EXPLORATION OF WILDLIFE MITIGATION MEASURES FOR THE ROADS THROUGH AND AROUND FISHERMAN ISLAND AND CHINCOTEAGUE NATIONAL WILDLIFE REFUGES, VIRGINIA

by

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FINAL REPORT

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16. Abstract Road mortality of northern diamondback terrapin (*Malaclemys terrapin terrapin*) along US Hwy 13 on Fisherman Island National Wildlife Refuge is a major concern. Since 2006, different types of barriers have been installed, including plastic netting and tubing, aimed at keeping diamondback terrapins off the highway. However, we found no evidence that these two barrier types reduced turtle road mortality. We suggest taller (1-2 ft tall) and more robust (e.g. concrete) barriers, potentially integrated into the roadbed, starting the barriers on opposite sides of the highway (i.e. not staggered), and safe crossing opportunities (2-5 ft wide culverts, perhaps every several hundreds of meters). We also suggest monitoring the effectiveness of new barriers in reducing road mortality of diamondback terrapins, and evaluating the need and the functioning of potential future dry culverts specifically designed to provide connectivity for diamondback terrapins. Further north on the Delmarva Peninsula, along Hwy 175 near Chincoteague National Wildlife Refuge, road mortality of northern diamondback terrapin is a major concern too. We suggest similar mitigation measures as formulated for Fisherman Island National Wildlife Refuge. Another section of Hwy 175 has a high concentration white-tailed deer-vehicle collisions. Here we suggest wildlife fences, jump-outs, wildlife guards or electric mats at the fence ends. For existing and new beach access roads on Chincoteague National Wildlife Refuge we suggest concrete barrier walls integrated into the roadbed (2-3 ft tall), culverts with open slotted roofs to allow for safe crossings by a range of amphibian and reptile species, and arboreal crossing structures for the recently delisted Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*).		
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Fisherman Island National Wildlife Refuge is located at the mouth of the Chesapeake Bay, Virginia. The refuge is bisected by the 4-lane US Hwy 13. Road mortality of northern diamondback terrapin (*Malaclemys terrapin terrapin*) is a major concern. Since 2006, different types of barriers have been installed, including plastic netting and tubing, aimed at keeping diamondback terrapins off the highway. However, we found no evidence that these two barrier types reduced turtle road mortality. This may be at least partially related to the variable search and reporting effort and the number of reported road-killed turtles in different years, and the short duration for the road section that was first equipped with barriers (phase 1; 2 years before, 2 years after). The plastic tubing was later extended (phase 2) with more data after installation of the tubes, but we still did not detect a reduction in road mortality. We suggest taller (1-2 ft tall) and more robust (e.g. concrete) barriers, potentially integrated into the roadbed, starting the barriers on opposite sides of the highway (i.e. not staggered), and safe crossing opportunities (2-5 ft wide culverts, perhaps every several hundreds of meters). We also suggest monitoring the effectiveness of new barriers in reducing road mortality of diamondback terrapins and evaluating the need and the functioning of potential future dry culverts specifically designed to provide connectivity for diamondback terrapins.

Further north on the Eastern Shore of Virginia, the 2-lane Hwy 175 cuts through coastal habitat between the mainland and Chincoteague National Wildlife Refuge. Road mortality of northern diamondback terrapin is a major concern here too. We suggest similar mitigation measures as formulated for Fisherman Island National Wildlife Refuge. Further west, Hwy 175 is located between Wallops Island NWR and NASA Wallops Flight Facility. It has a relatively high concentration of white-tailed deer-vehicle collisions. Here we suggest wildlife fences, jump-outs, wildlife guards or electric mats at the fence ends. For the existing and new beach access roads on Chincoteague National Wildlife Refuge we suggest concrete barrier walls integrated into the roadbed (2-3 ft tall), culverts with open slotted roofs to allow for safe crossings by a range of amphibian and reptile species, and arboreal crossing structures for the recently delisted Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*).

1. INTRODUCTION

1.1. The Roads Through and in the Vicinity of the Refuges

Fisherman Island National Wildlife Refuge is located at the mouth of the Chesapeake Bay (Figure 1). In 1964 the Chesapeake Bay Bridge–Tunnel was built, and the 4-lane US Hwy 13 (posted speed limit 55 MPH) bisects the refuge ever since. About 75 miles further north, the 2-lane Hwy 175 (posted speed limit 55 MPH) cuts through coastal habitat between the mainland and Chincoteague National Wildlife Refuge, Virginia (Figure 2). From the town of Chincoteague, a road continues to and through the refuge for beach access, and a new road providing beach access at a new location is in the planning and construction phase (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

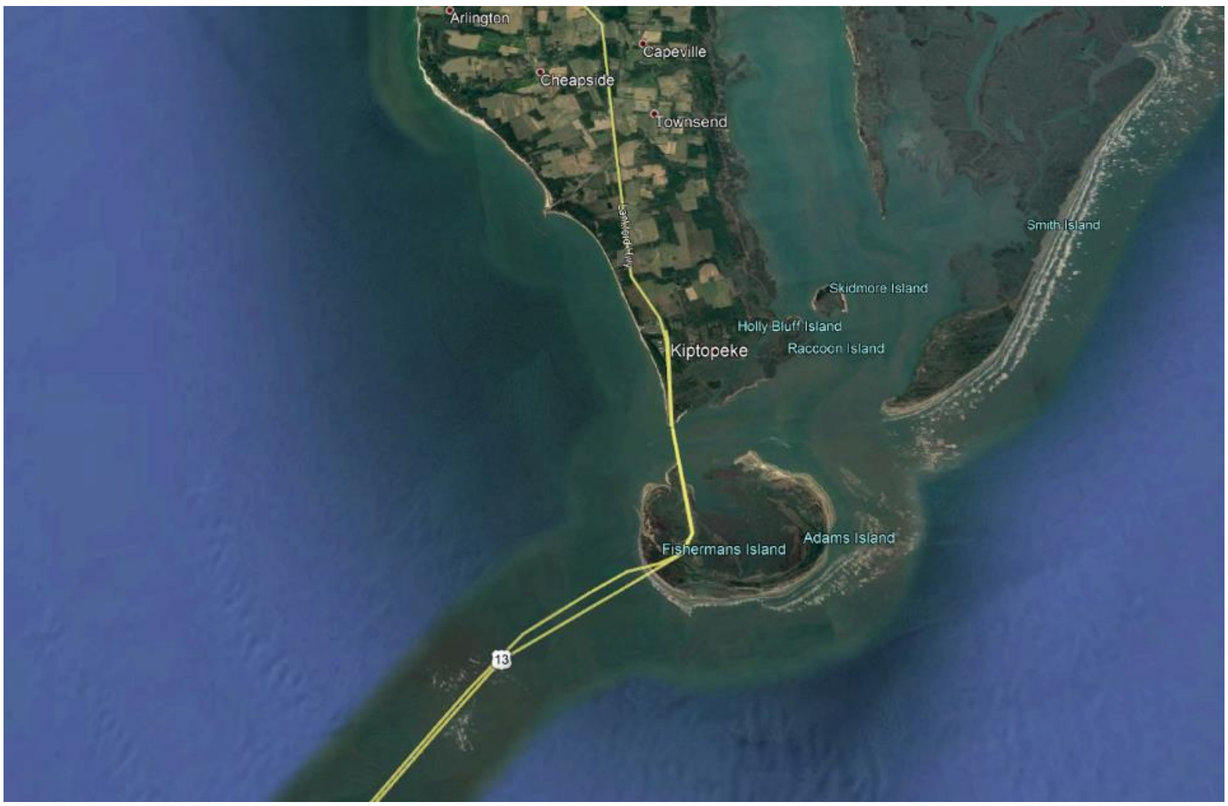

Figure 1: The location of Fisherman Island National Wildlife Refuge and US Hwy 13, Virginia, USA.

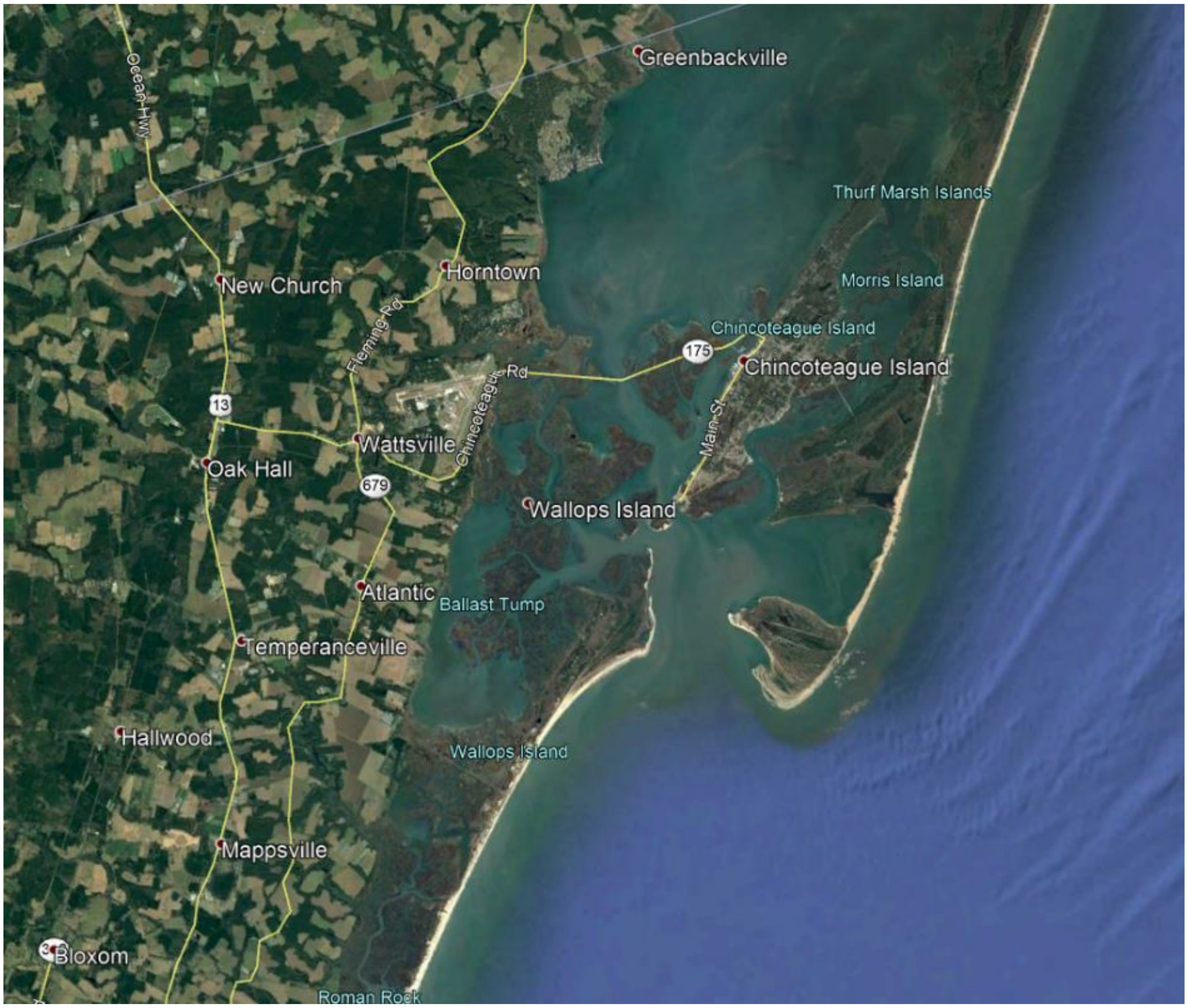

Figure 2: The location of Chincoteague National Wildlife Refuge and Hwy 175, Virginia, USA.

1.2. Wildlife and Hwy 13 Concerns Fisherman Island NWR

Road mortality of northern diamondback terrapin (*Malaclemys terrapin terrapin*) along US Hwy 13 through the refuge, is a major concern (Figure 3). The northern diamondback terrapin lives in brackish saltwater marshes, coastal bays, and lagoons, and is impacted by habitat loss, mortalities in crab pots, and road mortality. Nesting females appear especially vulnerable to road mortality when they move to higher nesting areas. The species is considered "Near Threatened" on an international level (IUCN, 2018), not listed on a USA Federal level, and is a species with a "Very High Conservation Need" on the state level (Virginia Department of Game and Inland Fisheries, 2015). Some people swerve or stop their vehicle along US Hwy 13 when they see a turtle on or near the road to save it (Holloway, 2016). Given the safety risks associated with swerving or stopping a vehicle along a high traffic volume (Average Annual Daily Traffic was 10,956 in 2017) and high-speed highway (posted speed limit 55 MPH), it is desirable to prevent turtles from accessing the road surface altogether and replace and lengthen the existing barrier (Holloway, 2016; Pers. com. Timothy R. Holloway, Chesapeake Bay Bridge-Tunnel).

Figure 3: US Hwy 13 on Fisherman Island National Wildlife Refuge, Virginia, USA.

1.3. Wildlife and Roads Concerns on and Around Chincoteague NWR

For the purpose of this report, we distinguish between four road sections on and around Chincoteague National Wildlife Refuge (CNWR) (Figure 4). We listed the type of concern (i.e. human safety or biological conservation) and the species of concern in Table 1).

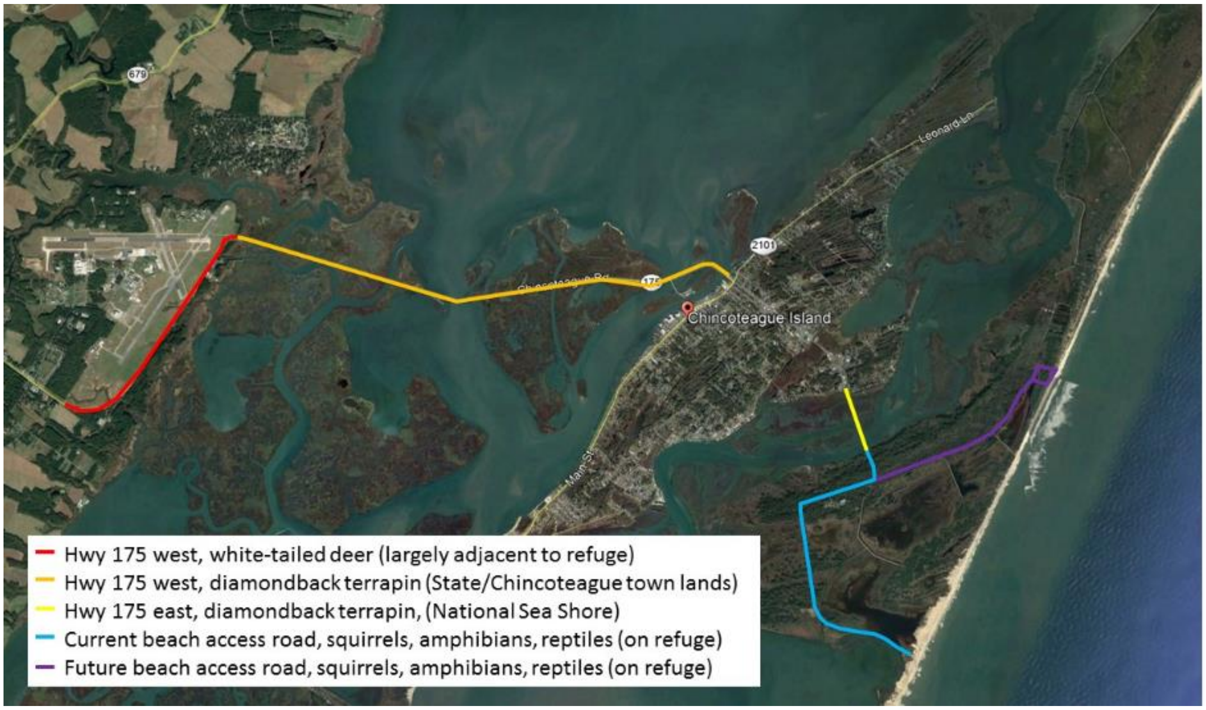

Figure 4: The roads on and around Chincoteague National Wildlife Refuge, Virginia, USA. Note that the road sections are based on ecological issues rather than land ownership.

Hwy 175 west (red in Figure 4) is located between Wallops Island National Wildlife Refuge (WINWR) and the National Aeronautics and Space Administration's Wallops Flight Facility (NASA-WFF). It has a relatively high concentration of white-tailed deer-vehicle collisions (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS). The refuge lands are mostly forested, whereas Hwy 175 has wide grassy shoulders. Note that there is a fence on the north-west side of the highway, keeping people, deer, and other wildlife species from entering the airport.

Another section of Hwy 175 west (orange in Figure 4) bisects Chincoteague Bay and salt marshes. Hwy 175 is a causeway with bridges across the major channels. The surrounding lands are managed by the NASA-WFF, Virginia Marine Resources Commission (VMRC), and the town of Chincoteague. Here, road mortality of northern diamondback terrapin is a major concern (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

Hwy 175 east (yellow in Figure 4) connects the town of Chincoteague on Chincoteague Island with Chincoteague NWR on Assateague Island. It crosses a salt marsh and the Assateague

Channel and is within the boundaries of the town of Chincoteague and Assateague Island National Seashore. Road mortality of northern diamondback terrapin is a concern here too (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

The current beach access road (blue in Figure 4) is located within Chincoteague National Wildlife Refuge and the Assateague Island National Seashore. The forested sections of this road have road mortality of the recently delisted Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*) (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS). Mortality and connectivity for frogs and toads, salamanders, snakes and turtles are a concern in the wetlands.

A new beach access road (purple in Figure 4) is under construction (vegetation has largely been cut) within Chincoteague National Wildlife Refuge and the Assateague Island National Seashore from Snow Goose Pool to just north of Pintail Pool. Likely future road mortality of the Delmarva Peninsula fox squirrel and likely future road mortality and reduced habitat connectivity is a concern for frogs and toads, salamanders, snakes and turtles (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

Table 1: Species of concern for the different road sections through and around Chincoteague NWR (USFWS, 2015; Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

Common species name	**Scientific species name**	**Type of concern**	**Chincoteague NWR and surroundings**			
			Current beach access road	**New beach access road**	**Hwy 175 west of Chincoteague**	**Hwy 175 east of Chincoteague**
Toads and fogs						
Fowler's toad	*Bufo woodhousii fowleri*	Biol. Cons.	X	X		
Green tree frog	*Hyla cinerea*	Biol. Cons.	X	X		
Bullfrog	*Rana catesbeiana*	Biol. Cons.	X	X		
New Jersey Chorus frog	*Pseudacris triseriata kalmi*	Biol. Cons.	X	X		
Green frog	*Rana clamitans melanota*	Biol. Cons.	X	X		
Southern Leopard frog	*Rana sphenocephala*	Biol. Cons.	X	X		
[Gray tree frogs]	*[Hyla versivolor]*	Biol. Cons.	X	X		
Salamanders						
Red back Salamander	*Plethodon cinereus*	Biol. Cons.	X	X		
Snakes						
Northern Black racer	*Coluber constrictor constrictor*	Biol. Cons.	X	X		
Black rat snake	*Elaphe obseleta obseleta*	Biol. Cons.	X	X		
Eastern Hognose snake	*Heterodon platirhinos*	Biol. Cons.	X	X		
Rough Green Snake	*Opheodrys aestivus*	Biol. Cons.	X	X		

Northern Brown snake	*Storeria dekayi dekayi*	Biol. Cons.	X	X		
Northern Water snake	*Nerodia sipedon sipedon*	Biol. Cons.	X	X		
[Ringneck snake]	*[Diadophis punctatus]*	Biol. Cons.	X	X		
Turtles						
Spotted Turtle	*Clemmys guttata*	Biol. Cons.	X	X		
Eastern Box turtle	*Terrapene carolina carolina*	Biol. Cons.	X	X		
Eastern Mud turle	*Kinosternon subrubrum*	Biol. Cons.	X	X		
Northern Diamondback	*Malaclemys terrapin terrapin*	Biol. Cons.	X		X	X
Eastern Painted turtle	*Chrysemys picta picta*	Biol. Cons.	X	X		
Red-bellied turtle	*Pseudemys rubriventris*	Biol. Cons.	X	X		
Common Snapping turtle	*Chelydra serpentina serpentina*	Biol. Cons.	X	X		
Mammals						
Delmarva Peninsula fox	*Sciurus niger cinereus*	Biol. Cons.	X	X		
White-tailed deer	*Odocoileus virginianus*	Human safety				

Species shown in brackets [ ] need confirmation

1.4. Tasks

The tasks for this project are:

1. Meet with stakeholders for the roads and refuges in and around Fisherman Island and Chincoteague National Wildlife Refuge
2. Review and analyze the historic roadkill data of diamondback terrapins along US Hwy 13 on Fisherman Island (data provided by USFWS). Data analyses will focus on the effectiveness of the barriers in reducing diamondback terrapin road mortality.
3. Review the proposed mitigation measures along US Hwy 13, especially in the context of reducing road mortality and providing habitat connectivity for diamondback terrapins.
4. Prepare a monitoring plan for the effectiveness of the proposed mitigation measures along US Hwy 13 that are projected to be installed in 2019-2020. The monitoring plan would address:
    a. Highway mortality
    b. Considerations for habitat connectivity for turtles across the highway
5. Suggest mitigation measures aimed at reducing road mortality and measures aimed at providing safe crossing opportunities for amphibians, reptiles, Delmarva Peninsula fox squirrel, and white-tailed deer for the roads through and around Chincoteague National Wildlife Refuge.

2. EFFECTIVENESS BARRIERS IN REDUCING ROAD MORTALITY DIAMONDBACK TERRAPINS ON FISHERMAN ISLAND NWR

2.1. Introduction

In this chapter we evaluate the effectiveness of two barrier types that were installed to reduce road mortality of diamondback terrapins along US Hwy 13 on Fisherman Island NWR.

2.2. Methods

2.2.1. Barriers

Between 2007 through 2018 there were three types of barriers installed for diamondback terrapins along US Hwy 13 on Fisherman Island NWR (Table 2, Figures 5-12) (Pers. comm. Pamela Denmon, Stacey Lowe, USFWS).

Table 2: Types of barrier, period present, and road section equipped with the barrier (USFWS, 2015; Pers. comm. Pamela Denmon, Stacey Lowe, USFWS). See Figure 5 for the location of the different phases of the barriers.

Type of barrier	Installed	Removed	Road section	Comments
Silt fence	Pre-nesting season 2007	Pre-nesting season 2008	Phase 1	This barrier was never effective. Wind, water and other erosion made it immediately permeable to northern diamondback terrapins
Plastic netting	Pre-nesting season 2008	Pre-nesting season 2010	Phase 1	This material was sensitive to damage from the sun (UV). It was repaired pre-nesting season 2009. This barrier was considered functional during the 2008 and 2009 nesting seasons. Note that open mesh fencing is no longer recommended for reptiles as they spend more time along the barrier, have more breaching attempts, and experience higher mortality rates (Peaden et al., 2017; Milburn-Rodríguez et al., 2018).
Corrugated plastic pipe (6 inch diameter)	Pre-nesting season 2010	Still present in November 2018	Phase 1	Tubing (similar to Reses et al., 2015) easily damaged by mowing. Tubing mistakenly moved to the edge of the shrubs and trees by road maintenance personnel. Tubing required more stakes over time to prevent terrapins from crawling under. This barrier was considered functional during the 2010 through 2018 nesting seasons, except for 2017 when the plastic pipe was insufficiently checked and staked down.
Extended road length corrugated plastic pipe (6 inch diameter)	Pre-nesting season 2012	Still present in November 2018	Phase 2	Length was extended compared to phase 1. The additional length of the barrier was considered functional during the 2012 through 2018 nesting seasons, except for 2017 when the plastic pipe was insufficiently checked and staked down.
Concrete beam barriers (20 ft long, height 1 ft, width 1 ft	Scheduled to be installed post-nesting season 2019	Installation scheduled for 2019-2020	Phase 3	Design plans approved, installation permitted. Installation scheduled for 2019, and potentially 2020.

Figure 5: The three phases of the barriers along US Hwy 13 on Fisherman Island NWR. Effective barrier phase 1: 2008-2018, phase 2: 2012-2018, phase 3: expected in 2019-2020 (see also Table 2) (data provided by USFWS).

Figure 6: The silt fence, Fisherman Island NWR, Virginia, considered an ineffective barrier and (partially) present for 2007 nesting season only (Photo credit USFWS).

Figure 7: The plastic netting fence, Fisherman Island NWR, Virginia, present for the 2008 and 2009 nesting seasons only (Photo credit USFWS).

Figure 8: The plastic corrugated pipe, Fisherman Island NWR, Virginia, present from 2010 through 2018 nesting seasons (phase 1: 2010-2011, extended road section for phase 2: 2012-2818).

Figure 9: The plastic corrugated pipe is staked down with rebar, pinning the pipe close to the ground to reduce the likelihood of diamondback terrapins crawling under the pipe, Fisherman Island NWR, Virginia, present 2010 through 2018 nesting seasons.

Communication and coordination with road maintenance crews is essential. At times, the tubing was moved further back by road maintenance crews before mowing and not put back in the correct location after mowing (Figure 10). It is important that the pipes are positioned away from the shrubs and trees and have short grass-herb vegetation on both sides of the pipe; tall vegetation adjacent to the pipe allows turtles to climb over the barrier. Vegetation maintenance was needed before every nesting season; refuge personnel applied herbicides to kill the vegetation close to the tube (1-2 ft on each side of the tube). The pipe also needs to be checked regularly for potential gaps between the ground and the pipe that would allow turtles to crawl under the pipe. Mowing close to the plastic pipe can damage the plastic pipe making the barrier ineffective in these places (Figure 11).

Figure 10: Pamela Denmon (USFWS) demonstrates where the plastic corrugated pipe should be located with short vegetation on both sides. The plastic corrugated pipe should NOT be located adjacent to the shrubs as the diamondback terrapins can use the taller vegetation to climb over the pipe.

Figure 11: The plastic corrugated pipe can be destroyed by mowing equipment, Fisherman Island NWR, Virginia, present 2010 through 2018 nesting seasons.

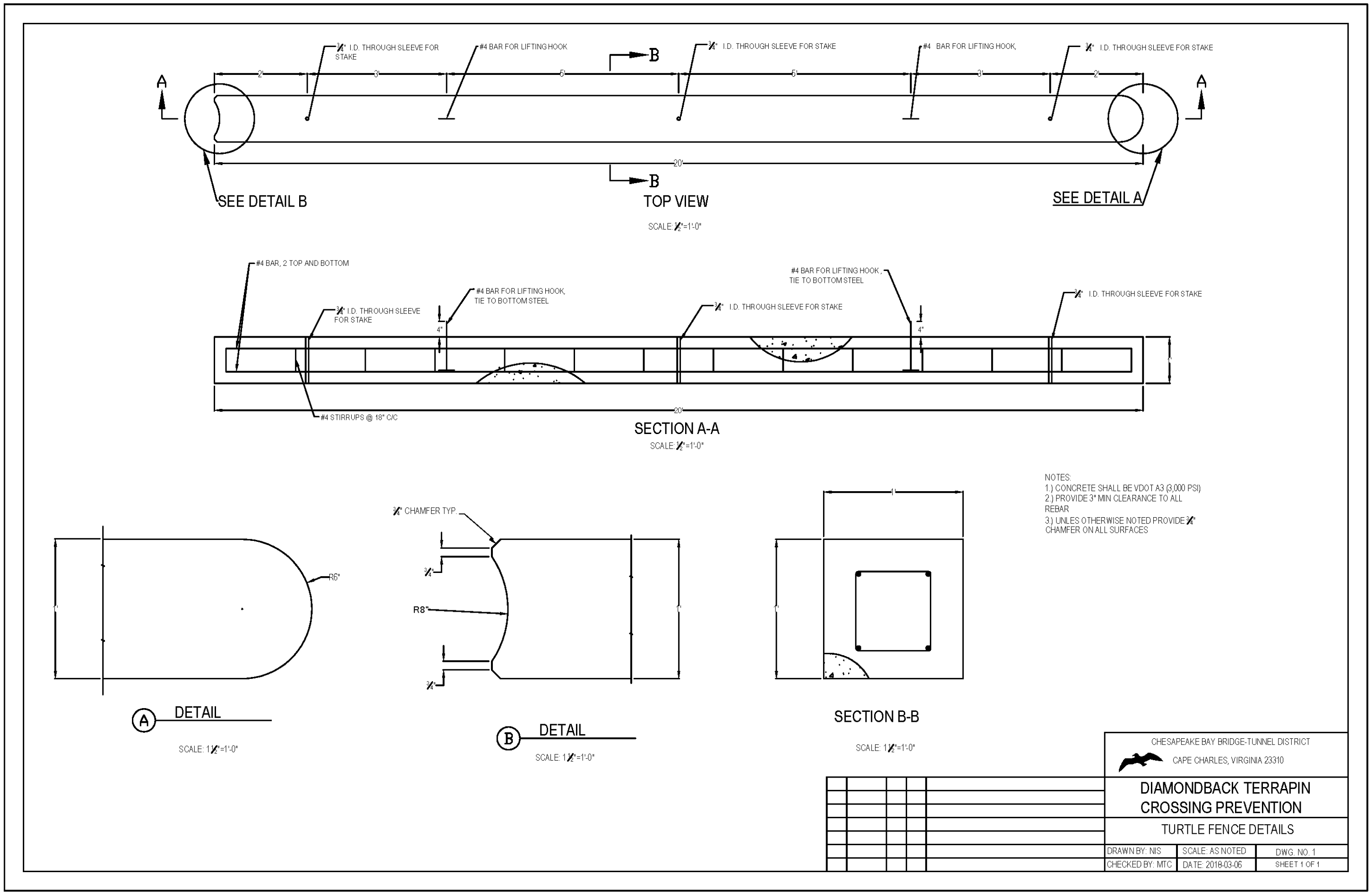

Figure 12: Technical drawing of the concrete barriers (prototype) that are scheduled to be installed in 2019, and potentially in 2020 (provided by Timothy R. Holloway, Chesapeake Bay Bridge-Tunnel). The concrete beams will be 20 ft long, 1 ft wide, and 1 ft high (Pers. com. Pamela Denmon, USFWS.

2.2.2. Diamondback Terrapin Observations along US Hwy 13

Refuge personnel and researchers inspected the road surface, shoulders and vegetated right-of-way for dead and alive diamondback terrapins during the nesting season (typically late May- mid July) between 2006 through 2018 (Pers. comm. Pamela Denmon, USFWS; Hackney et al., 2013) (Figure 13, Table 3). The road section that was inspected was from the northern edge of Fisherman Island until the southern end of the barriers just south of the parking area (Pers. comm. Pamela Denmon, USFWS) (Figure 13).

Figure 13: The Section of U.S. Hwy 13 on Fisherman Island that was monitored 2006 through 2018 (Pers. comm. Pamela Denmon, USFWS). South end coincides with the start of the barrier, north end coincides with the start of the bridge).

Table 3: Monitoring effort for diamondback terrapins along the monitoring route along U.S. Hwy 13, Fisherman Island, Virginia, USA (data provided by Pamela Denmon, USFWS).

				Interval between searches					
Year	**Start**	**End**	**Length period (days)**	**Average**	**SD**	**Median**	**Min**	**Max**	**Notes**
2006	2-Jun	28-Jul	56	1.30	0.71	1	1	3	
2007	27-May	30-Jul	64	1.00	0.00	1	1	3	2x per day
2008	30-May	17-Jul	48	?	?	?	?	?	Minimum estimates, 2x per day
2009	30-May	7-Jul	38	?	?	?	?	?	Minimum estimates, intense monitoring (>2x/day)
2010	28-May	5-Jul	38	?	?	?	?	?	Minimum estimates, Intense monitoring (>2x/day)
2011	?	?	?	?	?	?	?	?	Minimum estimates, 1x/day
2012	25-May	11-Jul	47	?	?	?	?	?	Minimum estimates, 1x/day
2013	4-Jun	16-Jul	42	?	?	?	?	?	Minimum estimates, Most days at least once
2014	28-May	28-Jul	61	?	?	?	?	?	Minimum estimates, Most days at least once
2015	22-May	27-Jul	66	1.57	0.99	1	1	4	
2016	31-May	28-Jul	58	1.38	0.76	1	1	3	
2017	25-May	19-Jul	55	1.67	1.22	1	1	7	Barrier moved, not well reinstalled, higher mortality resulted
2018	25-May	22-Jul	58	1.12	0.32	1	1	2	

2.2.3. BACI Study Design

We conducted Before-After-Control-Impact (BACI) analyses to evaluate the effectiveness of the plastic netting and the plastic pipes in reducing diamondback road mortality.

We plotted all diamondback terrapin observations (road-killed individuals only, excluding live observations) and assigned the following to each observation:

1. INSIDE road corridor vs. OUTSIDE monitored road corridor. Inside means on the pavement, shoulder or adjacent vegetation along the monitored section of U.S. Hwy 13 (see Figure 13) (Note: INSIDE must be on the road side of a barrier if the observation is in a section with a barrier). Notes associated with the observation prevailed over the plotted location.
2. For evaluation effectiveness plastic netting:
    a. BEFORE (2006-2007) vs. AFTER installation plastic netting (2008, 2009)
    b. Treatment: inside road section phase 1 (with plastic netting, PLASTIC NETTING PHASE 1) or outside road section phase 1 with plastic netting, but inside the monitoring route (CONTROL PLASTIC NETTING PHASE 1) (Figure 14). Notes associated with the observation prevailed over the plotted location. Only the road section that had barriers on both sides of the highway (phase 1, 2008 through 2011) was included as the “treatment” road section. The road section that had barriers on one side of the road only was excluded from the analyses. The road section that no barriers on both sides of the highway through 2011 was included as the “control” section.
3. For evaluation effectiveness plastic pipe phase 1:
    a. BEFORE (2006-2007) vs. AFTER installation plastic pipe (2010, 2011)
    c. Treatment: inside road section phase 1 (with plastic pipe, PLASTIC PIPE PHASE 1) or outside road section phase 1 with plastic pipe, but inside the monitoring route (CONTROL PLASTIC PIPE PHASE 1) (Figure 14). Notes associated with the observation prevailed over the plotted location. Only the road section that had barriers on both sides of the highway (phase 1, 2008 through 2011) was included as the “treatment” road section. The road section that had barriers on one side of the road only was excluded from the analyses. The road section that no barriers on both sides of the highway through 2011 was included as the “control” section.
4. For evaluation effectiveness plastic pipe phase 2:
    a. BEFORE (2006-2007) vs. AFTER installation plastic pipe (2012 through 2018, excluding 2017 because tube maintenance was deemed insufficient (See Tables 2, 3).
    d. Treatment: inside road section phase 2 (with plastic pipe, PLASTIC PIPE PHASE 2)) or outside road section phase 2 with plastic pipe, but inside the monitoring route (CONTROL PLASTIC PIPE PHASE 2) (Figure 14). Notes associated with the observation prevailed over the plotted location. Only the road section that had barriers on both sides of the highway (phase 2, 2012 onwards) was included as the “treatment” road section. The road section that had barriers on one side of the road only was excluded from the analyses. The road section that no barriers on both sides of the highway through 2018 was included as the “control” section.

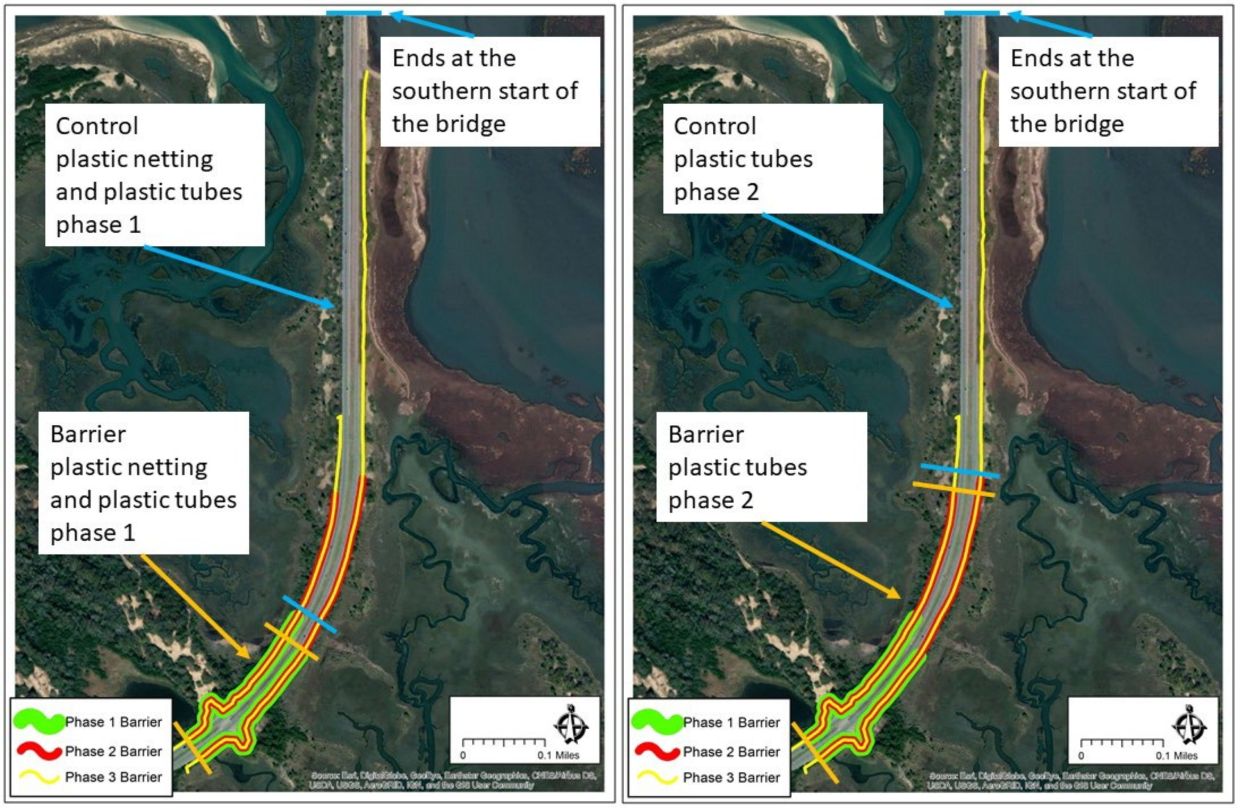

Figure 14: The Treatment (Barrier) sections) and the Control sections for the BACI analyses for phase 1 (left) and phase 2 (right). Note: The South end treatment (barrier) coincides with the start of the barrier of phase 1/2, north end control coincides with the start of the bridge.

We used the original counts in the analyses (no standardization per road length unit), but we did transform the counts (ln(x+0.1)) to make the count variable resemble a normal distribution. This allowed for the investigation of a potential interaction of the before-after and barrier-control parameters through an ANOVA. Should there be an effect of the treatment (i.e. the barrier), we expected the effect to result in fewer collisions rather than more. Hence our ANOVA was a one-sided test.

2.3. Results

Neither barrier type (plastic netting, plastic tubing), nor either barrier configuration (phase 1, phase 2) resulted in a detectable reduction in northern diamondback terrapin road mortality: Plastic netting phase 1: one-sided ANOVA $F_{1,4}$=0.01, P=0.470; Plastic tubing phase 1: one-sided ANOVA $F_{1,4}$=0.23, P=0.330; Plastic tubing phase 2: one-sided ANOVA $F_{1,12}$=0.06, P=0.404 (Figures 15-17).

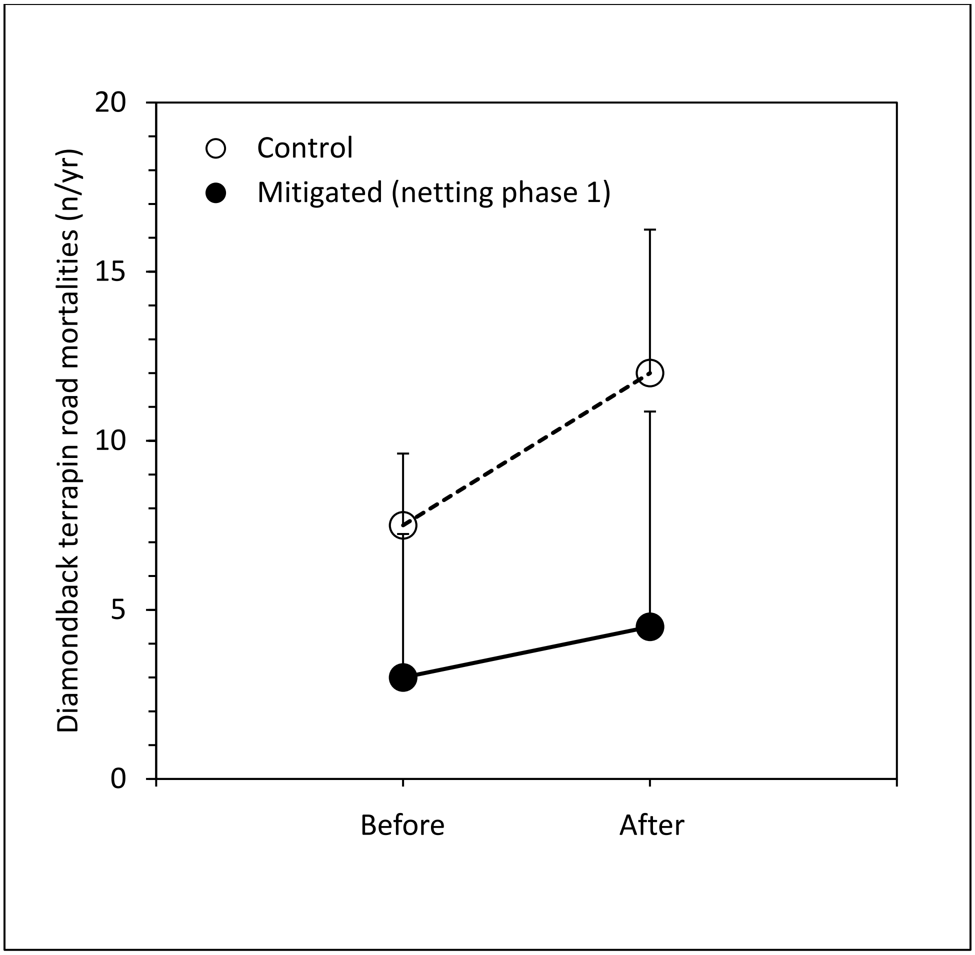

Figure 15: The number of road-killed diamondback terrapins per year and associated standard deviation reported from the unmitigated (control) and mitigated (impact) road section before (2006-2007) and after (2008-2009) the plastic netting (phase 1) was implemented.

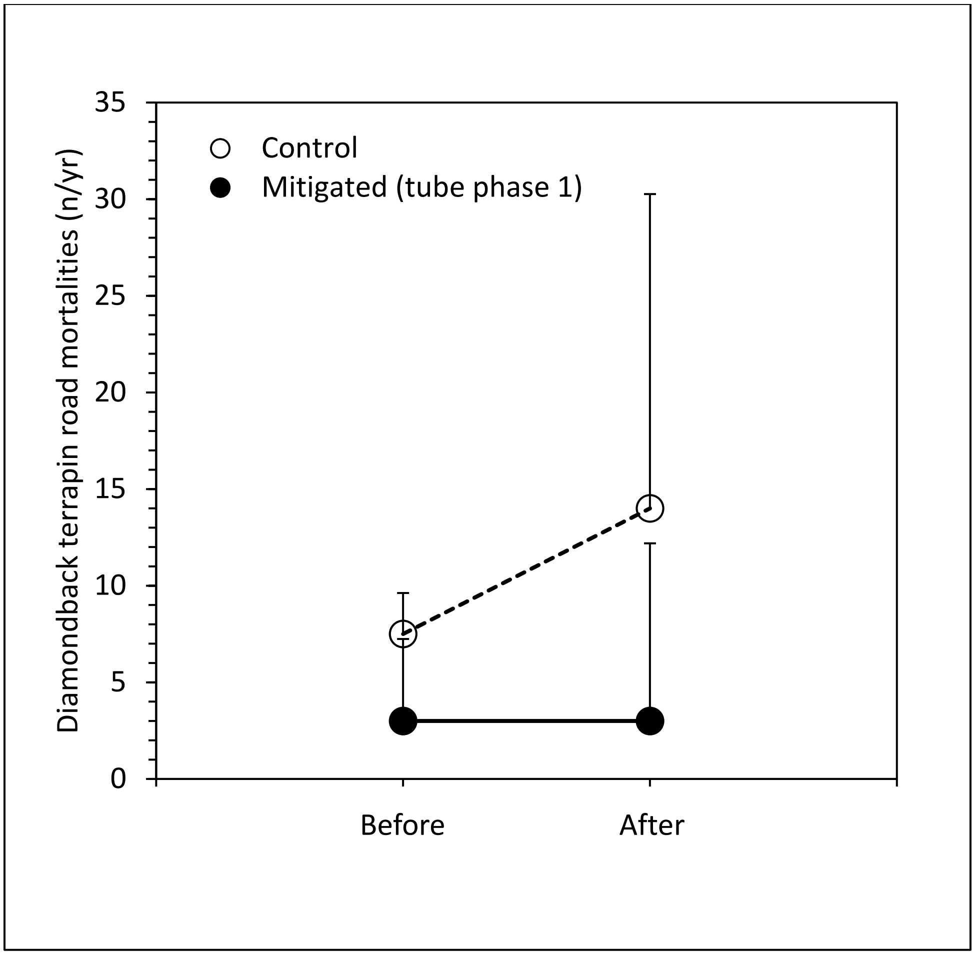

Figure 16: The number of road-killed diamondback terrapins per year and associated standard deviation reported from the unmitigated (control) and mitigated (impact) road section before (2006-2007) and after (2010-2011) the plastic tubing (phase 1) was implemented.

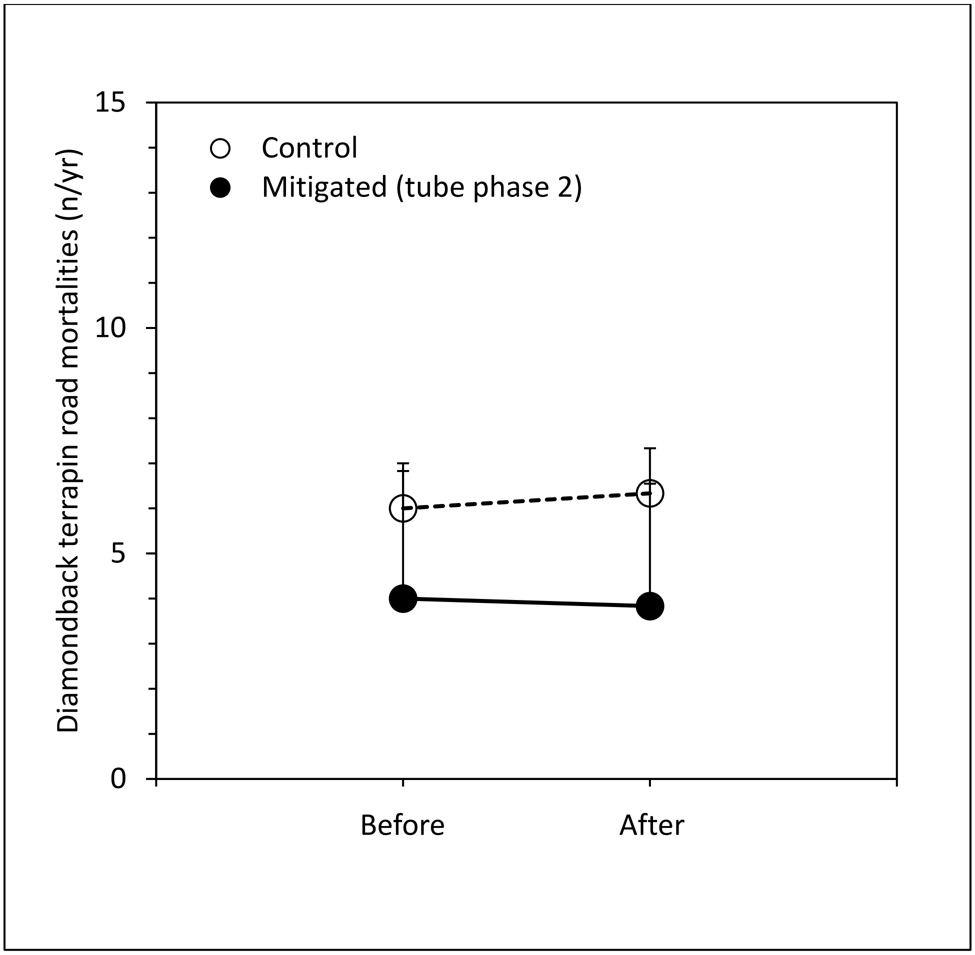

Figure 17: The number of road-killed diamondback terrapins per year and associated standard deviation reported from the unmitigated (control) and mitigated (impact) road section before (2006-2007) and after (2012 through 2018, excluding 2017) the plastic tubing (phase 2) was implemented.

2.4. Discussion and Conclusion

We did not detect a reduction in diamondback terrapin road mortality because of either the plastic netting or the plastic tubes. Variation in the number of road-killed turtles was relatively great from year to year making it hard to detect a potential reduction in mortality. This is at least partially because varying search and report effort for the road-killed turtles. The short duration for phase 1 (2 years before, 2 years after) also made it hard to detect a reduction in mortality should the barriers for phase 1 indeed have been effective. The number of years "after" installation of the tubing for phase 2 was greater (2012 through 2018, excluding 2017), but we still did not detect a reduction in road mortality because of the tubes.

We found that the plastic netting and the tubes were not an effective barrier for diamondback turtles in the field. In particular, the tubes may not be tall enough, vegetation maintenance may not be sufficient, there may be too many gaps under the tube, and there are gaps in the tube because of damage from mowing equipment. While the tubes may be an effective barrier on a small scale with captive animals (Reses et al., 2015), the tubes are not effective for a large-scale field application. We suggest taller and more robust barriers that are dug into the soil if the objective is to substantially reduce diamondback turtle mortality on this road section.

3. REVIEW PROPOSED MITIGATION FISHERMAN ISLAND

3.1. Introduction

The proposed barrier for diamondback terrapins along US Hwy 13 has been permitted already. However, in this chapter we review the proposed mitigation, and suggest modifications for potential adaptive management in the future.

3.2. Staggered Pattern Barriers

The concrete barriers are staggered on the north side; the barrier on the east side of the highway extends further north than the barrier on the west side of the highway (Figure 5, phase 3). This is because of the nature of the terrain on the west side of the highway. Rocks and concrete from the roadbed stick out above the ground (Figure 18). This makes it challenging for the 20 ft long concrete barriers to be installed snug to the ground level so that the diamondback terrapins cannot crawl under the barrier. However, in general it is a good idea to have barriers start and end on opposite sides of the highway, and to avoid a staggered pattern. Furthermore, a barrier should typically cover a collision hotspot and an additional buffer zone, and short sections of fence may suffer from reduced effectiveness (Markle et al., 2017). With the current plan, terrapins that move from west to east at the north side of Fisherman Island will still be able to access the highway. However, if the terrapins can cross the highway successfully, they will encounter the concrete barrier on the east side of US Hwy 13. This forces them to spend more time inside the road corridor before they find the fence end on the east side. Alternatively, it may force them to turn around and cross the highway once again. Therefore, we suggest bringing in gravel or soil to make the road shoulder on the north-west side also suitable for the installation of the concrete barriers. This would extend the length of the concrete barrier on the west side of US Hwy 13 to the north end of the island, opposite of where the barrier ends on the east side of the highway.

Figure 18: Roadbed with rocks on the north side of Fisherman Island (west side of US Hwy 13), resulting in uneven surface making installation of the 20 ft long concrete barriers a challenge.

3.3. Placement Concrete Barriers and Vegetation Maintenance

The concrete carriers should be placed in the roadbed with short (mowed) grass-herb vegetation on both sides of the barrier. If tall grass or herbs are present next to the barrier, the terrapins may be able to climb the barrier. Similarly, if the concrete barriers are placed on the outer side of the road bed, adjacent to shrubs and trees, the effectiveness of the barrier will be jeopardized. Mowing just before and during the nesting season, or the use of herbicides may be required to maintain the effectiveness of the concrete barrier.

Great care should be taken to level the surface on which the 20 ft long concrete barriers will be placed. There should not be any gaps under the concrete barriers that would allow the terrapins to crawl under the barriers.

It is considered good practice to have the barrier ends angle back, away from the road. This may avoid a concentration of animals crossing at a fence end, and it may encourage them to follow the barrier back towards a safe crossing opportunity (Jackson et al., 2015).

3.4. Escape Ramps

It is advisable to install escape ramps on the roadside of the barriers, similar to "jump-outs" for large ungulates (see Figure 19). This would allow turtles that do end up inside the road corridor to walk up to the height of the concrete barrier and then "tumble" to the safe side of the barrier. The escape ramp should stay clear of tall vegetation that may discourage the terrapins from walking up the slope.

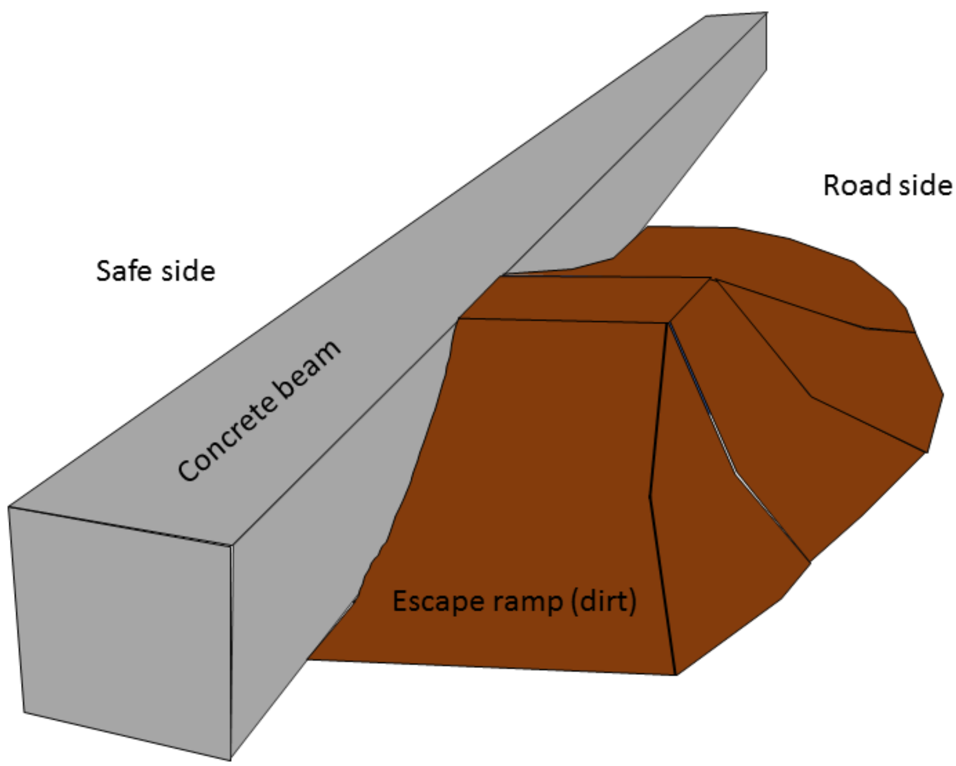

Figure 19: Conceptual drawing of an escape ramp for diamondback terrapins along a concrete barrier.

3.5. Alternative Barrier Types and Increased Height

The proposed concrete barriers will be 1 ft tall at a maximum. If the beam is partially buried into the soil, the height will be less than 1 ft. Perhaps this height will be sufficient for northern diamondback terrapins (Reses et al., 2015). However, a taller barrier may be more effective as experiments suggest a height of 2-3 ft (60-90 cm) for different turtle species (Woltz et al., 2008). However, for diamondback terrapin, a height of 1-2 ft may be sufficient (Pers. com. Kari Gunson, Eco-Kare International).

Silt fencing can reduce turtle road mortality by 99% (Aresco, 2005). However, as experienced on Fisherman Island, silt fencing is very vulnerable to damage (e.g. water, wind) (see also Baxter-Gilbert et al., 2015). Smooth plastic sheets (high-density polyethylene, Animex) were found to be a complete barrier to turtles in arena experiments (Milburn-Rodríguez et al., 2018). Recommended minimum height for turtles is 30 inches (Animex, 2018a) (Figure 20). These plastic sheets can be installed to existing fences or existing guard rails and should be buried into the soil.

Figure 20: Temporary demonstration installation of solid smooth plastic fence sheets (high-density polyethylene, Animex) designed as a barrier for herpetofauna, near Ballarat, Victoria, Australia.

More robust barriers consist of concrete (Figure 21). This barrier is 1.1 m tall, has a 15.2 cm overhang (or 'lip'), and was found to be 93.5% effective in reducing vertebrate mortality (including amphibians, reptiles and mammals, excluding hylid tree frogs) (Dodd et al., 2004). Snake road mortality was reduced by 88.5% and turtle road mortality was reduced by 98.1% (Dodd et al., 2004). An additional advantage of this type of barrier wall is that it can be integrated into the roadbed and that it does not affect the landscape aesthetics for people traveling on the highway.

Figure 21: Concrete barrier wall (1.1 m tall) with overhang or "lip' (15.2 cm) for reptiles, amphibians and small mammals, U.S. 441, Paynes Prairie Ecopassage, south of Gainesville, Florida, USA.

Another barrier wall (5 ft tall, polymer) along US Hwy 27, the Lake Jackson Ecopassage near Tallahassee, Florida was 100% effective at reducing turtle mortality (Gaskill, 2013) (Figure 22, 23). Note that this barrier wall is not integrated into the roadbed.

Figure 22: Barrier wall under construction, Lake Jackson Ecopassage, U.S. Hwy 27, Tallahassee, Florida, USA. The barrier wall (height 5 ft) is designed for turtles, alligators, snakes and amphibians.

Figure 23: Barrier wall under construction with concrete top and overhang or 'lip', Lake Jackson Ecopassage, U.S. Hwy 27, Tallahassee, Florida, USA. The barrier wall (height 5 ft) is designed for turtles, alligators, snakes and amphibians.

A concrete barrier wall for northern diamondback terrapins may not have to be as tall as in Lake Jackson or Paynes Prairie where alligators and snapping turtles are among the target species. However, concrete beams that are only 1 ft tall at a maximum, may not be an absolute barrier to this species. In addition, a barrier wall that is integrated into the roadbed does not affect landscape aesthetics as experienced by travelers on the highway.

Note that a section of US Hwy 13, just north of the parking area, already has a barrier wall over a short distance (Figure 24). This wall may be a remnant from military installations built during WWII.

Figure 24: Existing concrete barrier wall along west side U.S. Hwy 13, Fisherman Island National Wildlife Refuge, Virginia, USA.

3.6. Safe Crossing Opportunities

Most turtle species are relatively long-lived, have high adult survival, low levels of recruitment and delayed sexual maturity. In addition, many turtle species are attracted to roadbeds during the nesting season, making adult females particularly vulnerable to direct road mortality (Rytwinski & Fahrig, 2012; Andrews et al., 2015). For species with these characteristics, reducing road mortality by erecting impermeable barriers along roads may be immediately beneficial to the population survival probability. The loss of connectivity between areas on either side of the road may be less important, at least on the short term, especially if all required habitat types are available on both sides of the road in sufficient amount (Jaeger & Fahrig, 2004).

The proposed mitigation measures along US Hwy 13 on Fisherman Island NWR only relate to barriers for northern diamondback terrapin; they do not include designated safe crossing opportunities for diamondback terrapins. While there is an existing culvert under the highway on the south side of the area with the barriers, this culvert was originally designed for hydrology (Figures 25, 26). This culvert may or may not be used by northern diamondback terrapins; there are no data available. However, we do know that nest predation of northern diamondback terrapins is relatively high along the highway (Hackney et al., 2013).

Figure 25: The location of the existing culvert (red line), designed for hydrology, on Fisherman Island NWR.

Figure 26: The existing culvert under highway (west side) that may or may not be used by northern diamondback terrapins (*Malaclemys terrapin terrapin*), Fisherman Island National Wildlife Refuge, Virginia. It is a 24" Reinforced Concrete Pipe (RCP) (Pers. com. Timothy R. Holloway, Chesapeake Bay Bridge-Tunnel). It is subject to tidal influence.

Despite the likely immediate need for road mortality reduction through impermeable barriers, it is advisable to not increase the barrier effect of roads and traffic without also providing for safe and effective crossing opportunities. Therefore, especially on the long term, we suggest to also install designated safe crossing opportunities for northern diamondback turtles under US Hwy 13. Since USFWS stated that there are no other amphibian or reptile species of concern on the refuge, the safe crossing opportunities do not necessarily have to serve other species.

We distinguish between three possible types of crossing opportunities:

1. Wet culverts (Figure 27). Wet culverts can potentially be drilled from the side of the road without disrupting traffic. These types of crossings may not be used much during the nesting season when most turtles are hit by traffic. The turtles are looking for higher and dryer areas to nest and may bypass the wet culverts. While additional and larger wet culverts or bridges may allow for better connectivity for the terrapins outside the nesting season, we suggest dry culverts to address connectivity for northern terrapins during the nesting season.
2. Dry culverts with solid roofs (Figure 28). Dry culverts can potentially be drilled from the side of the road without disrupting traffic. These types of crossings should be above the

water level, but their roof is closed, and the culvert can be substantially below the road surface. The dry culverts should be connected to the concrete barriers. The concrete barriers would then not only keep the terrapins from entering the road corridor, but they would also guide the terrapins to these safe crossing opportunities, especially during the nesting season.

3. Dry culverts with open slotted roofs (Figure 29, 30). The difference with the dry culverts with solid roofs is that dry culverts with open slotted roofs have a ceiling that is also the road surface. They are not drilled from the side, but they are situated in a trench. Construction will be associated with some traffic disruption. The open slotted roof allows for light, and air and soil temperature and humidity to be similar to the surroundings. This is especially important for amphibians (Jackson et al., 2015). The bottom of the structure should be level with the surroundings, potentially partially or seasonally inundated.

Culverts of about 2 ft diameter have been used by turtles under two lane roads (Huijser et al., 2017). A wider road such as US Hwy 13 (4 lanes, median) may need to have wider culverts, perhaps at least 5 ft diameter (Smith, 2003; Gunson et al., 2016), especially if it is one structure without an opening in the median. Wider culverts (at least 5 ft) are also less likely to get blocked by debris during flooding and require less maintenance. Tunnels around 1 ft in diameter are not recommended for turtles (Woltz et al., 2008). The roadbed is sufficiently high above the ground and sea water level to allow for dry culverts under US Hwy 13 (Figure 31).

Based on a home range size of 0.54-3.05 km2, diamondback terrapins have a home range radius (annual basis) of 415-986 m (Sheridan et al., 2010). However, nearly half of all females captured and marked in a salt marsh in New Jersey searched for a nest site within 50 m of the area where they were initially tagged (Szerlag-Egger & McRobert, 2007). This suggests an interval of safe crossing opportunities of perhaps 50 m up to several hundreds of meters at the most.

Figure 27: Example of a "wet" underpass and barrier wall for reptiles, amphibians and small mammals, U.S. Hwy 441, Paynes Prairie Ecopassage, south of Gainesville, Florida, USA.

Figure 28: Example of a dry culvert (no openings in roof) used by turtles under a 2-lane road, Valentine National Wildlife Refuge, Ballard's South, Valentine, Nebraska, USA.

Figure 29: Example of an amphibian barrier wall and a dry amphibian tunnel (ACO) with an open slotted roof embedded in the pavement under a 2-lane road, Deelenseweg, between Hoenderloo and Arnhem, Gelderland, The Netherlands.

Figure 30: Example of an amphibian tunnel (ACO) with an open slotted roof embedded in the pavement under a 2-lane road, Deelenseweg, between Hoenderloo and Arnhem, Gelderland, The Netherlands.

Figure 31: The roadbed, showing the potential for drilling culverts under highway, US Hwy 13, Fisherman Island NWR.

4. MONITORING PLAN PROPOSED MITIGATION FISHERMAN ISLAND

4.1. Reduction in Direct Road Mortality

The main purpose of the concrete barriers is to keep diamondback terrapins off the highway and to reduce direct road mortality. Therefore, the most important research question is:

Question 1: Do the concrete barriers reduce direct road mortality of diamondback terrapins, and if so, by how much?

Study design for question 1: Since the concrete barrier on the east side of the highway will extend to (almost) the northern tip of the island, a Before-After-Control-Impact study design is no longer possible. A Before-After design is influenced by variables that change in time. This includes the effect of the installation of the concrete barriers, but also for example, potential changes in the population size of the diamondback terrapins and their interest in approaching and crossing the highway. Nonetheless, surveys for road-killed and live diamondback terrapins should continue after the installation of the concrete barriers, along the same road section, with an effort that is similar to that of previous years (about one survey per day in the nesting season (end-May through end-July). In addition to taking GPS coordinates, it should be recorded if the turtles are 1. Dead or alive; 2. Date of observation; 3. Along the Hwy 13 corridor or elsewhere; 4. Whether they are inside a road section with a. barriers on both sides of the highway; b. barriers on only one side of the highway; c. no barriers on either side of the highway; 5. If they are inside a highway section with barriers on both sides of the highway, what the distance is to the nearest barrier end. The latter notes are especially useful when GPS coordinates later prove inaccurate.

We used the roadkill data from the control section (the section that never had a barrier through 2018) to calculate how many years of monitoring would be required to detect an effect of the concrete barriers in reducing diamondback terrapin mortality (Power analysis, Figure 32). In general, large effects (lower portion of graph) are easier to detect (fewer years of monitoring) than small effects (upper side of the graph) which take many years to detect. Low variation (i.e. small standard deviations) also make it easier to detect an effect, should an effect indeed be present. With about 5 years of post-construction monitoring, there is 80% probability (power = 0.80) to detect a reduction of 20-25% or greater, should such an effect indeed be present (Figure 32).

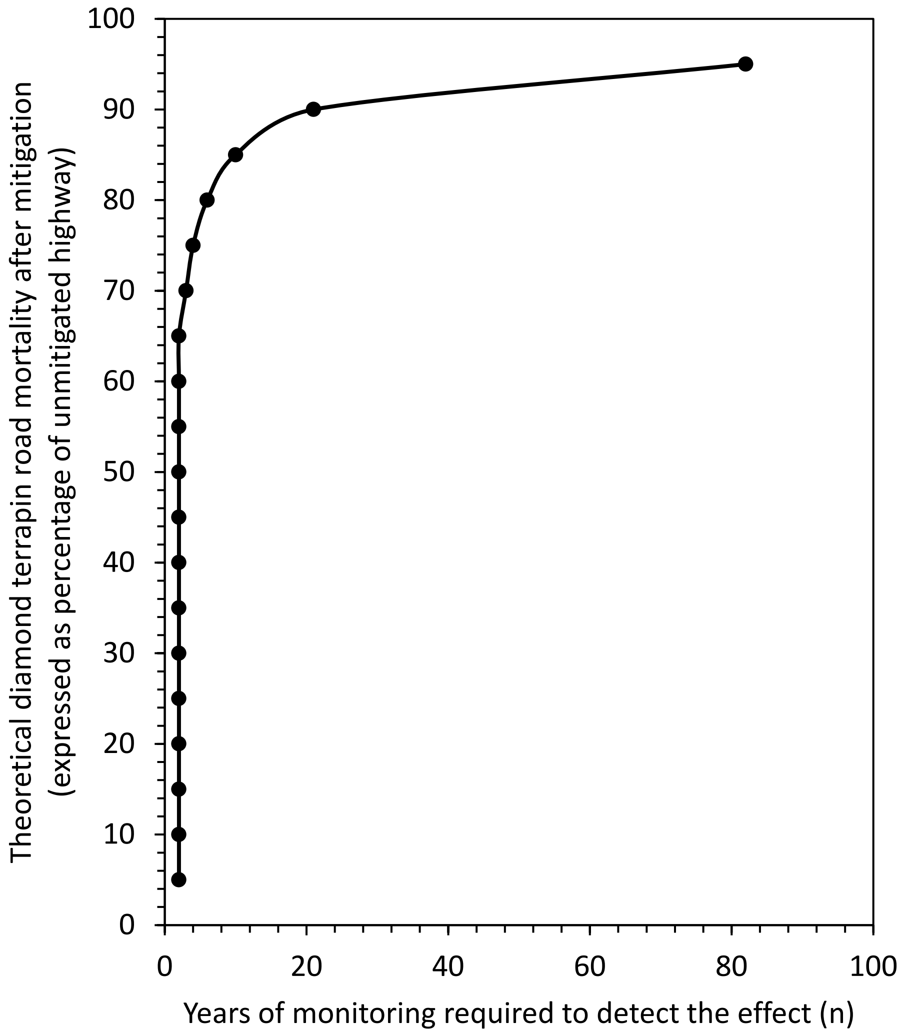

Figure 32: Power analysis showing how many years of monitoring are required to detect an effect of the concrete barriers (power = 0.80, p=0.05, one-sided test for means).

4.2. Maintenance of the Barriers

It is important to document the state of the barriers and if they are considered to meet the original design specifications before each nesting season and during each nesting season. If there are maintenance issues, they need to be addressed before the nesting season, or, if an issue is observed during the nesting season, the issue should be addressed as soon as possible, preferably the same day. Note that barriers that are sufficiently tall, robust, and dug into the soil are less likely to experience maintenance problems.

Question 2: What are the maintenance issues with keeping the concrete barriers functional as a barrier to diamondback terrapins?

Study design for question 2: Record the operation and maintenance issues associated with the concrete barriers. Potential issues can include damaged and ineffective barrier, tall vegetation growing adjacent and above the barrier, gaps between the ground and the barrier etc.

4.3. Level of Connectivity Provided

After the installation of the barriers, diamondback terrapins can no longer cross the highway on Fisherman Island. To reach the other side of the highway, they would need to swim under the bridges on the north or south side, or use the existing culvert (see section 3.6).

Question 3: Do diamondback terrapins use the existing (wet) culvert to reach the other side of US Hwy 13?

Study design question 3: To document whether diamondback terrapins use that culvert, a wildlife camera could be installed at one of the culvert entrances. Below are images of a culvert in Nebraska equipped with a wildlife camera aimed at recording turtles (Figure 33, 34). Pieces of concrete were used to "force" the turtles to the surface where they would trigger the camera. While use may occur in the entire summer season, use may be highest during the nesting season (end May through July), and that is the most important period to monitor the culvert.

Figure 33: Camera facing down to record turtles, and rock ramp in culvert to force turtles above the water surface when crossing through the culvert, Valentine NWR, Nebraska, USA.

Figure 34: Camera facing down, mounted on a horizontal fence post, to record turtles when crossing through the culvert, Valentine NWR, Nebraska, USA.

4.4. Use of Potential New Dry Culverts

Even if the one culvert (see section 3.6 and 4.3) is used by some diamondback terrapins, the level of connectivity it provides is likely very small compared to the number of turtles interested in crossing the highway. We suggest additional (dry) culverts (see section 3.6), connecting them to effective barriers, and monitoring diamondback use of these crossing structures.

Question 4: Are new dry culverts, connected to a barrier, used by diamondback terrapins?

Study design question 4: Install wildlife cameras at the new dry culverts (do not exist at this time, not planned at this time). While use may occur in the entire summer season, use may be highest during the nesting season (end May through July), and that is the most important period to monitor the culvert.

Question 5: What level of connectivity do the new dry culverts provide?

Study design question 5: Accompany wildlife cameras at the new dry culverts (do not exist at this time, not planned at this time) with a capture-mark-recapture experiment along the barriers in the vicinity of the culvert (Similar to Huijser et al., 2017). While use may occur in the entire *summer season, use may be highest during the nesting season (end May through July), and that is the most important period to monitor the culvert and conduct a capture-mark-recapture experiment.*

4.5. Willingness to Travel along Concrete Barriers

The spacing of (additional) safe crossing opportunities can be based on the home range of diamondback terrapins or the maximum distances they travel within one or two days. Another approach is to measure how long turtles are willing to travel along the concrete barrier before they give up and turn back.

Question 6: What is the home range size of diamondback terrapins on either side of US Hwy 13?

Study design question 6: Equip turtles with GPS data loggers and retrieve the data loggers at the end of the study (potential pre-programmed release date, floating data loggers). While the study could take place during the summer season, the nesting season is probably the most interesting period to target.

Question 7: What is the distance diamondback terrapins travel to lay eggs in the nesting season?

Study design question 7: Similar to the design for question 6.

Question 8: How far are diamondback terrapins willing to travel along the concrete barriers before they give up and turn back?

Study design question 8: Similar to the design for question 5, potentially program the GPS data loggers to increase the location recording frequency when the terrapins get close to the highway. While difficult, rare, and potentially influencing the behavior of the turtle, researchers could also visually monitor terrapins they happen to encounter along the concrete barriers.

4.6. Behavior along Barrier

Diamondback terrapins may follow the barriers, attempt to climb the barriers, or attempt to bury under the barriers.

Question 9: What is the behavior of diamondback terrapins along the concrete barriers?

Study design question 9: Install wildlife cameras along the concrete barriers (safe side, not road side), especially during the nesting season (end May through July). View and interpret the images, especially with regard to how the turtles may move alongside the barrier, attempt to climb the barriers, or attempt to bury under the barriers.

4.7. Do the Barriers Extended Far Enough?

In general, barriers should cover known mortality or crossing hotspots and cover an adjacent buffer zone. The road length covered by the barriers should be long enough so that no or only very few animals that follow the concrete barriers for some distance follow them all the way to the end of the barrier where they may then still access the highway.

Question 10: Do turtles follow the barriers to the 4 fence ends and do they then access the highway corridor?

Study design question 10: Place wildlife cameras at all four fence ends. View and interpret the images, especially with regard to if turtles move alongside the barrier near the end of the barrier, and what they do when the reach the end of the barrier.

4.8. Functioning of Potential Escape Ramps

Diamondback terrapins that are caught in between the barriers may use escape ramps to reach the safe side of the barrier (see section 3.4). We do not know if turtles use such escape ramps and how their use may be optimized.

Question 11: Do turtles use escape ramps and can their use be optimized by making modifications?

Study design question 11: Place wildlife cameras at escape ramps, monitor the behavior of turtles that walk along the road side of the barrier and evaluate if they use the escape ramps. Make modifications to the escape ramps based on the observed behavior.

5. SUGGESTIONS FOR ROADS THROUGH AND AROUND CHINCOTEAGUE NWR

5.1. Hwy 175 West, White-tailed Deer-Vehicle Collisions

Hwy 175 west (red in Figure 4) is located between Wallops Island NWR and NASA Wallops Flight Facility. It has a relatively high concentration of white-tailed deer-vehicle collisions (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS). The refuge lands are mostly forested, whereas Hwy 175 has wide grassy shoulders. Note that there is a fence on the north-west side of the highway, keeping people, deer, and other species from entering the airport (Figure 35).

Figure 35: Hwy 175 adjacent to Wallops Island National Wildlife Refuge and NASA Wallops Flight Facility (other side of fence), Wallops Island, Virginia, USA.

This is primarily a human safety issue as white-tailed deer are considered very numerous in the area, and there is no connectivity for large mammals to the area on the other side of the fence around the airport. The deer are likely attracted to the grass-herb vegetation in the right-of-way. We suggest making the road corridor inaccessible to white-tailed deer by also placing a fence (8 ft tall) on the other side of the highway, outside the clear-zone (Huijser et al., 2016) (Figure 36). This would make the road corridor, including most of the grass-herb vegetation, inaccessible to the deer. We also suggest deer guards or electric mats embedded in the pavement of the highway at the two fence ends to reduce the likelihood that the deer will still access the grass-herb vegetation by walking around the fence ends (Figure 37, 38). In addition, we recommend jump-outs (around 5 ft high) on the side of Wallops Island NWR that allow deer to escape from the fenced road corridor (Allen et al., 2013; Huijser et al., 2015; Figure 39). Obviously, no jump-outs should be installed along the fence on the other side of the highway as that would allow the deer to access NASA-WFF.

Figure 36: Wildlife fence (8 ft tall smaller mesh size towards bottom), U.S. Hwy 93, near Ravalli, Flathead Indian Reservation, Montana, USA.

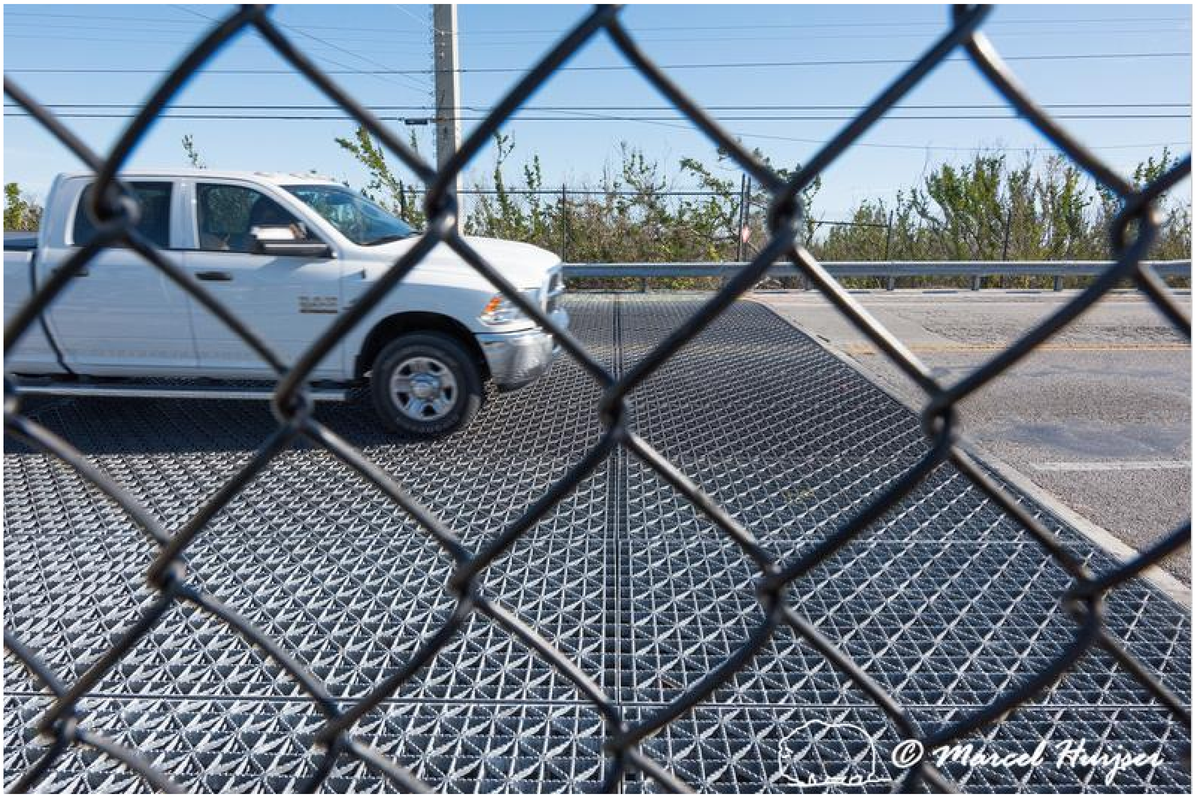

Figure 37: Wildlife guard at fence end on U.S. Hwy 1, Big Pine Key, Florida, USA.

Figure 38: Electric mat (Electrobraid™ / CrossTek™) associated with an animal detection and driver warning system at a fence end, S.R. 260 east of Payson, Arizona, USA.

Figure 39: Wildlife jump-out, near Thompson Falls, Montana, USA. Note the horizontal bar that increase the effective height for animals that want to jump into the fenced road corridor.

5.2. Hwy 175 west, Diamondback Terrapin Road Mortality

Another section of Hwy 175 west (orange in Figure 4) bisects Chincoteague Bay and saltmarshes. Here Hwy 175 is a causeway with bridges across the major channels (Figure 40, 41). The surrounding lands are managed by the NASA-WFF, Virginia Marine Resources Commission, and the town of Chincoteague. Here, road mortality of northern diamondback terrapin is a major concern (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS). The northern diamondback terrapin mortality primarily occurs during the nesting season between the end of May and mid-July (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS). It is suspected that adult females are attracted to the higher and drier soil of the roadbed to lay their eggs (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

Figure 40: Hwy 175 bridge through Chincoteague Bay and saltmarshes, Chincoteague Island, Virginia, USA.

Figure 41: Hwy 175 causeway through saltmarshes around Chincoteague Bay, Chincoteague Island, Virginia, USA.

We suggest concrete barrier walls that are (partially) integrated into the roadbed to keep northern diamondback terrapins off the highway and that help guide them to safe crossing opportunities (see section 3.5). A height of 1-2 ft may be sufficient for diamondback terrapins, but the structures should preferably at least 5 ft wide (Gunson et al., 2016). While there are several bridges across the channels, we also recommend culverts with open slotted roofs at intervals of 50 m up to several hundreds of meters at a maximum (see section 3.6). These culverts should preferably be at least 4-5 ft wide. Larger widths are less likely to result in debris inside the culverts and thereby help reduce maintenance.

5.3. Hwy 175 east, Diamondback Terrapin Road Mortality

Hwy 175 east (yellow in Figure 4) connects the town of Chincoteague on Chincoteague Island with Chincoteague NWR on Assateague Island. It crosses a saltmarsh and the Assateague Channel and is within the boundaries of the town of Chincoteague and Assateague Island National Seashore. Road mortality of northern diamondback terrapin is a concern here too (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

Our recommendations are identical to that for Hwy 175 west (section 5.2). In addition, we suggest impermeable barriers around the parking lot of business that are adjacent to the salt marsh (Figure 42).

Figure 42: Parking area at restaurant adjacent to Assateague Bay with the salt marsh and Chincoteague National Wildlife Refuge in the background, Virginia, USA.

5.4. Current Beach Access Road, Chincoteague NWR

The current beach access road (blue in Figure 4) is located within Chincoteague. The forested sections of this road have road mortality of the recently delisted Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*) (Pers. com. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS) (Figure 43). Mortality and connectivity for frogs and toads, salamanders, snakes and turtles are a concern in the wetlands (Figure 44). Common snapping turtles may be the best climbers among the amphibians and reptiles present on the refuge (tree frogs excluded).

For the amphibians and reptiles, a minimum barrier height of 30 inches is recommended (smooth plastic high-density polyethylene, Animex) (see section 3.5). The preferred option is to install concrete wall barriers integrated in the road bed (perhaps 2-3 ft height with an overhang as concrete is not as smooth as plastic sheets) (similar to the barrier walls in Paynes Prairie (see section 3.6). Culverts, preferably with open slotted roof that is part of the road surface are recommended as crossing opportunity; perhaps several hundreds of meters apart at the most. Crossings should be wide and tall enough to allow for large snapping turtles and debris during flooding (perhaps 5 ft wide at a minimum) (Smith 2003; Gunson et al., 2016). Height should be from the ground level (ground level of surrounding area) to the road surface (perhaps 2-3 ft).

Figure 43: Delmarva fox squirrel habitat present on both sides of the beach access road, near the visitor center, Chincoteague NWR, Virginia, USA.

Figure 44: Current beach access road and bicycle path adjacent to brackish wetlands, Chincoteague NWR, Virginia, USA.

Fox squirrels spent substantial time on the ground and can jump (Hennessy et al., 2018). The barrier wall for amphibians and reptiles is unlikely to be a substantial barrier for fox squirrels. However, arboreal crossing structures will likely be used by the fox squirrels. Arboreal crossings should be installed where tall trees are present on both sides of the highway (Figure 43). However, there will be no barriers guiding the squirrels to the crossing opportunities. Therefore, at-grade crossings by fox squirrels will continue, including direct road mortality. Nonetheless, some crossings, likely increasing numbers with time, will be on the arboreal structures. Note that while some species can start using arboreal crossing structures almost immediately, others may take 1-2 years before the first use is recorded (Soanes et al., 2013 Animex 2018b).

Arboreal crossing structures for squirrels can range from single wires or old fire hoses to rope ladders, to solid metal structures of variable design and width (see e.g. Figure 45, 46). Based on the behavior of the species fox squirrel (*Sciurus niger*) all types of arboreal structures are likely to be used by the Delmarva Peninsula fox squirrel (*Sciurus niger cinereus*). Female fox squirrels may have an average home range size on about 20 ha (Prince et al., 2014). Based on the home range radius, structures should be about 250 m apart at a maximum to allow, on average, all females that have the center of their home range on or adjacent to the road, access to at least one crossing structure. Care should be taken that the structure is physically connected to the canopy on both sides of the road (e.g. through multiple ropes between the end of the structure and the canopies of the surrounding trees).

Figure 45: Black-tufted marmoset (*Callithrix penicillata*) on an old firehose over a low volume single lane road, ESALQ campus, Piracicaba, São Paulo, Brazil.

Figure 46: Triangular shaped aluminum wildlife bridge manufactured by Animex (section shown at a conference booth). This type of structure was used readily by Eurasian red squirrel (*Sciurus vulgaris*) (Animex 2018b).

Further east, closer to the beach, the current beach access road is a causeway with salt marshes on either side of the road. There is only a small box culvert that allows the brackish water to flow in and out (Figure 47), resulting in restricted tidal flow to Swan Cove Pool. The water velocity appears too high to allow turtles to pass upstream. Restoring tidal influence, and thereby restoring habitat for northern diamondback terrapin seems possible. Part of the causeway can be made into a bridge (Figure 48). The bridge should preferably also have semi-aquatic and terrestrial habitat on both sides allowing for semi-aquatic and terrestrial species to pass under the bridge (Clevenger & Huijser, 2011).

Figure 47: Box culvert at the current beach access road, Chincoteague National Wildlife Refuge, Virginia, USA.

Figure 48: Causeway through saltmarshes close to the current beach access (Swan Cove Pool to the left, Toms Cove to the right), Chincoteague National Wildlife Refuge, Virginia, USA.

5.5. New Beach Access Road, Chincoteague NWR

A new beach access road (purple in Figure 4) is under construction (vegetation has largely been cut) within Chincoteague NWR and the Assateague Island National Seashore from Snow Goose Pool to just north of Pintail Pool (Figure 49, 50). Likely future road mortality of the Delmarva Peninsula fox squirrel and likely future road mortality and reduced habitat connectivity is a concern for frogs and toads, salamanders, snakes and turtles (Pers. comm. Nancy Finley, Kevin Holcomb and Robert Leffel, USFWS).

We suggest mitigation measures that are similar to the for the current beach access road (section 5.4), with the exception of restoring tidal influence. A barrier wall and associated crossings for reptiles and amphibians is of the greatest importance.

The parking area for the new beach access will be just behind the coastal dunes. We suggest that the beach visitors will cross the dunes on a boardwalk to minimize damage to the dune vegetation and to keep the roots intact to withstand water and wind erosion (Figure 51, 52).

Figure 49: Route cut through for new beach access road through maritime forest, Chincoteague National Wildlife Refuge, Virginia, USA.

Figure 50: Pintail Pool along route for new beach access road through wetlands and maritime forest, Chincoteague National Wildlife Refuge, Virginia, USA.

Figure 51: This will be the new beach access point, Chincoteague National Wildlife Refuge, Virginia, USA.

Figure 52: Boardwalk across coastal dunes to reduce erosion, east of Seagrove Beach. Florida, USA.

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