



Assessment and Mitigation of Road Mortality of Turtles at Colonial National Historical Park



Sign alerting visitors to turtles crossing park roads.

NPS / KAI SCARANGELLA

Assessment and Mitigation of Road Mortality of Turtles at Colonial National Historical Park

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Abstract

We studied seasonal and spatial patterns of road mortality of turtles at Colonial National Historical Park from March–October of 2024. The study area was the Jamestown Island Loop Drive (hereafter Loop Drive), a 7.7 km paved road that was open to cyclists during the entire study period and motor vehicles from mid-June onwards. The road is divided into two segments; a shorter “Small Loop” and a longer “Big Loop.” Turtle species found included Box Turtles, Snapping Turtles, Spotted Turtles, Painted Turtles, Red-Bellied Cooters, and two species of Mud Turtles (Eastern and Striped), that were classified together due to morphological similarity. We conducted a total of 281 road surveys from 26 March until 29 October 2024 during which we found a total of 330 turtles. Mud Turtles and Box Turtles were the most common species and Red-Bellied Cooters and Painted Turtles were the least common. Turtle activity reached a maximum in mid-May, declining gradually through the end of August and early September. Of the 330 turtles encountered, 80.3% were found alive and 19.7% were found either dead or badly injured. For turtle species with at least 10 observations, Mud Turtles had the highest probability of being found dead (24.6% dead), whereas Snapping Turtles had the lowest probability of being found dead (7.0% dead). This is attributed to the much larger body size of Snapping Turtles, which made them more visible and more easily avoided. Although some dead turtles were found in April and May (before the road was opened to vehicular traffic), the largest number of dead turtles was found in July (21 dead, representing 32.3% of all dead turtles). Mortality events in April and May were the apparent result of collisions with bicycles, rather than motor vehicles. Although more turtles were found on the Big Loop, we did not find any differences in patterns of road mortality between these road segments. For Mud Turtles, frequency of deaths was significantly higher for immature turtles than for adult females or adult males. Conversely, we did not find any significant differences in frequency of deaths among age classes for Box Turtles. Our management recommendations are to (1) continue current public outreach campaigns and (2) close the Loop Drive to motor vehicles from 15 March to at least 15 June each year, with the understanding that these dates can be modified as more information on turtle activity and population viability becomes available.

Introduction

Mortality from vehicle collisions (“road mortality”) is increasingly considered to be an important element underlying population declines of many species of wildlife (reviewed in FHWA 2011). Turtles and other reptiles are considered to be especially vulnerable to this form of anthropogenic mortality due to their elongated life spans (Howell and Seigel 2019; Steen et al. 2006).

Jamestown Island is a part of Colonial National Historical Park (COLO), located in James City County, Virginia. The National Park Service portion of the island is approximately 1,500 acres in size, consisting mainly of wetlands with upland forested ridges. According to the National Landcover Database, approximately 80% of the NPS portion of the island is open water or some form of wetland habitat (Murasaki and Geyer 2023). The Jamestown Island Loop Drive (hereafter Loop Drive) is composed of two connected loops that form a figure eight shape stretching through most of the length of the island. The small loop is approximately three miles, and the big loop, accessible through the small loop, adds an additional two miles. The Loop Drive is a one-way, single lane road approximately 3.8 m wide with a speed limit of 15 miles per hour. Culverts are installed under the road when passing through wetlands, and wooden bridges are used to cross over streams and marshes. The shoulder of the road is primarily grass, and there are no structures or barriers separating the road from natural habitats.

From 26 March–29 October 2024, we used bicycles to survey the Loop Drive at COLO to assess the number of turtles and other reptiles found alive and dead on the road. Our primary goals were to determine the following:

1. The presence of “hot spots” (areas along the Loop Drive where turtle activity was highest) and “hot moments” (periods when activity was greatest).
2. Whether road mortality was correlated with sex (male/female) or age class (adult/juvenile/hatchling) for the most abundant species.
3. Which species of turtles were most vulnerable to mortality from road traffic.
4. The extent of nesting activity along the Loop Drive.
5. The effectiveness of road closures to motorized vehicles during select months of the year.

We also conducted a preliminary status survey for Spotted Turtles (*Clemmys guttata*). Spotted Turtles have been petitioned for listing under the Endangered Species Act and officials from the Virginia Department of Wildlife Resources and the Smithsonian Institution requested that we attempt surveys for the species, as possible with our other studies.

Materials and Methods

During 2024, the Loop Drive was completely closed to motorized traffic in April and May and open to motorized vehicles three days per week (Friday–Sunday) from 07 June to 31 October. Pedestrians and cyclists were allowed on the roads during all periods. Surveys began at the end of March and surveys concluded at the end of October. To avoid bias from choosing weather conditions when turtle activity was highest, we used a stratified random design to select three days per week, and within each day a random start time within each time block (0700–1000, 1100–1400, and 1500–1800 hours), when surveys were conducted (times were adjusted in October due to shorter daylight hours). Adjustments were made when the randomly selected sampling periods were consecutive. In those situations, the sampling period in the latter time block was selected randomly until the sampling periods were no longer consecutive. During the period 07 June to 31 October, we modified our sampling design so that we always sampled on Fridays (when the Loop Drive was open to vehicles) and then two random days when the Loop was closed to vehicles.

All turtles encountered were identified to species with the exception of Mud Turtles as the two species of Mud Turtles (*Kinosternon subrubrum* and *K. baurii*) found at COLO are extremely hard to separate by color patterns or size, even by trained field workers (J. D. Kleopfer, Virginia Department of Wildlife Resources, personal communication, March 2024). All *Kinosternon* species were therefore categorized as “Mud Turtles” for the purposes of this study.

During each survey, we recorded the number and identity of all turtles found, both alive and dead. We also recorded body sizes (straight-line plastron length for turtles) to allow classification as adults, juveniles, or hatchlings, and sex was recorded when possible based on secondary sex characteristics. The cause of death was determined by visual inspection. Turtles with crushed shells were assigned vehicles as the cause of death. Turtles with no visible external damage were classified as unknown in terms of cause of death.

Turtles found in the process of nesting along the sides of the Loop Drive were observed from a distance of about 3 m and flagging was placed near apparent nests. We then monitored the sites for any nest predation over the next 5–10 days. We also recorded the location of any nests found destroyed by predators and attempted to identify nests to species of turtle based on clutch sizes and egg shapes.

We recorded local environmental conditions (air temperature, relative humidity, cloud cover, wind speed, precipitation from the previous day) at the start of each survey and GPS coordinates for all animals found. Data were recorded using ArcGIS Survey123 and exported to Microsoft Excel, R (4.4.3), or VassarStats (<http://vassarstats.net/newcs.html>) for further analysis.

In addition to road surveys for turtles, surveys for Spotted Turtles were carried out using a combination of ProMar traps (Howell et al. 2016) and hand-captures in three discrete tidal wetlands near the Loop Drive and adjacent to the COLO Visitor Center. Captured individuals were processed as above, except that we used a permanent marker to record an individual ID on the plastron of each

individual and made additional morphological measurements, including curved carapace length, straight-line maximum plastron length, and body mass for each Spotted Turtle.

In addition to data collected on turtles, we also collected limited data on the presence of road-killed snakes, lizards, and amphibians. These data are presented in the appendix.

Results

Road Survey Effort

We conducted a total of 281 road surveys from 26 March until 29 October 2024 during which we found a total of 330 turtles. Fifty-four surveys (19.2% of the total surveys) were conducted while the Loop Drive was open to vehicular traffic compared with 227 (80.8%) while the road was accessible to pedestrians and bicycles only (Table 1).

Table 1. Summary of surveys completed each month, including the number of surveys, breakdown of road closure status, and number of turtles observed.

Month	Number of Surveys	Road Status (Open:Closed)	# Alive (Observations per Survey)	# Dead (Observations per Survey)
Mar	9	0:9	0 (0.00)	1 (0.11)
Apr	40	0:40	33 (0.83)	11 (0.28)
May	42	0:42	105 (2.50)	2 (0.05)
Jun	36	10:26	56 (1.56)	7 (0.19)
Jul	35	9:26	21 (0.60)	21 (0.60)
Aug	43	14:29	16 (0.37)	8 (0.19)
Sep	37	9:28	28 (0.76)	9 (0.24)
Oct	39	12:27	6 (0.15)	6 (0.15)

Species Vulnerability

In total, six species of turtles (see Methods regarding turtle identification) were observed, which is all but one species (Diamondback Terrapin, *Malaclemys terrapin*) that have been historically observed at Jamestown Island (Table 2). The Diamondback Terrapin was not observed during our surveys in 2024, but there had been no observations of this species on the island in recent years. The most common turtle species found were Mud Turtles (179 individuals), Box Turtles (81 individuals), and Snapping Turtles (43 individuals).

Of the 330 turtles encountered, 80.3% were found alive and 19.7% were found either dead or badly injured. For turtle species with at least 10 observations, Mud Turtles had the highest probability of being found dead (24.6% dead), whereas Snapping Turtles had the lowest probability of being found dead (7.0% dead). These differences are statistically significant (contingency table analysis, $X^2 = 7.92$, $df = 3$, $P = 0.047$), with Snapping Turtles being 65% less likely than predicted to be found killed, whereas Mud Turtles were 23.3% more likely to be found killed than predicted by random chance alone. We interpret these differences as being a function of body size and visibility; i.e., given that Snapping Turtles are much larger than Mud Turtles they are more likely to be seen and avoided by drivers.

Table 2. List of turtle species encountered during 2024 sampling, showing numbers found alive versus dead or severely injured. See text for statistical analysis.

Common Name (Scientific Name)	Total Encounters	# Alive (%)	# Dead (%)
Box Turtle (<i>Terrapene carolina</i>)	81	66 (81.5%)	15 (18.5%)
Mud Turtle (<i>Kinosternon sp.</i>)	179	135 (75.4%)	44 (24.6%)
Painted Turtle (<i>Chrysemys picta</i>)	5	4 (80.0%)	1 (20.0%)
Red-Bellied Cooter (<i>Pseudemys rubriventris</i>)	4	4 (100%)	0 (0%)
Snapping Turtle (<i>Chelydra serpentina</i>)	43	40 (93.0%)	3 (7.0%)
Spotted Turtle (<i>Clemmys guttata</i>)	18	16 (88.9%)	2 (11.1%)
TOTAL	330	265 (80.3%)	65 (19.7%)

Seasonal Variation in Road Activity (Hot Moments I)

Figure 1 and Table 3 illustrate basic seasonal patterns of turtles found on the Loop Drive. Except for one week in October, there was some level of turtle activity during the entire study. Overall activity reached a maximum in mid-May, declining gradually through the end of August and early September. There was an increase in activity in mid to late September, followed by a sharp decline through the end of October.

Figure 1 and Table 3 also illustrate seasonal patterns of relative numbers of turtles found live and dead. Although some dead turtles were found in April and May (before the road was opened to vehicular traffic), the largest numbers of dead turtles were found in July (21 dead, representing 32.3% of all dead turtles). Although we cannot confirm this without data from deployed traffic counters, the high number of dead turtles in July likely represents an increase in visitors around the July holiday period, combined with the road being open to motorized traffic three days per week.

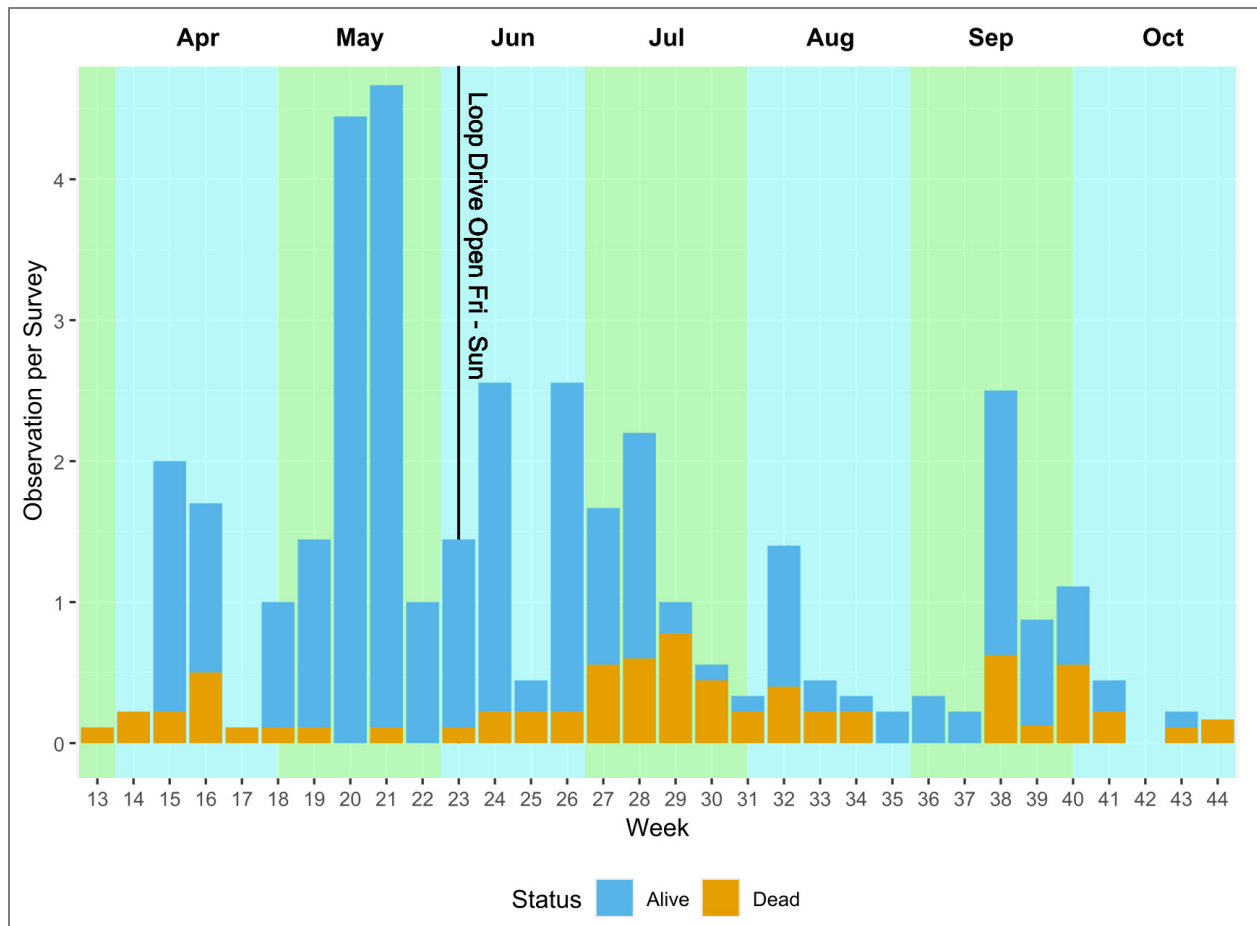


Figure 1. Weekly observation of live and dead turtles on the Loop Drive, adjusted by the number of surveys conducted. The Loop Drive opened to automobile traffic on Fridays, Saturdays, and Sundays starting 07 June (Week 23).

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Table 3. Weekly summary of dates, number of surveys completed, and the count and adjusted count of live and dead turtle observations on the Loop Drive.

Week	Dates	Surveys Completed	Live Count (# per Survey)	Dead Count (# per Survey)
13	03/24–03/30	9	0 (0.00)	1 (0.11)
14	03/31–04/06	9	0 (0.00)	2 (0.22)
15	04/07–04/13	9	16 (1.78)	2 (0.22)
16	04/14–04/20	10	12 (1.20)	5 (0.50)
17	04/21–04/27	9	0 (0.00)	1 (0.11)
18	04/28–05/04	9	8 (0.89)	1 (0.11)
19	05/05–05/11	9	12 (1.33)	1 (0.11)
20	05/12–05/18	9	40 (4.44)	0 (0.00)
21	05/19–05/25	9	41 (4.56)	1 (0.11)
22	05/26–06/01	9	9 (1.00)	0 (0.00)

Table 3 (continued). Weekly summary of dates, number of surveys completed, and the count and adjusted count of live and dead turtle observations on the Loop Drive.

Week	Dates	Surveys Completed	Live Count (# per Survey)	Dead Count (# per Survey)
23	06/02–06/08	9	12 (1.33)	1 (0.11)
24	06/09–06/15	9	21 (2.33)	2 (0.22)
25	06/16–06/22	9	2 (0.22)	2 (0.22)
26	06/23–06/29	9	21 (2.33)	2 (0.22)
27	06/30–07/06	9	10 (1.11)	5 (0.56)
28	07/07–07/13	5	8 (1.60)	3 (0.60)
29	07/14–07/20	9	2 (0.22)	7 (0.78)
30	07/21–07/27	9	1 (0.11)	4 (0.44)
31	07/28–08/03	9	1 (0.11)	2 (0.22)
32	08/04–08/10	10	10 (1.00)	4 (0.40)
33	08/11–08/17	9	2 (0.22)	2 (0.22)
34	08/18–08/24	9	1 (0.11)	2 (0.22)
35	08/25–08/31	9	2 (0.22)	0 (0.00)
36	09/01–09/07	9	3 (0.33)	0 (0.00)
37	09/08–09/14	9	2 (0.22)	0 (0.00)
38	09/15–09/21	8	15 (1.88)	5 (0.63)
39	09/22–09/28	8	6 (0.75)	1 (0.13)
40	09/29–10/05	9	5 (0.55)	5 (0.56)
41	10/06–10/12	9	2 (0.22)	2 (0.22)
42	10/13–10/19	9	0 (0.00)	0 (0.00)
43	10/20–10/26	9	1 (0.11)	1 (0.11)
44	10/27–11/02	6	0 (0.00)	1 (0.17)

Daily Activity Patterns (Hot Moments II)

We investigated whether there was an interaction between seasonal and daily activity patterns. In other words, does daily activity vary as a function of season? These data are illustrated in Figure 2 and show marked seasonal variation. Although activity in the morning hours was present in every month, the breadth of activity as indicated by the “IQR” (interquartile range where 50% of activity was found) was from 3–5 hours in length in April–July, expanding to six hours in August–September.

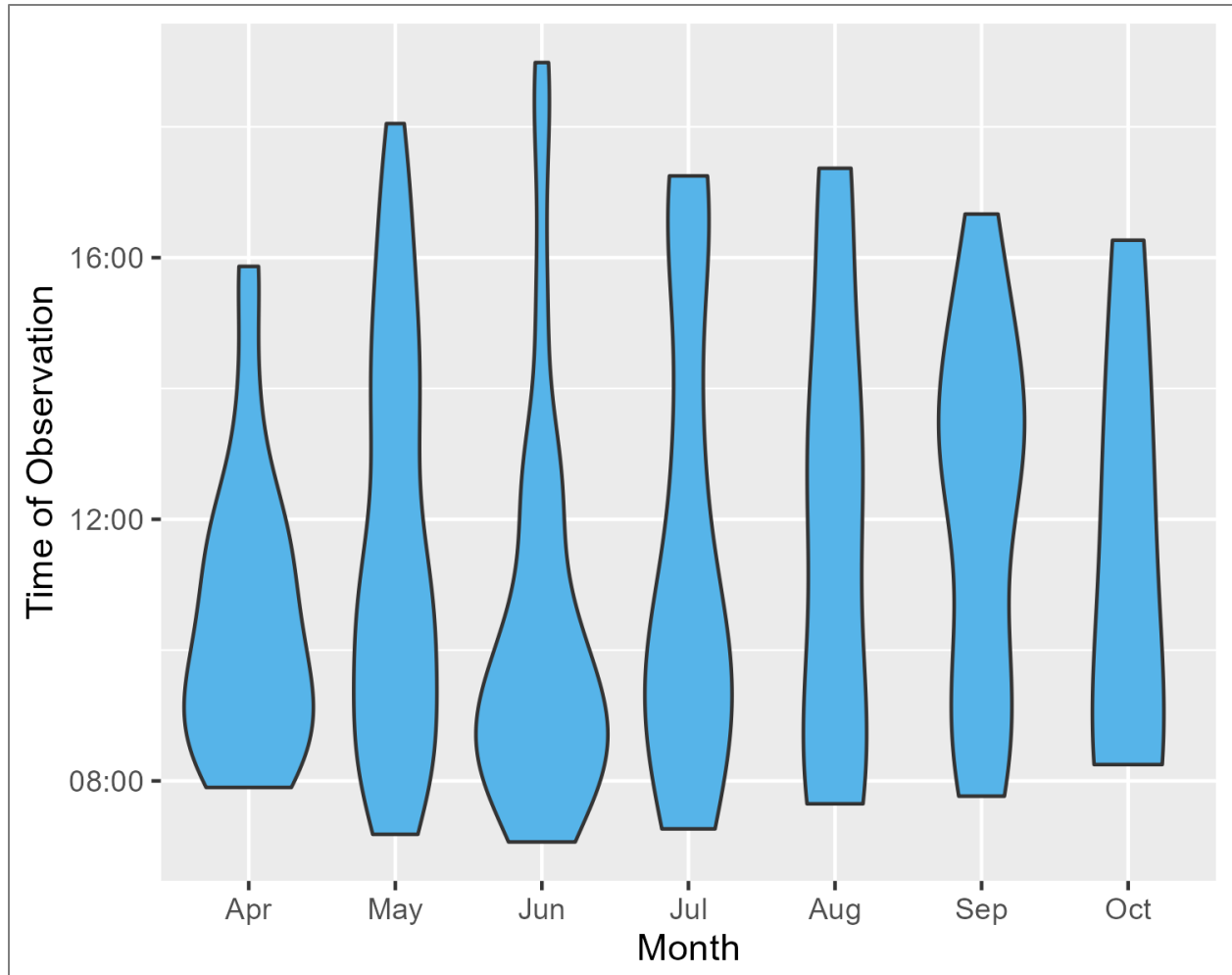


Figure 2. Distribution of the time of live turtle observations on the Loop Drive for each month of the study.
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These overall activity patterns likely reflect differential species responses to seasonal changes in temperature and humidity as illustrated in Figure 3. Snapping Turtles show the most obvious association between ambient environmental conditions and activity, with no activity found below 58.8% humidity or above 26.6° C. By contrast, Box Turtles were not found active below air temperatures of 17.1° C and most activity was found when temperatures were at least 24.2° C.

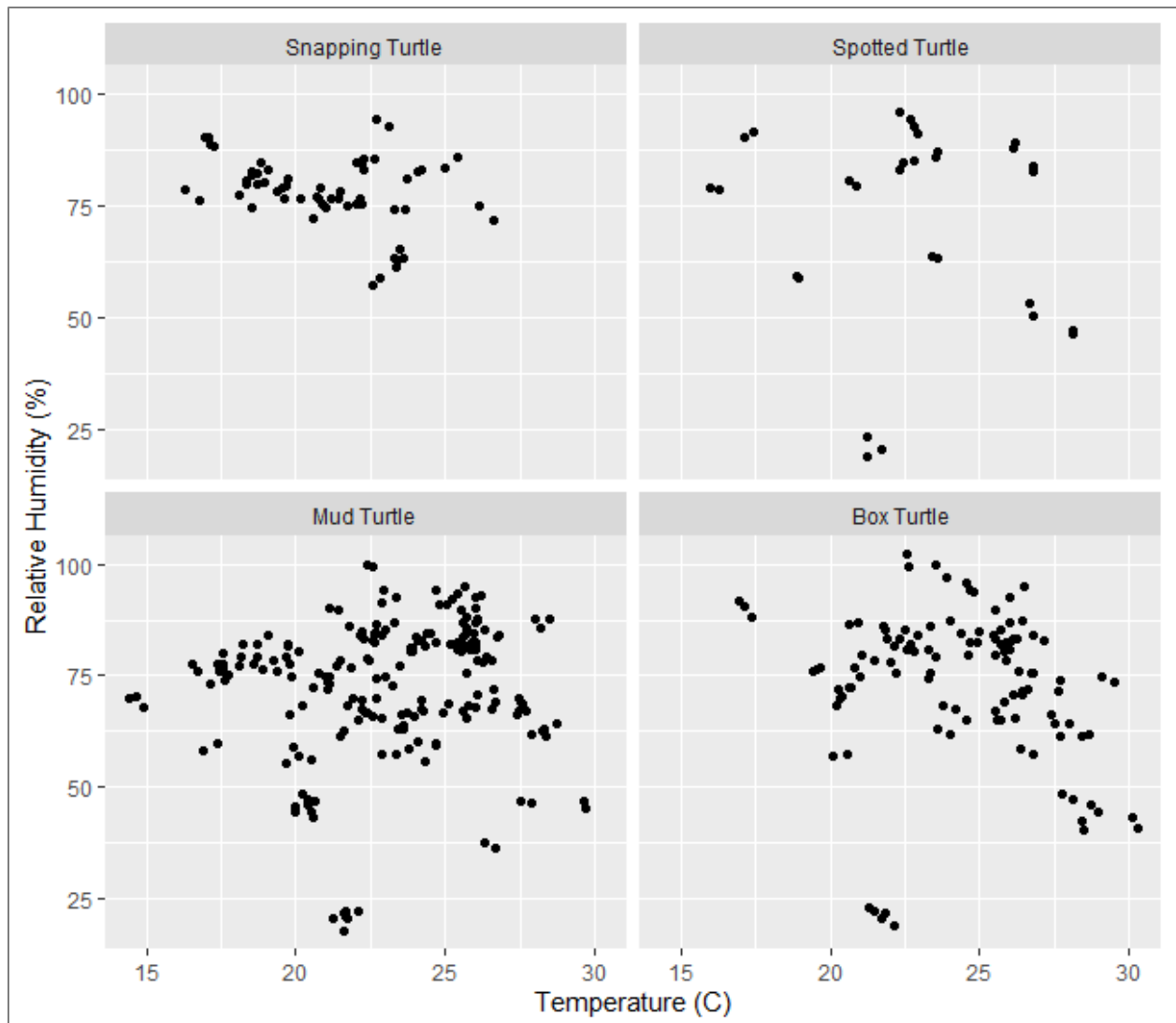


Figure 3. Temperature and relative humidity of live turtle observations for the four most common species of turtles.

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Spatial Distribution of Turtle Activity (Hot Spots)

Figure 4 is a “heat map” showing observations of all turtle species found on the Loop Drive during 2024. Turtles were observed throughout the Loop Drive except on bridges, which are identifiable in the below map by the absence of sightings, and the Small Loop “cut-through,” which was not surveyed. As all species of turtles found on Jamestown Island (except for Box Turtles) are aquatic or semi-aquatic, and the majority of the Loop Drive is situated within or in close proximity of wetlands, the overall pattern of distribution of turtles was as expected.

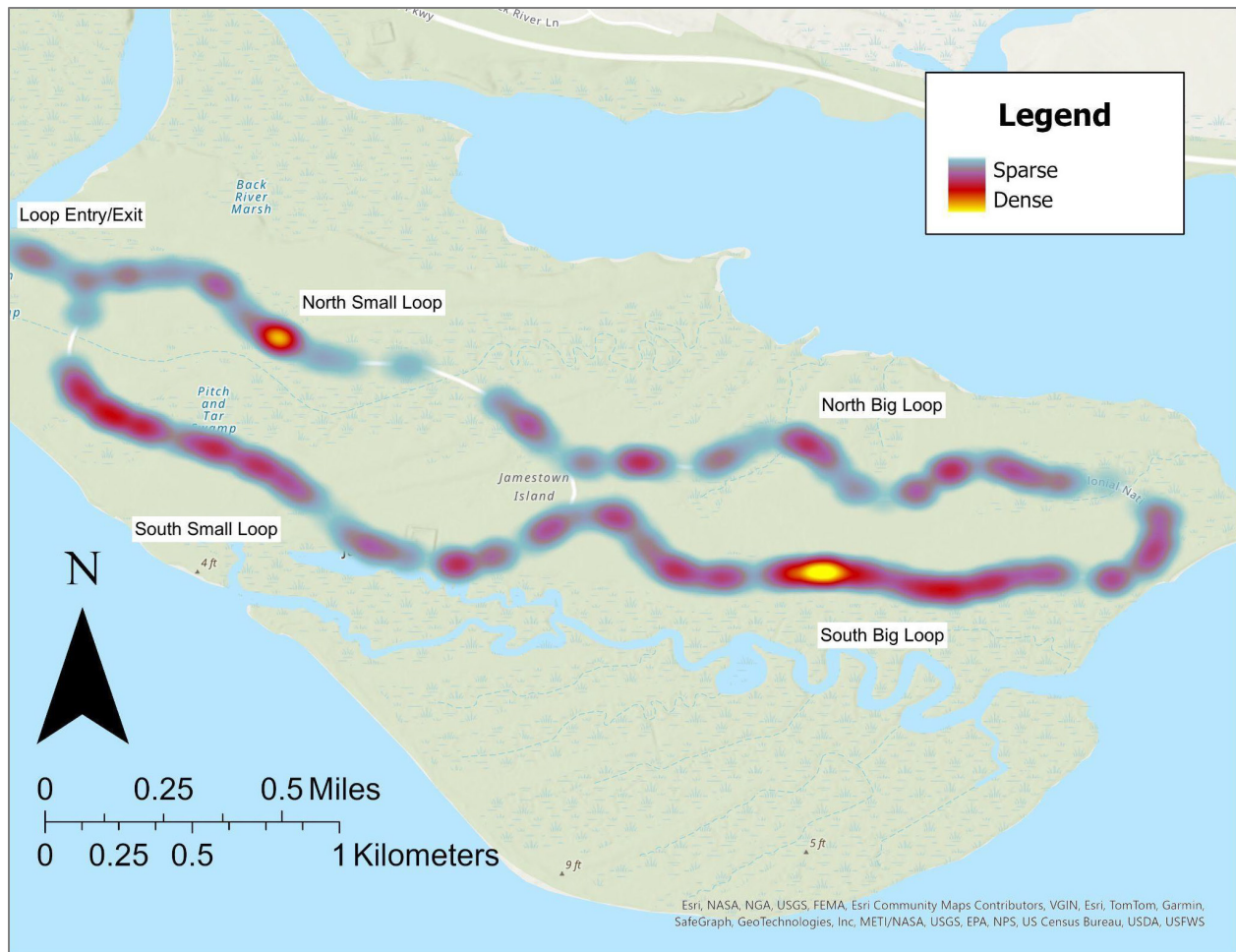


Figure 4. Map showing the “hot spots” for all turtle species found along the Jamestown Island Loop Drive. Blue and purple colors indicate fewer turtles found at a location whereas brighter colors (red and yellow) indicate more turtles.

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For the purposes of identifying specific localities where turtle activity was highest, the Loop Drive was divided into five distinct subsegments, Loop Entry/Exit, South Small Loop, South Big Loop, North Big Loop, and North Small Loop (Figure 4). Overall, about 23% more turtles were found on the Big Loop than on the Small Loop (Table 4). Within each loop, more turtles were found on the southern portions of the loops compared with the northern portions. Additionally, there was an apparent seasonal pattern to the spatial distribution on the Loop Drive; in April, August, September, and October, more turtles were observed on the Small Loop than on the Big Loop, although the differences in numbers were slight (Figure 5).

Table 4. Turtle observations by segment of the Loop Drive.

Segment	Subsegment	Alive	Dead	Total
Small Loop	Loop Entry/Exit	10 (90.9%)	1 (9.1%)	11
	South Small Loop	71 (81.6%)	16 (18.4%)	87
	North Small Loop	36 (72.0%)	14 (28.0%)	50
	Small Loop Total	117 (79.1%)	31 (20.9%)	148
Big Loop	South Big Loop	93 (80.9%)	22 (19.1%)	115
	North Big Loop	55 (82.1%)	12 (17.9%)	67
	Big Loop Total	148 (81.3%)	34 (18.7%)	182

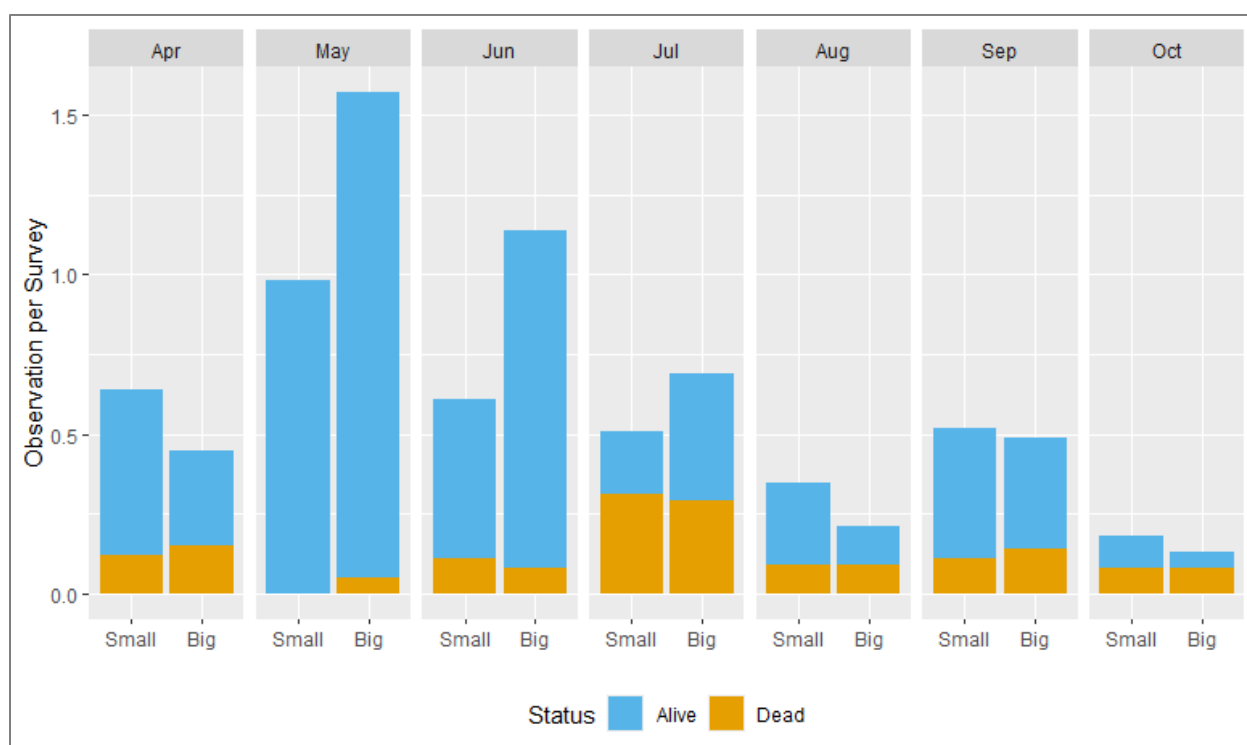


Figure 5. Histogram showing the monthly sightings and condition of turtles found on the Small and Big Loops of the Jamestown Island Loop Drive.

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We did not find any differences in patterns of road mortality between the two major road segments. The percentage of turtles found alive was almost the same for the Small Loop (79.1%) versus the Big Loop (81.3%) and this difference was not statistically significant (contingency table analysis, $X^2 = 0.14$, $df = 1$, $P = 0.71$).

Population Structure and Vulnerability to Vehicular Mortality

Population Structure: Sex Ratio and Age Class

Of the 161 Mud Turtles that we could assign to an age class (adult, juvenile, or hatchling), 90 (55.9%) were adults and 71 (44.1%) were juveniles or hatchlings. Of the 90 adults, the sex ratio was 78.9% females to 21.1% males and this ratio was significantly different from 1:1 ($X^2 = 30.4$, $df = 1$, $P = 0.001$). Of the 76 Box Turtles that we could assign to an age class, 69 (90.8%) were adults and only seven (9.2%) were juveniles or hatchlings. However, in contrast with Mud Turtles, the sex ratio of adult Box Turtles was significantly biased towards males (21.7% females:78.3% males, $X^2 = 22.0$, $df = 1$, $P = 0.001$). The ratio of adults to juveniles also differed significantly between Mud and Box Turtles (contingency table analysis, $X^2 = 26.9$, $df = 1$, $P = 0.001$), with more juveniles than expected for Mud Turtles and more adults than expected for Box Turtles.

Population Structure and Mortality

Table 5 shows the frequency of dead turtles as a function of age class for the two species with the most data (Box and Mud Turtles), with unknown classes omitted. For Mud Turtles, the frequency of deaths was significantly higher (Fisher's Exact Test, $P = 0.001$) for immature turtles (31.0% of immature turtles) than for either adult females (9.8%) or adult males (5.3%). Conversely, we did not find any significant differences in frequency of deaths among age classes of Box Turtles (Fisher's Exact Test, $P = 0.864$), with the highest frequency of dead turtles occurring in adult males (14.8%) and immatures (14.3%) and the lowest among adult females (6.7%).

Table 5. Ratios of live and dead Mud and Box Turtles as a function of age class and sex.

Species	Female (Live:Dead)	Male (Live:Dead)	Immature (Live:Dead)
Mud Turtle	64:7	18:1	49:22
Box Turtle	14:1	46:8	6:1

Sources of Mortality and Population Structure

Figure 6 shows a breakdown of sources of mortality (automobiles, bicycles, unknown causes) as a function of shell size for all turtle species. We attribute most of the observed mortalities among juvenile and hatchling turtles to bicycles (as opposed to NPS-authorized vehicles) based on shell damage that was not consistent with a heavy vehicle such as a truck (a hatchling turtle run over by a truck would be effectively flattened, whereas a collision with a bicycle would show much less damage). It is unsurprising that most turtles over about 50 mm in plastron length were killed by automobiles rather than bicycles; not only would such turtles be more resistant to shell damage from collisions, but their larger size likely makes them more noticeable and more easily avoided by bicyclists.

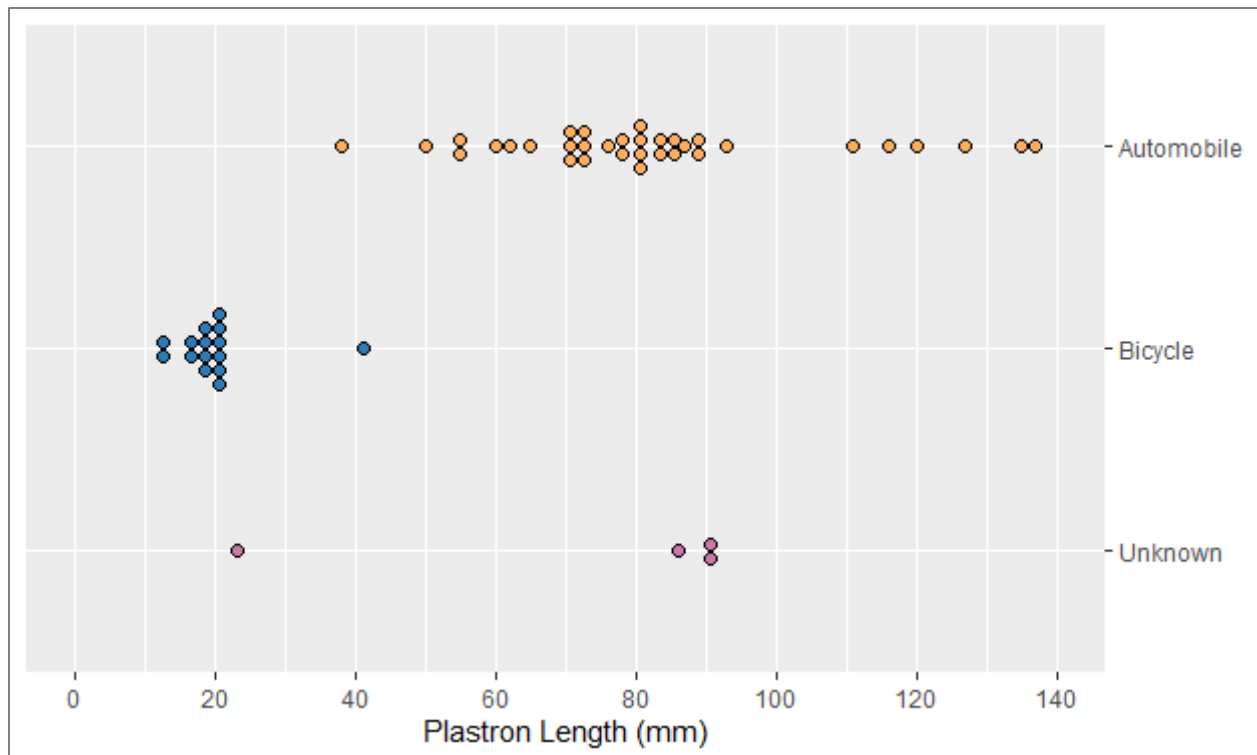


Figure 6. Plastron length of dead turtles by cause of mortality.
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Seasonal Activity and Vulnerability to Mortality

Figure 7 shows the relative numbers of live and dead turtles of all species found on the Loop Drive each month as a function of age class. A designation of “Unknown” was assigned to turtles that were so severely damaged that they could not be measured accurately and thus, an age class could not be determined. For all species, juvenile and hatchling turtles were found primarily in April and May (84.7% of juvenile and hatchling observations) and all turtles found dead during those months were juveniles and hatchlings (Figure 7). Among adult turtles, 114 of 141 (80.9%) of all adult females found on the Loop Drive were observed during May and June, whereas adult males showed much less seasonal variation.

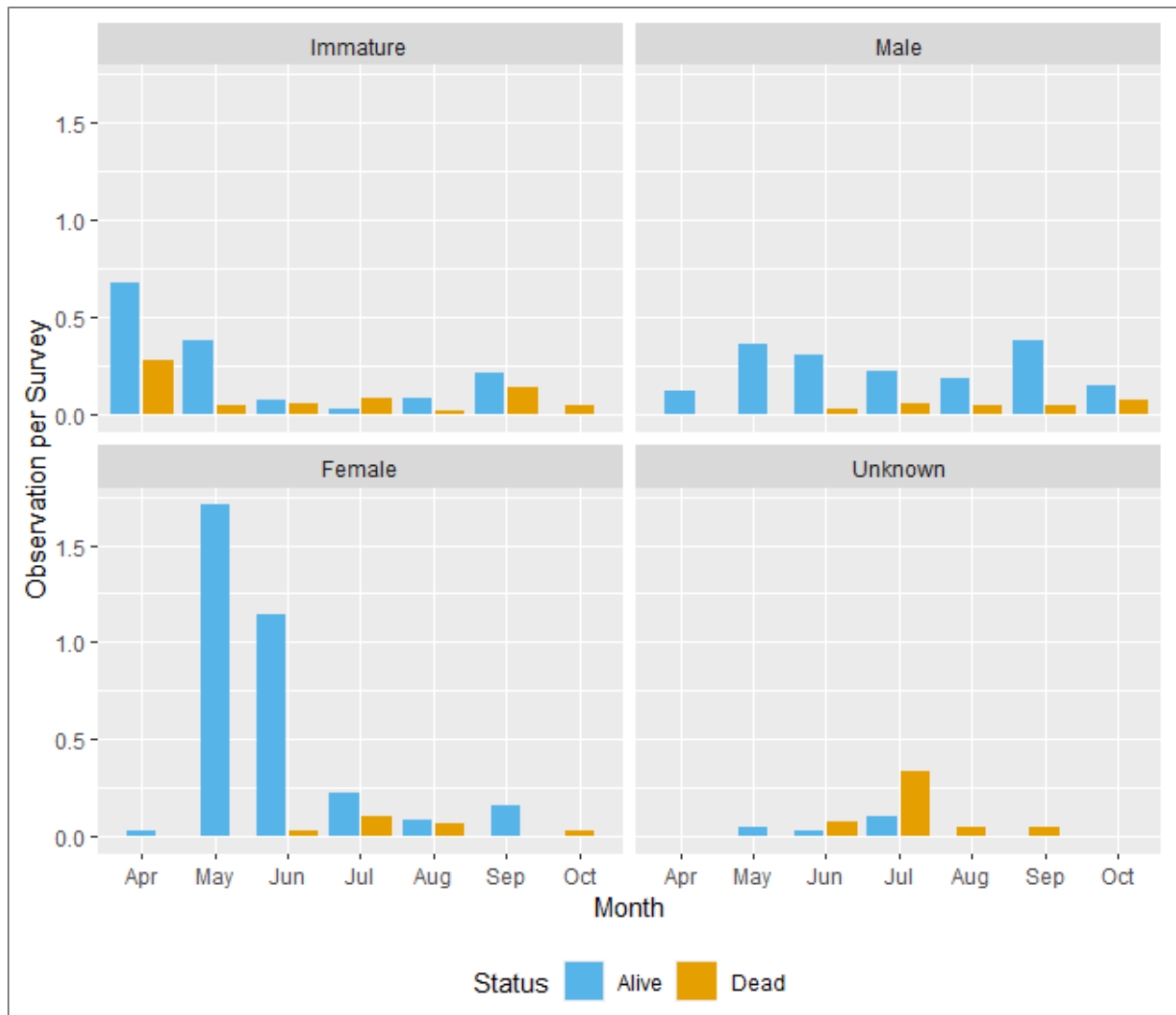


Figure 7. Live and dead turtle observations adjusted by number of surveys conducted, divided by month and age class.

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Figure 8 shows monthly variation in numbers of dead turtles broken down by source of mortality and day of the week. July showed the highest numbers of dead turtles, likely because visitation may be highest that month. However, data from traffic counters were unavailable to us as of the time of this writing, so this remains speculation. As noted above, almost all turtles killed in April and May were presumably killed by bicycles.

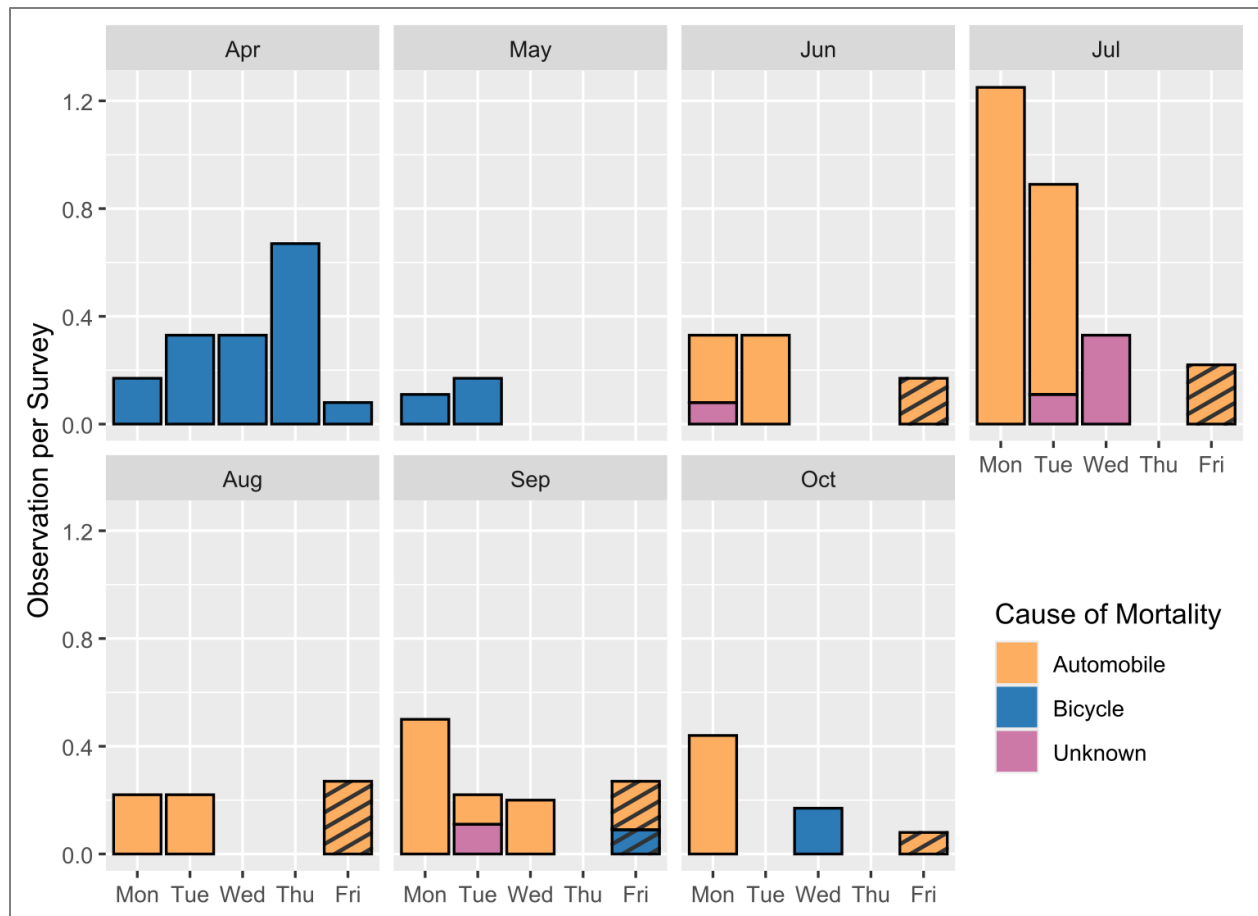


Figure 8. Monthly observations of dead turtles adjusted by number of surveys conducted, and broken down by cause of mortality. The striped bars on Friday indicate that the Loop Drive was open to automobile traffic on Fridays, Saturdays, and Sundays of that month. One observation of a dead turtle on a Friday in September occurred before the Loop Drive was opened, and the cause of mortality was determined to be from a bicycle.

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Figure 9 shows the effect of time of year on the activity and mortality of our two most abundant species (Mud Turtles and Box Turtles). For Mud Turtles, May had the highest number of turtles (45 individuals) found in any condition, whereas October had the lowest number (five individuals). For Box Turtles, June had the highest number of turtles (20 individuals) found in any condition, while April had the lowest number (three individuals).

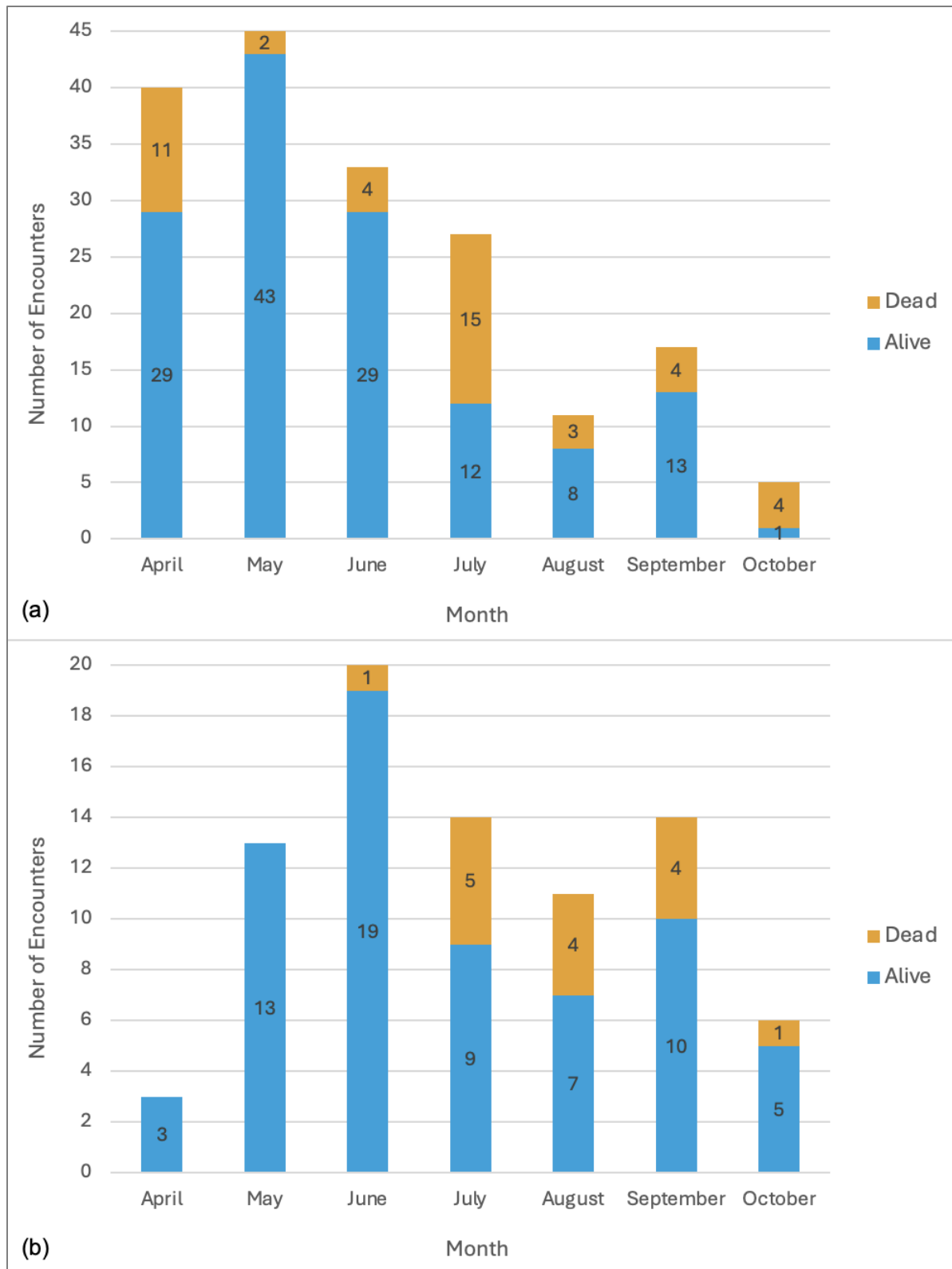


Figure 9. Histograms showing the effect of time of year (April–October) on the activity and mortality of Mud Turtles and Box Turtles. Top graph (a): Mud Turtles; bottom graph (b): Box Turtles.

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Unsurprisingly, road-associated mortalities were much lower in months when the Loop Drive was closed to motorized traffic (April and May) than in months when at least some vehicular traffic was permitted (June–October). Specifically, zero of 16 Box Turtles were found dead in April and May compared with 15 of 65 (23.1%) found dead in June–October (contingency table analysis, Fisher’s Exact Test, one-tailed $P = 0.025$). For Mud Turtles, 13 of 85 (15.3%) turtles were found dead in April and May compared with 30 of 93 (32.3%) found dead in June–October (contingency table analysis, $X^2 = 6.08$, $df = 1$, $P = 0.01$).

Nesting Activity

We located a total of 17 fresh nests (i.e., those found while being excavated by females and those that were positively identified through visual clues although no female was present) and 52 predated nests during May–October 2024 (Figure 10). Most nests were from Snapping Turtles (56.5%), followed by 4.4% from Red-Bellied Cooters, 2.9% from Mud Turtles, and 36.2% were unknown as to species. Of the 17 fresh nests found, 76.5% were predated after they were initially observed. We did not directly observe predation on nests, but raccoons are the most likely predator (R. Seigel, personal observation, March 2024).

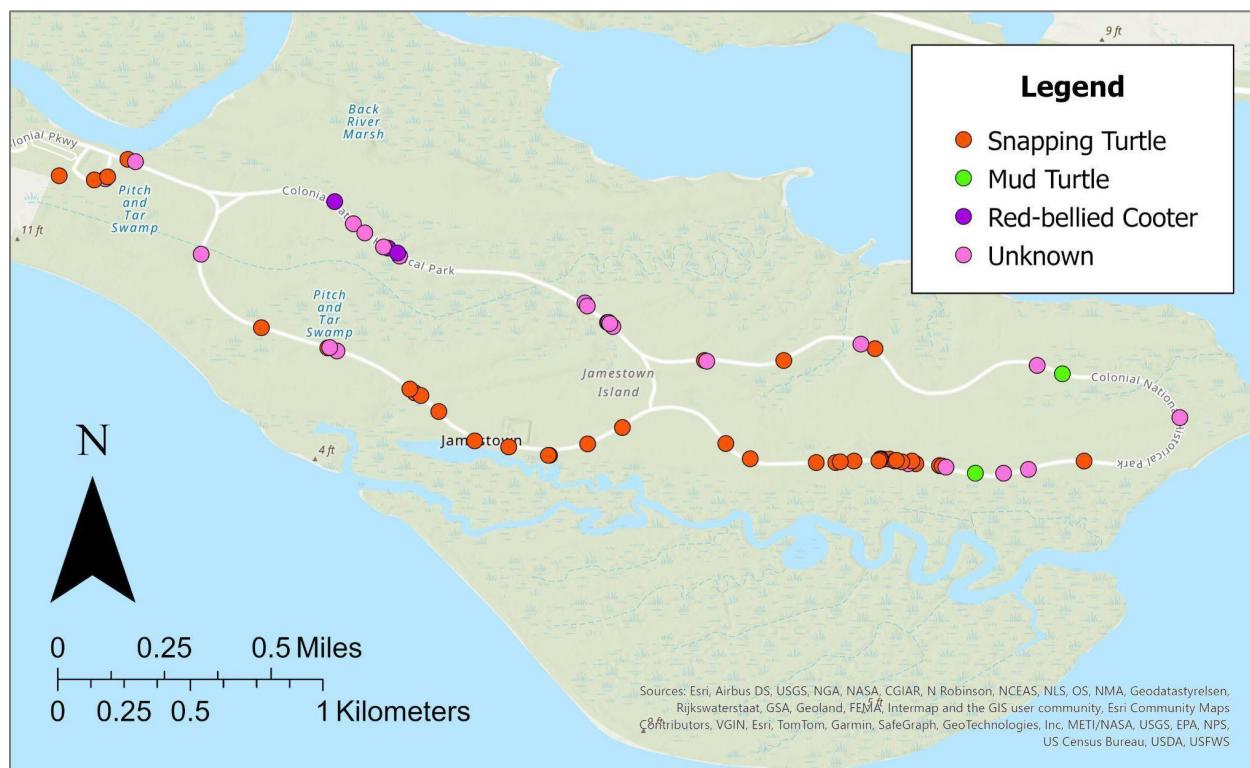


Figure 10. Map of observed turtle nest locations.

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Spotted Turtle Surveys

We conducted three trapping surveys for a total of 38 trap nights and six hand-capture surveys for Spotted Turtles during the period April–October 2024. Spotted Turtles were found in 100% of trapping surveys and 100% of hand-capture surveys.

We captured and processed a total of 60 Spotted Turtles, 13 (21.7%) from trapping, 29 (48.3%) from hand-capture surveys, and 18 (30.0%) from road surveys. Overall, we captured 24 adult males, 34 adult females, one juvenile, and one hatchling during 2024. While these data are limited in scope, they are suggestive of a substantial population of Spotted Turtles at COLO and we recommend that follow-up surveys be conducted as soon as possible to better determine the extent of the distribution of the species on Jamestown Island.

Discussion

Data Limitations

Our data have several limitations that should be considered before reviewing management options. First, counts of dead turtles likely represent underestimates of the actual numbers of turtles killed by automobiles and bicycles. Carrion feeders such as vultures and raccoons are known to remove dead animals from roads before they can be counted by investigators (e.g., Boyle et al. 2025), but we do not have data to quantify this. Such removals were most likely between the last survey in the late afternoon and evening and the first survey the following morning. It is also possible that Park visitors may have found injured or dead turtles on the road and either moved them off the road to prevent further injury or even removed them from the site altogether.

We also may be underestimating the numbers of turtles killed by bicycles rather than automobiles. We attributed mortality events to bicycles when the extent of shell damage was limited to that consistent with a bike and not an automobile (i.e., when the shell was not completely crushed). However, it is possible that some turtles, particularly those with plastron lengths <50 mm, may have been killed by a bicycle and subsequently run over by a car, resulting in an undercounting of bicycle-induced mortalities. In addition, cyclists may be more aware of having run over a turtle than automobile drivers and might move injured turtles off of the road surface to protect them.

A major limitation of our data is that our detailed observations are confined to a single year. Ectothermic species such as turtles are known to have variable movements depending on temperature and rainfall (among other environmental factors), so information from a single year may be biased depending on weather conditions (Bernardino and Dalrymple 1992). Some data from COLO are available from 2021 and 2022 but are very limited due to inconsistencies in how the surveys were conducted.

Finally, we lack data on levels of road traffic during periods when the Loop Drive was open to motorized vehicles. Such data were collected during some months in 2024 but have not been made available as of this writing.

Future Data Needs

We strongly recommend a series of follow-up studies to rectify the data limitations noted above. An additional year of road surveys using the protocols established in 2024 would allow for validation of the patterns seen during this study. We also recommend that an effort be made to establish basic population parameters for the species most affected by road mortality, especially Mud Turtles and Box Turtles. This would take the form of a mark-recapture study, which would allow at least a preliminary assessment of population size and the proportion of turtles that are killed by road traffic. Finally, a more detailed mark-recapture study of Spotted Turtles would be valuable in documenting current population sizes and spatial distribution.

Management Recommendations

Overview: Impacts of Road Mortality on Turtle Populations

An extensive body of research supports the conclusion that mortality resulting from wildlife-vehicle collisions is a significant threat to wildlife species in general and for turtles in particular (e.g., Andrews and Gibbons 2005; Andrews et al. 2015; Fournier et al. 2025; Gibbs and Shriver 2002; Howell and Seigel 2019; Laporte et al. 2013; Marsh et al. 2005; Steen et al. 2006). Turtles are especially vulnerable to vehicle-induced mortality because turtles have a unique suite of life history characteristics, including high age of maturity and high adult survivorship, that, coupled with low reproductive output and high mortality in the hatchling and juvenile stages, makes population viability highly dependent on extremely high survivorship in the subadult and adult life stages (Congdon et al. 1993, 1994; Steen et al. 2006). As a result of this suite of life history characteristics, even small reductions in survival in the subadult and adult life stages have been found to negatively impact turtle population viability (Howell and Seigel 2019; Steen et al. 2006).

An illustration of the impacts of road mortality on a population of Spotted Turtles (*Clemmys guttata*), a species found at COLO, is shown in Figure 11. The top graph (Figure 11A) shows the projected population trajectory over a 150-year period with no effects of road mortality. This population is declining quite slowly, with a range of outcomes that includes moderate population growth. There is no chance of local extinction under these baseline conditions. The bottom graph (Figure 11B) shows the effects of a 2% reduction in adult survival due to road mortality: here, the projected population size declines drastically, with about a 50% probability of local extinction within as little as 60 years. Note that if a hypothetical population of turtles contained 100 adults with an equal sex ratio (50 females and 50 males), a 2% increase in overall population mortality means that one female per year is killed by a car. Because female turtles have extremely long reproductive lifespans, such a seemingly trivial increase in mortality can thus have catastrophic effects on turtle populations.

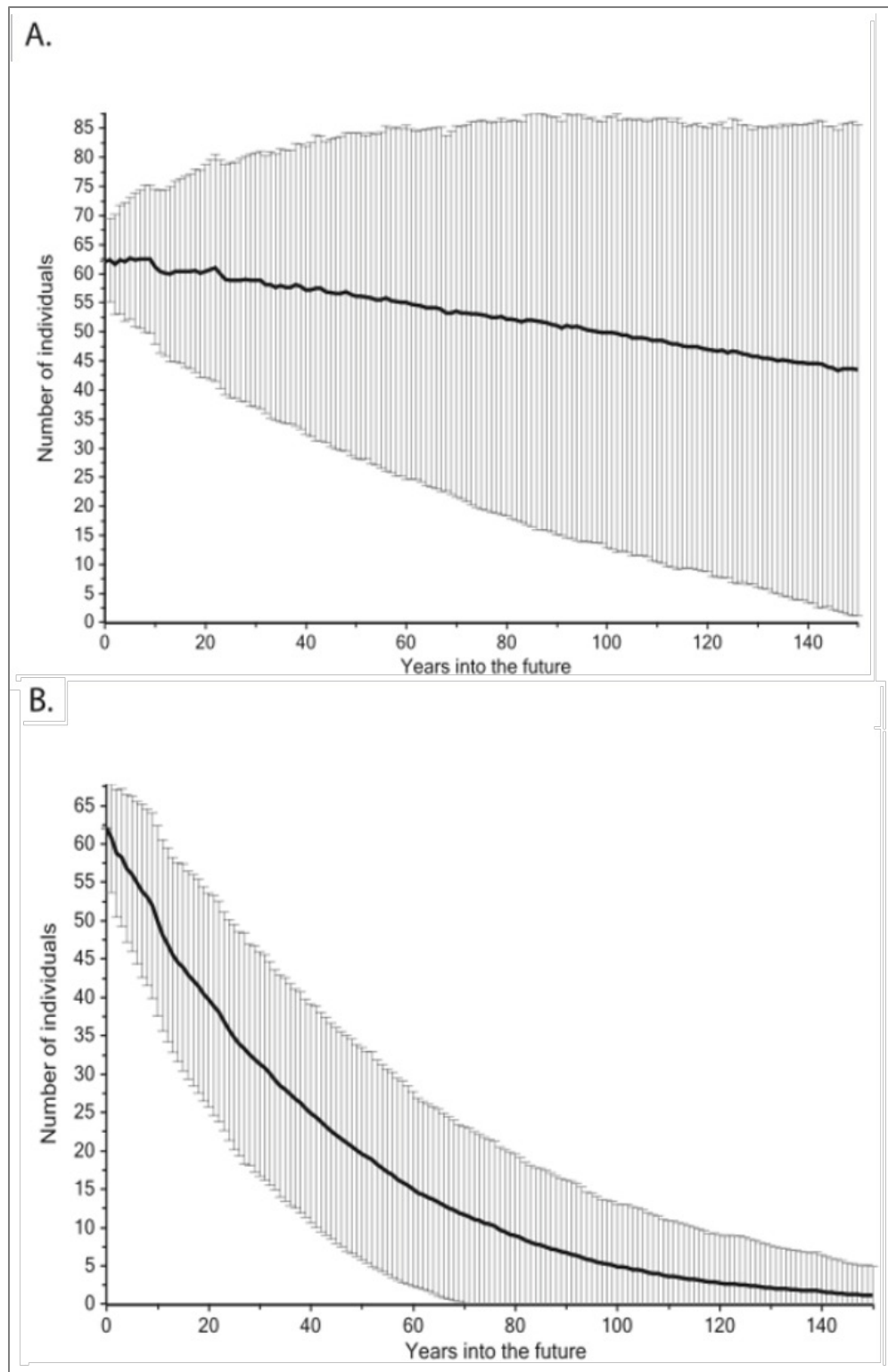


Figure 11. Population viability analysis for a hypothetical turtle population under no additive adult mortality and with a 2% added adult mortality from road kills. Top graph (a): no additive adult mortality; bottom graph (b) 2% added adult mortality from road kills.

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The high number of turtles (especially Mud Turtles and Box Turtles) found dead when the Loop Drive was open to motorized vehicles in both 2024 and previous years (Murasaki and Geyer 2023) thus presents a serious management issue. Although we lack detailed population data on any of these species, their basic life history patterns are similar to what has been used in previous population models. We consider that it is extremely likely that road mortality will result in lowered population viability of at least some of the species found at COLO. Additional data on population status and mortality rates via mark-recapture studies would be most useful in assessing the level of risk for these species.

Overview: Management Options for Reducing Road Mortality

Management options for reducing the impacts of road mortality on wildlife run the spectrum from low-cost and simple (e.g., road signs) to extremely expensive and complex (underground or above-ground road passages). Below, we review some of the most commonly used options to reduce wildlife mortality from vehicles and discuss which options are best suited for implementation at COLO. These are summarized in Table 6 and discussed in more detail below.

Table 6. Overview of management options for reducing the impacts of road mortality.

Option	Pros	Notes
Public outreach	Inexpensive; can be used in conjunction with road signs	Should be expanded to include reaching out to cycling groups and could include videos to be played at COLO Visitors Center and/or online; requires staff or volunteers
Road warning signs	Inexpensive; low impact	Effectiveness varies; need illustrative signs in proximity to hot spots; could lead to vandalism and/or poaching
Road patrols	Can be highly effective at known “hot spots”	Potential hazard to human escorts; requires extensive staffing and/or volunteers
Road passages	Can be highly effective	Extremely costly; requires high level of maintenance; species-specific requirements
Road closures	Highly effective	Major impact on visitors; mortality from bicycles not reduced

Recommendation I

- **Continue and expand public outreach programs and maintain turtle crossing signs during periods when turtles are active and the loop drive is open to vehicular traffic. In addition, inform cycling groups and riders that small turtles are vulnerable to collisions with bicycles.**
 - Efforts to educate and inform the public on the impacts of visitation on turtle populations are already in place at COLO and we recommend they be continued and expanded (Figures 12 and 13). Public outreach efforts have been largely in the form of bimonthly “Turtle Tents” and road warning signs. On a more casual basis, we also frequently interacted with visitors while conducting road surveys for turtles.



Figure 12. Current warning sign regarding turtle crossing on the Jamestown Island Loop Drive. We recommend these be replaced and supplemented by more realistic signs such as those shown on page 399 of Collinson et al. (2019).

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Figure 13. Photos of “Turtle Tent” events. These were held bimonthly during 2024 to inform the public about the impacts of road mortality caused by visitors.

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Realistic assessments of the success of road signs and public outreach in reducing road mortality have shown limited degrees of effectiveness (e.g., Collinson et al. 2019; Gunson and Schueler 2012). However, a recent experimental study (Collinson et al. 2019) found that success of signs in reducing road mortality can be enhanced by (a) using illustrative warning signs (i.e., those showing images of the wildlife in question), (b) placing signs close to “hot spots” (i.e., within 100 m from known crossing sites, and (c) making signs “novel,” so their message is not lost after many repeated

viewings. Signs that followed these principles were found to be effective for cheetahs and even snakes (Collinson et al. 2019) at a National Park in South Africa and were found to be especially effective for visitors who were new to the site, which may describe many of the visitors to COLO. Based on the “hot spots” observed along the Loop Drive (Figure 4), three additional sites for signage are proposed below (Figure 14).

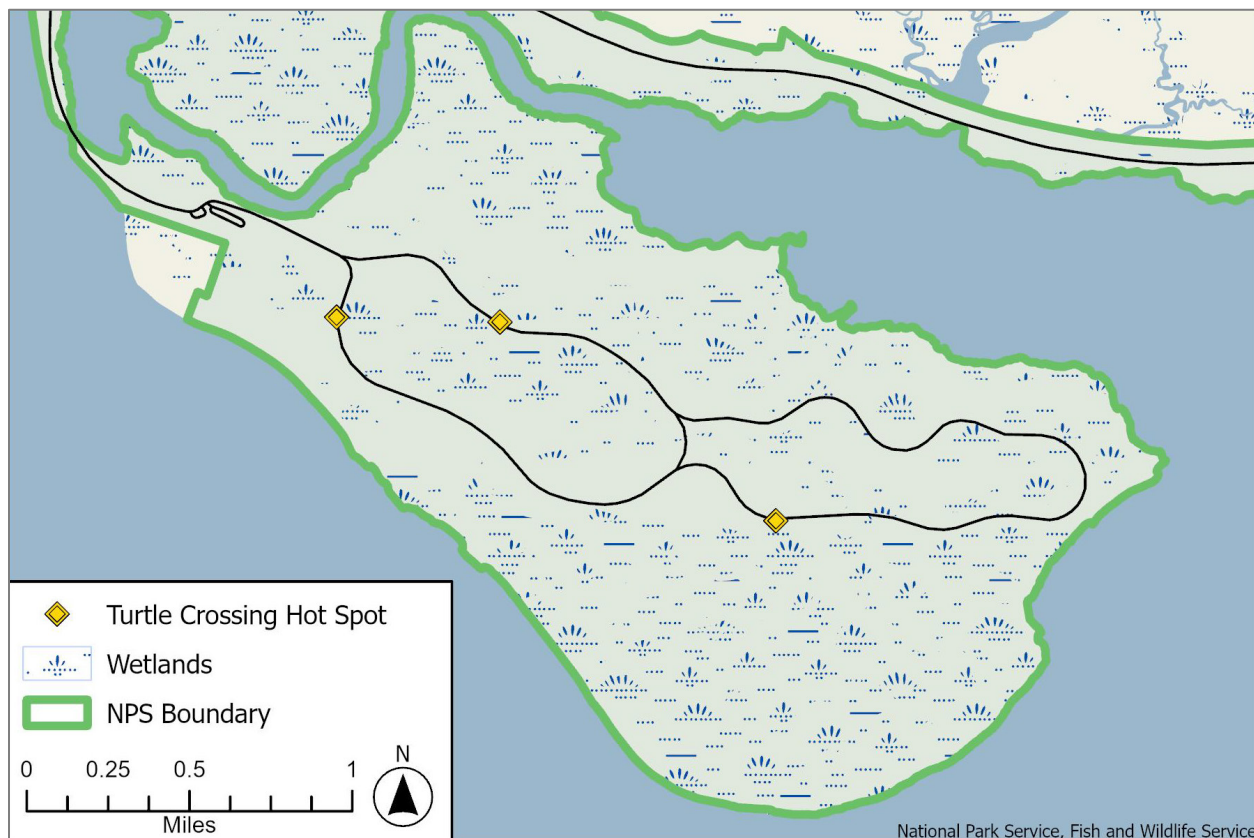


Figure 14. Proposed locations of additional road signs at COLO. Yellow diamonds designate proposed locations.

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In 2024, COLO personnel conducted “Turtle Tents” on 13 different days and made contact with 1,256 individuals, almost 100 contacts per day. Reactions to these events appeared to be largely positive. We recommend that COLO continue these public outreach programs and maintain and install additional road signs about turtle crossings. In order to keep the information conveyed by signs and public outreach programs most effective, we specifically suggest that both of these activities be confined to the months of May through October, when turtles are active and the Loop Drive is open to vehicular traffic. Signs can simply be covered (or removed, depending on NPS preference) during the months of November through March.

In addition to current outreach efforts, we recommend that a special effort be made to inform cycling groups and riders that hatchling turtles (which can be the size of a quarter) are especially vulnerable

to collisions with bicycles (Figures 6 and 8). It is likely that cyclists are unaware that small turtles are killed on the Loop Drive from bicycle collisions, mainly due to the inconspicuous size of the turtles involved.

Recommendation II

- **Road patrols for turtles are not recommended.**
 - Due to the fact that animals killed by vehicular traffic often remain visible to the public, many concerned citizens want to assist small animals such as turtles and amphibians in crossing roads. In many places, citizens have developed organized “road patrols” at known hot spots where large numbers of animals are observed. This is done commonly in Europe for amphibians (Froglife, n.d.) and for Diamondback Terrapins in the United States (Wetlands Institute, n.d.). Whether or not such road patrols result in enhanced population viability has not been documented, but these patrols are popular due to the desire of concerned citizens to “take action” to directly aid wildlife.
 - We do not recommend road patrols at COLO for two reasons. First, the narrow width of the Loop Drive would put staff/volunteers at risk of getting injured by vehicles. Even with appropriate fluorescent clothing, we suggest that the likelihood of a potentially hazardous situation outweighs the potential benefit to the local turtle species. Secondly, although there are a few relatively narrow “hot spots” where turtles frequently cross the road, the actual occurrence of road crossings over an eight-hour period is fairly low. Thus, it is likely that the direct benefit to the turtles would be limited, whereas the hazard to the humans would remain. For these reasons we do not feel that road patrols are an effective mechanism for reducing road mortality of turtle species at COLO.

Recommendation III

- **Wildlife passages are not recommended as a means of reducing road mortality.**
 - Wildlife passages are a widely used mechanism to reduce the impacts of road mortality on species at risk of vehicle collisions. These passages either take the form of tunnels that pass under roads or as overpasses above the road. When coupled with fences that run parallel to the road surface, wildlife passages allow animals to pass either under the road or above it, without encountering road traffic. Wildlife passages have been used, with varying degrees of success, for a variety of wildlife species, including turtles (Crawford et al. 2017; Dodd et al. 2004; Sievert et al. 2015; Woltz et al. 2008; Yorks et al. 2025). Actual effectiveness is determined by a variety of factors, including passage length and width, nature of the barriers used to guide species to passages, and the behavioral characteristics of the target species (see above references for review).

- Major limitations of wildlife passages include initial construction costs, on-going maintenance, and lack of effectiveness if barriers are not carefully maintained. In North Carolina, the cost of construction and placement of a single underground wildlife passage in 2010 was about \$129,000 (Smith 2011) and would be higher now due to inflation. In addition, the “guide fences” that run parallel to the road to channel turtles into passages require frequent maintenance or risk becoming ineffective (Baxter-Gilbert et al. 2015). It is also important to consider that each turtle species has specific requirements in terms of length of passage, light penetration, and substrate; this means what works for a terrestrial species such as Box Turtles may not work for an aquatic species such as Mud Turtles. Finally, the narrow shoulders of the Loop Drive provide limited space for installation of guide fences without compromising visitor safety. For these reasons, we do not recommend installation of wildlife passages as a means of reducing turtle mortality at COLO.

Recommendation IV

- **Seasonal closures of the loop drive to motor vehicles are recommended as the main means of reducing road mortality.**
 - Although placed last, this is our primary recommendation for reducing turtle mortality on the Loop Drive. As noted above, the large majority of all recorded road mortalities were attributed to automobiles (Figures 6 and 8). Closing the Loop Drive to all motor vehicles from *at least* 15 March to 15 June would substantially reduce turtle mortalities while still allowing visitors to drive the road during most months of the year. We would note, however, that even this reduced level of mortality might still result in a reduction of turtle population viability, and extending the period of road closures later in the summer season would be preferable. However, we recognize that high levels of visitation in mid-summer may make this untenable. We suggest more research is needed to strike an optimal balance between conservation of turtles and the public.
 - It should also be noted that we have some evidence of turtles killed by motor vehicles even when the Loop Drive was closed to visitor vehicles. These mortalities are presumably from NPS staff doing necessary work along the road. We recommend that NPS staff receive additional training regarding avoiding turtles at the onset of turtle activity in the spring each year, with 15 March being a good target date. Training materials could include images of turtle hatchlings (with everyday items included for scale) and some of COLO’s smaller species (e.g., Mud Turtles and Box Turtles) so that NPS staff are equipped with the proper turtle search images.

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Appendix: Information on Non-Target Species (Lizards, Snakes, and Amphibians) Found During Road Surveys in 2024.

Because of time and permit limitations, not all of the data collected for turtles are available for these species. Thus, we refrain from making interpretations of these data and simply provide the basic information for use in future surveys and studies (Table 7, Figure 15).

Table 7. List of non-target species found during road surveys.

Group	Species	Number Live (%)	Number Dead (%)
Snakes	Worm Snake	4 (57.1%)	3 (42.9%)
	Eastern Black Racer	1 (14.3%)	6 (85.7%)
	Ring-Necked Snake	1 (100%)	0 (0.0%)
	Northern Water Snake	2 (100%)	0 (0.0%)
	Rough Green Snake	7 (12.7%)	48 (87.3%)
	Eastern Rat Snake	2 (66.7%)	1 (33.3%)
	Dekay's Brown Snake	0 (0.0%)	1 (100.0%)
	Ribbon Snake	0 (0.0%)	4 (100%)
	Common Garter Snake	1 (50.0%)	1 (50.0%)
Lizards	Little Brown Skink	1 (100%)	0 (0.0%)
	Unidentified Skink	31 (53.4%)	27 (46.6%)
Amphibians	Coastal Plains Leopard Frog	3 (75.0%)	1 (25.0%)
	Eastern Newt	4 (80.0%)	2 (20.0%)

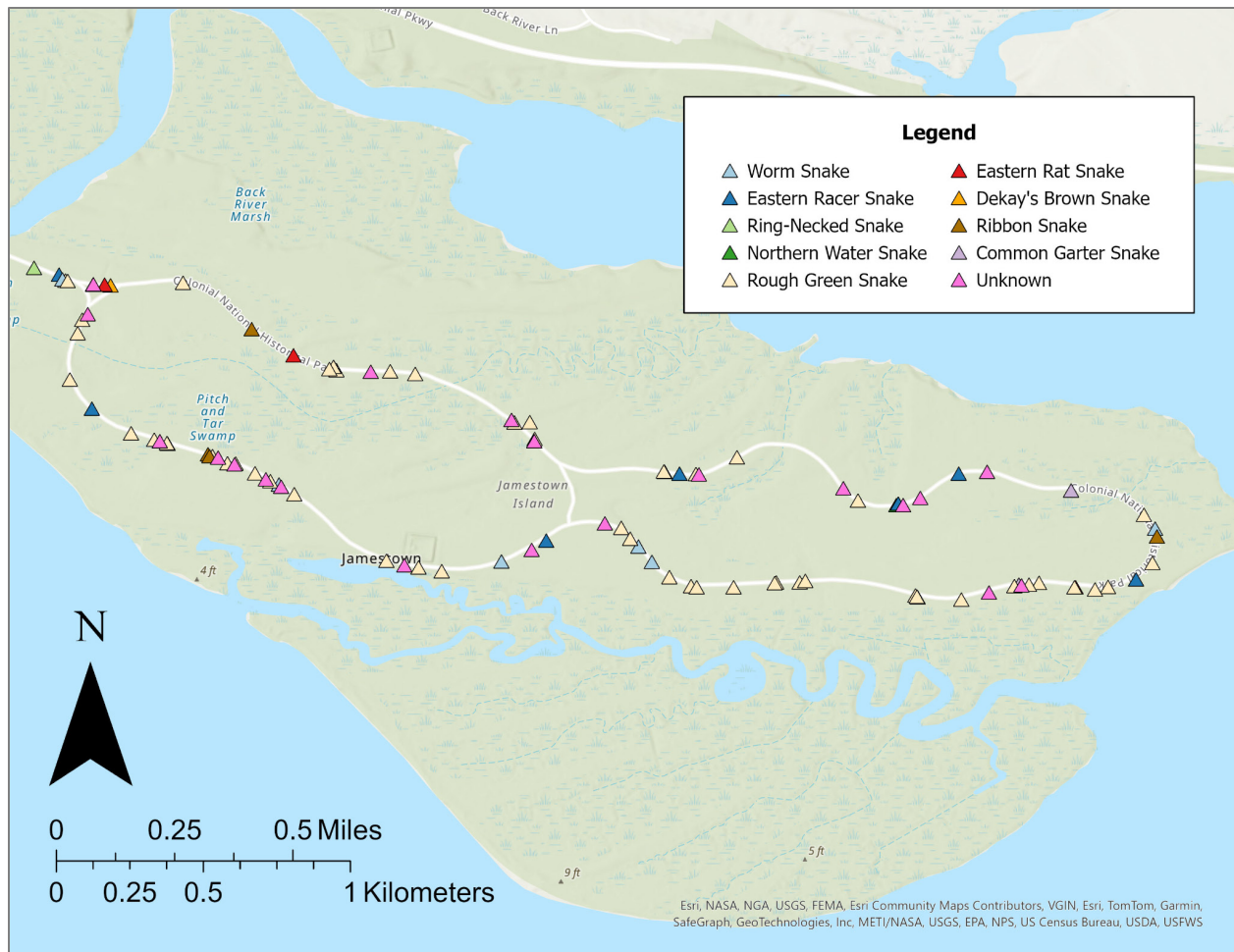


Figure 15. Spatial distribution of most common non-target species (snakes) found live and dead during road surveys.

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