Methodologies for Surveying Herpetofauna Mortality on Rural Highways

TOM A. LANGEN,[1] *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
ANGELA MACHNIAK, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
ERIN K. CROWE, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
CHARLES MANGAN, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
DANIEL F. MARKER, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
NEAL LIDDLE, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*
BRIAN RODEN, *Department of Biology, Clarkson University, Potsdam, NY 13699-5805, USA*

ABSTRACT Road mortality can contribute to local and regional declines in amphibian and reptile populations. Thus, there is a need to accurately and efficiently identify hotspots of road-mortality for hazard assessment and mitigation. In 2002, we conducted walking and driving surveys throughout an extensive rural highway network in northern New York, USA, to evaluate survey methods and to quantify spatial and temporal patterns of herpetofauna road-mortality. In 2004, we repeated the surveys at a subset of locations to quantify interannual repeatability. Reptile and amphibian species had different peak periods of road-mortality because they differed in the causes of movements that resulted in crossings. Spatial locations of herpetofauna road-mortality were concentrated at a limited number of hotspots. Hotspots overlapped across species and were located at consistent locations across years. Results of walking and driving surveys were highly repeatable among survey teams, but driving surveys underestimated the density of road-mortality because many animals were missed. Detection failure was higher in some taxa (e.g., frogs) than others (e.g., turtles). Our results indicate that it is possible to design a valid, efficient methodology for locating hotspots of reptile and amphibian road-mortality along a road network and, thus, pinpoint priority sites for mitigation. (JOURNAL OF WILDLIFE MANAGEMENT 71(4):1361–1368; 2007)

DOI: 10.2193/2006-385

KEY WORDS amphibians, New York, reptiles, road ecology, road-mortality, survey methodology.

High amphibian and reptile mortalities occur when animals cross roads during terrestrial movements to breeding, wintering, or summering habitat (Langton 1989, Ashley and Robinson 1996, Smith and Dodd 2003, Aresco 2005*a*). It also has been hypothesized that reptiles and amphibians are attracted to roads to elevate their body temperature on cool nights following sunny days because the road surface remains warmer than the air and surrounding landscape (e.g., Dodd et al. 1989, Rosen and Lowe 1994).

Road crossings of herpetofauna present a safety risk to motorists, who swerve to miss (or to hit) animals crossing the road (Langley et al. 1989) or stop and walk into the traffic lanes to remove crossing animals (e.g., Chadwick 2003, Lundy 2005). In our region, the St. Lawrence Valley of New York, USA, motorists complain that road surfaces become dangerously slick at certain localities due to accumulated animal remains during peak periods of road crossing by frogs.

Abundant road-kill may simply indicate locations where large, healthy populations of reptiles and amphibians occur (Hels and Buchwald 2001). However, there is increasing evidence that excessive road-mortality should be a conservation concern (Wright 2006, Andrews et al. 2007). In the northeastern United States and southeastern Canada, for example, road-mortality is associated with population declines and altered population structure of amphibians and reptiles (Fahrig et al. 1995, Marchand and Litvaitis 2004, Steen and Gibbs 2004, Gibbs and Shriver 2005). Amphibians such as the northern leopard frog (*Rana pipiens*) that travel long distances between breeding and foraging sites appear to be particularly vulnerable to population declines associated with excessive road-mortality (Pope et al. 2000, Carr and Fahrig 2001). Female turtles, which approach roads to nest, are also prone to excessive road-mortality, resulting in long-term population declines (Gibbs and Steen 2005, Steen et al. 2006).

Because of concerns about wildlife road-mortality, both in terms of impact on sensitive species and as a hazard to motorists, management agencies are seeking accurate methods of locating mortality hotspots (Evink 2002, Spellerberg 2002, Forman et al. 2003). Approaches to locating hotspots include road surveys made by driving or walking road segments (e.g., Kline and Swann 1998, Enge and Wood 2002, Clevenger et al. 2003), or predictive landscape models using Geographic Information Systems (GIS) that compare mortality incidents to features of the landscape and roads (Smith 1999, Clevenger et al. 2002, Barnum 2003, Ramp et al. 2005). To locate road-mortality hotspots within a road network, to validate predictive computer models of spatial patterns of road-mortality, and to monitor the effectiveness of mitigation techniques implemented to reduce herpetofauna road-mortality (e.g., barriers and passageways; Dodd et al. 2004, Aresco 2005*b*), it is essential that road-survey methodologies be developed and validated.

We evaluated methods of quantifying herpetofauna mortality in a regional rural highway network. Our main objectives were to determine which sampling methodology

[1] *E-mail: tlangen@clarkson.edu*

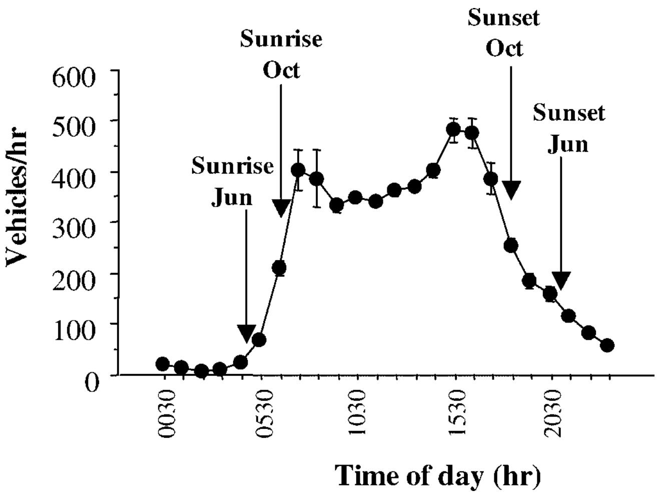

Figure 1. Daily traffic volume (vehicles/hr) on New York State Highway 68 at Upper and Lower Lakes Wildlife Conservation Area, New York, USA. We also indicate sunrise and sunset on 21 June and 15 October 2002, the minimum and maximum day-lengths during the period that herpetofauna are killed on this highway. Traffic data collected on 3 dates (22 Jul 1998, 18 Jun 2001, 27 Sep 2004; Ernest Olin, New York State Department of Transportation, unpublished data).

is most appropriate for documenting spatial and temporal patterns of road-mortality of reptiles and amphibians, and to quantify these patterns along highways within our region.

STUDY AREA

Our study encompassed 4 towns (Potsdam, Canton, Lisbon, Madrid) in St. Lawrence County, New York (75°15′N, 44°40′W). The total area was 976.4 km^2, of which 149.6 km^2 or 15.3% was classified as wetland by the United States Geological Survey. The elevation was 46–183 m above sea level. Three north-flowing rivers crossed our study area (Oswegatchie, Raquette, and Grasse Rivers), and the St. Lawrence River bordered on the north. The principal land-cover, aside from classified wetland, was northern hardwood and mixed hardwood–conifer forest, hay field, and cattle pasture. Minor land-uses included row crops (principally maize) and residential areas (St. Lawrence County Agricultural and Farmland Protection Board 2001). There were 32,166 residents among the 4 towns at the 2000 census, and population densities ranged from 13.1 people/km^2 (Town of Madrid) to 59.8 people/km^2 (Town of Potsdam). Most residents lived in 2 large villages (Canton, Potsdam).

Notable within our study area was the Upper and Lower Lakes Wildlife Management Area (3,554 ha), comprised primarily of marsh and shrub swamp. This protected area was managed for waterfowl hunting and breeding habitat of wetland and grassland birds. It was one component of an extensive network of wetlands, which included within our study area the 40,000-ha Lisbon Grasslands Important Bird Area (Wells 1998). Our study area was located in the core of what may have been the largest continuous network of freshwater swamps and marshes in the northeastern United States, most of which was on privately owned land and bisected by numerous roads.

There were 353.3 km of federal, state, and county highways among the 4 towns. These highways were 2-lane, excepting some short segments of additional lanes within the village limits of Canton and Potsdam, and most road segments were built at a slight elevation above the adjacent landscape. The average annual daily traffic (AADT) on surveyed highways ranged from 451 vehicles to 13,968 vehicles per day ($\bar{x} \pm SE = 2,555 \pm 115.6$ vehicles/d; E. Olin, New York State Department of Transportation [NYSDOT], unpublished data; I. Hazen, St. Lawrence County Highway Department, unpublished data); the speed limit on most stretches was 89 km per hour (55 miles/hr).

Upper and Lower Lakes Wildlife Management Area was bisected by New York State Highway 68. This segment of 2-lane highway had an AADT of 4,778 vehicles, with heaviest traffic volumes during summer soon after sunrise and just before sunset (Fig. 1). The road was a major thoroughfare for >150 years. The speed limit was 89 km per hour (55 miles/hr); the paved width of the highway along this stretch was 8–12 m (2 driving lanes plus broad paved shoulders), and the height of the road was generally 3–4 m above the surrounding landscape (range = 0.5–5.0 m). Vegetation growth within about 1.5 m of the road surface was controlled by annual spraying with a mixture of the herbicides glyphosate (Glypro® Plus; Dow AgroSciences LLC, Indianapolis, IN) and sulfometuron methyl (Oust® XP; DuPont Corp., Wilmington, DE) and by mowing vegetation within 2–4 m of the road surface twice per summer.

METHODS

We identified and tallied any amphibian or reptile found dead on the paved road surface, including old, desiccated remains during walking transect surveys, driving surveys, and point counts.

We delineated 3 transects along State Highway 68 as it bisected Upper and Lower Lakes Wildlife Management Area. We sited each transect at a known location for frequent road-mortality of turtles and frogs. The first transect (length = 910 m) bordered the Grasse River on the east side and large hay fields, shrub swamp, and shallow marsh on the west. The second transect (649 m) was a causeway bisecting deep marsh on the east side and shallow marsh, shrub swamp, and patches of swamp forest on the west. The third transect (385 m) was a causeway bisecting deep marsh on the east side and shrub swamp and open impounded water on the west.

Between April and October 2002, we walked the 3 transects on 73 days, for a cumulative 123.4 km of road surveys. This encompassed the entire period during which herpetofauna were active on land at our site (i.e., we detected no active animals and no road-mortality during spot checks in Mar and Nov). We walked both sides of the road of each transect along the paved shoulder between 0530 hours and 0830 hours. We tallied and removed each amphibian or reptile that was on the paved surface of the highway. We noted each animal's condition (live or dead) and species. In our paper, the term frog refers to all anurans (i.e., frogs and toads). Because there were no statistically significant differences among the 3 transects in density of amphibian and reptile mortality, when analyzing temporal patterns of road-mortality we treated each transect as a replicate and the unit of replication was the transect-day.

To measure inter-observer reliability in walking transect surveys and point counts (see below), the 5 main field surveyors each independently walked 10 100-m transects, including locations where road-mortality was abundant and where it was scarce.

Driving Surveys

From 13 May to 24 July 2002, we repeatedly drove the entire length of all 23 United States Federal, New York State, and St. Lawrence County highways (353.3 highway km) in the towns of Canton, Madrid, Lisbon, and Potsdam. Each of 2 survey cars contained 2 team members, a driver, and a spotter. We drove the roads in the morning (0530–1200 hr), at speeds $\leq$46 km/hour ($\bar{x}$ speed 32–46 km/hr). When we spotted an amphibian or reptile on the road, we stopped the car and the team inspected the animal to confirm the species identification. We noted locations that had frequent and exceptionally high abundances of herpetofauna road-kill, which we classified as putative hotspots. We surveyed roads on 23 dates, for a total of 1,021 km, driving each segment of road at least twice ($\bar{x} = 2.9$ times). To measure inter-observer reliability in road surveys, 2 car teams drove the same 11 segments of highway within 20 minutes of each other.

Point Counts

In July 2002, we surveyed for the presence of herpetofauna road-mortality at 137 points distributed every 3.2 km throughout the same state and county highway network covered by the driving survey. We surveyed each point once. To begin a road survey, we went to the origin of a highway, or to the first stretch within the border of our study area, and sited the first survey point at the first encountered highway mileage sign (state highway, located every 0.1 miles) or first utility pole (county highway, located approx. every 20 m). We selected subsequent points by driving until the car's odometer indicated 2.0 miles from the previous survey point and then stopping at the first encountered highway survey sign (state highway) or first utility pole (county highway). We surveyed $\geq$1 point along every highway within the study area; however, we inadvertently missed one 6-km segment of a surveyed highway. In addition to the uniformly spaced survey points, we also surveyed each of the 8 putative hotspots identified during the driving survey. Survey points for putative hotspots were located at the center of each.

At each survey point, we delineated a 50-m transect and walked in each direction from the center point, for a total road transect length of 100 m. We walked each side of the road, and tabulated any dead herpetofauna. We recorded the precise location of each survey point, using a Garmin S 76 brand Global Positioning System (GPS) with a Wide Area Augmentation System correction (spatial accuracy typically $\pm$5 m).

In July 2004, we resampled 41 points once each using the same survey methodology as in 2002. Resurveyed points included 1) all 8 putative hotspots, 2) 13 additional points encompassing the highest tallies of amphibians and reptiles in 2002, and 3) a random sample of 20 points from among the 112 points that had no road-mortality in 2002.

Additional Methodological Details

The New York State Department of Environmental Conservation (NYSDEC) provided permits for working at Upper and Lower Lakes Wildlife Management Area and for collecting herpetofauna (New York State Fish and Wildlife License 291). The St. Lawrence County Highway Department and NYSDOT provided permits to work along the highways. The Clarkson University Institutional Animal Care and Use Committee approved the survey protocols (IRB155/IACUC 03–1).

We verified that data distributions were normal and homoscedastic before applying parametric statistical tests, and we applied data transformations if warranted; otherwise, we used nonparametric statistical tests. We report 1-tailed probabilities in statistical hypothesis tests when the a priori hypothesis is clearly directional.

RESULTS

We detected 16 species of reptiles and amphibians during road surveys: 9 anurans (northern leopard frog, pickerel frog [*R. palustris*], bullfrog [*R. catesbeiana*], green frog [*R. clamitans*], mink frog [*R. septentrionalis*], wood frog [*R. sylvatica*], gray treefrog [*Hyla versicolor*], spring peeper [*Pseudacris crucifer*], American toad [*Bufo americanus*]), 1 salamander (red-spotted newt [*Notophthalmus viridescens*]), 3 turtles (painted turtle [*Chrysemys picta*], common snapping turtle [*Chelydra serpentina*], Blanding's turtle [*Emydoidea blandingii*]), and 3 snakes (common garter snake [*Thamnophis sirtalis*], northern water snake [*Nerodia sipedon*], redbelly snake [*Storeria occipitomaculata*]). Amphibian and reptile species present (as recorded in the New York State Herpetological Atlas, Gibbs et al. [2007], and our own observations) but not detected during the surveys were mostly uncommon or small, cryptic species, including 1 frog (western chorus frog [*Pseudacris triseriata*]), 1 turtle (wood turtle [*Glyptemys insculpta*]), 4 snakes (milk snake [*Lampropeltis triangulum*], smooth green snake [*Liochlorophis vernalis*], brown snake [*Storeria dekayi*], eastern ribbon snake [*Thamnophis sauritus*]), and several forest salamanders (e.g., spotted salamander [*Ambystoma maculatum*], blue-spotted salamander [*A. laterale*], Jefferson salamander [*A. jeffersonianum*], redback salamander [*Plethodon cinereus*], northern two-lined salamander [*Eurycea bislineata*]).

Walking Surveys

We tallied 21,764 frogs, 111 turtles, and 10 snakes over the 73 survey days and cumulative 124.6 km. The frog species that we most frequently tallied was the northern leopard frog (81.6%), followed by the bullfrog, green frog, and mink

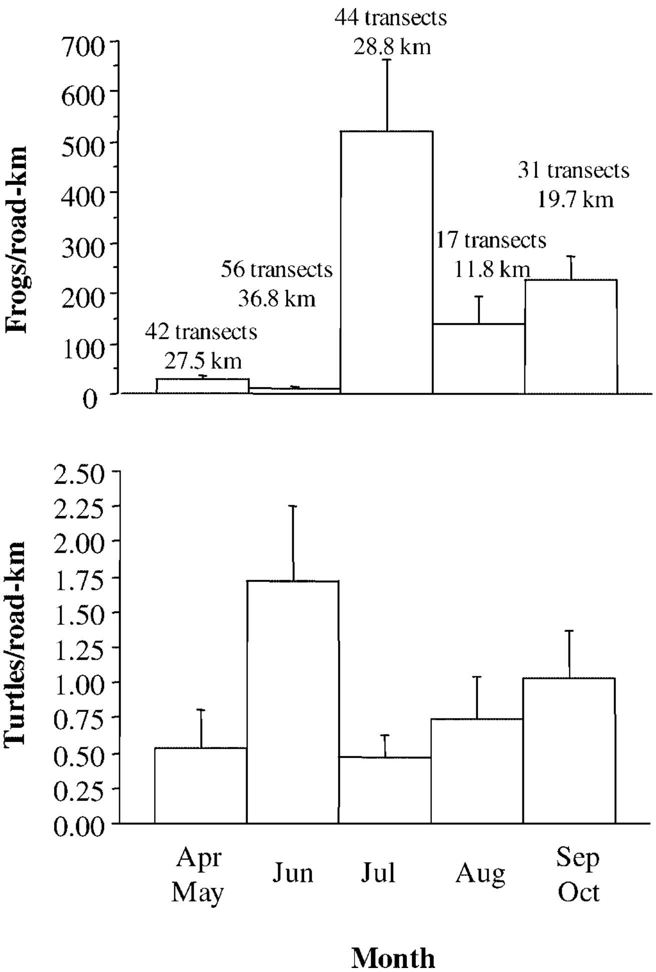

Figure 2. Temporal patterns of frog and turtle road-mortality (animals/road-km/sample-d) at 3 transects along New York State Highway 68 within Upper and Lower Lakes Wildlife Management Area in 2002, New York, USA. We indicate the number of transect-days and cumulative distance surveyed per month above the bars.

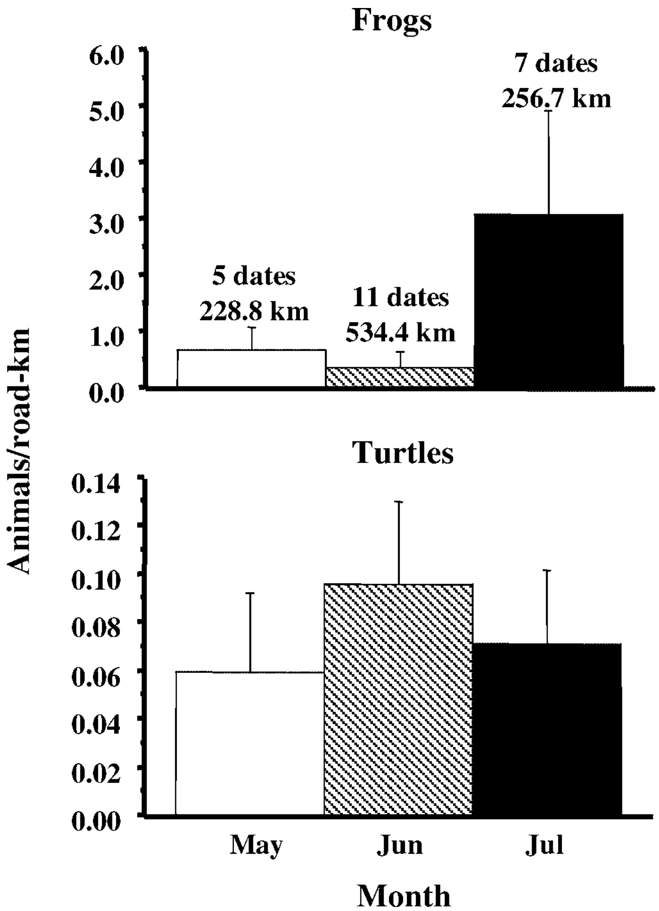

Figure 3. Density of frog and turtle road-mortality (animals/road-km/sample-d) detected during driving surveys along the highway network in St. Lawrence County, New York, USA from May to July 2002. We indicate the number of survey-day and cumulative distance surveyed per month above the bars.

frog (an aggregate 18.0%). The most frequently tallied turtle was the painted turtle (69.5%); the remaining were common snapping turtles. Most snakes (90%) were common garter snakes.

The inter-observer reliability at quantifying road-mortality during walking transects was good ($\bar{x} \pm$ SE Spearman rank correlation, corrected for ties: frogs = 0.70 ± 0.042, turtles = 0.75 ± 0.067). There were differences across months in frog road-mortality (Fig. 2; analysis of variance, $F_{4,184} = 23.4$, $P < 0.001$; Apr and May, Sep and Oct lumped, dependent variable transformed to ln[frogs/km + 1]), and in turtle road-mortality (Fig. 2; Kruskal–Wallis test, $H_4 = 17.0$, $P = 0.002$; Apr and May, Sep and Oct lumped). Frog mortality was relatively low from April through June, peaked in July, and remained high until the animals became inactive in late October. Turtle mortality peaked in June, with a minor peak in the autumn.

Although the most frequent interval between consecutive surveys at each transect was 1 day (49.7% of transect counts), there were many instances of longer intervals. This could provide a bias, if road-kill accumulates when not removed daily. In June, when road-mortality was highest for turtles, the likelihood of finding a dead turtle on a transect did not increase with the number of days since the previous survey (logistic regression, likelihood ratio $\chi^2 = 2.3$, $n = 56$, $P = 0.3$; interval range = 1–5 d). In July, when road-mortality was highest for frogs, the number of dead frogs tallied did not increase with the length of time since the last survey (linear regression, $F_{1,42} = 0.7$, $n = 44$, $P = 0.4$; interval range = 1–5 d, dependent variable transformed to ln([frogs/km + 1)]). We observed that dead frogs and turtles rarely persisted long on the highway; the remains disintegrated under crushing by vehicle tires, were thrown off the road surface by vehicles, or were removed by scavenging birds and mammals or by road maintenance crews.

Driving Surveys

We tallied 356 frogs, 62 turtles, and 1 snake as road-mortality during the 1,021 km of driving surveys. Temporal variation in the abundance of road-mortality during driving surveys qualitatively mirrored temporal patterns in the walking transect surveys (Fig. 3). There was a positive correlation between the density of frog road-mortality encountered during driving surveys and walking transect surveys conducted on the same day (Spearman rank correlation, $r_s = 0.39$, 1-tailed $P < 0.05$, $n = 20$ dates) but no such correlation for turtles (Spearman rank correlation, $r_s = 0.07$, 1-tailed $P > 0.3$). Inter-observer reliability measured between teams driving the same road segments was good (Spearman rank correlation, corrected for ties: frogs $r_s = 0.81$, turtles $r_s = 0.80$).

We identified 8 putative hotspots of amphibian and reptile road-mortality within the surveyed road network, based on the driving surveys. Five were located along 2 highways bisecting Upper and Lower Lakes Wildlife Management Area, including 3 hotspots that corresponded to the locations of the previously established walking transects. Six of 8 putative hotspots were causeways bisecting shallow wetlands. The seventh hotspot was the environs of a bridge crossing the outflow waterway of an impounded lake, which also had the form of a causeway. The eighth hotspot was a stretch of road paralleling a river, with wetlands and hayfields on the other side of the road. We estimated the average length of the hotspots to be 373 ± 68.4 m (range = 113–1,038 m) based on the length of road at each hotspot lying within 100 m of wetlands.

Point Counts

Among the 137 uniformly spaced points (13.7 km cumulative length), we detected 329 frogs, 1 snake, 1 salamander, and 1 turtle. Among the 8 hotspot points (0.8 km cumulative length), we detected 64 frogs and 5 turtles. Road-mortality had a highly aggregated dispersion for frogs (all points: variance/$\bar{x} = 110.7$, $\chi^2 = 15{,}941$, df = 144, $P < 0.001$; uniformly-spaced points only: variance/$\bar{x} = 98.6$, $\chi^2 = 13{,}410$, df = 136, $P < 0.001$; statistical test of dispersion from Sutherland [1996]). The number of turtles was inadequate for quantifying dispersion.

A higher fraction of the 8 putative hotspots had frog road-mortality present than did the 137 uniformly-spaced points (75% vs. 17% of points, Fisher's exact test $P < 0.001$), and we observed the same pattern for turtles (38% vs. 1% of points, Fisher's exact test $P < 0.001$). There was a positive correlation between the number of frogs and the number of turtles at survey points (Spearman rank correlation corrected for ties, $r_s = 0.15$, 1-tailed $P = 0.035$). Comparing only points where frog mortality was present, there was a trend for the 6 included hotspots to have higher total tallies of frogs than the 23 included uniformly-spaced points (Mann–Whitney test, $z = 1.6$, 1-tailed $P = 0.06$).

The estimated density of amphibian road-mortality was 42 times higher via the uniformly spaced point counts than the driving surveys conducted during the same period (Jul 2002: point counts = 23.91, driving surveys = 0.57 amphibians/road-km), whereas the reptile road-mortality estimate was 3.6 times higher (point counts = 0.14, driving surveys = 0.04 reptiles/road-km).

We resampled 41 survey points in July 2004, including the 21 points with the highest frog or turtle mortality in July 2002 and 20 points that were among the lowest (i.e., no road-mortality in 2002). Road-mortality was much more prevalent in 2004 than in 2002. In 2002, only 17% of the 137 uniformly spaced points had frog road-mortality present, whereas 86% of the resurveyed points that had no frog mortality in 2002 did have frog mortality in 2004 (Fisher's exact test, $P < 0.001$), as did 95% of the resurveyed points that had had frog mortality in 2002. Whereas only 1% of the 137 uniformly spaced points surveyed in 2002 had turtle mortality, 11% of the resurveyed points that had no turtle mortality in 2002 did have turtle mortality in 2004 (Fisher's exact test, $P = 0.002$), as did 33% of the resurveyed points that had turtle mortality in 2002. Although the density of road-mortality differed between years, there was a positive correlation of frog road-mortality at sample points between 2002 and 2004 (Spearman rank correlation, $r_s = 0.62$, 1-tailed $P < 0.001$). The trend was similar but weaker for turtle road-mortality ($r_s = 0.20$, 1-tailed $P = 0.1$).

DISCUSSION

We found that survey methods based on walking and driving roads can detect spatial and temporal patterns of herpetofauna road-mortality. We also found that although a driving survey can cover a greater expanse of the road network during a survey period than a walking survey, it has a significant detection bias against amphibian road-mortality. The spatial locations of reptile and amphibian road-mortality hotspots overlap in our area, but the timing of peak mortality does not coincide. Locations of road-kill were highly aggregated, and these road-mortality hotspots frequently occurred where wetlands were present on both sides of the road (i.e., causeways).

Results of road-mortality surveys of herpetofauna may vary due to methodological details, temporal patterns of mortality, and spatial patterns of mortality. Our results indicate that both walking and driving surveys of road-mortality have high inter-observer reliability. Both methods detect qualitatively similar spatial and temporal trends in road-mortality. However, although driving surveys can cover an order of magnitude greater spatial expanse than walking (walking = 5 km/hr vs. driving = 46 km/hr), driving surveys underestimate the density of road-mortality because many animals are missed. Detection failure is higher for some taxa (e.g., frogs) than others (e.g., turtles).

Our results also indicate that temporal variation in road-mortality is great, and different components of the herpetofauna of a region have different periods of peak mortality on roads. This occurs because reptile and amphibian species, and even sex and age classes within a species, differ in the causes of movements that result in road crossing (Gibbs 1998, Semlitsch 2000, Carr and Fahrig 2001, Andrews and Gibbons 2005, Steen and Smith 2006). The striking peak in frog mortality that we detected in July was due to dispersal of metamorph northern leopard frogs from wetlands to upland sites. A second peak in autumn likely resulted from migration of frogs from upland and shallow-water summering sites to hibernation sites in deep-water marshes. Turtle mortality peaked in June, coinciding with the nesting period of turtles in our region. A second peak in the autumn coincided with the migration of turtles from shallow wetlands back to hibernation sites in deep-water marshes. Thus, surveys on road-mortality of reptiles and amphibians must be conducted throughout the active season, if all species are to be surveyed, or else survey periods must be tailored to the natural history of the species of most interest. Although not our focus, additional variability in our results was caused by weather conditions (temp, precipitation, humidity), with peak road-mortality counts occurring during periods of warm, wet weather and low counts occurring during hot and dry or cold weather.

We found that reptile and amphibian road-mortality is spatially clustered within the highway network. The preponderance of road-mortality occurs at a small number of locations, each of which is short in expanse, and typically occurring where the road borders wetlands on both sides. Hotspots of road-mortality overlap across species and locations of hotspots are consistent across years. Thus, it should be possible to substantially reduce herpetofauna road-mortality by targeting mitigation activities to the small region of the road network where road-mortality is highest.

Methodological Challenges in Quantifying Herpetofauna Road-Mortality

Survey methods for herpetofauna road-mortality, like all survey methods, should be evaluated in terms of consistency of results among surveyors, accuracy at quantifying (in absolute or relative terms) the magnitude of road-mortality at survey locations, comparability of results across studies that apply the same survey methodology, and efficiency in terms of cost and time expended per unit of area surveyed (Heyer et al. 1994, Sutherland 1996). A methodological issue affecting road-mortality density estimates is differential persistence on roads. We observed that turtles and snakes persist in a recognizable form on a road for several days, because tough reptilian skin and shell is resistant to destruction by vehicle tires. Thus, frequently repeated surveys are likely to provide accurate absolute estimates of reptile road-mortality. Amphibians, on the other hand, usually do not persist. Scavenging mammals and birds readily remove road-killed amphibians day and night (cf. Antworth et al. 2005). During rainy periods (when amphibian road-mortality is highest), remains rapidly disappear under repeated crushing by car tires; often we could only detect a piece of skin as evidence of a road-killed frog. Conversely, during hot and dry weather (when amphibian road-mortality is low), the remains of frogs desiccate and fuse to the pavement and, thus, persist for a prolonged period. Given that persistence of road-mortality varies depending on weather conditions and abundance of scavengers, we conclude that walked transects and driving surveys only provide a rough index of the density of amphibian road-mortality. Hels and Buchwald (2001) came to similar conclusions in their study of road-mortality of frogs and newts in Denmark.

A principal difference between walked transects and driving surveys is that driving surveys result in lower density estimates of road-mortality, especially for amphibians. In our experience, amphibians are more frequently missed in driving surveys than turtles and snakes because amphibians are smaller and more fragile and, hence, less recognizable after repeated crushing under vehicle tires. Kline and Swann (1998) came to similar conclusions in their comparison of driving and walking survey methodologies.

Recently, new spatial statistical methods using clustering algorithms with GIS have been used to identify road-mortality hotspots from georeferenced locations of road-kill (Clevenger et al. 2003, Ramp et al. 2005). When undertaking driving surveys, the location of all road-mortality should be recorded using GPS (which, unfortunately, we neglected to do), so that these new methods of spatial data analysis can be applied.

One additional consideration is safety. Walked transects can only be done where there is a safe shoulder on which to walk, and protective clothing must be worn (e.g., reflective safety vests and helmets). Driving surveys can only be done on roads where it is not hazardous to drive at slow speeds, and hazard lights should be used when driving below the posted speed limit. Regardless of methodology, road surveys should only be conducted under permit from the relevant Department of Transportation.

Road-Mortality Patterns in Comparison to Other Studies

Besides our study, 4 other published papers present quantitative data from walking or driving surveys on reptile and amphibian road-mortality in the northeastern United States and southeastern Canada (Table 1). The only walking transect study (Ashley and Robinson 1996) recorded a lower density of frog and turtle mortality than the walking transects that we monitored intensively, but otherwise the results were qualitatively similar (Table 1). As in our study, the vast majority of animals found dead on the road by Ashley and Robinson (1996) were northern leopard frogs (>93% of 30,034 road-killed amphibians), most of which were juveniles that had recently metamorphosed and were dispersing from their natal wetlands. Again as in our study, the peak periods of mortality of reptiles and amphibians varied depending on the natural history of each species.

Within the region, 3 other studies have quantified mortality using driving surveys (Table 1). In 2 of these studies (Fahrig et al. 1995, Mazerolle 2004), roads were driven at night, and only amphibians were tallied. Despite differences in methodology, the average density of amphibian road-mortality was similar to ours. The third study (Oxley et al. 1974) surveyed roads with a range of development (gravel roads to divided highways). The estimated density of road-killed reptiles on highways was similar to ours, but the amphibian counts were far lower (Table 1). The primary objective of Oxley et al. (1974) was to evaluate road effects on small mammal populations. As we have shown, reptiles are easier to detect in driving surveys than amphibians. We suspect that Oxley et al.

Table 1. Density of road-mortality (animals/highway-km/sample-d) of amphibians and reptiles surveyed via walking or driving transects in 5 studies conducted within the northeastern United States and southeastern Canada.

Transect type	Location	Transect placement	Months surveyed	Total transect distance (km)	No. of sample-d	Distance (km)/ sample-d	Amphibian density[a]	Reptile density[a]	Reference
Walking	NY	2-lane[b]	Jul	13.7	11	1.2	23.9	0.1	Present study
Walking	NY	2-lane causeway[c]	Apr–Oct	1.9	73	1.9	180.2	1.1	Present study
Walking	ON	2-lane causeway	Apr–Oct	3.6	144	3.6	11.7	0.3	Ashley and Robinson 1996
Driving	NY	2-lane	May–Jul	353.3	23	44.4	1.3	0.08	Present study
Driving	NB	Road[d]	Apr–Sep	20.0	37	20.0	4.3		Mazerolle 2004
Driving	ON	Road and 2-lane	Apr–May	506.0	6	84.3	3.7		Fahrig et al. 1995
Driving	ON	Gravel road	May–Sep	24.3	20	23.7	0.002	0.01	Oxley et al. 1974
Driving	ON	Road	May–Sep	27.2	11	27.2	0.05	0.08	Oxley et al. 1974
Driving	ON	2-lane	May–Sep	45.0	20	42.1	0.05	0.06	Oxley et al. 1974
Driving	ON	4-lane[e]	May–Sep	32.0	20	30.7	0.03	0.06	Oxley et al. 1974

[a] Animals/road-km/sample-d.
[b] 2-lane highway.
[c] 2-lane highway bisecting a wetland.
[d] Paved secondary road.
[e] 4-lane divided highway.

(1974) undercounted amphibians as a consequence of their focus on mammalian road-mortality.

MANAGEMENT IMPLICATIONS

Walked transects provide better estimates of the density and composition of road-mortality than driving surveys, especially for amphibians, but are time-consuming and more laborious to conduct. Driving surveys are useful for surveying a large road network, and do detect some road-mortality hotspots. We recommend driving surveys as an efficient method, in terms of time and labor, for surveying large expanses of road. When conducting driving surveys, we recommend that detection bias be estimated (and corrected for) by walking segments of surveyed roads to quantify how many animals are missed during the driving survey (see also Kline and Swann 1998). We also recommend walking surveys to intensively study putative road-mortality hotspots. Careful attention to the timing of surveys is necessary, since peak periods of road-mortality differ among herpetofauna taxa. We recommend performing a preliminary survey throughout the active season of reptiles and amphibians in an area, to optimize the timing of a survey for species of greatest concern.

ACKNOWLEDGMENTS

This research was funded via a grant from the Clarkson Center for the Environment. Additional support came via the National Science Foundation Research Experiences for Undergraduates Site Program in Environmental Science and Engineering at Clarkson University (EEC-0138970) and a State Wildlife Grant (MOU AM05405) administered by NYSDEC. N. Mundy, W. Berkhoff, T. Rogers, and A. Rose provided additional help with the fieldwork and data processing. We appreciate the critical comments on this manuscript provided by J. Gibbs, G. Johnson, J. Schulte, III, E. Berg, and G. Perry. This is the Clarkson Center for the Environment contribution number 240.

LITERATURE CITED

Andrews, K. M., and J. W. Gibbons. 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. Copeia 2005:772–782.

Andrews, K. M., J. W. Gibbons, and M. Jochimsen. 2007. Ecological effects of roads on amphibians and reptiles: a literature review. Herpetological Conservation 3:in press.

Antworth, R. L., D. A. Pike, and E. E. Stevens. 2005. Hit and run: effects of scavenging on estimates of roadkilled vertebrates. Southeastern Naturalist 4:647–656.

Aresco, M. J. 2005*a*. The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles. Biological Conservation 123: 37–44.

Aresco, M. J. 2005*b*. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida Lake. Journal of Wildlife Management 69:540–551.

Ashley, E. P., and J. T. Robinson. 1996. Road-mortality of amphibians and other wildlife in the Long Point Causeway, Lake Erie, Ontario. Canadian Field-Naturalist 110:403–412.

Barnum, S. A. 2003. Identifying the best locations along highways to provide safe crossing opportunities for wildlife. Colorado Department of Transportation Research Branch Report CDOT-DTD-UCD-2003–9, Denver, USA.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15:1071–1078.

Chadwick, M. A. 2003. Turtle sparks car accident; 6 injured. Utica (New York) Observer – Dispatch. 16 June 2003. <http://www.uticaod.com/archive/2003/06/16/news/8404.html>. Accessed 17 Apr 2007.

Clevenger, A. P., B. Chruszcz, and K. Gunnison. 2003. Spatial patterns and factors influencing small vertebrate fauna road kill aggregations. Biological Conservation 109:15–26.

Clevenger, A. P., J. Wierzchowski, B. Chruszcz, and K. Gunnison. 2002. GIS-generated, expert-based models for wildlife habitat linkages and mitigation planning. Conservation Biology 16:503–514.

Dodd, C. K., Jr., W. J. Barichivich, and L. L. Smith. 2004. Effectiveness of barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118:619–631.

Dodd, C. K., Jr., K. M. Enge, and J. N. Stuart. 1989. Reptiles on highways in north-central Alabama, USA. Journal of Herpetology 23:197–200.

Enge, K. M., and K. N. Wood. 2002. A pedestrian road survey of an upland snake community in Florida. Southeastern Naturalist 1:365–380.

Evink, G. L. 2002. Interactions between roadways and wildlife ecology. National cooperative highway research program synthesis 305. Transportation Research Board, Washington, D.C., USA.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wegner. 1995.

Effect of road traffic on amphibian density. Biological Conservation 73: 177–182.
Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, D.C., USA.
Gibbs, J. P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in Southern New England. Journal of Wildlife Management 62:584–589.
Gibbs, J. P., A. R. Breisch, P. K. Ducey, G. Johnson, J. L. Behler, and R. C. Bothner. 2007. Amphibians and reptiles of New York. Identification, natural history, and conservation. Oxford University Press, United Kingdom.
Gibbs, J. P., and W. G. Shriver. 2005. Can road-mortality limit populations of pool-breeding amphibians? Wetlands Ecology and Conservation 13: 281–289.
Gibbs, J. P., and D. A Steen. 2005. Trends in sex ratios of turtles in the United States: implications of road-mortality. Conservation Biology 19: 552–556.
Hels, T., and E. Buchwald. 2001. The effect of road kills on amphibian populations. Biological Conservation 99:331–340.
Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster. 1994. Measuring and monitoring biological diversity. Standard methods for amphibians. Smithsonian Press, Washington, D.C., USA.
Kline, N. C., and D. E. Swann. 1998. Quantifying wildlife road-mortality on Saguaro National Park. Pages 23–31 *in* G. L. Evink, P. Garret, D. Zeigler, and J. Berry, editors. Proceedings of the international conference on wildlife ecology and transportation, 10–12 February 1998. U.S. Department of Transportation, Federal Highway Administration, Fort Meyers, Florida, USA.
Langley, W. M., H. W. Lipps, and J. F. Theis. 1989. Responses of Kansas motorists to snake models on a rural highway. Transactions of the Kansas Academy of Science 92:43–48.
Langton, T. E. S. 1989. Amphibians and roads: proceedings of the toad tunnel conference. ACO Polymer Products, Bedfordshire, United Kingdom.
Lundy, S. 2005. Girl, 6, killed helping turtle: North Fort Myers child runs on road, hit by car. (Southwest Florida) News – Press. 7 June 2005.
Marchand, M. N., and J. A. Litvaitis. 2004. Effects of habitat features and landscape composition on the population structure of a common aquatic turtle in a region undergoing rapid development. Conservation Biology 18:758–767.
Mazerolle, M. J. 2004. Amphibian road-mortality in response to nightly variations in traffic intensity. Herpetologica 60:45–53.
Oxley, D. J., M. B. Fenton, and G. R. Carmody. 1974. The effects of roads on populations of small mammals. Journal of Applied Ecology 11:51–59.
Pope, S. E., L. Fahrig, and N. G. Merriam. 2000. Landscape complementation and metapopulation effects on leopard frog populations. Ecology 81:2498–2508.
Ramp, D, J. Caldwell, K. A. Edwards, D. Warton, and D. B. Croft. 2005. Modeling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. Biological Conservation 126: 474–490.
Rosen, P. C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran Desert of Southern Arizona. Biological Conservation 68: 143–148.
Semlitsch, R. D. 2000. Principles for management of aquatic-breeding amphibians. Journal of Wildlife Management 64:615–631.
Smith, D. 1999. Identification and prioritization of ecological interface zones on state highways in Florida. Pages 209–230 *in* G. L. Evink, P. Garret, and D. Zeigler, editors. Proceedings of the third international conference on wildlife ecology and transportation. Florida Department of Transportation FL-ER-73–99, Tallahassee, USA.
Smith, L. L., and C. K. Dodd, Jr. 2003. Wildlife mortality on highway US 441 across Payne's Prairie, Alachua County, Florida. Florida Naturalist 66:128–140.
Spellerberg, I. F. 2002. Ecological effects of roads. Science, Enfield, New Hampshire, USA.
Steen, D. A., M. J. Aresco, S. G. Beilke, B. W. Compton, C. K. Dodd, Jr., H. Forrester, J. W. Gibbons, J. Greene-McLeod, G. Johnson, T. A. Langen, M. J. Oldham, D. N. Oxier, R. A. Saumure, F. W. Schueler, J. Sleeman, L. L. Smith, J. K. Tucker, and J. P. Gibbs. 2006. Relative vulnerability of female turtles to road-mortality. Animal Conservation 9: 279–273.
Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology 18:1143–1148.
Steen, D. A., and L. L. Smith. 2006. Road surveys for turtles: consideration of possible sampling biases. Herpetological Conservation and Biology 1: 9–15.
St. Lawrence County Agricultural and Farmland Protection Board. 2001. St. Lawrence County Agricultural Development Plan 2001. <http://www.co.st-lawrence.ny.us/slcpo>. Accessed 11 Sep 2006.
Sutherland, W. J. 1996. Ecological census techniques: a handbook. Cambridge University Press, United Kingdom.
Wells, J. V. 1998. Important bird areas in New York State. National Audubon Society New York, Albany, USA.
Wright, J. D. 2006. Traffic mortality of reptiles. Herpetological Conservation 2:169–182.

Associate Editor: Perry.