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Effectiveness of Chain Link Turtle Fence and Culverts in Reducing Turtle Mortality and Providing Connectivity along U.S. Hwy 83, Valentine National Wildlife Refuge, Nebraska, USA

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16. Abstract
We evaluated the effectiveness of existing turtle fences through collecting and analyzing turtle mortality data along U.S. Hwy 83, in and around Valentine National Wildlife Refuge, Nebraska, USA. We also investigated the level of connectivity for turtles provided through the culverts that were originally designed to pass water through a capture-mark-recapture experiment. While fenced valley sections had 33.1% fewer turtle observations than unfenced valley sections, the difference was not significant. However, we think that the effectiveness of the fence can be improved through fence repairs, other modifications of the fences, vegetation maintenance, and extending the length of the fences. Four of the five turtle species present in the study area used the culverts: common snapping turtle, painted turtle, Blanding’s turtle, and yellow mud turtle. However, we did not record ornate box turtle using the culverts. The culverts appear to have only provided marginal connectivity (7%) for the turtles that were interested in crossing the highway between 7 June and 30 September 2016. Assuming all turtles that passed the culverts in this period were originally marked, connectivity was still only 44%. We suggest implementing safe crossing opportunities (i.e. culverts or bridges) specifically designed for turtles, locating the culverts and bridges at intervals based on the home range size of the turtles, and maintaining the vegetation at the culverts and bridges so that they do not block turtle access to the crossings.

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1. INTRODUCTION

1.1. Background

Direct mortality is among the major threats to the Blanding's turtle (*Emydoidea blandingii*) due to their life history traits (Lang, 2004; Congdon & Keinath, 2006). Most turtle species have low recruitment rates, delayed sexual maturity, and low natural adult mortality. This combination of traits makes turtle populations susceptible to declines and possible extirpations when road mortality or other anthropogenic causes increase adult mortality (Congdon et al., 1993). The U.S. Fish and Wildlife Service is conducting a species status review to determine if listing the Blanding's turtle under the Endangered Species Act (ESA) is warranted. The current range of the species in Nebraska covers a large north central portion of the state. Should the species be listed, it would require that Nebraska Department of Transportation (NDOT) projects account for impacts and potential "take" (i.e. any direct mortalities and potential habitat destruction) of the species from construction, maintenance, and the operation of roadways.

There is a substantial population of Blanding's turtle on Valentine National Wildlife Refuge (NWR) and surroundings, located in north central Nebraska. The area consists of grass-covered sand dune ridges separated by lakes. The ridges and lakes run roughly northwest to southeast and they are bisected by U.S. Highway 83 which runs north to south (Figure 1, 2). In the 1990s and early 2000s, road mortality of the Blanding's turtle was substantial and was thought to have increased along US Hwy 83 (Lang, 2004). In response, NDOT installed chain-link turtle fencing and tied it into existing culverts at 5 locations along Highway 83, (4 locations within the boundaries of Valentine NWR) (Figure 3, 4). After initial fencing was installed in 2001, road mortality of turtles was observed to have decreased approximately 66% in the fenced road sections (Lang, 2004); however, turtle road mortality has continued in those valleys that have not been fenced (USFWS Valentine NWR staff, pers. com.). Additionally, since the last 2003 survey, the area has not been monitored to see if the fence is effective long-term, if turtles are using the culverts, and if this type of fencing design would work on future projects through similar Blanding's turtle habitat. This is particularly important if this species becomes protected under ESA.

1.2. Objectives

We evaluated the effectiveness of the existing turtle fences through collecting and analyzing turtle road mortality data. We also investigated the level of connectivity for turtles provided through the culverts that were originally designed to pass water through a capture-mark-recapture (CMR) experiment.

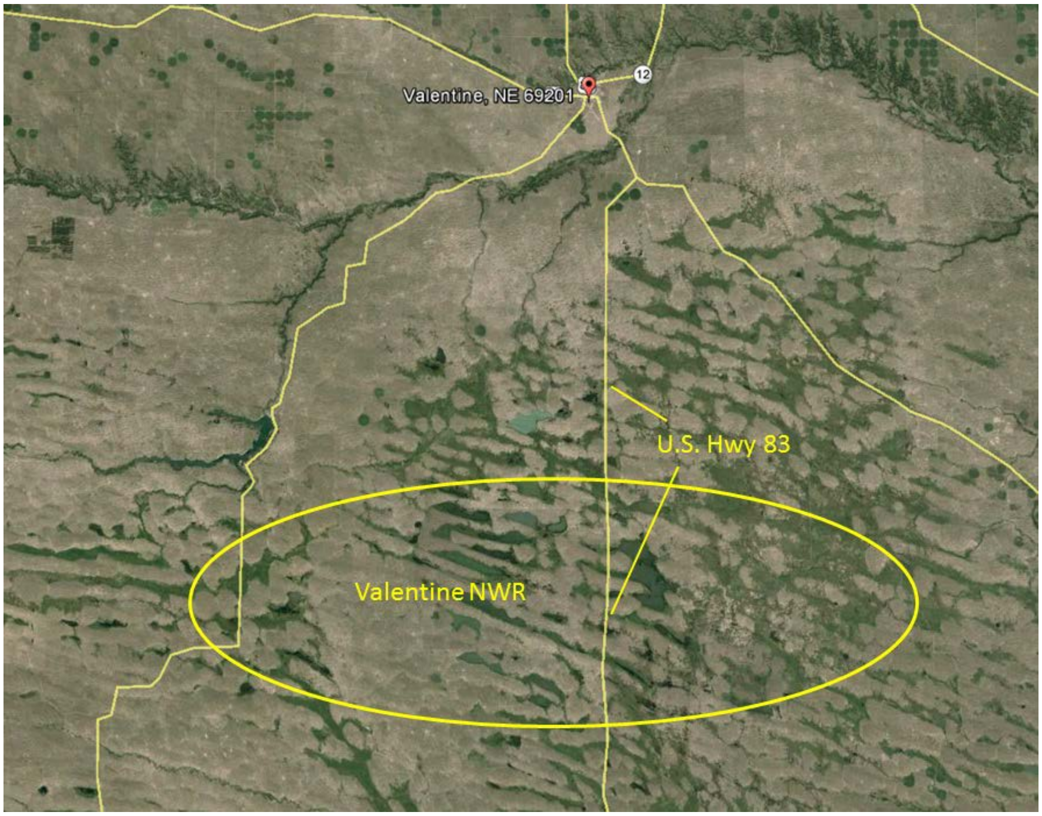

Figure 1: US Hwy 83 and Valentine National Wildlife Refuge, Nebraska.

Figure 2: Grass-covered sand dune ridges and lakes in and around Valentine National Wildlife Refuge, Nebraska.

Figure 3: Installing a camera at a culvert (Sweetwater) along US Hwy 83 through Valentine National Wildlife Refuge, Nebraska.

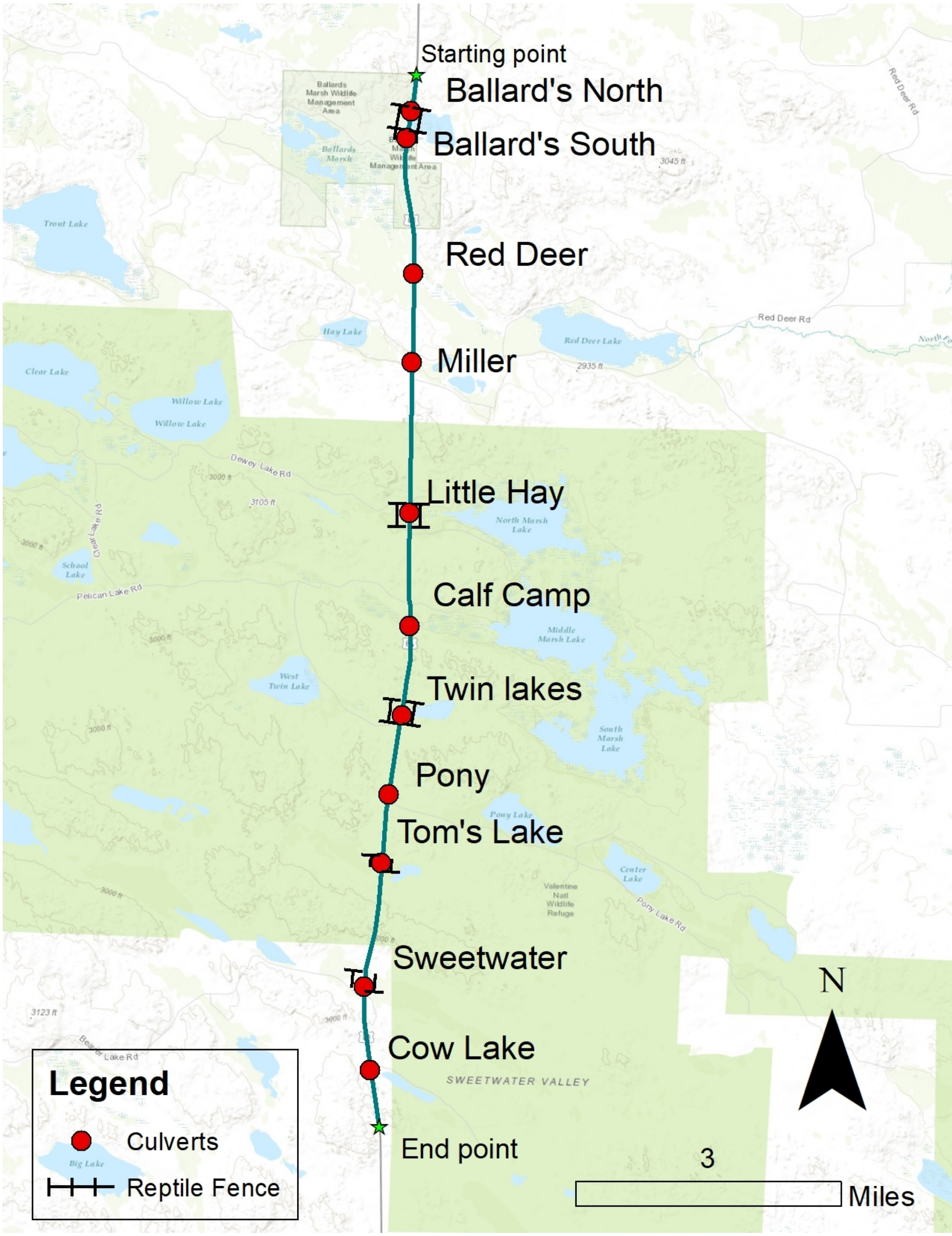

Figure 4: The culverts and road sections with turtle fence along US Hwy 83 in and around Valentine National Wildlife Refuge, Nebraska.
The start and end point indicate the road section that was monitored for turtles by the researchers.

2. EFFECTIVENESS OF THE TURTLE FENCE IN REDUCING TURTLE MORTALITY

2.1. Introduction

In the early 2000's, turtle fences were installed along five road sections in some of the dune valleys. The turtle fences were chain link, 3 ft (91 cm) tall, and buried 1.5 inches (3.8 cm) into ground. The fences were connected to culverts that were originally designed for hydrology. We investigated the effectiveness of the fences in reducing turtle road mortality through conducting surveys for turtles in fenced and unfenced road sections.

2.2. Methods

We conducted surveys along a 12.0 mi (19.3 km) long highway section to document turtles on the pavement (dead or alive) between 4-17 June 2016. We surveyed the road section between the dune ridge south of Cow Lake and the dune ridge north of Ballard's North (Figure 1). We surveyed the road section three times per day (just after sunrise, mid-day, just before sunset) in both directions, driving at about 45 mi/h (72.4 km/h). We distinguished between "valleys" and "ridges". The valleys were the low-lying wetlands and the ridges were the higher dry grass-covered sand dunes. The transition point between valleys and ridges was estimated in the field based on changes in the vegetation. Within the valleys, we also distinguished between the fenced and unfenced road sections and calculated their length (Figure 5, Table 1). The road sections between the valleys were always referred to as "ridges" (Figure 5, Table 2).

We conducted two types of analyses. For the first analysis we tallied all turtles "observed" (dead and alive) in the fenced and unfenced sections of the valleys. We ignored very short highway sections that had a turtle fence on one side of the highway only. Next, we calculated the "expected" number of turtles in the fenced and unfenced sections of the valleys should the observations have been homogenously distributed. We then conducted a one-sided t-test for proportions to test for a potential difference between the observed and the expected proportions of turtles in the fenced and unfenced valleys. Naturally, should there be a difference, we expected more turtle observations in the unfenced than fenced road sections in the valleys. We then proceeded with a second test (a two-sided t-test for proportions) between unfenced valleys and unfenced ridges for all species combined and species-specific analyses for species that had at least 5 expected observations in unfenced valleys and in unfenced ridges.

We used the Linear HotSpot Identification (LHI) tool in Siriema software to calculate kernel density (the number of turtles (dead and alive) in a given search distance) (Coelho et al., 2014). We used a search radius of 300 m and 500 road divisions to calculate a kernel density score for each 400 m road segment. LHI was also used to calculate the upper and lower confidence levels (90%) based on 100 random simulations of the observed turtles found on the road. When the calculated kernel density was above the upper confidence level, it was defined as a significant hotspot (i.e. more turtles occur at this location than expected by chance).

Finally, in April 2016, we walked the five fence sections and documented potential design or maintenance issues. Inspecting the turtle fence at this time of the year allowed us to observe potential maintenance issues before the vegetation started to grow.

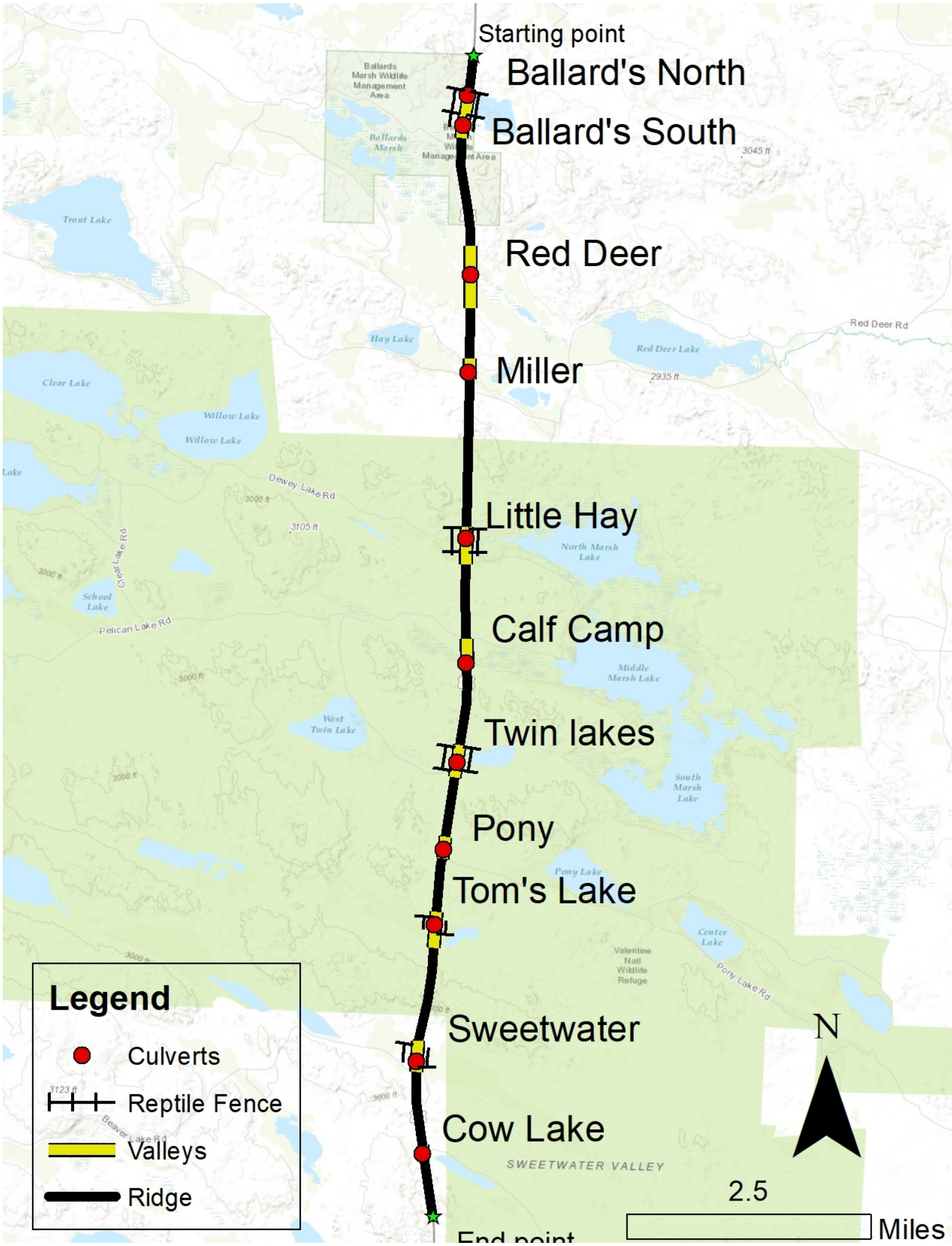

Figure 5: The valleys (fenced and unfenced) and ridges (always unfenced) along US Hwy 83, in and around Valentine National Wildlife Refuge, Nebraska.
The start and end point indicate the road section that was monitored for turtles by the researchers.

Table 1: The length of the fenced (both sides of the highway) and unfenced road sections in the valleys.

	Valleys	
Name Valley	Fenced (m)	Unfenced (m)
Cow Lake	0	188
Sweetwater	334	164
Tom's Lake	241	292
Pony	0	359
Twin Lakes	430	103
Calf Camp	0	467
Little Hay	463	155
Miller	0	341
Red Deer	0	1025
Ballard's South and North	654	171
Total	2122	3265

Table 2: The length of the road sections through the ridges (all unfenced).

Name ridge	**Length (m)**
South end - Cow Lake	998
Cow Lake - Sweetwater	1206
Sweetwater - Tom's Lake	1538
Tom's Lake - Pony	869
Pony - Twin Lakes	978
Twin Lakes - Calf Camp	1293
Calf Camp - Little Hay	1209
Little Hay - Miller	2415
Miller - Red Deer	807
Red Deer - Ballard's South	1790
Ballard's North - North end	523
Total	13626

2.3. Results

We found 108 turtles (79 dead, 29 alive) (45.4% painted turtle (*Chrysemys picta*), 29.6% ornate box turtle (*Terrapene ornata ornata*), 14.8% common snapping turtle (*Chelydra serpentina*), and 10.2% Blanding's turtle (*Emydoidea blandingii*)) (Figure 6, Table 3). While fenced valley sections had 33.1% fewer observed turtles (both alive and dead) per kilometer highway than unfenced valley sections, the difference was not significant (one-sided t-test for proportions, $Z = -1.060$, $P = 0.146$).

For all species combined, we observed far more turtles in the unfenced valleys than in the unfenced ridges (two-sided t-test for proportions, $Z = -6.578$, $P < 0.001$). The number of observed turtles per kilometer highway in the unfenced ridges was 89.1% lower than in the unfenced valleys. Specifies-specific analyses for painted turtle showed that the number of observed painted turtles per kilometer highway in the unfenced ridges was 82.7% lower than in the unfenced valleys ($Z = -3.980$, $P < 0.001$). However, ornate box turtles were found in similar numbers in the unfenced valleys and unfenced ridges ($Z = -1.018$, $P = 0.313$).

The hotspot analysis identified four hotspots along 2.1 km of the 19.3 km surveyed. Two of the hotspots included fenced road sections (Twin Lakes and Little Hay) and two were in unfenced valleys (Pony and Calf Camp).

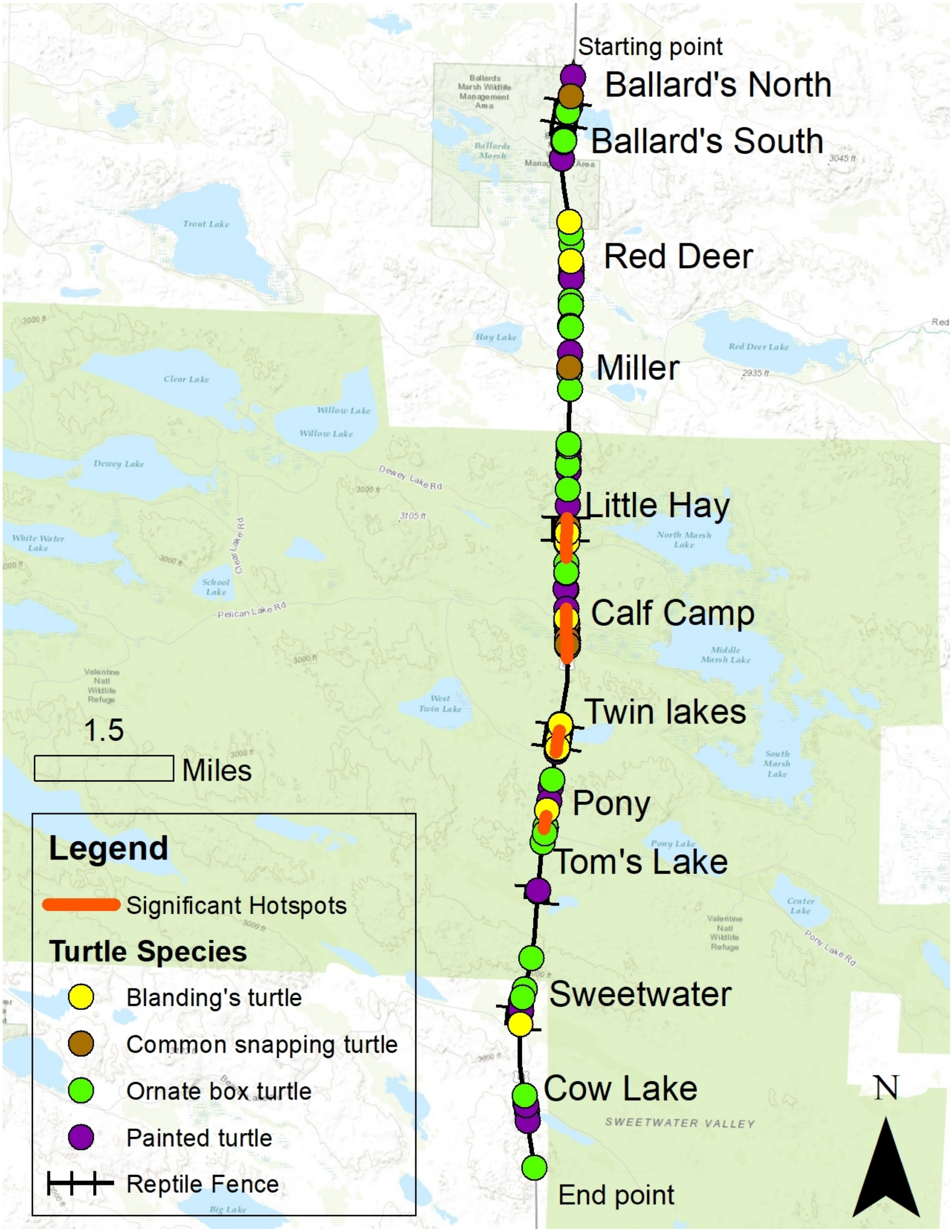

Figure 6: The species found dead and alive along the 12.0 mi (19.3 km) long highway section between the dune ridge south of Cow Lake and the dune ridge north of Ballard's North between 4-17 June 2016.

Table 3: The species found dead and alive along the 12.0 mi (19.3 km) long highway section between the dune ridge south of Cow Lake and the dune ridge north of Ballard's North between 4-17 June 2016.

Species	**Dead (n)**	**Alive (n)**	**Total (n)**	**Total (%)**
Blanding's turtle	7	4	11	10.19
Common snapping turtle	7	9	16	14.81
Ornate box turtle	25	7	32	29.63
Painted turtle	40	9	49	45.37
Yellow mud turtle	0	0	0	0.00
Total	79	29	108	100.00

The fence maintenance issues encountered included nearly submerged fences, broken fence posts, detached fence material from top wire and posts, gaps under the fence, and vegetation overgrowing the fence (Table 4, Figures 3-7).

Table 4: Maintenance issues observed during fence inspection April 2016.

Valley	Maintenance issues
Sweetwater	East side, just north of culvert: filled in 2 gaps with concrete pieces. Other maintenance issues remain: Two posts detached from top wire. East side, north fence end ends in water and suitable turtle habitat continues in unfenced section.
Tom's Lake	East side partially in water, partially with dead vegetation on and over fence. Same on west side. But west side fence has even higher water level. Fence should probably be extended on both sides, north and south. No actual breaches in fence detected.
Twin Lakes	East side, north end, multiple gaps under fence, could be easily filled with concrete blocks. West side, south end, two sections with fencing damaged, effectively lowering the fence. Both east and west fence top just above water level near the culvert.
Little Hay	Vegetation grows on and over fence in places. Erosion causes gaps under fence in places
Ballard's South and North	2 fence posts broken

Figure 7: The turtle fence is almost completely under water (Twin Lakes), April 2016.

Figure 8: The turtle fence has broken posts because a vehicle ran off the highway (Ballard's Marsh), April 2016.

Figure 9: Vegetation has overgrown the turtle fence (Tom's Lake), April 2016.

Figure 10: Gaps under the fence caused by erosion (Twin Lakes), April 2016.

Figure 11: Fence detached from top wire and posts (Twin Lakes), April 2016.

2.4. Discussion

We found 79 road-killed turtles along a 11.8 mi (19.0 km) long highway section in just 13 days (0.32 dead turtles per km per day). While fenced valley sections had 33.1% fewer turtle observations than unfenced valley sections, the difference was not significant. However, we think that the effectiveness of the fence in reducing turtle mortality can be improved. We suggest increasing the length of the fenced road sections, increasing the height of the fence in selected places with high water levels, re-attaching fence material to top wire and fence posts, replacing fence material in select locations, replacing broken fence posts, fixing gaps in the fence (including gaps caused by erosion), and removing vegetation that has overgrown the fence (see also Markle et al., 2017). While there were fence maintenance issues, we think that the fenced valley sections historically may have had more turtles on the road than the unfenced valley sections. This may have made it more difficult to demonstrate the likely benefits of the turtle fences in reducing turtle mortality.

The unfenced valleys had more turtle observations than the unfenced ridges. Hence, it is logical to extend the turtle fence in the valleys first. However, ornate box turtles were seen in similar numbers in the unfenced ridges and in unfenced valleys. Therefore, if the mitigation measures are intended to also reduce road mortality for ornate box turtles, fencing the ridges should also be considered. In addition, we found 2 Blanding's turtles in the ridges (both road-killed) and 4 in the unfenced or partially fenced (i.e. fence on one side of the highway) valleys (three alive, one road-killed). This suggests that fencing the ridges is important for Blanding's turtles as well. This may be especially true during the nesting season when adult females move long distances (several kilometers) searching for nesting sites in areas that are high and dry with sandy soils.

We recommend combining fence repairs and modifications in combination with providing safe and effective crossing opportunities specifically designed for turtles. See Chapter 3 for recommendations on safe crossing opportunities for turtles.

3. EFFECTIVENESS OF THE CULVERTS IN PROVIDING CONNECTIVITY FOR TURTLES

3.1. Introduction

We investigated the effectiveness of culverts that were originally designed for hydrology in providing connectivity for turtles between the two sides of the highway. For this purpose, we placed cameras at the culverts and we also conducted a capture-mark-recapture (CMR) experiment in the immediate vicinity of selected culverts. While Blanding's turtles were our primary target species, we included all turtle species in our study.

3.2. Methods

To document turtles using the culverts, cameras (Reconyx PC900 HyperFire) were installed at 8 of the 11 culverts (operational 1 April - 30 September 2016) (Table 5). At Tom's Lake and Twin Lakes it was not possible to install a camera as the culverts were completely under water in April 2016 and stayed under water at least through the end of the CMR experiment in mid-June 2016. At Calf Camp no camera was installed as there was a debris guard present on the west side and the spacing between the bars (4 inches, 10 cm) was insufficient for an adult Blanding's turtle to pass. "Turtle ramps" made out of concrete debris forced the turtles directly under the cameras and to the water surface so that the camera sensors would be triggered (Figure 12). The "lowest" point of the turtle ramp was a flat piece of concrete positioned 1-2 inches under the water level. The cameras were programmed to take 5 photos in rapid succession (in less than 5 s) each time they were triggered, with zero lag time before the next series of images could be taken. The cameras were checked once a month (new memory card) and were provided with new batteries (Energizer® Ultimate Lithium) after 3 months. Fort turtles and snakes we evaluated the series of images and then estimated whether an individual was likely to have crossed the culvert ("yes", "possibly", or "no").

At four culverts with cameras and turtle fences we also conducted a CMR experiment. The CMR experiment was designed to investigate what percentage of the turtles that appeared interested in crossing the highway ended up doing so by using the culverts. Pitfalls were installed at 25 m intervals (up to 75 m from a culvert) along the "safe side" of the turtle fence on both sides of the highway (Figure 13, 14, 15). Note that the shortest distance from a culvert to a fence end was about 75 m and that 75 m was well within the movement range for Blanding's turtles (Lang, 2004). There was no pitfall at the culvert, only a camera. Thus, there were pitfalls at 25, 50 and 75 m from a culvert, 6 pitfalls per side of the road per site, and 12 pitfalls per site (Figure 13). The researchers allowed the pitfall to be placed up to 5 m distance from the planned location to select the best site for a trap. A trap had to be in a dry area and immediately adjacent to the turtle fence.

A pitfall consisted of a white 5-gallon bucket that was dug into the ground so that the rim was level with the surrounding ground surface (Fisher et al., 2008; Figure 15). The buckets were white to reflect heat. The dimensions of a bucket are about 40 cm high, 30 cm diameter on top and 26 cm diameter at bottom. Normally, holes would be drilled into the buckets to allow for drainage. However, in our study area, the ground water level was so high that this would fill rather than drain the buckets. Therefore, we did not drill holes in the buckets. We also installed short sections of temporary fences (3 m long, geotextile fabric) perpendicular to the chain link turtle fence and connected to the pitfalls (Figure 14, 15). These temporary short sections of fence were designed to help guide turtles to the pitfalls and increase the probability that turtles will be caught in these pitfalls. We placed a wet sponge (for amphibians) and one 6-inch-long, 1.5 inches diameter, piece of PVC pipe (cover for small animals). Prior to installation, the buckets, sponges, and pieces of PVC pipes were washed with soapy water and rinsed thoroughly (Fisher et al., 2008). Each bucket had a stick standing up against the rim. This allowed most small mammal species to escape from the bucket. Each bucket had canopy to provide shade and shelter (geotextile fabric) from the rain (Figure 14, 15).

The capture effort took place between 7-15 June 2016. The pitfall traps were checked three times per day: at first light, mid-day, and just before dark. Turtles that were caught in the pitfalls along the fence and turtles that were captured by hand when checking the traps, were assumed to have been interested in crossing the highway. These animals were given an individual number on their shell with water resistant non-toxic paint (Craftsmart paint pen). When a turtle passed through the nearby culvert, the animals and its mark were photographed. For the CMR experiment we monitored the culverts between 7 June and 30 September 2016. The CMR experiment was approved by Montana State University's Institutional Animal Care and Use Committee. The U.S. Fish and Wildlife Service and the Nebraska Game and Parks Commission provided permits for the research activities. The CMR experiment ended on 15 June after 3-4 inches (7.5-10.0 cm) of rain fell during the night of 13/14 June. Rising ground water pushed up buckets, flooded buckets, and made about 65% of the pitfalls unusable in the days that followed.

Table 5: The characteristics of the culverts in April 2016.

Culvert #	Culvert name	Material culvert	Width (in)	Height (in)	Water - Top (in)	Fenced?	Length fence west side (m)	Length fence east side (m)	Camera installed?	Which side of the highway?	Where installed?	Turtle ramp installed?	Included in CMR experiment?	Comments
1	Cow Lake	metal	25	17	9	No	N/A	N/A	Yes	West	Inside culvert, screws	Yes	No	
2	Sweetwater	metal	47	47	27	Yes	334	334	Yes	West	Inside culvert, screws	Yes	Yes	
3	Tom's Lake	metal	22	20?	0	Yes	241	241	No	N/A	N/A	No	No	Culvert inundated
4	Pony Lake	metal	22	15	10	No	N/A	N/A	Yes	West	Inside culvert, screws	Yes	No	
5	Twin Lakes	metal	30	32	0	Yes	429	429	No	N/A	N/A	No	No	Culvert inundated
6	Calf Camp	metal	24	24?	12	No	N/A	N/A	No	N/A	N/A	No	No	Blocked to adult Blanding's by debris guard (4 inches between bars)
7	Little Hay	concrete	45	36	24	Yes	462	462	Yes	West	Inside culvert, epoxy	Yes	Yes	
8	Miller	concrete	42	26	9	No	N/A	N/A	Yes	West	Outside, t-post, facing down	Yes	No	
9	Red Deer	concrete	54	44	16	No	N/A	N/A	Yes	West	Outside, t-post, facing culvert	Yes	No	
10	Ballard's South	concrete	30	22	N/A	Yes	654	653	Yes	West	Inside culvert, epoxy and screws	Yes	Yes	Completely dry culvert
11	Ballard's North	concrete	32	20	7	Yes	654	653	Yes	West	Outside, t-post, facing down	Yes	Yes	

Figure 12: Turtle ramp made from concrete debris forced the turtles directly under the cameras and to the water surface (Pony Lake). Note that this culvert is not connected to a turtle fence.

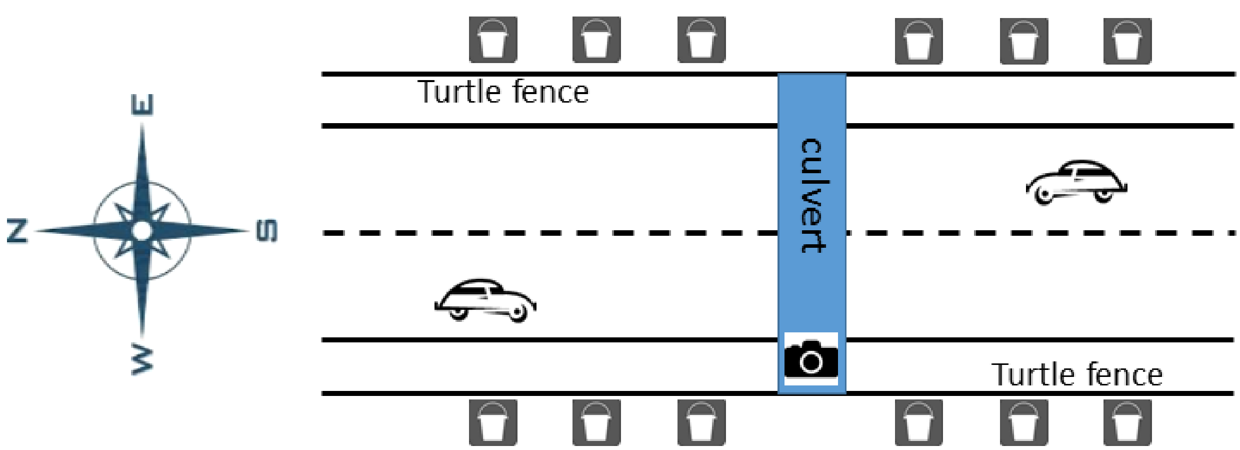

Figure 13: Schematic drawing of a site, the location of a camera at a culvert and the location of the pitfalls. The distance between a culvert and the first bucket is 25 m, distances between buckets are also 25 m.

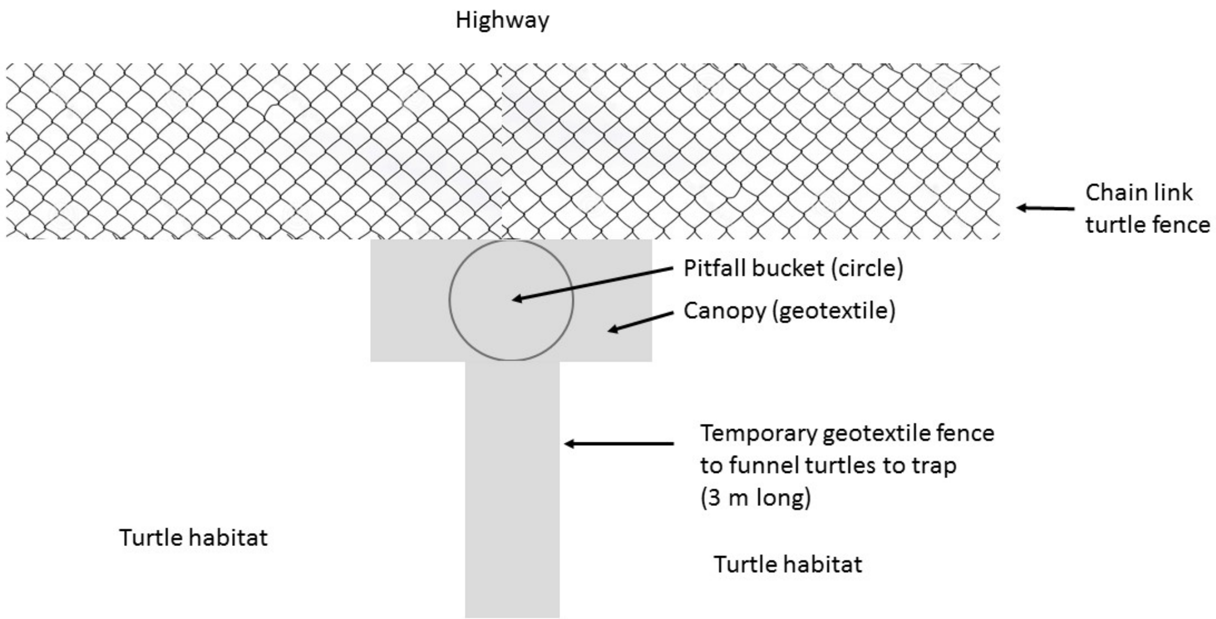

Figure 14: Schematic drawing of the location of a pitfall trap, including craft paper with sand and litter to camouflage trap, tooth picks to indicate travel direction of the turtles, and a temporary section of geotextile fence to help guide turtles towards the pitfall.

Figure 15: A pitfall arrangement in the field at Ballard's South.

3.3. Results

Between 1 April and 30 September 2016, the cameras recorded 57 possible or certain passages by turtles in the 8 culverts that had a camera installed (38 common snapping turtles, 9 painted turtles, 8 Blanding's turtles, 1 yellow mud turtle (*Kinosternon flavescens*), and 1 unidentified turtle (Figure 16). Certain or possible culvert crossings by Blanding's turtles were observed at 3 of the 8 culverts monitored: Little Hay (n=3), Ballard's South (n=2), and Ballard's North (n=3) (Figure 17). Other species and species groups observed at the culverts are summarized in Appendix A.

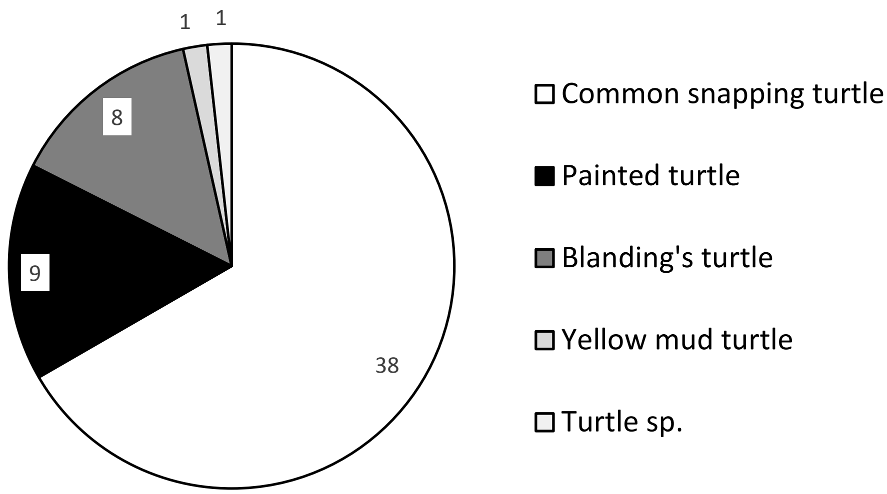

Figure 16: The number of turtles observed in the 8 culverts between 1 April - 30 September 2016.

Figure 17: A Blanding's turtle passing through a culvert (Little Hay).

In 8 days we captured and marked 71 individual turtles near the 4 culverts that were part of the CMR experiment (34 painted turtles, 28 common snapping turtles, 5 Blanding's turtles, and 4 ornate box turtles) (Figure 18, 19). Of these 71 individual turtles, only 5 (7.0%) used the culverts between 7 June and 30 September 2016 (4 (11.8%) painted turtles, 1 (3.6%) common snapping turtle) (Figure 19, 20). Assuming all turtles that passed the 4 culverts in this period (n=31) were originally marked, connectivity was still only 44%. During 8 days of capturing, only 2 previously marked turtles (all common snapping turtles) were observed on or alongside of the road (road side of the fence at Sweetwater and at Little Hay). Note that the CMR experiment did not result in any turtle injuries or fatalities. Non-target species caught in the pitfalls are summarized in Appendix B.

Figure 18: A painted turtle in the pitfall. Note the sponge, PVC pipe and the wooden stick.

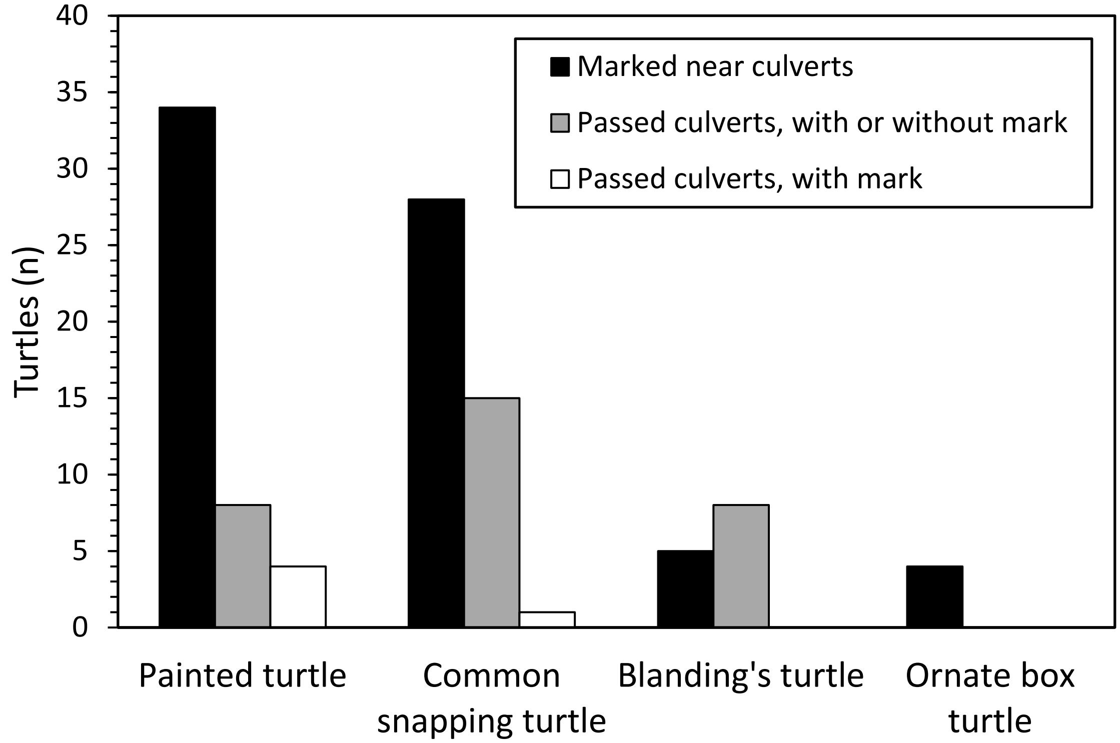

Figure 19: The number of turtles captured and marked near the 4 culverts between 7-15 June 2016, and the number of turtles that passed through the culverts (with or without mark, and with mark) between 7 June and 30 September 2016.

Figure 20: A marked painted turtle (#55) photographed at one of the culverts (Ballard's South).

The turtles (all species combined) were captured in similar numbers on both sides of the highway (Table 6; two-sided t-test for proportions, Z = 0.720, P = 0.473).

Table 6: The side of the highway the turtles were caught at (including multiple captures of the same individuals, based on both pitfall and captures by hand).

Species	Total (n)	West side (n)	East side (n)	On Hwy (n)
All turtle species combined	98	53	43	2
Painted turtle	43	27	16	0
Common snapping turtle	36	14	22	0
Blanding's turtle	11	8	1	2
Ornate box turtle	5	1	4	0
Yellow mud turtle	3	3	0	0

3.4. Discussion

Between 1 April - 30 September 2016, four of the five turtle species present in the study area used the 8 culverts that were monitored with a camera: common snapping turtle, painted turtle, Blanding's turtle, and yellow mud turtle. However, we did not record ornate box turtle using the culverts.

The 4 culverts that were part of the CMR experiment appear to have only provided marginal connectivity (7%) for the 71 turtles that appeared interested in crossing the highway between 7 June and 30 September 2016. Assuming all 31 turtles that passed the 4 culverts in this period were originally marked, connectivity was still only 44%. We have no evidence that the turtles breached the fence or crossed the highway in unfenced areas in great numbers; only 2 (both common snapping turtles) of the 71 marked turtles were observed on the highway or on the road side of the turtle fences. Thus, despite high number of turtles (dead and alive) observed on the highway, the fenced highway seems to be a substantial barrier to turtles and the existing culverts only provide marginal connectivity. We suggest implementing safe crossing opportunities (i.e. culverts or bridges) specifically designed for turtles, locating the culverts and bridges at intervals based on the home range size of the turtles, and maintaining the vegetation (i.e. keeping the area open) at the culverts and bridges so that they do not block turtle access to the crossings.

Note that our capture and marking effort took place between 7-15 June 2016 whereas monitoring the culverts for potential "re-sightings" lasted through 30 September 2016. If we would have captured and marked for longer, consistent with period we monitored the culverts for (through 30 September) we would have likely captured many more turtles that were presumably interested in crossing the highway. However, we would not have increased the number of turtles observed using the culverts, because we monitored through 30 September 2016 already. Therefore, we are currently overestimating the connectivity provided by the culverts, not underestimating. Despite the fact we overestimate, the level of connectivity provided by the culverts (between 7 and 44%) can be considered quite low. This strengthens our argument for implementing more crossings specifically designed for turtles.

The turtles (all species combined) were captured in similar numbers on both sides of the highway This indicated that the turtles as a group were not selecting a certain direction in their movements (either west or east), at least not during the CMR experiment. Rather, the results suggest that the direction of the turtle movements were either random or directed at the road and roadbed itself (Figure 21). Turtles are known to select high and dry soils of roadbeds as nesting habitat (e.g. Steen et al., 2006; Laporte et al., 2013). This has implications for the functioning of culverts. Because turtles are predominantly attracted to the roadbed for nesting, culverts may not provide the turtles with what they are looking for, at least not during the nesting season. However, in general, it is good practice to exclude turtles from roadside habitat with fencing because of the high risk of adult road mortality and nest predation (Aresco, 2004; Ashley et al., 2007; Hackney et al., 2013; Crump et al., 2016; Markle et al., 2017). In the case of our study site, turtle fencing alongside the highway does not impede access to nesting habitat because it is available to turtles in the sandy dune ridges on both sides of the highway. It appears though that a great number of turtles is attracted to the unnatural nesting habitat along the highway in the valleys as that may be the closest nesting habitat. Regardless of what turtles are looking for in the nesting season, it is still important for the long-term viability of the turtle populations to provide safe and effective highway crossing opportunities and not create absolute barriers in the landscape.

Figure 21: A highly motivated painted turtle attempting to climb or go through the turtle fence.

4. CONCLUSIONS AND SUGGESTIONS

- While fenced valley sections had 33.1% fewer turtle observations than unfenced valley sections, the difference was not significant. However, we think that the effectiveness of the fence in reducing turtle mortality can be improved. We suggest:
    - Increasing the length of the fenced road sections.
    - Increasing the height of the fence in selected places with high water levels.
    - Re-attaching fence material to top wire and fence posts.
    - Replacing fence material in select locations.
    - Replacing broken fence posts.
    - Fixing gaps in the fence (including gaps caused by erosion).
    - Removing vegetation that has overgrown the fence.

- The unfenced valleys had more turtle observations than the unfenced ridges. Hence, it is logical to extend the turtle fence in the valleys first. However, fencing the ridges is also recommended for ornate box turtles and nesting Blanding’s turtles and other turtle species.

- We recommend combining fence repairs and modifications in combination with providing safe and effective crossing opportunities specifically designed for turtles.

- Four of the five turtle species present in the study area used the culverts originally designed for hydrology: common snapping turtle, painted turtle, Blanding’s turtle, and yellow mud turtle. However, we did not record ornate box turtle using the culverts.

- The culverts appear to have only provided marginal connectivity (7-44%) for the turtles that were interested in crossing the highway. We suggest implementing safe crossing opportunities (i.e. culverts or bridges) specifically designed for turtles, locating the culverts and bridges at intervals based on the home range size of the turtles, and maintaining the vegetation at the culverts and bridges so that they do not block turtle access to the crossings. Improving and extending the existing turtle fences is also likely to result in higher turtle use of culverts.

The culvert at Calf Camp had a debris guard installed on the west side (the water flows from west to east). The space between the bars (4 inches, 10 cm) was insufficient to allow for adult Blanding's turtles to pass. The culvert also had maintenance problems due to erosion and roadbed material spilling through cracks in the culvert. In addition, the U.S. Fish & Wildlife Service expressed the desire to eradicate non-native fish (i.e. common carp (*Cyprinus carpio*) west of the highway and making the culvert impassable by carp. We found that Calf Camp is a hotspot for turtles observed on the highway, especially for common snapping turtles. Here we summarize our suggestions for the culvert at Calf Camp:

- Scenario 1: Include carp screen attached to inlet and/or outlet of new culvert. The culvert will not be passable for turtles at all, any species/size/age. Therefore, turtle mortality on that road section will likely continue, potentially even increase. We do not recommend this scenario.

- Scenario 2: The project to repair or replace the Calf Camp culvert is also aimed at reducing turtle mortality and at providing safe crossing opportunities for turtles (e.g. Gunson et al., 2016). Increasing the barrier effect of roads and traffic (e.g. through a fence or barrier wall) without safe crossing opportunities for wildlife is generally not recommended (Figure 22). Therefore, if turtle mortality is to be substantially reduced through fences or barrier walls, then also provide designated safe turtle passage(s) as an integral part of the project. Note that the turtle crossings would have to be above the high-water line to keep carp from crossing; the crossings would need to be “dry”. The crossings should be large enough for adult common snapping turtles; they were frequently observed as roadkill in the Calf Camp valley. Safe wildlife crossing opportunities receive higher use if they are connected to wildlife fences or barrier walls. Fences or barrier walls not only keep wildlife off the highway, they also guide wildlife to safe crossing opportunities. Therefore, for Calf Camp we recommend a combination of turtle fences and safe crossing opportunities.

Additional comments regarding Calf Camp:

- When providing safe crossing opportunities, also consider making them suitable for amphibians and snakes. Amphibian culverts typically have openings in the ceiling of the culvert at-grade with the road surface. This allows for the temperature and humidity inside the culvert to be similar to that of the surroundings. Larger structures are better, and if the size allows, debris (branches, root wads) can provide better habitat inside culvert for small animal species including invertebrates, amphibians, snakes, and small mammals.
- The current chain-link fence is a barrier to turtles, but not to amphibians and snakes. If amphibians and snakes are also to be excluded from the highway, then consider smooth ABS sheets attached to turtle fence or barrier walls integrated into the road surface (Figure 23).

Figure 22: Underpass and barrier wall for reptiles, amphibians and small mammals, U.S. 441, Paynes Prairie Ecopassage, south of Gainesville, Florida, USA.

Figure 23: Wildlife fences including smooth plastic amphibian screen, N302, Leuvenumseweg, Sonnevanck, east of Harderwijk, The Netherlands.

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APPENDIX A

The species observed at the 8 culverts between 1 April and 30 September 2016. Note: for turtles and snakes we also noted whether the animals crossed the culvert successfully.

Species	Total (n)	Culvert passage		
		Yes (n)	Possibly (n)	No (n)
Turtles				
Common snapping turtle (*Chelydra serpentina*)	49	34	4	11
Northern painted turtle (*Chrysemys picta*)	10	7	2	1
Blanding's turtle (*Emydoidea blandingii*)	9	6	2	1
Turtle Sp.	2	1		1
Yellow mud turtle (*Kinosternon flavescens*)	1		1	
Snakes				
Garter snake sp. (*Thamnophis* sp.)	74	17	24	33
Eastern racer (*Coluber constrictor*)	24	13	3	8
Bullsnake (*Pituophis catenifer*)	15	9	2	4
Mammals				
Mouse/vole/shrew sp.	478			
Muskrat (*Ondatra zibethicus*)	423			
American mink (*Neovison vison*)	305			
Raccoon (*Procyon lotor*)	164			
Eastern cottontail (*Sylvilagus floridanus*)	136			
Long-tailed weasel (*Mustela frenata*)	20			
Striped skunk (*Mephitis mephitis*)	5			
Birds	213			
Fish	321			

APPENDIX B

Non-target species caught in the pitfalls between 7-15 June 2016. Non-target species were defined as vertebrate species, excluding turtles.

Species	**Total**	**Alive**	**Dead**
Vole sp.	3	1	2
Barred tiger salamander (*Ambystoma mavortium*)	2	2	0
Northern leopard frog (*Lithobates pipiens*)	2	2	0
Shrew sp.	2	2	0
Garter snake sp. (*Thamnophis* sp.)	1	1	0
Woodhouse's toad (*Anaxyrus woodhousii*)	1	1	0