

M. L. 2018 Project Abstract

For the Period Ending June 30, 2022

PROJECT TITLE: Conserving Minnesota's Nine Species of Freshwater Turtles

PROJECT MANAGER: Seth Stapleton

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FUNDING SOURCE: Environment and Natural Resources Trust Fund

LEGAL CITATION: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03k as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

APPROPRIATION AMOUNT: \$300,000

AMOUNT SPENT: \$280,716

AMOUNT REMAINING: \$19,284

Sound bite of Project Outcomes and Results

The Minnesota Zoo conducted research and implemented conservation actions including nest site protection and head-starting to bolster wood turtle populations. We studied methods to mitigate road mortality of turtles, with results suggesting that simple tube barriers may be effective. Our outreach efforts raised awareness and encouraged action to benefit conservation.

Overall Project Outcome and Results

Native turtles are a key component of diverse, healthy, and resilient aquatic ecosystems, inspiring connections to nature for children and adults alike. However, populations of turtles in Minnesota face numerous threats, including habitat loss and degradation, high predation of incubating nests, and mortality on roadways. With this project, the Minnesota Zoo sought to improve the conservation of turtles by 1) collecting data to quantify two key threats – road mortality and nest predation – and implement and evaluate mechanisms to mitigate these threats; and 2) building public awareness by developing educational and outreach materials for use during on- and off-site programming.

We outfitted imperiled wood turtles with radio and GPS transmitters, improving our understanding of their habitat needs and allowing us to identify and protect nesting sites. We reared hatchling wood turtles in captivity for their first year of life to improve their chances of survival in the wild and bolster depleted populations while other threats are addressed. To date, we have successfully released 68 one-year-old wood turtles back to the wild.

We also investigated strategies to mitigate mortality of turtles on Minnesota's roadways via cost-effective mechanisms including wildlife warning signs and small barriers. Although warning signs did not significantly reduce turtle mortality, corrugated pipe barriers were promising and yielded a decline in mortality of ~50%.

Finally, a variety of materials, including interpretive signage, a 3-dimensional snapping turtle model, and a children's book, were created to support educational and outreach programming and inspire public action to benefit the conservation of turtles. Healthy populations of turtles are an integral component of aquatic systems, and we anticipate that our results will inform effective management strategies that can benefit conservation at sites state-wide.

Project Results Use and Dissemination

Sharing information about the importance of turtles and their conservation was a key objective of this project. The Minnesota Zoo used a variety of platforms to disseminate significant findings and engage the general public in the conservation of Minnesota's aquatic resources, ranging from informal talks, public lectures and tabling events to media spotlights and distributing content on our social media channels. Media highlights include features on PBS's *Prairie Sportsman*, Kare 11's *Minnesota Bound*, a Minnesota Lottery commercial, and a variety of other print and television media outlets. This professionally-produced [video](#) highlights the ecology and conservation of turtles in Minnesota.



Environment and Natural Resources Trust Fund (ENRTF)

M.L. 2018 ENRTF Work Plan Final Report (Main Document)

Today's Date: August 15, 2022

Final Report

Date of Work Plan Approval: June 5, 2018

Project Completion Date: June 30, 2022

PROJECT TITLE: Conserving Minnesota's Nine Species of Freshwater Turtles

Project Manager: Seth Stapleton

Organization: Minnesota Zoo

College/Department/Division: Conservation Department

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Location: Dakota County /statewide

Total ENRTF Project Budget:

ENRTF Appropriation: \$300,000

Amount Spent: \$280,716

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Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03k as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

Appropriation Language: \$300,000 the second year is from the trust fund to the Minnesota Zoological Garden to improve the long-term viability of Minnesota's imperiled turtle populations by researching threats, identifying mitigation strategies, implementing mechanisms to reduce threats and mortality, and creating related outreach and educational materials. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18. ENVIRONMENT AND NATURAL RESOURCES TRUST FUND EXTENSIONS. [to June 30, 2022]

I. PROJECT STATEMENT:

With its vast network of lakes and waterways, Minnesota is home to an abundance of aquatic and semi-aquatic wildlife, including nine species of native freshwater turtles. Turtles are a key component of diverse, healthy, and resilient aquatic ecosystems, often functioning as an indicator species that reflect broader environmental conditions. Turtles also inspire connections to nature for children and adults alike.

Minnesota's turtles, however, face numerous threats during different life stages, including habitat loss and degradation, collection for the pet trade, high predation of incubating nests, and mortality of juveniles and adults on Minnesota's roadways. These issues threaten the long-term viability of some populations, and as a result, two species – the Blanding's turtle and the wood turtle – are now listed as threatened in the State and globally endangered.

With the support of ENRTF, the Minnesota Zoo will work to improve the long-term viability of turtle populations in Minnesota. We will expand our current partnership with Minnesota Department of Transportation (MnDOT) and Department of Natural Resources (DNR) to quantify two of the primary threats facing imperiled turtles and implement and evaluate mechanisms to mitigate these threats. The Zoo will also use its large visitor-ship and its expertise in education and outreach programming to promote public awareness of turtle conservation and encourage individual actions that benefit healthy and biodiverse aquatic systems. We anticipate that local and state management authorities will be able to use the results of this project to devise and implement effective management strategies that can benefit conservation of turtles at sites state-wide.

The specific objectives for this project are:

- 1) To collect foundational data that characterizes two key threats – road mortality and nest predation – currently facing Blanding's turtles, wood turtles, and other Minnesota species;
- 2) To implement and evaluate at least 3 mechanisms to improve the conservation of imperiled turtles, including cost-effective measures to reduce mortality on roadways and strategies to improve hatching success;
- 3) To develop educational and outreach materials and use on- and off-site programming as vehicles to share key conservation messages to >1 million annual visitors at the Zoo and beyond.

II. OVERALL PROJECT STATUS UPDATES:

First Update January 31, 2019

The Minnesota Zoo's freshwater turtle conservation initiative, supported by the Environment and Natural Resources Trust Fund, completed a successful initial field season. Dr. Tricia Markle was hired to conduct research and outreach activities and began her full-time position during July, 2019. We vetted and selected 17 sites from across the greater metropolitan region and collected foundational data quantifying road mortality during summer and early fall, 2018. We documented high rates of turtle mortality at several sites and will be installing and testing mitigation treatments beginning this spring. We also outfitted 8 wood turtles across 5 sites in southeastern Minnesota with GPS transmitters to document their movements, spatial ecology and habitat use. We are currently analyzing locality data to evaluate potential nesting sites at which predator exclusion fencing may be most effective in protecting turtle eggs.

Zoo staff also have worked to disseminate information on turtle ecology and their conservation both at the Zoo and off-site. We are in the process of developing education and outreach materials, and we are working with other departments to further raise public awareness of turtle conservation by creating on-site displays and social media resources. We have participated in multiple speaking engagements and are expanding our turtle conservation partnerships.

Second Update June 30, 2019

The Zoo's Conservation staff have continued to successfully implement our freshwater turtle conservation initiative over the past 5 months. During May, we resumed monitoring at sites around the greater metro region as part of a study designed to quantify rates of turtle mortality on Minnesota's roads and explore cost-effective alternatives for mitigation. At 3 sites, we installed temporary turtle crossing signs, which will remain in place during the period of peak turtle activity (May – July) to evaluate their efficacy in reducing mortality. We are investigating additional strategies that may be implemented in 2020 to mitigate mortality.

In partnership with the Department of Natural Resources, we are continuing to track wood turtles to inform management and conservation efforts. During May and June, we deployed GPS transmitters on 10 adult wood turtles to quantify habitat use and identify nesting sites. We constructed electrified fencing at 2 prospective nesting sites this spring to evaluate its effectiveness in reducing predation and improving recruitment.

Zoo staff also developed several outreach materials during the winter months, including creating a coloring and fact sheet about wood turtles, printing Blanding's turtle stickers to complement this handout, and devising a hands-on activity to raise awareness about turtles. We are partnering with departments across the Zoo to develop on-site signage, a public awareness video, and a 3-dimensional model for use with outreach programming. We are assisting the Zoo's Education staff with an initiative tracking wild turtles on-site, offering a unique, hands-on citizen science initiative, and we continued to disseminate information about turtle conservation through public talks and events, email blasts to Zoo members, and other outlets.

Third Update January 31, 2020

We completed the second full field season of the Minnesota Zoo's freshwater turtle initiative in mid-October, 2019. We conducted road mortality surveys at 15 sites across the greater metro region during 2019, with mitigation treatments (temporary turtle crossing signs) installed at 3 sites in Washington County. Additional data collection in 2020 will provide two complete seasons of before – after data to analyze the effectiveness of road signs in reducing mortality of turtles and other small wildlife. The Zoo is exploring options with Dakota and Hennepin Counties for deploying additional mitigation strategies (such as road paint and / or dynamic traffic signs) at sites in spring, 2020.

In close collaboration with the DNR, Zoo staff continued researching wood turtle populations and implemented conservation actions in southeastern Minnesota. Through summer and fall, 2019, we tracked 19 turtles over three sites with GPS and VHF transmitters. Data are being used to quantify movements, habitat use, potential threats, and locations of nesting sites, all of which are critical in developing management strategies for this species. At two nesting sites, we constructed predator exclusion electric fencing; we maintained and monitored these fences through summer, 2019. Two wood turtles nested within the fenced enclosure at one of these sites, and hatchlings were observed there in late summer. This is a significant development for this population, which is believed to have high nest predation and very low levels of recruitment. During analysis of GPS data from wood turtles tracked during 2017 – 2019, we identified new potential nesting sites and plan to expand nest protection measures in 2020.

Zoo staff continue to share information about Minnesota's turtle populations, the threats they face, how the Zoo, DNR and other partners are working to improve turtle conservation in the state, and what the general public can do to help. News clips, social media posts, and public talks continue to provide a platform for us to tell the story of turtle conservation efforts in Minnesota, while Zoo Conservation and Education staff connect directly with various groups both on- and off-site. We are developing new materials, including an interpretive sign that will be installed at the Zoo this spring, and we have disseminated hundreds of copies of the children's book "A Turtle's Dangerous Journey."

Amendment Request January 31, 2020

We are requesting that funds be shifted within budget category Equipment/Tools/Supplies from the predator exclusion fencing line to the GPS transmitter line (both within Activity 2).

- Predator exclusion fencing line would be reduced by \$8,500 to a revised budget of \$11,775.
- GPS transmitter budget would increase by \$8,500 to a revised budget of \$22,500.

Supplies associated with predator exclusion fencing are significantly less than anticipated, and we are requesting to reallocate some of that funding to purchase additional GPS transmitters to track wood turtles at our study sites. These transmitters have proven critical to identifying specific nesting sites so that we are able to 1) construct the predator exclusion fences in the best possible locations and 2) monitor the individual nests to evaluate predation and hatching success. We used all funding in the current ENRTF budget for GPS transmitters deployed during 2018 and 2019. Deploying additional transmitters during 2020 will be very valuable to evaluating the effectiveness of the fencing and improving wood turtle conservation in the state.

Amendment Approved by LCCMR 2/8/2020

Fourth Update June 30, 2020

The COVID-19 pandemic presented challenges to project implementation over the past several months. Essential fieldwork generally has proceeded as planned, but most outreach and educational activities were cancelled or postponed. We initiated road mortality research during the first week of May. We are monitoring 12 sites during 2020, including 4 sites with temporary “turtle crossing” signs designed to raise driver awareness and 1 site with an 8-inch pipe barrier that we are evaluating as a means to reduce attempted road crossings; the remainder serve as reference (control) sites. We are not collecting data from 3 sites in Dakota County that were monitored in previous years, as the county is planning a major road reconstruction at these sites beginning this summer.

We continued tracking wood turtles outfitted with VHF transmitters through the winter months. In partnership with the Minnesota DNR, we deployed GPS and VHF transmitters on more than 20 adult and juvenile wood turtles in May, including 15 adult turtles outfitted with GPS devices for fine scale monitoring of habitat use. In mid-June, DNR and Zoo staff monitored nesting turtles for several nights and protected 8 wood turtle nests. Eggs from some nests were returned to the Zoo for incubation to safeguard against predation and other potential threats (e.g., inundation due to heavy rain). A subset of hatchlings will be reared at the Zoo during their first year and released next summer. From eggs incubated in 2019, 13 wood turtles were reared at the Zoo over the winter and released back to the site at the end of June, 2020. We also installed predator exclusion fences at 2 sites to further protect nests and inform our assessment of fencing efficacy.

Finally, numerous outreach activities and the development of educational materials were postponed due to COVID-19, including production of a video highlighting turtle conservation in Minnesota, creation of a 3D turtle model, and implementation of an on-site citizen science initiative. Zoo staff continue to share key messages about turtle ecology and conservation via social media and online platforms.

Fifth Update January 31, 2021

We completed the project’s third field season during October 2020. Despite continued challenges stemming from the Covid-19 pandemic, we collected field data as planned throughout the year. For the road mortality study, we conducted surveys at 12 sites around the greater metro region. Mitigation treatments were installed at 5 sites, including 4 sites with temporary turtle crossing signs and 1 site with a small barrier comprised of corrugated pipe. We now have collected a full season of data before and after installation of mitigation treatments. Preliminary data suggest mixed results for the warning signs, but the pipe barrier results are promising.

We continued tracking wood turtles during summer – fall, 2020, including 22 adults and 4 juveniles outfitted with GPS or VHF transmitters. Unfortunately, an adult female was killed by farming equipment in July, and 2 other adult turtles later went missing in the same area, presumed to have been killed during by agricultural activities. These losses highlight some of the human-induced threats facing wood turtles. We maintained predator exclusion electric fencing at 2 nesting sites through the summer, and in partnership with the DNR, we confirmed 8 wood turtle nests at 2 of 4 study areas. A subset of eggs from these nests was returned to the Zoo for incubation and head-starting; 35 of these 38 eggs hatched. Fifteen hatchlings were released near the nesting sites in mid-September, and we are rearing the remaining 20 individuals at the Zoo as a continuation of our head-starting initiative. We found evidence of successful hatching at 2 remaining protected nests.

Outreach efforts continued to be hampered by the Covid-19 pandemic. A large inflatable Blanding's Turtle was featured at "Nature Illuminated," the Zoo's winter drive-through event, and we highlighted turtle conservation efforts through social media channels. Additional accomplishments included the completion of a durable, 3-dimensional snapping turtle model for use during outreach activities and the near-completion of a short film highlighting Minnesota's turtles and our efforts to conserve them.

Project extended to June 30, 2022 by LCCMR 6/30/21 as a result of M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18, legislative extension criteria being met.

Sixth Update June 30, 2021

The project's fourth field season began in May 2021. Although we completed most road mortality data collection last year, we are continuing to monitor one site outfitted a corrugated pipe barrier (and a corresponding control site) to further inform the utility of pipe as a potential road mortality mitigation measure. We also are collecting another year of data from several sites in Dakota County in anticipation of a road reconstruction project that will begin later this year. This project is near the Zoo and will include wildlife underpasses that may be monitored by Minnesota Zoo and Dakota County Park staff in the future.

The Zoo's wood turtle conservation efforts are continuing to demonstrate success. In partnership with the DNR, we are currently tracking ~30 wood turtles outfitted with VHF and GPS transmitters in southeastern Minnesota, including 6 new adults added to the sample this spring, 5 of which are mature females. During June, Zoo and DNR staff collected 68 wood turtle eggs that are being incubated at the Zoo. Additional eggs are incubating with the DNR, and we protected one additional nest *in situ*. A subset of these hatchlings will be reared at the Zoo for the coming year as part of our collaborative head-starting program. Twenty head-start wood turtles collected as eggs last year and reared at the Zoo for the past 11 months were released back to their natal sites earlier in June.

Education and outreach efforts continue to be significantly impacted by the COVID-19 pandemic: school groups and summer camps have not yet returned in-person to the Zoo, and many other educational activities related to turtle conservation remain on hold. However, the Zoo has continued to provide important conservation messaging to the public via other mechanisms. Our short film on Minnesota's turtles and the ongoing work to conserve this important natural resource is complete and is being shared online and on Zoo site. Recent media coverage includes a piece on WCCO-TV, articles in the Star Tribune and Dakota County Tribune, and filming for an upcoming PBS show.

Seventh Update January 31, 2022

A one-year extension to our timeline (resulting from the pandemic) enabled us to complete an additional season of field research. This included collection of road mortality data at five sites in the greater Twin Cities metro region. The additional year of data will enable a more robust assessment of whether corrugated tubes can act as effective barriers to keep turtles off roadways. Data also will inform an upcoming road reconstruction project in Dakota County where mitigation efforts will include wildlife underpasses and barriers.

In summer 2021, we also continued to track wood turtles in southeastern Minnesota using VHF radio telemetry. Several new adult turtles were found during the season and incorporated into the study, increasing the number of individuals monitored this year to 32. Working closely with the Minnesota DNR, Zoo staff assisted in locating multiple wood turtle nests. To improve survival and recruitment of wood turtles, we collected eggs from several of these nests for incubation at the Minnesota Zoo. Of 68 total eggs, 62 successfully hatched. Half of these were released to their natal sites in the fall, and the remainder are being reared at the Zoo until spring, 2022 to increase their likelihood of survival.

In addition, GPS data collected during previous years of this project are being analyzed to quantify the spatial ecology of wood turtles at our study sites. Preliminary analyses suggest that female wood turtles move faster and further than male turtles. Females also tend to have larger home ranges and spend less time in the river than males. We are continuing to analyze these data to improve our understanding of their habitat use.

Finally, communication of turtle conservation efforts continues through social media outlets, conference presentations and other venues. Two new interpretive signs will soon be installed at the Minnesota Zoo to raise public awareness about the life history and conservation needs of Minnesota's common snapping and painted turtles.

Final Update June 30, 2022

Fieldwork for the project was completed in fall, 2021, and for the past several months, we have focused on data analysis, interpretation and writing. For the road mortality research, our results suggest that corrugated plastic pipes may offer an inexpensive barrier alternative, reducing turtle mortality at the study site by an average of 50% across the two years. Temporary warning signs targeting driver awareness were less effective, with mortality decreasing at some sites, but increasing at others.

We have continued our work to improve the conservation of wood turtles this spring and summer with the support of a second grant from the Environment and Natural Resources Trust Fund. In partnership with the Minnesota DNR, we tracked more than a dozen adult female wood turtles at 3 sites during the nesting season. In addition, we will release 31 head-started wood turtles, reared at the Minnesota since last summer, back to the wild in the next few weeks. We are continuing to modify our analyses of wood turtle spatial data to better understand their habitat use and nest site selection.

Finally, turtle conservation in Minnesota has been highlighted via the Zoo's social media outlets, features in PBS's *Prairie Sportsman* and an upcoming episode of *Minnesota Bound*, and a television spot produced by the Minnesota Lottery.

Overall Project Outcomes and Results

Native turtles are a key component of diverse, healthy, and resilient aquatic ecosystems, inspiring connections to nature for children and adults alike. However, populations of turtles in Minnesota face numerous threats, including habitat loss and degradation, high predation of incubating nests, and mortality on roadways. With this project, the Minnesota Zoo sought to improve the conservation of turtles by 1) collecting data to quantify two key threats – road mortality and nest predation – and implement and evaluate mechanisms to mitigate these threats; and 2) building public awareness by developing educational and outreach materials for use during on- and off-site programming.

We outfitted imperiled wood turtles with radio and GPS transmitters, improving our understanding of their habitat needs and allowing us to identify and protect nesting sites. We reared hatchling wood turtles in captivity for their first year of life to improve their chances of survival in the wild and bolster depleted populations while other threats are addressed. To date, we have successfully released 68 one-year-old wood turtles back to the wild.

We also investigated strategies to mitigate mortality of turtles on Minnesota's roadways via cost-effective mechanisms including wildlife warning signs and small barriers. Although warning signs did not significantly reduce turtle mortality, corrugated pipe barriers were promising and yielded a decline in mortality of ~50%.

Finally, a variety of materials, including interpretive signage, a 3-dimensional snapping turtle model, and a children's book, were created to support educational and outreach programming and inspire public action to benefit the conservation of turtles. Healthy populations of turtles are an integral component of aquatic systems, and we anticipate that our results will inform effective management strategies that can benefit conservation at sites state-wide.

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Reducing mortality of turtles on Minnesota's roadways

Description:

Turtle mortality on Minnesota's roadways is a significant challenge, particularly during the spring and late summer as turtles move among feeding grounds, reproductive sites, and overwintering areas. The Zoo, in close partnership with the Minnesota Department of Transportation (MnDOT), will conduct research to better quantify this threat and evaluate potential mechanisms to mitigate turtle mortality on our roads. Study sites around the greater metropolitan region, as well as southern and central Minnesota, will be selected based on the presence of turtles (particularly imperiled species) and the logistical feasibility of monitoring and installing signs and other measures. Roadways managed by state or local authorities will be considered during the initial vetting process.

We will collect foundational data to document turtle use of and mortality along selected segments of roadways. These efforts will begin at a limited scale prior to the granting period (i.e., during early 2018) and continue through 2018. We will complete at least weekly foot patrols of study sites during seasons of peak movement (late spring, early summer, and late summer), with less frequent surveys at other times of the active season. In collaboration with MnDOT and after consultation with local authorities (where appropriate), we will then implement mechanisms (at select sites) to mitigate turtle mortality such as dynamic traffic signs, road paint and temporary speed reduction zones. We will monitor their impact for two years post-installation. We will also develop training materials for use by citizen scientists to broaden our reach and potentially increase monitoring capacity. Activity 1 will yield information on cost-effective options for reducing mortality of turtles on roads, and we anticipate that effective mitigation measures may be applied elsewhere in the State and at larger spatial scales. To achieve the desired outcomes for both Activities 1 and 2, the Zoo must dedicate a staff person to conduct field surveys, analyses and reporting.

ENRTF BUDGET: \$133,113

Outcome	Completion Date
1. Road surveys conducted to collect baseline movement and mortality data.	October, 2018
2. Mechanisms to reduce mortality on roads installed.	April, 2019
3. Efficacy of potential mitigation measures evaluated via post-implementation surveys.	October, 2020
4. Completion of final analyses and preparation of project report and manuscript for publication in peer-reviewed literature, summarizing key findings and recommendations.	June, 2021

First Update January 31, 2019

In summer 2018, the Minnesota Zoo hired a turtle biologist, Dr. Tricia Markle, to conduct field work and research for the road mortality study and other activities associated with this award. Beginning in early June 2018, we identified and vetted 17 sites along state, county, and city roads for surveys. These sites cover 3 general areas in the greater Twin Cities metro region: north of the Twin Cities (near Scandia), west of Minneapolis in the vicinity of Lake Minnetonka, and south of St. Paul in areas around the Minnesota Zoo (Figure 1). We used online databases of turtle records, such as HerpMapper (<https://www.herpmapper.org/>), to narrow the pool of candidate sites to focus on those with historical records of turtle mortality. Sites were ultimately selected based on their proximity to wetland areas (i.e., near habitat for turtles), the presence of turtle remains in preliminary searches, and the feasibility of monitoring and installing mitigation measures. Further, localities around Scandia and the Minnesota Zoo fall within the known distribution of the State of Minnesota Threatened Blanding's turtle and are thus priority areas for road mortality mitigation.

During this initial field season, we collected foundational, pre-treatment data on turtle road mortality, and we opportunistically documented other observations of wildlife mortality. Data collection at these sites began in early June 2018 and ended in mid-October. By mid-fall, temperatures had dropped to a point where turtles were no longer found on roadways. Sites were typically sampled on a weekly basis, resulting in 17 to 20 total visits per site. Sites with fewer visits were those that were not added until near the start of the state fiscal year 2019, corresponding to availability of funding associated with this award and the transition of Dr. Markle's position to full-time status.

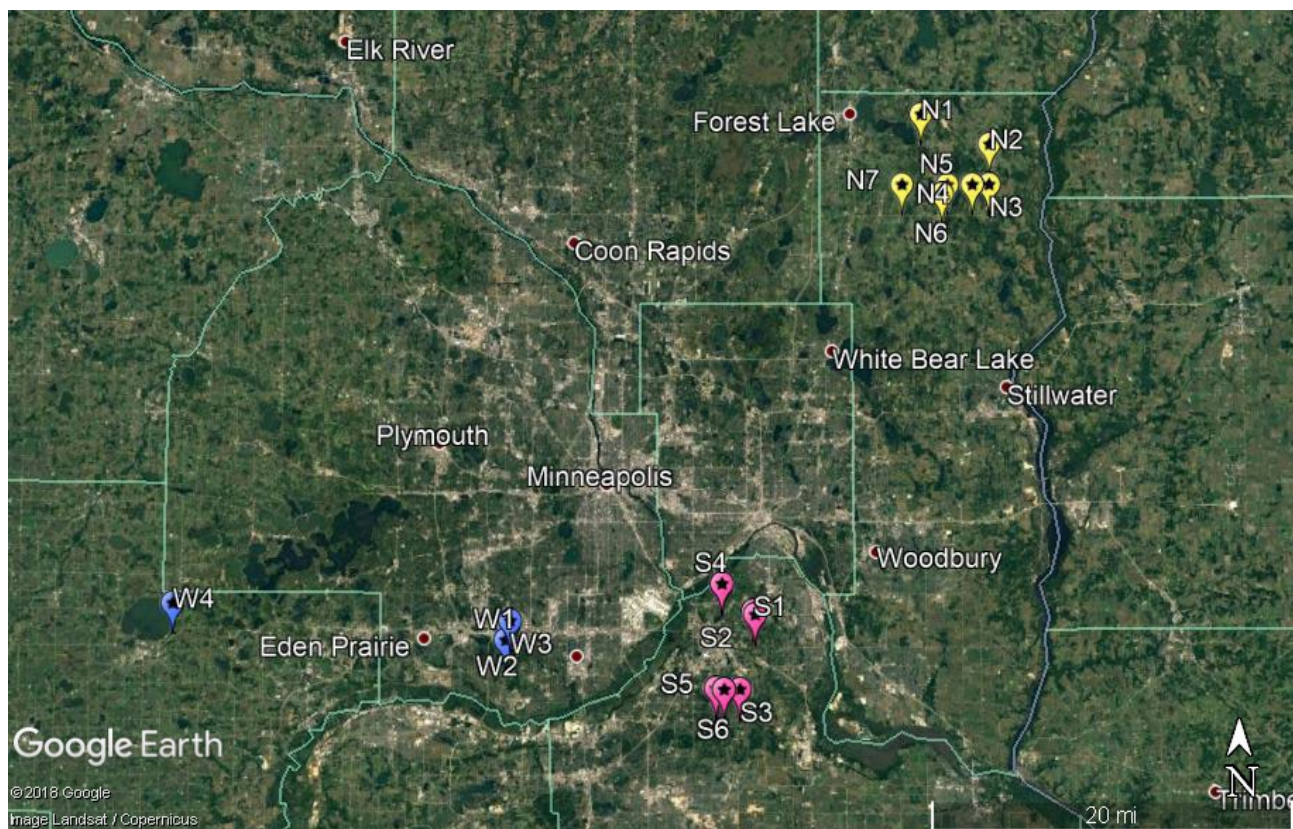


Figure 1. Road mortality study survey sites monitored during late spring – early fall, 2018, in the greater Twin Cities metropolitan region.

To collect mortality data, observers walked single file along each road segment, recording all deceased (and any live) animals on roads and within the first ~2 feet of the shoulder. Site boundaries were delineated with spray paint to ensure consistency in monitoring effort. Over the course of the season, we encountered a total of 313

turtles (Table 1); the vast majority of these observations were deceased. A small number of live turtles (6) were encountered on roads during the surveys. When safe to do so, live turtles were assisted across the highway in the direction they were headed.

Sites varied greatly in frequency of turtle encounters, ranging from 2 to 47 total turtles over the course of the season. Because sites varied in length from ~400 to ~1,800 f, we standardized for segment length to better facilitate comparisons among sites (see Table 1). We observed the highest rate of encounters at site North 2 (N2; 3.3 turtles/100 feet), where we documented only 0.3 turtles / 100 feet at site West 4.

Turtle movements (based on mortality rates) seasonally varied, reaching peaks in late spring and again in the early fall. Presumably, the increased activity in June was related to movements to foraging areas from overwintering sites and / or females searching overland for appropriate nest sites. The peak in early fall is likely related to the movements of turtles back to overwintering sites. We also observed several snapping turtle hatchlings on roads in the early fall.

In cooperation with state and county road authorities, we currently are selecting sites for the installation of measures to mitigate turtle mortality on Minnesota's roadways. Before turtles emerge this spring (i.e. by late April), we anticipate installing seasonal, flashing signs to raise driver awareness of turtle crossing hotspots at a sample of sites. These treatment sites will be paired with corresponding controls. Our selection of sites for mitigation treatments is semi-randomized, based on the presence of turtles, logistical feasibility of sign installation, and broad geographic representation. Because monitoring at some sites did not begin until mid-summer, 2018 due to capacity constraints, we will continue to collect baseline data in these areas to ensure that we are best able to evaluate the effectiveness of mitigation strategies via our before-after control-impact study design. As such, installation of mitigation measures may extend to spring, 2020. We will continue to explore alternative techniques for mitigation, such as road paint.

Table 1. Observations of turtles documented during mid-June - October, 2018 at sites north of the Twin Cities (near Scandia), west of the Minneapolis near Lake Minnetonka, and south of St. Paul in areas around the Minnesota Zoo. Sites: N = North, S = South, and W = West.

Site	Painted Turtles	Snapping Turtles	Unknown Species	Total Turtles	Site Length (feet)	Turtles / 100ft
N1	19	4		23	1,155	2.0
N2	18	2	1	21	638	3.3
N3	6		1	7	1,250	0.6
N4	24	3		27	1,437	1.9
N5	16	3		19	1,738	1.1
N6	26	10		36	1,392	2.6
N7	20			20	1,456	1.4
S1	22	9		31	1,155	2.7
S2	6	4	1	11	638	1.7
S3	13	1		14	1,250	1.1
S4	4	2		6	1,437	0.4
S5	32	7	8	47	1,738	2.7
S6	5	1	1	7	1,392	0.5
W1	19	4	1	24	1,805	1.3
W2	1		1	2	378	0.5
W3	10	5		15	813	1.8

W4	3	4		3	1000	0.3
Total	244	55	14	313		

Following installation of initial mitigation measures during spring 2019, we will monitor sites weekly (after temperatures are warm enough to promote movement of turtles) to document their effectiveness in reducing road mortality. We will also deploy traffic counters in 2019 to quantify traffic volume and speed as a potential predictors of road mortality.

Second Update June 30, 2019

We began monitoring sites as part of the road mortality study on May 6, 2019. As in 2018, sites were distributed among regions north of the Twin Cities near Scandia, southwest of the Twin Cities in the Bloomington area, and south of St. Paul around the Minnesota Zoo. Of the 17 sites that were monitored last year, we stopped monitoring 2 this season due to road construction. We removed a third site from the study because of low documented rates of mortality and replaced it with a site that we believe will yield higher rates of mortality and thus strengthen our results and inferences. Weekly foot-based surveys will continue through late summer / early fall until about mid-October, after most turtle movements have ended for the season.

To evaluate the effectiveness of relatively inexpensive mitigation strategies, we selected 3 sites in the Scandia area for installation of turtle-crossing signs. Selection of sites for mitigation was semi-randomized, based on the presence of target species, logistical feasibility of sign installation, and geographic representation of the area. We worked with Washington County Public works to produce six identical signs (one facing each direction of traffic at each of the three sites) reading “Turtle Crossing Next 600 Ft” (Figure 2). The 600 foot-distance represents the average length of turtle crossing “hotspots” in the area. After discussion with Washington County Public Works and MnDOT staff, we decided that a silhouetted image of a turtle on signs may make them targets for theft; hence, we designed signs using exclusively text.

Signs were temporarily installed on May 30 and will remain in place until July 15, a window which corresponds with the period of peak turtle activity (associated with movements among foraging areas and to / from nesting sites). Other research has suggested that temporary wildlife warning signs are more effective than permanent installations since the public may become desensitized to signs over a relatively short period of time (i.e., within weeks). In addition, the temporary appearance of the sign installation (i.e., signs posted on sandbag-supported frames along the road shoulder) is believed to be more effective in attracting driver attention. We anticipate that assessing temporary warning signs as a mitigation strategy will continue next year; data collected in 2019 and 2020 will be analyzed with pre-treatment data to evaluate the effectiveness of temporary signs. Each treatment site also has a corresponding control site along the same stretch of road to help control for variation among sites and across years in factors such as traffic volume and local environmental conditions. Further, we are temporarily deploying traffic counters at each site to better understand the relationship between traffic volume and turtle mortality.

We are continuing to collect baseline road mortality data for the remaining sites in anticipation of testing additional mitigation measures in 2020.



Figure 2. Temporary turtle crossing road sign installed in Washington County to evaluate its effectiveness at reducing turtle road mortality.

Third Update January 31, 2020

We began road mortality surveys this season on May 6, 2019 and completed them on October 23, 2019, at a point when most turtle movements had ceased. As in 2018, we conducted weekly, foot-based surveys and documented mortality of turtles and other small wildlife (e.g., mammals, snakes, birds, and amphibians). Sites were surveyed an average of 24 times through the season.

Three sites that were monitored in 2018 (Sites N1, W4, and S4) were removed from surveys for 2019. At Site N1, construction is scheduled to begin in 2020, and the site is located on a blind curve that we considered too dangerous for surveying. At W4, we documented a small number of turtles in 2018, suggesting that it is not a site with particularly high mortality, and there was not a comparable site along the road to provide a control. At S4, the local jurisdiction added fencing along both sides of the road to prevent public access to certain areas. This new fence likely impacted wildlife crossings there and thus limited its utility in this study. To offset the removal of these sites, we added a new site (N8) to our northern cluster, bringing the current number of sites we are monitoring to 15 (Figure 3).

Turtle movements again varied by season, with a strong peak in activity during late spring (May – June) and another peak in late summer / early fall (August – September). We documented 430 turtle mortalities during 2019, with encounters by site ranging from 7 to 61 (Table 2). After standardizing for site length, we recorded the highest encounter rate at site S5 (5.2 turtles / 100 ft), whereas site S6 had the lowest encounter rate (0.5 turtles / 100 ft). Mortality numbers were higher during 2019 than 2018, presumably because the 2019 field season started nearly 2 months earlier at most sites (i.e., early May versus late June). We documented a relatively small number of hatchlings ($n = 35$) during sampling; we also observed 10 live turtles crossing roadways and assisted them to the other side of the road. One important note is that 4 mortalities documented in 2019 were state-threatened Blanding's turtles. We did not confirm a dead Blanding's turtle at any sites in 2018, but this may be due to the later start date of surveys in 2018. Female Blanding's turtles are known to move long distances to find nesting sites, and June is typically when they face the highest road mortality threat.

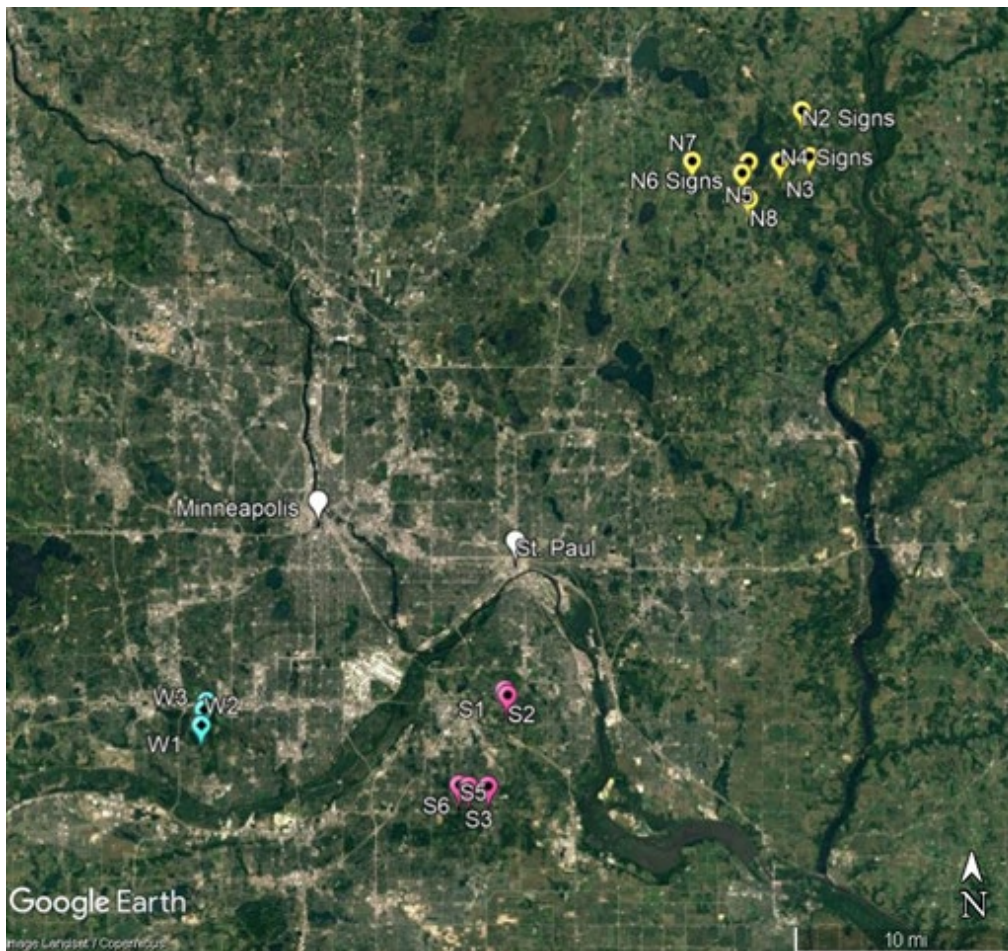


Figure 3. Road mortality sites monitored in 2019, including 15 total sites in the greater Twin Cities metropolitan area, with three sites (N2, N4, and N6) receiving mitigation treatments (temporary “Turtle Crossing” signs).

In spring 2019, we began to deploy treatments to test the effectiveness of relatively inexpensive mitigation measures. Three sites in Washington County were chosen for initial treatment with wildlife warning signs reading “Turtle Crossing Next 600 Feet”. Signs were temporarily installed at sites during peak turtle movement (May 29th to July 12, 2019). We monitored corresponding control sites along the same stretch of road to account for between-year and among-site variability. We intentionally installed signs on a temporary basis, as drivers may become desensitized to wildlife signs after a period of a couple of months. After signs were removed, we continued to collect mortality data until the fall.

In addition to turtle crossing signs, we deployed traffic counters at each site on a temporary basis. Traffic counters allowed us to collect data on traffic volume and timing over a multi-day period. This data will be integrated in modeling to help us better understand the relationship between traffic volume and wildlife mortality. Along with the treatment and primary control sites, we continued to monitor the remaining 9 sites to obtain multi-year baseline road mortality data and to provide secondary controls. We anticipate incorporating additional mitigation treatment sites in 2020, potentially including road paint, dynamic road signs, and small barriers. We are currently exploring options with road authorities in Dakota and Hennepin Counties.

For three of our study sites along Cliff Road in Dakota County, road mortality data are being used to inform a road reconstruction project in which multiple wildlife underpasses are being considered. Zoo staff are actively partnering with the Dakota County Parks and Transportation staff to address wildlife considerations for this project. Early construction is scheduled to begin in late 2020, so we are not considering other road mitigation at these mortality hotspots (Sites S3, S5, and S6) in the short-term. We also are collaborating with Parks staff to

develop a monitoring plan for these sites post-construction to evaluate the effectiveness of the newly installed wildlife underpasses.

Table 2. Observations of turtles documented during May 6 – October 23, 2019 at sites north of the Twin Cities (near Scandia), south of St. Paul in areas around the Minnesota Zoo, and west of the Twin Cities near Hyland Park. Sites: N = North, S = South, and W = West.

Site	Painted Turtle	Snapping Turtle	Blanding's Turtle	Unknown Species	Total Turtles	Site Length (feet)	Turtles / 100ft
N2	22	0	0	0	22	638	3.4
N3	58	2	1	0	61	1,250	4.9
N4	21	1	0	0	22	1,437	1.5
N5	21	2	1	0	24	1,738	1.4
N6	24	21	2	0	47	1,392	3.4
N7	20	5	0	0	25	1,456	1.7
N8	16	8	0	1	25	1,175	2.1
S1	32	7	0	0	39	1,155	3.4
S2	4	5	0	0	9	638	1.4
S3	12	5	0	0	17	1,250	1.4
S5	36	17	0	0	53	960	5.52
S6	2	5	0	0	7	625	1.1
W1	40	8	0	0	48	1,805	2.7
W2	5	2	0	0	7	378	1.9
W3	17	7	0	0	24	813	3.0
Total	330	95	4	1	430		

Fourth Update June 30, 2020

We began monitoring road sites for the 2020 season during the week of May 4. We are conducting weekly surveys of 12 sites throughout the summer, a reduction from the 15 sites sampled in 2019. Specifically, we removed 3 sites along Cliff Road in Dakota County this year, as the road will be reconstructed in the near future. Mortality data collected there during the past 2 years is being used to inform mitigation strategies for the reconstruction project: Dakota County Transportation staff are recommending installation of 3 wildlife underpasses at sites with high wildlife mortality, as well as retaining walls and fencing to direct animals under the road for safe passage. Initial construction of utilities is scheduled this spring and summer, while the full reconstruction will not be complete until at least 2021. Although the Zoo is unlikely to conduct post-construction surveys to determine if these underpasses are effective in reducing wildlife mortality, Dakota County Parks staff hope to gather post-installation data.

To inform our evaluation of mitigation strategies, we once again installed temporary turtle-crossing signs at 3 locations in the Scandia area of Washington County. We implemented a crossover design and switched control and treatment sites from 2019 to obtain a complete season of reference data and post-installation treatment data at each site. In addition, we installed signs at a site in the south metro, yielding a total of 4 'treatment' sites this year. Signs are identical, reading "Turtle Crossing Next 600 Ft," with the 600-foot distance representing the average length of turtle crossing hotspots in the study. Signs were installed the first week of May and will remain in place until the first week of July. This timeline aligns with the seasonal peak in movements as adult female turtles seek out nesting sites. We are also monitoring corresponding control sites and deploying traffic counters to quantify traffic volume. Preliminary data suggest that vehicle traffic is reduced this spring, presumably as a result of COVID-19 pandemic-related impacts.

Finally, we partnered with Dakota County Transportation staff to evaluate the efficacy of a new barrier design in mitigating wildlife road mortality (Figure 4). Dakota County installed a section of 8-inch corrugated drainage pipe at the base of a guard rail, in addition to a corresponding section near a pond on the other side of the road. The ends of the pipe were curved back to the wetland to encourage turtles to stay off the roadway. Unfortunately, we were unable to add a barrier adjacent to a section of the lake to the south due to driveway placement and a narrow shoulder. We added sandbags adjacent to the pipe, which can function as ‘exit’ ramps for wayward turtles that find their way onto the road. The pipe, which is rolled out near the road and then staked to ground, is relatively easy to install and much less expensive than other barrier (e.g., fencing) options. If preliminary results are promising, we hope to evaluate this alternative at additional sites next year.



Figure 4. Construction of new 8-inch pipe barrier in Dakota County to keep turtles and other small wildlife off roadways.

Fifth Update January 31, 2021

As a result of an unseasonably cool October, we completed the 2020 road surveys on October 15. We visited each of the 12 sites 24 times over the course of the season via weekly surveys. We documented 207 turtle mortalities in 2020, with sites ranging from 4 to 42 occurrences (Table 3). Due to Covid-19 restrictions, traffic was reduced for at least the first half of the summer; this reduction likely is contributing to the overall decrease in turtle road mortality this season. However, we documented similar patterns of activity as in previous years, with peak turtle movements in May – June, followed by a secondary spike in late summer. We observed the highest mortality rate (based on standardization by length) at site N6 (3.02 turtles / 100ft); site N5 had the lowest mortality rate (0.29 turtles / 100ft).

Table 3. Observations of turtles documented May 4 - October 15, 2020 at sites north of the Twin Cities near Scandia, south of St. Paul in areas around the Minnesota Zoo, and west of the Twin Cities near Hyland Park. Sites: N = North, S = South, and W = West. Shaded rows indicate sites with mitigation treatments: N3, N7, N8, and W3 had temporary road crossing signs, and a pipe barrier was installed at S1.

Site	Painted Turtle	Snapping Turtle	Blanding's Turtle	Unknown Species	Total Turtles	Site Length (feet)	Turtles / 100ft
N2	10	1			11	638	1.72
N3	18				18	1,250	1.44
N4	10				10	1,437	0.70
N5	3		1	1	5	1,738	0.29
N6	33	7	2		42	1,392	3.02
N7	18		1		19	1,456	1.30
N8	16	9			25	1,175	2.13
S1	24	2			26	1,155	2.25
S2	15				15	638	2.35
W1	18	5			23	1,805	1.27
W2	4				4	378	1.06
W3	8	1			9	813	1.11
Total	177	25	4	1	207		

We removed the temporary turtle crossing signs (installed at 4 sites [N3, N7, N8, and W3] in early May) on June 30, 2020, such that their installation encompassed peak turtle activities associated with nesting movements. After signs were removed, we continued to monitor both treatment and control sites for the duration of the season. Preliminary results suggest a reduction in turtle mortality when the signs were in place. However, the pandemic-related reduction in traffic volume likely is related to this decrease in mortality. As such, statistical analyses will need to accommodate traffic volume to determine if signs are having the desired effect. As in 2019, we documented 4 deceased state-Threatened Blanding's turtles this year. We also encountered 8 live turtles at sites during our surveys. Seven painted turtles were assisted across the road, but a large snapping turtle was found injured and was taken to a wildlife rehabilitation center for treatment. We observed a total of 20 hatchling turtles on roads in 2020.

In addition, we partnered with Dakota County Transportation to install 2 ~800 ft sections of 8-inch corrugated pipe at site S1, allowing us to evaluate its effectiveness as a barrier to turtle movements. The pipe is much less expensive than other potential barriers such as chain link fencing, and its installation was completed in a single morning. Initial results appear promising: turtle mortality decreased from 20 in 2019 to 6 in 2020 (~70% reduction) along that stretch of road in which the pipe was installed on both sides (Figure 5). However, the barrier could not be installed along the entire length of this wetland complex, so some turtles accessed the roadway from an adjacent pond to the southwest. In general, the pipe held up well over the course of the summer, but a modest amount of maintenance was required where a small mammal dug under the pipe and where a section was damaged by a mower. We anticipated that tall vegetation falling over the pipe might create a ramp for turtles to crawl over the barrier, but we found no evidence of this issue. Although we collected only 1 year of pre- and post-treatment data from a single site, we believe that the results of this pilot study are encouraging enough to justify additional research. This work is likely beyond the scope of this study, but the Minnesota Department of Transportation has expressed an interest and may test similar barriers in the future.



Figure 5. Site S1 before (top) and after (bottom) pipe barrier installed. Barrier indicated by blue lines. Turtle mortality was dramatically reduced from 2019 to 2020 after the barrier was put in place. Note that some turtles still have access to the roadway from a pond in the southwest where a barrier could not be installed.

Sixth Update June 30, 2021

Despite the challenges presented by the pandemic, we completed most road mortality data collection in 2020 as initially planned. However, we are continuing to monitor several sites this year to bolster our dataset. We began monitoring these sites the week of May 3 and will conduct weekly surveys until mid- to late October 2021. The sites that we are continuing to monitor (S1, S2, S3, S5, and S6) are located in Dakota County and occur along Cliff Road and Argenta Trail.

At Site S1, an 8-inch corrugated drainage pipe barrier that was installed in Spring, 2020 has remained in place. To further evaluate the effectiveness of this mitigation measure, we are monitoring the site this summer, which will provide 2 years of data post-treatment installation. Site S2 is located along the same stretch of road and serves as a control. We initially hoped to expand this treatment type to additional sites this year, but reduced capacity as a result of the pandemic precluded scaling up this work in 2021.

Sites S3, S5, and S6 occur along Cliff Road in a section slated for reconstruction starting in Fall, 2021. The Zoo is working with Dakota County Parks staff to continue monitor these sites and establish baseline data on road mortality. County reconstruction plans include small animal exclusion fencing and wildlife underpasses at two of the sites. We anticipate continuing to monitor post-construction to quantify the effectiveness of the project for reducing road mortality of turtles and other small wildlife. Trail cameras will be installed in the underpasses to document wildlife usage of these tunnels.

Seventh Update as of January 31, 2022

We continued to monitor five sites in association with our road mortality study during 2021 (S1, S2, S3, S5, and S6). All sites are located in Dakota county and occur along Cliff Road and Argenta Trail; data collection for the season concluded on October 21, 2021. We documented a total of 119 turtle mortalities this year, with sites ranging from 5 to 42 occurrences (Table 4). We observed the highest mortality rate (based on standardization by length) at site S5 (4.4 turtles / 100ft); site S2 had the lowest mortality rate (0.8 turtles / 100ft).

Table 4. Observations of turtles during road mortality surveys at sites near the Minnesota Zoo, May 3 - October 21, 2021. A pipe barrier mitigation treatment was installed at Site S1 (shaded).

Site	Painted Turtle	Snapping Turtle	Blanding's Turtle	Total Turtles	Site Length (feet)	Turtles / 100ft
S1	22	5	0	27	1,155	2.3
S2	5	0	0	5	638	0.8
S3	28	2	0	30	1,250	2.4
S5	31	11	0	42	960	4.4
S6	8	7	0	15	625	2.4
Total	94	25	0	119		

In our second year of data collection in association with the pipe barrier in place along Argenta Trail, we documented 14 turtles along the section of road where the pipe was installed on both sides (Figure 6). Unfortunately, a car drove through the barrier towards the end of the season, and a small number of turtles appeared to have accessed the road through a gap before repairs could be made. Despite the compromised integrity of the pipe barrier, total mortality remained below the recorded pre-treatment levels (20).

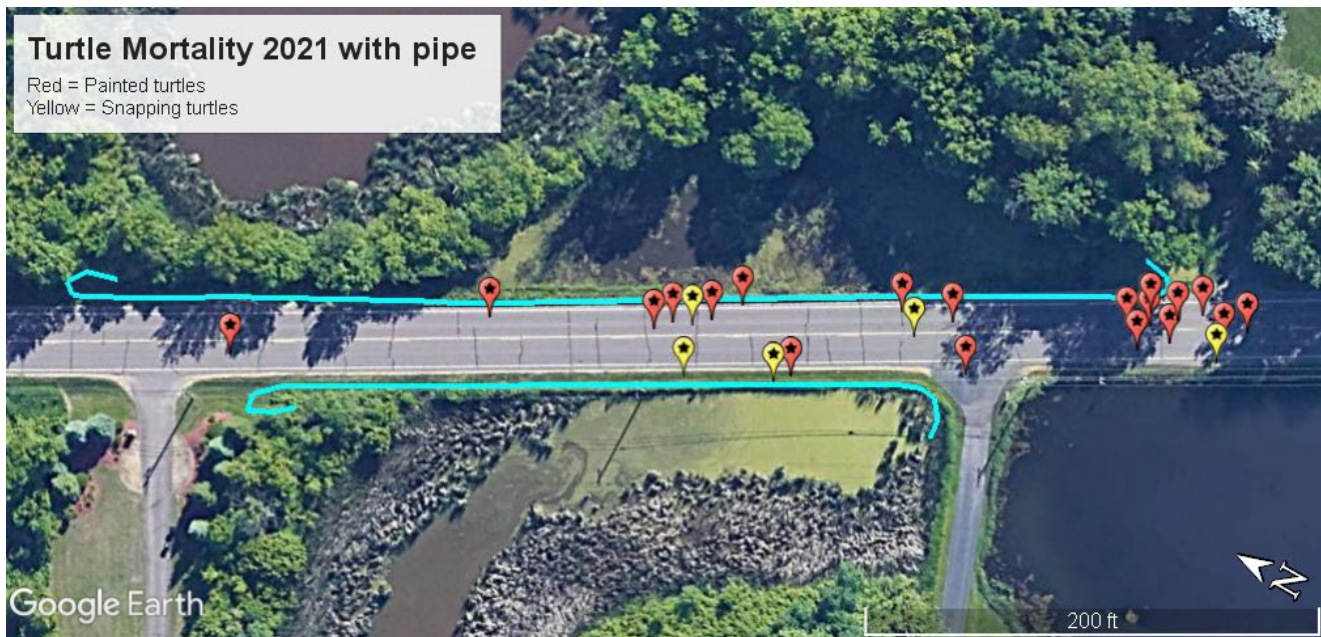


Figure 6. Turtle mortality documented at Site S1 during 2021. The pipe barrier is indicated by blue lines. Note that some turtles still have access to the roadway from a pond in the southwest where a barrier could not be installed.

Data gathered from sites S3, S5, and S6 along Cliff Road further establish baseline numbers on road mortality in that area. The Zoo will continue to partner with Dakota County Parks to monitor the effectiveness of mitigation efforts for an upcoming road reconstruction project at that site, which may include barriers and wildlife underpasses.

Final Update June 30, 2022

We completed road mortality data collection during fall, 2021. The corrugated pipe barrier yielded a reduction in turtle mortality by ~50%, on average, over the two years of this study, an encouraging result that warrants further research. We have been in contact with staff from Washington County who may explore this design at a site there. During a complimentary study supported by the Minnesota Department of Transportation, we found that fencing barriers with wrap-around end treatments and fine mesh hardware cloth at the base are a very effective means to reduce turtle mortality on Minnesota's roadways. Both studies suggest that these designs successfully direct turtles away from roadways.

Our preliminary results suggest that warning signs may be less effective at reducing mortality of turtles: we documented slight decreases in mortality at some sites and increases at others. We are currently conducting a multi-year analysis to more rigorously evaluate whether warning signs yield statistically significant reductions in overall turtle mortality. We hope to have results finalized later this summer and will publish our findings in a scientific journal.

Finally, Dakota Country has started reconstruction work on Cliff Road where mortality data were collected in previous years. Plans include barriers and wildlife underpasses; we intend to work with Dakota County Parks staff to monitor mortality at the sites post-construction.

Final Report Summary

Road mortality poses a significant threat to turtles, with estimates suggesting that tens of thousands of individuals are killed on Minnesota roadways every year, including Threatened Blanding's and wood turtles. Our work sought to quantify turtle road mortality and evaluate cost-effective measures for mitigation. In partnership

with the Minnesota Department of Transportation and Dakota, Hennepin, and Washington Counties, we tested two potential cost-effective measures: temporary warning signs denoting turtle crossing zones and small tube barriers. Although other options including road paint and reduced speed zones were considered, these were deemed less desirable by local road authorities.

To assess temporary warning signs, we selected 17 sites in the greater Twin Cities Metro area for collection of weekly pre-treatment data in 2018, with 307 turtle mortalities recorded at these sites. We installed temporary “Turtle Crossing” signs at three sites in 2019 and at four different sites again in 2020. Data were collected both before and after sign installation at treatment and corresponding control sites. Our preliminary results suggest that warning signs may not be effective at reducing mortality of turtles: we documented slight decreases in mortality at some sites, but increases in mortality at others. We are currently conducting additional analyses to more rigorously evaluate whether warning signs may yield significant reductions in turtle mortality.

We also investigated the efficacy of 8-inch corrugated drainage tubes. A key feature of this design was wrap-around “j-hook” end treatments to direct turtles back to the wetlands. The pipe barrier worked well and yielded a reduction in turtle mortality of ~50%, on average, over the two years of this study. While this design was only tested at a single site, the decrease in mortality warrants further investigation to see if it may offer an effective low-cost alternative for some locations.

This project is already impacting local development projects. Dakota County is using road mortality data that we collected to inform a road reconstruction project in which multiple wildlife underpasses are under currently under construction. These underpasses will be tied into effective turtle barriers. Another wildlife passage is being considered in Hennepin County, and a metal grate from a previously blocked culvert passageway in Washington County where Blanding’s turtles are present has been removed. We also have received communication that concerned citizens have been asking the local governments to identify means to help turtles.

ACTIVITY 2:

Description: Improving hatching success of riverine turtles

Loss of incubating eggs and hatchlings remaining in nests to predators such as raccoons is a significant issue for Minnesota’s turtles. For imperiled species such as the wood turtle, nest predation poses a major threat to long-term population viability, particularly in areas with higher human populations and recreational activity: the presence of people often brings mammalian predators if visitors leave trash and other belongings behind.

To collect baseline data on nest predation and to evaluate mechanisms to improve hatching success, we will outfit endangered wood turtles with GPS transmitters. (Surveys to locate wood turtles will be led by the Minnesota DNR.) Transmitters will be programmed to collect regular positional data, enabling us to identify key nesting sites for wood turtles and likely other species. This work began in 2017 in the Cannon and Straight River watersheds and, with ENRTF support, will be expanded to additional watersheds in central and southern Minnesota in 2018 and 2019. We will then install electrified fences at selected nesting sites that will allow turtle access to nests but exclude mid-sized mammalian predators. Cameras will also be installed at each site to document visitation rates by turtles and predators. Nest site monitoring will continue through spring 2021. Fencing will be installed at the beginning of the nesting season in 2019 and 2020. We will visit sites regularly (at least weekly) to quantify sign such as tracks, evidence of digging and nesting, and evidence of predation, to maintain camera systems, and to ensure the fencing is structurally sound and functioning properly. We will remove fencing in late summer (September) and excavate nests which appear to have hatched. As an ancillary benefit, transmitters will enable us to document habitat use of wood turtles. Results from Activity 2 will be used to inform effective management strategies to improve hatching success.

ENRTF BUDGET: \$152,387

Outcome	Completion Date
1. Surveys conducted, and wood turtles outfitted with transmitters to collect nesting site and movement data.	October, 2019
2. Predator exclusion fencing constructed and maintained at select nesting sites. Fencing of nesting sites will begin during spring, 2019.	September, 2020
3. Sites monitored post-installation to assess effectiveness in reducing mortality. Monitoring of nesting sites will begin during spring, 2019.	September, 2020
4. Completion of final analyses and preparation of project report and manuscript for publication in peer-reviewed literature, summarizing key findings and recommendations.	June, 2021

First Update January 31, 2019

In partnership with the Minnesota DNR, Minnesota Zoo staff affixed GPS transmitters to the carapace (upper shell) of 8 wood turtles (6 females and 2 males) in May – June 2018. Five of these individuals were previously tracked in 2017 and were outfitted with VHF radio transmitters to facilitate easy recovery. The other 3 individuals were located in new areas by standard search methods. One additional male was opportunistically captured during September 2018 and subsequently was outfitted with a VHF transmitter, bringing the total to 9 adult wood turtles tracked during 2018. Watersheds where wood turtles are being monitored include the Cannon, Straight, and Zumbro Rivers, all of which are located in the southeast portion of the state. (We note that, because GPS transmitters were deployed prior to the beginning of this award (i.e., July 1, 2018), transmitters were purchased with another source of funding in 2018; during 2019, GPS transmitters will be purchased with ENRTF support.)

After GPS transmitters were deployed, we relocated each turtle about every 2 weeks to download locality data. We programmed transmitters to collect positional data every four hours during deployment. Data were typically downloaded remotely (on site, at a maximum distance of ~200 m from the turtle), minimizing the need for disturbance. GPS positional data were collected until September 2018, when battery power was starting to run low for the transmitters. During September, we exchanged the GPS transmitters for standard VHF transmitters, which have a longer battery life. These transmitters have allowed us to monitor site use over the winter (all turtles were located during late fall) and will facilitate relocating them during spring, 2019, for redeployment of GPS transmitters.

We are now analyzing spatial data from the 2018 field season. Locality data are being used to determine potential nesting sites where nest protection measures can be deployed beginning in spring 2019. Wood turtles tend to nest in open, sandy areas adjacent to rivers and streams. Based on these criteria, we will identify potential nesting sites where female turtles were present during the 2018 nesting season (late May – late June). As female wood turtles often nest in the late afternoon and evening, positional data from this time of day are of particular interest. We are also using Geographic Information Systems (GIS) and statistical software to quantify movements, estimate home ranges, and calculate habitat use.

For spring 2019, we plan to select at least two sites for nest protection. At each site we anticipate testing two different types of predator exclusion fencing: an electric fence and an enclosed “turtle box”. Electrified fences will be constructed to permit access to all species of turtles, including large snapping turtles, but will help to exclude mammal predators such as raccoons, which have a tendency to climb over rather than under obstacles. Box enclosures will be wood turtle-specific, with a wire enclosed top to exclude predators and an opening only large enough to permit access to smaller turtle species. Both methods have been employed for wood turtle conservation in Wisconsin and have relative benefits and limitations. Electric fences have higher material costs

and require more maintenance, but benefit all turtle species. Turtle boxes have lower material and maintenance costs, and the screen top can be more effective at excluding predators. However, they exclude species larger than wood turtles. With both predator exclusion options constructed at the same sites, we will test relative effectiveness at protecting turtle nests and whether wood turtles more readily use one design. We will install multiple cameras at each site to document visitation by turtles and predators. In addition to treatments, we will also monitor control areas at each site. Sites will be surveyed at least weekly through the spring and summer to check for signs of nesting and predation attempts and for maintenance.

Second Update June 30, 2019

Minnesota Zoo staff continued to monitor overwintering wood turtles outfitted with VHF transmitters during February – April, 2019, as conditions allowed. Major early spring flooding, however, presented challenges with accessing several sites.

During May – June, 2019, Zoo staff worked with the Minnesota DNR to attach GPS transmitters to the carapaces of 10 adult wood turtles at 3 locations in southern Minnesota. Six of these turtles were monitored in 2018, and we exchanged their VHF units for GPS transmitters to facilitate collecting regular positional data. The other 4 turtles outfitted with GPS transmitters were located via foot-based surveys jointly conducted by the Zoo and DNR this spring. Our sample includes 2 individuals (1 male and 1 female) from a site along the Cannon River and 8 individuals (7 females and 1 male) from two sites along the Straight River. We refocused our telemetry efforts at these 3 sites because we believe that there may be opportunities to partner with the land managers and landowners to implement management strategies that will ultimately benefit wood turtles.

In addition, we outfitted 4 wood turtles (3 females, 1 male) with VHF transmitters at a relatively high-density site in southeastern Minnesota (the same site where 4 individuals are being monitored with GPS transmitters). Three juvenile wood turtles from a headstarting initiative in 2017 were also tracked in 2019 with VHF. (We note that all VHF transmitters were purchased via other, non-ENRTF sources of funding.) We will continue to monitor turtles through about mid-September. We are remotely downloading data from turtles outfitted with GPS transmitters about biweekly; the DNR and Zoo are jointly tracking turtles with newly-affixed VHF transmitters about once per week. These data will be pooled with data collected during previous years and in 2020 to better quantify the movements, habitat use, and general spatial ecology of wood turtles in southeastern Minnesota.

To evaluate strategies that may reduce nest predation, we first examined positional data collected with GPS units deployed on wood turtles in 2017 and 2018. This process allowed us to identify a small number of potential nesting sites. Wood turtle nesting sites are typically open, sandy, and south-facing, located in close proximity to a river. After consultation with landowners, we identified two initial sites for installation of predator exclusion fencing during spring, 2019. Although we hypothesize that nest ‘boxes’ constructed largely of lumber and hardware cloth are likely effective in protecting wood turtle nests, we decided to use electric fences for nest protection at these sites due to challenges with access and topography.

Installation of predator exclusion fencing included clearing the perimeter of vegetation and laying down weed fabric, which precludes vegetation from growing and rendering the electric fence ineffective. We then installed rabbit fencing on top of the weed fabric to prevent small mammalian predators from digging under the electric fence. Initial preparation at the first site also included clearing vegetation from the interior area and adding a large quantity of sand to make it more appealing to nesting turtles (Figure 7). The second site was sufficiently sandy and open and did not require additional preparation.



Figure 7. Predator exclusion electric fencing to protect wood turtle nesting area.

We next installed a solar-powered electric net fence beginning 4 inches from the ground and extending 24 inches high, with the lowest hot (i.e., electrified) wire set at 8 inches. These specifications enable all sizes of turtles to pass beneath the fence, but encourage small to mid-sized mammalian predators to attempt to cross over the fence, at which point they receive an electric shock that we anticipate will deter further movement into the nesting site. The fencing perimeter at both sites is ~100 feet, yielding a protected area of ~400 square feet per site. At least 3 trail cameras are set-up per site to help determine if 1) turtles are entering and nesting in the fenced areas and 2) the electric fence is an effective deterrent for mammalian predators.

We are visiting nest protection sites at least weekly to confirm the fence is functioning properly, to maintain the camera systems, and to look for any evidence of turtle use or predation. We also note that intensive telemetry (conducted by the DNR and Zoo) was especially critical during the June nesting season to identify actual nesting sites. As of mid-June, we have confirmed that 2 wood turtle nests have been laid within one of the enclosures.

Fencing will be removed during fall (after any nests laid within the protected area have hatched). We anticipate scaling-up this work in 2020 and possibly exploring other fence designs (e.g., the turtle nesting ‘box’ described above) to continue to evaluate the efficacy of exclusion fencing in reducing nest predation and improving hatching success and recruitment.

Third Update January 31, 2020

We continued to track wood turtles outfitted with GPS and VHF transmitters through summer, 2019 (Figure 8). Across 3 study sites in southeastern Minnesota, we monitored a total of 14 adult turtles (10 with GPS transmitters and 4 with VHF transmitters). In addition, we tracked 3 juvenile turtles fitted with VHF transmitters. We located 2 new adult turtles in fall, 2019 (a male and female); these individuals were outfitted with VHF transmitters, bringing the total number of wood turtles we are tracking to 19.

From May to October, 2019, we visited each site about every 1 – 2 weeks, during which time we collected positional and other data from turtles fitted with VHF transmitters and downloaded GPS data from other

transmitters. DNR staff also tracked turtles to help ensure frequent and regular monitoring. These data will be pooled with information collected during previous years (and in 2020) to better quantify movements, habitat use, and general spatial ecology of wood turtles in southeastern Minnesota. The data will also be used to help inform additional nesting sites to consider for protection in 2020.



Figure 8. Adult wood turtle with GPS transmitter attached (left). Adult wood turtle with VHF transmitter (above).

Throughout the summer, we monitored and maintained two predator exclusion fences that were constructed in the spring. Routine fence site maintenance included camera and fence checks to ensure proper function, and removal of overgrown weeds from within the enclosure and along the fence line. In addition, we looked for evidence of turtles entering the fenced area (e.g., turtle tracks, digging areas) and indications that predators were breaching the fence (e.g., depredated turtle nests, damage to the fence itself). Fencing material was removed in late September, several weeks after any hatchlings would have left their nest sites.

At protected site 1 (the newly constructed nesting area at which supplemental sand was added), we know from GPS data that 2 female wood turtles moved through the area, but there was no evidence (e.g., camera footage, tracks) of turtles entering the protected nesting area or attempting nesting within the enclosure. Trail cameras did reveal attempts by raccoons to enter the enclosed area; on one occasion, a raccoon was indeed successful in entering. It remains unclear how the raccoon entered, although the electric fence may have been breached in an area where it was slightly higher from the ground. The spot was modified, and no further raccoons (or other turtle predators) were observed in the fence area. Of the 3 female wood turtles monitored at this site, an individual was observed digging 'test' nests on an unstable cutbank of the river, another is believed to have nested further upstream at a site that may be amenable to future nest protection, and the third remained in a new location downstream that was created after spring flooding.

At the second protected nest site, 5 trail cameras were set along the fence perimeter and were successful in capturing images of a wood turtle (and a softshell turtle) entering and nesting in the site. In addition, DNR staff were present for several consecutive nights during the nesting season and documented 2 wood turtles nesting inside the enclosure and an additional 3 individuals nesting outside the enclosure. As the fencing design was still in the experimental stage, small screen boxes were placed over each confirmed nest to provide added protection (Figure 9). Additional cameras were set to monitor each individual nest to document nest predation attempts and signs of hatching. On 2 consecutive nights, we captured footage of a raccoon breaching the electric fence. We believe that this occurred during a flooding event in which the bottom section of the fence became submerged in water and the fence's electrical current automatically switched off. The raccoon, however, did not attempt to dig into nests protected within the fence. For 2020, we plan to move the fencing structure higher on the bank to reduce issues with flooding. In late August, we found that all of the cameras at the fence site had been stolen. Fortunately, DNR staff were on-site during one of the hatching days and



confirmed

Figure 9. Electric fence installation at site 2 (left). Additional nest protection box for wood turtle nest (right).

9 wood turtle hatchlings in the nesting area and hatchling exit holes at each of the nests. This is a great success, given that estimates suggest that >95% of unprotected turtle nests are depredated and recruitment levels in this population are believed to be very low.

Of the 5 nests documented at the second nest protection site, 3 nests were in very precarious locations – 1 in a corn field, and 2 that were low on the riverbank and susceptible to being destroyed in flooding events. The DNR requested the Zoo's assistance in initiating an impromptu head-starting program to incubate these eggs and raise the young until they reach a larger size and are less vulnerable to predation. All eggs were removed from 2 nests; with the third nest, half the eggs were collected and the other half were moved higher up the embankment.

Thirteen eggs incubated at the Zoo successfully hatched in early August. These individuals are being reared until late spring – early summer, 2020 (Figure 10) and will be released back to the site when conditions are favorable. A subset of the largest head-starts will be monitored with VHF transmitters to document post-release survival, movements and habitat use.



Figure 10. Headstart hatching wood turtles at MN Zoo, Aug. 3rd, 2019 (left). Two of the thirteen successfully hatched wood turtles for headstarting program at MN Zoo (right).

For spring 2020, we plan to again install electric fencing at the two nesting areas from 2019. The fenced area for the second site will be doubled, and we hope to construct an electric fence in at least one more location in southeastern Minnesota. We are also considering testing a large “turtle nesting box” structure (constructed of wood and hardware cloth or metal screening) adjacent to an electric fence. The box structure will be fully covered with screen and allow us to evaluate which design is more effective at keeping out mammalian predators, as well as whether wood turtles are more likely to nest in sites protected by 1 of the 2 designs.

Fourth Update June 30, 2020

We monitored wood turtles outfitted with VHF transmitters (16 adults and 3 juveniles) during the winter to quantify overwintering sites. In May, Zoo staff, in close collaboration with the DNR, deployed new GPS and VHF transmitters on wood turtles to facilitate monitoring during the 2020 season. Unfortunately, 2 adult female turtles, both monitored during previous seasons, died from unknown (likely natural) causes during winter – spring. These are the first recorded mortalities in this study and represent a significant loss to the depleted wood turtle population in southeastern Minnesota.

During 2020, turtles were outfitted with GPS and VHF transmitters at the 3 sites monitored in previous years as well as a new site in southern Minnesota. Despite the loss of 2 adult females during winter - spring, a number of new turtles were discovered this spring and incorporated into the study, bringing the total individuals currently outfitted with transmitters to 24 (21 adults [14 females and 7 males] and 3 juveniles; 15 GPS transmitters and 9 VHF transmitters). We continue to visit sites about every 2 weeks to relocate individuals and download positional data from GPS transmitters. The DNR also continues to partner with landowners to further restoration efforts at these sites.

As in 2019, we constructed 2 electric predator exclusion fences, removed some vegetation to entice turtles to nest at these sites, and installed camera traps to monitor access by nesting turtles and potential predators. This year, we doubled the size of the protected area at the site at which we documented multiple wood turtles nesting in 2019 (Site 2). Recent land management near this historic nesting area has created a large amount of potential nesting habitat. Given the availability of nesting habitat and the low densities of turtles, we did not install an additional wooden “turtle box” enclosure, as such efforts are typically more effective at sites where larger numbers of turtles nest in smaller areas.

Zoo and DNR staff tracked turtles for several nights during nesting season in mid-June and confirmed 8 wood turtle nests, including one located within the protected enclosure at Site 2. As in 2019, eggs from several nests

considered particularly vulnerable were returned to the Zoo for incubation. Most will be released shortly after hatching, but a subset will remain through the winter and spring as part of a head-starting initiative.

During late June, 13 juvenile wood turtles hatched in 2019 and subsequently reared at the Zoo were released at the site at which the eggs were initially collected (Figure 11). Within minutes, these turtles were exploring their new environment and finding food to eat. Each individual was uniquely marked with a microchip (PIT tag) to facilitate future identification. We did not outfit these turtles with VHF transmitters due to COVID-19 related constraints, but hope to track future cohorts.



Figure 11. One-year old head-start wood turtles were released to the wild during late June 2020 (left and right).

Fifth Update January 31, 2021

The 2020 field season was full of challenges related to the Covid-19 pandemic. Despite capacity limitations and other constraints, we succeeded in monitoring wood turtles outfitted with GPS and VHF transmitters. At one of our sites in southeastern Minnesota, we found 2 additional turtles and incorporated them into the study in early summer, increasing our sample of telemetered individuals to 22 adults and 4 juvenile (15 GPS transmitters and 11 VHF transmitters) in 2020. Three juveniles that were head-started at the Zoo and released in 2018 continue to do well. Unfortunately, one adult female was killed by farming machinery in a field, and two other adult turtles (1 male and 1 female) disappeared late in the summer and are suspected to have suffered similar fates. Loss of even a single breeding adult can significantly impact a small population of turtles. These losses highlight the threats that these turtles face and the urgency for action.

Throughout the field season, Zoo and DNR staff visited each site on average every 2 weeks, with GPS data downloaded monthly. The GPS data collected over the past four years are being analyzed to quantify movements, habitat use, and general spatial ecology of wood turtles in southeastern Minnesota.

We continued to monitor and maintain the two electric predator exclusion fences that were installed in the spring. (Due to capacity limitations resulting from the pandemic, we were unable to expand nest protection efforts in 2020 to test the effectiveness of other exclusion fences, such as larger turtle nesting box structures.) The exclusion fence at site 2 was installed higher on the bank this year and did not require repairs from flooding damage as it did in 2019. Regular maintenance included camera checks, removal of overgrown weeds, and ensuring that wires remained evenly spaced. Our cameras captured some turtle activity at site 2, but as in 2019, we did not identify turtle activity at site 1. We are continuing to review camera footage, but to date have not evidence that small mammalian predators breached the fence in 2020. At site 2, a single turtle nested inside the

fenced enclosure; this nest subsequently was protected with a smaller nest box. We removed fencing material in late September, several weeks after any hatchlings would have left the nesting sites.

In partnership with the DNR, we were able to confirm 8 wood turtle nests in 2020, including one that was located within the protective fence enclosure at site 2. Five nests were found at site 2 and 3 at site 4. No nests were confirmed at the other two sites despite multiple evenings of tracking female turtles during peak nesting season. Although we initially protected all nests with hardware cloth, one nest was completely depredated by a mole that dug underneath. Two other nests protected with wire fabric and flagging stakes were destroyed by farming equipment in early July after miscommunication with the landowner (Figure 12). All eggs were lost from one nest, but we were able to salvage and transport 6 eggs from the other nest to the Zoo to incubate. As in 2019, partial or whole clutches from several nests considered particularly vulnerable nests were returned to the Zoo for incubation. Thirty-five of the 38 eggs returned to the Minnesota Zoo for incubation successfully hatched in early August. A few weeks after hatching, 15 of these individuals were released near their nest sites. The remaining 20 turtles are being head-started at the Zoo and will be released in summer 2021, after they reach a larger size that is less vulnerable to predation.



Figure 12. July, 2020. Left: Protected wood turtle nest destroyed by farming equipment. Right: Wood turtle outfitted with GPS transmitter found on edge of field that was tilled just hours before.

The nest laid within the electric fence at site 2 successfully hatched by August 2020. We excavated the contents and identified shells from 5 hatched eggs, 1 deceased embryo remaining within the egg, and 10 eggs that did not develop. A second nest protected by a small nest box also successfully hatched, with 3 hatchlings and one nonviable egg documented (6 eggs from this nest were removed earlier and incubated at the Zoo).

Sixth Update June 30, 2021

Minnesota Zoo and DNR staff continued to radio-track 26 wood turtles through winter, 2021 to document their overwintering sites. We have not recorded any mortalities of turtles outfitted with transmitters this year, and an additional 6 turtles (5 adult females) were incorporated into the study this spring. The majority of this sample is outfitted with VHF transmitters, although the DNR deployed several GPS transmitters on wood turtles at a site with more significant data gaps. Data collected via GPS transmitters deployed in previous years is being analyzed to quantify important characteristics of wood turtle spatial ecology including home ranges, movements, and seasonal habitat use.

During June, DNR and Zoo staff worked collaboratively to collect as many wood turtle eggs as possible across several sites in southeastern Minnesota. Eggs were collected during the evening hours (when wood turtles typically nest; Figure 13); it was also during this time that most new turtles were located and added to this

study. We collected 88 eggs from 9 nests and further protected 1 nest *in situ*. Sixty-eight eggs were returned to the Zoo for incubation (with the balance incubated by the DNR); a subset of these hatchlings were reared at the Zoo as part of our head-starting initiative, with a targeted release in spring, 2022. The remaining hatchlings will be released shortly after hatching.

In addition, the 20 one-year old wood turtles head-started at the Zoo for the past year were released at their natal sites in late June 2021. These turtles were uniquely marked to facilitate their identification in the future. We are not radio-tracking these juvenile turtles, but we anticipate outfitting a sample of newly released head-starts with VHF transmitters in 2022 to allow us to document their survival, habitat use and general spatial ecology.

We did not establish any electric fences to protect nesting areas this year, based on our experiences in previous years. With the small and fragmented wood turtle population in southeastern Minnesota, it can be very difficult to predict exactly where individuals will nest in a given year. In addition, wood turtles are opportunistic in selecting their nesting sites; if weather conditions are not favorable, or if more suitable habitat is created elsewhere, turtles may nest in new areas. For example, a freshly tilled agricultural field or new river cutbank (created by a storm event) may be attractive to turtles, but these sites may not be conducive to the establishment of an electric fence (e.g., due to flood events, challenging topography or agricultural equipment). During 2019 and 2020, we created and fenced 2 protected areas: we did not document turtles nesting at the first site in either year, and we recorded two nests in 2019 and a single nest in 2020 at the second site. This return on our investment of time – particularly given our limited capacity – was too low to justify deploying fences again this year. As environmental conditions change and the population recovers, predator exclusion fences may prove to be a useful management tool in the future.



Figure 13. A wood turtle outfitted with a GPS transmitter excavates her nests before laying eggs during June 2021.

Seventh Update as of January 31, 2022

Despite capacity limitations and other constraints associated with the Covid-19 pandemic, we were successful in monitoring wood turtles outfitted with VHF transmitters in southeastern Minnesota throughout the summer and into the fall. When possible, detailed locality and behavioral data were recorded for individuals. In addition

to adult turtles, we continued to monitor three juvenile turtles who were released as head-starts in 2018 (Figure 14).



Figure 14. VHF tracked juvenile (left) and adult male (right) wood turtles. Turtles were found foraging in reed canary grass in close proximity to one another in summer, 2021.

Of the 68 eggs incubated at the Zoo during summer, 2021, 62 successfully hatched during late July and early August, 2021. A few weeks after hatching, 31 young turtles were released near their natal sites. The remaining 31 turtles are being head-started at the Zoo and will be released in spring 2022, after they reach a size that is less vulnerable to predation.

We also are analyzing GPS data collected during previous years to quantify movements and estimate home range size of wood turtles. Using the R package ‘amt’ (Signer et al. 2011), we calculated movement speed for all turtle relocations occurring four hours (+/- 5 min.) from the previous successful GPS fix (movement distance [m]/time[hour]). Overall, female turtles had faster average movement rates (3.62 m/hr) compared to males (2.95 m/hr). Female movement rates were fastest in June and July, whereas male turtles maintained relatively consistent movement rates throughout the active season (Figure 15).

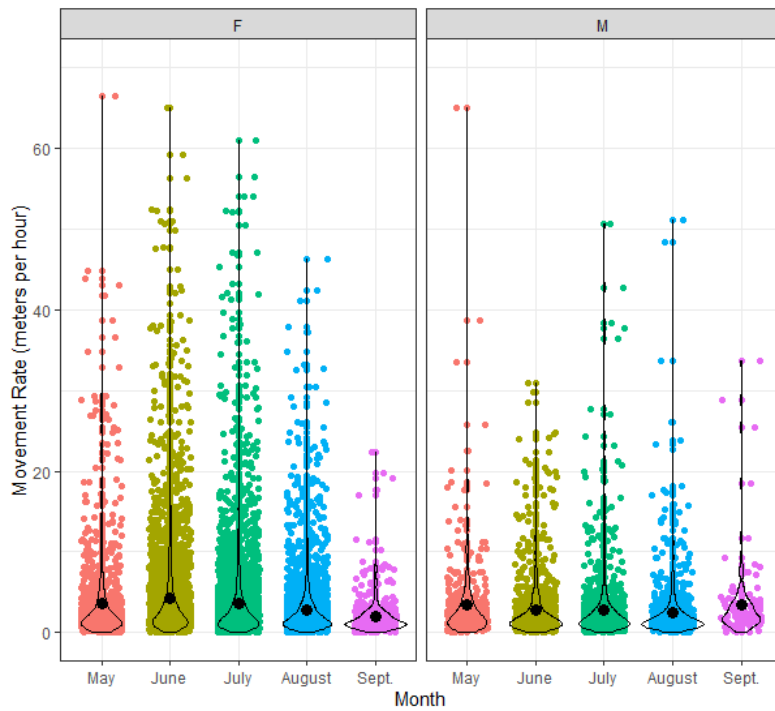


Figure 15. Movement rates by month by sex (females = left panel; males = right panel). Large black points represent mean values for the month.

We also calculated both 50% and 95% home range areas for turtle-years (i.e., for those turtles monitored in multiple years, we estimated home range size for each year) based on the following estimators: 1) minimum convex polygon (MCP), 2) kernel density estimator (KDE), 3) local convex hull (LoCoH), and 4) the autocorrelated KDE (aKDE) that first requires fitting a continuous-time movement model to the relocation data for each turtle-year. We chose to use multiple estimators because the MCP and KDE provide values that are comparable to most historical studies; the LoCoH is a very conservative estimator that is often applied when relocation data are limited in space due to physical barriers or behaviors that result in relocations along linear features (e.g., along rivers and streams); and the aKDE accounts for uncertainty related to fix frequency and movement characteristics. The resulting home range sizes were averaged by sex (Table 5).

Home range sizes varied based on estimator, and as expected, the largest differences were between the most (LoCoH) and least (aKDE) conservative estimators. Female wood turtle home range sizes were larger than males on average, and significantly larger based on the aKDE approach. Variation among individuals was far greater for females than males, driven by some individual females who traveled greater distances from streams, often to use crop fields.

Table 5. Mean and 95% confidence intervals for wood turtle home range sizes (km²) using the 95% value (95% isopleth, 95% MCP) by sex.

Estimator	Sex	Mean	SE	Lower 95% CI	Upper 95% CI
MCP	F	0.15	0.04	0.06	0.24
MCP	M	0.07	0.02	0.02	0.12
KDE	F	0.30	0.11	0.07	0.53
KDE	M	0.14	0.04	0.04	0.24

LoCoH	F	0.03	0.01	0.02	0.04
LoCoH	M	0.02	0.00	0.01	0.03
aKDE	F	1.06	0.23	0.60	1.51
aKDE	M	0.27	0.05	0.16	0.37

Final Update June 30, 2022

We are continuing to modify our analyses of the multi-year, GPS telemetry dataset collected from adult wood turtles across southeastern Minnesota. This work will improve our understanding of the spatial ecology of wood turtles, including seasonal variability in movements, ranges, and habitat use as well as important characteristics of nesting sites, information which will be critical as we work to create and restore nesting areas over the next few years. As part of the new ENRTF grant supporting phase 2 of this project, we have continued monitoring wood turtles via radio telemetry this spring. In close collaboration with the Minnesota DNR, we tracked more than a dozen adult female wood turtles at 3 sites during the nesting season and successfully collected ~70 eggs, which will be hatched at the Zoo this summer. A subset of these individuals will be reared (i.e., head-started) at the Zoo until summer, 2023. Later this summer, we will release 31 head-start wood turtles, reared at the Minnesota Zoo for the past 11 months, to their natal sites in the southeastern portion of the State.

Final Report Summary

Mortality of incubating turtle eggs and hatchlings remains a primary threat to the long-term recovery of depleted wood turtle populations. To quantify this risk and inform conservation efforts targeting improved hatching success, we outfitted adult female wood turtles with VHF and GPS transmitters, facilitating the identification of nesting sites at four locations in southeastern Minnesota. Once nesting sites were identified, we installed electric fencing to exclude mid-sized mammalian predators such as raccoons, skunks, and foxes.

Over 2 years, a total of 3 wood turtle nests were successfully protected within the electric fencing. The majority of wood turtles, however, nested outside the enclosures, necessitating the use of small nest protection boxes to prevent access by predators. Despite these efforts, nests were still lost to agricultural activity and predators such as moles digging under the protective structures. As other nests remained in areas susceptible to flooding and/or agriculture, in 2019 the Zoo initiated a head-starting program at the request of the DNR, incubating eggs and raising young in captivity until they reached a size less vulnerable to predation. In the first year, we successfully hatched 13 eggs at the Zoo and reared these individuals for one year before releasing them to the wild in 2020. In the two years following, an additional 97 eggs successfully hatched at the Zoo, with roughly half released shortly thereafter and 50 raised for a year as headstarts. This program has been expanding and will continue for the next few years with the support of a second ENRTF appropriation. Although electric fencing may be appropriate for some turtle populations that congregate in high densities in specific areas, it did not meet expectations for small and fragmented populations of wood turtles in southeastern Minnesota, as many of these turtles nest opportunistically in different areas each year. Collecting eggs and rearing hatchlings has provided much greater returns, despite intensive staff efforts required for egg collection and head-start care.

In addition to using spatial data of female turtles to locate nesting sites, we continued to track 8 to 26 wood turtles each year, including adult males, adult females, and juveniles. Analysis of GPS data revealed that female wood turtles move faster than males on average and have larger home range sizes. These spatial data also were useful in identifying additional potential nesting sites and key habitat characteristics. We are continuing to analyze the multi-year spatial dataset to better understand seasonal variability of movements and habitat use, which will inform future management and habitat restoration projects.

ACTIVITY 3:

Description: Building public awareness at the Zoo and beyond

The Zoo will leverage its ~1.3 million annual visitors and its expertise in education and outreach programming to raise public awareness about the conservation of turtles in Minnesota and our aquatic resources. Our efforts will include both on-site programming and outreach events at communities around the State. The Zoo's well-regarded Zoomobile programs, which feature Blanding's and wood turtles, give citizens from across Minnesota the opportunity to experience wildlife up-close in their own communities. Using Zoomobile as a platform to share key conservation messages off-site, we will develop outreach materials centered on Minnesota's turtles, such as workbooks and informational booklets, which can be shared and left behind after any Zoomobile program that incorporates turtles.

At the Zoo, we will develop similar turtle conservation messaging with the Zoo's Close Encounters program, which enables visitors the opportunity to experience wildlife up-close at the Zoo. We will also develop and install interpretive graphics and contract a videographer to produce a short (3 – 5 minute) video to convey these same conservation messages to Zoo visitors.

ENRTF BUDGET: \$14,500

Outcome	Completion Date
1. Outreach materials promoting the conservation of turtles in Minnesota developed and printed.	June, 2019
2. Interpretive graphics and video outlining the biology and conservation of freshwater turtles developed and installed.	June, 2019
3. Outreach materials disseminated via Zoomobile and other programs. Dissemination of these materials will begin during summer, 2019.	June, 2021

First Update January 31, 2019

We are working with several Zoo departments to raise public awareness about turtle conservation on-site. We are collaborating with the Zoo's interpretive program staff to design new signage to highlight turtle ecology and conservation, and we are developing a video to detail research and conservation efforts as well as actions the public can take to promote turtle conservation. We also are exploring opportunities for interactive activities and interpretive materials that may be used by our volunteer corps and in conjunction with the Zoo's Close Encounter programs (e.g., 3-dimensional, durable turtle model to educate Zoo visitors about turtle anatomy and engage them in conservation). With graphic design staff, we created an outreach poster outlining turtle biology and our conservation efforts for use at future public events. In addition, we are partnering with the Zoo's Education and Zoomobile teams to identify ways to better incorporate turtle conservation messaging in their programs. Initial ideas include affixing VHF transmitters to turtles naturally found on the Zoo's property, providing student groups an opportunity to gain hands-on experience with scientific field research, learn about habitat needs of turtles, and participate in citizen science data collection.

Zoo staff also contributed to the development of a children's book. The book's story-telling approach highlights the perils that a Blanding's turtle may face, including road mortality, predation, and habitat degradation - all of which are very relevant to our conservation messaging. We anticipate using these books in our classroom-based education programs and in outreach activities such as Zoomobile programs.

Second Update June 30, 2019

We are continuing to partner with departments across the Zoo to develop and implement a variety of activities designed to promote public awareness of Minnesota's turtles and improve their conservation. During the winter, Conservation staff worked with our colleagues in the Zoomobile and Education departments to create a

wood turtle coloring and fact sheet for children. This handout has been distributed – and well-received – at several events over the past 5 months. To supplement this handout, we printed turtle stickers that feature an image of a Blanding’s turtle from the forthcoming children’s book to which the Zoo contributed as fun giveaways. We also submitted an order for 1,000 copies of the children’s book (as part of its first printing) and anticipate that these copies will be available early in fiscal year 2020. Books will be distributed by Zoomobile and Education staff during off-site outreach events and on-site visits by school groups.

New signage highlighting Minnesota’s turtles and their conservation is under development and will be installed by the end of the summer. We have identified a videographer to develop a short public awareness video and are finalizing the script. We anticipate that filming will take place in late summer / early fall so that the videographer, who is currently traveling, is able to accompany Zoo staff in the field. In addition, we are working with the Zoo’s interpretive and volunteer services staff to create a rugged, 3-dimensional model of a turtle that can be disassembled. This model will serve as an outreach tool to help facilitate discussions about turtle biology. We have identified an artist to complete this project and currently are compiling model specifications.

Conservation staff created a hands-on activity for kids (and adults) for use at outreach events. This activity provides experience with radio telemetry, a frequently used technique in wildlife management and conservation, as participants attempt to find a ‘hidden’ toy turtle. Once individuals have located the turtle and developed an understanding of the field method, they bring their ‘data’ to a map which allows us to document the location of the turtle. This format provides an opportunity to discuss the risks that wild turtles face and their conservation needs. The activity has proven to be an effective tool for communicating about Minnesota’s turtles and the Zoo’s initiative.

Finally, Conservation staff are assisting the Zoo’s STEM educators with an on-site initiative providing students with an opportunity to track wild turtles at the Zoo. We have deployed VHF transmitters on 2 painted turtles and 1 snapping turtle as part of this project (funding for VHF transmitters is provided by other, non-ENRTF sources). This initiative will allow children to track turtles and participate in data collection as part of a unique citizen science initiative.

Third Update January 31, 2020

In the latter part of 2019, the Zoo continued to work on several efforts to build awareness for turtle conservation. On-site at the Zoo, staff developed a large interpretive graphic highlighting turtle conservation (Figure 16); the sign has been printed and is ready for installation this spring. In addition, Zoo staff helped to provide content for the children’s book “A Turtle’s Dangerous Journey.” This book was printed during summer, 2019, and is currently being disseminated to the public (Figure 17). Over 200 copies have been provided to school and community groups and the general public via tabling events, school group visits, and Zoomobile outreach programs. Minnesota Zoo e-blasts and newsletters continue to highlight turtle conservation initiatives, including recent internal posts on our head-starting project and a piece on what turtles do during the winter months. January was also Members Month at the Zoo, and turtle conservation was a featured topic, with a tabling event and associated outreach materials.

In spring and summer 2020, turtle conservation staff will be partnering with Zoo Education staff to help implement a new STEM-based summer camp program. The course will include tracking wild turtles on Zoo site, presentations by Conservation staff, and independent projects developed by the campers.

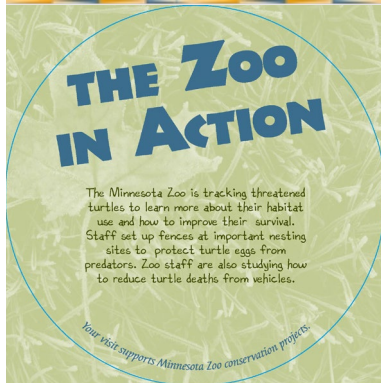


Figure 16. Two components of a new interpretive sign being installed at the Minnesota Zoo this spring.

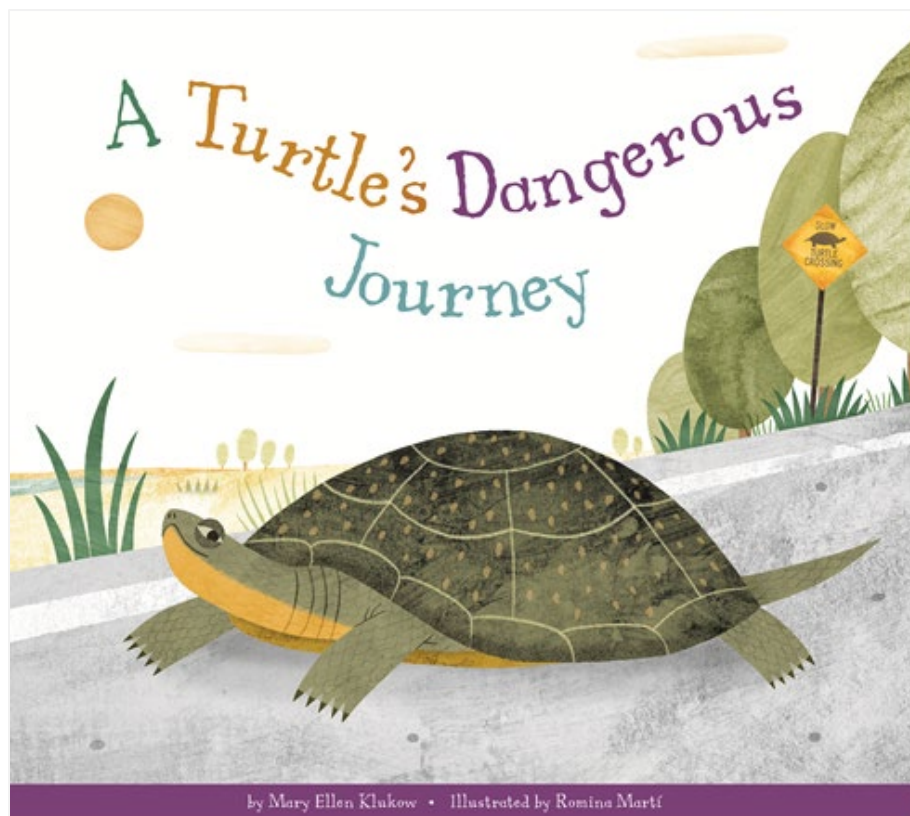


Figure 17. Cover of the children's book "A Turtle's Dangerous Journey".

We have secured a videographer for a short video highlighting turtle conservation and research efforts in Minnesota. Zoo staff are drafting the script, and filming is scheduled for May 2020. Our original plan to film in the fall was delayed due to scheduling conflicts and the early onset of winter temperatures. We anticipate that the film will be completed by early summer, 2020.

Off-site, Zoo staff continued to engage the public through events and talks. Turtle conservation was featured by the Zoo at a tabling event during STEM day at the Minnesota State Fair. With a hands-on turtle telemetry activity, turtle biofacts (shells, eggs, photos), and the children's book, we interacted with hundreds of fair attendees throughout the day. The Zoo's road mortality research also has received media attention, initially through an internal video for MnDOT, followed by an interview with KSTP news which aired on the evening news.

Notably, a staff member at St. John Lutheran School saw the KSTP piece and reached out to Zoo Conservation staff for guidance on a competitive STEM project that were completing. The students were compelled to help turtles on roads and created a presentation and plan to raise awareness and funds for turtle crossings in their community. The group even advanced to a state-level competition for their idea.

Fourth Update June 30, 2020

Whereas the research elements of the project proceeded generally as planned during early 2020, many outreach activities, as well as the development of educational materials designed to raise public awareness about turtle conservation, have been postponed or cancelled due to COVID-19. Summer camps, an on-site citizen science initiative, and public presentations – all outlets for disseminating information and improving the conservation of turtles – have been impacted by the pandemic.

In addition, a videographer was scheduled to film and produce a short video about the conservation of Minnesota's turtles this spring, for dissemination at the Zoo and through our social media outlets. Filming remains on hold, but we hope to move forward with this project later this year. Finally, we are partnering with an artist to create a 3D turtle model that may be disassembled and used with outreach and education programs. We anticipate this project's completion anticipated later this summer.

Fifth Update January 31, 2021

Although outreach activities continued to be hindered by the COVID-19 pandemic during the second half of 2020, we were able to advance a handful of activities that will build public awareness about turtle conservation. In partnership with Saint Paul Public Schools Nutritional Services, Zoo Education staff distributed materials at 3 different sites (Harding High School, Cherokee Heights Elementary School, and Mayfield Elementary School) during August 2020. The goal of this effort was to get books and resources about conservation into the hands of children who may not have had access to technology over the summer. Some 600 copies of the book "A Turtle's Dangerous Journey" were distributed to kids picking up curbside meals at these sites.

During the summer, a volunteer film student joined Conservation staff to document the release of head-start wood turtles hatched at the Zoo in 2019. The student is finalizing a short video that will allow the Zoo to share this head-starting initiative with the public. In addition, we contracted with a professional videographer to facilitate filming our conservation activities in early August. The videographer is creating a short film highlighting Minnesota turtles and associated conservation efforts. We anticipate that the video will be completed and available for sharing with the general public by the spring.

Finally, the 3-dimensional, life-size snapping turtle model was completed this fall. This durable piece was custom-designed and 3D printed. The top shell (carapace) can be removed to view the internal anatomy; 8 organs are detailed, with several that are removable (Figure 18). The model will support our outreach activities and serve as a great engagement tool to help build awareness about Minnesota's native turtles.



Figure 18. 3D-printed snapping turtle model. Top: External view of model. Bottom: Shell removed for view of internal anatomy. Several organs are removable.

Sixth Update June 30, 2021

The Minnesota Zoo's education and outreach efforts continued to be significantly impacted by the pandemic during the first half of 2021. Summer camps remain virtual, but Zoo education staff highlight turtle ecology and our conservation work in these programs. Increased visitation capacity also will expand opportunities to engage visitors with conservation messaging on campus.

We are creating 2 new interpretive signs for display at the Zoo that will share information with the public about Minnesota's turtles. These signs will feature snapping turtles and painted turtles, species that exist on Zoo campus and are commonly observed by the public at the Zoo's Main Lake. These new additions will complement the interpretive sign addressing turtle conservation that was previously designed and installed.

We also are excited to share that the short film highlighting Minnesota's turtles and ongoing efforts to conserve this natural resource is now complete. A link to the video, which already has been shared with thousands of the Zoo's member and donor households, is located [here](#); visitors have the opportunity to view the video on campus as well.

Seventh Update as of January 31, 2022

Many of the outreach-associated activities and events that were enjoyed by the public before the pandemic (e.g., summer camps) will be returning to the Minnesota Zoo later this year. In addition, two new interpretive signs have been designed and will be installed near the Zoo's Main Lake this spring. The signs highlight information on snapping and painted turtles that are native to the Zoo's campus and often observed by the public. This will compliment other turtle conservation messaging on site. Finally, we have ordered an additional 1,000 copies of the book "A Turtle's Dangerous Journey," promoting turtle awareness and conservation, to distribute to kids during on and off-site events.

Final Update June 30, 2022

On-site education and interpretive programming returned to the Minnesota Zoo this spring and summer! School groups resumed visitation and field trips earlier this year, and in-person summer camps are again underway following a multi-year, pandemic-induced hiatus. Zoo staff are sharing turtle conservation messages with campers and the general public, and the Conservation and Education teams are creating opportunities for campers and other visitors to learn about – and contribute to – wildlife research by conducting radio telemetry of native turtles on Zoo grounds. In addition, the conservation of Minnesota's turtles will be featured at a [Wild Nights](#) event at the Zoo later this summer.

Finally, signs detailing the ecology of turtles commonly observed at the Zoo – as well as ongoing conservation efforts – have been installed around the Zoo's Main Lake, providing a new means to share information with visitors.





Figure 19. Painted turtles, snapping turtles, and associated turtle conservation efforts are highlighted in new signs installed at the Zoo’s Main Lake.

Final Report Summary

The Minnesota Zoo created a diversity of tools and resources to build public awareness and encourage action on behalf of turtles and other aquatic wildlife with this project. Despite major setbacks associated with the COVID-19 pandemic beginning in early 2020, the Zoo continued its role as a valued resource for conservation messaging and outreach. When it was not possible to gather together, virtual camps were used to connect students to turtle ecology and engage them in problem-solving for turtles at risk.

Education and Conservation Departments partnered to create a wood turtle coloring and fact sheet, turtle stickers, a poster for tabling events, and a hands-on turtle tracking game. In addition, the Zoo provided content and feedback to a publisher creating a children’s book on turtle conservation - “A Turtle’s Dangerous Journey.” The Zoo has distributed >1000 copies to the public via tabling events, school group visits, and outreach programs. These hand-outs and activities have proven to be effective tools for communicating about Minnesota’s turtles and our conservation initiatives.

To further highlight the Zoo’s conservation efforts, we contracted with a professional videographer to film and produce a short video, which has been widely shared on the Zoo’s social media outlet. In addition, a local artist designed and created a life-sized, 3-D printed snapping turtle with take-apart internal anatomy. This model is now being used for interpretive programs and serves as a great engagement tool to help build awareness about Minnesota’s native turtles. Further, three signs detailing the ecology of turtles commonly observed at the Zoo – as well as ongoing conservation efforts – have been installed around the Zoo’s Main Lake, providing a new means to share information with visitors.

Finally, Conservation staff are assisting the Zoo’s STEM educators with an on-site initiative, providing students an opportunity to track wild turtles outfitted with radio transmitters at the Zoo. We have deployed VHF transmitters on 2 painted turtles as part of this project for students to collect and analyze real scientific field data.

IV. DISSEMINATION:

Description:

Updates on activities and progress will be shared with collaborators via regular reports, and information about this work will be disseminated to the general public by the Zoo's Conservation, Marketing and Education departments as frequently as possible. These communications may include ZooMobile and other public presentations by staff and sharing information on the Minnesota Zoo's web page and social media outlets. In addition, Zoo staff and volunteers will be instructed in speaking with the public about turtles and the benefits of turtles for healthy aquatic ecosystems. Results of research addressing mechanisms to mitigate road mortality and improve hatching success will be submitted for publication in peer-reviewed scientific journals and presented at professional conferences.

First Update January 31, 2019

The Zoo raised awareness of freshwater turtle conservation through several venues during 2018:

- Dr. Markle outlined our turtle conservation initiative at the Zoo's Director's Reception in September 2018.
- In October 2018, we participated in the international "Imagine a Day without Water" campaign, where Zoo staff called attention to the importance of clean water. One of the features addressed how turtles help to keep our aquatic environments healthy and, in turn, how they need a clean environment to survive.
- In November 2018, we contributed content to the Zoo's regular e-newsletter and wrote a blog outlining the negative consequences of road and sidewalk salts on freshwater ecosystems, as well as ways that the public can help reduce their impact. In January 2019, we drafted additional content for the e-newsletter and authored a blog describing the fascinating ways that turtles survive cold winters in Minnesota.
- Also in January, Dr. Markle presented our turtle conservation initiatives at a state-wide herpetological coordination meeting. She shared our work with students and staff at Carleton College during a talk there as well.
- Finally, Zoo staff were invited to contribute to the state's Minnesota Wood Turtle Conservation plan as members of the newly formed Wood Turtle Team. This planning process will be ongoing throughout 2019.

Second Update June 30, 2019

The Zoo continued to promote awareness of Minnesota's freshwater turtles and encourage public action on behalf of turtle conservation during the first half of 2019:

- Zoo Conservation staff drafted content about 1) the impacts of plastics on both freshwater and marine turtles and how the public can help to reduce plastic pollution (February 2019) and 2) increased turtle activity during spring and how the public can safely help turtles cross roads (May and June, 2019). Content was distributed by email to >40,000 Zoo member and supporter households.
- In March 2019, Dr. Markle was featured in an interview on Fox 9 Morning Buzz. She discussed the turtle conservation initiatives conducted by the Minnesota Zoo. This interview was part of a promotion for a Women in Science Day at the Bakken Museum, at which Zoo staff tabled with information, activities, and giveaways to promote turtle conservation.
- Zoo Conservation staff shared information on Minnesota's water resources and freshwater turtle conservation efforts at a meeting of the Minnesota Herpetological Society, a public talk in Eagan, and a naturalist training course at the Zoo.

- Throughout the winter and spring, Zoo staff continued to contribute to the state’s Wood Turtle Conservation Plan through meetings and information sharing. A draft of the Plan is anticipated later this year.

Third Update January 31, 2020

We continued to share information about turtle conservation in Minnesota and the ongoing efforts of the Zoo and our partners during the second half of 2019:

- Zoo staff participated in a full-day tabling event at the Minnesota State Fair as part of STEM day (August 22, 2019). Education and Conservation staff interacted with several hundred fair attendees, providing information on our freshwater turtle conservation program, conducting a hands-on telemetry activity, and sharing the children’s book.
- In November 2019, Dr. Markle presented on the Zoo’s turtle conservation and research program at the national Spotted, Blanding’s and Wood Turtle Symposium in Berkeley Springs, West Virginia.
- Dr. Markle was interviewed about the road mortality project for an internal MnDOT video describing the inter-agency partnership, which was shared across multiple social media channels. Subsequently, she completed an interview with KSTP News that aired on the evening news.
- We drafted a short article for an internal newsletter describing threats to wood turtles and detailing the Zoo’s new head-starting initiative. Other internal communications included a talk to the Zoo’s volunteer corps during the fall. External talks detailing the Zoo’s turtle initiative have included public lectures in Eagan and Minnetonka.
- The Zoo featured freshwater turtle conservation during a recent Members Appreciation Day (Jan. 23, 2020). Activities included an outreach tabling event and children’s book signing.
- Zoo staff across various departments have distributed >200 “A Turtle’s Dangerous Journey” books, highlighting the threats turtles face in Minnesota and the Upper Midwest and what we can do to help, to school and community groups and the general public.

Fourth Update June 30, 2020

As a result of the COVID-19 pandemic and the Minnesota Zoo’s closure in mid-March, the past several months have presented challenges in disseminating information. However, recent activities have included:

- In February, Dr. Markle discussed the conservation of Minnesota’s turtles at a seminar hosted by the University of Minnesota’s Conservation Sciences Graduate Program and at the Twin Cities’ monthly “Nerd Nite Out” event.
- Conservation staff presented information about the Zoo’s turtle conservation initiative at winter and spring board meetings and internal Zoo-wide staff meetings.
- The Zoo featured educational pieces about turtle conservation and the State’s ongoing conservation efforts through various social media channels.
- Zoo staff continue to contribute to the state’s Wood Turtle Conservation Plan. A final draft of the plan is now being reviewed by team members.

Fifth Update January 31, 2021

The pandemic continued to limit our ability to conduct outreach. As such, our activities largely have pivoted to online and virtual platforms. Highlights from the past several months include:

- In July, a blog outlining the release of one-year-old wood turtles head-started at the Zoo was incorporated in the Zoo’s monthly member newsletter and shared on the Zoo’s Facebook page.

- In August, the State’s Wood Turtle Planning Team (of which Zoo Conservation staff are members) completed the Minnesota Wood Turtle Conservation Plan. The purpose of the plan is to identify strategies to advance the conservation and recovery of wood turtles. The document identifies issues, 10-year goals, prioritized strategies, and targeted implementation activities.
- In November, Dr. Markle gave an online presentation to the American Association of State Highway and Transportation Officials’ Committee on Environment and Sustainability, detailing our efforts to reduce turtle road mortality.
- From November – January, Minnesota turtle conservation was highlighted as part of the Zoo’s outdoor special event “Nature Illuminated”. The drive-through event featured a giant inflatable Blanding’s turtle (a species categorized as Threatened by the State of Minnesota) and associated messaging outlining the threats facing and conservation of Minnesota’s turtles.
- Conservation staff again presented information about Minnesota’s turtles and our efforts to conserve them at internal Zoo-wide staff meetings.

Sixth Update June 30, 2021

Although in-person events and speaking engagements remain limited, the Zoo’s turtle conservation initiative has received considerable media coverage in recent months. Highlights of media coverage and other dissemination outlets include:

- In April, the Zoo’s road mortality research and partnership with MnDOT was featured in the Star Tribune: <https://www.startribune.com/roadside-fences-show-promise-for-reducing-minnesota-turtle-fatalities/600042873/?refresh=true>
- In May, the Zoo’s new quarterly Conservation Connection newsletter, which included a feature story about turtle conservation, was distributed to thousands of member and donor households. In honor of World Turtle Day, the newsletter also included a link to the Zoo’s new [short film](#) about turtle conservation.
- Also in May, an article in the Dakota County Tribune detailed the Zoo’s partnership with the DNR and our ongoing efforts to conserve Minnesota’s wood turtles. https://www.hometownsource.com/zoo-continues-wood-turtle-conservation-project/article_01e3ebb4-be6a-11eb-ab1e-6f80732fd24c.html
- In June, journalists from PBS’s “Prairie Sportsman” filmed elements of the wood turtle conservation work, including the release of head-started wood turtles earlier in the month. Additional filming will take place later this summer.
- Also in June, Zoo Conservation staff were filmed and interviewed by Morrie’s Auto Group to highlight our partnership and share information about our conservation work.
- Finally, at the end of June, the Minnesota Zoo’s turtle road mortality research project with MnDOT was featured in a short segment on WCCO-TV’s evening and morning news. <https://minnesota.cbslocal.com/2021/06/28/minnesota-zoo-mndot-partner-to-address-dwindling-blandings-turtle-population/>

Seventh Update as of January 31, 2022

- In July 2021, the Minnesota Zoo became an official partner in the Association of Zoos and Aquariums (AZA) new SAFE American Turtle Program. The SAFE (Saving Animals From Extinction) program is designed to leverage the collective support and expertise of zoos and aquariums from across the country to coordinate efforts and implement strategic conservation actions to save wildlife.

- In September 2021, Dr. Markle gave a virtual presentation titled “Mitigating Small Animal Road Mortality” at the International Conference on Ecology and Transportation. A link to the recorded presentation is found [here](#).
- Also in September, the Zoo’s quarterly Conservation Connection newsletter included a feature story about our road mortality mitigation project and partnership with the Minnesota Department of Transportation. In December 2021, the newsletter incorporated a “Science in Action” piece on our telemetry research.
- For Give to the Max Day (November 18, 2021) the Minnesota Zoo Foundation posted short video clips of interviews with Zoo Conservation staff on social media to highlight the Zoo’s field conservation efforts.
- In December 2021, Minnesota Zoo Conservation staff working on the turtle initiative were invited to join the Midwest Wood Turtle Working Group, which brings together researchers from across the Midwest to share current research efforts and coordinate conservation initiatives.

Final Update June 30, 2022

Highlights of media coverage and other dissemination outlets include:

- In March 2022, Dr. Markle gave a virtual presentation for the West Metro Chapter of the Minnesota Master Naturalists titled “Minnesota Turtle Conservation”.
- In April 2022, turtle conservation work in Minnesota was a feature story in PBS’s [Prairie Sportsman](#) in a segment called “Save the Turtles”. This piece originally aired on Pioneer PBS on April 17, 2022 and later aired on multiple PBS stations in Minnesota, Wisconsin and Iowa.
- Also in April, the Zoo’s Conservation Connection newsletter, distributed electronically to member and donor households, profiled turtle conservation activities planned during the 2022 field season.
- On May 23, 2022, the Minnesota Zoo promoted World Turtle Day by sharing turtle conservation messaging on social media platforms.
- Finally, in June 2022, the Zoo’s turtle conservation initiative was featured in a TV spot during a Minnesota Twins game; this segment was produced by the Minnesota Lottery to promote ENRTF supported projects.

Final Report Summary

Sharing information about the importance of turtles and their conservation was a key objective of this project. The Minnesota Zoo used a variety of platforms to disseminate significant findings and engage the general public in the conservation of Minnesota’s aquatic resources, ranging from informal talks, public and academic lectures and tabling events to media spotlights and distributing content on our social media channels. Relevant content also was disseminated via email to >40,000 Zoo member and donor households. Media highlights included features on PBS’s *Prairie Sportsman*, Kare 11’s *Minnesota Bound*, and a Minnesota Lottery commercial, and stories on a variety of other print and television media outlets such as the Fox 9 Morning Buzz, KSTP’s evening news, WCCO-TV’s evening and morning news, and newspaper articles in the Star Tribune and Dakota County Tribune. This [video](#) highlights the ecology and conservation of turtles in Minnesota. We also shared findings at scientific meetings including the National Spotted, Blanding’s and Wood Turtle Symposium and the International Conference on Ecology and Transportation.

V. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview: See attached budget spreadsheet

Explanation of Capital Expenditures Greater Than \$5,000:

N/A

Explanation of Use of Classified Staff:

Two staff positions will be supported by these ENRTF funds. The Biologist position, which will be primarily funded by ENRTF (with supplemental funding received from another funding source), will be hired upon initiation of this project. The Principal Investigator / Project Manager is classified. S. Stapleton, current staff at the Zoo, has the necessary expertise to successfully oversee Activities 1, 2, and 3 as the PI / Project Manager. However, without the support of the ENRTF funding, he would not have the ability to work on this project and instead would need to focus on other position responsibilities. Incorporating existing expertise at the Zoo will be essential for the completion of this project.

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: 5,928	Divide by 2,080 = TOTAL FTE: 2.85
--	-----------------------------------

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: ~100	Divide by 2,080 = TOTAL FTE: ~0.02
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B. Other Funds:

SOURCE OF AND USE OF OTHER FUNDS	Amount Spent	Status and Timeframe
Other Non-State \$ To Be Applied To Project During Project Period:		
Minnesota Zoo Foundation; supplies, equipment and other expenditures in support of the Zoo's turtle conservation initiative. Estimate.	\$ 20,000	FY19 – FY22
Other State \$ To Be Applied To Project During Project Period:		
MN Zoo, General Operating Budget: Utilities and administrative costs, estimated at 15% of expended funds.	\$ 42,100	FY19 – FY22
Minnesota Zoo's appropriation from State of Minnesota's Clean Water, Land and Legacy amendment. Additional costs associated with project implementation including equipment, supplies and staff time. Estimate.	\$30,000	FY19 – FY21
Minnesota Department of Transportation, grant to MN Zoo for complementary work, entitled "Reduced vehicle-animal collisions with installation of small animal exclusion fencing."	\$ 110,776	FY18 – FY22; Additional funding remained within MnDOT for installation of roadside exclusion fencing.

VI. PROJECT PARTNERS:

The Minnesota Zoo would be the sole recipient of ENRTF funds under this proposal. Zoo Conservation staff will plan and implement Activities 1 and 2 in partnership with MnDOT and DNR. Zoo Conservation and Education staff will jointly plan and implement Activity 3. We anticipate developing partnerships with other organizations, potentially including local governments and management authorities, universities, and NGOs, as work progresses.

A. Partners receiving ENRTF funding: N/A

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
Chris Smith	Wildlife Ecologist, Protected Species Coordinator	Mn DOT	Key partner for implementation of Activity 1. Roles include technical advice on selection of roadways for study, coordination with road management authorities, selection and installation of mitigation mechanisms, and monitoring.
Peter Leete	Transportation Hydrologist (DNR – MnDOT Liason)	MN DNR	Key partner for implementation of Activity 1. Roles include technical advice on selection of roadways for study, coordination with road management authorities, selection and installation of mitigation mechanisms, and monitoring.
Elizabeth Brown	Environmental Program Specialist	Mn DOT	Key partner for implementation of Activity 1. Roles include technical advice on selection of roadways for study, coordination with road management authorities, selection and installation of mitigation mechanisms, and monitoring.
Carol Hall	Herpetologist	MN DNR	Key partner for implementation of Activity 2. Roles include selection of study sites, surveys for and capture of turtles to be outfitted with GPS transmitters, technical advice on nesting site selection for installation of predator exclusion fencing, and monitoring. Additional advice on site selection for Activity 1.
Krista Larson	Nongame Research Biologist	MN DNR	Key partner for implementation of Activity 2. Roles include selection of study sites, surveys for and capture of turtles to be outfitted with GPS transmitters, technical advice on nesting site selection for installation of predator exclusion fencing, and monitoring. Additional advice on site selection for Activity 1.
Jaime Edwards	Nongame Wildlife Specialist	MN DNR	Key partner for implementation of Activity 2. Roles include selection of study sites, surveys for and capture of turtles to be outfitted with GPS transmitters, technical advice on nesting site selection for installation of predator exclusion fencing, and monitoring. Additional advice on site selection for Activity 1.

Barb Perry	Natural Resources Technician	MN DNR	Key partner for implementation of Activity 2. Roles include selection of study sites, surveys for and capture of turtles to be outfitted with GPS transmitters, technical advice on nesting site selection for installation of predator exclusion fencing, and monitoring. Additional advice on site selection for Activity 1.
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VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The goal of this project is to improve the conservation of Minnesota’s imperiled turtles by mitigating two important sources of mortality. We will also promote public awareness about turtles and identify actions Minnesotans can take to benefit the conservation of our aquatic resources. This is particularly important at present, as both Blanding’s and wood turtles are currently undergoing status reviews by the US Fish and Wildlife Service to determine whether they should be proposed for listing under the federal Endangered Species Act (ESA). Working proactively to improve the health of local turtle populations may avoid the regulatory burden and potential economic impacts associated with a possible listing under the ESA. Aspects of our work, such as reducing road mortality, will benefit other wildlife, including reptiles and amphibians. This project also meets an objective of the DNR’s 2015 – 2025 Wildlife Action Plan, which calls for collecting data to update the status of wood turtles in Minnesota and inform the state’s wood turtle conservation plan.

Evaluating and implementing strategies that improve the long-term viability of turtle populations may require several years. As such, we anticipate that the Zoo’s activities to promote the conservation of turtles may continue beyond the scope of this grant. Hence, the Zoo will continue to explore non-ENRTF funding sources for this project and may submit a future proposal to fund this work.

VIII. REPORTING REQUIREMENTS:

- The project is for 4 years, will begin on July 1, 2018, and end on June 30, 2022.
- Periodic project status update reports will be submitted January 31 of each year.
- A final report and associated products will be submitted between June 30 and August 15, 2022.

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

- A. Budget Spreadsheet
- B. Visual Component or Map
- C. Research Addendum

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2018 Budget Spreadsheet



Project Title: Conserving Minnesota's Nine Species of Freshwater Turtles

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 03k

Project Manager: Seth Stapleton

Organization: Minnesota Zoo

College/Department/Division: Conservation

M.L. 2018 ENRTF Appropriation: \$300,000

Project Length and Completion Date: 4 years, June 30, 2022

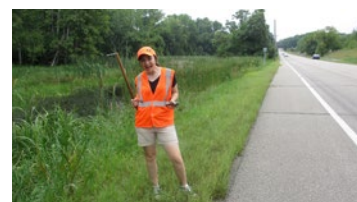
Date of Report: June 30, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Revised Budget 2/8/2020	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	\$233,225	\$233,225	\$0
S. Stapleton, Principal Investigator / Project Manager. (1 person, 72% salary / 28% benefits), 0.05 FTE for 3 years - \$16,225			
Biologist (to be determined). Research Analyst Intermediate or similar classification. (1 person, ~64% salary / 36% benefits). ~0.90 FTE for 3 years - \$217,000			
Professional/Technical/Service Contracts			
Videographer contract to develop a short (3 - 5 min) video about Minnesota's turtles.	\$5,000	\$4,800	\$200
Equipment/Tools/Supplies			
Road mortality mitigation measures, including traffic signs, lights, and road paint	\$15,000	\$4,480	\$10,520
GPS transmitters to track movements of wood turtles (~\$1,400 / unit; 16 total units for 2018, 2019, and 2020)	\$22,500	\$22,452	\$48
Predator exclusion fencing and monitoring equipment (est. at \$5,000 / unit, including hardware, fencing, batteries, and cameras; 4 units plus small contingency for additional supplies)	\$11,775	\$6,076	\$5,699
Printing			
Printing of outreach materials, potentially including educational workbooks and / or booklets, that raise awareness and promote the conservation of turtles.	\$7,500	\$7,500	\$0
Travel expenses in Minnesota			
Fuel / mileage and meals to travel to field sites in southern and central Minnesota: \$1,000 / yr for 3 years. Reimbursement rates as allotted per the State of Minnesota travel regulations.	\$3,000	\$1,615	\$1,385
Other			
Zoo-based turtle conservation educational and outreach, including photo licensing and interpretive signage and displays	\$2,000	\$568	\$1,432
COLUMN TOTAL	\$300,000	\$280,716	\$19,284



Mitigating Road Mortality

Road mortality is one of many threats faced by turtles in Minnesota. Although warning signs may be suitable in some circumstances, our research found that simple barriers are the most effective strategy for reducing turtle mortality.





Building Public Awareness

To raise awareness about the conservation of turtles, we developed educational materials including a durable, life-sized model of a snapping turtle, a video highlighting conservation efforts, and interpretive graphics. We also provided content for a children's book and disseminated printed copies during programming. On and off-campus programs provided the public with the opportunity to view turtles and other wildlife first-hand.





Tracking Imperiled Turtles

We attached radio and GPS transmitters to threatened wood turtles to improve our understanding of their habitat needs and inform turtle conservation in Minnesota. We also identified turtle nesting sites, allowing us to protect some nests with predator exclusion fencing and collect eggs from other nests to support head-starting efforts at the Zoo.



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

Seth Stapleton, Principal Investigator
Department of Conversation and Research
Minnesota Zoo

JUNE 2022

Research Report
Final Report 2022-19

To request this document in an alternative format, such as braille or large print, call [651-366-4718](tel:651-366-4718) or [1-800-657-3774](tel:1-800-657-3774) (Greater Minnesota) or email your request to ADArequest.dot@state.mn.us. Please request at least one week in advance.

Technical Report Documentation Page

1. Report No. MN 2022-19	2.	3. Recipients Accession No.	
4. Title and Subtitle Reduce vehicle-animal collisions with installation of small animal exclusion fencing		5. Report Date June 2022	
		6.	
7. Author(s) Tricia Markle and Seth Stapleton		8. Performing Organization Report No.	
9. Performing Organization Name and Address Minnesota Zoo Department of Conservation and Research 13000 Zoo Blvd Apple Valley, MN 55124		10. Project/Task/Work Unit No.	
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12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research & Innovation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899		13. Type of Report and Period Covered Final Report, FY2018-FY2022	
		14. Sponsoring Agency Code	
15. Supplementary Notes https://www.mndot.gov/research/reports/2022/202219.pdf			
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.			
17. Document Analysis/Descriptors Animal vehicle crashes, Barriers (Roads), Fences, Road kill, Roadside fauna, Wildlife, Wire mesh		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 45	22. Price

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

FINAL REPORT

Prepared by:

Tricia Markle and Seth Stapleton
Department of Conservation and Research
Minnesota Zoo

June 2022

Published by:

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This report represents the results of research conducted by the authors and does not necessarily represent the views or policies of the Minnesota Department of Transportation or Minnesota Zoo. This report does not contain a standard or specified technique.

The authors, the Minnesota Department of Transportation, and Minnesota Zoo do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.

ACKNOWLEDGMENTS

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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).

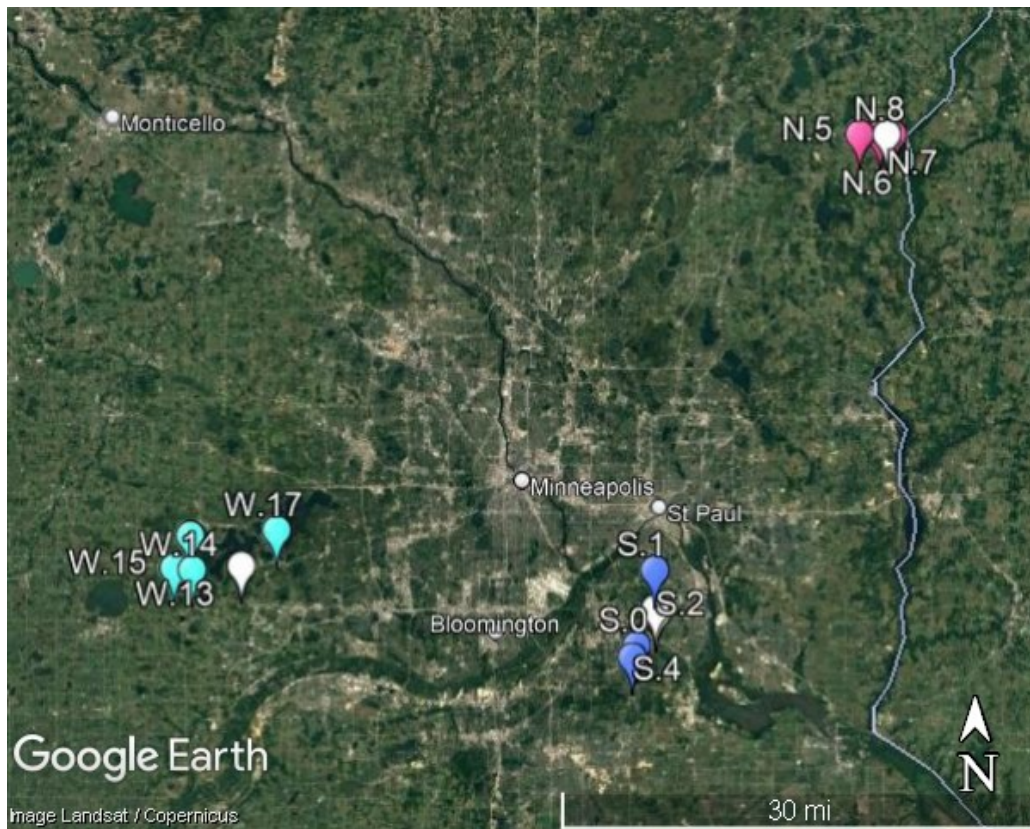


Figure 1. Fifteen study sites were located around the greater Twin Cities Metropolitan region in 3 general geographic areas: West (Carver County – Minnetonka area [light blue]), North (Washington County - Scandia area [pink]), and South (Dakota County – Eagan area [dark blue]). The 4 sites labelled in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

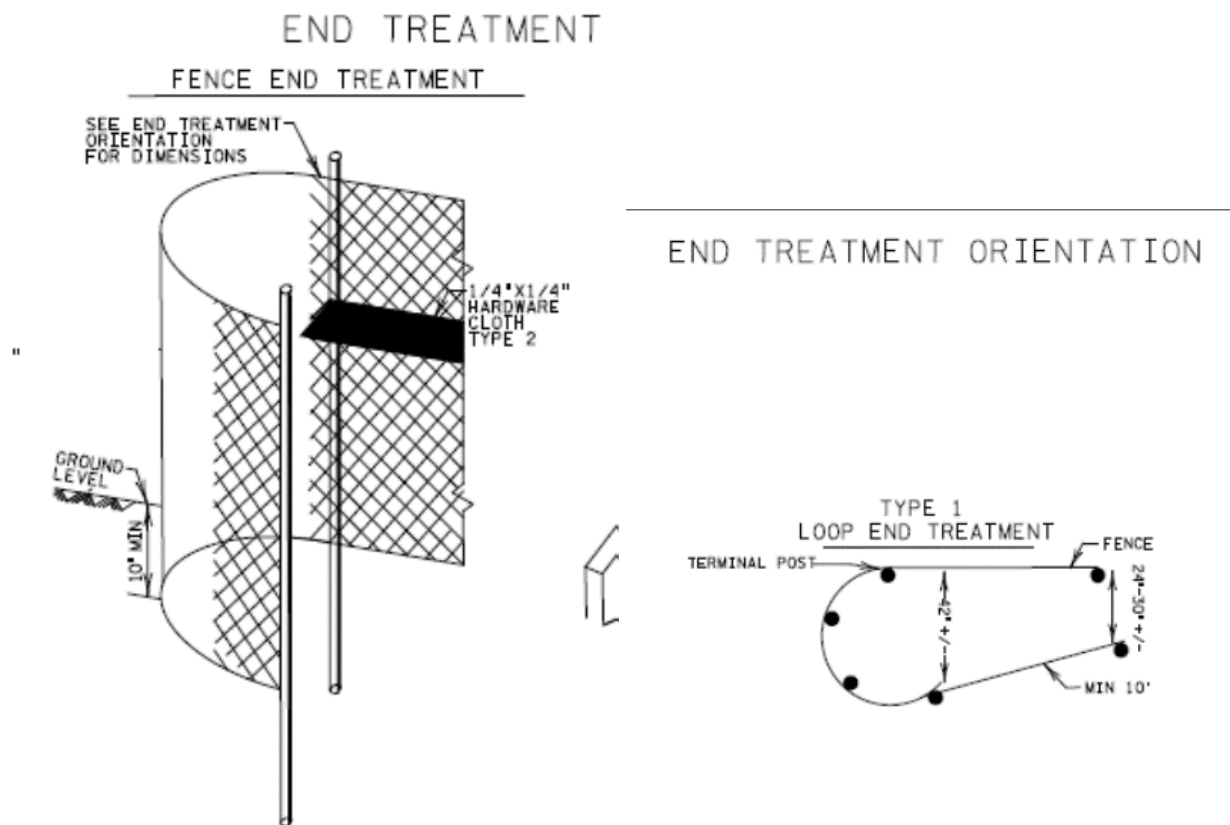


Figure 3. Fence end treatment specifications, as outlined in MnDOT standard plan for small animal fencing.



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 ($\alpha=0.05$) 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	4220	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 Herpetofau na	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.

<i>All Turtles</i>				
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
<i>Adult Turtles</i>				
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
<i>Juvenile Turtles</i>				
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

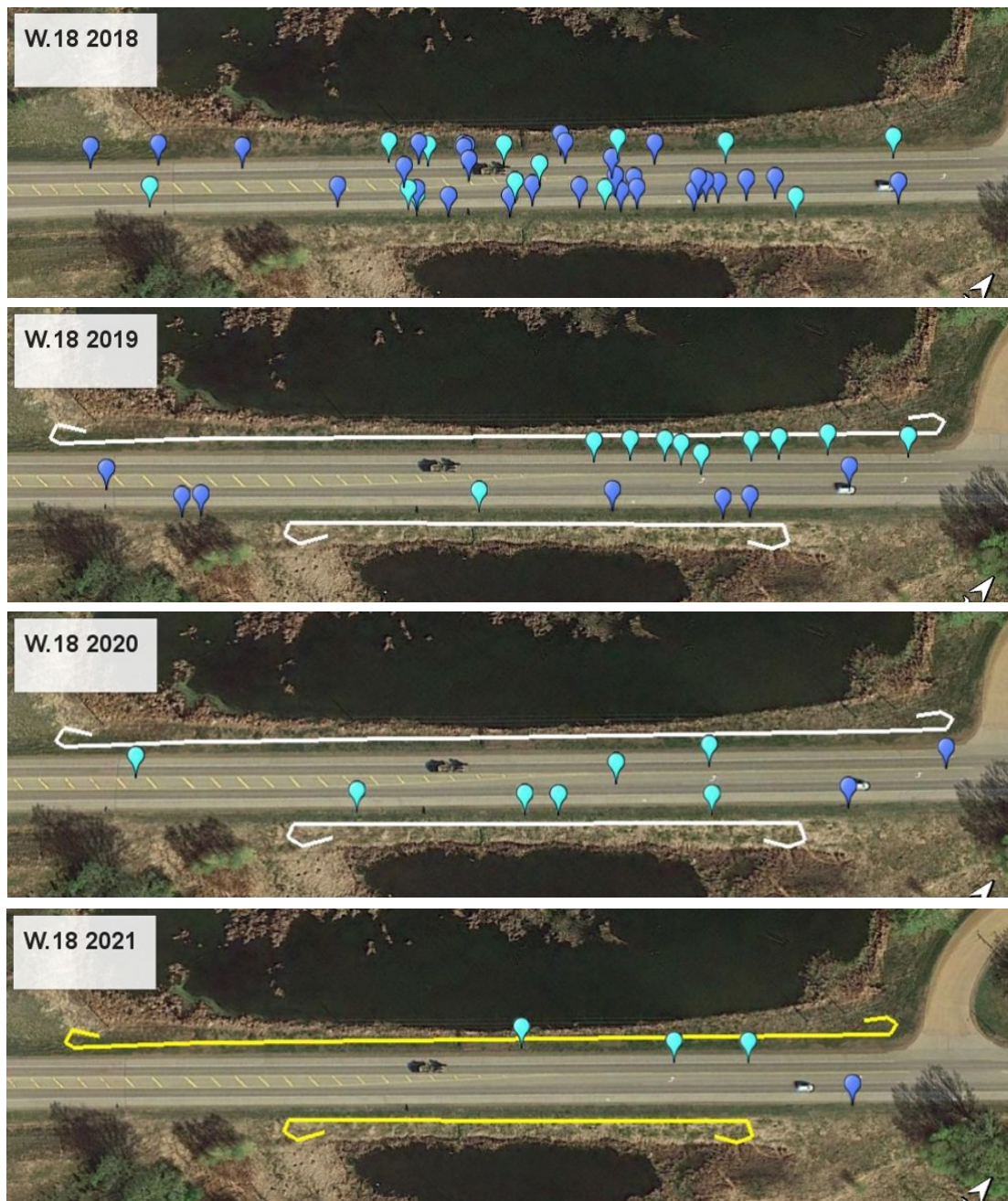


Figure 5. Turtle mortality data by age class (Dark blue = Adults, Light blue = Juveniles) at fence treatment site W.18 in Waconia during a.) 2018 (pre-treatment) b.) 2019 (chain link fence year 1) c.) 2020 (chain link fence year 2) d.) after 1/2-inch hardware cloth installation. We defined juveniles 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.

<i>All Turtles</i>				
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
<i>Adult Turtles</i>				
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
<i>Juvenile Turtles</i>				
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

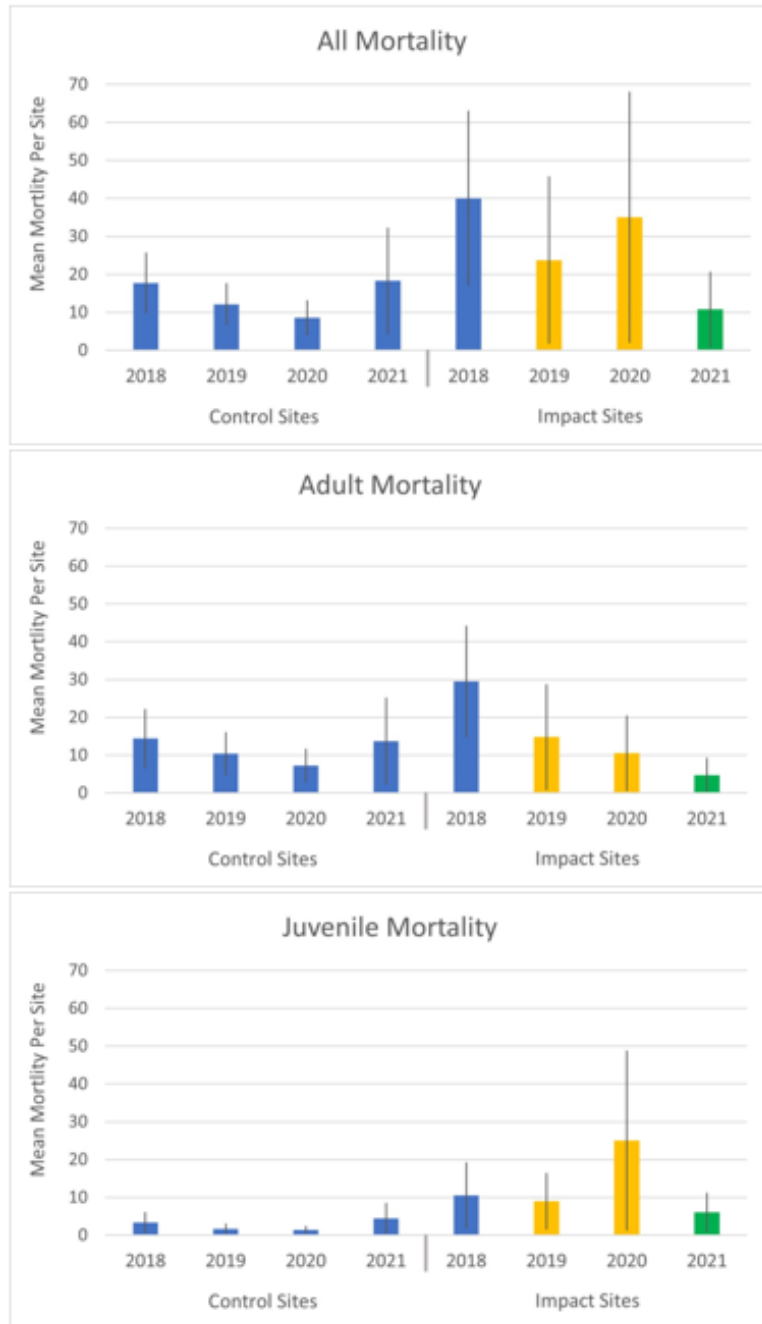


Figure 6. Mean turtle mortality per site by year and treatment (Control versus Impact) for each size class: All Turtles (top), Adults (middle), and Juveniles (bottom). Blue indicates no treatment, orange is chain-link fencing, and green is fine mesh retrofit. Error bars represent standard error about 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 Egan 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.

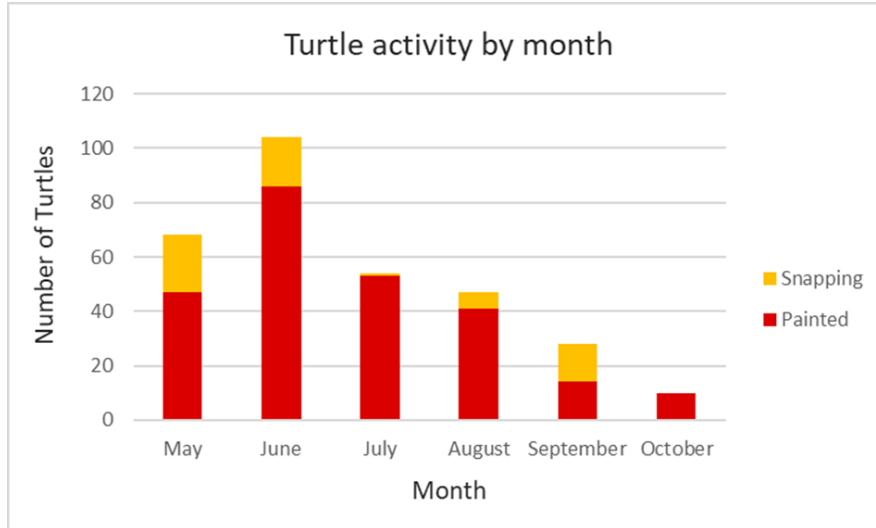


Figure 8. Seasonal activity of all identifiable turtles, including both dead and live individuals in baseline year 2018. Figure reflects total number of turtles by species: painted turtles (n= 312) and snapping turtles (n=60).

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).

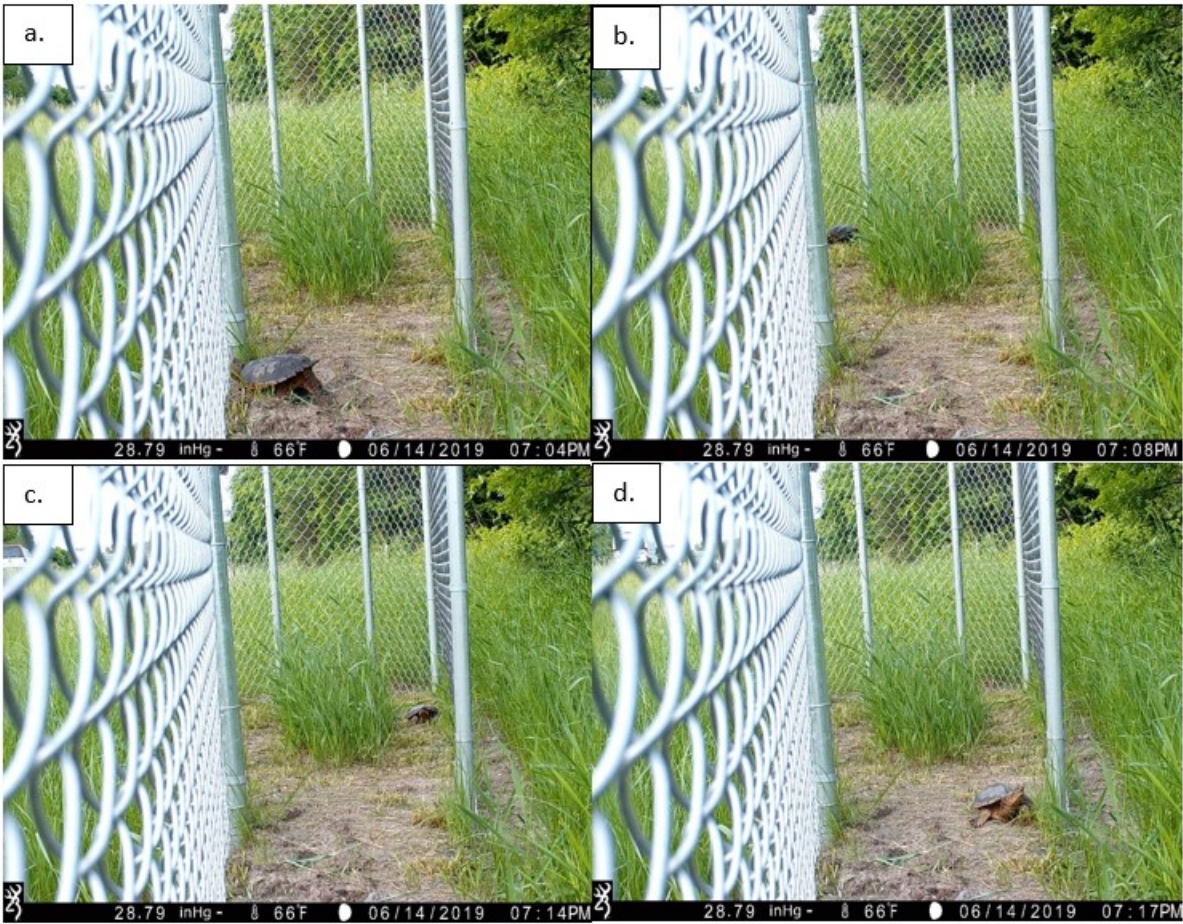


Figure 9. Time lapse images of snapping turtle turning around and returning to wetland due to fence end treatment at Site N.5 during 2019.

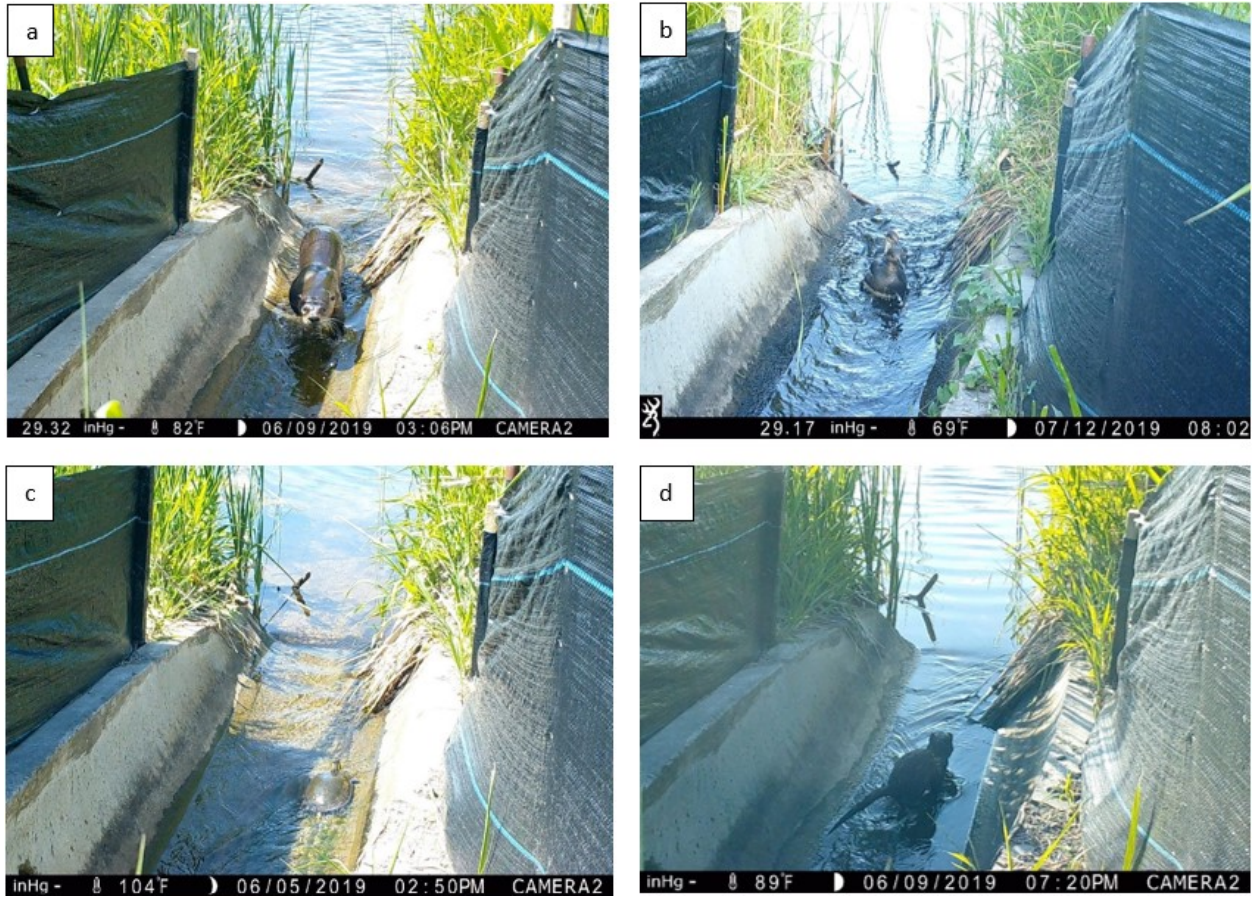


Figure 10. Examples of wildlife use of culvert at site W.18 in 2019 included a.) otter, b.) ducks, c.) painted turtle, and d.) mink.

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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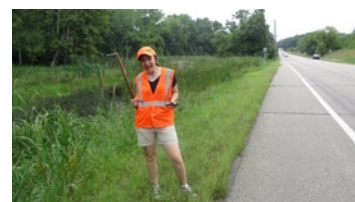
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Mitigating Road Mortality

Road mortality is one of many threats faced by turtles in Minnesota. Although warning signs may be suitable in some circumstances, our research found that simple barriers are the most effective strategy for reducing turtle mortality.





Building Public Awareness

To raise awareness about the conservation of turtles, we developed educational materials including a durable, life-sized model of a snapping turtle, a video highlighting conservation efforts, and interpretive graphics. We also provided content for a children's book and disseminated printed copies during programming. On and off-campus programs provided the public with the opportunity to view turtles and other wildlife first-hand.





Tracking Imperiled Turtles

We attached radio and GPS transmitters to threatened wood turtles to improve our understanding of their habitat needs and inform turtle conservation in Minnesota. We also identified turtle nesting sites, allowing us to protect some nests with predator exclusion fencing and collect eggs from other nests to support head-starting efforts at the Zoo.

