GEORGIA DOT RESEARCH PROJECT 22-33

Final Report

EXPERIMENTAL TESTS FOR AN EFFECTIVE BARRIER DESIGN TO EXCLUDE DIAMONDBACK TERRAPINS (*MALACLEMYS TERRAPIN*) FROM ROADS

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16. Abstract

The objective of this project was to conduct experimental testing on fence designs that are effective in preventing diamondback terrapins (*Malaclemys terrapin*) from entering roadways to prevent the species from being impacted by road mortality. The diamondback terrapin is listed as a State Species of Concern in the State of Georgia. They are the only native brackish-water dwelling turtle species along the eastern seaboard of the United States and are facing population declines as a result of human encroachment and habitat modification. Specifically, this species experiences widespread road impacts throughout their range around coastal transportation infrastructure. This conflict between wildlife and transportation infrastructure occurs most frequently with nesting females, a critical demographic to the long-term viability of populations. Therefore, our goal was to devise an affordable structural option to prevent terrapins from entering US-80 (the Tybee Island Causeway) that aligns with the Georgia Department of Transportation construction, maintenance, and driver safety protocols. Specifically, we determined the height and angle specifications for the exclusion fencing implementation by testing three reverse curb designs: 90º flat surface, 90º with a 3" lip, and 70º reverse angle. Each curb had 2' sections of 4 different heights: 6", 8", 10", and 12". The most effective heights were 12", successfully excluding 100% of animals attempting to climb the barrier for the 90-degree, 98% of animals for the 70-degree reverse angle & 100% for 90 degree with 3" lip. Next, the 10" height successfully excluded 96% of animals for the 90-degree, 100% for the 70-degree reverse angle, and 100% for the 90-degree with 3" lip. At the 8" height, 70% of animals were excluded from the 90-degree, 97% from the 70-degree reverse angle, and 96% from the 90-degree with 3" lip. Lastly at the shortest 6" curb, only 64% of animals were excluded from the 90-degree, 96% were excluded from the 70-degree reverse angle, and 87% were excluded from the 90-degree with 3" lip. Overall, the 10" and 12" heights of the 70-degree reverse angle curb and the 90-degree with 3" lip curb were most successful at excluding terrapins. This research can guide GDOT towards adapting a concept into an effective barrier design that will be permanent, reduce maintenance costs, and increase safety on US-80 and future causeway or coastal projects where impacts to terrapins need to be mitigated. These results have broader application to diamondback terrapins throughout their range and to other hard-shelled chelonids on a global scale.

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GDOT Research Project 22-33/ T.O

Final Report

EXPERIMENTAL TESTS FOR AN EFFECTIVE BARRIER DESIGN TO EXCLUDE DIAMONDBACK TERRAPINS (*MALACLEMYS TERRAPIN*) FROM ROADS

By

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[1] University of Georgia Marine Extension and Georgia Sea Grant

Contract with
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In cooperation with
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January 2025

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
fl	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
fl2	square feet	0.093	square meters	m2
yd2	square yard	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
fl3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
	NOTE: volumes greater than 1000 l shall be shown in m^3			
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or 't")
	TEMPERATURE (exact degrees)			
'F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	oc
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbffln^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	11
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m2	square meters	10.764	square feet	112
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi2
	VOLUME			
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m3	cubic meters	35.314	cubic feet	113
m3	cubic meters	1.307	cubic yards	yd3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or"t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact degrees)			
"C	Celsius	1.8C+32	Fahrenheit	"F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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EXECUTIVE SUMMARY

Diamondback terrapins are a unique turtle, being the only species exclusive to tidal saltmarshes along the eastern United States. They are particularly vulnerable to road mortality as reproductive females emerge from the marsh creeks during high tides in search of high, dry grounds to nest during late spring and summer in the southeastern United States (seasonality varies with region). Typically, their natural nesting habitat is the hard Spartina-vegetated "high" marshes, though causeways have introduced terrestrial ground of competitive elevation, thereby attracting nesting females to causeway shoulders to nest and increasing their likelihood wildlife-vehicle conflicts. This differential removal of reproductive, adult females is problematic as they are the least expendable demographic from a standpoint of long-term wildlife population viability.

United States (US)-80 is a two-way, two-lane, rural highway in coastal Georgia and serves as the only connection between Tybee Island and the Georgia mainland. This causeway, along with bridge approaches at either end, serve as critical nesting grounds for protected diamondback terrapins. With the causeway and bridges both in need of improvement and over a decade of monitoring data on vehicle strikes of terrapins, the Georgia Department of Transportation (GDOT) consulted with agency and community partners to determine the most feasible solution for reducing terrapin-vehicle collisions. After consulting with the University of Georgia (UGA) Marine Extension and Georgia Sea Grant, their research team conducted a literature review of scientific peer-reviewed publications, unpublished and published reports, media references, conference presentations, and expert input. A permanent, reverse curb solution was identified as the preferred method to exclude terrapins from the roadway, while reducing long-term maintenance costs, and taking safety design considerations into account.

The overarching goal of the UGA research team was to reduce terrapin mortality from wildlife-vehicle collisions by devising an affordable structural barrier that will prevent terrapins from entering roads and that is line with Department of Transportation construction, maintenance, and driver safety protocols. The team conducted experimental testing on three reverse curbing designs to determine which heights and angles terrapins were ineffective at climbing over (trespass). The curbs presented three angles: 90º straight, vertical surface [hereafter, 90º], 90º with a 3" lip [lip], and 70º angle [angle]. Each curb had 2' sections of 4 different heights: 6", 8", 10", and 12". The team conducted runway experiments with wild-caught animals that were tested at the capture location and released immediately following the trial.

All curb experimental trials were conducted in May-July 2024 using wild terrapins caught by road cruising, pedestrian and bike surveys, and seining methods (n=121). The team had two experimental sites: Fort Pulaski National Monument (Chatham County) and UGA Marine Extension and Georgia Sea Grant facility in Brunswick (Glynn County). Each animal was tested on all three curb sections and were released within 4-48 hours of capture (most frequently released within 6 hours of capture). The most effective heights were 12", successfully excluding 100% of animals attempting to climb the barrier for the 90º, 98% of animals for the 70º reverse angle & 100% for 90º with 3" lip. Next, the 10" height successfully excluded 96% of animals for the 90º, 100% for the 70-degree reverse angle, and 100% for the 90-degree with 3" lip. At the 8" height, 70% of animals were excluded from the 90º, 97% from the 70º reverse angle, and 96% from the 90º with 3" lip. Lastly at the shortest 6" curb, only 64% of animals were excluded from the 90º, 96% were excluded from the 70º reverse angle, and 87% were excluded from the 90º with 3" lip. Based on these results, the 10" and 12" heights of the 70º reverse angle curb and the 90º with 3" lip curb were most successful at excluding terrapins overall.

These curbs will be most successful if they are combined with guide fencing at terminal points, which will aid in redirecting terrapins towards the marsh and prevent wrap-around effects and fence-end mortality. Additionally, curbs should be casted without a brush finish to allow a smooth surface on the concrete that discourages climbing. The team advises a regular curb maintenance schedule post-implementation to prevent the accrual of debris along the curbs (especially after stormy weather and high tides), which will quickly result in eased trespass for the terrapins and negated effectiveness of the barrier. The team strongly cautions against implementation of the 6" heights for any of the curb designs. The 90º with 3" lip curb presented an additional disadvantage as terrapins frequently became wedged and stuck under the overhang during experimental trials. This research will guide GDOT towards adapting a concept into an effective barrier design that will be permanent, reduce maintenance costs, and increase safety on US-80 and future causeway or coastal projects where impacts to terrapins need to be mitigated. These results have broader application to diamondback terrapins throughout their range and to other hard-shelled chelonids on a global scale.

CHAPTER 1. INTRODUCTION & RESEARCH NEED

Diamondback terrapins (*Malaclemys terrapin*) is listed as a state species of concern, and classified as Vulnerable on the IUCN Redlist (Fig. 1). Diamondback terrapins are a unique turtle, being the only species exclusive to brackish-water, tidal saltmarshes along the eastern United States. They are known to have long life spans, are sensitive to impacts, and slow to recover from persistent removal from stable or increasing populations. They are a species of conservation concern as they are facing population declines range-wide as a result of human encroachment and habitat modification. Following, they are particularly vulnerable to road mortality as reproductive females emerge from the marsh creeks during high tides in search of high, dry grounds to nest during late spring and summer in the southeastern United States (seasonality varies with region). Typically, their natural nesting habitat is the hard Spartina-vegetated "high" marshes, though causeways have introduced terrestrial ground of competitive elevation, thereby attracting nesting females to causeway shoulders to nest and increasing their likelihood wildlife-vehicle conflicts. This differential removal of reproductive, adult females is problematic as they are the least expendable demographic from a standpoint of long-term wildlife population viability.

Figure 1. Photo. Study focal species. The species of focus, diamondback terrapin (*Malaclemys terrapin*).

The east coast is the most populous area of the United States, hosting 36% of the nation's residents and over 50 million people visit annually (US Census Data 2020). Unfortunately, the peak emergence activity for nesting terrapins coincides with the peak of coastal tourism. Increased traffic from cars and turtles has created population-level impacts in multiple locations throughout this species' range. Further, these on-road losses are confounded by mortality from in-water threats of bycatch in crab traps, pollution, development, and loss of habitat from climate change. As international tourism numbers and coastal resident populations continue to rise, development and human infrastructure will increase accordingly. Additionally, native saltmarsh habitats are being impacted and reduced by habitat degradation, and rising coastal water levels, thereby increasing the importance of roadside spaces for critical nesting habitat for terrapins and other species. Following, there is more pressure than ever on transportation and biological professionals to devise infrastructure designs that avoid and mitigate for conflicts with wildlife without incurring issues for driver safety, hindrances for roadside maintenance, or unbudgeted cost burdens.

Roadsides can be designed to accommodate or restrict nesting, depending on the local impacts in need of mitigation and whether the amount and quality of habitat extending from the right-of-way can accommodate nesting. Barrier designs have been developed to exclude diamondback terrapins from roads and to facilitate their use of appropriate nesting habitats on roadsides. In coastal Georgia in April 2022, Jekyll Island installed Animex® fencing (Animex 2024) to exclude terrapins from entering the road at a nesting hotspot at the entrance of GA State Route 520 (Downing Musgrove Causeway). Additionally, they have conducted research and shown continued effectiveness of artificial "nest boxes" that are constructed to allow for nesting while excluding predators (Quinn et al. 2015). Another successful example is from New Jersey where researchers at The Wetlands Institute installed corrugated pipe along 11 miles on the causeway to Seven Mile Island to prevent the trespass of terrapins onto the road (Egger 2016) and have installed this design in other locations where locals have sought mitigation of mortality. Further, there are preliminary concepts that have been developed through previous discussions about the mitigation needs for terrapins on US-80 to Tybee Island, in addition to other designs that have been developed for freshwater turtles and land tortoises and offer the potential for customization for this project (Andrews et al. 2015).

There are a number of considerations to incorporate when designing a barrier fence for a given location. Some of the important features to consider regardless of site-specific conditions are: a) effectiveness in preventing trespass of the terrapins onto roads; b) likelihood of being able to use different materials according to roadside design standards, installation costs, state transportation maintenance plans; and c) logistics of installation and repair. Other factors that should be customized to site due to a high degree of variation among projects, environmental conditions, socio-geography, and other local or regional conditions are: d) safety of animals encountering the fence (i.e., target mitigation species for exclusion, non-target species who need connectivity and reducing fragmentation concerns); e) durability from chronic or seasonal weather exposure; f) damage risk to materials from maintenance activities; and g) aesthetics and local perceptions of appearance. Some testing on fencing materials has occurred in New Jersey (The Wetlands Institute 2019) and Ontario (Ontario Canada 2012), both of which have online information through these links. However, Georgia has many site-specific conditions that prevent application of already-established techniques, including but not limited to: our high tidal amplitude; extremely warm summer temperatures; and high salinity that accelerates degradation of some materials.

United States (US) Route 80 is a two-way, two-lane, rural highway in coastal Georgia and serves as the only connection between Tybee Island and the Georgia mainland. This causeway, along with bridge approaches at either end, serve as critical nesting grounds for protected diamondback terrapins. With the causeway and bridges both in need of improvement and almost two decades of monitoring data on vehicle strikes of terrapins, the Georgia Department of

Transportation (GDOT) consulted with agency and community partners to determine the most feasible solution for reducing terrapin-vehicle collisions. US-80 also has a very narrow right-of-way, and these space constraints exclude application of many existing wildlife barrier designs. Therefore, GDOT decided to fund research conducted by the University of Georgia to specifically test various curb designs to find characteristics that lead to an effective barrier. Given that high-ground nesting is the principal biological need to accommodate (rather than connectivity across roads), the UGA team (hereby referred to as the team) focused on exclusion measures as their mitigation action. Specifically, a permanent, reverse curb solution was identified as the preferred method to exclude terrapins from the roadway, while reducing long-term maintenance costs, and taking safety design considerations into account. Additionally, the planned offset bridge replacements provide an opportunity to repurpose the existing bridge approaches for increasing terrapin nesting habitat in an area of marshland already impacted.

The team's overarching goal was to reduce terrapin mortality from wildlife-vehicle collisions by devising an affordable structural barrier that will prevent terrapins from entering roads and that is line with Department of Transportation construction, maintenance, and driver safety protocols. The team's short-term goal was to identify a feasible barrier design that can be installed on US-80 to Tybee Island. Their long-term goal is to be able to apply this design as needed elsewhere in Georgia and for it to serve as a model for other states applying mitigation options for terrapins or freshwater turtles. The research objective of this project was to conduct experimental testing on barrier fence designs that are effective in preventing diamondback terrapins from entering roadways to prevent the species from being impacted by road mortality. Specifically, the team determined the height and angle specifications for the exclusion fencing implementation.

CHAPTER 2. LITERATURE REVIEW

In 2023, the team conducted a global literature search of references that included information on fencing, exclusion, and barrier structure option for preventing chelonids from entering roadways. The team included peer-reviewed scientific literature, published and unpublished reports, websites, and news articles. The team further engaged expert-based opinions of transportation and wildlife ecologists who have experience with fencing designs and had relevant observations to offer. These experts were identified based on known colleagues by PI Andrews and presentations from relevant professional conferences (e.g., International Conference on Ecology and Transportation (international), The Wildlife Society (national), Southeastern Partners of Amphibian and Reptile Conservation (regional)). Citable references were compiled into an Excel spreadsheet (n = 41); 39 references were made into pdfs and files were linked to the corresponding row in the spreadsheet. The two references that are not linked and included with this report are a book (Andrews et al. 2015) and an ArcGIS Story Map website (Monkton Wildlife Crossing; contact: Chris Slesar, Vermont Department of Transportation). The excel file listing all references included in the Literature Review is provided as Appendix 1; additionally, citations for all references are included in the References section below.

CHAPTER 3. METHODOLOGY & EXPERIMENTAL TRIALS

Reverse Curb Designs

The dimensions of the three reverse curb designs from a cut section are show in Figure 2. The dimensions of the angled curb (70º reverse angle) for the 6”, 8”, 10”, and 12” heights are shown in row 1, while the dimensions of all four heights for the 90º (90º straight vertical surface) curb and the lip (90º with a 3” lip) curb are shown in rows 2 and 3, respectively. Figure 3 also shows cut-section images for all three curb designs at the 6” height for reference.

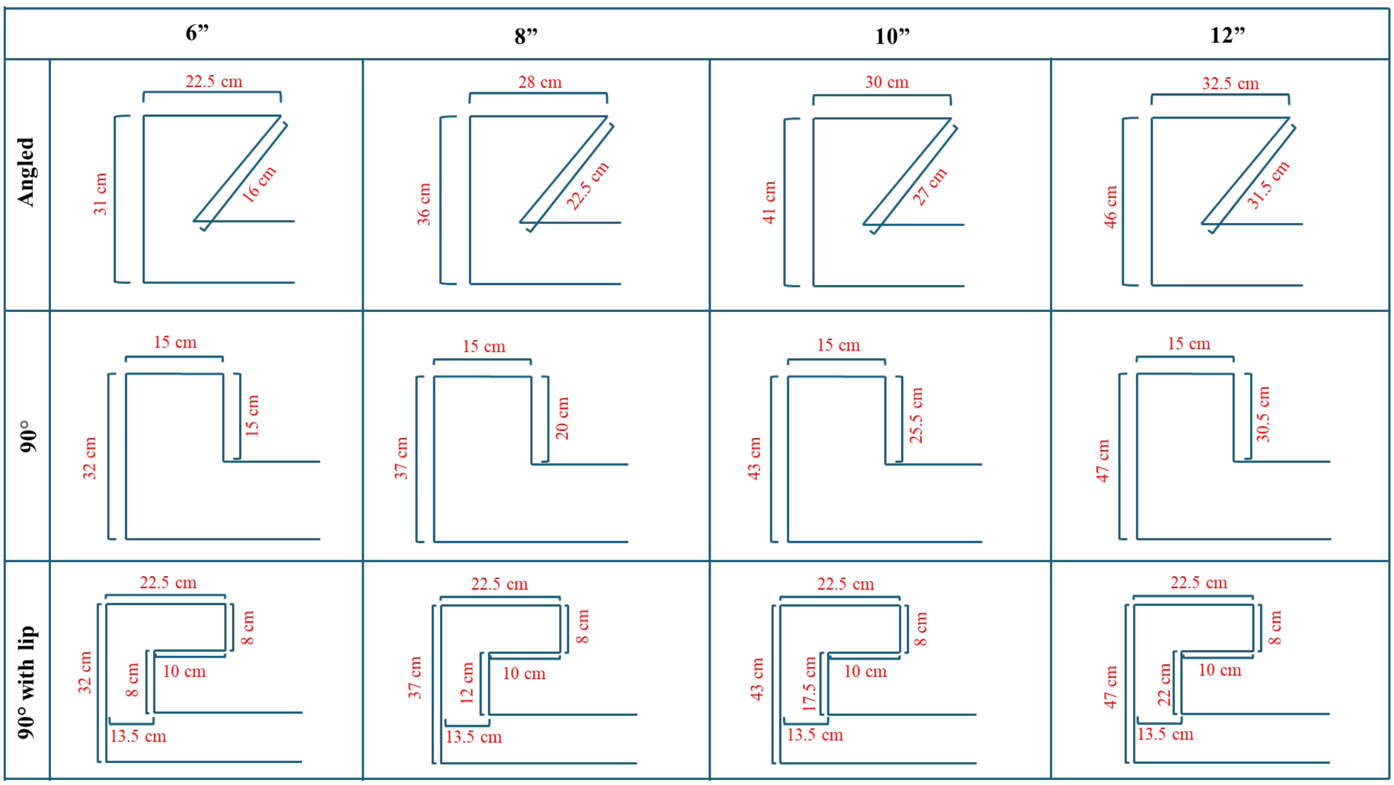


Figure 2. Table. Curb dimensions. Dimensions of all three reverse curb designs cut sections per each of the four heights.

Figure 3. Photo. Curb cut sections. Cut section images of all three curb designs at the 6” height for reference to table in Figure 2.

Field Sites

The team selected two field sites to conduct the terrapin trials on the experimental reverse curb designs (Fig. 4). The team based site selection on locations where terrapins are locally abundant and for their relevance to the objectives and outcomes of this research. The team’s first site was Fort Pulaski National Monument managed by the National Park Service (Chatham County), who has been heavily engaged and concerned about the levels of mortality on US-80. Additionally, this location is near the Tybee Island Marine Science Center (TIMSC) whose director, Chantal Audran, has been involved in the long-term terrapin monitoring and mortality counts on the US-80 causeway

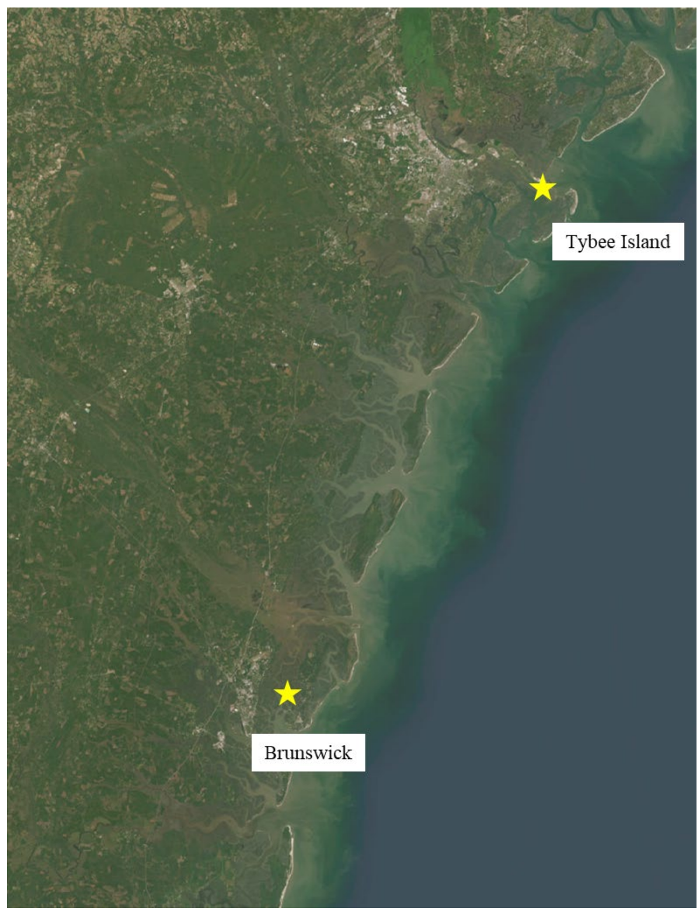


Figure 4. Map. Sampling sites. The two sampling sites on the Georgia coast where wild terrapins were collected for the experimental trials. The northernmost star shows Tybee Island Causeway, while the southern star shows Hawkins Island by Saint Simons Island.

since it’s initiation in 2005. The team’s second site was at the UGA Marine Extension facility in Brunswick, Georgia (Glynn County) where PI Andrews and her Coastal Ecology Lab (in the Marine Extension and Georgia Sea Grant department) are located. The UGA team coordinated with the GDOT District 5 Maintenance team to cast the experimental reverse curb sections. They were delivered and put in place at both sites on April 15, 2024 (Fig. 5).

Figure 5. Photo. Curb installation. Left: The three types of reverse curb designs used in the experiment. Right: D5 Maintenance Crew with PI Andrews at the Brunswick test site when the curbs were being delivered.

All experimental testing took place in the field at two testing sites constructed at Fort Pulaski and Brunswick. At both sites, the tests were conducted with the curbs facing the water so that the site of the water would motivate the terrapins to crawl toward and attempt to climb over the curbs. The test site at Fort Pulaski was located on Cockspur Island along Tybee Coast Guard Station Drive (Fig. 6, Left), while the test site in Brunswick was located behind the University of Georgia Marine Extension and Georgia Sea Grant building along East River (an offshoot of Turtle River, Fig. 5, Right, and Fig. 6, Middle and Right). Both locations had identical testing curbs that included the three curb types and the four heights for each type. All terrapins were tested against the curbs typically within 4 hours of capture but no more than within 24 hours of capture. The Fort Pulaski test site was located under a pine tree canopy that provided shade during the trials, and shade tents were placed over the test sites in Brunswick to prevent heat stress in the terrapins during the trials since it was open and had no tree canopy.

Figure 6. Photo. Testing sites. Visual setting of experimental test sites. Left: Fort Pulaski, Middle and Right: Brunswick

Capture Methodology

The use of live diamondback terrapins was necessary to this experiment because the purpose of this research is to test and examine how diamondback terrapins will respond to the various types of fencing; therefore, the team needed to be able to observe their behavior while interacting with the different curb designs (IACUC Animal Use Proposal A2023 03-004-Y1-A0). Including captive animals in the study was considered; however, there were insufficient numbers of adult terrapins in captivity in coastal Georgia education centers for a minimum acceptable sample size for the testing treatments. Also, diamondback terrapins in captivity behave differently than terrapins from the wild; this was confirmed during initial tests with two captive animals from TIMSC. Hence, the team used various methods of sampling and capture to find wild diamondback terrapins to test against the curb designs. This sample demographic also allowed the team to confidently report behavioral results of how wild terrapins will react to these curbs in their natural habitat.

The first method of capturing diamondback terrapins was by road cruising, or driving a car back and forth along US-80 (the Tybee Island causeway) to survey for live terrapins along the road, especially focusing on "hotspots" where terrapin road mortality has been monitored to be the highest. The research team's vehicle was outfitted with magnets labeled "frequent stops" and "terrapin research," along with a strobe light for safety for the patrol team and additional awareness for passing drivers (Fig. 7). Crew members wore high visibility safety vests for additional protection while getting terrapins off the road while pulled over and to show official UGA branding as the team did not want their actions to inspire observing drivers to take intervention in removing terrapins from the road (Fig. 7). The vehicle was maintained at a speed of 40 mph and if a terrapin was spotted on the road or on the shoulder, the vehicle was safely pulled over off the side of the road and the terrapin was collected. These individuals found on roads were recorded as "AOR" or "Alive-on-Road" under their capture information. Road cruising took place on a 4.3-mile stretch of US-80 from the East end of the causeway after the bridge over Bull River on a pull-off by a tidal creek off the main river (Bull Creek) to the Lazaretto Creek Fishing Pier at the end of the road by the Lazaretto Creek Boat Ramp Road (Fig. 8, red lines).

Figure 7. Photo. Research vehicle. Road cruising vehicle outfitted with strobe light and magnet next to field researcher in high visibility safety vest holding a terrapin that was found alive on the road (AOR) on US-80.

The second and third methods of diamondback terrapin capture were through pedestrian sampling by either walking or biking (Fig. 8, blue lines). During each capture, researchers surveyed a 9-km (5.6 miles) gravel biking and walking trail positioned parallel to the South Channel Savannah River directly north of US-80 named McQueen's Island Historic Trail (also

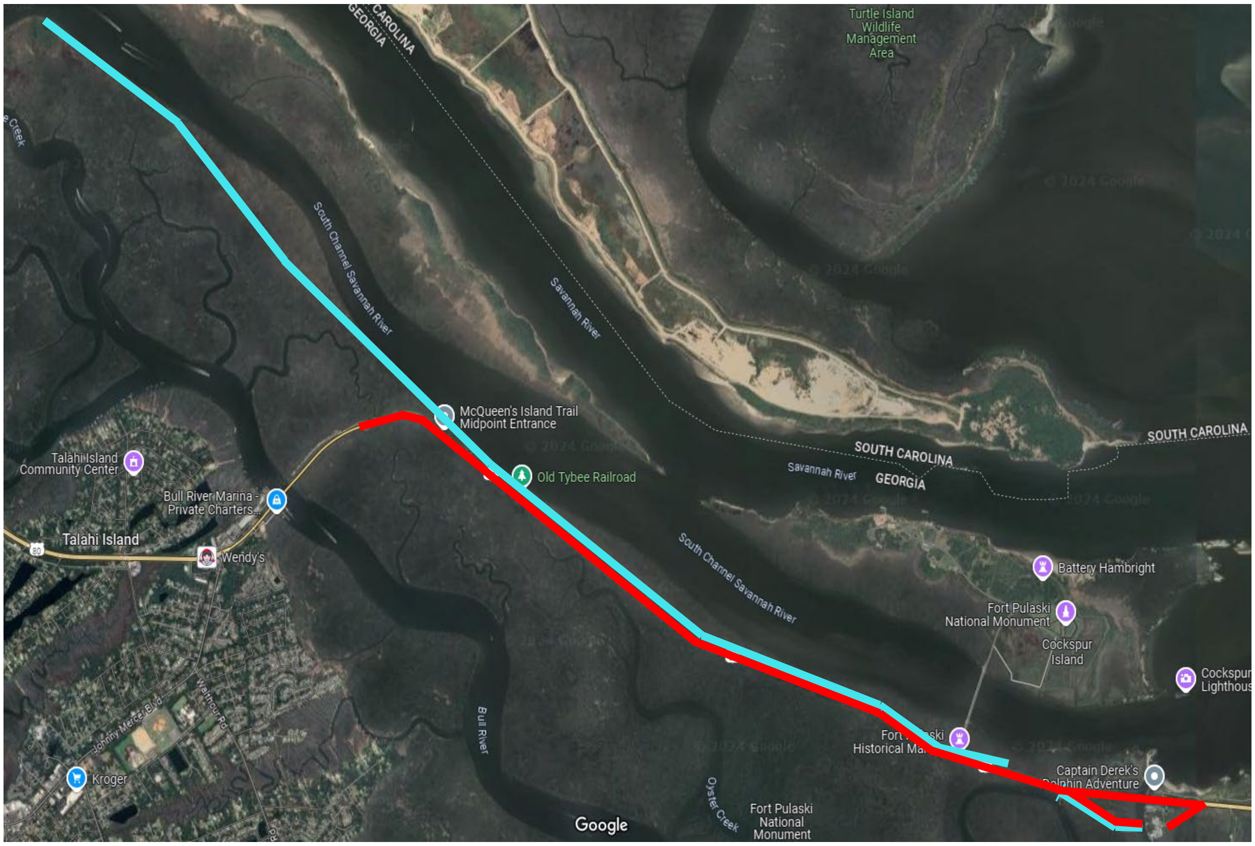


Figure 8. Map. US-80. Map showing US 80 going towards Tybee Island. Blue lines show foot paths for pedestrian and biking surveys, while red lines show the path for road cruising surveys.

known as "Rails to Trails"). This trail stretches from Fort Pulaski National Monument Entrance Station at Fort Pulaski Road and US-80 on its Eastern end to McQueen's Island at Bull River on its western end. Sampling was focused on spots along the river that diamondback terrapins were observed to come on to land in high densities, mainly a 4.83-km (3 miles) stretch of the trail between McQueen's Island Trail Midpoint Entrance and the Fort Pulaski National Monument Entrance Station. An additional 1.61-km (1 mile) stretch of McQueen's Trail that is no longer maintained was also surveyed to the east of the Fort Pulaski National Monument Entrance Station (Fig. 8, blue lines). A 0.61 km (0.38 mile) section of road on the east end of US-80 stretching from the Lazaretto Creek Boat Ramp to the Lazaretto Creek Fishing Pier was surveyed by road cruising, pedestrian, and biking sampling (Fig. 8, red and blue lines). This road runs along the Lazaretto Creek, allowing terrapins to also be sampled from the south side of US-80.

The fourth and last method of capturing diamondback terrapins was by seine net, which is a long fishing net that hangs vertically in the water with floats at the top and weights at the bottom edge where the ends are drawn together to encircle the terrapins and funnel them into a “basket” at the center of the net (Fig. 9). Seining took place in a tidal creek in Brunswick, Georgia that started off the Frederica River (an extension of the Mackay River off Manhead Sound) and stretched along the west side of Hawkins Island (Fig. 10). A 16-foot Carolina skiff was launched from the Lanier Island boat ramp 2-3 hours before low tide and taken about 2.41 km (1.5 miles) to the tidal creek entrance. Prior to seining specifically, drone surveys using an unmanned aerial vehicle (UAV Drone) were conducted prior to sampling creeks (seining)

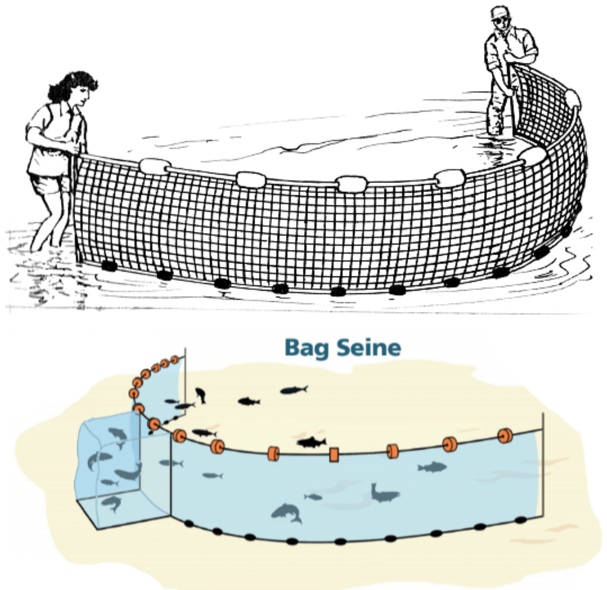


Figure 9. Seine net. Seine net with “bag” used for in-water terrapin captures. Photo Credits: Top, https://www.netsandmore.com/products/fishing-nets/seines; Bottom: https://duluthfishnets.com/store/seines/small-mesh-6-deep-seines/

Figure 10. Map. Hawkins Creek. Map of Hawkins Creek, where all in-water captures occurred.

for diamondback terrapins at a height of 15-20 m above the water surface. The purpose of this was to collect aerial photographs and video of the sampling area and to determine if the level of terrapin presence and activity warranted in-water seining.

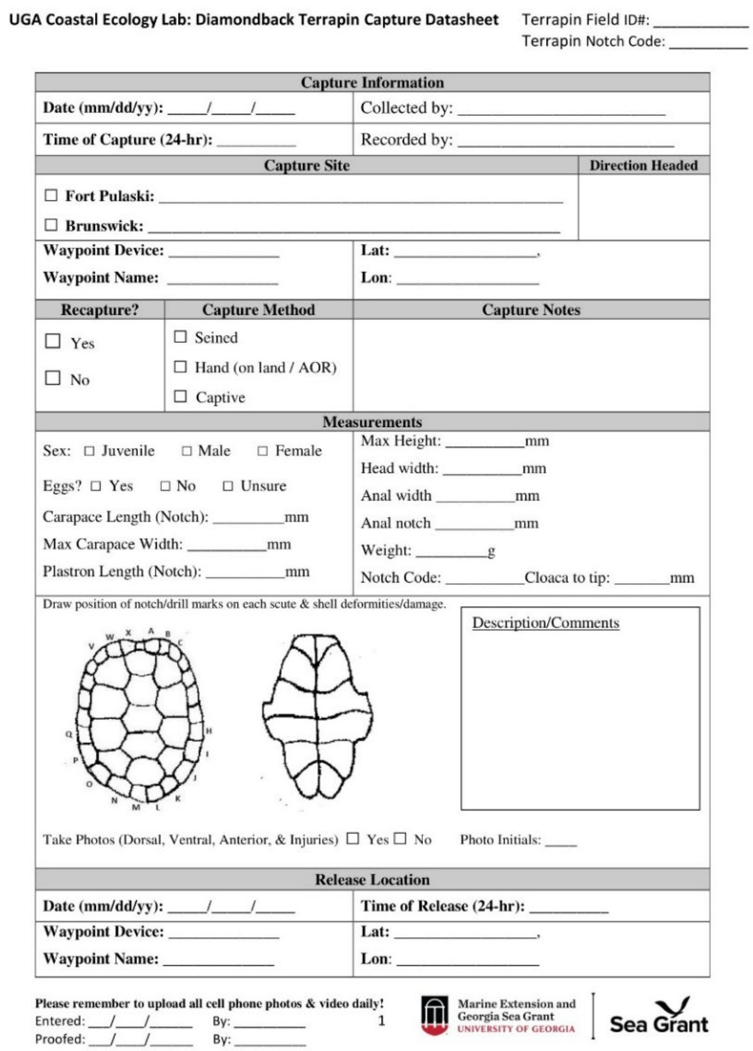
In the tidal creek, the 50-foot long seine net was deployed and stretched from bank to bank across the creek and then pulled by hand by four researchers at a time. Every 91-374 m (100-300 yards), the seine net was gathered and pulled on to the bank, where the basket was then dumped and any terrapins inside were collected while other bycatch (which included various fish, stingrays, and crabs) were returned to the water. Seining at low tide allowed the researchers to stand in the tidal creek and pull the net through the water without allowing for any gaps for terrapins to escape, and the lower water level also concentrated the terrapins in a smaller volume of water, allowing for more efficient captures.

After a terrapin was captured, they were placed in storage containers (Fig. 11, Left). Three types of storage containers were used: 5-gallon circular buckets with handles and lids, repurposed square cat litter buckets with handles and lids that varied in size but were all approximately 5-gallons and measured 12”x10”x14”, and tote bins with lids measuring 22”x17”x10.” The buckets were primarily used during road cruising, pedestrian captures, and biking due to the carrying convenience of the handle, while the tote bins were primarily used during seining so that multiple smaller individuals could be stored in the same container (Fig. 11, Right) and so that containers could be stacked with lids for safe transportation on the boat. Each terrapin storage container

Figure 11. Photo. Terrapin containment. Terrapins in litter buckets and blue totes that were used to contain animals between initial capture and release. Wet towels and lids were included to keep terrapins

received a lid and was filled with either 1” of water (collected at the capture site) or a wet towel to prevent dehydration. Storage containers were kept in air conditioning whenever possible between capture and testing to prevent overheating or dehydration of the animals.

Immediately after capture, terrapins were given a preliminary field identification number (starting with 1 on each sampling day), which was marked on their carapace with an animal-safe paint pen. This allowed the team to identify individuals before they received their notch code post-testing. Capture data collected (Fig. 12) included the date of capture (DD/MM/YY), the time of capture (on a 24-hour clock), the initials of the researcher that conducted the capture, the initials of the researcher that recorded the capture data, the capture area (Fort Pulaski or Brunswick), the latitude and longitude of the capture location (recorded on either a Garmin GPS device or a smart phone [iPhone or Android] using Google Maps), the name of the waypoint device and the waypoint itself, the capture method (either “by hand”, which


UGA Coastal Ecology Lab: Diamondback Terrapin Capture Datasheet
Terrapin Field ID#: ___________
Terrapin Notch Code: _________

Capture Information
Date (mm/dd/yy): ____/____/____ Collected by: ______________________
Time of Capture (24-hr): _________ Recorded by: ______________________

Capture Site | Direction Headed
☐ Fort Pulaski: ______________________________
☐ Brunswick: ______________________________
Waypoint Device: ____________ Lat: ________________,
Waypoint Name: ____________ Lon: ________________

Recapture? | Capture Method | Capture Notes
☐ Yes ☐ No | ☐ Seined ☐ Hand (on land / AOR) ☐ Captive |

Measurements
Sex: ☐ Juvenile ☐ Male ☐ Female
Eggs? ☐ Yes ☐ No ☐ Unsure
Carapace Length (Notch): _________mm
Max Carapace Width: _________mm
Plastron Length (Notch): _________mm
Max Height: _________mm
Head width: _________mm
Anal width _________mm
Anal notch _________mm
Weight: ________g
Notch Code: _________Cloaca to tip: _______mm

Draw position of notch/drill marks on each scute & shell deformities/damage.
Description/Comments
Take Photos (Dorsal, Ventral, Anterior, & Injuries) ☐ Yes ☐ No Photo Initials: ____

Release Location
Date (mm/dd/yy): ____/____/____ Time of Release (24-hr): _________
Waypoint Device: ____________ Lat: ________________,
Waypoint Name: ____________ Lon: ________________

Please remember to upload all cell phone photos & video daily!
Entered: ___/___/_____ By: _________ 1
Proofed: ___/___/_____ By: _________
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Sea Grant

Figure 12. Photo. Data sheet. Front page of the data collection sheet showing information collected for both capture and animal morphometrics.

included road cruising, pedestrian, and biking, or "by seining"), and whether the terrapin was a recapture or not (only 1 individual throughout the entire study was a recapture and was tested twice, but only one of the tests was used in the analysis to avoid repeated measures). The direction that the terrapin was headed towards when it was captured was also recorded so it could be oriented in its intended direction upon release.

All terrapins were returned to their site of capture within a minimum of 4 hours after testing and not exceeding 48 hours. Terrapins that were captured by seining were returned to the tidal creek midpoint of the starting and stopping points of the original seine capture area. Terrapins that were caught by hand were returned to the coordinates of their capture location and were placed in the direction they were originally heading. Individuals found on US-80 were placed either in the marsh on the road shoulder in the direction they were headed or, in cases where there was not a safe shoulder to pull off on to return the terrapins, they were placed on the footpath directly adjacent to where they were found in the road.

Due to behavioral differences between terrapin sexes relative to the variation in method and time of capture throughout the season, there was a difference in the ratio of terrapin sexes collected between sites. At Fort Pulaski, capture methods consisted strictly of hand captures on dry land (road cruising, pedestrian, and biking). Sampling at this location occurred three hours before and after the daily peak high tide on the Savannah River. During this time, gravid or nesting females leave the water in search of more elevated, drier ground to nest on (this behavior is one of the main reasons why terrapins occur on roads and are suffering from increased road mortality as infrastructure and habitat fragmentation increase). This means that the terrapins captured by the team on Tybee Island up until around mid-July largely consisted of gravid females. Alternatively, seine netting occurred in Brunswick during the second half of terrapin season starting two hours before peak low tide. Because researchers were capturing terrapins directly from the water at the Brunswick site, the majority of individuals from this test site were males (who rarely leave the water). No juveniles were captured at all throughout this study and the youngest age group tested consisted of a few sub-adult females.

Trial Methodology

Since captures at Fort Pulaski were land-based, animals were typically released within 4-6 hours of capture. However, at the Brunswick test site, terrapins were captured by boat and transported back to the UGA Marine Extension and housed (separately from the captive teaching collection). They were tested and released back to their capture location within 48 hours of capture. During captivity, they were provided with a water source that was replaced every 12 hours and they were health checked throughout the experimental trials.

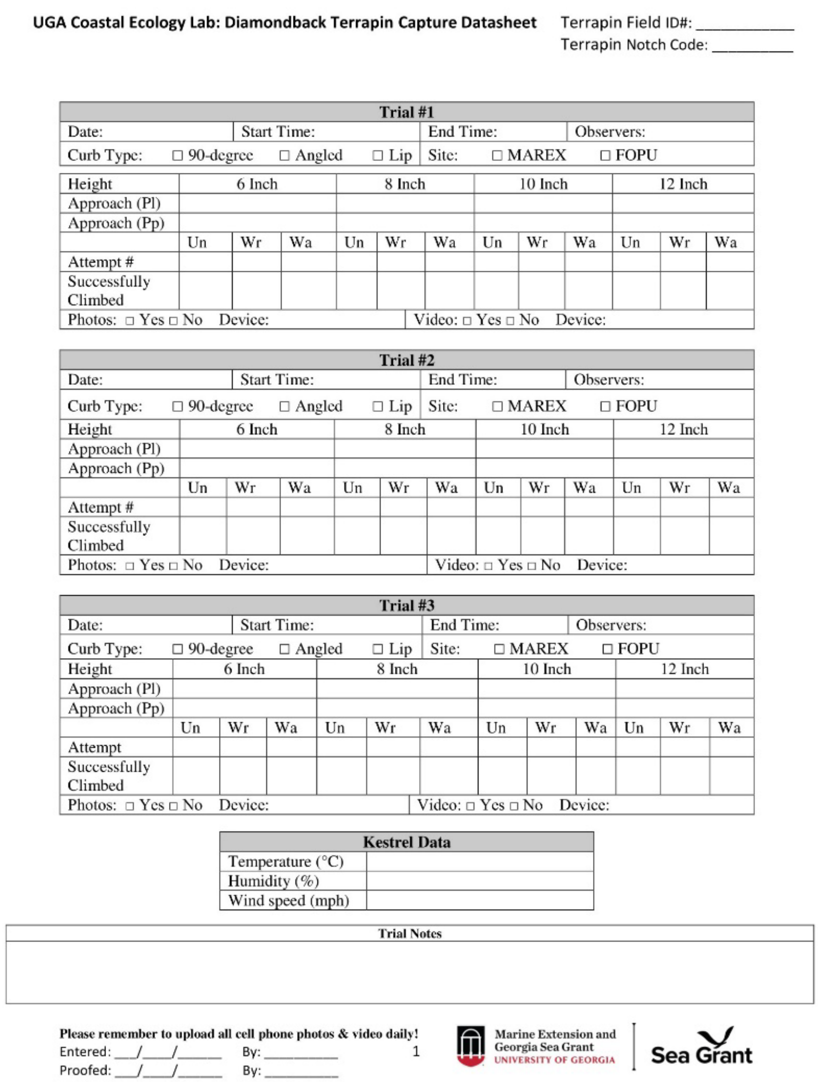
One to three terrapins were tested at a time, with only one terrapin present on a single curb design at once. Each researcher present for trials was assigned to observe one terrapin at a time. Each trial site included the three sections of reverse curbing, with each curb section including different heights (6”,8”, 10”, and 12”, Figs. 2,3,5). Within each curb section, the curb was separated in the middle with the 6” and 8” heights on one side, and the 10” and 12” heights on the other side (Fig. 13, Middle) to prevent terrapins from following the perimeter of the runway and only encountering the 6” and 12” heights. The perimeter of the experimental site was lined with silt fencing designed to contain the terrapins to one curb at a time, allow the terrapin a visual over the curb they are attempting to trespass, and also block the terrapin’s view from the observing researchers to eliminate behavioral changes around humans (Fig. 13, Left). The inside perimeter of the silt fencing was lined with Polywall® (a brand of smooth flexible waterproof reinforced plastic wall panels) to prevent terrapins from climbing the silt fence, with the corners rounded to redirect them towards the curbs (Fig. 13, Left and Right).

Figure 13. Photo. Runway trial. Left: Polywall® placed around entire inside perimeter of runway trial. Middle: Divider separating 6" and 8" height curbs from 10" and 12" curbs. Right: Polywall® curved at corners to replicate directional fencing.

The order of curb design that each terrapin was tested on was selected at random per individual, and the starting curb side (i.e., heights [either 6"/8" or 10"/12"]) were also selected at random. One trial determinate was considered, which was terrapin size by plastron length. Plastron length (PL) is the total length of the bony underside of a terrapin's shell from the anterior end to the posterior end (Fig. 16). If the PL of a terrapin was over 125mm, they were tested for 5 minutes on both halves of the curb (5 minutes against the 6"/8" side and 5 minutes against the 10"/12" side), for a total trial length of 10 minutes per curb. If the PL of a terrapin was less than or equal to 125mm (primarily included small males and sub-adult females), they were tested for 7 minutes on the 6" and 8" heights first. If a terrapin under 125mm trespassed either of these two heights unassisted, they were then moved to the other half of the curb and tested against the 10" and 12" heights for 7 more minutes for a total trial length of 14 minutes. If a terrapin with a PL under 125mm did not trespass the 6" or 8" heights, their trial ended after 7 minutes.

"Trespass" refers to when the terrapin successfully climbed over a curb, while "no trespass" means the curb design succeeded at preventing the terrapin from climbing over. An "unassisted trespass" indicates that the terrapin trespassed on clear curbing with no aid from wrack or the side wall, while "assisted trespass" indicates that the terrapin trespassed on the curb using aid from 1" of marsh wrack (added to trial after three attempted, but unsuccessful trespasses on the same height) or used the interface of the side wall and curb to trespass the curb.

Data collected during the trials (Fig. 14) included the site, date of trial, starting and ending times of each trial, total trial length, trial observer, starting curb design, starting heights, whether the terrapin approached the curb parallel or perpendicular, the number of attempts by the terrapin to trespass on the curb and whether those attempts were unassisted, with wrack, or with the wall, if the terrapin succeeded in trespassing the curb (and whether it has assistance or not), and whether photos or videos were taken during the trial and by who. Immediately after trials concluded, the terrapins were processed for



UGA Coastal Ecology Lab: Diamondback Terrapin Capture Datasheet Terrapin Field ID#: ___________
Terrapin Notch Code: _________

Trial #1												
Date:			Start Time:			End Time:			Observers:			
Curb Type: ☐ 90-degree ☐ Angled ☐ Lip						Site: ☐ MAREX ☐ FOPU						
Height	6 Inch			8 Inch			10 Inch			12 Inch		
Approach (Pl)												
Approach (Pp)												
	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa
Attempt #												
Successfully Climbed												
Photos: ☐ Yes ☐ No Device:						Video: ☐ Yes ☐ No Device:						

Trial #2												
Date:			Start Time:			End Time:			Observers:			
Curb Type: ☐ 90-degree ☐ Angled ☐ Lip						Site: ☐ MAREX ☐ FOPU						
Height	6 Inch			8 Inch			10 Inch			12 Inch		
Approach (Pl)												
Approach (Pp)												
	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa
Attempt #												
Successfully Climbed												
Photos: ☐ Yes ☐ No Device:						Video: ☐ Yes ☐ No Device:						

Trial #3												
Date:			Start Time:			End Time:			Observers:			
Curb Type: ☐ 90-degree ☐ Angled ☐ Lip						Site: ☐ MAREX ☐ FOPU						
Height	6 Inch			8 Inch			10 Inch			12 Inch		
Approach (Pl)												
Approach (Pp)												
	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa	Un	Wr	Wa
Attempt												
Successfully Climbed												
Photos: ☐ Yes ☐ No Device:						Video: ☐ Yes ☐ No Device:						

Kestrel Data	
Temperature (°C)	
Humidity (%)	
Wind speed (mph)	

Trial Notes

Please remember to upload all cell phone photos & video daily!
Entered: ___/___/_____ By: _________ 1
Proofed: ___/___/_____ By: _________

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Figure 14. Photo. Data sheet. Back page of the data collection sheet showing information collected during the experimental trials.

morphometric measurements. A Kestrel® weather meter was used to record the average wind speed, the temperature, and the humidity prior to each trial.

Morphometrics Collection Methodology

Immediately after trials were completed, terrapins first were visually assessed to determine sex. Female terrapins were generally larger in body size, had more domed carapaces, wider heads, and shorter tails relative to their body size, while male terrapins were generally smaller in body size, had smaller heads, and larger tails relative to body size (Fig. 15). Females were hand-palpated to detect if they were gravid (if they contained eggs). In addition to determining sex, terrapins were placed in an age category (either juvenile, sub adult, or adult). The majority of terrapins caught were adults, although a couple of subadult females were captured. No juveniles or hatchlings were collected.

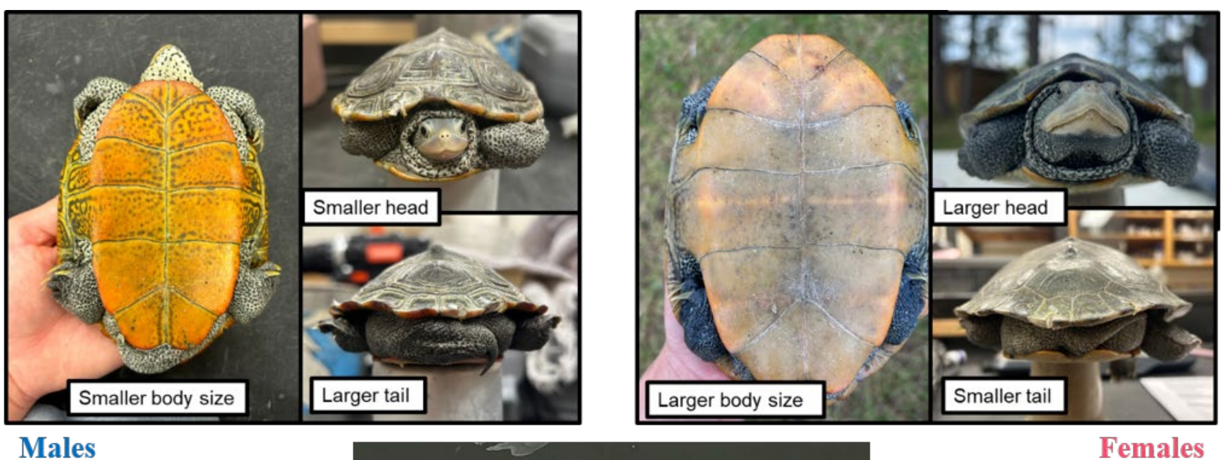

Figure 15. Photo. Sexual Dimorphism. Collage of photos showing sexual size dimorphism used to determine individual sex of terrapins. Left, top collage: Males. Right, top collage: Females. Bottom picture: Side-by-side comparison of sexes.

A variety of morphometric measurements were collected and recorded from each individual terrapin post-experimental test (Figs. 12, 16). The following measurements were collected: carapace length (the total length of the terrapin's carapace from the edge of the nuchal scute on the anterior end to the edges of the two pygal scutes on the posterior end), carapace width (total width of the carapace from the edges of the bridge scutes at the widest point between the right and left ventral sides), plastron length (total length of the plastron from the center edge of the gular scutes to the center edge of both anal scutes), height (the total height of the terrapin from the dorsal/plastron to ventral/ carapace surface at the tallest point), head width (width of the terrapin's head at the widest point), anal width (the width between the longest points of both ventral anal scutes), anal notch (the distance between the center edge of the anal scutes on the plastron to the center edge of the pygal scutes on the carapace), cloaca to tail tip length (total length of the tail from the cloacal vent to the tip of the tail), and weight (g, Fig. 16).

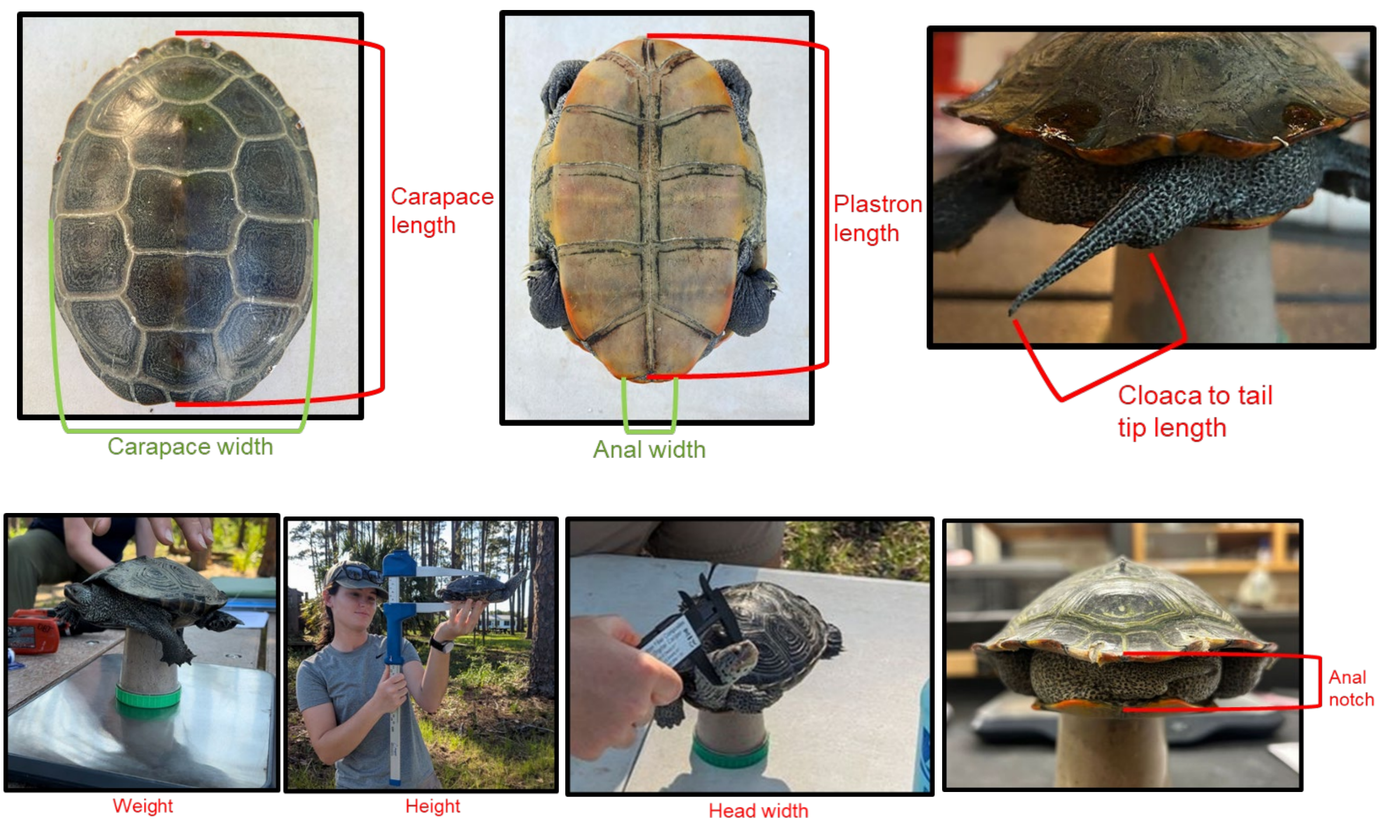

Figure 16. Photo. Morphometrics. Collage of photos showing the morphometric measurements collected on each terrapin.

Terrapins were assigned a notch code, which is a unique five- or six-letter identification code that allows individual visual shell identification. Each individual terrapin received identification markings; the technique included placing identifying marks correlating the notch code with specific marginal scutes (the scales on the exterior edge of a turtle's upper shell) using a metal file or handheld power drill using a 1/8" drill bit (Fig. 17). The marginal areas of the carapace (top shell) were cleaned with betadine-soaked gauze followed by removal with isopropyl alcohol-soaked gauze. Marking was not done on bridge scutes and these marks did not cause discomfort. Any equipment used to notch or drill tortoises was sterilized in between individuals to reduce and risk of cross contamination or disease transmission (the drill bit or file used for marking was cleaned via immersion in chlorhexidine solution). The shell cleaning and marking process took under two minutes per animal. In addition to receiving a notch code, terrapins were visually assessed and descriptive comments were recorded over unique characteristics or physical appearance, including any abnormalities, deformities, or injuries. Dorsal, ventral, lateral, anterior, and posterior pictures of all terrapins were taken.

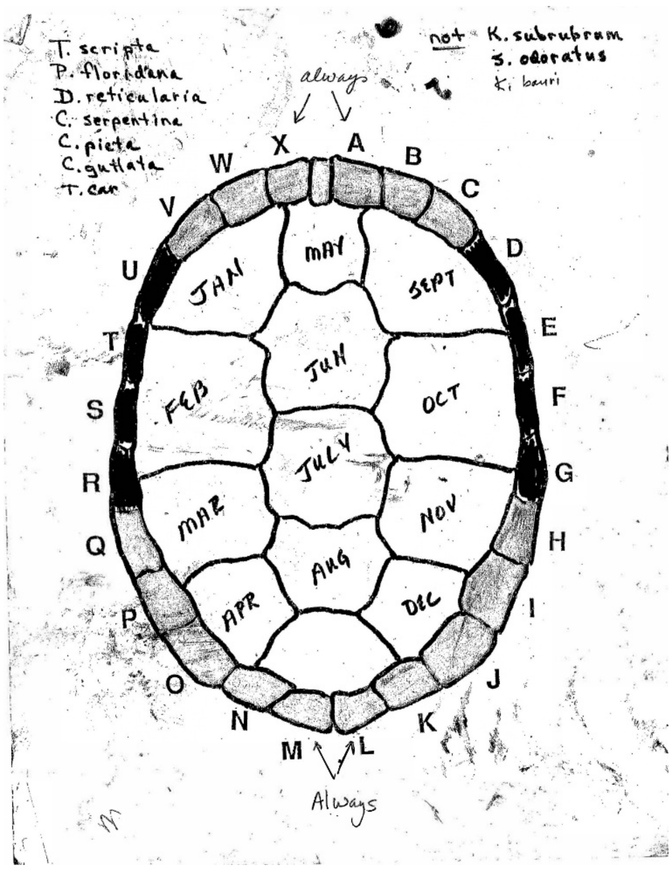

Figure 17. Photo. Notch codes. Schematic of terrapin notch code system used to assign unique marks to each individual.

Data Processing & Analysis

All data were entered and proofed in two separate Excel databases; one for capture and morphometric data, and one for trial data. Raw data were converted into summary statistics and then condensed. A terrapin's trial was excluded if there were not at least two approaches on two different curb heights (e.g., one approach on the 6", one approach on the 8").

For the summary statistics, individual trials were first grouped by curb type. For each curb type and height, the number of individuals that had a parallel or perpendicular approach to the curb, and the number of individuals that had at least one attempt on the curb either unassisted, with wrack, or with the wall were calculated. Next, the team calculated the number of individuals that successfully trespassed the curb either assisted (with the help of wrack or the sidewall) or unassisted was calculated. After that, the total number of attempts (including multiple attempts per some individuals) on a curb, either unassisted or assisted (i.e., with the help of wrack or the wall), was calculated. Lastly, the number of unassisted successes were calculated. After the data were condensed, three tables were made to summarize the information for each curb type to include: % of individuals that attempted to climb all three curbs out of total individuals tested, % of individuals successfully trespassing each height for each curb (including assisted and unassisted trespasses), and % animals with assisted trespass broken down by wrack-assist and wall-assist. All of these results were graphed to show percentages of occurrence out of total number tested.

CHAPTER 4. RESULTS

121 wild terrapins were captured for the experimental trials. The team's catch per unit effort was 2.42 hours per terrapin (293 person-hours for surveys: 82 road cruising, 52 pedestrian, 30 biking, 129 seining). An additional 224 person-hours were spent running the trials, processing, and releasing the terrapins. The team's total field person-hours, that included commute time and other non-office tasks were 660.25 person-hours. The first four columns of the personnel effort table (Fig. 18) show the total hours required for surveying (pedestrian, road cruising, biking, and seining), while the fifth column shows the total of all surveying hours. The sixth column shows time required for all terrapin testing, processing, and release, while the last column on the right (517) shows the total overall person hours required for this project, excluding additional commute time and other non-office tasks. There were four people primarily conducting the research, but the total team assisting in May-July 2024 included eight individuals. Office time in data management, analysis, writing, meetings, and other administrative tasks are available upon request.

Total Person Hours Pedestrian	Total Person Hours Road Cruising	Total Person Hours Biking	Total Person Hours Seining	Total Time Surveying	Total Person Hours Testing, Processing, Releasing	Total Person Hours Overall
52	82	30	129	293	224	517

Figure 18. Table. Personnel effort. Effort table showing total personnel hours for this project.

Of the 121 trials, three terrapin trials were excluded under the criteria to be included in the analysis. Two animals were eliminated since they did not have at least two approaches on two different curb heights. There was only one recaptured terrapin throughout the experiment who was tested twice against the curb designs, and only one of these tests were included in the analysis as to avoid repeated measures. This left 118 terrapin trials to be used in the analysis and included in the summary statistics.

The results of the percentage of individual terrapins that attempted to climb curbs (includes all attempts, whether they successfully trespassed or not) are shown in a series of bar graphs in Figure 19. For the 90° curb (Fig.19, Left), 68% of the 118 terrapins tested attempted to climb the 6" height, 75% of the 118 tested attempted to climb the 8" height, 51% of the 75 terrapins tested attempted to climb the 10" height, and 40% of the 75 terrapins tested attempted to climb the 12" height. For the 90° curb with a 3" lip (Fig. 19, Middle), 45% of the 118 terrapins tested attempted to climb the 6" height, 36% of the 118 tested attempted to climb the 8" height, 14% of the 63 tested attempted to climb the 10" height, and 16% of the 63 tested attempted to climb the 12" height. For the 70° reverse angle curb (Fig. 19, Right), 61% of the 118 terrapins tested against the curb attempted to climb the 6" height, 19% of the 118 terrapins tested attempted to climb the 8" curb,

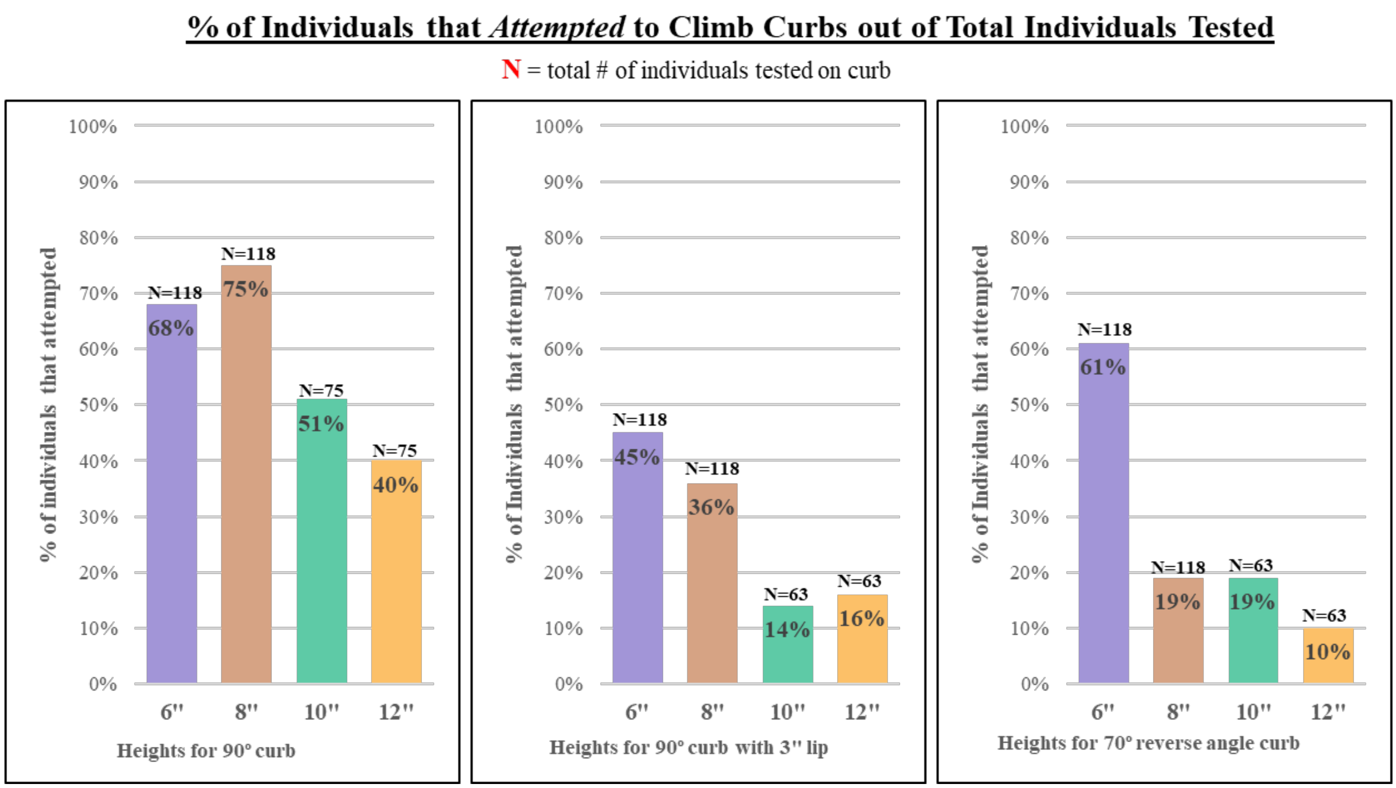

Figure 19. Graph. % of attempted trespasses. Bar graphs showing the percentage of individuals that attempted to climb the 90° curb (Left), the 90° curb with a 3" lip (Middle), and the 70° reverse angle curb (Right).

19% of the 63 terrapins tested attempted to climb the 10" height, and 10% of the 63 terrapins tested attempted to climb the 12" height.

The total percentage of individual terrapins that successfully trespassed (climbed over) the curbs, including both types of trespasses (unassisted and assisted) and are shown in Figures 20 (90°), 21 (90° curb with a 3" lip), and 22 (70º reverse angle). Of the 118 terrapins that were tested against the 6" height of the 90° curb, 36% of them successfully trespassed, with 28% of the trespasses being unassisted and 8% of them being assisted. Of the 118 terrapins that were tested against the 8" height of the 90° curb, a total of 30% trespassed, with 17% being unassisted and 13% being assisted. Of the 75 terrapins that were tested against the 10" height of the 90° curb, a total of 4% trespassed, with 3% of those trespasses being unassisted and 1% of them being assisted. Of the 75 terrapins that were tested against the 12" height of the 90° curb, no terrapins trespassed at all (Fig. 20).

90°

% of Individuals that Trespassed - Unassisted and Assisted

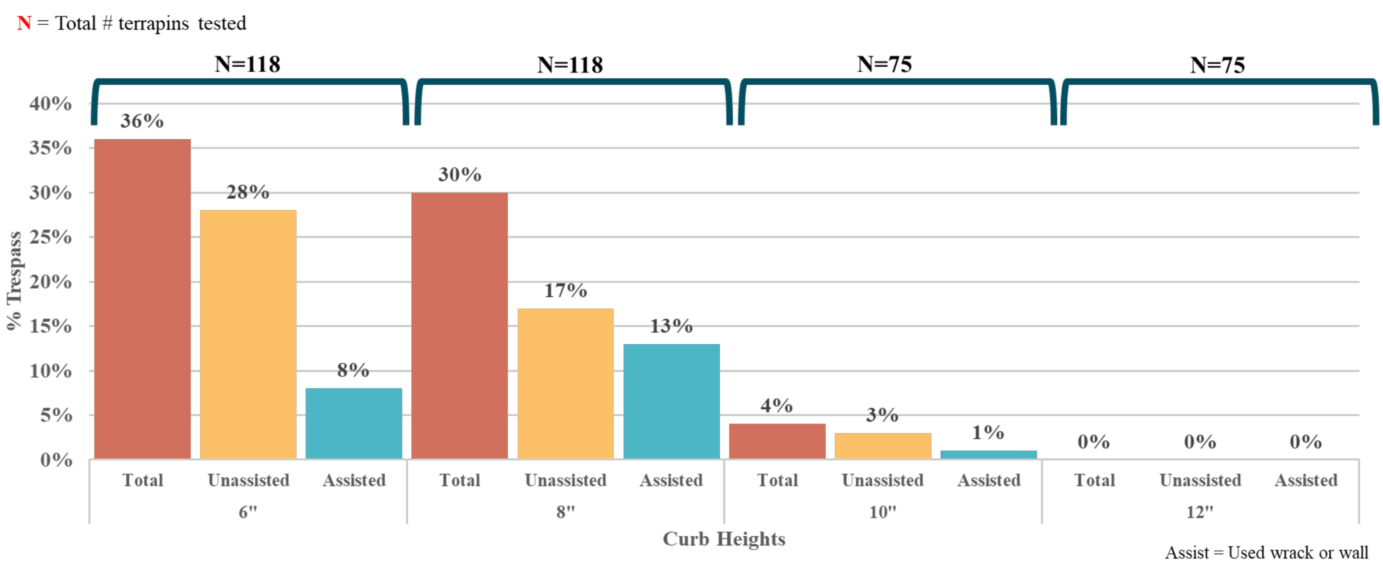

Figure 20. Graph. % of 90° trespass. Percentage of the total (unassisted and assisted) trespasses on all four heights of the 90° curb out of all individuals tested on a given height.

Of the 118 terrapins that were tested against the 6” height of the 90° curb with a 3” lip, a total of 13% of them successfully trespassed, with 8% of the trespasses being unassisted and 5% of them being assisted. Of the 118 terrapins that were tested against the 8” height of the 90° curb with a 3” lip, a total of 4% of them trespassed, with 1% of those trespasses being unassisted and 3% of them being assisted. Of the 63 terrapins that were tested against both the 10” and 12” heights of the 90° curb with a 3” lip, no terrapins trespassed either height (Fig. 21).

90°with 3” lip

% of Individuals that Trespassed - Unassisted and Assisted

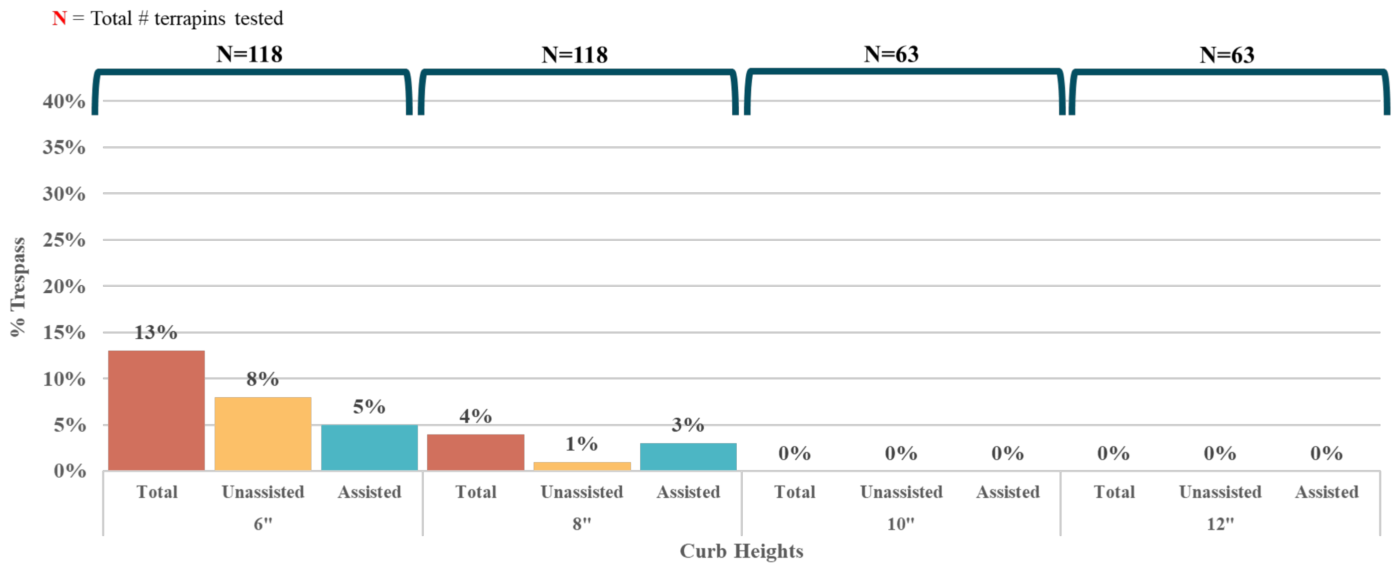

Figure 21. Graph. % of 90° with 3” lip trespasses. Percentage of the total (unassisted and assisted) trespasses on all four heights of the 90° curb with a 3” lip out of all individuals tested on a given height.

Of the 118 terrapins that were tested against the 6” and 8” heights of the angled (70º reverse) curb, a total of 4% and 3% (respectively) of the individuals successfully trespassed, with all of those trespasses being assisted. Of the 63 terrapins that were tested against both the 10” and 12” heights of the angled curb, no terrapins successfully trespassed the 10” height of the angled curb, and only 2% of terrapins successfully had an assisted trespass on the 12” height (Fig. 22).

70º Reverse Angle
% of Individuals that Trespassed - Unassisted and Assisted

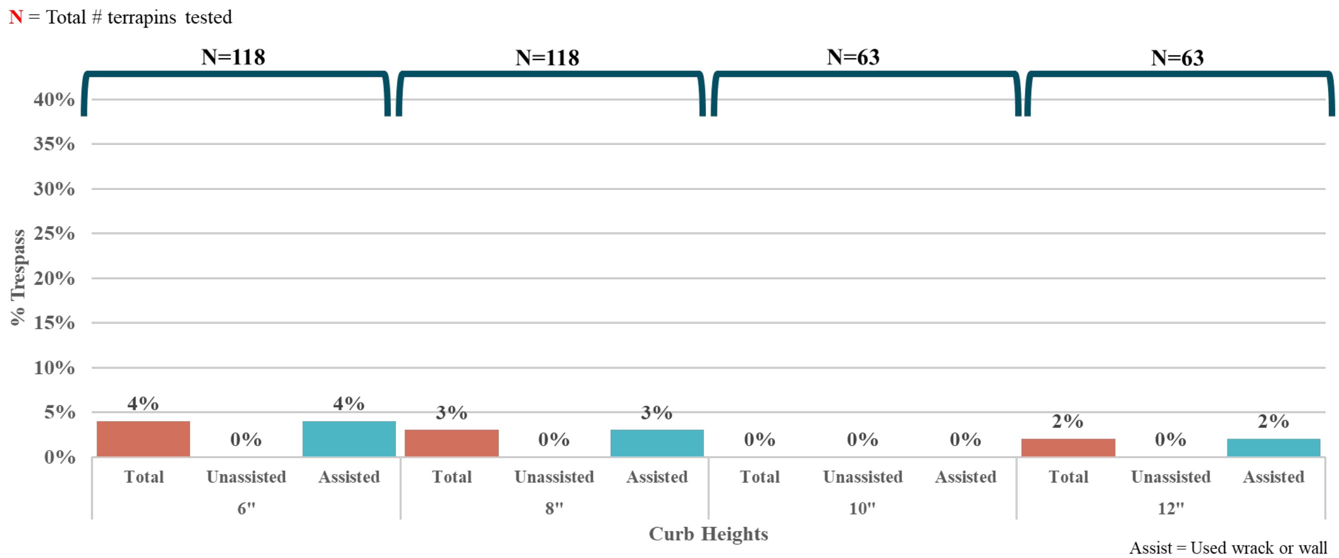

Figure 22. Graph. % of 70° trespasses. Percentage of the total (unassisted and assisted) trespasses on all four heights of the 70° reverse angle curb with a 3" lip out of all individuals tested on a given height.

Figure 23 shows a series of three bar graphs for each curb design that visualize the total percentage of assisted trespasses and whether they were done using the wrack or the sidewall of the runway trial. N represents the total trespasses, while gray bars represent wall trespasses and brown bars represent wrack trespasses. For the 90º curb, a total of 9 assisted trespasses occurred for the 6" height; 33% of those trespasses were done using the wall, while 67% of the trespasses were done using the wrack. For the 8" height of the 90º curb, a total of 15 assisted trespasses occurred, with 67% of those being done using the wall and 33% of them using the wrack. One assisted trespass occurred on the 10" height of the 90º curb using the wall. No assisted trespasses occurred on the 12" height of the 90º curb. Six assisted trespasses occurred on the 6" height of the 90º curb with a 3" lip; 67% of those were done using the wall, while 33% of them were done using the wrack. Four total assisted trespasses occurred on the 8" height of the 90º curb with a 3" lip, with all of them using the wall. No assisted trespasses occurred on either the 10" or 12" heights of the 90º curb with a 3" lip. Five total assisted trespasses occurred on the 6" height of the 70º reverse angle curb, with all five trespasses being done using wrack. Four total assisted trespasses occurred on the 8" height of the angled curb, with 75% of those using the wall and 25% using wrack. No assisted trespasses occurred on the 10" height of the angled curb, and only two assisted trespasses occurred on the 12" height with one using the wall and one using wrack.

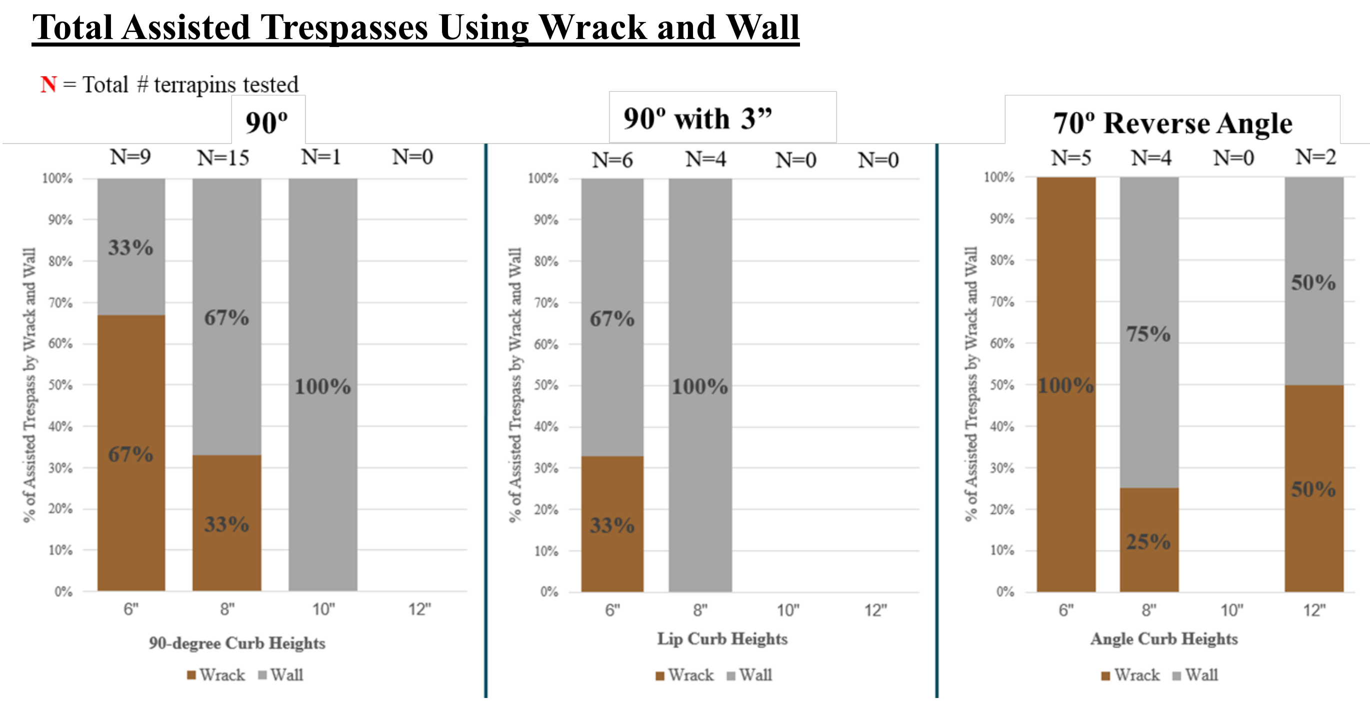

Figure 23. Graph. Total assisted trespasses. Total assisted successful trespasses on all four heights of the 90º curb, the 90º curb with a 3" lip, and the 70° reverse angle curbs. Grey bars represent wall assists, while brown bars represent wrack assists.

CHAPTER 5. CONCLUSIONS & RECOMMENDATIONS

In summary, the most effective heights for all three curb designs were 12”, successfully excluding 100% of animals attempting to climb the barrier for the 90º, 98% of animals for the 70º reverse angle & 100% for 90º with 3” lip. Next, the 10” height successfully excluded 96% of animals for the 90º, 100% for the 70º reverse angle, and 100% for the 90º with 3” lip. At the 8” height, 70% of animals were excluded from the 90º, 97% from the 70º reverse angle, and 96% from the 90º with 3” lip. Lastly at the shortest 6” curb, only 64% of animals were excluded from the 90º, 96% were excluded from the 70º reverse angle, and 87% were excluded from the 90º with 3” lip. Based on these results, the 10” and 12” heights of the 70º reverse angle curb and the 90º with 3” lip curb were most successful at excluding terrapins overall.

Based on these research results, the most strategic curbs and heights to implement (i.e., least likely to be trespassed and will require the least maintenance) are the 10” and 12” heights of the 70º reverse angle curb, the 12” height of the 90º curb, and the 10” or 12” heights of the 90º curb with a 3” lip. The 8” height of the 70º reverse angle curb and the 10” height of the 90º curb would be effective only with frequent maintenance (trespass is much more likely and the maintenance burden would be higher). The least effective curbs at excluding terrapins are the 6” and 8” heights of the 90º curb, the 6” height of the 70º reverse angle curb, and the 6” and 8” heights of the 90º curb with a 3” lip. These curbs likely would allow trespass and the maintenance burden would be very high. Recommendations are summarized below (Fig. 24).

Figure 24. Photo. Recommendations. Recommendations for curb heights and angles relative to the degree of likelihood of trespass and maintenance burden based on the research results.

These curbs will be most successful if they are combined with guide fencing at terminal points, which will aid in redirecting terrapins towards the marsh and prevent wrap-around effects and fence-end mortality. Fencing can be seasonal, using a shorter-term material, such as Animex® products, or longer-term and permanent, such as an extended concrete barrier. While the UGA team recommends guide fencing terminal points to be curved (without sharp angles) and have a smooth surface to deter climbing, they are not issuing recommendations of guide fencing length, radius, or offset due to the fact that those parameters were not tested in this research, are conditional upon those allowable by GDOT Design, and are dependent on the right-of-way constraints of where the curb sections are ultimately installed. Additionally, GDOT’s District 5 Maintenance Crew cast these trial curbs without a brush finish to allow a smooth surface on the concrete that discourages climbing, and the research team recommends replicating this finish on any implemented curbs. The team strongly cautions against implementation of the 6” heights for any of the curb designs. The 90º with 3” lip curb presented an additional disadvantage as terrapins frequently became wedged and stuck under the overhang during experimental trials. One variable that may decrease long-term durability of these curbs but may also increase project timelines and cost to mitigate are the accrual of wrack and substrate against the base of the barrier, which would require frequent maintenance to clear. The team advises a regular curb maintenance schedule post-implementation to prevent the accrual of debris along the curbs (especially after stormy weather and high tides), which will quickly result in eased trespass for the terrapins and negated effectiveness of the barrier. Exact specifications for a maximum acceptable height of wrack accrued against the curb that would still prevent trespass were not tested in this research. However, given the amount of wrack that can accrue during high tides on US 80, which exceeds 6", the team does not recommend any of the 6" heights of the curb designs, regardless of the trespass levels observed in this research. If GDOT is interested in field-testing wrack accrual levels, the UGA team still has the reverse curb sections used in the experimental trails and additional research could be supported for some brief, seasonally constrained trials. Intermittent exposure to brackish water due to salt spray and flooding may also be a concern as it may degrade the concrete over the long-term.

This research will guide GDOT towards adapting a concept into an effective barrier design that will be permanent, reduce maintenance costs, and increase safety on US-80 and future causeway or coastal projects where impacts to terrapins need to be mitigated. These results have broader application to diamondback terrapins throughout their range and to other hard-shelled chelonids on a global scale and will contribute a beneficial and timely model for wildlife exclusion and road mortality mitigation solutions.

Additional research is needed to determine the post-installation effectiveness of these curbs for excluding diamondback terrapins from entering the road. In particular, the team is interested in assessing the performance of the reverse curbing in combination with the seasonal or permanently installed directional (also known as guide or lead) fencing to guide terrapins back to the marsh and to avoid wrap-around and fence-end mortality effects. The greatest standing research need is to monitor the nesting behaviors adjacent to the fences. There are opportunities to develop best management practices for artificial or subsidized nesting habitat on the marsh side of the fences (opposite of the road). Compensating critical nesting habitat will be timely for maintaining the necessary reproductive activities currently occurring in these rights-of-way – the ultimate goal is to manage terrapin use of roadsides in a manner that reduces mortality and sustains critical life history functions for population persistence. Transportation and biology professionals certainly can figure out practices for terrapins and roads coinciding without detriment or expense to the operations of our ecological assets or transportation infrastructure. The team hopes to continue these conversations with GDOT and to have an opportunity to support the development of strategic roadside management practices.

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APPENDICES

Appendix 1. Exported table from literature review database.

Thompson, Oscar P. & Kimberly M. Andrews. University of Georgia, Marine Extension and Georgia Sea Grant									
Prepared for Georgia Department of Transportation for RP 22-33									
Reference #	**Title**	**Summary**	**Location**	**Focal Species**	**Design Specs**	**Design/ Installation Photos**	**Affiliation**	**Publication Type**	**Publisher**
1	Roads and Ecological Infrastructure: Concepts and Applications for Small Animals	Book containing design considerations and case studies of ecological infrastructure and the associated challenges. Specifically has sections on designing and retrofitting wildlife crossings as well as barrier fences and walls. Pdf not available, but the book can be acquired on the Johns Hopkins University Press publication site.	Various - global	Amphibians; Reptiles; Small Mammals	Discusses various applications and design considerations for exclusion fences & barrier walls, under- & over-passes, and the accompanying maintenance needs.	Yes	Kimberly M. Andrews - University of Georgia, Priya Nanjappa - AFWA, Seth P.D. Riley - NPS	Book	Johns Hopkins University Press
2	Reptiles: Overlooked but Often Risk from Roads	Discusses need for reptile fencing and the challenges associated with it. Discusses short-term and permanent fencing types and considerations for materials.	Various (North America, Europe)	Various, turtles, lizards, Diamondback terrapin	Didn't go into any detail but mentioned considerations & photos.	Yes	Kimberly M. Andrews – UGA; Tom A. Langen - Clarkson University; Richard P. J. H. Struijk – RAVON Foundation	Book Chapter	John Wiley & Sons
3	Literature Synthesis of the Effects of Roads and Vehicles on Amphibians and Reptiles	Detailed review for FHWA on the impacts of roads on assorted herpetofauna, specifically the effect of roads on the surrounding environments and factors of herpetofauna life history that increase their risk to road-caused impacts. Discusses pre- & post-construction solutions, and monitoring needs of crossing structures & barriers to confirm effectiveness.	Various - global	Reptiles and Amphibians	No	No	Kimberly M. Andrews, J. Whitfield Gibbons - University of Georgia, Savannah River Ecology Laboratory; Denim M. Jochimsen - Idaho State University, Department of Biological Sciences	Technical Report	FHWA
4	Ecological Effects of Roads on Amphibians and Reptiles: A Literature Review	Book chapter discussing the effects of roads on herpetofauna, including direct (ex. mortality) and indirect (ex. ecological/ behavioral) changes. Discuses solutions including crossing structures and wildlife barriers.	Various - global	Reptiles and Amphibians	No	No	Kimberly M. Andrews, J. Whitfield Gibbons - University of Georgia, Savannah River Ecology Laboratory; Denim M. Jochimsen - Idaho State University, Department of Biological Sciences	Book Chapter	Society for the Study of Amphibians and Reptiles

5	AMX40 Temporary and Permanent Wildlife Fencing	Specification and installation guide for AMX40 temporary and permanent fencing	Various	Lizards; Newts; Salamanders; Small Mammals; Snakes; Toads, Tortoises; Turtles	Yes	Yes	Animex	Manufacturer's Brochure	Animex
6	AMX48 Temporary and Permanent Wildlife Fencing	Specification and installation guide for AMX48 temporary and permanent fencing	Various	Frogs; Large Lizards; Small Mammals; Large Turtles	Yes	Yes	Animex	Manufacturer's Brochure	Animex
7	Highway Mortality of Turtles and Other Herpetofauna at Lake Jackson, Florida, USA, and the Efficacy of a Temporary Fence/Culvert System to Reduce Roadkill	Installation of temporary silt fence barriers along roadway bisecting a lake, examined all species crossing. Temp fences successfully reduced turtle trespass (99%)	Lake Jackson Florida, USA	Aquatic turtles	Temporary, Silt fencing. (20cm buried, 40cm above ground), returns towards end to prevent pacing along fence and bypassing at ends, daily research monitoring.	No	Matthew J. Aresco, Florida State University 2003	Peer-reviewed article	ICOET 2003 Proceedings
8	Mitigation Measures to Reduce Highway Mortality of Turtles and Other Herpetofauna at a Northern Florida Lake	Installation of temporary silt fence barriers along roadway bisecting a lake, examined all species crossing. Temp fences successfully reduced turtle trespass (99%)	Lake Jackson Florida, USA	Aquatic turtles	Temporary, Silt fencing. (20cm buried, 40cm above ground), returns towards end to prevent pacing along fence and bypassing at ends, daily research monitoring.	Yes	Matthew J. Aresco, Florida State University 2005	Peer-reviewed article	Journal of Wildlife Management
9	Mitigating Reptile Road Mortality: Fence Failures Compromise Ecopassage Effectiveness	Conducted pre- & post-mitigation monitoring; Paired exclusion fencing with culverts. 20% increase of DOR snake & turtles post mitigation, not seen at control site. Hypothesized that animals that breached the fence were trapped and spent more time on the road and increases from 2 lanes (pre) to 4 lanes (post).	Burwash Ontario, Canada	Snakes & Turtles	Temporary; reptile fencing consisting of a heavy gauge plastic geotextile extending 0.8 m above- and 0.2 m below-ground with a 0.1 m wide lip running perpendicular underground (A). The fence was affixed to a 2.3 m tall, large mammal, wire fence.	Yes	James H. Baxter-Gilbert, David Lesbarrères, Jacqueline D. Litzgus - Laurentian University, Sudbury, Ontario; Julia L. Riley - Magnetawan First Nation, Britt, Ontario	Peer-reviewed article	PLOS One
10	The Effect of Roads, Barrier Fences, and Culverts on Desert Tortoise Populations in California, USA	Equipped desert tortoises with transmitters to study their movement around a highway lined with a 24km tortoise proof fence with culvert underpasses. Discussed design consideration on opaque vs. mesh fences and how opaque	San Bernardino County California, USA	Desert tortoises	60cm wide 1cm mesh hardware cloth buried 15 cm into the ground. Backed by a 1.5m six strand wire fence.	Yes	William I. Boarman – USGS; Marc Sazaki – California Energy Commission; W. Bryan Jennings – Department of Zoology, University of Texas, Austin	Peer-reviewed article	Proceedings of the Conservation, Restoration, and Management of Tortoises and Turtles

		can stop tortoises but mesh will cause the tortoise to walk along the fence to a crossing point.							
11	Road-effect Mitigation Promotes Connectivity and Reduces Mortality at the Population-Level	Examined and reduced road mortality of turtles, snakes, and amphibians. Fencing & crossing structures reduced mortality of turtles and amphibians but not snakes.	Presqu'ile Provincial Park Ontario, Canada	Multi-species, Turtles, Snakes, Frogs, Salamanders	Animex fencing and installation of underground crossing structures.	No	Sean P. Boyle, M.G. Keevil, Jacqueline D. Litzgus - Laurentian University; Don Tyerman, David Lesbarrrès - Ontario Parks	Peer-reviewed article	Biological Conservation
12	Research to Inform Caltrans Best Management Practices for Reptile and Amphibian Road Crossings	Technical report for Caltrans by the USGS, sections includes state assessment for road risks, spatial mapping, movements of species along barrier fencing & underpasses, and the effectiveness of fence turnarounds. While most sections are tailored to California, fencing design and testing sections are applicable to our needs. Found that herpetofauna is likely to interact with fencing by poking with noses, pacing back and forth, and attempting to climb.	California, USA	Various species, focus on California Tiger Salamanders & Yosemite Toads	Compared solid vs. mesh fencing, found some animals (e.g., salamanders) traveled much faster along solid fencing and were less likely to turn around, while others (e.g., toads) were not affected by fencing type. Compared high vs low jump outs – similar results. Compared turnarounds, solid was less effective at changing an animal's direction vs mesh.	Yes	Cheryl S. Brehme and Robert N. Fisher – USGS; Tom E.S. Langton – Transport Ecology Services (HCI LTD); Anthony P. Clevenger – Montana State University; in addition to multiple other contributing authors.	Technical Report	USGS for Caltrans
13	Wildlife Crossing Structure Handbook: Design and Evaluation in North America	Discusses considerations for fencing and crossings. Provides general design & application recommendations. Widely applicable and not focused on turtles, much more focused on large mammals. Several appendix sections (Hot sheets 13 & 14) applicable for small vertebrate fencing & escape gates/ramps.	North America	General	Varies: Recommend burying fencing 6-10" below ground. Primarily focuses on the use of hardware cloth or wire mesh. Recommends bending the top 2-3 inches of wire mesh over at 45 degrees to create a lip or overhang.	Yes	Anthony P. Clevenger and Marcel P. Huijser - Western Transportation Institute	Technical Report	FHWA
14	Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions	Discusses the effectiveness of wildlife exclusion fencing & crossings in reducing wildlife-vehicle collisions in Banff national park. Shows higher rates of collisions near fence ends where animals were able to bypass the fence.	Banff National Park, Canada	Primarily Ungulates	No	Yes	Anthony P. Clevenger - Montana State University; Bryan Chruszcz - Parks Canada; Kari Gunson - Eco-Kare International	Peer-reviewed article	Wildlife Society Bulletin

15	Roads, Reptiles, and Recovery: Applying a Collaborative Decision-Making approach for Diamondback Terrapin (Malaclemys terrapin) Conservation in Georgia	PhD dissertation examining nesting behaviors & survival, road management and the behaviors of drivers, and analysis of how to evaluate management decisions. Discussed results of surveys on potential management options. While some were widely supported, such as nest boxes, others were such as fencing & signs were less supported.	Jekyll Island Georgia, USA	Diamondback terrapin	No	No	Brian Crawford - UGA	PhD dissertation	University of Georgia
16	Mitigating Road Mortality of Diamond-Backed Terrapins (Malaclemys terrapin) with Hybrid Barriers at Crossing Hot Spots	Use of nest boxes as barriers to allow nesting females to leave the marsh and enter a protected nesting area to lay eggs. The road side of nest boxes was closed to prevent terrapins from continuing through the nest box and into the road. Modification of the prior deployments of individuals nest boxes.	Jekyll Island Georgia, USA	Diamondback terrapin	No, referenced a different paper for design specs.	Yes	Brian A. Crawford, John C. Maerz– UGA, Warnell School of Forestry & Natural Resources; Clinton T. Moore – USGS, GA Cooperative Fish and Wildlife Research Unit; Terry M. Norton – Georgia Sea Turtle Center	Peer-reviewed article	Herpetological Conservation and Biology
17	A Review of Mitigation Measures for Reducing Wildlife Mortality on Roadways	Review of multiple studies discussing the effectiveness of crossing structures & exclusion fencing. Includes table of previous paper and type of structure and focal species.	Various - global	Amphibians; Mammals; Reptiles	No	No	David Glista - Indiana DOT, Travis DeVault – USDA Wildlife Services, Andrew DeWoody – Purdue University	Peer-reviewed article	Landscape and Urban Planning
18	Effects of Roads and Crabbing Pressures on Diamondback Terrapin Populations in Coastal Georgia	Article discussing the relationship of roads and crabbing on the population demographics and estimated populations of terrapins. While they found a relationship between crab pots and reduced terrapin populations, they did not see an effect of roads on the populations. They hypothesize this is due to the large areas of saltmarsh that are isolated from roads on our barrier islands, and caution that roads may play a large impact on localized populations, which was observed along the Tybee & Jekyll causeways.	Coastal Georgia, USA	Diamondback terrapin	No	No	Andrew Grosse, John Maerz, Jeffery Hepinstall-Cymerman – UGA; Michael Dorcas – Davidson College	Peer-reviewed article	Journal of Wildlife Management

19	Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario	Design considerations and best practices for multi-species fencing. Includes flow charts for timeline and mitigation plan development and info sheets on different types of crossing structures as well as fencing designs.	Ontario, Canada	Amphibians; Reptiles	Yes, many for fencing & crossing.	Yes	Kari Gunson - Eco-Kare International; Joe Crowley - Government of Ontario, Canada; David Seburn - Canadian Wildlife Federation	Technical report	Ontario Ministry of Natural Resources and Forestry
20	Exploration of Wildlife Mitigation Measures for the Roads through and Around Fisherman Island and Chincoteague National Wildlife Refuge	Examination of existing diamondback terrapin barriers and proposed barriers that have been permitted. Has a number of photos and diagrams. Original “more temporary” designs had little effect; therefore, proposed concrete barrier walls made of precast 20’ segments that were 1ft tall, which had been permitted but not installed at time of publication.	Chesapeake Bay Virginia, USA	Diamondback terrapin	Various: Plastic netting & tubing – no effect on reducing mortality Concrete barrier (planned) – includes technical drawings.	Yes	Marcel Huijser, James Begley – Western Transportation Initiative, Montana State University	Technical Report	USFWS
21	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	Added chain-link turtle exclusion fencing along roadways in areas with culverts to keep turtles off the road and direct them to culverts for crossing. While fencing reduced turtle observations, it did not produce a statistically significant change. Made recommendations for improvements.	Valentine National Wildlife Refuge Nebraska, USA	Blanding’s turtle, and other native turtles observed	Yes	Yes	Marcel P. Huijser - Montana State University-Bozeman; Kari E. Gunson - Eco-Kare International; Elizabeth R. Fairbank - Montana State University-Bozeman	Technical Report	Nevada Department of Transportation Research
22	Improved Exclusion Barriers for Desert Tortoises	Effectiveness of tortoise guards for use in areas where gates are not feasible.	California, USA	Desert tortoises	Yes, Temporary or permanent drive-over tortoise barrier consisting of 2 I-Beams that are held apart and buried to create a gap that tortoises cannot cross but a vehicle can drive over.	Yes	Harold G. Hunt - Caltrans Division of Research, Innovation, and System Information	Technical Report	Caltrans Division of Research, Innovation, and System Information
23	Spatial Patterns of Road Mortality: Assessing Turtle Barrier Conservation Strategies	Examined the effectiveness of barriers and the effect of road mortality on diamondback terrapin populations in New Jersey. Compared the effectiveness of different types of barriers. Found that installed pipe barriers lowered mortality by around 13%	Cape May County New Jersey, USA	Diamondback terrapin	2 types: purposely installed barriers (pipes) & bulkheads installed for erosion control.	Yes	Dorothy Ives-Dewey, James P. Lewandowski – West Chester University of Pennsylvania	Peer-reviewed article	Middle States Geographer

		while bulkheads lowered mortality ~48%.							
24	A Literature Review of the Effects of Roads on Amphibians and Reptiles and the Measures Used to Minimize Those Effects	Detailed review for USFS over the impacts of roads on assorted herpetofauna, specifically the effect of roads on the surrounding environments. Has a section devoted to methods that can be used to minimize the ecological effects of roads including avoidance, seasonal road closures, and various types of crossing structures. Includes case studies. Goes on to discuss the challenges associated with crossing structures regarding design and maintenance.	Various - global	Reptiles and Amphibians	No	No	Denim M. Jochimsen - Idaho State University, Department of Biological Sciences; Kimberly M. Andrews, J. Whitfield Gibbons - University of Georgia, Savannah River Ecology Laboratory	Technical Report	USFS
25	Effectiveness of a Barrier Wall and Culverts in Reducing Wildlife Mortality on a Heavily Traveled Highway in Florida	Examined the effectiveness of a culvert/barrier wall system via pre- & post- construction mortality detections; found 90%+ reduction. Use of culverts increased for crossings. Type A fence was found to not be effective.	Payne's River Basin (US441) Florida, USA	All vertebrates (excluded tree frogs)	Permanent, 2 types: Concrete barrier wall with culverts - 1.1m high with 15.2cm overhang, Type A fencing - 2 stacked guard rails with buried hardware cloth	Yes	C. Kenneth Dodd Jr., William J. Barichivich, Lora L. Smith - Florida Integrated Science Centers, US Geological Survey	Peer-reviewed article	Biological Conservation
26	Monitoring Functionality and Durability of the New York State Highway 30 Turtle Barrier and Adjacent Nesting Substrate	Monitored exclusion fencing installed by NYSDOT as part of a reconstruction project. The road had existing culverts & bridge span to allow for wildlife passage. Installed various forms of fencing (wooden boards & mesh). Monitored and modified fencing over several years. Appeared to cut down on mortality; however, no pre-fence data was collected and had maintenance issues.	Franklin County, New York, USA	Various Turtle Species	2 types of barrier: Wooden fencing: 3 boards (1x10") affixed to pressure treated 4x4 posts with 1" gaps. Concerns about wooden fencing being a potentially dangerous "fixed object" only installed behind guardrails. Maintenance issues with wooden boards and undercutting via erosion. Metal Fencing Barrier: 0.6m high, 5x10cm vinyl gauge mesh fencing affixed to metal posts or existing guard rail with cable ties. When attached to guard rail the base is flush with the road surface, and the top with the guardrail. When on	Yes	Tom A. Langen – Clarkson University, Dept of Biology	Technical Report	New York State Department of Transportation

					metal posts, the base was buried a few inches; later added a fine mesh to prevent hatchlings from passing through and raised the fence from 2 to 3ft high including an overhang. Included wings at the end to divert turtles away from the road. Maintenance issues with undercutting via erosion.				
27	The True Cost of Partial Fencing: Evaluating Strategies to Reduce Reptile Road Mortality	Examined the effectiveness of turtle exclusion fencing and culvert crossing along roadways. Found that while complete fencing reduced turtle numbers on roadways, incomplete areas in fencing actually lead to an increase of turtles in the road.	Southwestern Ontario, Canada	Turtles	Silt fence, then replaced with woven geotextile fencing (48" fencing mounted pressure treated 2x4s), replaced with PVC or galvanized hardware cloth in certain areas due to soil conditions. Still maintenance heavy and not long term, switching to Animex.	No	Chantel E. Markle, Patricia Chow-Fraser – Department of Biology, McMaster University; Scott D. Gillingwater – Upper Thames River Conservation Authority; Rick Levick – Long Point World Biosphere Foundation	Peer-reviewed article	Wildlife Society Bulletin
28	Reduce Vehicle-Animal Collisions with Installation of Small Animal Exclusion Fencing	Chain-link fencing along major roads to exclude turtles; not effective for hatchlings that fit though. Reduced adult mortality and retrofitted areas reduced juvenile mortality.	Minnesota, USA	Blanding's turtles, Wood turtles	Permanent: 6ft chain-link trenched 10-12" into the ground; posts set 4ft into ground. Wrap around "j-hook" end treatments were used. Minimum of 10ft long, curved to create a 24-30" gap at the end of the J. Later retrofitted with the addition of 1/2" hardware cloth to the chain link, buried 6" and leaving 2ft above ground.	Yes	Tricia Markle and Seth Stapleton - Minnesota Zoo Department of Conservation and Research	Technical Report	Minnesota Department of Transportation
29	The Preservation of Bog Turtle Metapopulation Dynamics by a Transportation Improvement Project in Southeastern Pennsylvania	Effects of a road/bridge construction project in Pennsylvania. Discussed mitigation measures used during construction to keep turtles off roads and design considerations used in the project.	Southeastern Pennsylvania, USA	Bog Turtles	Yes, silt fence attached to chain link. Buried 12" deep. Also attached orange construction fence to improve visibility to workers.	No	Teresa McElhenny, Andy Brookens - Skelly and Loy, Inc.	Peer-reviewed article	ICOET 2003 Proceedings
30	Reptile and Amphibian Exclusion Fencing: Overview of Proven Design and Installation	Overview of design and installation techniques for reptile & amphibian fencing in Ontario. Discussed effective depths to bury fences for	Ontario, Canada	Multi Species: Turtles, snakes, toads, skinks, salamanders	Yes; Silt fence, wire backed silt fence, hardware cloth, snow fence, concrete, sheet metal/vinyl walls.	Yes	Government of Ontario, Canada	Technical Report	Government of Ontario, Canada

	Techniques for Reptile and Amphibian Exclusion Fencing	various species, along with pros of each material and lists applicable uses.							
31	Nesting Mounds with Protective Boxes and an Electric Wire as Tools to Mitigate Diamond-backed Terrapin (Malaclemys terrapin) Nest Predation	Description of the initial design and placement of terrapin nesting mounds and nest boxes, prior to a group being aggregated into a continuous barrier.	Jekyll Island Georgia, USA	Diamondback terrapin	Constructed 24' long x 12' wide x 4' tall nesting areas using dredge spoils along the edge of the causeway. Placed 12' long x 4' wide x 2' tall nest boxes over the mounds to protect them from predation. Added an electric fence wire to help keep racoons from entering the nest boxes.	Yes	Daniel P. Quinn, S. Michelle Kaylor, Terry M. Norton – Georgia Sea Turtle Center; Kurt A. Buhlmann – University of Georgia Savannah River Ecology Lab	Peer-reviewed article	Herpetological Conservation and Biology
32	Nesting Success and Barrier Breaching: Assessing the Effectiveness of Roadway Fencing in Diamondback Terrapins (Malaclemys terrapin)	Ongoing efforts where multiple types of "temporary" fencing have been used over the years. Involved examining nesting sites to help determine effectiveness of barriers. Also built an "arena" to test the ability of terrapins to penetrate the barrier by finding gaps under it. Did observe results in preventing terrapins from accessing roadways; however, local ground conditions had an impact on effectiveness.	Southern New Jersey, USA	Diamondback terrapin	3 types, temporary, adjusted over the years following observations: Silt fence, Plastic mesh, and Plastic tubing.	Yes	Hannah Reses, Alison Davis Rabosky - The University of Michigan; Hannah Reses, Roger Wood - The Wetlands Institute	Peer-reviewed article	Herpetological Conservation and Biology
33	Design of Roadway Barriers to Reduce Desert Tortoise Mortality on Paved Road Infrastructure	New publication conducting lab testing barriers made from 8 different materials to observe behaviors and escape methods.	Nevada, USA	Desert tortoises	Limited, wire mesh & solid barriers.	TBD	Douglas E. Ruby - University of Maryland Eastern Shore; W. Bryan Jennings - University of California, Riverside; Gilbert Goodlett - EnviroPlus Consulting; James R. Spotila - Drexel University; Henry R. Mushinsky - University of South Florida	Abstract - Publication not yet available online	Chelonian Conservation and Biology
34	Behavioral Responses to Barriers by Desert Tortoises: Implications for Wildlife Management	Experimental testing of the effectiveness of various types of barriers to assess how well they would keep desert tortoises off of roadways using captive tortoises. Examined response to tortoises in the	Nevada, USA	Desert Tortoises	Numerous types; chain-link fence, hardware cloth, chicken wire, concrete block, wooden timbers/logs, ½ PVC pipe in trench, etc.	Yes	Douglas E. Ruby, James R. Spotila, Stacia K. Martin and Stanley J. Kemp	Peer-reviewed article	Herpetological Monographs

		different pens and how well the materials held up.							
35	Sea Isle Road Gets "Turtle Exclusion Fencing"	News report about the installation of fencing along the Sea Isle Boulevard. Discussed type of fencing used, chain link, and seen as an improvement over plastic pipe barriers. Installation of barrier required by NJ DEP as part of a roadway reconstruction project (19,417 linear ft of fencing)	Cape May County, New Jersey, USA	Diamondback terrapin	Black poly-coated chain link fence installed along the backside of a guardrail.	Yes	Donald Wittkowski – Sea Isle News	Newspaper Article	Sea Isle News
36	Tunnel and Fencing Options for Reducing Road Mortalities of Freshwater Turtles	Conducted behavioral trials of how turtles transected passage systems with variations in lighting, openness, and barriers. Tested how quickly turtles would move along an opaque barrier vs translucent barriers and ability to direct turtles with different types. Also included testing exclusion gates to allow one-way passage by turtles.	Massachusetts, USA; primarily field lab trials	Painted Turtles, Spotted Turtles, Blanding's Turtles	Various fencing, chain link, chicken wire, plastic sheeting. Easily set up for lab trials.	Yes	Paul R. Sievert and Derek T. Yorks - University of Massachusetts, Department of Environmental Conservation	Technical Report	FHWA
37	Movin' Lizards	Summary of project efforts with design, construction, and public outreach information	Addison County Vermont, USA	Salamanders	Yes	Yes	Chris Slesar - VTRANS	Public Interest Article	Orianne Society
38	Monkton Wildlife Crossing	Underpass crossing constructed to allow for passage of amphibians across a busy road. Used concrete blocks for exclusion fences to funnel salamanders into the crossing structure.	Addison County Vermont, USA	Amphibians; Salamanders	Specs: concrete underpass structure. Used concrete blocks as a retaining/barrier wall to funnel salamanders into the crossing.	Yes	VT Agency of Transportation/Vermont Fish & Wildlife	ArcGIS StoryMap	Vermont Agency of Transportation & Vermont Fish & Wildlife
39	Fencing: A Valuable Tool for Reducing Wildlife-Vehicle Collisions and Funneling Fauna to Crossing Structures	Book chapter discussing applications and considerations for different fencing types. Shows multiple examples of small vertebrate and reptile fences. Also addresses designs that allow animals to escape from the roadway if they do manage to breach the fencing.	Various - global	Small and large vertebrates, including endo- and ectothermic taxa	Yes, various for multiple species.	Yes	Rodney van der Ree - Australian Research Centre for Urban Ecology & The University of Melbourne; Jeffrey W. Gagnon - Arizona Game and Fish Department; Daniel J. Smith - Department of Biology, University of Central Florida	Book	John Wiley & Sons

40	A Guide to Building Terrapin Barriers and Fencing	Discussed multiple different fencing and barrier types for diamondback terrapins, including pros & cons of each type, as well as testing and observed success.	Coastal New Jersey, USA	Diamondback terrapin	Temporary: Silt fence, Plastic mesh, Corrugated pipe. All presented maintenance challenges from short-term, seasonal installations (e.g., UV damage, wind/snow damage).	Yes	The Wetlands Institute	https://wetlandsinstitute.org/conservation/terrapin-conservation/a-guide-for-building-terrapin-barriers-and-fences/	The Wetlands Institute
41	Road Crossing Structures for Amphibians and Reptiles: Informing Design through Behavioral Analysis	Conducted experiments on frogs and turtles to examine behavioral choices of various frog and turtle species to crossing structures and fence designs. Found that most species preferred mid-diameter crossings and were stopped by 0.6-0.9m barriers.	New York, USA	Frogs (Green & Leopard) & Turtles (Snapping & Painted)	Yes; Experimental design & layout.	Yes	Hara W. Woltz - Columbia University; James P. Gibbs - SUNY College of Environmental Science and Forestry; Peter K. Ducey - State University of New York at Cortland	Peer-reviewed article	Biological Conservation