Turtle Road Mortality in Grafton, Massachusetts

Corinne I. Lackner, M.S. Student
Center for Animals and Public Policy
Tufts- Cummings School of Veterinary Medicine

Final Project Report: Submitted in Partial Fulfillment of Graduation Requirements

31 August 2006

Acknowledgements

I am grateful to Natural Heritage and Endangered Species Program: MA Division of Fisheries and Wildlife for funding this research and granting me permission to study native turtles in the field. In particular, I thank Turtle Conservation Biologist, Lori Erb for providing assistance throughout my study. I thank Allen Rutberg, PhD for all his insightful comments, suggestions and enthusiastic support throughout the summer. I am grateful to the Tufts University Center for Conservation Medicine GIS Research Assistant, Sean Griffin for his assistance with sample design and the ArcGIS software and to Louise Maranda, MVZ, MSc, PhD for her statistical guidance. I would especially like to thank the veterinarians and technicians at the Tufts Wildlife Clinic for sharing their space, incubating turtle eggs, and radiographing and dissecting my study's dead turtles.

Table of Contents

Summary

Native turtle populations are diminishing in numbers throughout the United States, and road mortalities account for a large percentage of this decline. Different strategies are available to help overcome this problem, but the only way to choose the most effective tools is to first understand where turtles are most likely to be hit by vehicles (HBVs). We performed a field study to identify hotspots where turtle habitat, vehicles, and vulnerable species intersect in Grafton, Massachusetts. ArcGIS9 software was utilized to select our sample road segments based upon native turtles' habitats and spring movements. We systematically sampled 53, 100meter Grafton road segments for dead turtles between May 27, 2006 and July 15, 2006, using a GPS unit to pinpoint exact locations.

We located road mortality hotspots and identified risk factors that could help predict future sites that turtles may be HBVs. We found twenty- two individuals on ten of the 53 road segments. Sixteen individuals were painted turtles, four were snapping turtles and two were spotted turtles. We were more likely to find turtles HBVs on roads that touch wetlands, cross water, include a culvert, do not cross residential areas and/ or are not in contact with open land (grassland, pasture, or cropland). There was no significant association between the likelihood of finding turtles HBVs on roads that touched powerlines or forest. A road's class or terrain type did not influence our likelihood of finding a turtle HBV. We were more likely to find turtles HBVs on road segments adjacent to construction than on segments without wetland disturbance. This study's data may protect ecosystems by possibly influencing effective habitat management decision- making processes and future environmentally- friendly policy.

Introduction

Approximately 20% of the world's terrestrial, freshwater, and sea turtle species are native to the United States (Klemens 2000). As of August 11, 2006, the United States Fish and Wildlife Service (USFWS) Threatened and Endangered Species System (TESS) lists 39 of these species as federally endangered or threatened (USFWS 2006). Massachusetts, where our study took place, is the home of ten native terrestrial and/or freshwater turtles: the Blanding's (*Emydoidea blandingii),* bog (*Clemmys muhlenbergii*), Eastern box (*Terrapene carolina carolina*), Eastern painted (*Chrysemys picta picta*), Eastern snapping (*Chelydra serpentina*), musk (*Sternotherus odoratus*), Northern diamond-back terrapin (*Malaclemys terrapin terrapin),* Plymouth redbelly (*Pseudemys rubriventris bangsi),* spotted (*Clemmys guttata*), and wood (*Clemmys insculpta*). Of these ten, seven are listed under the Massachusetts Endangered Species Act (MESA). Two MESA species are also listed federally (MassWildlife 2006) (Table 1).

The two major threats to freshwater and terrestrial turtle populations are habitat loss and exploitation (Mitchell and Klemens 2000, Thorbjarnarson et al 2000). The first, habitat loss, can be defined as "the elimination of natural vegetation and alteration of the land surface to such an extent that it no longer is able to support its indigenous biota" (Mitchell and Klemens 2000). Various anthropogenic activities, including urbanization, road construction, agriculture, and the flooding of low-lying areas following dam construction, can cause habitat destruction (Mitchell and Klemens 2000). The second threat, exploitation, is the result of a growing wildlife trade for pets, medicinal, or subsistence purposes (Thorbjarnarson et al 2000).

Table 1: Status of Native Massachusetts Turtles

Species	**MESA Listing**	**Federal Listing**
Blanding's Turtle *Emydoidea blandingii*	Threatened	
Bog Turtle *Clemmys muhlenbergii*	Endangered	Threatened
Eastern Box Turtle *Terrapene carolina carolina*	Species of Special Concern	
Eastern Painted Turtle *Chrysemys picta picta*		
Eastern Snapping Turtle *Chelydra serpentina*		
Musk Turtle *Sternotherus odoratus*		
Northern Diamondback Terrapin *Malaclemys terrapin terrapin*	Threatened	
Plymouth Redbelly Turtle/Cooter *Pseudemys rubriventris bangsi*	Endangered	Endangered
Spotted Turtle *Clemmys guttata*	Species of Special Concern	
Wood Turtle *Clemmys insculpta*	Species of Special Concern	

MassWildlife (2006)

Scientists hypothesize that road mortality is a main cause of turtle populations decreasing throughout the United States (Garber& Burger 1995, Mitchell & Klemens 2000). Compared to other vertebrate species, reptiles are particularly vulnerable when crossing roads because they move slowly and are not cognizant of the danger presented by vehicles (Ashley & Robinson 1996). Turtle road mortalities affect more than unlucky individuals; they can wipe out rare and isolated populations. Vehicles may eventually create “kill zones” along roads that can ultimately deplete the area of turtles. Populations also become fragmented and the probability of successful gene movement decreases tremendously (Mitchell& Klemens 2000).

There are three main factors that could influence turtle movement, sometimes encouraging them to cross roads: environmental (such as daily and seasonal temperature, weather, and habitat condition), demographic (including population density and sex ratio) and the turtle’s physiological state (such as gender and body size) (Gibbons et al 1990). Turtles move for a variety of reasons including feeding, basking, mate seeking (adult males only), copulation, nesting (adult females only), travel from nest (juveniles only), hiding, and departure from unsuitable habitat (Gibbons et al 1990). The movements undertaken by turtles vary by species as well as by individual populations. For example, Gibbs & Shriver (2002) show that pond-turtle species move annually from pond-to-nest-to-pond while terrestrial species travel daily throughout their home ranges. Most MA turtle species live near water sources and could be at a high risk of being HBV since roads closest to wetlands and ponds seem to have the highest numbers of vertebrate road kill (Forman & Alexander 1998).

A turtle population’s sex ratio is important because it has the potential to change various population dynamics including time individuals spend searching for receptive mates, intrasexual competition and annual egg productivity (Gibbons 1990). Four factors that could determine the functional sex ratio in a population are the sex ratio of hatchlings, differential mortality of the genders, differences of ages at maturity of the genders and differential emigration and immigration of the genders in the population (Gibbons 1990). Bowne et al (2006) found that adult female turtles' movement patterns are influenced more by surrounding habitat than are those of all other age-sex classes, and it has been hypothesized that breeding females are more likely to be killed by vehicles since they often cross roads in search of appropriate nesting sites (Gibbs and Steen 2005). The prevalence of male-biased turtle population sex ratios throughout the United States is consistent with this presumed high rate of female mortality (Steen and Gibbs 2004, Marchland and Litvaitis 2004). Once a turtle population's sex ratio becomes male-biased, the chance of inbreeding increases dramatically due to a reduction in effective population size (Smith & Scribner 1990). Males may also need to undertake longer terrestrial migrations in search of mates, which could increase their chances of being HBVs on traveled roads.

The long term effects of altered population sex ratios are unknown, but research suggests that the loss of adults is especially detrimental to turtle species because of their low annual recruitment rates and delayed sexual maturity (Steen and Gibbs 2004). Turtle evolution did not factor in adult deaths caused by vehicles, so a decreased adult survival rate will require a greater number of juveniles to survive in order to keep stable population numbers (Congdon & Dunham 1997). The trait values associated with long-lived turtle life histories combine and limit populations' abilities to respond to increased accidental mortalities of adults.

If skewed sex ratio and variability of reproductive output can dramatically reduce effective population size, an increased number of turtles killed by vehicles will lead to decreased current and future turtle population sizes (Smith & Scribner 1990). Gibbs and Shriver (2002) estimated that road mortality has the potential to limit populations of turtles and various studies pertaining to box turtles imply that the accidental loss of one adult per population per year is not sustainable (Mitchell & Klemens 2000). Findlay and Bourdages (2000) suggest that the effects of road mortality on long-lived turtle species may be drastically underestimated by the current short- term environmental assessments of roads on wetland biodiversity; the full effects of road construction on species- loss may not be detectable for several more decades.

Road impacts are more serious when a species is already threatened with extinction (Forman et al 2003), but abundant species merit attention as well (Gibbs & Amato 2000). “We hope that concern for the common snapping turtle does not have to wait until populations are so reduced that recovery will be difficult or impossible. A worthy goal for conservation programs is to keep the common snapping turtle common” (Condgon et al 1994). By the time drastic decreases in turtle numbers are visible, it may be too late to save the population from extinction.

The Use of Mitigation Devices

Mitigation devices, including culverts, fences, and road underpasses, can offer effective and humane ways to divert wildlife from roads. Roads that already have effective culverts in place can become more turtle-friendly when fences are added to force the animals to use them, rather than cross on the road surface. For example, in San Bernardino County, California, biologists discovered that while many endangered desert tortoises were being HBVs on certain parts of State Highway 58, some individuals were utilizing previously built storm-water culverts underneath the road. After the state put up fences to guide the tortoises under the highway and through the culverts, mortality decreased by ninety-three percent over four years (Chilson 2003).

In 1989, the French Highway Society undertook two major strategies to reduce vehicular impacts on a population of Hermann’s tortoises, already threatened by habitat loss and fragmentation, when it designed a new road structure. Fences were installed to keep tortoises off the road while culverts and tunnels were constructed so individuals had a safe place to move between separated habitat areas. Four years later, short- term studies showed low road mortality rates since the tortoises were effectively diverted by fences into the new culverts and tunnels (Guyot & Clobert 1997).

However, there is not a “one-size fits all solution” for wildlife crossing structures (Forman et al 2003). Effective diversion devices can only be implemented once specific road mortality hotspots are identified as they were in California and France.

Land- use planners, conservation officials, and engineers need to know what the ecological risks are for a given set of construction options (road size, surface type, traffic volume) and land- use categories, so they can design appropriate mitigation devices and more environmentally- sound roads (Andrews & Gibbons 2005, Findlay and Bourdages 2000). The first step in mitigating wildlife road mortalities should be the identification of particular fatality hotspots. Turtle road mortality usually occurs when an individual walks across a road in search of desired habitat, but turtles can also be attracted to road features (Ashley & Robinson 1996). Many turtle species prefer to lay their eggs in open areas with short vegetation and unfortunately numerous road-sides are “ecological traps”, mimicking traditional turtle cues for habitat choice (Schlaepfer et al 2002). Once specific ecological traps and/or turtle habitats separated by roads are detected, hot spot models can be created to help predict where future mortality could occur (Ashley & Robinson 1996, Havlick 2004, Ramp et al 2005).

The paradigmatic study was completed in 1996 on the Long Point Causeway, Lake Erie, Ontario. A 3.6km section of road was surveyed for HBV reptiles from spring through autumn for two, two-year periods. It was reported that reptile road mortality did not begin until nesting season and that turtle road mortality was significantly associated with adjacent open water areas (Ashley and Robinson 1996).

I have been unable to find any studies involving exact locations and/ or risk factors for turtle (or any other long-lived species) road mortality in the eastern United States. This study begins to fill this void.

Goals and Objectives

Our field study of turtle road mortality in Grafton, Massachusetts had three primary goals. The first goal, to identify hotspots where turtle habitat, vehicles, and vulnerable species intersect, was accomplished by searching for turtles that were HBVs. The second goal was to determine if any correlation exists between these hotspots, road type and culvert placement. The third goal was to model and identify the risk factors associated with turtle road mortality so that effective habitat management can be initiated to decrease further turtle road mortalities.

Results from this study will be shared with the Massachusetts Natural Heritage and Endangered Species Program (NHESP) who may utilize the information in their statewide conservation plans to ensure that turtle populations in Grafton, Massachusetts are considered in future management decisions.

Natural History of Turtles Native to Grafton, Massachusetts

Six out of the ten turtle species native to Massachusetts can be found in Grafton: the common musk (*Sternotherus odoratus*), Eastern box (*Terrapene carolina carolina*), Eastern painted (*Chrysemys picta picta*), snapping (*Chelydra serpentina*), spotted (*Clemmys guttata*) and wood (*Clemmys insculpta*). Before designing the study, we compiled an extensive literature review of the natural histories of each native turtle found in Grafton. (Table 2)

All Grafton turtles rely on water, vernal pools or wetlands during the spring. A wetland can be defined as a biologically diverse area characterized by soil covered by shallow water with intermingled submerged or emergent vegetation (Lee et al 2006). A vernal pool is a seasonal wetland containing water on a wet-dry cycle that is utilized by indicator species and precludes permanent fish populations (Kenney & Burne 2001). For example, spotted turtles in Massachusetts depend upon vernal pools and wetlands earlier in the spring most likely for food, basking, and copulation. Their dependence changes later in the spring; their exit dates from these seasonal pools to adjacent upland habitat (less than 400m away) often coincides with the pool drying up as well as nesting season (Milam & Melvin 2001).

Table 2: Native Turtles Located in Grafton, MA and their respective habitats

Species	**Months Active**	**Spring Habitat**	**Nesting Habitat**	**Approximate Movement Distances and/or Home Ranges (state studied is noted)**
Spotted Turtle ***Clemmys guttata*** MA Special Concern Status removed 7/2006	March-October [17]	* Rely heavily on seasonal pools & permanent wetlands that are bordered by larger upland habitat[14] *Most movement occurs between open emergent wetlands and forested vernal pools[10,12,14]	*Open, non-forested sites such as field, meadow, or road edge[3,14,15] * Deposit eggs end of May-June [15]	* Maximum MA distance covered between wetlands ~1150m[7] * Average MA home range ~ 3.5ha.[7] * MA Nesting travel between 50- 570m[7]
Wood Turtle ***Clemmys insculpta*** MA Species of Special Concern	March-October[17]	* Rely on vernal pools[11] * Riparian species- use wetlands and uplands in vicinity of streams[8,11, 17] *Travel between forest & open areas (meadows, fens, etc) [5]	* Open/ grassy areas with low canopy cover[5] *Riparian gravel bars[5],[17] * Nest May- June[3]	* ME Activity areas within ~300m from rivers and streams[5]
Eastern Box Turtle ***Terrapene carolina carolina*** MA Species of Special Concern	April-September[17]	*Essentially terrestrial (forested upland), but will travel through wetlands and vernal pools[9,10,11]	* Open upland areas with sandy/loamy soil & sparse vegetation[17] * Nest May- July[3]	* Average MA home range ~3.26 ha [10] (complicated movement patterns within the home range[18]). * Normal MD daily movement ~370 feet[18]
Snapping Turtle ***Chelydra serpentina***	April-November[17]	*Aquatic (ponds, lakes, rivers) [6,17] * Occasionally vernal pools[11]	*Open areas with short vegetation [16] * Nest May-June with peak laying in June[3]	* Females travel 'some' large distance from the water to lay eggs, but I can not find a number. [3]
Eastern Painted Turtle ***Chrysemys picta picta***	April-September[17]	*Aquatic (ponds, lakes, river) [11,17] * Occasionally vernal pools[11]	* Pond perimeters [2] *Open canopies, well- drained soils (lawns, fields, trails, roadsides) [2] * Deposit eggs late May- late June [19]	* NH travel less than 500 meters from ponds. [13] * VA & NH nesting travel ~ 100m- ~275 m [4,13]
Common Musk Turtle ***Sternotherus odoratus***	April-October[17]	*Still or slow- moving bodies of water [17] *Rarely leave the water[3]	*Nests under muskrat lodge walls, rotting stumps, etc. [3] *May lay eggs along roads [1] * Nests May- June[3]	* Rarely leave the water[3]

Table 2 Citations

1. Aresco (2005)
2. Baldwin et al (2004)
3. Behler and King (2000)
4. Bowne et al (2006)
5. Compton et al (2002)
6. Congdon et al (1994)
7. Fowle (2001)
8. Garber and Burger (1995)
9. Hagood (2006)
10. Kaye et al (2001)
11. Kenney and Burne (2001)
12. Litzgus and Mousseau (2006)
13. Marchland and Litvaitis (2004)
14. Milam and Melvin (2001)
15. NYSDEC (n.d.)
16. Schlaepfer et al (2002)
17. Schwartz and Golden (2002)
18. Stickel (1950)
19. Tinkle et al (1981)

Methods

Study Area

Grafton, Massachusetts is a small residential town (about 22.83 square miles) located in Worcester County, southeast of the city of Worcester (Town of Grafton n.d.). Grafton supports light industrial business as well as many acres of forests, freshwater coastlines, wetlands (including bog, deep marsh, marsh, shrub swamp, and wooded swamp), and agricultural landscapes. As in most of Massachusetts, land development in Grafton is increasingly altering the habitats of native wildlife.

Sampling Scheme

Prior to choosing the study samples, ESRI ArcGIS 9 was used to download public Geographic Information System (GIS) data from the MassGIS website. Relevant data layers included Massachusetts counties and roads, Massachusetts land use, NHESP "2005 Estimated Habitats of Rare Wildlife", the Concord and Blackstone watersheds (for streams, rivers, and bodies of water), wetlands, and potential vernal pools. Grafton borders were selected from all layers so that only pertinent Grafton information was revealed. Massachusetts NHESP provided additional GIS information including certified vernal pools and Grafton species of special concern (wood turtle, spotted turtle and box turtle) sightings. The Geographic Coordinate System used was GCS_North_American_1983 and the Projected Coordinate System was NAD_1983_StatePlane_Massachusetts_Mainland_FIPS_2001.

According to the MassGIS road data layer, Grafton is comprised of 1313 road segments from 5 different road classes. There are three segments in Class 1, Limited Access Highways. These segments are all part of the Massachusetts Turnpike and were eliminated for consideration in our sample for safety reasons. Class 3, other numbered routes, comprises 158 segments and

Class 4, major routes, comprises 31 segments. There are 716 segments in class 5, minor roads and streets with inventory information. There are 405 segments in class 6, which are also minor roads and streets, but unlike class 5, they do not have inventory information. Class 6 roads were eliminated from the sample because they are all unnamed and most likely private.

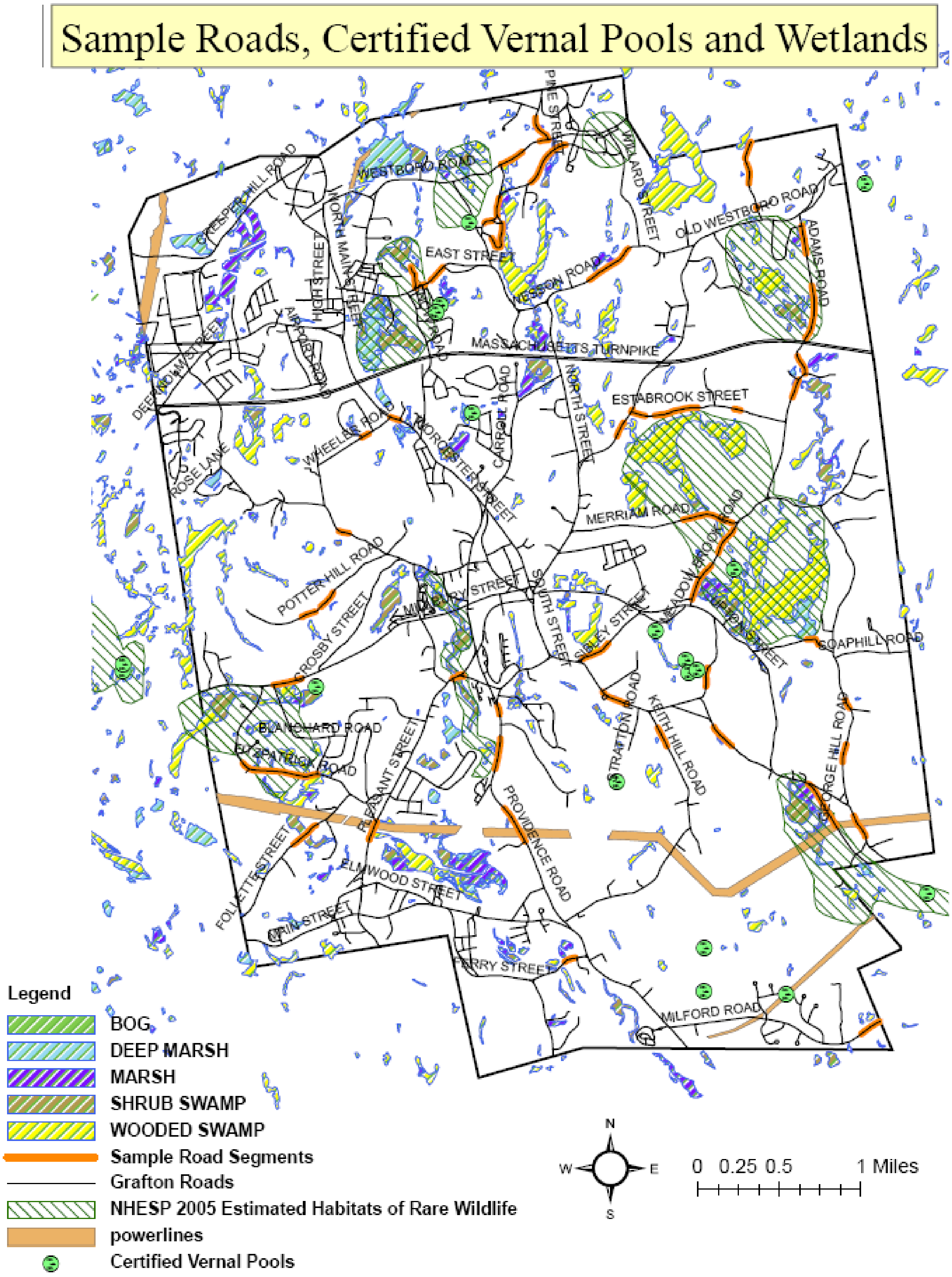
Specific criteria to narrow down the road sample were determined based upon native turtles' habitat usage, home ranges, and movements (Table 2). All Grafton species' normal daily movements and movements for egg laying are greater than 100 meters, and all depend on vernal pools and/or wetlands throughout the spring and summer. Since the species share these traits, ArcGIS9 was used to pinpoint all road segments within 100 meters of wetland and/or certified vernal pools. Potential vernal pools were not used as a determining factor because they are not officially certified by the state of MA and, in any case, most fall within wetlands and were already accounted for by the wetland data layer. This left 609 road segments within 100 meters of certified vernal pools and/ or wetlands. ArcGIS9's 'Select by location' tool was used for the subsequent narrowing down of road segments.

Pond turtles follow a pond-nest-pond movement (Gibbs and Shriver 2002), so fresh-water coastal and recreational freshwater beach, found in the land use layer, were used as inclusion criteria. Seven segments within 100 meters of wetland and/ or certified vernal pool cross the outline of freshwater coast and were included in the sample. There are no road segments within 100 meters of wetland and/or certified vernal pool that also cross the outline of recreational freshwater beaches.

Many species, including wood and box turtles, sometimes forage and prefer to lay their eggs in open areas with low canopy covers such as powerlines, mining areas, and cropland (Compton et al 2002, Hagood 2006). Four road segments that lie within 100 meters of vernal pools or wetlands also intersect powerlines, and 42 segments within 100 meters of vernal pools or wetlands are also crossed by the outline of cropland. There are no road segments within 100 meters of wetland and/or certified vernal pool that also cross the outline of mining.

Our final road sample includes 53 100-meter road segments distributed throughout Grafton, MA. Seven of the segments are class 3, two are class 4, and forty-six are class 5 roads. Some roads contain multiple 100 meter segments (Figure 1 and Appendix 1). Roads were grouped into nine variable categories using a combination of field and MassGIS website descriptions (Appendix 2). Road characteristics such as class, terrain, and the presence of a culvert and/ or powerline were included as variables and segments crossing an intermittent stream, stream or river were labeled as such. Road segments were also categorized by whether they touch residential land, a wetland, a forest or a forest that separated a wetland from the road, or open land (including cropland, pasture or grassland). Grassland, cropland, and pasture were grouped together because they are essentially all grassy open land that we assume would seem similar to a turtle.

Figure 1


Sample Roads, Certified Vernal Pools and Wetlands
WESTBORO ROAD
PINE STREET
WILLARD STREET
OLD WESTBORO ROAD
ADAMS ROAD
CREEPER HILL ROAD
NORTH MAIN STREET
HIGH STREET
EAST STREET
WESSON ROAD
AIRPORT ROAD
MASSACHUSETTS TURNPIKE
DEER POND STREET
CARROLL ROAD
NORTH STREET
ESTABROOK STREET
ROSE LANE
WHEELER ROAD
WORCESTER STREET
MERRIAM ROAD
MEADOW BROOK ROAD
POTTER HILL ROAD
MILLBURY STREET
SOUTH STREET
SIBLEY STREET
UPTON STREET
SOAPHILL ROAD
CROSBY STREET
BLANCHARD ROAD
FITZPATRICK ROAD
PLEASANT STREET
STRATTON ROAD
KEITH HILL ROAD
GEORGE HILL ROAD
PROVIDENCE ROAD
FOLLETTE STREET
ELMWOOD STREET
ERRIN STREET
FERRY STREET
MILFORD ROAD
Legend
BOG
DEEP MARSH
MARSH
SHRUB SWAMP
WOODED SWAMP
Sample Road Segments
Grafton Roads
NHESP 2005 Estimated Habitats of Rare Wildlife
powerlines
Certified Vernal Pools
N
W
E
S
0 0.25 0.5 1 Miles

Road Surveys

Prior to sampling, a protocol was submitted to the Tufts-Cummings School of Veterinary Medicine Institutional Animal Care and Use Committee (IACUC) and approved by expedited review. We also obtained a permit from the Massachusetts Division of Fisheries and Wildlife authorizing the hand capture and release of all living species of turtles located on or near roadways for the purpose of identification and for the salvage of any dead turtles in Worcester County, MA.

A pilot study was performed to test how long it would take to observe each segment. Including driving and walking times, approximately 6 road segments could be examined per hour. The 53 road segments were separated into 3 groups clustered by location and we tried to sample each group every third day between 4pm and 8pm. Every 100 meter sample segment was checked by walking up the shoulder of the road on one side and then back on the other side's shoulder.

A Garmin III GPS device was used to plot the exact location animals were found. When a dead turtle was discovered, we recorded (when possible) species, gender, approximate age, approximate size and whether it was gravid (Appendix 3). One dead spotted turtle, a Massachusetts species of special concern, was found and transported to the Massachusetts Division of Fisheries and Wildlife in Westborough, MA as required by our MassWildlife permit. Two freshly killed painted turtles were gravid females, so the cadavers were quickly transported to the Tufts Wildlife Clinic (so that viable eggs could be extracted and incubated by a licensed veterinarian) as described in our MassWildlife permit. All other carcasses were removed from the road after recording to avoid double counting.

To help determine culvert effectiveness, we located culverts present in our sample road segments. The exact locations were plotted with a Garmin III GPS receiver. Culvert type, size and condition were described and recorded on a data sheet (Appendix 4).

A digital data set containing the locations of HBV turtles and culverts was uploaded from the Garmin III receiver using DNR Garmin software and projected onto a map of Grafton using ArcGIS9. Data were analyzed using chi square tests and logistic regressions to identify Grafton turtle road mortality hotspots and associations between various road characteristics and turtles HBVs.

Results

Species Composition of Road Mortality

Twenty- two individual turtles were found on ten of the 53 road segments. Of these, only seventeen were actually HBV. The other five were classified as HBV because they were situated on the road in just a way that they would have been HBV if we were not there to move them along towards their destinations. The majority (sixteen) of the individuals were painted turtles. Four out of the 22 were snapping turtles and the other two were spotted turtles (Figure 2 and Appendix 3).

For the purpose of statistical analysis, roads were either categorized as having at least one HBV turtle or none since our sample was too small to account for non- independence.

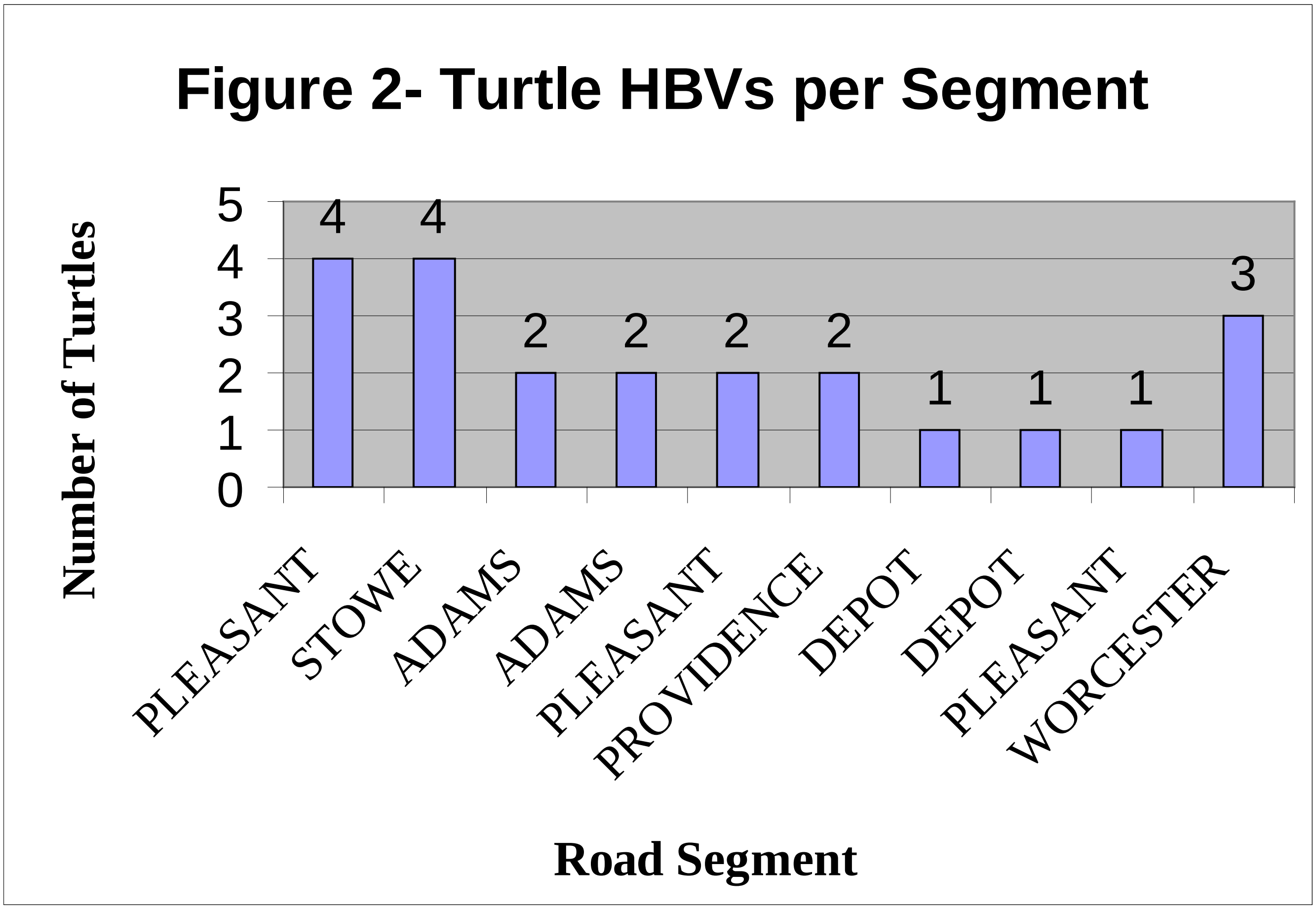


Figure 2- Turtle HBVs per Segment

Association of Turtle Mortality and Roadside Traits

Visual interpretation of maps can offer significant inferences. Grafton turtle HBVs were in close proximity to vernal pools and estimated habitats of rare wildlife (Figure 3). The map illustrating Grafton turtle HBVs compared to wetlands suggests that a turtle HBV was more likely to be found on a road that is in close proximity to a wetland (Figure 4). Likewise, a map showing Grafton turtle HBVs and culverts located on our sample roads appears to show that a turtle HBV was more likely to be found on a road containing a wet culvert versus a road that does not (Figure 5).

The ten road segments that possessed turtles HBVs can be categorized by the environmental traits present on either side (Table 3). The two road segments with the most turtle HBVs (4 on each road) touch wetlands on both sides. On these two roads, we assume that the turtles were HBV as they crossed the road to get from one wetland to the other. We can not assume reasons turtles cross the roads with different land use attributes on either side since we were unable to identify which direction the turtle was crossing when it was hit.

Statistical analysis seems to support the conclusions drawn from the maps. In univariate tests, a turtle HBV ($p < 0.05$) was more likely to be found on a road segment that touches wetlands, crosses water, includes a culvert, and/or is not in contact with open land (grassland, pasture, or cropland; Table 4). A turtle HBV is also more likely ($p < 0.10$) to be found on a road segment that does not cross residential areas. The likelihood of finding a turtle HBV was not significantly associated ($p > 0.10$) with road class, road terrain, and/or road segments that touch powerlines or forest.

Figure 3

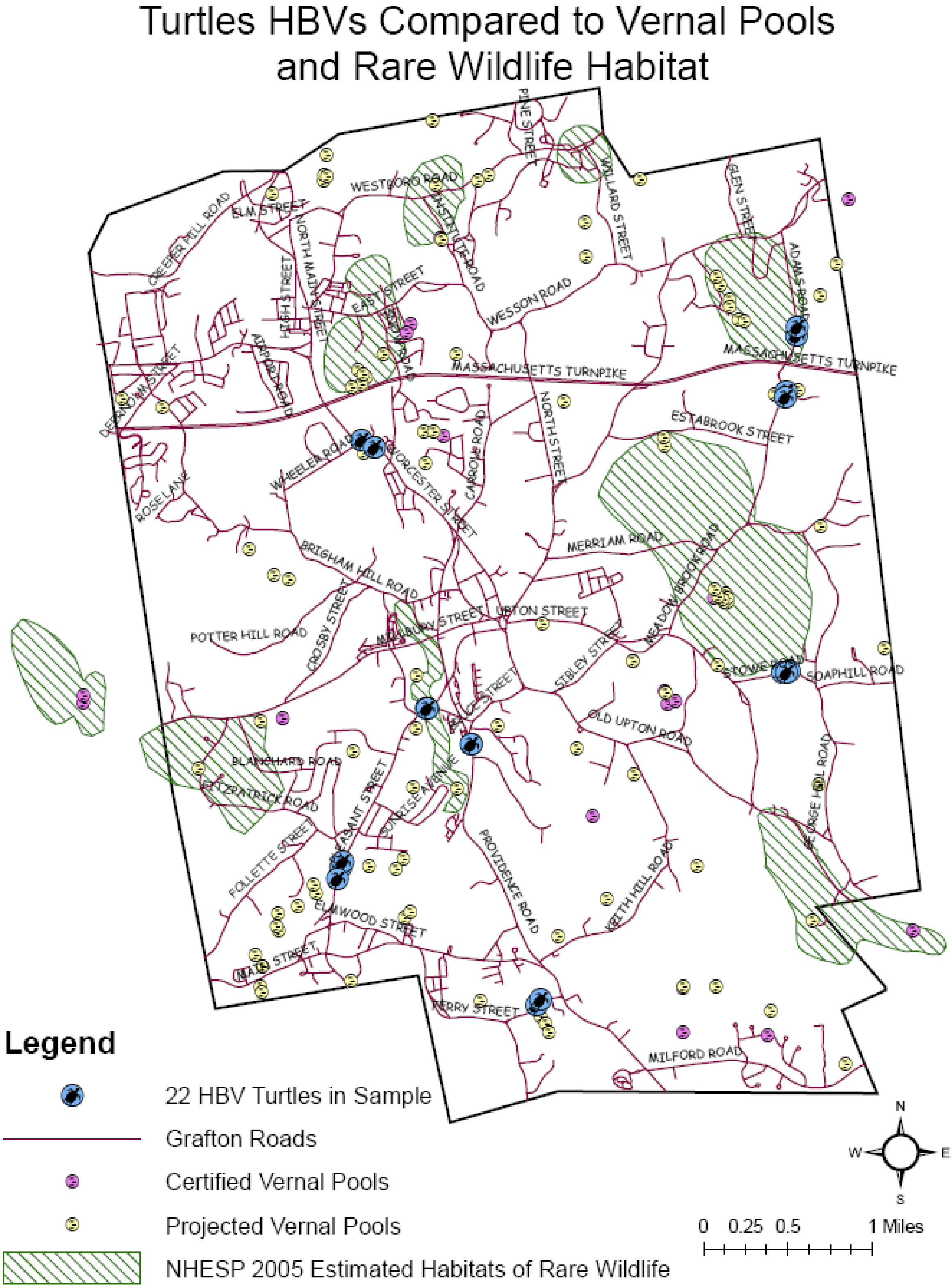

Turtles HBVs Compared to Vernal Pools and Rare Wildlife Habitat
PINE STREET
WESTBORO ROAD
WILLARD STREET
GLEN STREET
ADAMS ROAD
ELM STREET
CREEPER HILL ROAD
NORTH MAIN STREET
HIGH STREET
INSTITUTE ROAD
EAST STREET
WESSON ROAD
MASSACHUSETTS TURNPIKE
DEERING STREET
AIRPORT ROAD
NORTH STREET
ESTABROOK STREET
WHEELER ROAD
WORCESTER STREET
CARROLL ROAD
ROSE LANE
MERRIAM ROAD
BRIGHAM HILL ROAD
MEADOW BROOK ROAD
POTTER HILL ROAD
CROSBY STREET
MILLBURY STREET
UPTON STREET
SIBLEY STREET
STOWE ROAD
SOAPHILL ROAD
OLD UPTON ROAD
BLANCHARD ROAD
FITZPATRICK ROAD
PLEASANT STREET
SUNRISE AVENUE
GEORGE HILL ROAD
FOLLETTE STREET
PROVIDENCE ROAD
KEITH HILL ROAD
ELMWOOD STREET
MAIN STREET
PERRY STREET
MILFORD ROAD
Legend
22 HBV Turtles in Sample
Grafton Roads
Certified Vernal Pools
Projected Vernal Pools
NHESP 2005 Estimated Habitats of Rare Wildlife
N
W
E
S
0
0.25
0.5
1 Miles

Figure 4

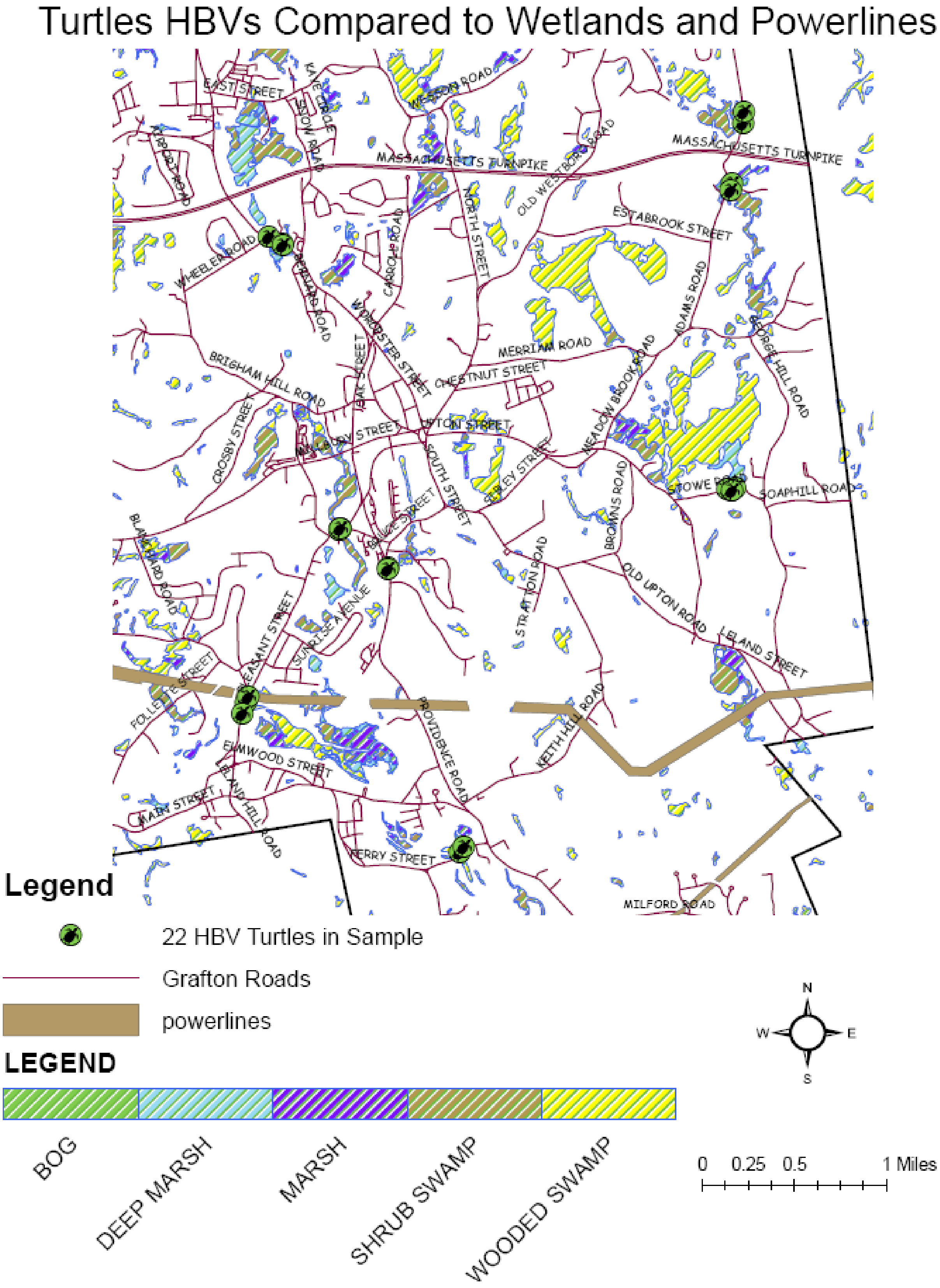

Turtles HBVs Compared to Wetlands and Powerlines

Figure 5

Turtles HBVs Compared to Culvert Placement

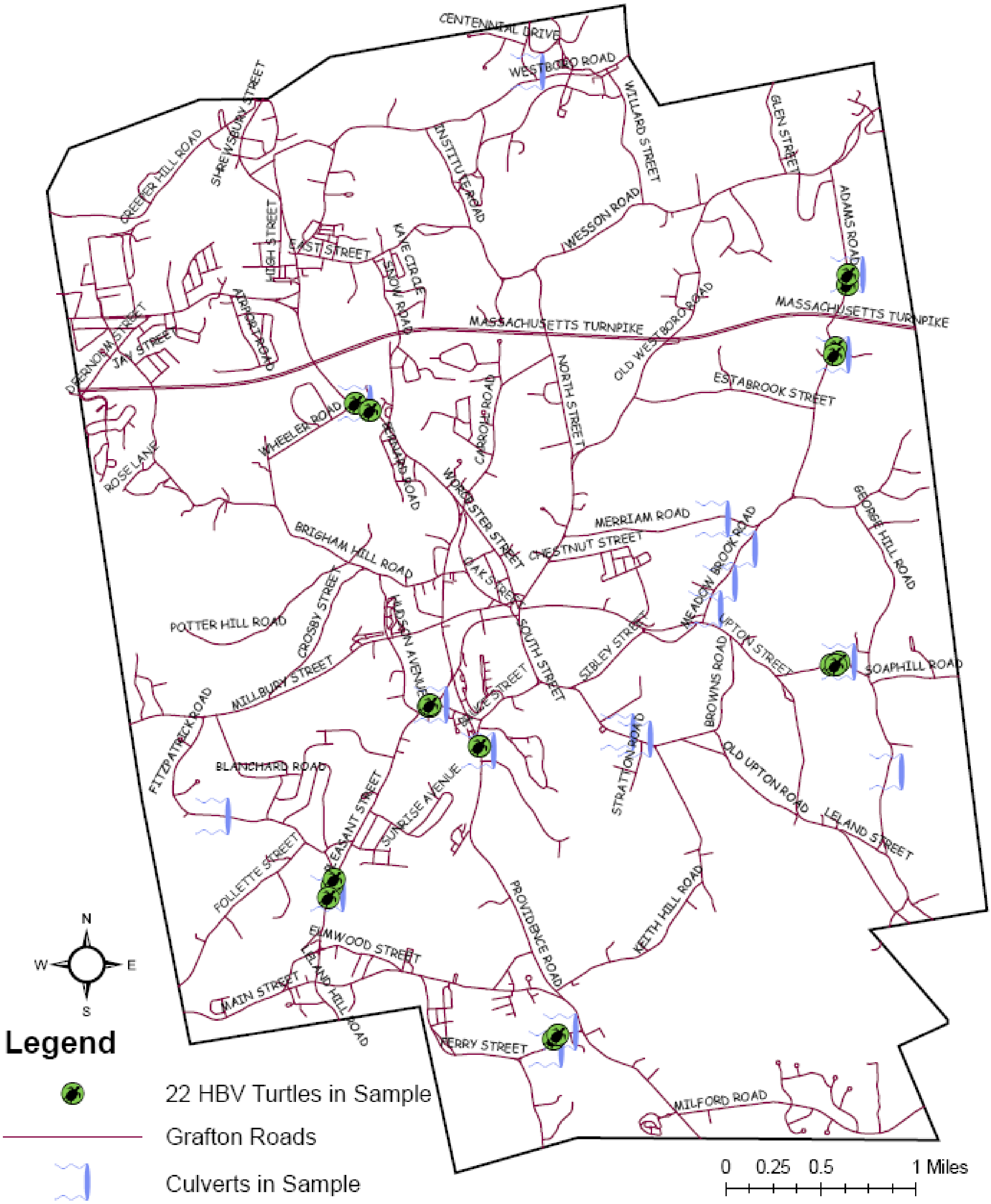


Table 3: Road Segments Dead Turtles found and the Associated Environmental Traits

STREET NAME	CLASS	TERRAIN	LAND USE ONE SIDE- LAND USE OTHER SIDE	CROSS STREAM/RIVER?	WET CULVERT?	TURTLE HBV #
ADAMS	5	Level	Forest- Touching Wetlands	Intermittent Stream	yes	2
PLEASANT	5	Level	Touching Wetlands- Touching Wetlands	River	yes	4
STOWE	5	Rolling	Touching Wetlands- Touching Wetlands	Stream	yes	4
WORCESTER	3	Level	Forest- Touching Wetlands	River	yes	3
PLEASANT	5	Level	Powerline- Powerline	NO	NO	2
PROVIDENCE	3	Level	Grassland/Cropland/Pasture-Touching Wetlands	Intermittent Stream	yes	2
ADAMS	5	Level	Residential- Touching Wetlands	NO	yes	2
DEPOT	5	Level	Forest- Forest	River	yes	1
DEPOT	5	Level	Forest- Forest	Intermittent Stream	yes	1
PLEASANT	5	Level	Residential- Touching Wetlands	River	yes	1

`

<u>Land use categories I chose to pick from:</u>
Forest (forest alone, or forest separating the road from a wetland)
Grassland/Cropland/Pasture
Powerline
Residential
Touching wetland directly

Please note:
The ‘Cross Stream or River?’ is from the MassGIS website’s hydrography data layer, so it may not correlate with the ‘Wet Culvert Present’ column which is from personal observations in the field.

Table 4: Incidence of Turtle Road Mortality with Respect to Environmental Variables: Univariate Analysis

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	9 (50%)	9 (50%)	18
Touching Wetlands	NO	1 (3%)	34 (97%)	35
		10	43	53
Significant				
Chi Squared	17.258			
p value	0.0000			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	8 (62%)	5 (38%)	13
Crosses stream/river	NO	2 (5%)	38 (95%)	40
		10	43	53
Significant				
Chi Squared	20.488			
p value	0.0000			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	1 (6%)	17 (94%)	18
Touching Residential	NO	9 (26%)	26 (74%)	35
		10	43	53
CAN BE Significant				
Chi Squared	3.156			
p value	0.0757			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	9 (53%)	8 (47%)	17
Wet culvert present	NO	1 (3%)	35 (97%)	36
		10	43	53
Significant				
Chi Squared	18.982			
p value	0.0000			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	1 (4%)	24 (96%)	25
Touching Open Land	NO	9 (32%)	19 (68%)	28
		10	43	53
Significant				
Chi Squared	6.833			
p value	0.0089			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	5 (21%)	19 (79%)	24
Touching Forest	NO	5 (17%)	24 (83%)	29
		10	43	53
NOT Significant				
Chi Squared	0.111			
p value	0.7394			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	Class 3&4	2 (22%)	7 (78%)	9
Class	Class 5	8 (18%)	36 (82%)	44
		10	43	53
NOT Significant				
Chi Squared	0.080			
p value	0.7777			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	YES	1 (20%)	4 (80%)	5
Touching Powerline	NO	9 (19%)	39 (81%)	48
		10	43	53
NOT Significant				
Chi Squared	0.005			
p value	0.9458			

		Segment with Dead Turtle		
		YES	NO	
Road Factor:	Rolling	1 (9%)	10 (91%)	11
Terrain	Level	9 (21%)	33 (79%)	42
		10	43	53
NOT Significant				
Chi Squared	0.867			
p value	0.3518			

Logistic regressions were run for land use factors (class, terrain, hydrography and culvert placement) to distinguish maximum likelihood estimates. In the multivariate, saturated logistic regression model (deviance on 48 degrees freedom= 26.129), a turtle HBV was significantly more likely ($p < 0.05$) to be found on a road segment that has a wet culvert (Table 5).

A multivariate, unsaturated logistic regression model (deviance on 49 degrees of freedom= 26.201) was then run using the variables terrain, hydrography and culverts (excluding the variable class). A turtle HBV was still significantly more likely ($p < 0.05$) to be found on a road segment with a culvert versus a segment without. With this regression model, a turtle HBV was more likely ($p<0.10$) to be found on a segment that crosses an intermittent stream, stream or river (Table 6) than a road that does not cross water.

We attempted to use a logistic regression for the other factors (powerlines, wetlands, forest, residential and open land). This was unsuccessful since the variables did not converge, most likely due to a small sample size. Only chi squares were used in their analysis.

Supplementary Results

While sampling, we noticed that some segments, many of which had Massachusetts Department of Environmental Protection (MA DEP) wetland permits posted, were undergoing constant active construction and seemed to have a high frequency of turtles HBVs. Twelve out of the twenty-two total dead turtles were found on or adjacent to segments undergoing construction. This incidental finding prompted the hypothesis that the presence of visible MA DEP/ Grafton wetland permits and/or the presence of ongoing construction adjacent to wetlands could increase the likelihood of finding a turtle HBV. Univariate statistics were used and the results were substantial (Table 7). A turtle HBV was significantly more likely ($p < 0.05$) to be found on a road segment that is adjacent to construction than one without wetland disturbance.

Table 5: Incidence of Turtle Road Mortality with Respect to Environmental Variables: Saturated Logistic Regression Model

Deviance on 48 DF= 26.129
Likelihood Ratio Statistic on 5 DF= 47.345, $p < 0.05$

Land Use	**Coefficient**	**Standard Error**	***p*-value**	**Odds Ratio**	**95% Confidence Bounds**	
Class	-.4082	(1.53)	.789	.6648	.3340E-01	13.23
Terrain	1.740	(1.36)	.199	5.696	.3995	81.21
Hydrography	1.798	(1.14)	.116	6.039	.6406	56.93
Culvert	3.142	(1.38)	. 023	23.14	1.548	345.9

.

Table 6: Incidence of Turtle Road Mortality with Respect to Environmental Variables: Land Use Regression Model without ‘Class’

Deviance on 49 DF= 26.201
Likelihood Ratio Statistic on 4 DF= 47.272, $p < 0.10$

Land Use	**Coefficient**	**Standard Error**	***p*-value**	**Odds Ratio**	**95% Confidence Bounds**	
Terrain	1.794	(1.35)	.183	6.012	. 4280	84.43
Hydrography	1.876	(1.11)	.092	6.530	.7347	58.04
Culvert	3.043	(1.31)	.020	20.97	1.602	274.5

Table 7: Incidence of Turtle Road Mortality with Respect to DEP Permits and/or Construction: Univariate Analysis

		Segment with Dead Turtle		
		Yes	No	
Road Factor:	Yes	5 (63%)	3 (37%)	8
Permit/ Construction	No	5 (11%)	40 (89%)	45
		10	43	53

Significant	
Chi^2	11.718
p value	0.0006

Discussion

Map inspections, chi-square analysis, and logistic regression all indicate that there is a strong association between finding a turtle HBV and certain road characteristics. Hotspots where turtle habitat, vehicles, and vulnerable species intersect in Grafton, MA include ten different road sample segments (Figure 2). There is an increased likelihood of finding a turtle HBV in the presence of a wet culvert, water, and/or wetlands and absence of residential areas and/or open land (grassland, pasture, or cropland). A turtle HBV was not more likely to be found on roads with differing terrains and/or classes or on road segments that border powerlines or forest.

Powerlines and cropland/grassland/pasture were included in the study's design because they are open, sunny areas that could attract a nesting female turtle. One road segment that is entirely surrounded by powerlines had two hatchling painted turtles HBVs early in July. This most likely suggests that a female from the neighboring wetland laid her eggs in the adjacent powerline corridor. When the young hatched, they most likely attempted to cross the road in search of appropriate habitat. Segments entirely bordered by grassland/cropland/pasture did not reveal the same results. The only time a turtle HBV was found on a road touching grassland/ cropland/ pasture was when a wetland touched the other side of the road. According to our results, the absence of grassland/cropland/ pasture is strongly correlated to finding a turtle HBV and the presence of a powerline is not. Because our sample is small, it is probably premature to conclude that there is a significant difference between the use of grassland/pasture/cropland open areas and powerlines for nesting, and future MA turtle nesting studies comparing grassland/ cropland/ pasture and powerlines are warranted.

Univariate analysis, logistic regression and descriptive results all indicated that there is an increased likelihood of finding a turtle HBV in the presence of a wet culvert (Figure 5). While collecting data on Depot Street, however, we observed an adult snapping turtle swimming downstream through the culvert, indicating that at least some turtles bypass road surfaces by using culverts. This invites future research to recognize both the number of turtles that actually use wet culverts and the number of individuals that cross the road above the culvert, and why. Additionally, it seems likely that the higher the local population density of a certain turtle species, the more likely it is you will find that species dead on an adjacent road. A long- term study testing the hypothesis that a turtle species' habitat choice and population density are correlated to the number of individuals found HBVs in certain areas is essential.

Class and terrain were included in our analysis because it was hypothesized that a greater number of turtles are HBVs on flat, frequently traveled large roads than on back roads with rolling terrains. All road development can fragment populations by disrupting ecosystems and isolating habitat patches that were once connected. But, large, flat roads usually have a greater number of cars passing at higher speeds, and are thus known to kill larger numbers of turtles via road mortality than roads with less traffic (Mitchell and Klemens 2000). There was unexpectedly no correlation between finding a turtle HBV and road segments' class or terrain. One hypothesis is that turtle populations adjacent to large class 3 and 4 roads are less likely to exist due to prior habitat fragmentation and road mortalities. We theorize that the smaller the population density, the less likely you are to find a turtle HBV. The other hypothesis is that we did not find important relationships because our random sample was skewed towards small class 5 roads with flat terrain. This skew could have masked correlations that may have appeared with a larger, more balanced sample of road segments. All the Grafton segments that fit our initial criteria were included in the sample, so the only way to have prevented a skewed sample of segments would have been to include road segments of neighboring towns.

We were more likely to find a turtle HBV in a non-residential than a residential area. Similar to the road class phenomenon, this could imply that past residential development already depleted abundant local turtle populations via fragmentation and road mortality. Another hypothesis for the residential phenomenon could be that people drive slower and more attentively in residential areas, thus seeing and avoiding turtles crossing the road. Further studies of driver reactions to turtles crossing the road and correlations between turtles HBVs and vehicle speed are warranted.

Vernal pools, wetlands and rare species habitats are important turtle environments and there is a strong correlation between these areas and turtles found HBVs (Figure 3 and 4). When we modeled risk factors associated with turtle road mortality, these areas had the largest association with turtle road mortality. Future Grafton turtle habitat management and turtle-friendly road design can only be effective if special attention is paid to these important risk factors.

Study Limitations

The limited number of road segments sampled probably had a substantial effect on the number of turtle HBVs that were found. Although we attempted to maximize sampling efficiency by focusing on segments within 100 meters of wetlands and vernal pools and, thus, a high likelihood of having turtles, we presume that some turtles HBVs in Grafton were not accounted for simply because they were not killed within our sample segments. If we had found more HBV turtles, we could have compared male versus female or young versus adult HBV data. Unfortunately, our data set of 22 turtles was too small to carry out these statistical analyses.

To help compensate for both the small road sample size and few found HBV turtles, we included live turtles discovered crossing sample segments. We assumed that these turtles could have been HBV if we were not there to find and carry them to a safe location across the street. More intensive observations of each road segment would be useful to determine when and how many turtles crossed in particular hotspots, and what the chances are that each crossing turtle would be HBV.

There was a limited combination of road segment and habitat types within Grafton that fit our initial criteria. It might have helped to go beyond Grafton and into neighboring towns so that equal numbers of road classifications were included in the sample. A less skewed sample could have produced different and more meaningful results.

The MassGIS data did not always correspond exactly to our field descriptions, presumably because we studied a town that has experienced a large amount of development within the past few years. For instance, ArcGIS 9 initially located four roads that intersected powerlines, but as we noticed in the field, five of our sample road segments actually touched powerlines. Sample design error could have occurred if all roads fitting our initial criteria were not produced by ArcGIS in the beginning stages. Similarly, observed culverts did not exactly match the roads that MassGIS indicates cross a stream, intermittent stream or river. To compensate for these discrepancies, we corrected the MassGIS data with field descriptions when categorizing the road segments for analysis.

Policy and Management Implications and Conclusion

Although limited in many ways, this appears to be the first study of this design for turtles native to the Northeast United States. Repeatable results are likely, but to be certain, future projects need to be take place over a greater than three month time span. A similar, yet long term project using our data should be completed for a few consecutive springs to test the significance of our results. According to Forman and Alexander (1998), "Little information exists on crossing rates relative to population sizes, movement rates away from roads, predation rates, home range locations, and so forth". These in depth future studies could include turtle population surveys to determine whether crossing rates are relative to population size, population density, et cetera.

Three steps in ecologically sensitive road planning are: avoidance (preventing ecological impact all together), mitigation (minimizing the ecological impact), and lastly if the other two are not feasible, compensation (providing an equivalent amount of habitat in the local region to balance the impact) (Forman et al 2003). The best option would be to ban road- building through wetlands and other sensitive habitats. Unfortunately, as a greater number of people migrate to small towns such as Grafton, MA, the building and paving of new roads is usually inescapable. The next best option is for land- use planners, engineers and conservation officials to take prime wetland habitat and the adjacent upland ecosystems into strong consideration by linking conservation with public policy agendas. This is especially important with land use planning, watershed management, landscape preservation and the promotion of legislation that enhances environmentally friendly land use planning (Forman et al 2003). If roads absolutely must be built through prime wildlife habitat, then legislation (including development and mitigation guidelines) should be implemented so that the least amount of habitat destruction occurs.

We can not be certain why residential areas are associated with fewer turtles found HBVs, but we can reasonably assume there are decreased turtle populations in residential areas in comparison to undeveloped areas. If fewer found turtle HBVs can imply smaller population densities caused by development, then building in prime turtle habitat with large population densities is not warranted because the same thing can happen to them.

The male spotted turtle in our sample was found walking across the road away from a construction site (with a MA DEP wetland permit) and towards what seemed to be untouched wetlands. We hypothesize that this turtle, as well as others in our sample, may have crossed the road to get to intact wetlands on the other side. The Massachusetts Wetlands Protection Act (WPA) requires that “persons” apply for a special permit prior to altering a wetland. If authorities decide to grant the permit (after a public hearing), a DEP file number is assigned and posted in the construction area (Massachusetts General Laws 1996). The Pleasant Street Bridge used in this analysis was under construction throughout the study, but despite the ensuing wetland damage, it does not hold a MA DEP permit. This bridge reconstruction probably falls under a special provision of the WPA and does not require a permit number, but it was counted in the analysis because three dead turtles were found in close proximity to it. Future scientific research needs to detect if turtles HBVs were originally displaced by the ongoing environmental impact caused by construction adjacent to and including wetlands, and whether the turtles retreat back to the original wetland site once the construction ceases. If studies illustrate that this type of construction does indeed lead to an increased number of turtles HBVs, stricter DEP wetland permit requirements (including mitigation devices and when permits should even be allowed) should be passed to save the remaining MA wetland ecosystems.

Culverts seem to be important risk factors for turtles HBVs, so in order to design the most effective habitat management plans, MA habitat research needs to encompass the specifics of wet culverts and turtle movement. An observational study involving a large sample of specific types of culverts could be useful if the number and type of species using each culvert can be analyzed. The researcher could compare culvert effectiveness by size (width and/ or length), hydrography (river, stream, or intermittent stream) or material (cement versus corrugated metal).

Effective policy decisions can be determined once scientists narrow down why some wet culverts are used more for turtle movement than others.

The majority of our hotspots occurred on segments where culverts are already present, so future Grafton efforts should also focus on upgrading the design and maintenance of existing culverts and means to channel turtles into them. For example, the culvert that connects ponds and wetlands on Stowe Road, one of the two biggest hotspots in our study, is full of organic debris. The upstream debris clogs the cement culvert and creates a fast current under the bridge. Four painted turtles were found dead on the road above the culvert. Although we do not know for a fact, we assume that snapping turtles also inhabit the ponds and wetlands associated with this culvert. Perhaps snapping turtles are large enough to climb over the debris while painted turtles prefer to walk across the culvert on land rather than expend the extra amount of energy that is probably necessary to climb over the large pile of plant debris. There is also a possibility that the painted turtles did not swim under the bridge on days when the water level is at the height that a strong current is created by the debris. If either of these is the case, simple culvert maintenance may alleviate the number of turtles HBVs on Stowe Road. A specific culvert study could help determine if debris is a risk factor for turtles HBVs.

Fencing and/ or walls may not be appropriate everywhere (Mitchell and Klemens 2000) since they can fragment turtle populations by creating boundaries between habitats. On the other hand, fencing or rock walls can be advantageous when used in a habitat already fragmented by a road. In this case, the benefits of coercing a turtle to use a culvert most likely outweigh the possible risks of further fragmenting the population. Once scientists believe that a particular culvert is turtle-friendly, research can be completed to determine the best ways to direct turtles into it. For instance, the cement culvert on Depot Street (that we witnessed a snapping turtle swimming through) is unlike many of the other culverts in our study because it includes cement walls on both sides. Only one turtle (hatchling painted) was found HBV on this segment, so there is a possibility that adults crossing between wetlands use this culvert on a regular basis. A study should be completed to determine what it is about this culvert that attracts turtles; it could be the simple fact that the cement walls prevent turtles from walking up the sides and onto the road. Upgrading culvert design to include fencing or walls could be an effective means of minimizing turtle HBVs and should be studied further.

An effective link can be created when applied research studies, such as this one, are disseminated in ways that may influence the decision- making and policy process (Klemens 2000). This study is important because it pinpoints turtle HBV hotspots and risk factors in Grafton. It will be shared with MA NHESP who may use the data in future statewide conservation plans to ensure that turtle populations in Grafton, Massachusetts are considered in future management decisions.