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Spatial Patterns of Road Mortality: Assessing Turtle Barrier Conservation Strategies

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SPATIAL PATTERNS OF ROAD MORTALITY: ASSESSING TURTLE BARRIER CONSERVATION STRATEGIES

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ABSTRACT: *Road mortality is one of the greatest threats to the diamondback terrapin (Malaclemys terrapin). For species at-risk of drivers, reducing the risk of road mortality is a common element of many conservation strategies. This research investigates the spatial variation of road mortality for the diamondback terrapin in Cape May County, New Jersey. Diamondback terrapins in the northeastern United States are especially susceptible to road mortality due to life history and habitat traits that increase their contact and vulnerability to human populations. This research analyzes the spatial distribution of roadkill for the diamondback terrapin in an area where barrier strategies are employed as part of a diamondback terrapin conservation program. The primary purpose of the research is to assess the effectiveness of a barrier strategy in conservation programs to protect diamondback terrapins. Turtle kill data was collected during high nesting season and mapped in relation to a number of environmental features and human-made barriers. Spatial analyses of the data reveal important insights on the effectiveness of barrier strategies to protect turtles.*

Keywords: *Malaclemys terrapin, road mortality, New Jersey, conservation, negative binomial*

INTRODUCTION

Designing programs for the conservation of threatened or endangered species involves identifying specific threats to the population and developing measures to mitigate those threats. One of the major threats to the diamondback terrapin (*Malaclemys terrapin*) is road mortality. Each summer, thousands of female terrapins are killed by motor vehicles as they cross roads adjacent to their nesting habitat (Wood and Herlands, 1997). In response, the implementation of road barriers is a key part of a conservation strategy to protect the species. The purpose of this research is to assess the effectiveness of barriers using geographic information systems (GIS) and spatial analysis. Road mortality data for the diamondback terrapin were collected during the height of nesting season in the summer of 2012 in Cape May County, New Jersey. The data were mapped in relation to human and environmental factors and spatially analyzed to determine if there is a systematic relationship between the presence of barriers and clusters of kills. The findings indicate that barriers are effective in reducing turtle mortality, but different types of barriers demonstrate different levels of effectiveness. The findings thereby reveal important insights on the effectiveness of constructed barriers as part of a conservation strategy to protect the diamondback terrapin. The methods used in the study can help to inform conservation research by demonstrating applications of GIS and spatial analysis.

LITERATURE REVIEW

Road Mortality as an Ecological Threat

Roads have been recognized as a widespread ecological threat in terrestrial and aquatic communities (Forman and Alexander 1998; Trombulak and Frissell 2000). Road mortality has been found to have a range of negative effects on wildlife populations including reducing population sizes and densities (Fahrig et al, 1995), shifting sex ratios (Gibbs and Steen 2005), and reducing genetic diversity (Noel et al., 2007). Certain wildlife populations have been shown to be highly impacted by road mortality including snakes (Dalrymple and Reicheinbach, 1984), crocodile (Kushlan, 1988), and turtles (Lode 2000, Hels and Buchwald 2001, Gibbs and Shriver 2002). Patterns of road mortality have been found to be species specific and related to life history traits (Beaudry, et. al., 2008). Turtles have been shown to be highly susceptible to road mortality because of their proximity to dense settlement areas and breeding traits.

Road mortality often results in spatially-patterned distributions, rather than an even distribution along a roadway. Previous research on a number of taxa, including a range of turtle species, has identified spatial patterns of road crossings, usually by correlating roadkill locations with environmental factors (e.g. Clevenger et al., 2003; Taylor and Goldingay, 2004). Researchers have established the significance of "hot spots" and "hot moments". Hot spots are places where the threat occurs at a higher rate than in the surrounding area; hot moments are times when the risk of mortality is the highest. Hot spots have been found to be associated with the habitat where each species is most commonly observed and factors such as distance to the nearest water body have been shown to have a significant relationship with road mortality (Cureton and Deaton, 2012). Hot moments generally occur during species-specific breeding seasons, and coincide with roadkill patterns (Cureton and Deaton, 2012). Understanding species movement patterns and the specific nature of the threats can aid in the design and implementation of mitigation measures.

A comprehensive program of turtle conservation commonly includes measures to mitigate road mortality. When kills are found to be clustered, spatial factors influencing mortality patterns can be identified and incorporated into conservation plans and strategies that attempt to mitigate these risks (Gunson, et al., 2009). Common conservation strategies to mitigate road mortality include warning signs posted along high-travelled routes or areas of higher mortality to alert drivers to the presence of wildlife. Another commonly-used strategy is the installation of constructed barriers to direct wildlife away from high risk areas.

Background on Diamondback Terrapins

The diamondback terrapin (*Malaclemys terrapin*) is a small, estuarine species of emydid turtle. Endemic to United States coastal salt marshes, diamondback terrapins live in tidal marshes, estuaries and lagoons where they favor the brackish waters. Most live along the Atlantic coast from Maine to North Carolina. Their preferred nesting sites are sandy beaches.

The population of diamondback terrapins is in decline throughout their range (Siegel and Gibbons, 1995). The decline in population has resulted in the species' status and its listing as a "species of Special Concern" in a number of states (Wood and Herlands, 1997). Population declines have been attributed to a variety of human-induced factors, but two major threats are prevalent. One threat comes from commercial crab traps where turtles get caught up and drown (Seigel and Gibbons, 1995; Wood and Herlands, 1997, Feinberg and Burke, 2003). However, the leading cause of death for the diamondback terrapin is road mortality (Avisar, 2006). In New Jersey, the primary habitat for the diamondback terrapin is barrier islands. Coastal development has resulted in a considerable loss of habitat. Development on the barrier islands has destroyed most of the sand dunes that originally served as primary nesting area for the diamondback terrapins. Today, diamondback terrapins in southern New Jersey, share the landscape with a large human population and extensive road network. With the disappearance of sand dunes, females have to find alternative nesting grounds. Their new preferred locations are primarily the shoulders of roads adjacent to and crossing their native salt marshes.

Mortality from increasing coastal traffic in fast-growing coastal communities is considerable. In southern New Jersey, the nesting season for diamondback terrapins lasts from late-May to mid-July, with the greatest activity occurring during six weeks in June and July. During this time turtles move from marsh creeks to beaches and alternative nesting sites to lay their eggs. Maximum egg-laying activity usually occurs during high tide, ensuring that eggs will be laid above the high-water level. Female terrapins will cross roads to ensure that they are at the highest point possible. These frequent overland migrations and road crossings make them extremely vulnerable to road mortality. Moreover, this time period corresponds with prime tourist season in Atlantic shore communities, and the increased motor vehicle traffic on the causeways between the mainland and the barrier islands of coastal southern New Jersey.

Diamondback Terrapin Conservation Program

The Wetlands Institute in Stone Harbor, New Jersey has a well-established diamondback terrapin conservation program. Established in 1989, the Terrapin Conservation Project assesses the impact of human activities on diamondback terrapins and ways to reduce those impacts. Conservation strategies are tailored to local conditions, including monitoring, population reintroduction and tagging. A key component of their conservation strategy is the erection and maintenance of barrier fencing along major roadways that traverse the nesting habitat. During terrapin nesting season (late May-July), student researchers monitor local salt marsh roads for female terrapin mortalities. Only female terrapins are found on land because they are looking for a place to lay their eggs.

Purpose of the Research

The purpose of this study is to assess the effectiveness of the barriers in reducing turtle mortality. Road mortality data of the diamondback terrapin is spatially analyzed in relation to the presence of constructed barriers to determine if there is a systematic relationship between barrier type and road mortality. Two types of barriers are included in the analysis, including installed barrier fencing that is specifically designed to obstruct terrapin crossings (see Figure 1, left) and bulkheads, which are a popular erosion control measure along the shoreline of many bays and estuaries (see Figure 1, right) It is expected that the presence of a barrier would result in a decline in the number of kills.

Figure 1. If properly installed, a female diamondback terrapin is unable to climb over an installed barrier fence (left). Standard wood bulkhead (right).

Study Area

Fieldwork was conducted in Cape May County, in southern New Jersey. Cape May is the southernmost county in New Jersey. Most of the county is low and coastal, as much of the area lies on a peninsula that juts into the Delaware Bay (Figure 2) The low elevation terrain is characterized by a chain of low-lying, but heavily built-up barrier islands, a wide band of salt marsh wetlands, and a low-lying mainland area composed of freshwater wetlands, woodlands and rural and suburban developed areas.

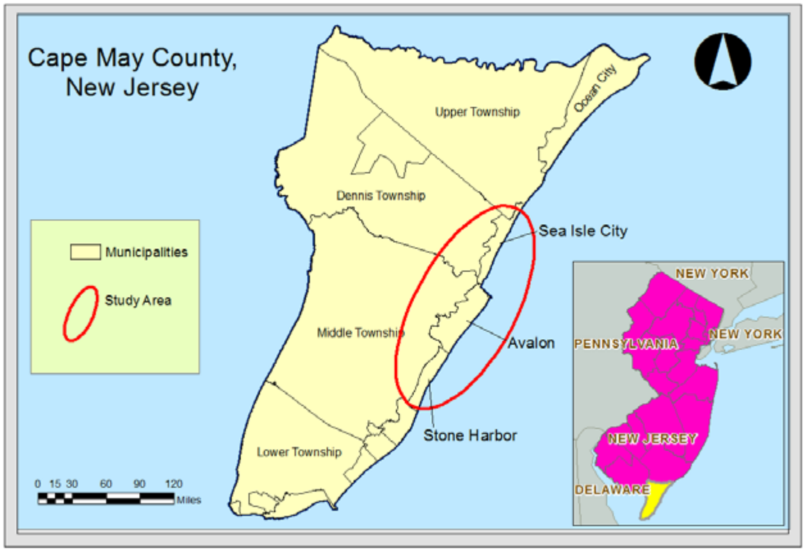

Figure 2. Regional Location of Study Area

Roadkill data were collected along the major arteries that traverse the area (see Map 2.) Conservation efforts by the Wetlands Institute determined these arteries as being most at-risk for turtle kills. The road patrol area covered a distance of 28 miles. Nearly 12 miles are along causeways that link the barrier islands to the mainland, and traverse the shore communities of Stone Harbor, Avalon, Sea Isle City and Ocean City. The remaining 16 miles are along the barrier islands themselves which have experienced a great deal of development and are built-up areas today. Two types of barriers are present along the transect including bulkheads and installed fencing. The bulkheads in the study area are vertical wall structures, designed to protect adjacent properties. The turtle barrier fencing, which is installed and maintained by the Wetlands Institute, is located primarily along the causeways linking the barrier island to the mainland. As indicated in Figure 3, there are a number of segments along the transect that are not protected by an installed barrier.

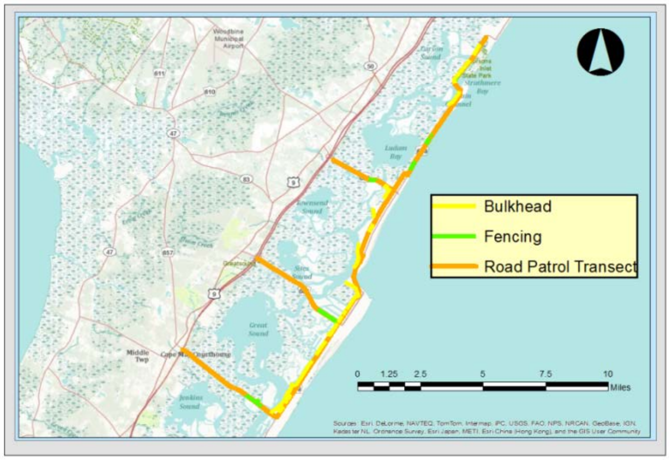

Figure 3. Road Patrol Transect and Barrier Location

Turtle mortality data were collected by student researchers at the Wetlands Institute during the summer of 2012 as part of the Terrapin Conservation Project. During an eight-week period between May 25, 2012 and July 16, 2012, road patrols occurred five times each day starting at 5:30am, 9:30am, 1:30pm, 4:30pm and 7:30pm. Student researchers in teams of two patrolled the entire area looking for terrapins, alive, injured or dead. They recorded and geocoded the location of mortalities, injuries and saves. Injured turtles were brought back to the Institute to recover any viable eggs which were then incubated in a turtle head-start program. A total of 194 kills were recorded. Road kill data were mapped using ArcGIS 10.1. Figure 3 shows the distribution of turtle mortality data along the road patrol transect. This map also shows the location of the two constructed barrier types.

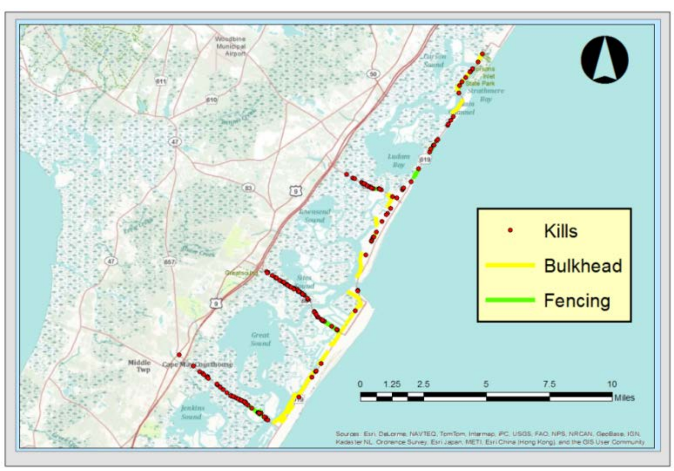

Figure 4. Distribution of Road Mortality

METHODS

To assess the effectiveness of the barriers, roadkill data are analyzed to determine if there is a systematic relationship between the presence of barriers and mortality. Roads in the study area are segmented into "zones of turtle mortality" (ZoTM) based upon the geographical spacing of turtle deaths, using natural breaks between "clusters" of kills to delineate the borders of zones. There are a total of 67 ZoTMs in the study area. Each zone is treated as a sampling station, turtle mortality is inventoried, and landscape features in each zone are recorded. It is standard procedure in wildlife management to segment roads and transects, treat each as a sampling station and record data (Joachimson et al 2004, Jones 1986).

The inventoried turtle mortality is then modeled as a function of landscape features in ZoTMs, specifically the presence of one of the two barrier types. The negative binomial distribution is commonly applied to model wildlife inventories, typically using count data (Krebs 1989, McComb et al 2010, O'Brien et al 2009, Vesssely et al 2006, Seavey et al 2005, Sauer and Droege 1990, White and Bennetts 1996), and is applied here to the inventory of turtle mortality. Specifically, the count of "kills" across segments (ZoTMs) is modeled as a function of the "barrier-type" in the segment in order to determine if there is any systematic relationship between barrier types and the count of turtle mortality.

The Negative Binomial Distribution

The negative binomial distribution is described by the mean and a dispersion parameter, k, which expresses the extent of clumping (or "clustering"). The negative binomial allows $s^2 > \text{avg}(x)$ and the index of dispersion (*I*) to be greater than 1.0. Data exhibiting this condition are said to be over-dispersed. The value of k can be approximated with: $k = \text{avg}(x)^2 / (s^2 - \text{avg}(x))$.

Negative binomial regression

Negative binomial regression accounts for over-dispersion by assuming that there will be unexplained variability among individuals who have the same predicted value. This additional unexplained variability between individuals leads to larger variance in the overall outcome distribution but has no effect on the mean. This additional variability is conceptually similar to the inclusion of an error term in OLS regression. In the negative binomial model, the error function is a mixture of two different probability distributions, the Poisson and gamma distributions (Cameron and Trivedi 1998).

Counts of dead turtles across ZoTMs are modeled as a function of landscape features, specifically barriers to turtle crossings. Results of the negative binomial regression of categorical data on turtle mortality allow the relative efficacy of barriers to be determined.

RESULTS

The functional form of the model to be estimated is confirmed using a LaGrange Multiplier test (Greene 1997, p. 744). The test reports the presence (or absence) of over-dispersion in the data, and is used to determine the appropriate model (Poisson vs. Negative Binomial) to be employed in the analysis. The LaGrange Multiplier statistic is Chi-Square distributed with one degree of freedom. Converted to a standardized score, the results indicate that the data are over-dispersed (Z=2.468; p=0.014). Therefore, the negative binomial model is appropriate for estimating the relationship between counts of turtle mortality and barriers.

The Omnibus test which tests the hypothesis that the estimated Negative Binomial model is better at explaining the count data that the "null" (or intercept-only) model, indicates that the estimated Negative Binomial model explains the turtle mortality data better than the null model to a statistically significant degree (likelihood ratio Chi Square = 532.634, p=0.000). The estimated Negative Binomial Regression coefficients for fencing and bulkhead barriers are 0.336 (p=0.016) and -1.60 (p=0.085) respectively while the intercept coefficient is 1.025 (p=0.000). The chi square measure of the model's "fit" shows it to be statistically significant (chi square = 89.766, critical chi square = 83.68 for p=0.05 and 64 df)

The reported negative binomial regression coefficient is interpreted as follows: for a one-unit change in the independent variable, the difference in the logs of the expected counts is expected to change by the respective regression coefficient, given that the other independent variables in the model are held constant.

Assessing the relative impact of barriers, fencing versus bulkhead, is possible by first calculating the exponentiated negative binomial regression coefficient for each barrier to derive their Incidence Rate Ratio (IRR) (Hilbe, 2007), and then measuring each barrier's IRR (fencing = 1.40, bulkhead = 0.85) relative to a common base – the IRR of road segments with no barrier (1.64). The product is a directly comparable Compound Incidence Rate Ratio (CIRR). The CIRR for bulkhead is (0.85/1.64) or 0.518 and the CIRR for road segments with fencing is (1.40/1.64) or 0.875. These findings can be interpreted to mean that turtle mortality along road segments with bulkheads is roughly 52% of, or 48% lower than, turtle mortality along road segments with no barriers, while turtle mortality along road segments with fencing is roughly 13% lower that turtle mortality along road segments with no barriers, given equal lengths of road segments and barriers. Said another way, for any given length of road, bulkheads lower turtle mortality by roughly 48% and fencing lowers turtle mortality by about 13%. These reductions are statistically significant.

DISCUSSION

The results of the analysis indicate that the barriers are effective at reducing road mortality of diamondback terrapins in the study area during the study period. These findings indicate that barrier protection measures are, therefore, effective as part of an overall conservation program for the diamondback terrapin. The results further indicate that, comparing the two types of barriers, bulkheads are more effective at reducing mortality than the turtle fencing barriers. This could be due to the nature of the installed turtle fencing itself, which is not permanent and needs regular inspection and maintenance to ensure that it stays secure and gaps do not emerge. Installing additional turtle barrier fencing and increased vigilance in maintaining them is likely to result in reducing turtle mortality.

While the findings affirm the effectiveness of barriers, it's important to note that the study is narrow in its scope and does not speak to additional measures to mitigate road mortality. Barriers are one part of a comprehensive conservation strategy to mitigate road mortality. Additional factors might include measures to changing driver behaviors such as alerting them to the presence of wildlife with street signs. In order to test the effectiveness of other components, it's important to have a richer understanding of spatial and temporal variables that impact road crossings. Future research should incorporate additional geographic variables, both spatial and temporal. The analysis did not account for temporal factors that would expect to impact patterns of road mortality such as tides, phases of the moon, and traffic volumes. Similarly, certain spatial factors were not included in the analysis that would likely explain some of the variation, such as speed limits and characteristics of the roadway that impact visibility. This analysis is also build on assumptions that need further verification or modification. In particular the analysis assumes that the turtle population is evenly distributed over the study area. Future research could refine and specify the catchment area for each zone of turtle mortality to get a sense of the density of turtle population. In this study, this information is unknown and therefore accounted for in the error term of the model. A verification of the limits to turtle travel would also be instructive in future studies. Currently it is not known how far a terrapin will travel before nesting. Future research could also expand the geo-statistical analysis. The scope of the analysis did not include any visualization of the statistical results. Utilizing tools of spatial visualization such as those found in ArcGIS could enable a richer understanding of spatial variability of turtle mortality.

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