DEPARTMENT OF TRANSPORTATION

Reduce vehicle-animal collisions with installation of small animal exclusion fencing

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16. Abstract (Limit: 250 words)

The presence of small animals on Minnesota's roadways presents a public safety concern and negatively impacts wildlife populations. For the past four years, the Minnesota Zoo has partnered with the Minnesota Department of Transportation to test and evaluate the effectiveness of standard plans for small animal exclusion fencing, with the goal of redirecting turtles and small wildlife away from roadways and to existing through-road infrastructure where practicable. Wildlife can pose a significant threat on roadways, and driver avoidance of or direct collisions with small animals can result in substantial damage or injury, particularly for motorcyclists and bicyclists and those who stop to assist wildlife across roadways. Turtles are the focus of this research as their unique life histories and slow population growth rates make them particularly vulnerable to impacts from road mortality.

To address this, we implemented a before-after-control-impact study at 11 sites around the greater Twin Cities region during the 2018–2021 period. Our results showed that standard chain-link fencing (including trenching and wrap-around end treatments) can effectively reduce mortality of adult turtles. However, this design did not result in decreases in mortality of juvenile and hatchling turtles. After retrofitting fences with ½-inch wire mesh, we documented a substantial reduction in the mortality of all age classes (up to 91% over pre-treatment) of turtles, thereby demonstrating its utility as an effective mitigation strategy. The development and adoption of a vetted standard plan will increase efficiency, reduce costs, improve public safety, and reduce mortality of turtles and other wildlife on Minnesota roads.

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Reduce Vehicle-Animal Collisions with Installation of Small Animal Exclusion Fencing

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EXECUTIVE SUMMARY

Synopsis of Research Issue

The presence of small animals on Minnesota's roadways presents a public safety concern and may threaten the persistence of local wildlife populations. In partnership with the Minnesota Department of Transportation, the Minnesota Zoo evaluated the effectiveness of standard plans for small animal exclusion fencing during the 2018-2021 period. The goal of exclusion fencing was to redirect small wildlife away from roadways and to existing through-road infrastructure (i.e., culverts) where practicable, thereby addressing safety, economic, and environmental considerations.

Roadways present a direct threat to wildlife via mortality resulting from vehicle collisions. Roads also fragment habitat and may result in increased isolation among populations over time. Turtles are particularly vulnerable to the impacts of roads due to their unique life histories and limited rates of population growth. Adult female turtles also comprise a disproportionately high percentage of turtle mortality on roads due to their movements during the nesting season, further hindering recovery efforts. In Minnesota, two of nine native turtle species, Blanding's (*Emydoidea blandingii*) and wood turtles (*Glyptemys insculpta*), are categorized as Threatened by the state of Minnesota and currently are under consideration for federal protection under the Endangered Species Act.

The occurrence of wildlife on roadways poses a public safety concern as well. Whereas most incidents are attributable to larger mammals, drivers may swerve erratically or stop suddenly to avoid hitting small wildlife, and motorists may stop and venture into traffic to rescue animals. Direct hits of even small animals can result in vehicle damage and injury, particularly for motorcyclists and cyclists. Although it is difficult to quantify the threat posed by small wildlife on roadways, implementation of mitigation efforts is likely to benefit both human safety and property.

Many road mortality mitigation measures have been implemented for larger animals, yet relatively few have focused on small wildlife, and even fewer studies have evaluated their effectiveness. This project seeks to quantify reductions in wildlife mortality at fenced sites and establish small animal exclusion fencing standards to inform best management practices, which will streamline implementation in the future and reduce design costs. Here, we use a before-after-control-impact (BACI) study design to compare mortality data collected pre- (i.e., before) and post- (i.e., after) installation at sites identified for fence installation (i.e., impact) and sites not identified for fencing (i.e., control). Throughout the 4 years of research, fences were installed at 4 of the 11 sites monitored; such replication at both spatial and temporal scales is relatively unique among studies evaluating the efficacy of mitigation techniques.

Main Findings

The results of our study suggested that standard 6-foot chain-link fencing effectively reduced the mortality of adult turtles on Minnesota's roadways when trenched into the ground and designed with wrap-around end treatments. However, mortality of juvenile and hatchling turtles increased after fence installation. When chain-link fencing was further retrofitted with ½-inch wire mesh attached directly to the chain link fencing, we documented a significant reduction in the mortality of all age and size classes of turtles, up to 91% over pre-treatment. No mortality clusters were observed at fence ends, indicating that end treatments worked as intended. In addition, photographs collected via camera trapping provided evidence that turtles were directed back to the wetlands or safe crossing locations by the wrap-around end treatments and confirmed that turtles and other small wildlife use existing culverts.

The standard chain-link fences maintained their structural integrity well during the 3 years post-installation. We did not document gaps at the bottom of the fence, heaving associated with freeze/thaw events, or any vertical or horizontal displacement from the initial positioning at installation. The off-the-shelf materials used for this study were readily available, likely at substantially reduced costs (in comparison to custom products) and were familiar to staff to better facilitate installation and repair.

Significance of Research, Potential Benefits and Conclusions

With this project, we sought to evaluate the effectiveness of a standard plan for small animal exclusion fencing and identify recommendations to best meet safety, economic, and environmental objectives. Although standard chain-link fence that included trenching and wrap-around end treatments reduced mortality of adult turtles, it did not decrease mortality of juveniles and hatchlings and thus did not yield the desired results for the turtle population as a whole. Following the retrofitting of fences with ½-inch wire mesh, we documented a substantial reduction in the mortality of all age classes, thereby demonstrating its utility as a mitigation strategy.

Road safety is a critical component of highway planning efforts. Wildlife can pose a significant threat on roadways, and driver avoidance of or direct collisions with small animals can result in substantial damage or injury. In addition to improving safety for motorists and pedestrians by keeping wildlife off roads, benefits of this work include increased efficiencies in resource use by establishing vetted standard plans for fencing and reduced mortality of imperiled turtles and other wildlife on Minnesota roadways. Given that Blanding's turtles and wood turtles are currently undergoing status assessments for possible listing under the federal Endangered Species Act, it further behooves the state of Minnesota to take a proactive approach to conservation. Working to mitigate key sources of mortality now ultimately will be more cost-effective than addressing the conservation of species after a listing decision.

The development and adoption of a vetted standard plan will save design and planning costs when exclusion fencing is implemented at other sites in the future. Multiple years of data collection post-installation improve our understanding of the efficacy of fencing in reducing mortality, how well fences maintain their integrity over time, and what costs and labor can be anticipated with long-term maintenance. The use of readily available, off-the-shelf materials also provides economic benefits by reducing costs of installation and better facilitating fence repairs. Effective barriers will aid populations of both common and threatened wildlife and yield public safety and economic benefits by reducing the number of vehicle collisions.

Recommendations and Next Steps

The effectiveness of exclusion fences in reducing wildlife mortality on Minnesota roads and their maintenance of structural integrity suggest that fencing may be an advantageous addition to some construction projects, benefitting both public safety and wildlife. High priority sites for implementation of small animal exclusion fencing could include any site with a high potential for wildlife-vehicle collisions and could be particularly beneficial in areas frequented by threatened or endangered species. Factors to consider in identifying appropriate sites could include the presence of potential habitat for target wildlife, traffic volume and speed, public safety considerations, and documented presence of road mortality. Habitat connectivity is an important consideration, and sites should have either existing through-road infrastructure (i.e., culverts) or include a plan to create a suitable crossing. Pairing any crossing structure with an exclusion fence will be critical for mitigation success and ensure habitat connectivity; design modifications could be required to help guide animals to safe crossing locations.

The retrofit modification attaching ½-inch wire mesh to the existing chain-link fence substantially reduces turtle mortality as a whole and will be an important element for future projects. We recommend affixing the wire mesh during initial fence installation to minimize costs and installation logistics (e.g., trenching and backfilling for both the standard chain-link fencing and the mesh). We also suggest using the excavated soil for backfill or, if additional material is needed, adding a heavy sand or clay-based soil (where permissible under applicable wetland regulations); the material must be compacted into the trench. We recommend the use of chain-link fencing materials as they are readily available and easily installed, and their durability over time makes them cost-effective. The materials also are flexible and can be shaped to follow specifications for the wrap-around fence end treatments. Longer, continuous fences are likely to be more effective at reducing mortality than shorter fragmented fences as they offer fewer breaks where wildlife can potentially enter the road. Where driveways and intersections make continuous fence infeasible, wrap-around end features are important and future modifications (e.g., lengthening end treatments down driveways) can be explored.

CHAPTER 1: INTRODUCTION

Wildlife-vehicle collisions present a public safety concern and may threaten the persistence of local wildlife populations (Trombulak & Frissell, 2000; Underhill & Angold, 2000). With an ever-expanding network of roads in Minnesota and nationwide, considerations need to be made as to how best to meet transportation needs while preserving driver safety and keeping wildlife populations intact. Wildlife barriers and underpasses are becoming more common on the landscape and offer habitat connectivity for small animals while keeping them off roadways (Rytwinski et al., 2016; Heaven et al., 2019). Testing and developing standard plans for mitigation strategies will help to improve outcomes and reduce future costs.

While many animals face risks from roads, turtles are among the taxa most significantly impacted (Gibbs & Shriver, 2002; Seiler, 2003; Aresco, 2005). In Minnesota, two of nine native turtle species, the Blanding's turtle (*Emydoidea blandingii*) and the wood turtle (*Glyptemys insculpta*), are categorized as Threatened by the state of Minnesota, classified as globally Endangered (IUCN, 2021), and currently under consideration for federal protection under the Endangered Species Act. These trends are alarming, as turtles play a pivotal role in maintaining diverse and healthy aquatic ecosystems (Lovich et al., 2018). Roads not only present a direct threat to turtles attempting to cross, but the resultant habitat fragmentation can lead to population isolation and loss of genetic diversity over time (Holderegger & Di Giulio, 2010; Laporte et al., 2013; Laurance & Balmford, 2013). Turtles are characteristically slow, and their main defense mechanism (tucking into their shell) does little to protect them from a vehicle strike. Aresco (2005) estimated that up to 98% of individuals are killed during their first road crossing attempt. Unfortunately, the fragmentation created by roadways often compels turtles to cross them, as they seek access to feeding grounds, nesting sites, overwintering sites, and mating opportunities (Gibbons et al., 1983; Bodie & Semlitsch, 2000; Joyal et al., 2001).

The unique life histories of turtles means that they are especially vulnerable to high levels of additive mortality among adult and subadult age classes, such as that associated with roadways (Congdon et al., 1993; Gibbs & Shriver, 2002). Unlike most mammals, birds, and amphibians, turtles may take a decade or more to reach sexual maturity, thereby limiting potential population growth rates (Wilbur & Morin, 1988; Congdon & Gibbons, 1990). Indeed, survival of eggs and hatchlings in the wild is very low, such that turtles in some populations live decades just to produce a single successful replacement. Moreover, adult female turtles searching for suitable nesting sites make up a disproportionately high percentage of turtle road mortality (Marchand & Litvaitis, 2004), further hindering the recovery of depleted populations (Gibbs & Steen, 2005; Dupuis-Desormeaux et al., 2017).

The presence of turtles and other wildlife on roadways poses a public safety concern as well. Road safety is a critical component of highway planning efforts, and vehicle-wildlife collisions cause over 200 combined injuries and fatalities every year (Office of Traffic Safety, 2022). Whereas most of these incidents are attributable to larger mammals such as deer, drivers may swerve erratically or stop suddenly to avoid hitting small wildlife, and motorists and pedestrians may stop and venture into traffic to rescue animals, creating public safety concerns and potentially causing serious accidents. Direct hits of even small animals can also result in vehicle damage and injury, particularly for motorcyclists and cyclists. Although it is difficult to quantify the threat posed by small wildlife on roadways, implementation of mitigation efforts likely benefits human safety and property as well.

Whereas many road mortality mitigation measures have been implemented for larger animals, relatively few have focused on small wildlife, and even fewer have been evaluated for their effectiveness (see van der Grift et al., 2013; Heaven et. al., 2019). Mitigation efforts targeting areas with high animal crossings can include barriers, wildlife underpasses and overpasses, warning signs, and animal detection systems (Smith et al., 2009; Langen, 2012; Baxter-Gilbert et al., 2015; Colley et al., 2017; Crawford et al., 2017; Markle et al., 2017; Rytwinski et al., 2016; Heaven et al., 2019). Considerations as to which measure to use at a particular site include material and labor cost, likelihood of effectiveness, ease of installation/repair, longevity, and maintenance. Barriers combined with underpasses or overpasses are considered the most effective mitigation, yet are also the most expensive (Rytwinski et al., 2016). Design considerations are important, as some barriers have failed as a result of animals breaching or circumnavigating walls (Dodd et al., 2004; Aresco, 2005; Markle et al., 2017) or avoiding or using underpasses less than anticipated (Woltz et al., 2008; Baxter-Gilbert et al., 2015). The need for continual maintenance and repair also may limit their utility (Aresco, 2005; Baxter-Gilbert et al., 2015; Colley et al., 2017; Markle et al., 2017). New barrier designs have improved on past failures and added features such as wrap-around end treatments help to direct animals away from the road and to safe crossings (Baxter-Gilbert et al., 2015; Crawford et al., 2017).

Here, we evaluate the effectiveness of small animal exclusion fencing in reducing wildlife mortality, using turtles as an indicator species. With the support of the Minnesota Department of Transportation, we vet a standard plan for fencing that uses chain-link fence materials and wrap-around “j-hook” end treatments to direct turtles back to the wetland. Adoption of a standard plan for wildlife barriers will streamline implementation in the future and reduce costs associated with developing new and custom designs. Specifically, we quantify road mortality at several treatment and control sites in the greater Twin Cities area using a before-after control-impact (BACI) study design. We also monitor connectivity among wetlands linked via standard culverts under the road with time lapse trail cameras. We hypothesize that the mortality of turtles will be significantly reduced following the installation of exclusion fences, relative to sites at which fences are not installed. In addition, we predict that the end treatments will deter movements across the roadway and effectively redirect turtles back to the wetland from which they traveled, or to a safe crossing structure, a hypothesis that will be supported by an absence of mortality concentrated just beyond the fence ends. Finally, we outline recommendations to best meet safety, economic, and environmental objectives.

CHAPTER 2: METHODS

2.1 STUDY SITES

We initially scoped candidate study sites around the greater Twin Cities Metropolitan area in 2017. To ensure replication across different landscapes and regions, we selected 15 sites along trunk highways maintained by MnDOT from three general areas: West (Carver County; MN 5 and MN 7), North (Washington County; MN 97); and South (Dakota County: MN 3) (Fig. 1). Selection criteria included: 1) potential for turtle mortality, as evidenced by shell fragments and historical reports or observations (e.g., via Herpmapper, 2017); 2) logistical feasibility of monitoring and installing a fencing treatment; 3) presence of wetlands (e.g., pond, marsh, or small lake) on both sides of the roadway; and 4) multiple potential sites along a single stretch of road. We collected baseline data from all 15 sites in 2018 but elected to reduce the sample to 11 sites due to safety considerations, ongoing or imminent road construction, and / or minimal turtle mortality (Figure 1).

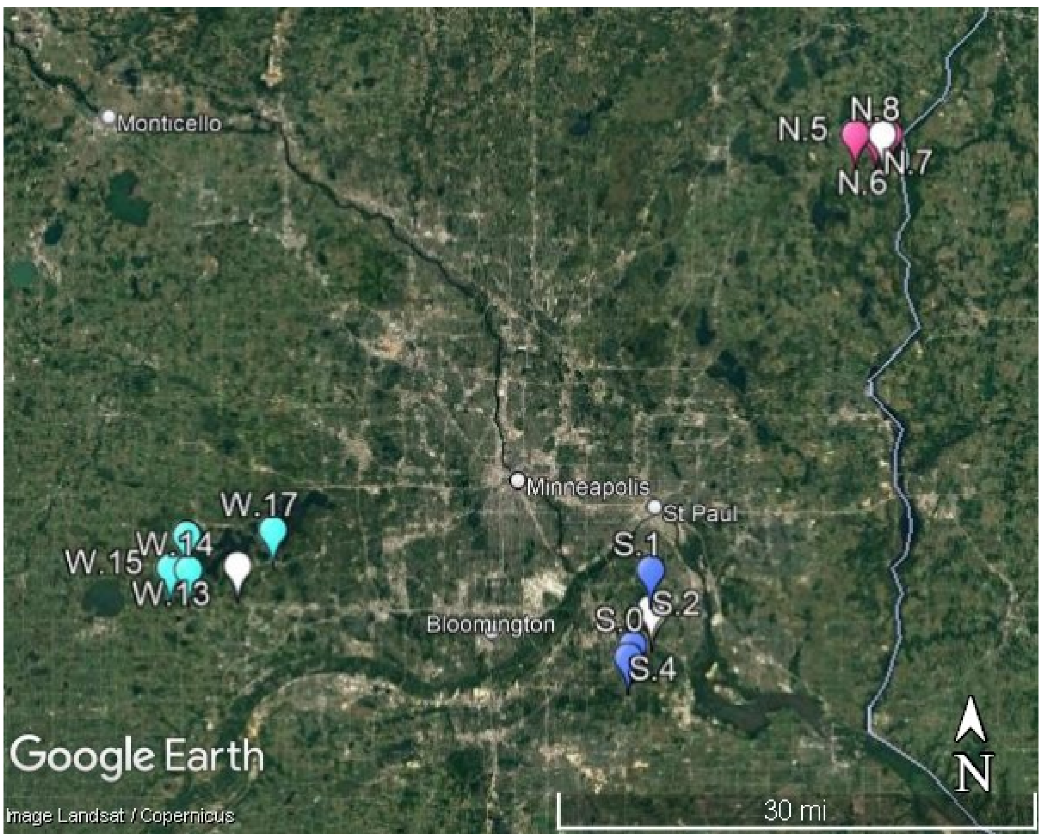

Figure 1. Fifteen study sites were located around the greater Twin Cities Metropolitan region in 3 general geographic areas: West (Carver County – Minnetonka area [light blue]), North (Washington County - Scandia area [pink]), and South (Dakota County – Eagan area [dark blue]). The 4 sites labelled in white were ultimately removed from monitoring.

The majority of the 11 sites monitored throughout the duration of this project and included in the analyses were two-lane paved roadways with traffic in opposite directions, posted speed limits of 55 mph, and wide paved and / or gravel shoulders. Exceptions included S.1 along Robert Trail (MN 3), which has a slightly reduced speed limit of 50 mph, and W.17 (MN 7), which has four lanes of traffic separated by a narrow grassy median and an additional turning lane. Daily average traffic volume estimates for each area range from 5,500 to 33,000 (Table 1). Lands adjacent to study sites generally were privately owned and included residential development and agricultural fields; nearby waterbodies were commonly adjoined by mixed deciduous forest. A few sites in Carver County abutted Three Rivers Park District lands.

2.2 STUDY DESIGN

To quantify the efficacy of mitigation fencing treatment in reducing mortality of small wildlife, we implemented a before-after-control-impact (BACI) study design, which is a robust means to evaluate mitigation methods (van der Grift et al., 2013; Rytwinski et al., 2016). Sites for fencing treatments were chosen based on a semi-randomized selection process that incorporated criteria including the presence of target species (i.e., turtles), financial constraints, fence installation feasibility, existing infrastructure (e.g., the presence of culverts to promote connectivity among sites bisected by roadways) and broad geographic representation. Although high mortality sites are ultimately a priority for mitigation strategies, control and treatment sites were chosen via the semi-randomized process, given the above financial and logistical considerations to facilitate robust statistical analyses. In addition, we used survey data collected in 2018 to inform the positioning and length of potential fences.

Table 1. Specifications of treatment sites.

Site	Site Length (feet)	Total Fence Length (feet)	Annual Average Daily Traffic (AADT) Volume, 2018-2020
S.4 Eagan	1000	1640	12,900
N.5 Scandia	850	1340	5,500
W.17 Excelsior	620	610	33,000
W.18 Waconia	1025	1640	8,581

Five treatment sites were jointly identified by MnDOT and MN Zoo. Of the 5 candidate treatment sites, 4 were ultimately selected for fencing: sites S.4 (Eagan), N.5 (Scandia), W.17 (Excelsior), and W.18 (Waconia), representing each of the three general study regions (Fig. 1). Site W.13 (Arboretum) was identified initially as a candidate site but was not selected for installation of fencing treatments: although we documented high rates of mortality during 2018, the length of the site made the installation of fencing there cost-prohibitive. Our selection process ensured that each treatment site would be paired with 1 to 2 corresponding and comparable control sites along the same stretch of road.

The inclusion of control sites and sufficient replication over appropriate time and spatial scales are important, but often overlooked considerations (Rytwinski et al., 2016).

2.3 FENCING MITIGATION

Chain-link fencing was installed at 4 treatment sites in 2019. Fencing installation began in the early spring (once the ground thawed) and was completed at 3 sites (S.4, W.17 and W.18) during April – May, 2019 (Figure 2). At the fourth site (N.5), high water levels delayed construction until September. Site preparation included mowing vegetation within 3 feet of the fence line. Fencing material consisted of 6-foot chain-link fence material that was trenched 10-12 inches into the ground, leaving approximately 5 feet of fencing above ground. The trench was backfilled with excavated materials to preclude animals from digging underneath and to prevent gaps created by erosion. The standard 6-foot chain-link fence was selected for this project because it is readily available, easily installed, and thus has the potential for use in applications state-wide. The height also was important to ensure that the fence showed above the snow line (particularly where placement needed to accommodate active snowmobile trails) and to prevent turtles from climbing over. Due to freezing and potential for heaving of metal posts, all posts were set >4 feet into the ground. Wrap-around "j-hook" fence end treatments also were installed, since such designs can be effective in mitigating the mortality of wildlife by directing turtles back to wetlands and limiting their access to roadways (Heaven et. al., 2019). End treatments (i.e., the return courses) were a minimum of 10 feet in length, with the curved end creating a 24-30 inch gap with the primary fence (Figure 3). Fence installation resulted in little disturbance to surrounding vegetation and no reseeding or restoration was necessary.

Fencing lengths were sized to cover the areas with the greatest number of turtle crossings, acting as a barrier for the whole length of the wetland on each side of the road, plus a buffer area. Total fencing lengths were: 1640 ft (S.4), 1340 ft (N.5), 610 ft (W.17), and 1640 ft (W.18). Culverts were located at 2 of 4 treatment sites (N.5 and W.18) and were situated well within the bounds of the fence. Where fences were further from culvert openings, short segments of silt fencing were installed to help direct turtles from the fence into the culverts (Figure 2).

Monitoring post-installation suggested that the initial fence design was ineffective in reducing the mortality of hatchling and juvenile turtles, presumably because they are able to fit through

Figure 2. Initial chain-link fence treatment sites. Top: Site preparation and installation of posts and wrap-around end treatments. Middle: Completed chain link fence and end treatment. Bottom: left- MnDOT signage, right- silt-fencing to guide animals into culvert opening.

the standard 2" chain link fence mesh (Figure 4). To further mitigate mortality of smaller turtles, 3 of the 4 existing fences (W.18, N.5, and S.4) were retrofitted with fine, 19 gauge (½ inch) hardware cloth. Selection of these three sites was based on the presence of small turtles and the logistical feasibility of hardware cloth installation. Because we did not document the same level of mortality of small turtles at the fourth site (W.17), hardware cloth was not installed there. This installation was completed in late March, 2021. The hardware cloth was attached directly to the existing fence, buried 6 inches below ground, and extended 2 feet above ground (Figure 4). We hypothesized that most small turtles would be unable to climb above this height.

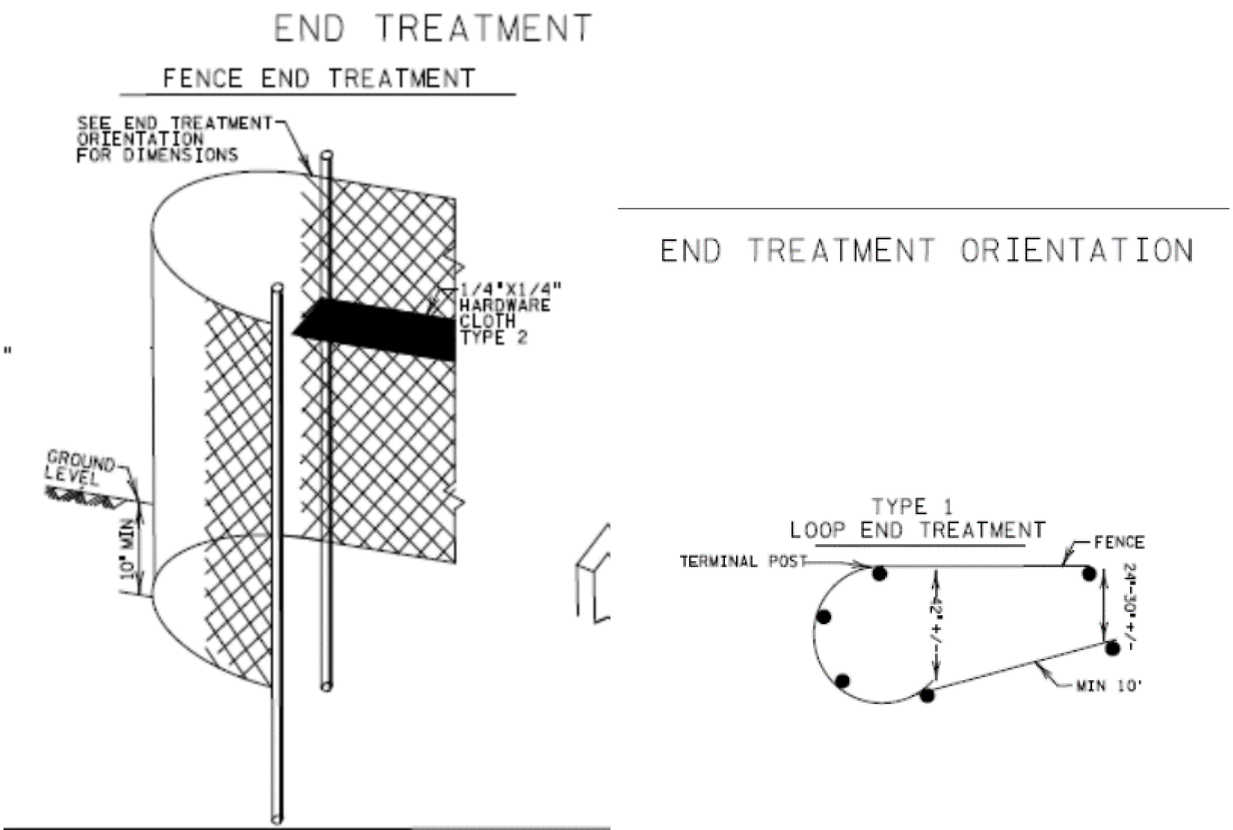

Figure 3. Fence end treatment specifications, as outlined in MnDOT standard plan for small animal fencing.

Figure 4. Top left: Small (i.e., juvenile turtles less than 2 inches in width) are able to fit through standard chain-link fence mesh and access roadway. Top right: Hardware cloth was retrofitted onto the existing chain-link fence at 3 of 4 treatment sites in 2021. Bottom: Small painted turtle found on roadway.

2.4 MONITORING

We monitored each of the 11 sites on a weekly basis for four years from 2018 to 2021. The 2018 data collection was intended as baseline (pre-mitigation) data collection, followed by three years of post-installation data collection.

Monitoring typically occurred mid-morning to early afternoon, with every site visited once per week. We attempted to sample during the same day and time each week (pending weather conditions and other obligations). Season end and start dates were determined by a combination of animal activity and weather; monitoring typically began the first week of May and continued until the third week of October. We sampled each site 22– 25 times during a given field season. In two instances, active road construction (i.e., resurfacing) prevented access to a site for a given week. Study sites were delineated with spray paint to ensure consistency in monitoring effort. A minimum of one (but often two) researchers collected road mortality data by walking single file using visual sweeps, recording all mortality (and any live animals) on roads and within the first two feet of the shoulder. In addition to turtles (our focal taxa), we recorded snakes, lizards, frogs, toads, birds, mammals, monarchs, and bumble bees. We identified turtle species, estimated age class, collected positional data (i.e., latitude and longitude) using a handheld GPS receiver (Garmin GPSMAP 78sc), and photographed all mortality events. Dead turtles then were removed from the study site to avoid recounting during subsequent surveys. On occasion, live turtles were found on roadways during the surveys and assisted in the direction they were heading. Given weekly surveys, we expect that we did not document all road mortality events since scavengers (e.g., crows, raccoons, foxes) may feed on and remove roadkill. However, data collection was consistent among sites, thus enabling us to evaluate the effectiveness of the mitigation measures.

To evaluate the effectiveness of end treatments in redirecting wildlife back to wetlands and wildlife use of existing culverts to cross under the road, we installed trail cameras (Browning Dark Ops Extreme infrared camera) for one season at all fencing end treatments and at the two sites (18.W and 5.N) with culverts. As turtles are ectotherms, they often don't have enough thermal contrast with the environment to trigger infrared cameras. To account for this, we set cameras with both motion activation (three-photo rapid capture) as well as time lapse capture every 1 minute from sunrise to sunset for the duration of the study season. In most cases, cameras were attached directly to the fence, approximately 5 feet from the j-hook end treatment wrap-around. Cameras were aimed to capture animals entering and exiting the wrap-around and were secured with anti-theft locks. For the culverts, we mounted cameras on posts just behind the culvert opening and angled down to capture any animals entering or exiting.

In addition to collecting mortality data, we deployed traffic counters at the sites to quantify traffic volume and speed. We pooled these data with information collected annually by MnDOT to summarize traffic volume at our study sites.

2.5 STATISTICAL ANALYSES

We summarized weekly observational data of turtles (including mortalities and live turtles, which were deemed to be high risk; Heaven et al. 2019) by site for the 4-year period. We compiled three observational datasets including 1) all turtles, regardless of size or age-class; 2) adult and large subadult turtles only; and 3) hatchling and small juvenile turtles only. We integrated these datasets into 2 sets of analyses, allowing us to rigorously evaluate the efficacy of 1) the chain link fencing treatment alone and 2) the retrofitted fence with ½ inch hardware cloth affixed to the bottom of the fence. Preliminary review of the raw, weekly count data suggested some overdispersion (as indicated by the ratio of variance : mean with a Poisson distribution). As such, we log-transformed these data for modeling to accommodate this overdispersion.

We analyzed data using a Generalized Linear Mixed Model (glmm), which facilitated the inclusion of both random and fixed effects, and specified a Poisson distribution. We modeled the data as a function of Period (i.e., before or after treatment installation; fixed effect), Treatment (i.e., Impact vs. Control; fixed effect), and the interaction of Period and Treatment. We also included random effects for Site and Year to accommodate the repeated, weekly sampling at individual sites as well as inter-site and inter-annual variability. With this modeling approach, the effectiveness of fencing and retrofit treatments is indicated by a significant (α=0.05) interaction between Period and Treatment (i.e., a decrease in turtle observations at treatment [Impact] sites post-installation, versus no difference in observations at control sites over time). We used R statistical software (version 4.0.4 [R Core Team, 2021]) and package lme4 (v1.1-26; Bates et al., 2015) to analyze data. For the scope of this work, statistical analyses were limited to turtles, but data for other taxa are available to other researchers as needed.

CHAPTER 3: RESULTS

3.1 ROAD SURVEYS AND ANALYSES

In 2018, the baseline (i.e., before) year, we encountered 4 to 73 turtles across the 11 research sites (Table 2). We observed the highest amount of mortality at site N.5 and the lowest rate at site N.8.

Raw count data from our first year of fence treatment in 2019 suggested that fencing may be an effective tool to reduce turtle mortality (Table 3). At the three sites with fences installed in the early spring, we documented significant reductions in turtle mortality ranging from 60% to 87% in the first year of monitoring (Figure 5). Most mortalities documented at fenced sites were small turtles (i.e., hatchlings or juveniles; 21 of 33; Table 4). In our second year of post-installation data collection in 2020, the effectiveness of fencing is more nuanced (Table 5). For 3 of 4 fence sites, mortality was lower than pre-installation. However, at site S.4, mortality counts were significantly higher in 2020 than the previous two years, including the pre-installation baseline year. We note that 55 of 68 (81%) of the documented turtle mortalities were juveniles (including 36 hatchlings) that can fit through the standard 2-inch wide spaces of the fence (Table 5). At site N.5, mortality decreased from pre-fence years, but a large number of adult and juvenile turtles accessed the road through a driveway that occurs mid-site on the southern side of the road. Many of the mortalities also occurred very early in the season (May) and may be associated with rapid water reduction in one of the ponds.

For the analyses evaluating the effectiveness of chain link fence alone (i.e., pre-installation versus post-fence installation; 2018 – 2020), GLMM modeling with the ‘all turtle’ dataset did not identify a significant interaction between Period and Treatment (Table 6), indicating that mortality at the fence treatment sites did not change post-treatment in comparison to control sites. However, the ‘adults only’ dataset yielded a significant interaction, suggesting that mortality at the fenced sites was significantly reduced post-installation (Table 6). By contrast, mortality of hatchling and juvenile turtles was significantly greater at fenced sites post-installation (Table 6).

Raw count data suggested that the installation of the 1/2-inch hardware cloth in 2021 may be effective in decreasing the mortality of juvenile and hatchling turtles (Table 7). We recorded less mortality of turtles – particularly juveniles – at fenced sites in 2021 relative to previous years (Table 4). For instance, at site S.4 (Eagan), we documented a decrease in mortality from 68 turtles in 2020 to 21 in 2021 (69% reduction). At site N.5 in Scandia, we also documented a significant decrease in turtle mortality, including 25 fewer juvenile turtles in 2021. The 18 total turtles documented during 2021 represent a 69% reduction from 2020 and ~75% fewer turtles than pre-treatment surveys in 2018 and 2019. The mid-site driveway on the south side continued to act as a corridor for turtle movement onto the road, although less so than in 2020. Since the original fence installation, only a small number of mortalities – all juveniles – have been documented each year. Finally, at site W.18 in Waconia, we recorded a ~56% decrease in mortality from 2020 to 2021 (Figure 5).

Analyses evaluating the effectiveness of the retrofitted fence versus non-retrofitted sites (i.e., post-installation fenced sites and controls, 2019 – 2021) resulted in a significant interaction between Period and Treatment (Table 8; Figure 6), providing strong support that the retrofitted fence reduced mortality over standard chain link fence. This interaction was statistically significant for both adults and juvenile turtles when tested separately.

Observations at control sites remained relatively consistent among years, but we did observe modest declines at some sites in 2020 followed by an increase in mortality in 2021 (Figure 7). We note that our inclusion of random effects can help to control for such variation.

Table 2. Summary Field Season 2018: Pre-treatment (baseline) site monitoring. Observations of turtles and other wildlife collected from May 9 to October 17, 2018.

Site	Turtles			Anurans				Snakes	Other Herpeto-fauna	Birds	Mammals	Insects		Site Totals
	Painted turtles	Snapping turtles	Unknown	Leopard Frogs	Green Frogs	American toads	Other / Unknown	All species	All other species / Unknown	All species	All other species	Bumble bees	Monarchs	
S.0	29	6		24	2	4	8	2		10	12			**97**
S.1	11	4	1	1		5			1	1	5			**29**
S.4	30	9		24		8	7			4	9		5	**96**
N.5	64	8	1	14	1	5	6	5	1	13	3	8	5	**134**
N.6	20			5	3	13	18	1	1	4	2		5	**72**
N.8	4			3		8	6	1	1	1	1	1	2	**28**
W.14	16	6		20	60	12	207	3		27	9	2	8	**370**
W.15	16	10	2	10	13	12	86	3	2	14	4	4	2	**169**
W.16	11	1		5	27	10	53	2		18	5	3	4	**148**
W.17	14	1		2	1	1			1	2				**22**
W.18	36	5	2	82	23	10	105	3	2	8	3	4	10	**293**
Total	**251**	**50**	**6**	**190**	**130**	**88**	**496**	**20**	**9**	**102**	**53**	**4 22 0**	**41**	**1458**

Table 3. Summary of Field Season 2019: Post-fence installation site monitoring. Observations of turtles and other wildlife collected from May 6 to October 23, 2019. Treatment (fenced) sites are shaded. Site N.5 (dark shade) is a treatment site, but fence construction did not begin until September, 2019.

Site	Turtles		Anurans			Snakes	Other Herpetofauna	Birds	Mammals	Insects		Site Totals
	Painted turtles	Snapping turtles	Leopard frogs	American toads	Other / Unknown	All species	All other species / Unknown	All species	All other species	Bumble bees	Monarchs	
S.0	12	14	18	3				3	2		3	**55**
S.1	5		14					1	2	1	4	**27**
S.4	8	5	27	5	2		2	4			2	**55**
N.5	60	8	8	3	4	2	5	16	3	5	9	**123**
N.6	11	1	1	3		2	3	3	1	1	4	**30**
N.8	5		4	4	1		4	1	2		2	**23**
W.14	15	2	16	5	11	3		19	5	7	8	**91**
W.15	13	4	18	5	10	3	3	8	4	6	3	**77**
W.16	7		10	5	8	8	5	7	5	3	6	**64**
W.17	1	1	1		1					1		**5**
W.18	15	1	56	12	13	8	1	18	5	6	6	**141**
Total	**152**	**36**	**173**	**45**	**50**	**26**	**23**	**80**	**29**	**30**	**47**	**691**

Table 4. Total turtle mortality (# of juveniles < ~2 inches in width) documented by site and year. Shaded cells = post-installation monitoring. Fences were retrofit with ½ inch hardware cloth prior to monitoring in 2021.

Site #	2018	2019	2020	2021
S.4	39 (6)	14 (8)	68 (55)	21 (11)
N.5	77 (19)	68 (16)	59 (36)	18 (11)
W.17	15 (3)	2 (2)	6 (6)	1 (1)
W.18	43 (12)	17 (11)	9 (7)	4 (3)

Table 5. Summary of Field Season 2020: Post-fence installation site monitoring. Data collected from May 4 to October 15, 2020. Monitoring occurred weekly. Treatment (i.e., fencing) sites are indicated by shaded cells.

Site	Turtles		Anurans			Snakes	Other Herpetofauna	Birds	Mammals	Insects		Site Totals
	Painted turtles	Snapping turtles	Leopard frogs	American Toads	Other / Unknown	All species	All other species / Unknown	All species	All other species	Bumble bees	Monarchs	
S.0	12	3	4	3				4	6	1	2	**35**
S.1	9		4				1	2	2		1	**19**
S.4	29	39	18	4	2			3		3		**96**
N.5	54	5	6	5	7	2	1	8	1	7	1	**97**
N.6	13			1	3			1		2	1	**21**
N.8	7			2	7			2				**18**
W.14	8	6	5	6	13	3		14	1	11		**67**
W.15	4	2	10	2	11	6		5	4	11		**55**
W.16		3	4		25	3	3	9	1	2		**50**
W.17		6		2	8			3	1			**20**
W.18	7	2	26	7	21	8		15	3	8	3	**100**
Total	**143**	**64**	**77**	**32**	**97**	**22**	**5**	**66**	**19**	**45**	**8**	**578**

Table 6. Modeling results from analyses evaluating effectiveness of small animal exclusion fencing using data collected pre- and post-installation of standard chain-link fencing.

All Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	-0.4947	0.1557	-3.178	0.0015
Treatment	0.6934	0.3775	1.837	0.066
Period*Treatment	0.1343	0.1652	0.813	0.416
Adult Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	-0.4605	0.1377	-3.245	0.00082
Treatment	0.6638	0.3937	1.686	0.092
Period*Treatment	-0.6853	0.2118	-3.235	0.0012
Juvenile Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	-1.0218	0.4146	-2.465	0.0137
Treatment	1.1333	0.4751	2.385	0.017
Period*Treatment	1.1357	0.3411	3.329	0.00087

Table 7. Summary of Field Season 2021: Post-wire mesh cloth installation site monitoring. Data were collected during weekly monitoring from May 3 to October 21, 2021. Treatment (i.e., fencing) sites are indicated by shaded cells.

Site	Turtles		Anurans			Snakes	Other Herpetofauna	Birds	Mammals	Insects		Site Totals
	Painted turtles	Snapping Turtles	Leopard frogs	American Toads	Other / Unknown	All species	All other species / Unknown	All species	All other species	Bumble bees	Monarchs	
S.0	45	2	14	3	2	1	1	13	6	0	0	**87**
S.1	8	2	1	2	0	0	0	0	1	0	0	**14**
S.4	12	9	10	2	4	0	0	8	4	2	0	**51**
N.5	15	3	3	4	3	0	1	2	3	1	2	**37**
N.6	26	0	0	0	1	0	0	2	0	1	0	**30**
N.8	6	0	3	0	3	1	0	1	0	0	0	**14**
W.14	9	1	2	15	5	1	1	14	3	3	0	**54**
W.15	15	3	7	3	3	0	1	6	2	3	0	**43**
W.16	10	2	2	10	8	1	0	5	6	4	0	**48**
W.17	1	0	0	4	0	0	0	1	0	1	0	**7**
W.18	2	2	5	1	3	3	0	17	5	3	2	**43**
Total	**149**	**24**	**47**	**44**	**32**	**7**	**4**	**69**	**30**	**18**	**4**	**428**

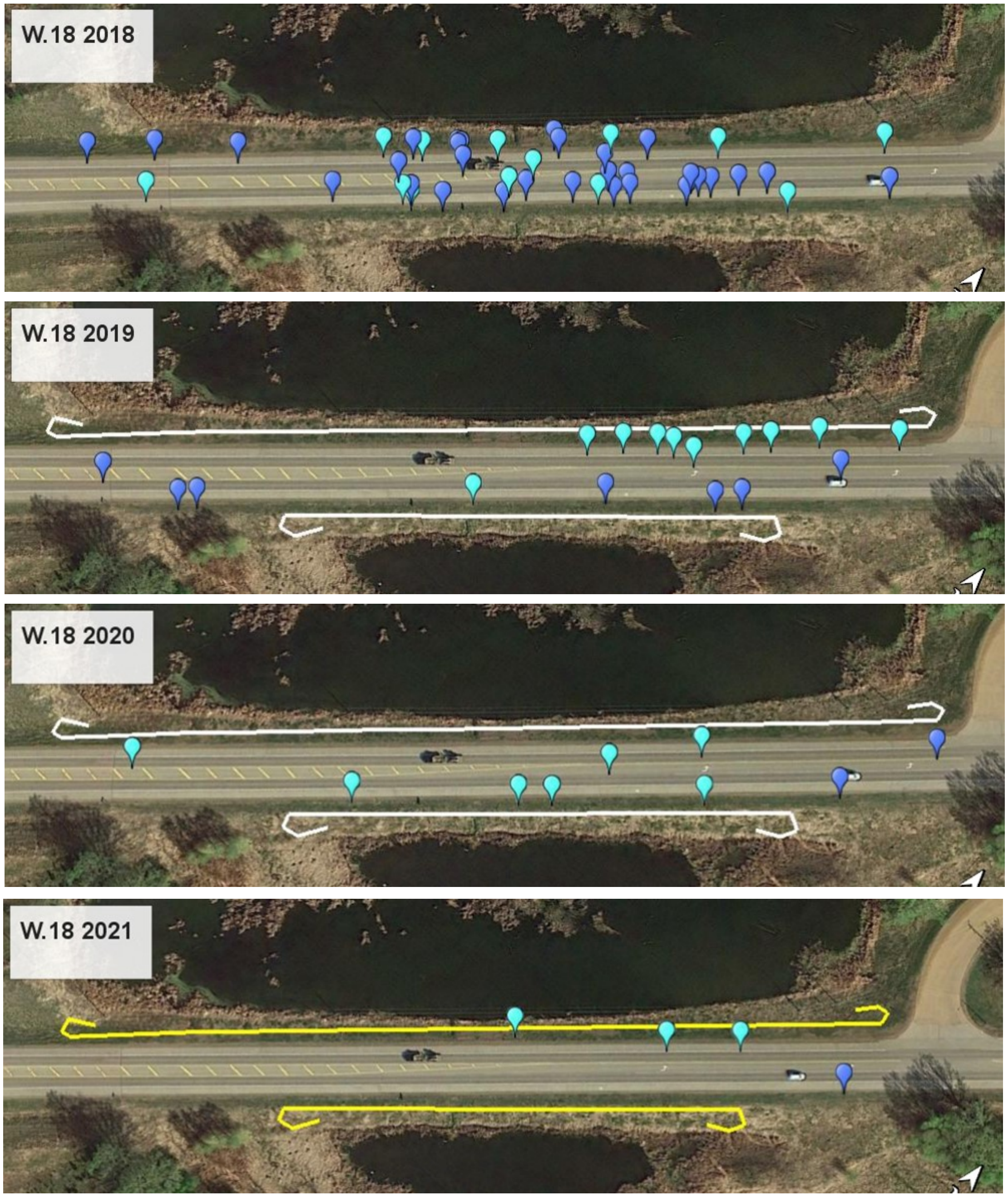

Figure 5. Turtle mortality data by age class (Dark blue = Adults, Light blue = Juveniles) at fence treatment site W.18 in Waconia during a.) 2018 (pre-treatment) b.) 2019 (chain link fence year 1) c.) 2020 (chain link fence year 2) d.) after 1/2-inch hardware cloth installation. We defined juveniles as turtles < ~2 inches in width (i.e., able to fit through the original fence mesh before hardware cloth installation).

Table 8. Modeling results from analyses evaluating effectiveness of small animal exclusion fencing using data collected after installation of standard chain-link fencing in comparison to data collected after installation of hardware cloth retrofit.

All Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	0.4935	0.1668	2.958	0.0031
Treatment	0.5759	0.4984	1.156	0.248
Period*Treatment	-1.4217	0.2185	-6.505	<0.0001
Adult Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	0.4291	0.1409	3.045	0.0023
Treatment	-0.3550	0.6178	-0.575	0.566
Period*Treatment	-1.0911	0.3028	-3.603	0.0003
Juvenile Turtles				
Parameter	**Estimate**	**Std. Error**	**Z value**	**P-value**
Period	1.6065	0.6083	2.641	0.0082
Treatment	2.2145	0.5453	4.061	<0.0001
Period*Treatment	-2.0767	0.3615	-5.744	<0.0001

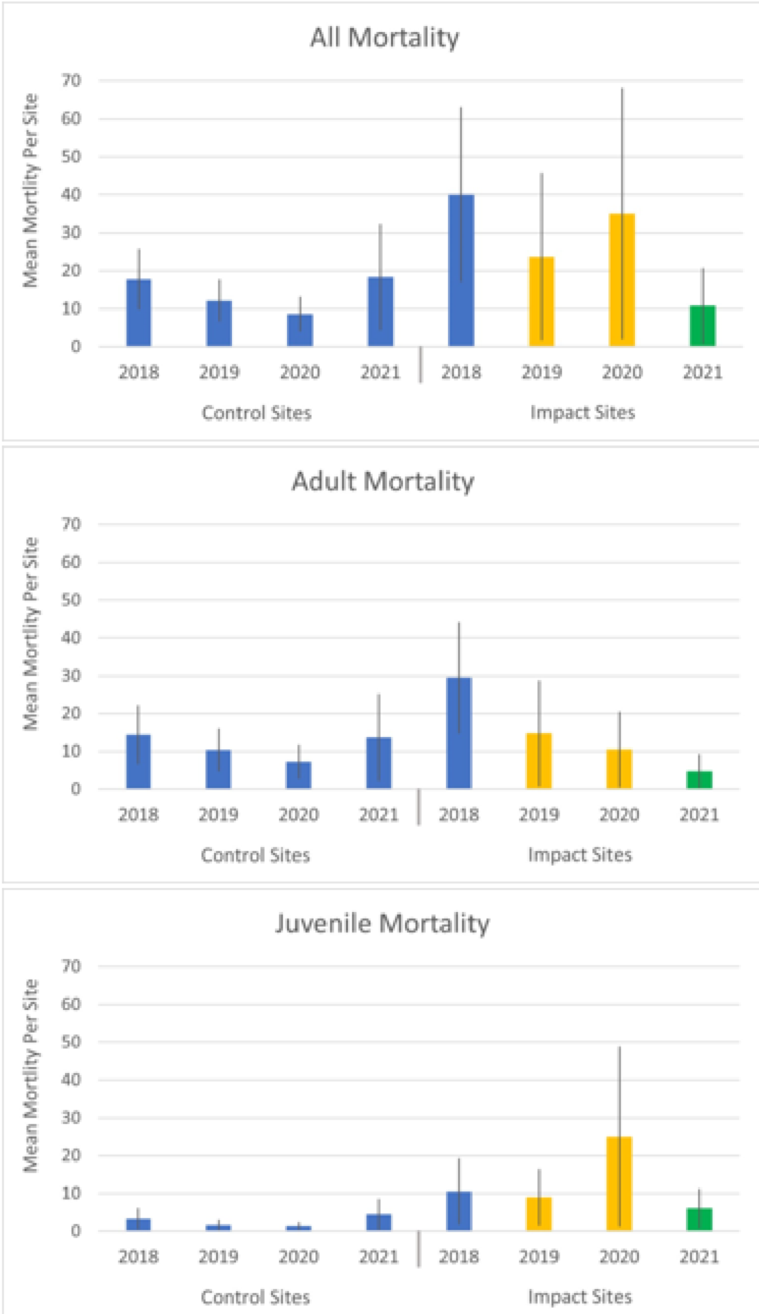

Figure 6. Mean turtle mortality per site by year and treatment (Control versus Impact) for each size class: All Turtles (top), Adults (middle), and Juveniles (bottom). Blue indicates no treatment, orange is chain-link fencing, and green is fine mesh retrofit. Error bars represent standard error about the mean. Note that mortality data for site N.5 is included in 'Impact' for 2019 although fencing was not installed there until late in the season.

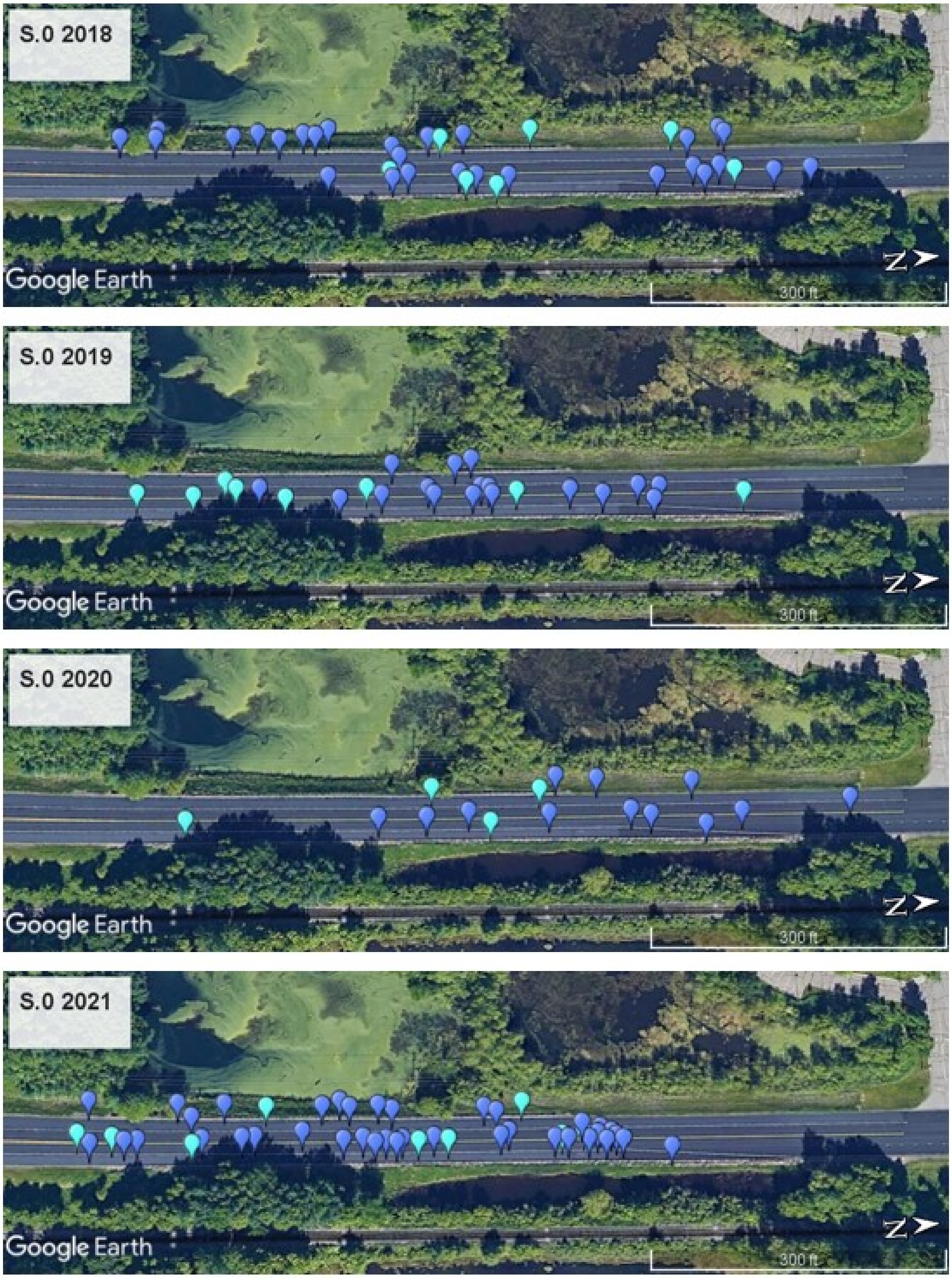

Figure 7. Turtle mortality data by age class (Dark blue = Adults, Light blue = Juveniles) at Control site S.0 in Eagan during 2018 (n= 35), 2019 (n=26), 2020 (n=15), and 2021 (n= 47).

3.2 SEASONAL TURTLE MOVEMENT

We also investigated seasonal movements of turtles (Figure 8). We documented an increase in turtle activity in late spring and again in the early fall. In addition, there were some slight differences in movements between painted turtles and snapping turtles, with painted turtles more active in the mid-summer months and snapping turtles most active during spring and late summer.

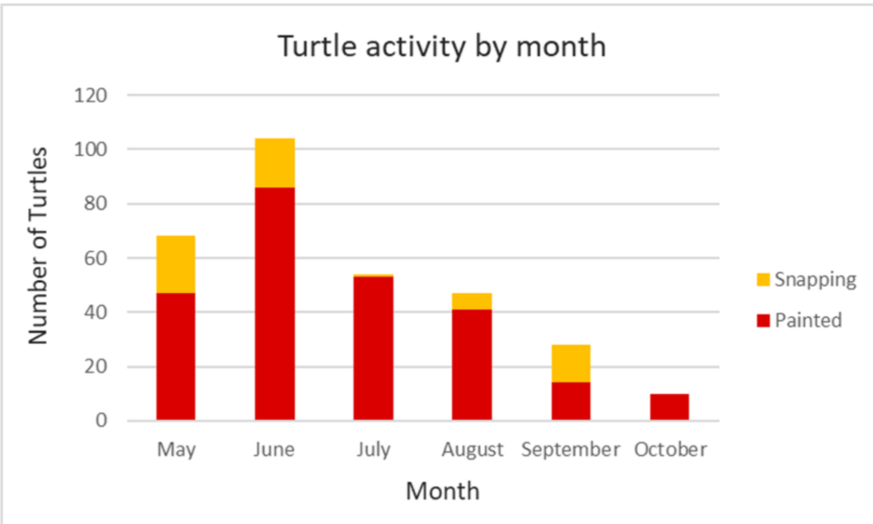

Figure 8. Seasonal activity of all identifiable turtles, including both dead and live individuals in baseline year 2018. Figure reflects total number of turtles by species: painted turtles (n= 312) and snapping turtles (n=60).

3.3 CAMERA TRAPPING

We identified 13 instances of painted and snapping turtles being directed back to wetlands by the j-hook end treatments with camera trapping data (Figure 9). There were no obvious instances of turtles circumnavigating the end treatments. At Sites W.18 and N.5, where cameras were installed in 2019 and 2020, we documented 12 events in which turtles appeared to use existing culverts to cross under the roadway. Many other small animals also were observed using the culverts as a passage, including raccoons, beavers, otters, ducks, geese, and mink (Figure 10).

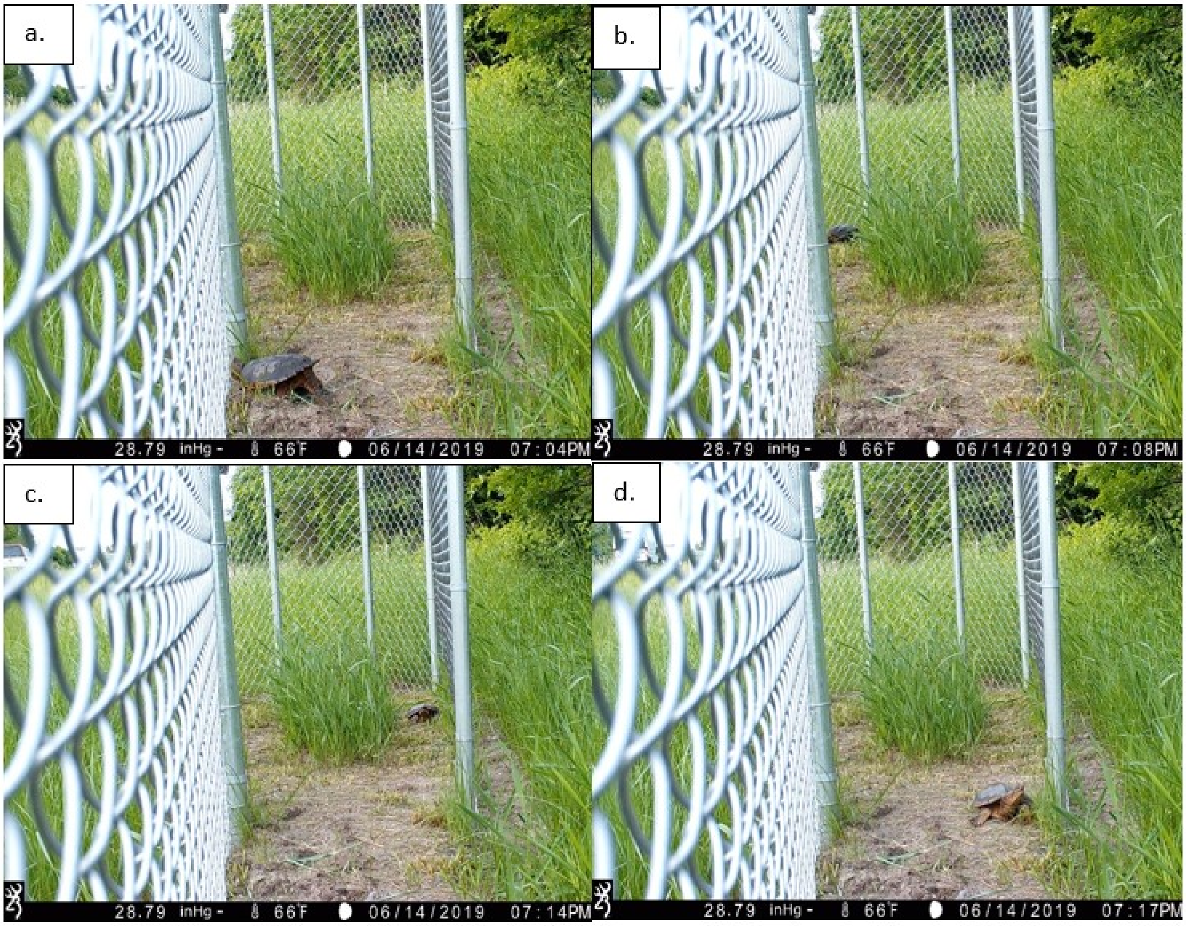

Figure 9. Time lapse images of snapping turtle turning around and returning to wetland due to fence end treatment at Site N.5 during 2019.

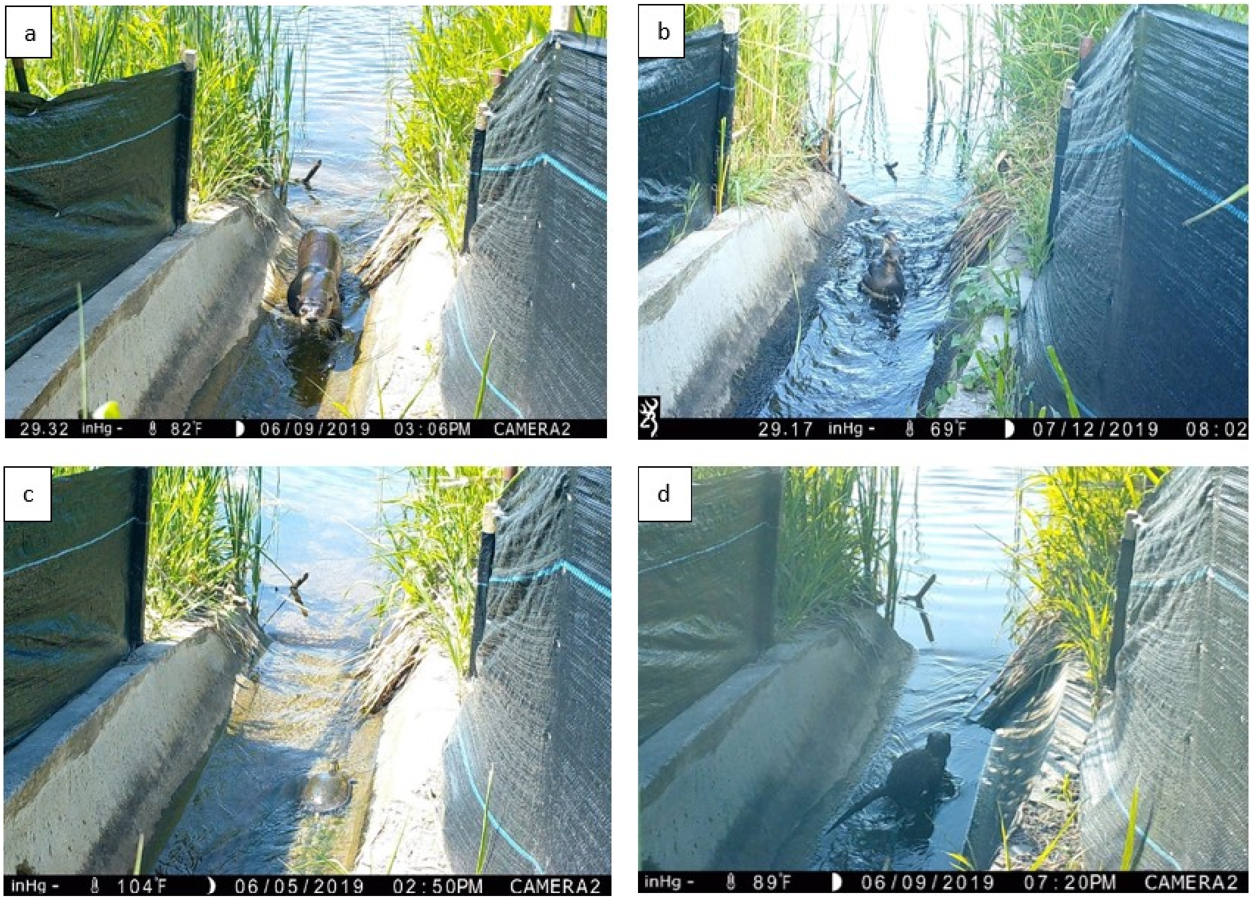

Figure 10. Examples of wildlife use of culvert at site W.18 in 2019 included a.) otter, b.) ducks, c.) painted turtle, and d.) mink.

CHAPTER 4: DISCUSSION

Mortality of small animals on Minnesota roadways presents a public safety concern and may threaten the persistence of local wildlife populations. Populations of turtles, in particular, struggle with such additive mortality due to their unique life histories and movement patterns. For the past 4 years, the Minnesota Zoo has partnered with the Minnesota Department of Transportation to test and evaluate the effectiveness of standard plans for small animal exclusion fencing, with the goal of redirecting turtles and small wildlife away from roadways and to existing through-road infrastructure (i.e., culverts) where practicable.

4.1 EFFECTIVENESS OF FENCES IN REDUCING TURTLE ROAD MORTALITY

We implemented a before-after-control-impact study design and initially assessed the utility of chain-link fencing in mitigating mortality of turtles on Minnesota's roads. We documented a reduction in presence of turtles on roads after fences were installed at both treatment and control sites. However, modeling did not yield a statistically significant interaction between period and treatment, meaning that the observed decline in mortality at treatment sites was not significantly different than the decline documented at control sites. We believe that the study-wide decline in mortality following the installation of fences may be a product of other factors. Specifically, we hypothesized that environmental conditions may have differed in the years post-fence installation, thereby impacting the movements of turtles. For example, 2019 was a particularly wet year; the heavy rains filled ponds and wetlands, providing ideal conditions for summer foraging in aquatic habitats. Turtles may have been less compelled to search for suitable habitat and thus were less likely to encounter roadways. Furthermore, traffic volume may impact road mortality (Lin, 2016), and the 15-20% reduction in traffic volume during spring and summer of 2020 stemming from the covid-19 pandemic (MnDOT Traffic Reports, 2020 to present) likely contributed to some of the observed declines in road mortality that year. Further analysis will be needed to better understand the relationship between traffic volume and observed mortality.

Anecdotal observations led us to hypothesize that the effectiveness of chain-link fencing in preventing movements across roadways differed by turtle size classes. Our analyses supported this hypothesis: standard chain-link fencing effectively reduced the mortality of adult and large sub-adult turtles but was ineffective for hatchling and smaller juvenile turtles. In fact, we documented significantly more juvenile turtles on roads at treatment (impact) sites after fence installation, compared to the control sites. Many dead juvenile turtles were observed near the midpoint of fences, and their sizes suggested that they were simply passing right through the 2-inch openings, rather than navigating around the j-hook end treatments. The large majority of these individuals were hatchling turtles. This finding was especially evident at site S.4 where we observed more hatchling snapping turtles in 2020 than 2018 and 2019 combined (Table 4). We hypothesized that this increase in the mortality of juvenile and hatchling turtles at fenced sites post-installation — a pattern driven primarily by higher mortality at those sites in 2020 — may have stemmed from the fact that fencing effectively protected the adult turtle population from road mortality for two nesting seasons (i.e., 2019 and 2020). This, in turn, yielded a greater number of mature females to lay eggs, resulting in a hatchling boom in 2020. The statistically significant interaction term (albeit in an unanticipated direction) indicated that this finding was unique to the treatment sites and thus was not simply attributable to other (e.g., environmental) factors. At site N.5 near Scandia, mortality of juvenile turtles also remained high at least partially because of a sudden pond drying event in the early spring that displaced many individuals. Unfortunately, unless the youngest turtles were also prevented from accessing roadways, then population-level benefits were essentially negated. Following the installation of the finer (1/2 inch) mesh in 2021, we documented a significant decrease in mortality for all age classes at the fenced sites (i.e., the statistically significant interaction between period and treatment), indicating that the fence retrofitted with the fine mesh effectively reduced the movements of turtles across roadways.

4.2 EVIDENCE SUPPORTING THE EFFICACY OF END TREATMENTS AND FENCE HEIGHT

The j-hook wrap-around end treatments also appeared to work as intended in keeping turtles off roadways. With standard, straight-line fence ends, clusters of mortality often were observed near the fence end as animals navigated along the fences and then entered the roadway (Markle et al., 2017; Clevenger et al., 2001). We did not observe any mortality clusters at the fence ends at our treatment sites, and mortality numbers beyond the fence ends were consistent with pre-treatment data. These findings suggested that wrap-around fence ends effectively reduced movements of turtles across roadways and redirected them back to wetlands. In addition, we have documented 13 instances (via camera trapping) of painted and snapping turtles being turned around by end treatments. We are continuing to review hundreds of hours of time-lapse footage, but to date, we have not observed any turtles circumnavigating around the end treatments. Although some turtles likely can navigate around the end treatments, mortality observed near the fence ends was more likely due to turtles that did not encounter the fence, as such observations typically occurred several meters beyond the end of the fence. In addition, there was anecdotal photo evidence that the end treatments also could have been effective at redirecting other small wildlife, particularly waterfowl (e.g., ducks and geese with their young).

The standard 6-foot height of the chain-link fence also appeared to function well in reducing movements of turtles across roads. Snapping turtles have been recognized as good climbers — indeed, there are reports of adult snapping turtles scaling chain-link fences (Langen, 2011) — but we did not observe snapping turtles scaling fences in this study. We believe that the few adult turtles that were documented in the area between fences likely entered the roadway beyond the fence ends or successfully navigated the fence ends and then moved onto and along the road. Fence damage, as occurred mid-summer at Site S.4, also permitted a small number (n=3) of turtles to enter the roadway. We also note that turtle remains can be moved by scavengers and further scattered by subsequent vehicle strikes. However, after the fine mesh was retrofitted to chain-link fences, we observed a small number of hatchling snapping turtles (n=5) on the roadway near the mid-point of some fences. In these instances, we believe that turtles successfully climbed the 2-foot tall fine mesh and passed through the wider mesh above. Although other studies implemented overhangs to deter climbing by small animals (Langen, 2011), the relatively small number of these occurrences suggested that this problem was not widespread and thus further mitigation is not necessarily warranted.

4.3 CULVERT USE AND HABITAT CONNECTIVITY

The final fence design — incorporating wrap-around end treatments and fine mesh — effectively decreases the movements of turtles across roadways and thus reduces road mortality and improves public safety. However, we note that connectivity among sites bisected by roadways is critical to maintain healthy populations, and considerations remain for how to assist turtles and other small animals with safe passage across roadways. For example, habitat fragmentation and lack of connectivity can lead to a loss of genetic diversity over time and put smaller populations at risk of extirpation (Holderegger & Di Giulio, 2010; Laporte et al., 2013; Laurance & Balmford, 2013). Fortunately, underpass structures such as culverts can enable movements and reconnect habitats when spaced and sized appropriately. Simple modifications to existing structures such as removing grates, creating ramps, and improving lighting around entrances may promote use by wildlife (Zani, 2017; Heaven et al., 2019; Read &Thompson, 2021). We suggest that evaluating a standard design for box culverts as wildlife passages is a logical next step. Various wildlife, including painted, snapping, and Blanding's turtles, readily use culverts as underpasses when certain criteria such as natural lighting (high openness ratio), natural substrate (especially for amphibians), and appropriate length are met (Lang, 2000; Woltz et al., 2008; Heaven et. al., 2019). Additionally, although turtles will travel through wet or dry passageways, they will not use those that are filled with water (Read & Thompson, 2021). In general, our data suggest that hotspots for turtle crossing are found in locations where water comes closest to the road; we suggest that these sites can be targeted for future road underpass installations and improvements. Incorporating passageways with fencing or another barrier is critical for successful conservation.

At sites W.18 and N.5, camera traps provide evidence that turtles and many other small animals (e.g., raccoons, otters, mink, ducks) are using culverts at sites where they already exist and perhaps are further encouraged to do so after fence installation. However, there is not a culvert or other crossing structure at site S.4, although our mortality data suggest there is a need to restore connectivity there. We hypothesize that turtles at this site travel from wetlands to the east of the road and regularly nest on the slope inside the eastern fence. Hatchlings then attempt to cross the road to get to the closest waterbody (i.e., the western side of the road), but the retrofitted fence now prevents them from doing so. A wildlife underpass at this site would improve connectivity for turtles and other small wildlife.

Another potential solution for sites with connectivity challenges if the spatial distribution of the habitats suggests beneficial outcomes is to create desirable nesting areas on the inside of the fence, since many of the turtles killed on roadways are females searching for nesting sites (Buhlmann & Osborn, 2011; Crawford et al. 2017; Heaven et al. 2019).

4.4 STRUCTURAL INTEGRITY OF FENCES

The original chain-link fences installed in 2019 remain in good condition. We have not observed gaps under the fence due to erosion or animal digging, indicating that the 10–12-inch trenching and backfill is sufficient and working as expected. Fences also maintained their overall structural integrity; we did not observe heaving from the freeze — thaw cycles or other displacement since installation, and the chain-link material remains tight and in place. Likewise, the fine mesh retrofitted to the chain-link fence remains functionally sound and securely attached through the first year post-installation.

However, we documented 3 instances during the study (1 event at each of sites W.18, S.4 and N.5) in which vehicles left the road and ran into fences. Damage was not extensive but did create temporary gaps in fences that required repair by appropriate MnDOT staff or contractors. The damage at site S.4 occurred mid-summer during the data collection season; prior to repair, 3 adult turtles were believed to have accessed the road through the opening. The fourth fence site W.17 was protected by an existing guardrail and less likely to be damaged.

4.5 OTHER FACTORS IMPACTING THE EFFICACY OF FENCES

Certain landscape features may reduce the effectiveness of fences by limiting the footprint of the installation. In particular, driveways and intersections are common features even in rural areas and present obstacles to continuous, unbroken fence lines. For example, at site N.5, a driveway mid-site on the south side of the site appeared to funnel turtles onto the roadway and was a hotspot for turtle mortality. Existing utilities also may impact fence placement. We note that every break in a fence line offers turtles and other small wildlife an opportunity to access the road, even when turn-arounds are installed on fence ends. Additional end treatments also increase fencing costs for materials and installation. While such obstacles cannot be avoided, additional modification at the end treatments could help to alleviate the problem (Markle et al., 2017; Heaven et al., 2019).

4.6 ASSOCIATED COSTS AND BENEFITS

Road safety is a critical component of highway planning efforts. Wildlife can pose a significant threat on roadways, and driver avoidance of or direct collisions with small animals may result in substantial damage or injury, particularly for motorcyclists and bicyclists. In addition to improving safety for motorists and pedestrians, benefits of this work include increased efficiencies in resource use (which will yield cost savings) and reduced mortality of imperiled turtles and other wildlife on Minnesota's roadways. Furthermore, the development and adoption of a vetted standard plan will save design and planning costs in the future when roadside exclusion fencing is implemented at other key sites with high volume animal crossing. Multiple years of data at test sites improve our understanding of how effective fencing will be at reducing mortality as well as how well it will hold up over time and what costs and labor can be anticipated with long-term maintenance as well. Testing and using readily available off-the-shelf materials will reduce costs and facilitate fence repair when needed.

Installation costs of fences were higher than originally anticipated, limiting the total length of fencing that could be installed and impacting those sites that were ultimately selected. Specifically, 2 shorter sites were selected for fencing rather than the much longer site W.13 (near the Minnesota Landscape Arboretum; monitoring there stopped in 2019) due to financial constraints. Site W.13 was the longest site initially identified for treatment during our semi-randomized selection process, but its inclusion as a treatment was not possible because of installation costs. We note that although this site was not fenced as part of this study, we documented very high rates of mortality of turtles and other wildlife during 2018 and suggest it as a strong candidate for future mitigation.

4.7 CONSIDERATIONS FOR IMPERILED TURTLES

Mitigating road mortality of all wildlife to address public safety and conservation needs is important, but fencing applications may be particularly beneficial in areas frequented by at-risk wildlife. For Minnesota's two species of threatened turtles, the Blanding's turtle and wood turtle, reducing additive mortality and creating safe passage under roadways will benefit the recovery of depleted populations. Both species also are undergoing status assessments to inform potential listings under the federal Endangered Species Act. A proactive approach in evaluating and implementing measures to reduce road mortality now may help MnDOT and other agencies reduce costs and construction delays in the future, in the event that these species are categorized as Threatened or Endangered at the federal level. We did not find evidence of Blanding's turtle mortality at these study sites, but they are known to occur near treatment sites N.5 and S.4.

In addition to turtles, we collected road mortality data a variety of other taxa including mammals, birds, snakes, amphibians and invertebrates including monarch butterflies and bumble bees. Although it is outside the scope of this project to analyze these data at this time, anecdotal data suggest that fencing may reduce road mortality in some other small animals as well.

CHAPTER 5: CONCLUSION

With this project, we sought to evaluate the effectiveness of a standard plan for small animal exclusion fencing and identify recommendations to best meet safety, economic, and environmental objectives. Few projects have focused efforts on mitigating the mortality of small animals on roadways, and even fewer have formally evaluated mitigation measures to determine effectiveness. This study also was unique in the large number of site replications over both spatial and temporal scales. With a barrier design that included trenching and wrap-around end treatments, we found that chain-link fencing maintains its structural integrity over time and is effective in reducing mortality of adult turtles on roadways. During the first two years post-installation, overall turtle mortality was reduced by an average of ~50% across the four treatment sites. However, standard chain-link fence did not reduce the mortality of juvenile and hatchling turtles and thus did not yield the targeted results for turtle populations as a whole. We documented a substantial reduction in the mortality of all age classes following the retrofitting of fences with ½-inch wire mesh with overall reductions up to 91% over pre-treatment, thereby demonstrating its utility as an effective and cost-efficient mitigation strategy. The wrap-around end treatments worked as intended; we did not observe clusters of mortality at the fence ends, and camera traps documented several instances of turtles being redirected to the wetlands from which they came. Cameras also provided evidence of turtles and other small animals using existing culverts. Indeed, when combined with an effective barrier, simple wildlife underpasses can ensure safe passage under roadways and improve habitat connectivity for wildlife. A vetted standard plan for wildlife barriers will streamline implementation in the future and reduce costs associated with developing new and custom designs. Effective barriers will aid populations of both common and threatened wildlife and yield public safety and economic benefits by reducing the number of vehicle collisions.

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