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The potential of diversion structures to reduce roadway mortality of the endangered Hine's emerald dragonfly (*Somatochlora hineana*)

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Abstract Roadways near wetlands and ponds inflict high roadkill rates on a wide variety of taxa. For threatened or endangered species that typically do not have large adult populations, fast reproduction rates, and/or rapid recolonization rates, such mortality is likely to have significant population consequences. Thus, exploring ways to reduce roadkill rates will have considerable conservation benefits. In this study, we evaluate whether a diversion structure can be used to modify flight behavior of the endangered Hine's emerald dragonfly (*Somatochlora hineana*) in ways that would reduce roadway mortality. Flight behavior of adult *S. hineana* was observed with and without two 3 m high nets spaced at 6 and 12 m to simulate a small and a larger roadway. The netting significantly deterred ($p < 0.0001$) *S. hineana* adults from crossing the simulated roadway. Flight height was also influenced significantly ($p = 0.0025$) with flight heights over the 6 m net spacing being higher than those over the 12 m spacing. This study suggests that the use of diversion netting in areas where sensitive dragonfly species interact with motor vehicles might aid in reducing roadway mortality and might help reduce the overall impact of roadways on wetland ecosystems.

Keywords Roadkill · Endangered species · Mitigation · Insect conservation · Diversion netting

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Introduction

In an increasingly developed world, roads cover an ever larger part of the landscape. Roadway density (i.e. the ratio of the total length of roads to a country's area) ranges widely but is especially high in developed areas of Europe and Asia (World Bank 2015) where the impacts of roads on natural communities is of great concern (Markham 1996). Even where roadways cover a relatively low proportion of the landscape, such as in the United States where roadway cover is only about 1 % (National Research Council 1997), their direct and indirect impacts on wildlife populations are more widespread than indicated by land coverage alone (Forman et al. 1997; Forman and Deblinger 1998). Some of the most important impacts of roads on animal populations are when they act as direct sources of mortality (animal-vehicle collisions) or when they operate as physical and behavioral barriers that subdivide populations (Forman and Alexander 1998; Trombulak and Frissell 2000). For many animal species that have some combination of large populations, fast reproduction rates, rapid recolonization rates, and rapid growth, even high rates of roadway mortality may not significantly impact populations. However, roadway mortality even at relatively low levels may present a substantial threat for long-lived, rare, or endangered species. For example, yearly roadway mortality of the Florida panther (*Felis concolor coryi*) accounted for 10 % of its population prior to mitigation efforts (Harris and Scheck 1991; Evink et al. 1996), Key deer (*Odocoileus virginianus clavium*) suffer annual losses equivalent to about 16 % of the population (Calvo and Silvy 1996); McKenna et al. (2001) estimated that over 500,000 monarch butterflies (*Danaus plexippus*) are killed on interstates in Illinois in just 1 week. Roadways can also impact both endangered and common species if they

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fragment populations (Mader 1984). For example, Mader et al. (1990) studied carabid beetles and lycosid spiders and found that paved and graveled roads decreased the rate of movement between habitat patches, potentially impacting survival of metapopulations.

Roadways near wetlands in particular can generate high roadkill rates in both invertebrates and vertebrates (Forman and Alexander 1998). For example, Yamada et al. (2010) reported a total of 2414 road-killed insects/km on 12 collection days along a road next to a lake, while Harris and Scheck (1991) recorded over 1700 road-killed frogs/km/year near a wetland area. Such mortality rates might seem relatively low and insignificant for many short-lived wetland insects (e.g. mayflies), but some wetland species (e.g. diving beetles, large Hemiptera, and dragonflies) forage, reproduce, and disperse over an extended period of time, making them much more likely to be impacted by roadway deaths (Soluk et al. 2011). Adult dragonflies are one of the most frequently killed wetland taxa along roadways (Rao and Girish 2007). Soluk et al. (2011) reported estimates of mean dragonfly mortality to be between 2 and 35 adults/km/day on Chicago area roadways, and Riffell (1999) reported a mean of 87.7/km/day on a two-lane highway in northern Michigan. It is highly probable that such high death rates could significantly impact some dragonfly species, especially habitat specialists that persist in small populations scattered through the landscape. For such species, effective conservation measures should include strategies to reduce direct losses, particularly of breeding adults along roadways.

It is inevitable that roads will be constructed near wetlands and other areas sensitive to disturbance, so developing approaches to reduce their impacts should be an important focus. Mitigation techniques have been implemented for many animal species that walk across roadways and may include passageways such as tunnels, pipes, and underpasses and/or overpasses, typically in combination with fencing and vegetation to increase wildlife crossing (Hunt et al. 1987; Forman and Alexander 1998). The effectiveness of these strategies for larger walking taxa varies based on species, human activity, landscape features, and design of crossing structures (Clevenger and Waltho 2000; Mata et al. 2004; Bager and Fontoura 2013). Barriers and other structures are a common method used to reduce wildlife mortality and have aided in the reduction of roadkills for some vertebrate species. For example, the 24-h kill rate of wildlife on U. S. Highway 441 through Paynes Prairie State Preserve in Florida decreased by 67 % after construction of barriers and underpass structures (Barichivich and Dodd 2002). Problems with barriers arise when they make the road a more impenetrable barrier, trap wildlife, and/or move roadkill hotspots elsewhere (Jaeger and Fahrig 2004; Huijser et al. 2007; Bager and Fontoura 2013). Use of barriers for reducing roadkill rates of walking insects remains largely unexplored.

Mitigation practices specifically designed to reduce the roadway mortality of smaller or flying organisms are generally uncommon, and their efficacy has seldom been tested (Zielin et al. 2011). Flying organisms such as dragonflies and butterflies are especially difficult to deal with and may require very different approaches because they may be able to circumvent diversion structures or may be reluctant to fly below them. Possible mitigation techniques for these species may include traffic speed and/or volume reduction measures (Rao and Girish 2007; Soluk et al. 2011) and road verge management (Skórka et al. 2013). Another approach to reduce interactions with vehicles on roadways is to alter the behavior of species using diversions such as poles for terns (Bard et al. 2002) or netting and hedges for butterflies (Dover and Fry 2001; Smith 2007; Hsu 2010).

One species that has many of the characteristics that make it potentially vulnerable to mortality generated by roadways is the Hine's emerald dragonfly (*Somatochlora hineana* Williamson 1931). This species occurs in small, isolated populations in the Great Lakes region and Missouri and is listed as endangered in the United States and parts of Canada. The larval stages have highly specific habitat requirements (i.e. groundwater-fed fens with distinctive hydrology, see Soluk et al. 2000), and thus the species has a very patchy distribution on the landscape. It is a long-lived species that spends 4 to 5 years as larvae before emerging as adults, which live only 6–8 weeks (Foster and Soluk 2004; Pintor and Soluk 2006), making it slow to recover from disturbance. Surveys have indicated that large numbers of *S. hineana* can be killed on roadways. In Door County, Wisconsin, an estimated 3300 adults were killed on roadways in just 1 year (Soluk and Moss 2003). The extent to which this mortality impacts the local population is unclear, but such high death rates should be of concern for any endangered species.

For adult *S. hineana*, reduction of speed has promise to lower mortality rates (Furness 2014), and lower speed limits have been used as a mitigation practice along one stretch of road in Door County, Wisconsin (Soluk and Moss 2003). However, it is also clear that there are a number of locations where meaningful speed reduction will be difficult or impossible to implement because of safety or political considerations. In these areas, use of diversion structures might be another way to reduce mortality rates because their flight behavior is one of the primary reasons that *S. hineana* experience high roadway mortality. Although they have been observed to fly upwards of 23 m above the ground, adult *S. hineana* more typically fly 2 m or lower when they cross or use roadways as dispersal corridors. A seemingly simple strategy for reducing roadway mortality would be to either divert adults away from roads, or cause them to fly at a greater height over them. The benefits of diversion are obvious although there are potential costs in terms of population fragmentation or the relocation of roadkill hotspots. On the other hand, even minor modification of flight height might be beneficial if it allows *S. hineana* to avoid most motor vehicles on the road such as cars and light duty trucks which are typically <2 m in height (Soluk et al. 2011). Our study experimentally evaluates whether a netted diversion structure can be used to significantly deter crossing or to raise flight height of adult *S. hineana* over simulated roadways of varying width. If successful, use of diversion structures could be a solution to roadkill issues along some roadways.

Methods

This study was conducted in Door County, Wisconsin in July 2012 and 2013 in a meadow near a forest edge at Toft Point State Natural Area (45.1°N, 87.1°W). This area was ideal for adult behavioral studies because it is frequented by extremely large numbers of adult *S. hineana* during the flight season. Observations indicate that the flight heights of individuals over this meadow were similar to those observed over asphalt and gravel roadways for *S. hineana* and other dragonfly species (Furness personal obs., Soluk et al. 2011). All activities with *S. hineana* in this study were approved under endangered species permits issued by the United States Fish and Wildlife Service (TE805269-14) to D. A. Soluk and by the Wisconsin Department of Natural Resources to D. A. Soluk (#430) and A. N. Furness (#799).

To evaluate the response of *S. hineana* to roadside netting, two 12 m long simulated roadways, either 6 or 12 m wide, were created in the meadow at Toft Point. Roadways were marked with a North–South orientation initially with flags and finally using six 3 m tall metal poles (three on each side) supported by steel t-posts (Figs. 1, 2). For treatments "with nets" two 3 m × 6 m segments of knotless netting (0.64 cm square mesh) were clipped between each set of 3 m tall poles to create two vertically-oriented nets 3 m tall by 12 m long (Figs. 1, 2). Nets were erected on both sides of the simulated roadways in order to elevate flights across the roadway from either direction (i.e. west or east). For treatments "without nets", nets and/or poles were removed. In order to determine whether or not poles alone had an effect, some treatments were run with poles in place. No modifications to the ground vegetation were made in the simulated roadway because the purpose of the experiment was solely to evaluate the role of the diversion structures. Vegetation in the meadow consisted of grasses generally under 30 cm and forbs under 50 cm (Figs. 1, 2). Observations were made over a 6 m wide roadway in 2012 and over both a 6 m and a 12 m roadway in 2013.

Fig. 1 Simulated 6 m wide roadway in a meadow at Toft Point State Natural Area in Door County, Wisconsin. The *lower photo* shows the 3 m high diversion nets raised, and the *upper photo* shows diversion nets removed. The *arrows* indicate location of poles along simulated roadway edges. The roadway was 20 m long and in a north to south orientation

Flight behavior of adult *S. hineana* was recorded by two observers extensively trained in the identification of adult dragonflies in flight, as well as recognition of behaviors (e.g. foraging, patrolling), and estimation of distances/heights. Knowing the height of the poles/netting aided observers in estimating flight heights. Observers were located on the northeast and southwest corners of the simulated roadway area. Observations with and without nets erected were made under optimal flight conditions (sunny, temperatures 21.8–30.9 °C, low wind) and during peak flight times (∼09:00 to ∼13:00) with 1 day between treatments. Observation sessions were an hour long consisting of three 15 min observation periods followed by a 5 min break between periods and a 15 min break between sessions, to reduce observer fatigue. Observers recorded the time of each observation, confidence level of identification, sex,

Fig. 2 Simulated 12 m wide roadway in a meadow at Toft Point State Natural Area in Door County, Wisconsin. The *lower photo* shows the diversion nets raised, and the *upper photo* shows diversion nets removed. The *arrows* indicate location of poles along simulated roadway edges. Height of diversion netting, length, and orientation of the roadway were the same as in Fig. 1

variability in flight height, general behavior (i.e., foraging, traveling), reaction(s) to the netting, location along roadway, and flight direction. In addition to the responses of the dragonflies, temperature, wind direction, and wind speed were also recorded for each observation period.

If flights were not over (e.g. east to west, northwest to southeast) or were deterred from the simulated roadway, they were not used in analyses comparing flight heights. If a dragonfly crossed the simulated roadway at any time, it was counted as a cross. The lowest flight height over the simulated roadway was used, and midpoints were taken for height ranges (e.g. 1.25 m was used for a 1–1.5 m flight range).

Analyses

All analyses were performed using SAS (version 6.1, SAS Institute, Inc., Cary, North Carolina). Fisher's exact tests were used to determine whether there were significant differences between the frequencies of crosses when nets were present and when nets were absent for the 6 and 12 m spacing setup, across the entire study. A three-factor ANOVA was run to determine whether or not flight behavior (traveling vs. foraging), treatment (nets present or absent), and spacing (6 or 12 m) had significant independent or interactive effects on mean flight heights of *S. hineana.* When a significant effect was found, a Tukey–Kramer procedure was run to determine which treatment-spacing combinations yielded mean flight heights significantly different from one another.

Results

Observations were made on 8 different days with a total of 4 person-hours without nets and 16 person-hours with nets. We recorded a total of 342 flight observations. Of these, 239 were made with nets, 20 were without nets, and 83 were without nets and poles. Comparisons of flight heights with poles alone (mean ± SE 1.47 ± 0.72 m) and without poles (mean ± SE 1.24 ± 0.82 m) were similar, indicating no effect of the poles alone on flight height, thus we treated all contrasts as "without nets" versus "with nets". Not all observations could be used because the dragonflies did not always attempt to cross the simulated roadway.

Without nets, there were 68 individuals that interacted with the roadway. With netting up, at 6 m and 12 m, there were 159 usable observations. Results of the 3-factor ANOVA indicate that there was an interactive effect of treatment and distance apart on flight height ($F_{2,314} = 9.56$, $p = 0.0025$) but no effect of flight behavior. A Tukey–Kramer procedure indicated that the 6 m net spacing significantly increased flight height (mean ± SE of 2.94 ± 0.11 m) relative to the 12 m net spacing (mean ± SE of 1.75 ± 0.5 m) and no net treatments (Fig. 3). Flight height did not differ significantly ($p = 0.9956$) between the net and no net treatments for the 12 m spacing or for no nets at 6 and 12 m spacing (Fig. 3). Without nets, 13.8 % were above 2 m, and flight heights ranged from 0.5 to 7 m with an overall mean flight height (±SE) of 1.29 ± 0.9 m. With nets, 82 % of flight heights were 2 m or higher, ranging from 1 to 5 m, with an overall mean flight height (±SE) of 2.85 ± 0.87 m.

The presence of nets dramatically decreased crossing. Of the observations made with netting up (6 and 12 m), 55 flew over the simulated roadway, and 104 were deterred (Fig. 4). Of the 68 observations made without nets, only 3 individuals did not cross. When netting was up and spaced at 6 m, *S. hineana* were deterred from crossing the simulated roadway significantly (Fisher's exact test, $df = 1$, $p < 0.0001$) more than when the netting was

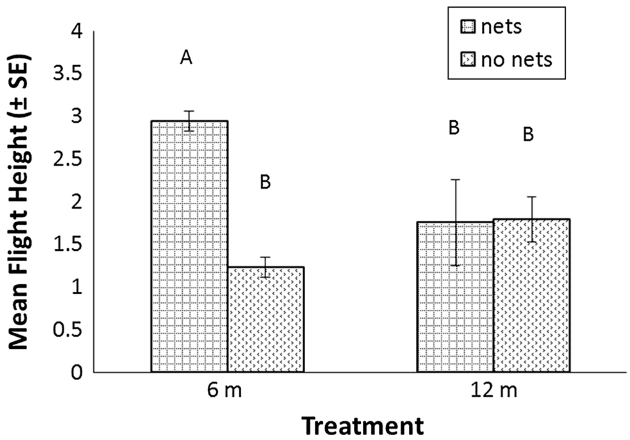

Fig. 3 The relationship between *S. hineana* mean flight height (±SE) and net presence and spacing; *letters* indicate significant differences between treatments. Only 6 m spacing with nets raised was significantly ($p < 0.0001$) different from the other treatments

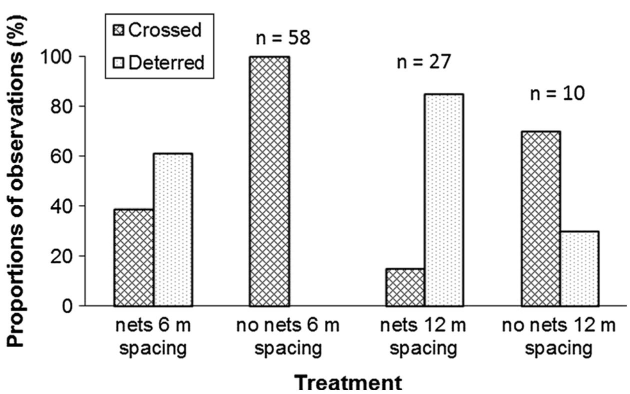

Fig. 4 Proportion of observations of *S. hineana* that approached the simulated roadway and then either crossed or were deterred from crossing by the presence of the 3 m high diversion structures

absent. When the nets were spaced 12 m apart, results also show that *S. hineana* were significantly (Fisher's exact test $df = 1$, $p < 0.0001$) deterred from crossing the simulated roadway more often than when the netting was absent (Fig. 4).

Discussion

Behavioral observations previously conducted in Door County indicate that up to 67 % of *S. hineana* typically fly over paved roadways at heights (below 1.8 m) where they are vulnerable to automobile encounters (Soluk and Moss 2003). Results of this study indicate that diversion structures have potential to successfully modify flight behavior of *S. hineana* in ways that could reduce fatal encounters with motor vehicles. When spaced 6 m apart, the 3 m high nets caused *S. hineana* to significantly increase their flight heights above that of most vehicles. While this is a positive result, it is unclear that such a relatively low diversion structure would be useful on many wider roadways because we did not observe an increase in flight height over a 12 m wide simulated roadway. This was likely due to an observed tendency for flight height to decrease towards the center of the simulated roadway whatever the width. This tendency to dip suggests that the benefits of any upward diversion of flight height will decrease with increased distance between the nets. Roadway width is quite variable; for example, small rural roads are approximately 5 m wide while two-lane secondary highways are approximately 7.5 m wide, and four-lane highways can be wider still. This is compounded by the fact that, in general, wider roads have higher posted speed limits. To reduce the likelihood of vehicle-dragonfly encounters on wider roadways might require higher diversion structures to compensate for the downward dipping of dragonfly flight height. The exact shape of the relationship between diversion structure height, road width, and *S. hineana* flight height cannot be determined from this study alone and might be complex, especially if highways are divided by a median. However, in general, our observations suggest that diversion structures for increasing flight height will be most useful on smaller secondary roads rather than expressways.

One unexpected finding of this study was that a diversion structure, even this small, can direct *S. hineana* flights away from the roadway entirely (i.e. it can function as a partial barrier). Butterflies are known to show similar responses to simple barriers (i.e. 1.5 and 3.5 m high) (Fry and Robson 1994; Dover and Fry 2001). It is important to distinguish between a diversion structure and a barrier structure. A diversion structure it is not intended to prevent roadway crossing but rather to alter behavior in ways that reduce crossing mortality. In contrast, barriers such as conservation fencing along roads may or may not decrease a road's effect on the persistence of a population (Jaeger and Fahrig 2004), and sometimes the fencing itself can become a threat (Hayward and Kerley 2009). Like conservation fencing, diversion structures are meant to limit threats to local biodiversity (Hayward and Kerley 2009). The nets used in this experiment act as partial barriers causing 65 % of individuals approaching to turn away (Fig. 4). Any sort of barrier, even a partial one, could contribute to population fragmentation; however, a combination of deterrence and increased flight heights is likely a better outcome than the current rates of roadkill. Longer and higher structures may divert larger numbers of *S. hineana* from the roadway, which would not be ideal because of the potential for compounding the barrier function of roads, further isolating sub-populations. Dover and Fry (2001) suggest that incorporating such knowledge of responses to barriers is important in the development of management strategies for butterfly populations. There is a balance to be struck between building diversion structures that negatively affect populations through fragmentation while at the same time providing the benefit of limiting death rates from vehicular collisions.

Although diversion netting may be a way to significantly reduce *S. hineana* roadkill, there are difficulties associated with diversion and barrier structures in that they need to end somewhere. For example, Bager and Fontoura (2013) found that where capybara (*Hydrochoerus hydrochaeris*) roadkills occurred was simply altered when a wildlife protection system was used. It is possible that *S. hineana* may cross the roadway where nets end, resulting only in a change in the location where they are hit rather than a reduction in mortality rates. In our study this did not appear to be the case because only 5 % of all *S. hineana* that flew parallel to or turned away from the nets later crossed the simulated roadway where it was open. This suggests that if nets are lengthened beyond stretches of roadway where *S. hineana* are known to suffer from collisions with vehicles, it may prevent them from simply flying around the nets. For barriers and diversion structures to function efficiently requires careful preliminary surveys to determine the areas in which adults most frequently cross the roadway and some post-construction evaluation of the specific response of *S. hineana* to the structure after it is installed.

Nets may present issues for wildlife such as trapping individuals between diversion structures. One potential way to ensure the safety of other organisms would be to leave a sizeable gap between the bottom of the nets and the ground. Additionally, nets could be put up only during times of flight activity (mid-June to mid-August), which may also reduce monitoring and maintenance costs. An alternative to artificial structures might be to use natural diversions such as shrubs or trees to direct flights away from the road. Such plantings might decrease monitoring and maintenance time and be more easily integrated into the natural environment. However, it is unclear whether such diversions would function as well for dragonflies as they do for butterflies (Severns 2008), and they may increase the number of collisions with other forms of wildlife or reduce visibility for drivers. Overall it is important to evaluate all aspects of this diversion technique because well-performed evaluations of mitigation strategies are needed in order to effectively spend monetary resources and protect the viability of wildlife populations (van der Grift et al. 2013).

This preliminary study indicates that it might be possible to reduce the number of *S. hineana* killed by motor vehicles on some roadways through use of simple diversion structures. Much basic research into diversion heights and configurations and into the role of various roadway surfaces (e.g. gravel, dirt, asphalt) in modifying dragonfly flight behavior still remains to be done. Even given this, erecting nets in areas where *S. hineana* and other dragonfly species are vulnerable to collisions with motor vehicles seems likely to be one of the most effective and inexpensive tools for their conservation and would potentially reduce the overall impact of roadways on wetland ecosystems. This will be especially true if they are used in conjunction with speed reduction and measures to reduce traffic volumes in sensitive areas.

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