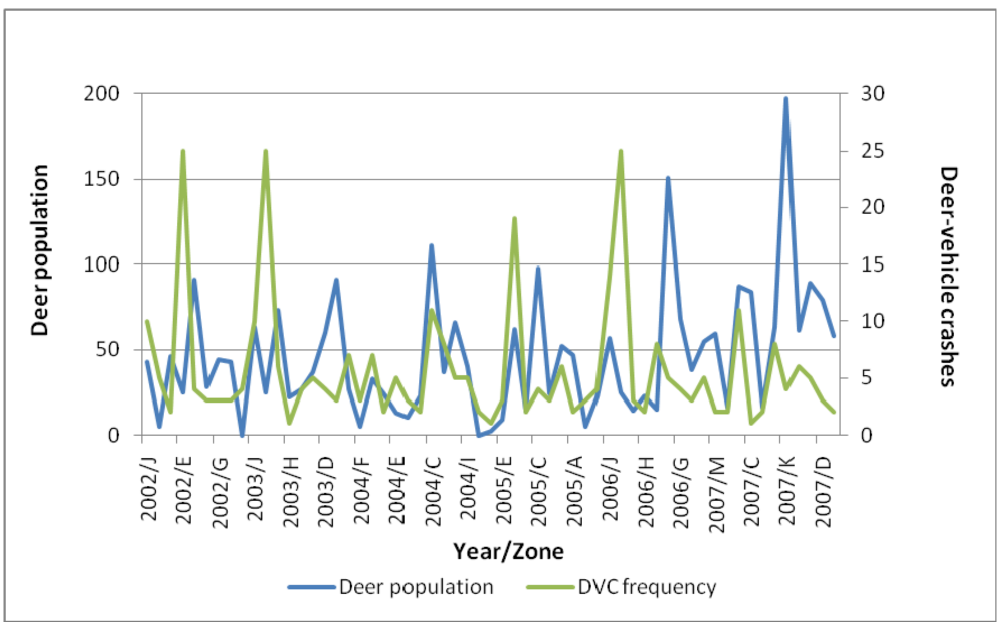
Figure B.8. Comparison of crashes per lane mile

APPENDIX C. ADDITIONAL DEER-VEHICLE CRASH AND DEER POPULATION COMPARISONS



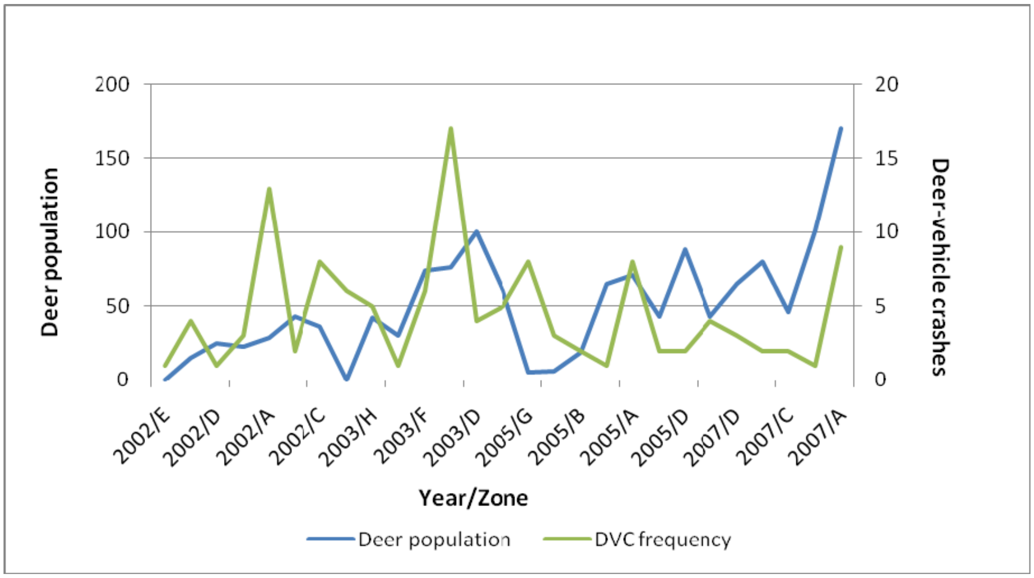
Note: No deer survey data available in 2004; also, data for 2002 and 2005 incomplete or not available for some zones.

Figure C.1. Comparison of deer-vehicle crash frequency and deer population in Cedar Rapids' deer management zones, 2002 to 2007



Note: Incomplete deer survey data for some years and zones.

Figure C.2. Comparison of deer-vehicle crash frequency and deer population in Dubuque's deer management zones, 2002 to 2007



Note: No deer survey data available in 2004 and 2006.

Figure C.3. Comparison of deer-vehicle crash frequency and deer population in Iowa City's deer management zones, 2002 to 2007

APPENDIX D. ADDITIONAL MAPS

D.1 Cedar Rapids

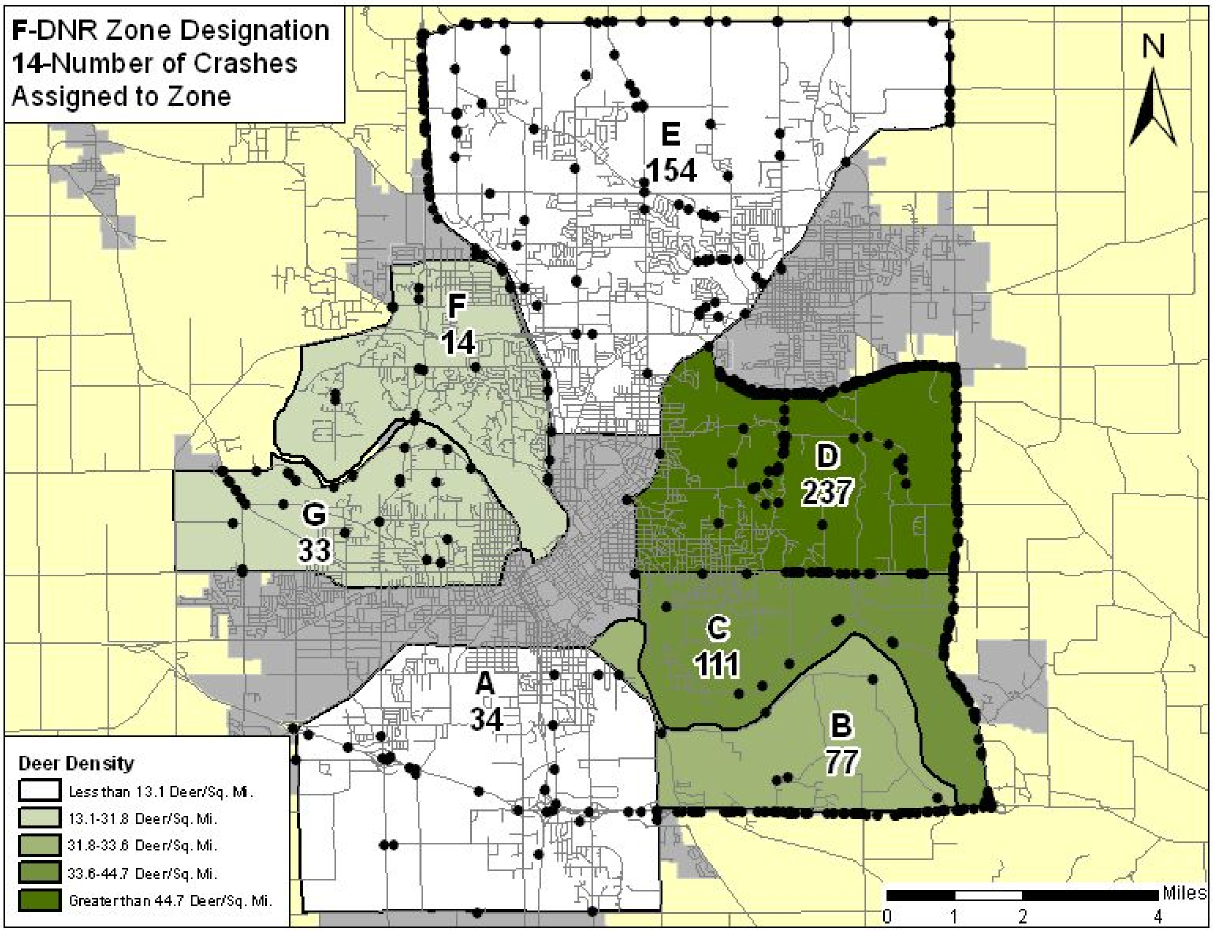


Figure D.1. Deer density and deer-vehicle crashes in Cedar Rapids

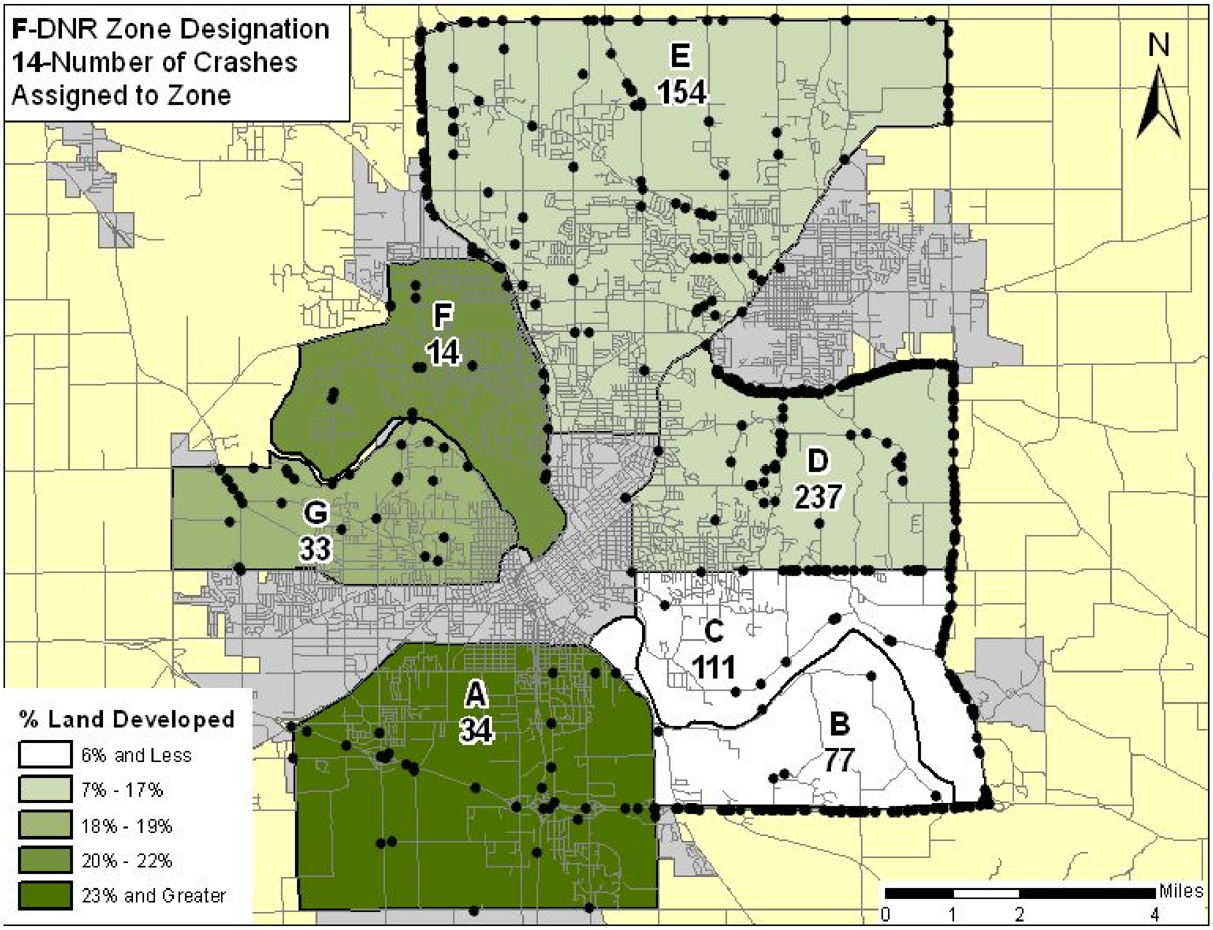


Figure D.2. Percentage of land developed and deer-vehicle crashes in Cedar Rapids

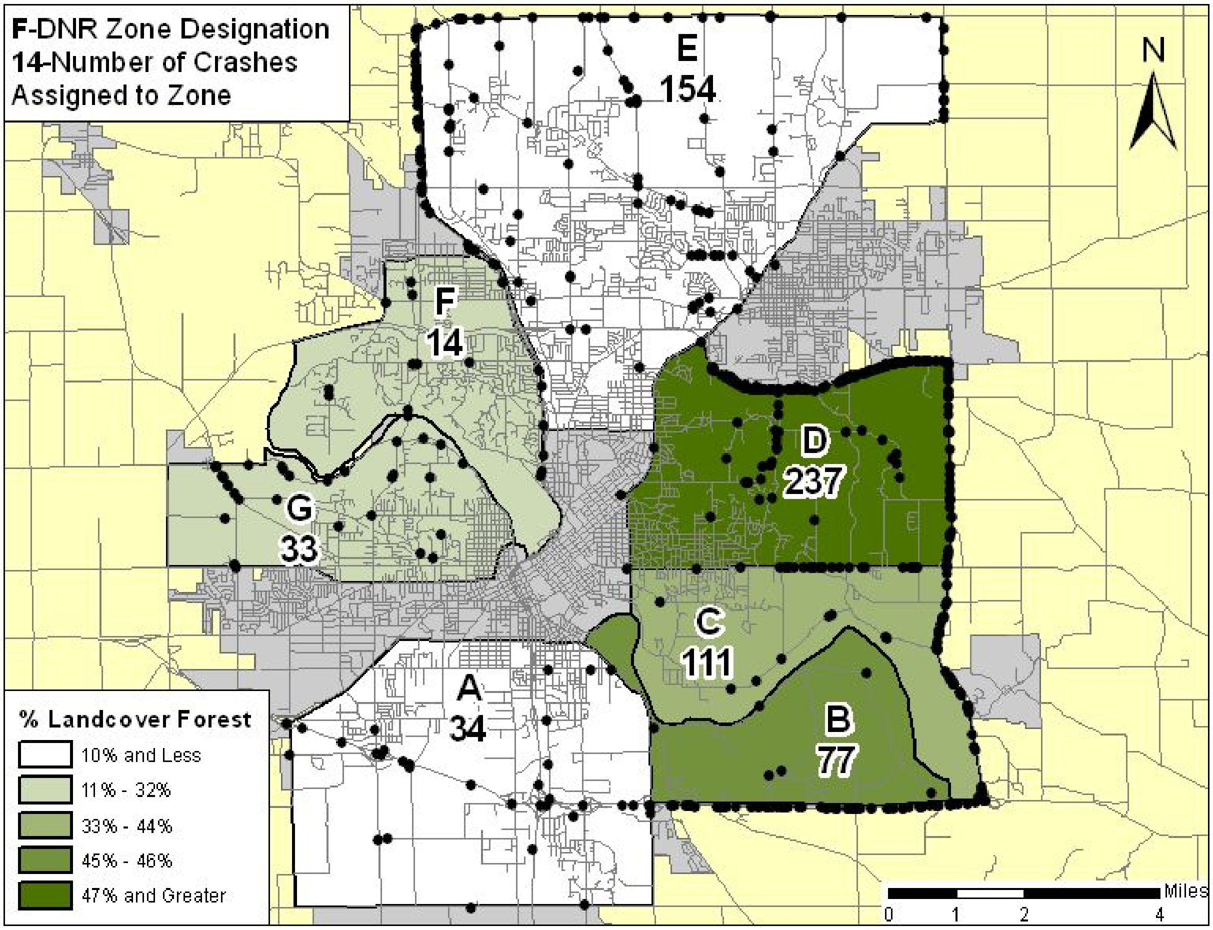


Figure D.3. Percentage of forestland and deer-vehicle crashes in Cedar Rapids

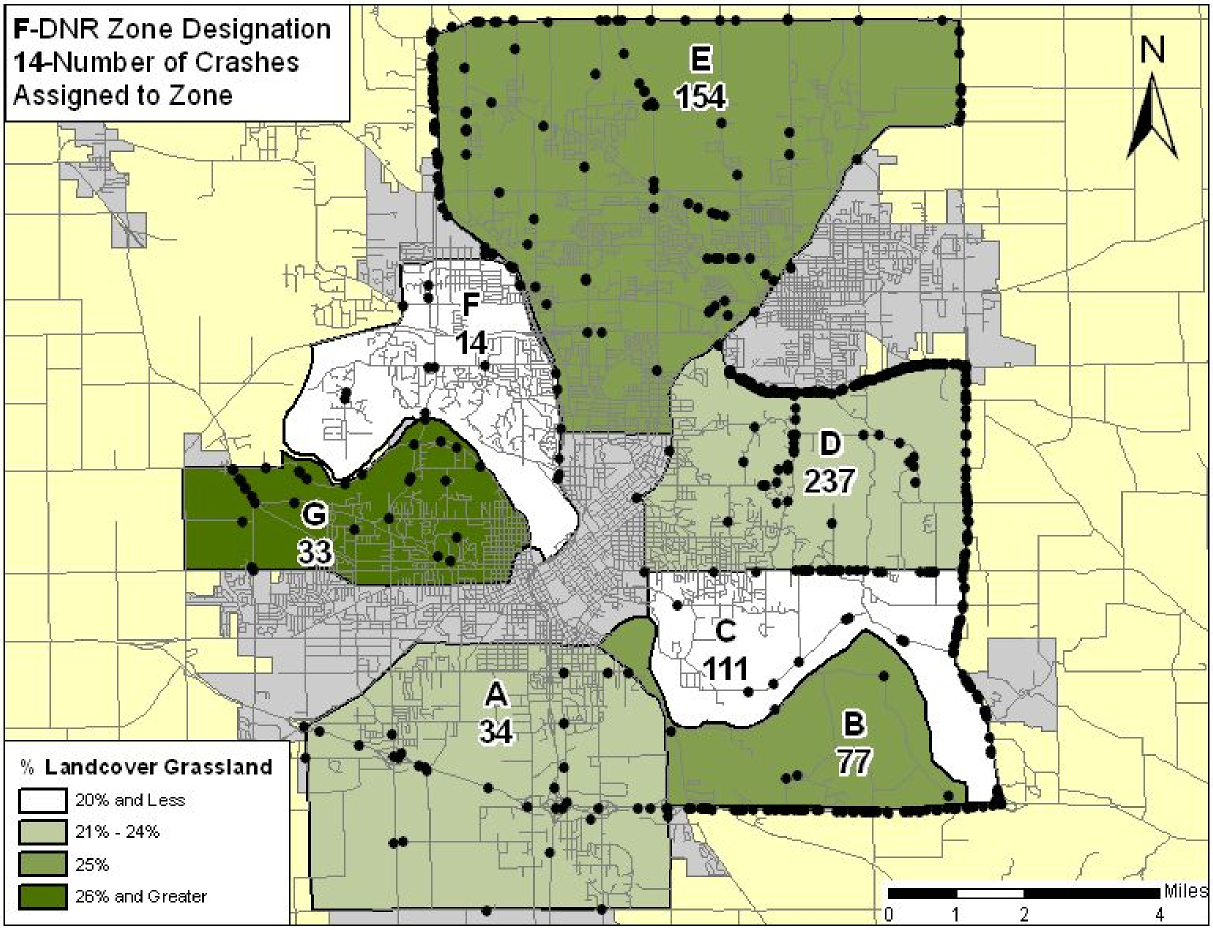


Figure D.4. Percentage of grassland and deer-vehicle crashes in Cedar Rapids

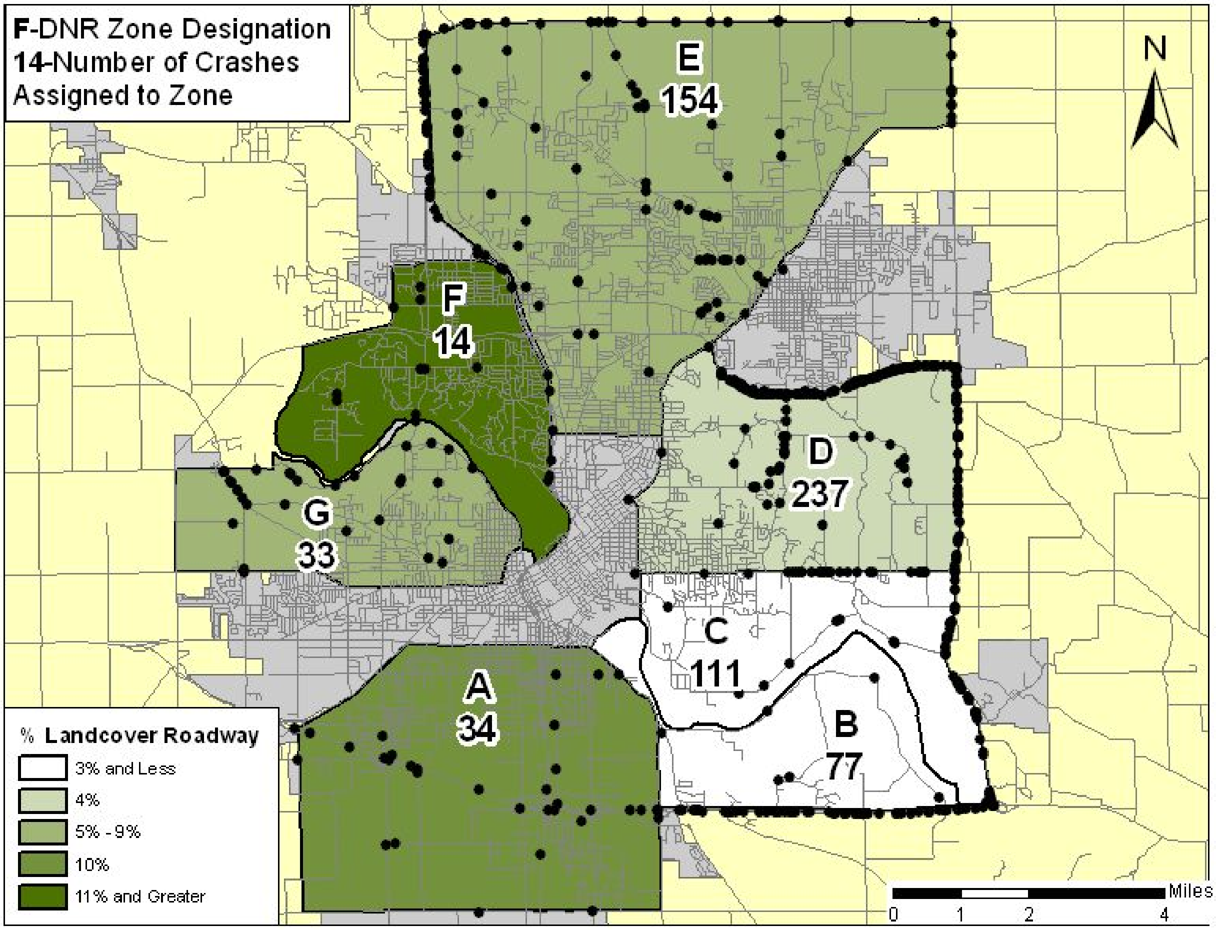


Figure D.5. Percentage of roadways and deer-vehicle crashes in Cedar Rapids

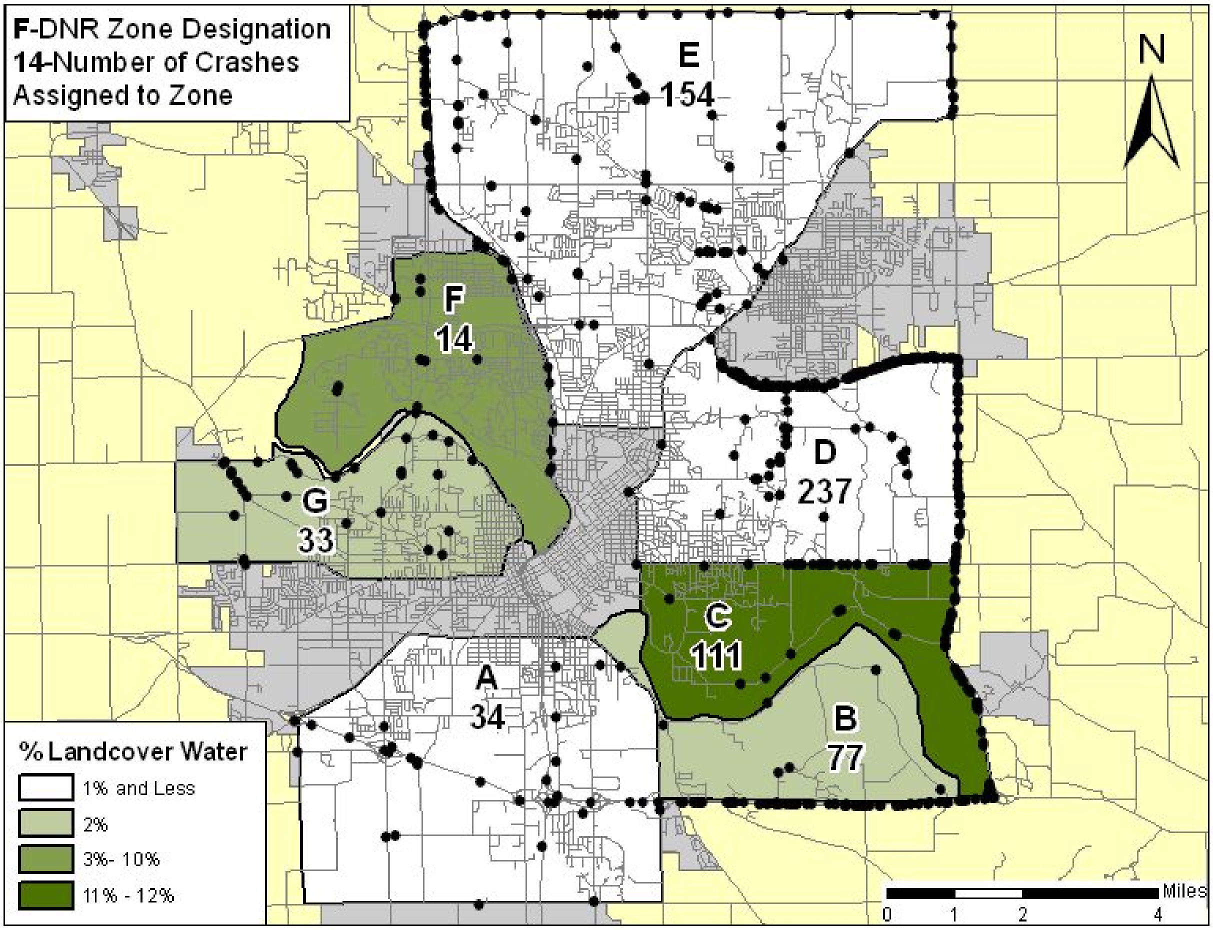


Figure D.6. Percentage of water/wetland and deer-vehicle crashes in Cedar Rapids

D.2 Dubuque

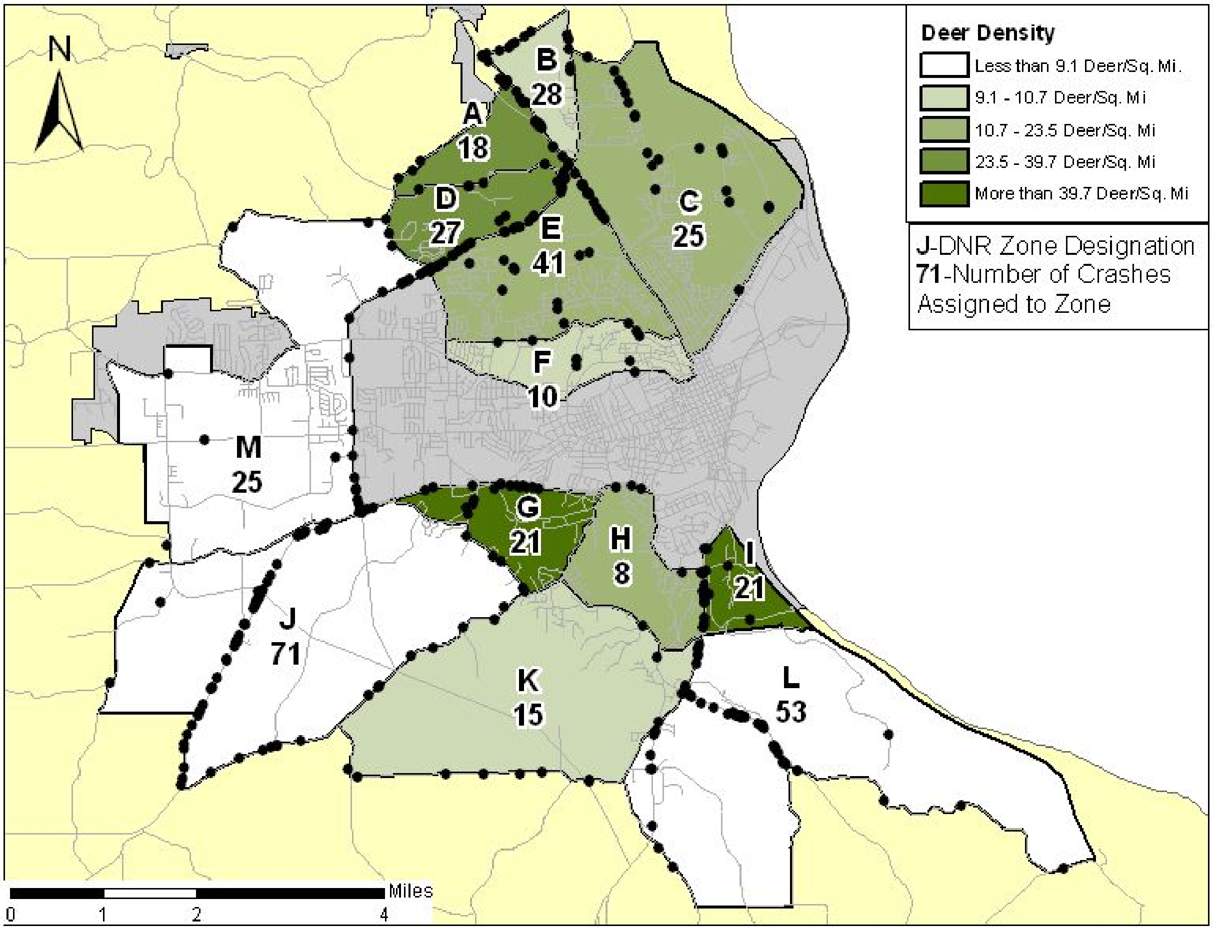


Figure D.7. Deer density and deer-vehicle crashes in Dubuque

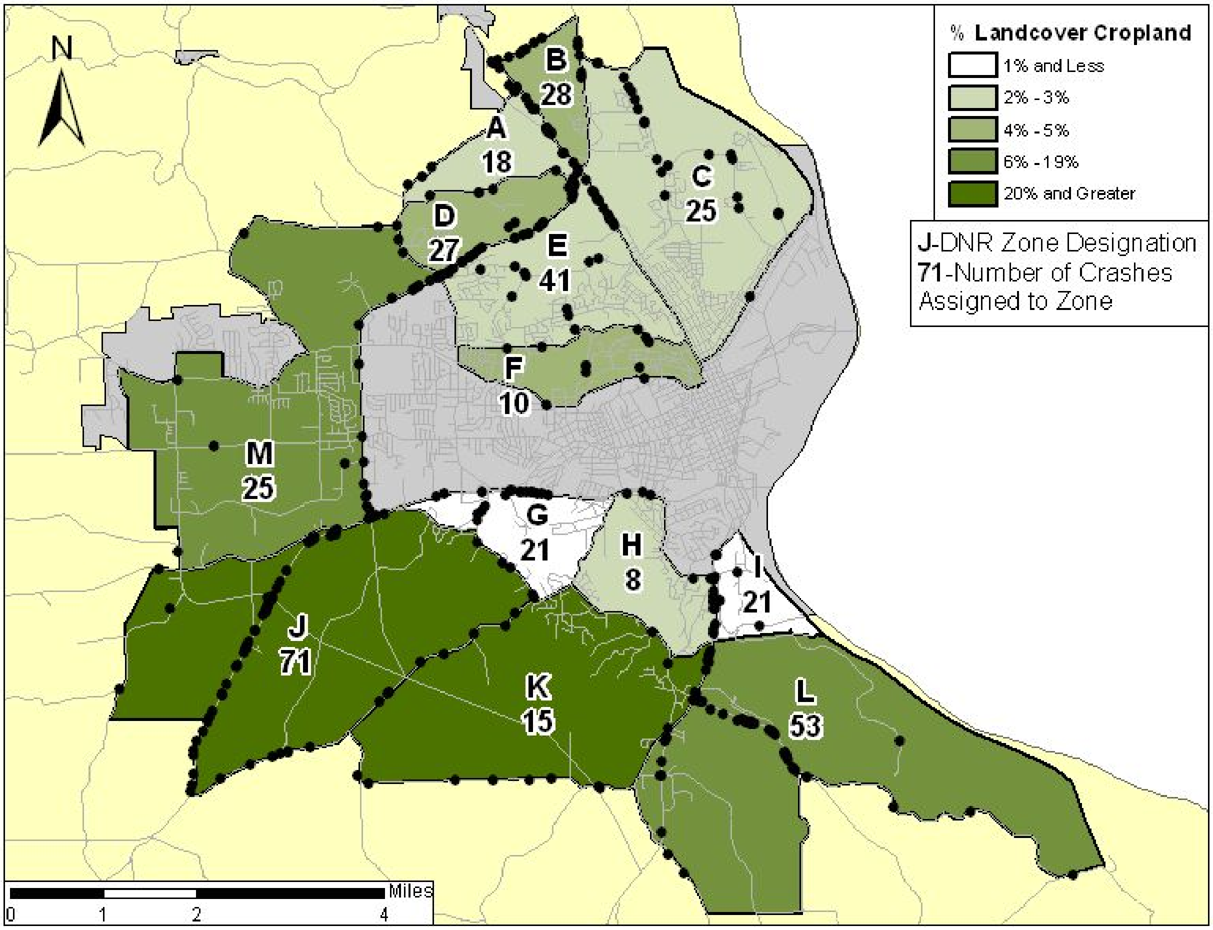


Figure D.8. Percentage of cropland and deer-vehicle crashes in Dubuque

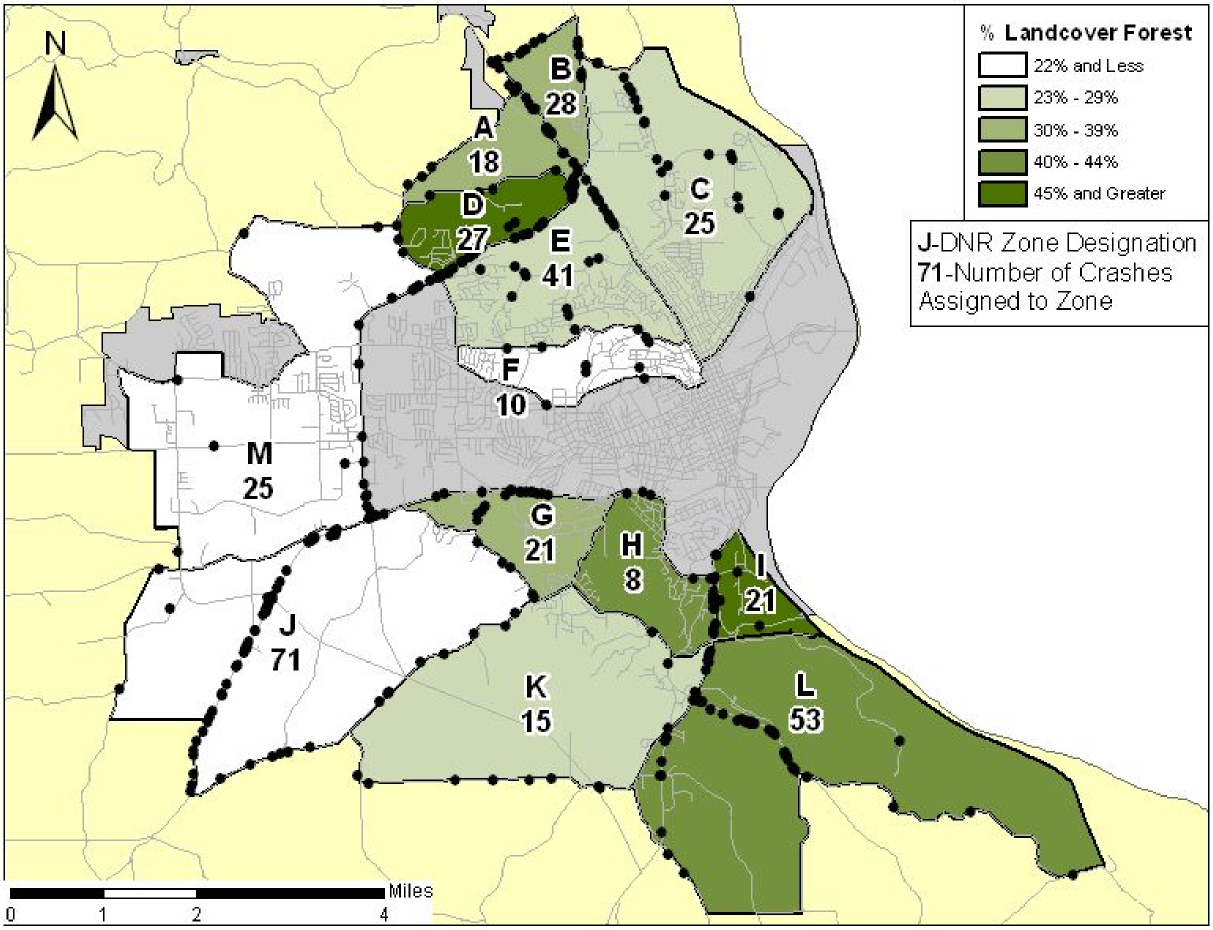


Figure D.9. Percentage of forestland and deer-vehicle crashes in Dubuque

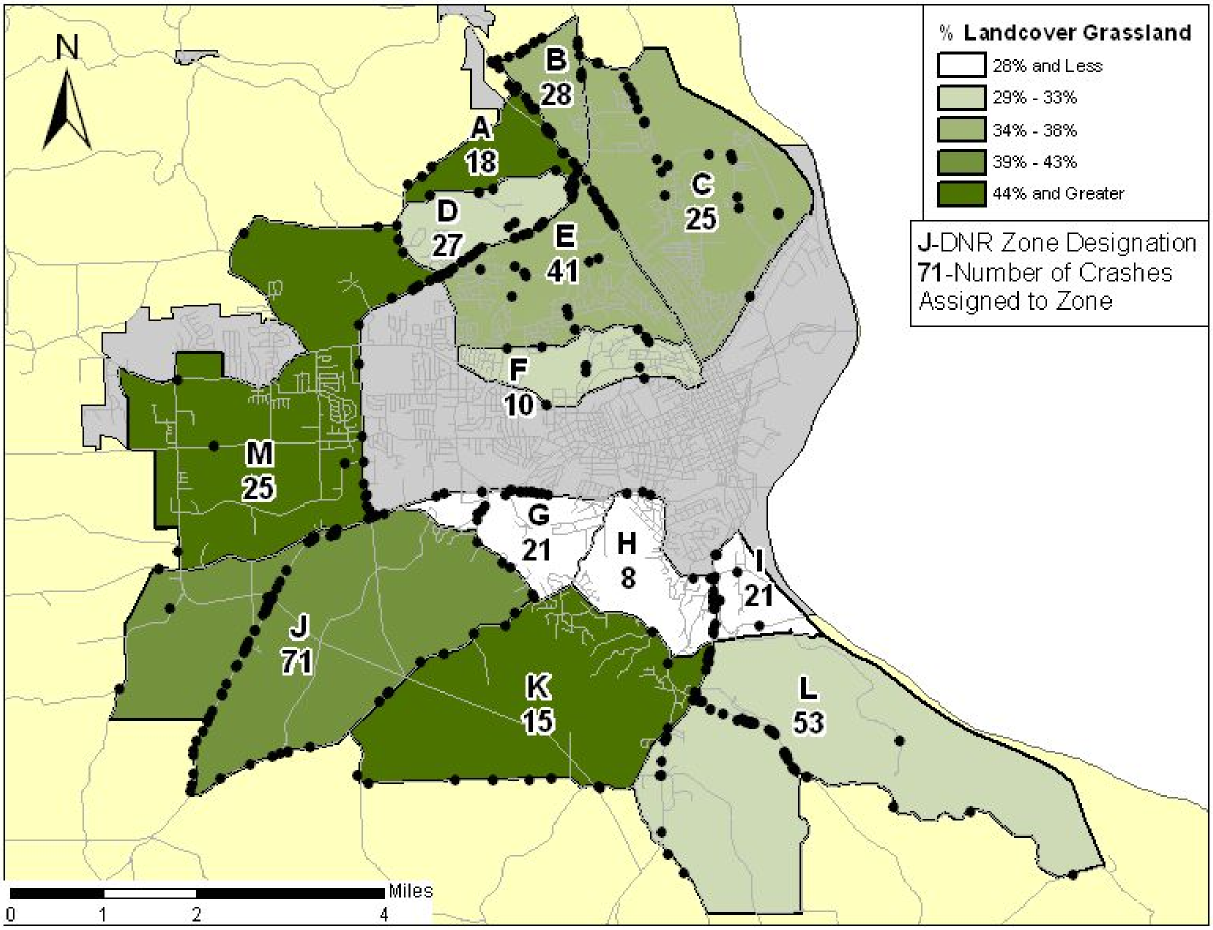


Figure D.10. Percentage of grassland and deer-vehicle crashes in Dubuque

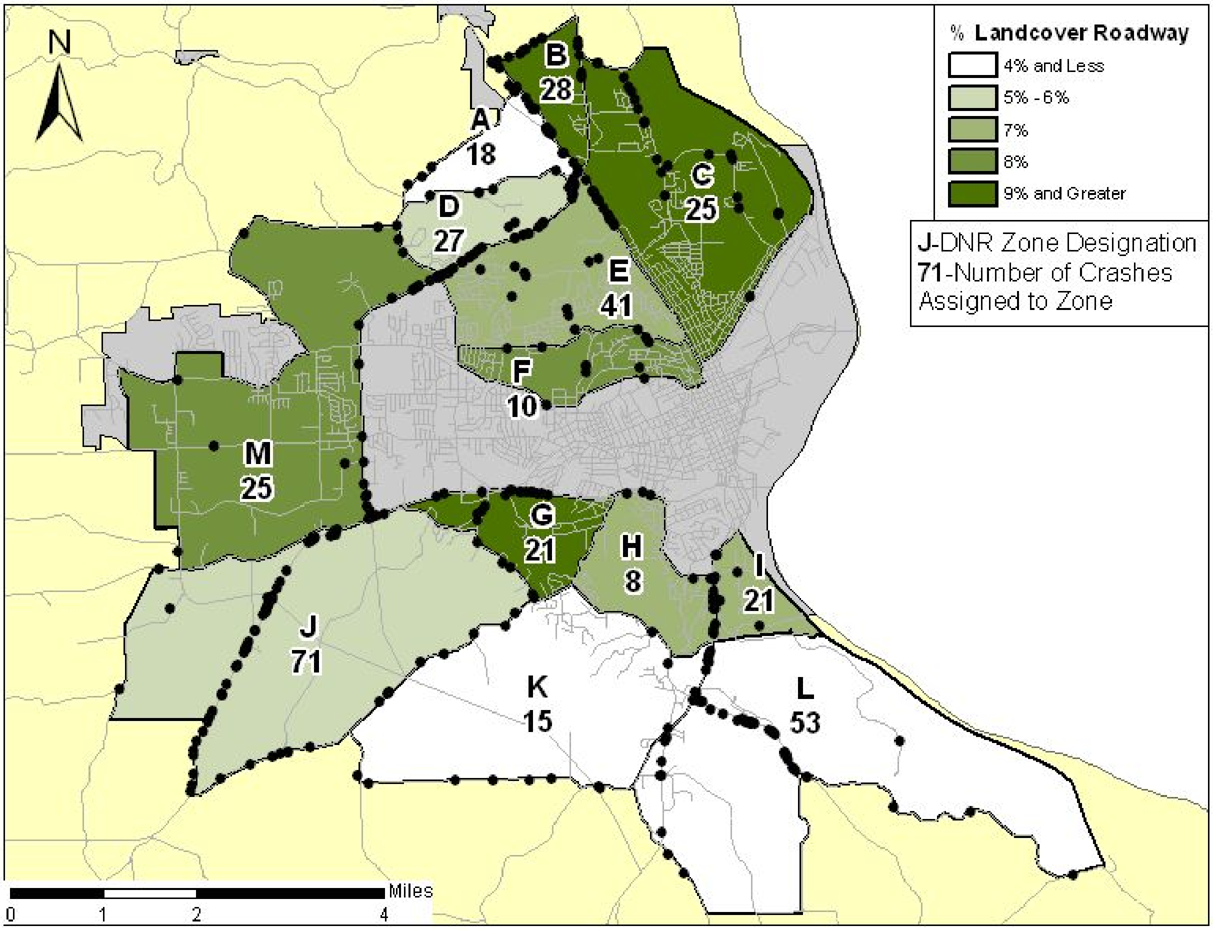


Figure D.11. Percentage of roadways and deer-vehicle crashes in Dubuque

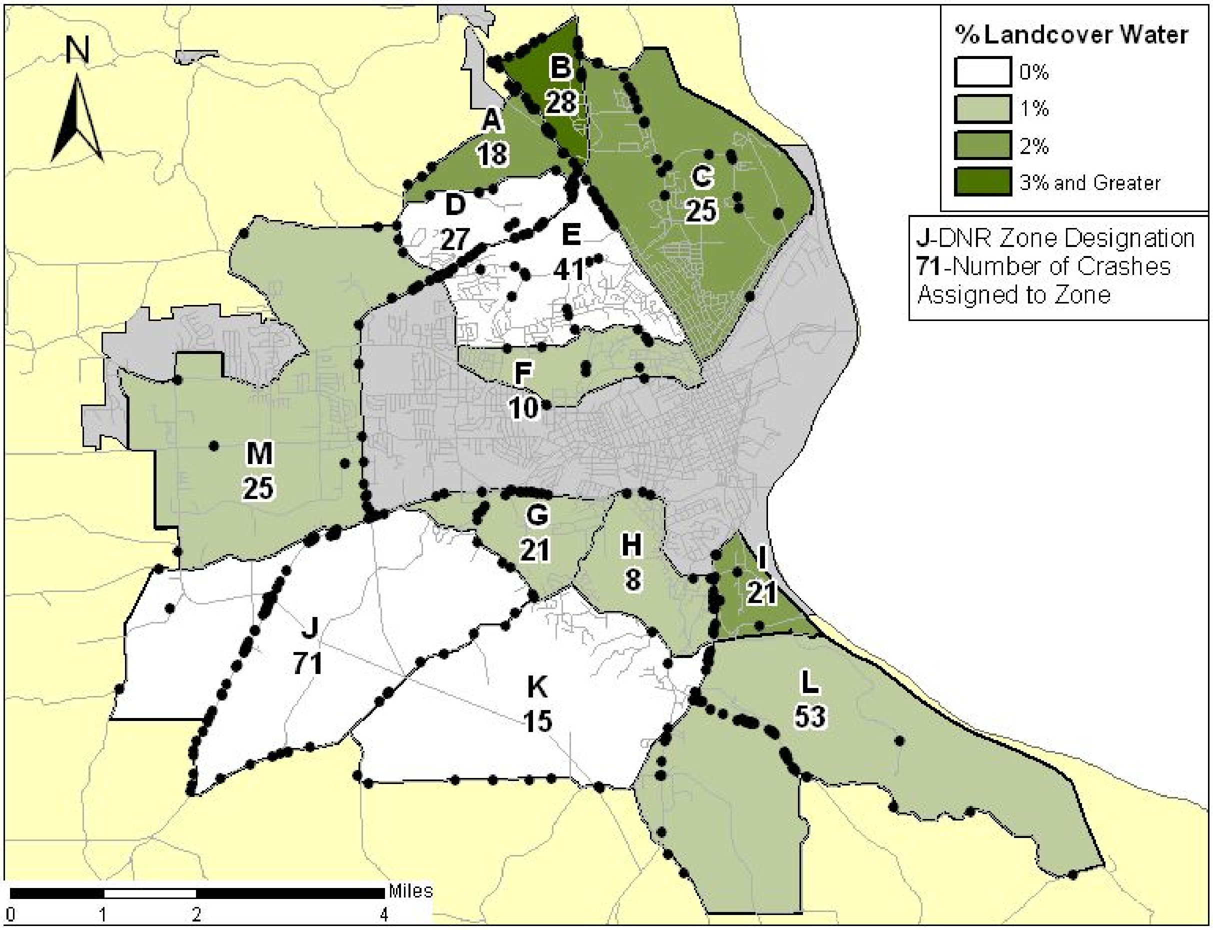


Figure D.12. Percentage of water/wetland and deer-vehicle crashes in Dubuque

D.3 Iowa City

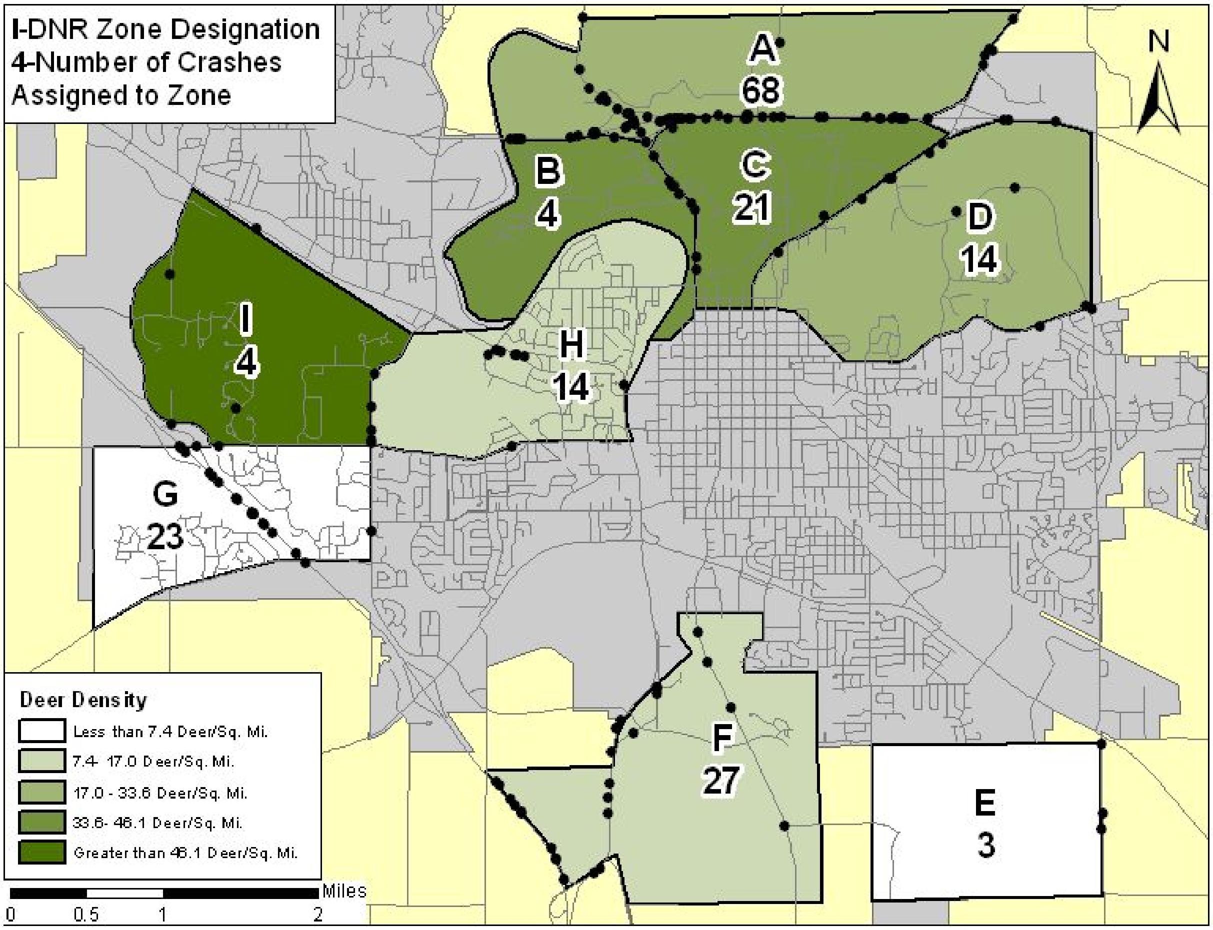


Figure D.13. Deer density and deer-vehicle crashes in Iowa City

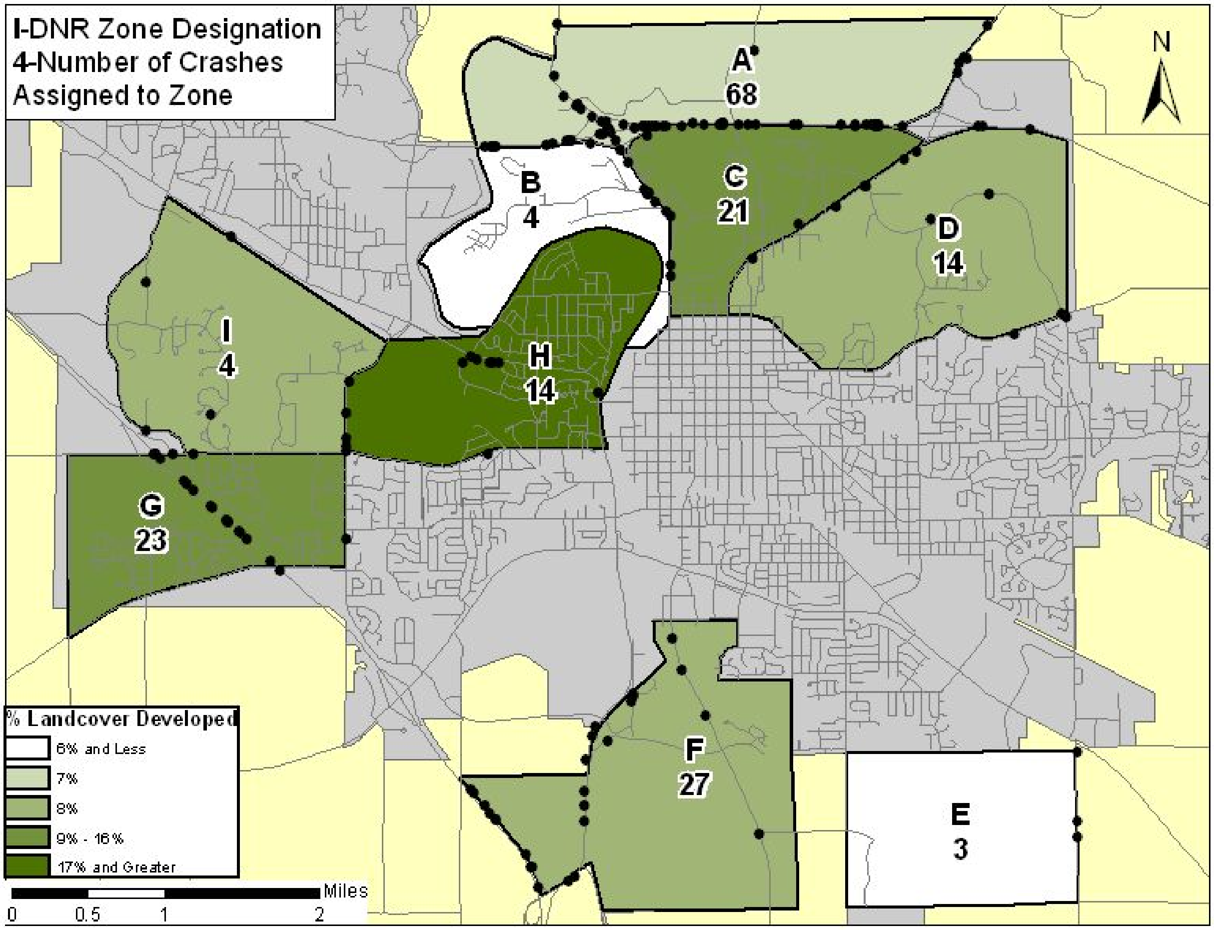


Figure D.14. Percentage of land developed and deer-vehicle crashes in Iowa City

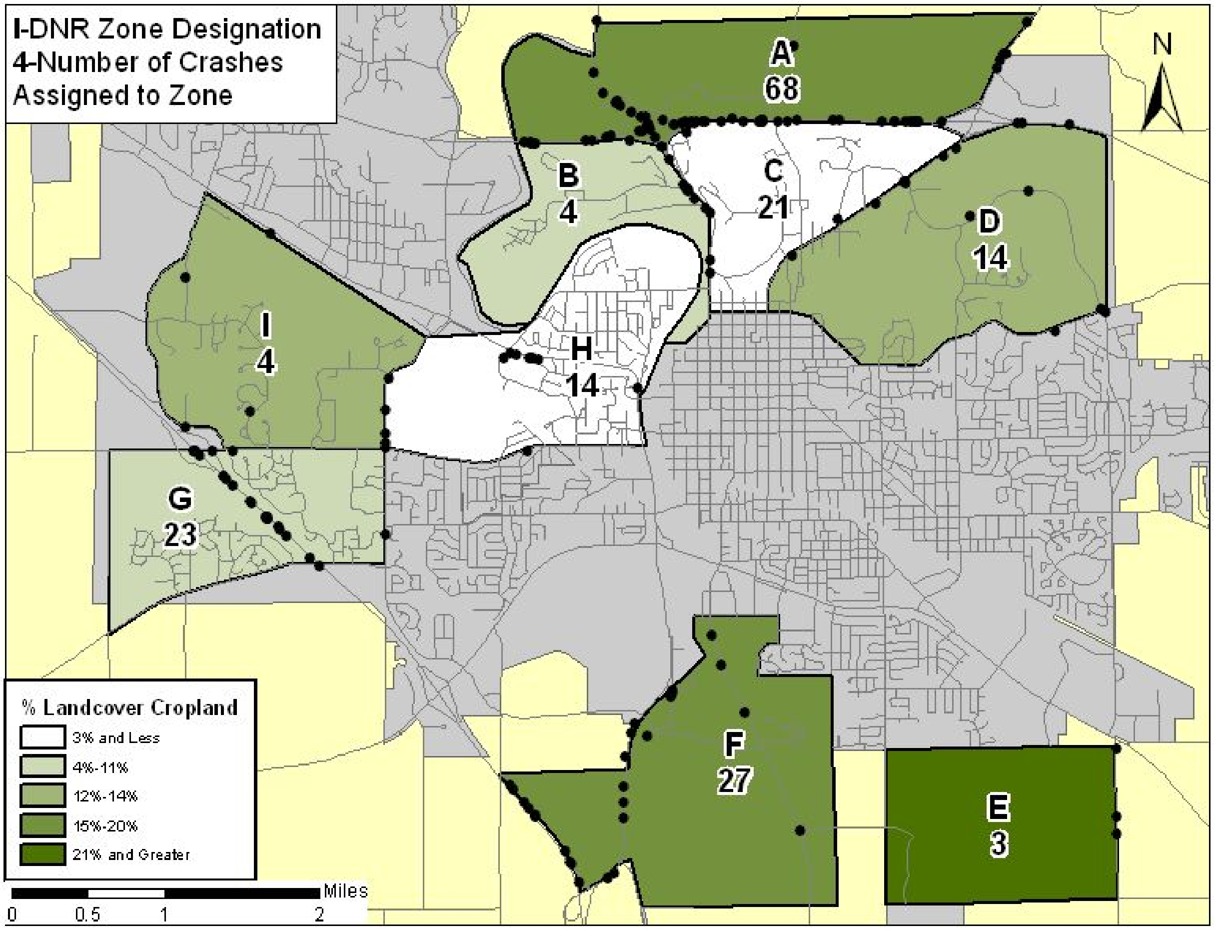


Figure D.15. Percentage of cropland and deer-vehicle crashes in Iowa City

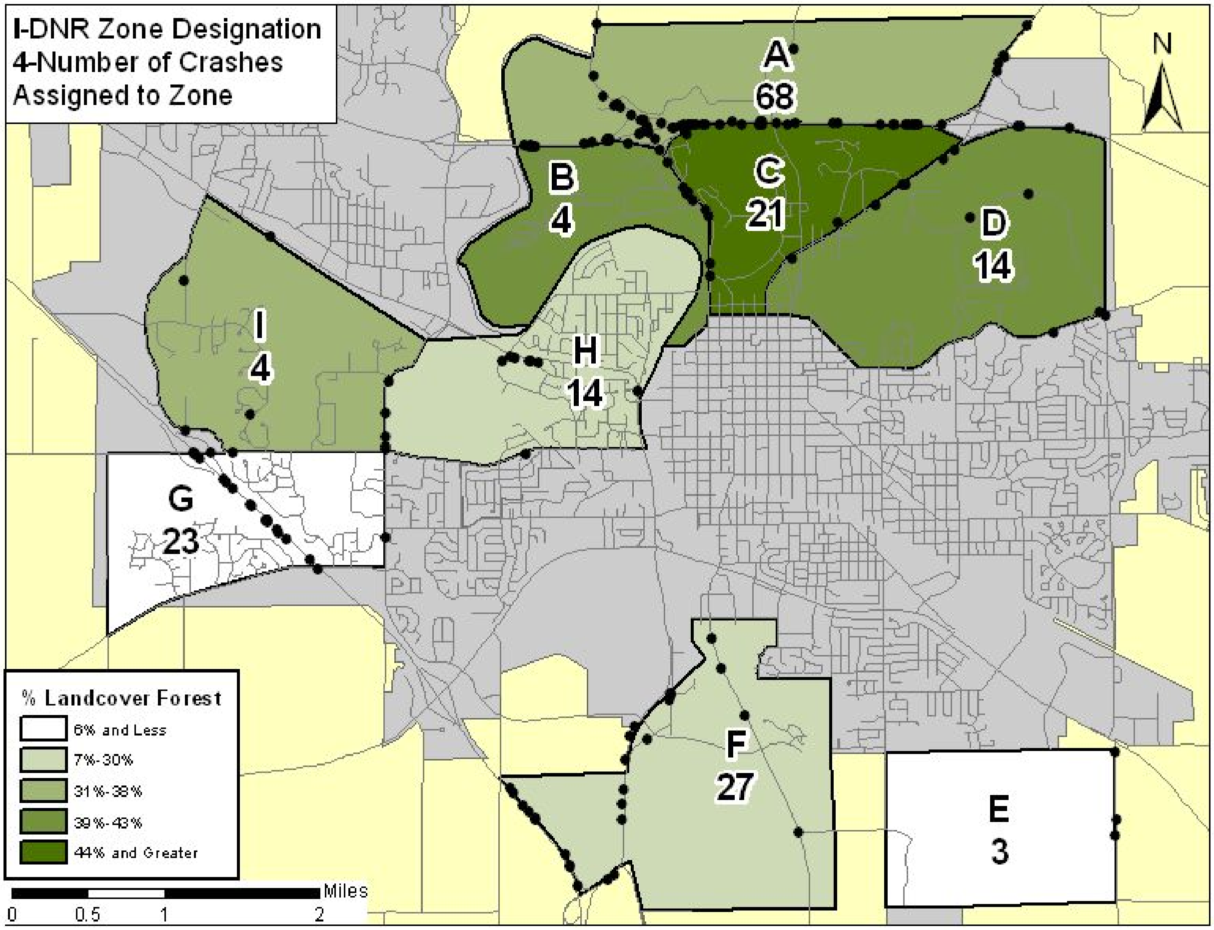


Figure D.16. Percentage of forestland and deer-vehicle crashes in Iowa City

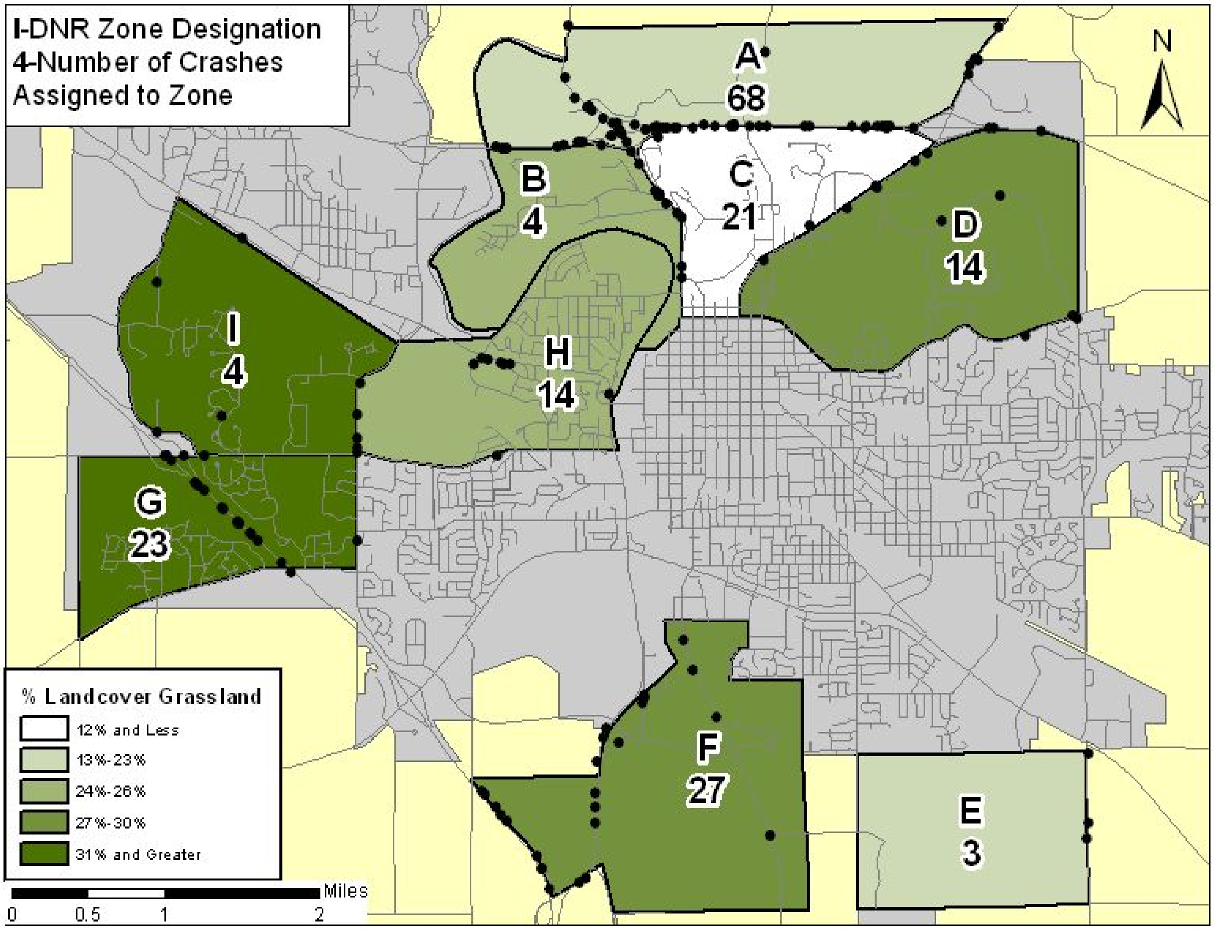


Figure D.17. Percentage of grassland and deer-vehicle crashes in Iowa City

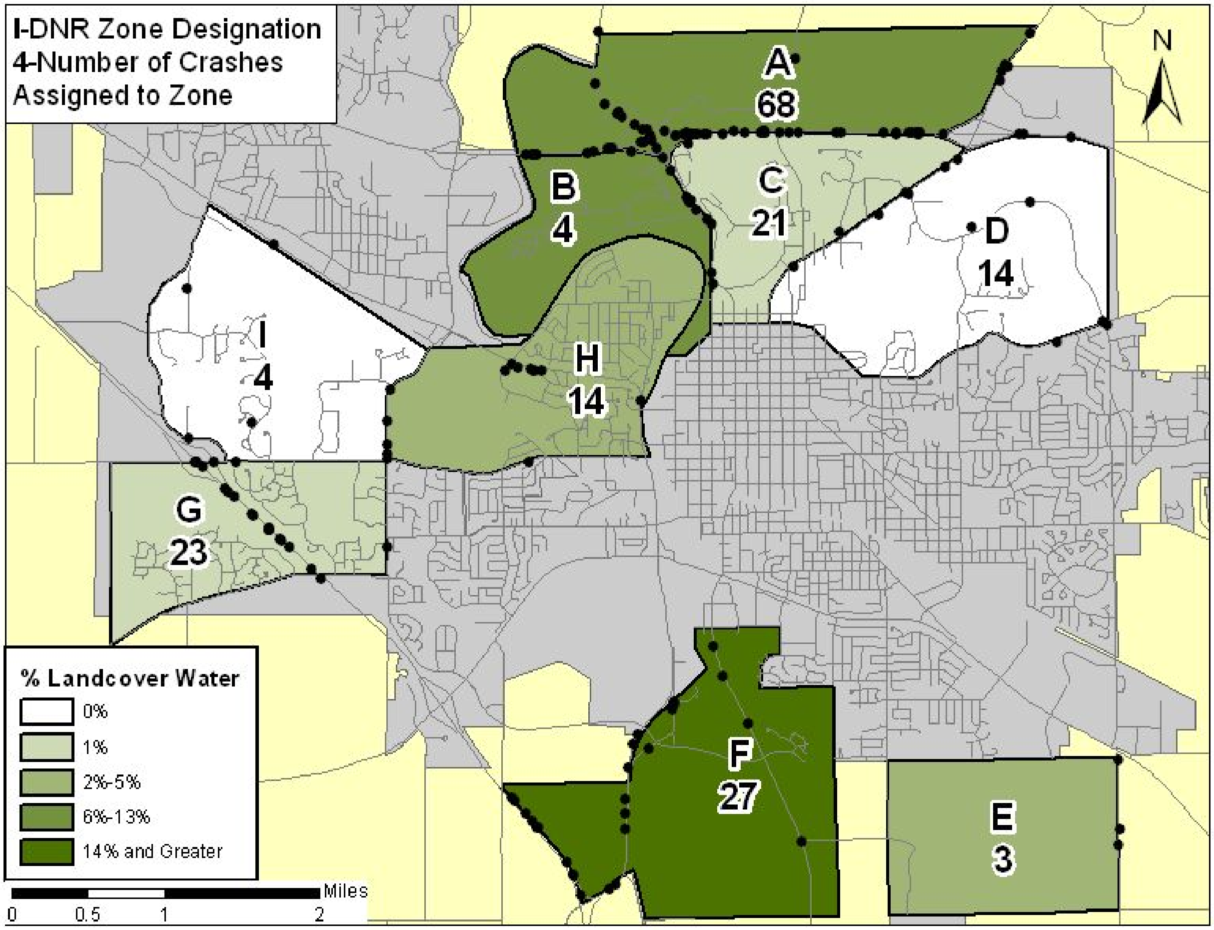


Figure D.18. Percentage of water/wetland and deer-vehicle crashes in Iowa City

APPENDIX E. STATISTICAL MODEL OUTPUTS

E.1 Frequency of Deer-Vehicle Crashes in Urban Deer Management Zones

<u>Negative Binomial Regression Model</u>

```
--> negbin;lhs=x5; rhs=one,x4,city,crop,comres$
+---------------------------------------------+

+---------------------------------------------+
| Negative Binomial Regression                |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 11, 2009 at 03:52:41PM.|
| Dependent variable           X5             |
| Weighting variable         None             |
| Number of observations        108           |
| Iterations completed          11            |
| Log likelihood function    -320.9481        |
| Number of parameters          6             |
| Info. Criterion: AIC =     6.05459          |
|  Finite Sample: AIC =     6.06230           |
| Info. Criterion: BIC =     6.20360          |
| Info. Criterion:HQIC =     6.11501          |
| Restricted log likelihood   -519.9524       |
| McFadden Pseudo R-squared   .3827356        |
| Chi squared          398.0086               |
| Degrees of freedom          1               |
| Prob[ChiSqd > value] =     .0000000         |
| NegBin form 2; Psi(i) = theta               |
+---------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|  1.76415176     .39877651    4.424   .0000
 X4    |   .01430965     .00437452    3.271   .0011  28.7149815
 CITY  |  -1.68407194     .41697296   -4.039   .0001   .59638889
 CROP  |  2.74529493   1.58279093    1.734   .0828   .10534445
 COMRES |  3.99988339   1.93405796    2.068   .0386   .12755598
---------+Dispersion parameter for count data model
 Alpha  |   .51555067     .09460894    5.449   .0000
```

Negative Binomial Regression Model—Interaction Effects

--> negbin;lhs=x5; rhs=one,deercity,deercrop,deercomr$

```
+---------------------------------------------+
| Negative Binomial Regression                |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 11, 2009 at 03:53:44PM.|
| Dependent variable              X5          |
| Weighting variable            None          |
| Number of observations           108        |
| Iterations completed             13         |
| Log likelihood function    -326.4676        |
| Number of parameters             5          |
| Info. Criterion: AIC =     6.13829          |
|  Finite Sample: AIC =     6.14374           |
| Info. Criterion: BIC =     6.26246          |
| Info. Criterion:HQIC =     6.18864          |
| Restricted log likelihood   -567.5563       |
| McFadden Pseudo R-squared   .4247838        |
| Chi squared          482.1774               |
| Degrees of freedom          1               |
| Prob[ChiSqd > value] =     .0000000         |
| NegBin form 2; Psi(i) = theta               |
+---------------------------------------------+
+--------+-------------+---------------+--------+--------+----------+
|Variable| Coefficient | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+-------------+---------------+--------+--------+----------+
 Constant|  1.85200106    .14700129  12.599  .0000
 DEERCITY|  -.04730099    .01287802  -3.673  .0002  17.7224109
 DEERCROP|   .18046389    .03435777   5.252  .0000  2.29036730
 DEERCOMR|   .15702589    .05367838   2.925  .0034  3.67027338
---------+Dispersion parameter for count data model
 Alpha   |   .57966751    .11438386   5.068  .0000
```

E.2 Frequency of Injuries in Deer-Vehicle Collisions in Urban Deer Management Zones

Poisson Regression Model

```
--> poisson;lhs=x18; rhs=one,dark,ocnvdc,x72,x27,gravelr,crop,road,under55$
+---------------------------------------------+
| Poisson Regression                          |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 11, 2009 at 03:55:55PM.|
| Dependent variable             X18          |
| Weighting variable             None         |
| Number of observations          921         |
| Iterations completed            9           |
| Log likelihood function     -344.5763       |
| Number of parameters            9           |
| Info. Criterion: AIC =        .76781        |
|  Finite Sample: AIC =         .76802        |
| Info. Criterion: BIC =        .81496        |
| Info. Criterion:HQIC =        .78580        |
| Restricted log likelihood   -369.2071       |
| McFadden Pseudo R-squared   .0667128        |
| Chi squared          49.26168               |
| Degrees of freedom              8           |
| Prob[ChiSqd > value] =      .0000000        |
+---------------------------------------------+

+---------------------------------------------+
| Poisson Regression                          |
| Chi- squared =  920.65823 RsqP=   .1281     |
| G - squared =  476.18259 RsqD=   .0938      |
| Overdispersion tests: g=mu(i) : 1.552       |
| Overdispersion tests: g=mu(i)^2: 1.888      |
+---------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|  -1.94169765     .39211855   -4.952   .0000
 DARK    |   .44997927     .18886151    2.383   .0172   .36807818
 OCNVDC  |  -.30281145     .18810609   -1.610   .1074   .49837134
 X72     |  -.07831055     .03960457   -1.977   .0480  4.16286645
 X27     |   .22669514     .05829809    3.889   .0001  3.66449511
 GRAVELR |  -.66031655     .21703212   -3.042   .0023   .55591748
 CROP    |  1.00214629     .51135174    1.960   .0500   .14933066
 ROAD    | -6.45153290    3.58509377   -1.800   .0719   .05999848
 UNDER55 |  -.50754406     .20976946   -2.420   .0155   .50054289
```

Poisson Regression Model—Interaction Effects

```
--> poisson;lhs=x18; rhs=one,dark,ocnvdc,x72,x27,gravelr,deercrop,under55$
+---------------------------------------------+
| Poisson Regression                          |
| Maximum Likelihood Estimates                |
| Model estimated: Nov 11, 2009 at 03:56:37PM.|
| Dependent variable          X18             |
| Weighting variable          None            |
| Number of observations        921           |
| Iterations completed           9            |
| Log likelihood function     -346.3015       |
| Number of parameters           8            |
| Info. Criterion: AIC =       .76938         |
|  Finite Sample: AIC =       .76956          |
| Info. Criterion: BIC =       .81130         |
| Info. Criterion:HQIC =       .78538         |
| Restricted log likelihood   -369.2071       |
| McFadden Pseudo R-squared   .0620400        |
| Chi squared           45.81121              |
| Degrees of freedom          7               |
| Prob[ChiSqd > value] =     .0000000         |
+---------------------------------------------+

+---------------------------------------------+
| Poisson Regression                          |
| Chi- squared =  930.77960 RsqP=  .1185      |
| G - squared =  479.63306 RsqD=  .0872       |
| Overdispersion tests: g=mu(i) : 1.607       |
| Overdispersion tests: g=mu(i)^2: 1.906      |
+---------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
 Constant|  -2.19136192     .35134418  -6.237  .0000
 DARK    |   .42660711    .18805283   2.269  .0233  .36807818
 OCNVDC  |  -.28801016     .18762205  -1.535  .1248  .49837134
 X72     |  -.08689355    .03988096  -2.179  .0293  4.16286645
 X27     |   .21568877    .05819478   3.706  .0002  3.66449511
 GRAVELR |  -.58234330     .20635715  -2.822  .0048   .55591748
 DEERCROP|    .02521093     .01647958   1.530  .1261  3.59799350
 UNDER55 |  -.55888150     .21228752  -2.633  .0085   .50054289
```

E.3 Severity of Deer-Vehicle Crashes in Urban Deer Management Zones

Binary Probit Model

```
--> probit; lhs=pdo; rhs=one, singlocc,x27, frid,
dry,othprinc,gravelr,spl65,...
Normal exit from iterations. Exit status=0.

+---------------------------------------------+
| Binomial Probit Model                        |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 11, 2009 at 03:57:31PM.|
| Dependent variable           PDO             |
| Weighting variable           None            |
| Number of observations        921            |
| Iterations completed          1              |
| Log likelihood function    -280.3524         |
| Number of parameters          11             |
| Info. Criterion: AIC =      .63269           |
|  Finite Sample: AIC =      .63300            |
| Info. Criterion: BIC =      .69032           |
| Info. Criterion:HQIC =      .65468           |
| Restricted log likelihood   -322.6850        |
| McFadden Pseudo R-squared   .1311887         |
| Chi squared          84.66526                |
| Degrees of freedom          10               |
| Prob[ChiSqd > value] =     .0000000          |
| Hosmer-Lemeshow chi-squared =  .00000        |
| P-value= 1.00000 with deg.fr. =    8         |
+---------------------------------------------+
+--------+-------------+--------------+--------+--------+----------+
|Variable| Coefficient | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+-------------+--------------+--------+--------+----------+
---------+Index function for probability
 Constant|    .36550286    .44710043    .817  .4136
 SINGLOCC|    .71119521    .12363548    5.752  .0000   .69381107
 X27     |  -.13335085    .03680178  -3.623  .0003  3.66449511
 FRID    |   .35554263    .17614360   2.018  .0435  .18023887
 DRY     |  -.23744069    .12259973  -1.937  .0528  .41368078
 OTHPRINC|   -.36790320    .17665407  -2.083  .0373  .54180239
 GRAVELR |    .52725743    .16550594   3.186  .0014  .55591748
 SPL65   |  -.46902981    .14836538  -3.161  .0016  .28664495
 LNAADT  |    .11701412    .05011052   2.335  .0195  8.94456471
 CROP    |  -.91141466    .35266538  -2.584  .0098  .14933066
 ROAD    |  3.12523509   2.08868142   1.496  .1346  .05999848
```

Binary Probit Model—Interaction Effects

```
--> probit; lhs=pdo; rhs=one, singlocc,x27, frid,
dry,othprinc,gravelr,spl65,...
Normal exit from iterations. Exit status=0.

+---------------------------------------------+
| Binomial Probit Model                        |
| Maximum Likelihood Estimates                 |
| Model estimated: Nov 11, 2009 at 03:58:49PM.|
| Dependent variable            PDO            |
| Weighting variable            None           |
| Number of observations          921          |
| Iterations completed              3          |
| Log likelihood function    -281.9650         |
| Number of parameters             10          |
| Info. Criterion: AIC =       .63402          |
|  Finite Sample: AIC =        .63428          |
| Info. Criterion: BIC =       .68641          |
| Info. Criterion:HQIC =       .65401          |
| Restricted log likelihood   -322.6850        |
| McFadden Pseudo R-squared   .1261913         |
| Chi squared          81.44006                |
| Degrees of freedom          9                |
| Prob[ChiSqd > value] =     .0000000          |
| Hosmer-Lemeshow chi-squared =  .04212        |
| P-value= 1.00000 with deg.fr. =    8         |
+---------------------------------------------+
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
---------+Index function for probability
 Constant|    .44391117     .44290598    1.002   .3162
 SINGLOCC|    .70636802     .12332320    5.728   .0000   .69381107
 X27     |   -.12681853     .03654461   -3.470   .0005  3.66449511
 FRID    |    .32723206     .17403568    1.880   .0601   .18023887
 DRY     |   -.21431291     .12146951   -1.764   .0777   .41368078
 OTHPRINC|   -.33151509     .17229703   -1.924   .0543   .54180239
 GRAVELR |    .48542065     .16275059    2.983   .0029   .55591748
 SPL65   |   -.45555561     .14813422   -3.075   .0021   .28664495
 LNAADT  |    .11982510     .04869205    2.461   .0139  8.94456471
 DEERCROP|   -.02425905     .01135722   -2.136   .0327  3.59799350
```