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Testing a road mortality risk model to prioritize and design turtle eco-passages at wetland-road crossings in New Hampshire, USA

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Abstract

Intersections of roads and wildlife movement pathways can lead to wildlife road mortality, resulting in population-level impacts. Wetland-road crossings are vulnerable locations for freshwater turtles that conduct inter- and intra-wetland movements during their active period to mate, forage, and nest. Identifying turtle road mortality hot spots may enable managers to implement mitigation efforts, such as locating and designing eco-passages. We assessed a predictive model for turtle road mortality risk by observing eighteen wetland-road crossing sites ranked by the model. For eleven weeks during the turtles' active period (May-July), we surveyed sites for road mortality and used cameras to observe movements across the road of four species: Blanding's turtles (*Emydoidea blandingii*), spotted turtles (*Clemmys gutta*), snapping turtles (*Chelydra serpentina*), and eastern painted turtles (*Chrysemys picta*). We demonstrate that the predictive model identifies sites with higher rates of turtle road mortality ($p < 0.01$) and that road accessibility is a significant factor in road mortality rates ($p = 0.02$). Fewer turtles were observed on the road above wetland-road crossing structures (i.e., culverts) with larger openness ratios ($p = 0.06$). These findings may inform the design of road mortality mitigation structures, such as eco-passages, fencing, guide walls, and driver-awareness mechanisms. We also provide a conceptual engineering design to demonstrate how to reduce road accessibility and expand openness ratios to mitigate turtle mortality in a case study of one of our highest-risk sites.

Introduction

The intersection of wildlife habitat and the human-built environment has created many vulnerabilities for wildlife, including the lethal consequences of road infrastructure. Habitat connectivity is a landscape feature critical for species richness, wildlife movement, and population health (Cosgrove et al. 2018, Thiele et al. 2018). When individuals can move across a landscape, genetic flow increases and genetic isolation decreases (Christie and Knowles 2015). When migratory routes are cut off, populations are weakened, biodiversity can decline (Becker et al. 2007, Iwamura et al. 2013), and resources are more difficult to access. Roads are a common form of habitat fragmentation that disrupt migration routes for both terrestrial and aquatic wildlife (Keller and Largiadèr 2003, Beebee 2013, Cullen et al. 2016). This disturbance is detrimental for two overarching reasons: individuals can be barred from crossing the road, which harms populations and communities through a lack of genetic flow, and individuals can be killed when they attempt to cross, which creates population-scale vulnerabilities as these mortalities remove reproductive individuals from the mating pool (Ashley and Robinson 1996, Beaudry et al. 2008, 2010a). Additionally, barriers to connectivity degrade the ecosystems the wildlife inhabit as flows of resources, materials, nutrients, and energy across the landscape are restricted (Becker et al. 2007, Iwamura et al. 2013, Christie and Knowles 2015).

Among species impacted by road mortality, amphibians and reptiles face severe threats of population reduction and habitat fragmentation. Vehicle collisions are the leading cause of death for freshwater turtles, and conservation efforts should be taken to reduce turtle road mortality (Gibbs and Shriver 2002, Congdon et al. 2011, Walston et al. 2015). In New Hampshire, four semi-aquatic freshwater turtle

species are particularly vulnerable to road mortality: the eastern painted turtle (*Chrysemys picta;* common), snapping turtle (*Chelydra serpentina;* common), spotted turtle (*Clemmys gutta;* threatened), and Blanding's turtle (*Emydoidea blandingii;* endangered). The reproductive females of these species nest in sandy material, often found in anthropogenically disturbed areas such as roadsides (Beaudry et al. 2010b). Additionally, gravid spotted and Blanding's turtles undergo long pre-nesting migrations between wetlands and into upland areas, traversing up to 6.7 km and 1.6 km, respectively. Within a season, these females are likely to cross roads more than once (Joyal et al. 2001, Walston et al. 2015). Experts agree that addressing adult road mortality is a top-priority conservation effort for these threatened and endangered species (Meck et al. 2023).

New Hampshire hosts nearly 40% of the Northeastern United States' Blanding's turtle population, whose distribution range encompasses most of the southeastern region and overlaps with the state's four highest populated counties and three counties with the greatest population increase from 2010–2020 (New Hampshire Fish and Game 2015, Economic and Labor Market Information Bureau 2023). Human density and population growth are accompanied by increased urban development, which greatly reduces the adult survival rates of Blanding's turtles in a manner that predicts population-level quasi-extinction (Auge et al. 2023). Broad-scale efforts to protect Blanding's and other semi-aquatic turtles from road mortality through habitat protection may be particularly effective, especially for species that utilize a habitat complex through the active season. Unfortunately, this approach is unlikely to be implemented properly in areas where roads have already been built (Joyal et al. 2001, Congdon et al. 2011, Auge et al. 2023). Alternatively, addressing mitigation efforts on a road-segment scale by designing and implementing eco-passages can be useful in reducing road mortality and improving crossing success (Beaudry et al. 2008).

Many wildlife species have been observed using eco-passage structures, such as bridges, tunnels, and culverts (Gloyne and Clevenger 2001, Gordon and Anderson 2003, Colley et al. 2017, Dillon et al. 2020), which are especially efficient when paired with adequate barriers to road access (Cunnington et al. 2014, Baxter-Gilbert et al. 2015, Markle et al. 2017). Several species of freshwater turtles have been documented using eco-passages built under roads (Woltz et al. 2008, Taylor et al. 2014, Heaven et al. 2019, Read and Thompson 2021). In New Hampshire, most wetland-crossing structures were designed only for hydraulic capacity without considering wildlife passage requirements. However, modifications to these structures can restore habitat connectivity and eliminate the need for turtles and other semi-aquatic animals to cross over the road where they face potential road mortality. Identifying which road segments and culverts to upgrade from hydraulic-only to wildlife eco-passage capacity is critical when leveraging funding and resources to yield the greatest benefit to turtle populations.

Predictive models identify roadkill hotspots for a variety of wildlife species, including freshwater turtles, for which roadkill is often clustered at road-wetland crossings, typically by focusing on the density of cars on a given road (Ashley and Robinson 1996, Litvitius and Tash 2008). In New Hampshire, motivated by a desire to reduce deaths of adult Blanding's turtles, an interdisciplinary research group created a predictive model that did not include car density and instead examined wetland road crossing structural

characteristics and localized road accessibility (Ballestero et al. 2023). Assessments of this model followed, with an expectation that there would be more turtle mortality at sites ranked higher risk by the predictive model. Other site characteristics were tested for a correlation with turtle road mortality and turtle presence on the road, including road and wetland-crossing structure characteristics such as structure openness ratio and road curve. The identification of models and site characteristics that serve as predictors of turtle road mortality or turtle occurrence on roads can be used to prioritize design and locate effective eco-passages for turtles, thereby reducing road mortality and conserving threatened populations.

Methods

Site Selection and Model Development

The New Hampshire Stream Crossing Initiative (NHSCI) maintains a database of all hydraulic crossing structures across the state. The wetland-crossing structures in this database were overlain with a map of Blanding's turtle priority conservation areas provided by New Hampshire Fish and Game, thus identifying 270 wetland-crossing sites of interest. These sites are located across Rockingham and Strafford counties in the southeast of New Hampshire, which have a temperate climate and landscapes with a mixture of (sub)urban development, forested habitat, freshwater wetlands, and agrarian landscapes. Most wetlands consisted of palustrine habitats with emergent or scrub-shrub vegetation and a smaller percentage with floating aquatic and overstory/forested vegetation. A few sites resembled riverine habitats directly upstream or downstream of the wetland crossing while transitioning to palustrine habitats further from the structure.

All 270 wetland crossing sites were run through the turtle road mortality risk model (Fig. 1) developed by Ballestero and colleagues in 2023. The model was designed as a flowchart that assesses each wetland crossing site by three characteristics: culvert passability (yes or no), road accessibility score, and line of sight (full, partial, or none). The model has three main outputs for each site: a risk classification (High Risk or Low Risk), a road accessibility score, and a ranking of risk relative to other assessed sites (Overall Risk). Eighteen sites, nine High Risk and nine Low Risk, were selected for further surveying as part of this field study to determine the accuracy of the model at predicting turtle road mortality risk.

Data collection

Wetland crossing site data were harvested from the NHSCI database and a supplement wetland crossing turtle survey (Ballestero et al. 2023, Appendix A) for the eighteen field sites including structure openness ratio (inlet opening area (m^2)/length of structure (m)), line of sight (full, partial, or none), inlet width (m), embankment slope, road length (m), embankment nesting habitat presence, structure blockage, screen presence, outlet grade, and riparian vegetation continuity status. Additional road-related data were collected from the New Hampshire Department of Transportation (DOT) Roads dataset hosted on the New Hampshire Granit database, including AADT (annual average daily traffic), road width

(m), and a shapefile to calculate a road-curve proxy (road length within 130m buffer around each wetland crossing site, calculated in QGIS v. 3.28). The speed limit at each site was collected from the nearest speed limit sign during field visits in 2023. AADT was reported as a magnitude larger than other characteristics and was scaled around 0 with a standard deviation of 1 for modeling.

Field data were collected between May 6 and July 19, 2023, during peak turtle migration and nesting season in the Northeast. Weekly road surveys were conducted at all sites using a protocol modified from Baker (2022) by walking the length of the wetland on both sides of the road, during which time the road and the embankments were visually scanned for evidence of turtle roadkill. Only complete carcasses were counted to avoid artificially inflating the number of turtle roadkill based on shell fragments. If roadkill was found, a photo would be taken of the carcass as it lay, its species and age class would be identified, and the carcass would be removed to avoid double-counting.

Two cameras (Browning Strikeforce Apex HD or Bushnell Trophy Cam HD) were placed at each site and affixed to nearby trees or stakes. One 'road-facing' camera was set up with a view of the road above the culvert. The road-facing camera recorded images at a fixed

time interval from dawn to dusk. For the first three weeks, the time interval was 5 minutes, which was then reduced to the next smallest interval of 2 minutes for the duration of the 10-week season to improve capture rates. The second camera was set up with a view of the culvert opening, and 'culvert-facing' images were taken with motion capture. Each week, all SD cards were downloaded, batteries were checked, and pictures were briefly reviewed to determine if the camera needed repositioning. Vegetation was removed from the camera vicinity sparingly. A single reviewer (L. White) analyzed the photos. Photos captured using Browning Timelapse were viewed using VLC viewer on a PC, and non-Browning Timelapse photos were viewed using the University of Calgary Timelapse software on a PC or gallery view on a Mac. Each turtle sighting was categorized as one of eight event types: Known Dead, Known Survival and Crossing Success, Assumed Survival, Known Survival and Turns Back, Embankment Only, Known in Culvert, In Water Around Culvert, or On Culvert Embankment. Turtle species were identified to the best of the researcher's ability.

Analyses

Negative binomial regressions were conducted to test the turtle road mortality risk model performance and identify predictors of turtle road mortality and turtle road occurrence. This analytical model was chosen based on the characteristics of the data as follows. Two main response variables were the focus of this analysis: the total turtle roadkill count collected from the road surveys, and the total turtle road camera observation count (turtle events) collected from the cameras and photo analysis. Both response variables failed to meet assumptions of normality and homoskedasticity, even with square root and log(x) transformations. The predictors were grouped for analysis into three groups: 1) model performance, 2) road characteristics, and 3) other site characteristics. Model performance variables (risk classification, road access score, and overall rank) were analyzed to assess the accuracy of the model. Road characteristics (AADT, road curve, road width, and speed limit) and other site characteristics

(structure openness ratio) were tested for correlations with turtle roadkill and turtle on-road events. Both Poisson and negative binomial regressions were explored. Frequentist analyses demonstrated that negative binomial models consistently fit the data better than Poisson models. All negative binomial regressions were run in R with the MASS package (ver. 7.3–60), and regressions were visualized with 95% confidence intervals using *ggpredict*. Backward stepwise regressions were used to assess the road characteristics' correlations with the response variables. Model fit and ranking were evaluated using Akaike's Information Criterion (AIC Δ_i), calculated using maximum likelihood estimates, where $\Delta_i >= 2$ indicates a substantial difference in the fit of the model (Burnham and Anderson 2002). Significance was determined using $\alpha = 0.05$. All data analyses were conducted in R (version 4.3.2).

Results

Four turtle species (*Emydoidea blandingii, Clemmys guttata, Chrysemys picta, and Chelydra serpentina*) comprised a total of 183 turtle observations during the 2023 field season between the three monitoring methods: road surveys, road-facing cameras, and culvert-facing cameras. Sixty-nine roadkills were discovered via road surveys, and two of the eighteen wetland-crossing sites accounted for over 50% of the roadkills documented using this method. Spotted and Blanding's turtles, two of New Hampshire's listed threatened and endangered species, respectively, were discovered only at sites with other common turtle species roadkill and consisted of 13% of all documented roadkills (10 individuals). The road-facing cameras captured 78 turtle events: 10% depicting mortality via vehicle collision (Known Dead), 32% Known Survival and Crossing Success, 49% Assumed Survival, and 13% Turned Back and Embankment Only. Human interventions, defined as instances where motorists or cyclists stopped and exited their vehicles to guide turtles across the road, accounted for 22% of all complete turtle crossings and 17% of all turtle observations documented with the road cameras. There were too few observations of turtles in the culverts, such that the data collected were insufficient to draw conclusions about site characteristics and culvert passage success, and were not included in further analyses.

The distribution of turtle road mortality and turtle event observations throughout the field season (May 6 to July 19, 2023) displays disjoint peaks across the two methods of data collection: roadkill survey and road cameras. Roadkill observations via road surveys peaked the week of July 1-July 7, while road-facing cameras observed the most turtles from June 10-June 16. The road surveys displayed steady weekly rates of roadkill, while the camera method produced wide-ranging counts per week.

Model performance

The turtle road mortality model reflected the relative occurrence of turtle road mortality documented via road surveys across various sites. Sites classified as High Risk had significantly more roadkill present during the 2023 field season road surveys than sites classified as Low Risk ($p < 0.01$; Fig. 2a). An average of 6.4 turtle roadkills were discovered per High Risk site over the eleven-week season, more than 5x the Low Risk average of 1.2 turtles per site during the field season. Based on the model structure, sites are classified as High/Low risk by dividing the road accessibility score into binary groups based on

the median score. The road accessibility score itself, ranging in this study from 10 to 21, also demonstrates a positive correlation with turtle road mortality observations ($p = 0.02$; Fig. 2b). When applying the site variables that comprise the road accessibility score (embankment slope, nesting habitat, road length, and riparian continuity to a backward stepwise multiple regression, no logical, significant trends were identified. The turtle road mortality risk model also ranked the 18 sites relative to each other, creating the third model output "Overall Rank"; a rank assigned to each site where least risky = 1 and most risky = 15 (some sites tied). This overall relative rank value positively correlates with the number of roadkill observed at each site ($p = 0.04$; Fig. 2c).

Road characteristics

Apart from testing the appropriateness of the turtle road mortality risk model to identify sites of high risk, other site characteristics were correlated with turtle roadkill counts (from roadkill surveys) and turtle on-road events (from the road-facing camera data). *Total roadkill ~ AADT + road curve* demonstrated the best model fit for the roadkill survey counts (AIC 78.8; $\Delta_{i=}0$), where AADT had a significant positive relationship with road mortality ($p < 0.01$), and the road curve indicated a negative but non-significant relationship ($p = 0.18$; Fig. 3). AADT alone had a significantly positive relationship with turtle roadkill, and the model fit is not meaningfully different than AADT and road curve combined ($p < 0.01$, AIC 79.3; $\Delta_{i=}0.5$). AADT varied from 90 to 8779 cars/day, and Kruskal-Wallis tests show a near-significant difference between the mean AADT of sites where motorists intervened to help a turtle cross the road, which is nearly 5 times less than at sites where no human intervention occurred ($p = 0.07$). *Turtle on-road events ~ road width* model demonstrated the optional model fit of road characteristics after a backward step-wise regression for the turtle event counts from the road-facing camera data (AIC 90.9; $\Delta_{i=}1.3$), where road width had a negative but non-significant relationship to the total number of turtles observed on the road per site ($p = 0.11$).

Site characteristics

Structure openness ratio was not included in the model, though variables such as line of sight, structure blockage, and inlet width were, which similarly assess the amount of space inside a crossing structure. Roadkill data does not have a significant relationship with the openness ratio ($p > 0.05$; AIC 92.8; $\Delta_{i=}14$). However, turtle on-road events have a near-significant negative relationship with openness ratio ($p = 0.06$; AIC 89.6; $\Delta_{i=}0$; Fig. 4), demonstrating that more turtle events were observed on roads above structures with smaller openness ratios.

Discussion

Model assessment: Monitoring of freshwater turtle activity and mortality at wetland crossing locations in southeast New Hampshire supported the road mortality risk model developed by Ballestero et al. (2023). By both model outputs, High/Low risk classification and Overall Rank, the model adequately identified, on average, which wetland crossing sites have relatively higher rates of road mortality. The road accessibility metric that the model calculated to sort the sites into these outputs also predicted

road mortality rates. All three model measurements demonstrated significant relationships with total roadkill counts. This model is not alone in its goal to identify roadkill hotspots: predictive models have been used to identify wildlife-vehicle collision locations and to mitigate road mortality for many species (Malo et al. 2004), including freshwater turtles (Litvaitis and Tash 2008, Langen et al. 2012). However, these past models have primarily relied on AADT measurements, not wetland crossing structures or other site characteristics. Litvaitis and Tash (2008) conclude that species-specific monitoring using the Hels and Buchwald (2001) equation compares the number of vehicles per minute, the kill zone width (ratio of tire width to animal size), and the average velocity of the species of interest. If using species-specific monitoring (comparing roadkill rates amongst only one type of species), the only variable that changes between sites is the AADT. With this equation, Litvaitis and Tash (2008) calculated that Blanding's turtles have a > 40% chance of being struck by a vehicle in the majority of southeastern New Hampshire.

We concur that AADT has a significant relationship with turtle road mortality totals, but this value is not included in our model. Instead, our model was built on three overarching elements of a wetland crossing site: whether the structure is passable or not, how easily the road is accessible from the water, and the clarity of a line of sight through the structure. Our model indicated which wetland crossing sites are high or low risk using a measure of road accessibility, which is a unique modeling approach and provides guidance to address turtle road mortality. Reducing road access at wetland crossing sites could decrease turtle road mortality; this may include interrupting riparian continuity by installing rip-rap along embankments or by building turtle-proof fencing. Previous research has shown which fence elements are important to restricting turtle movement, including extending the fence the entire length of the wetland adjacent to the road, curving the fence ends back towards the wetlands (Aresco 2005, Markle et al. 2017, Heaven et al. 2019), embedding the fence up to 15cm into the ground, and adding a 45° lip angled back towards the wetland to prevent animals going over or under the fence (Read and Thompson 2021). Regular inspection and maintenance are required of these fences to ensure continued structural integrity and function (Baxter-Gilbert et al. 2015, Huijser et al. 2017).

Site characteristics

While the turtle roadkill data demonstrated that the road mortality model meets its goal of identifying high-risk sites, analyses also found that AADT is a measure by which locations with high turtle road mortality can be identified. Pairing AADT data with model outputs may help prioritize wetland crossing sites for restoration. AADT is not just relevant to turtle death, but to human safety. Although not statistically significant, we found that sites with fewer cars/day had greater numbers of motorists stopping and even exiting their vehicles to help a turtle cross the road.

We also found that structures with smaller openness ratios correlated with greater numbers of turtles observed on the road. This suggests that when eco-passages are constructed or retrofitted to encourage wildlife crossings, it is beneficial to increase the openness ratio to improve line of sight and light conditions. The openness ratio is a function of the inlet surface area and the length of the structure.

Since the length of the structure is rarely able to be shortened, eco-passage designs should increase the height and/or width of the opening. Regional entities suggest an openness ratio > 0.25m to encourage wildlife passage and meet stream crossing standards (New Hampshire Stream Crossing Guidelines 2009, Massachusetts Division of Ecological Restoration 2018). Our data suggest that turtle road use decreased at sites with openness ratios greater than 0.4m (Fig. 4). Larger inlet openings may increase the amount of natural light that enters the structure, which may be favorable for wildlife crossings. Blanding's and painted turtles completed more crossings in brightly lit structures than in structures with dim or no light (Sievert and Yorks 2015). Taylor et al. (2014) found that skylights in their crossing structures warmed stones on which turtles were observed basking.

Additionally, community involvement emerged as a theme for success: this study found that of successful turtle crossings, 22% were facilitated by motorists, though these actions were more likely on low-traffic roads. During the field season, passersby frequently paused to talk to the survey team, expressing knowledge and concern about the turtles, and reporting instances where they aided turtles across the roads or erected turtle crossing signs. The survey team also found temporary turtle-crossing signs erected at multiple sites to increase awareness of turtle vulnerability. Encouraging community participation and buy-in could increase public awareness of road mortality risk and inspire positive action (Santori et al. 2021). When possible, incorporating community involvement and volunteerism into management projects could improve community support and project success.

Study limitations

This study was an exploratory investigation into wetland crossing characteristics to build and assess a new model and inform management efforts to reduce turtle road mortality. The research was limited in spatial and temporal scope, using data from 270 crossings to develop the model and selecting 18 sites to observe one season of turtle crossing and mortality. Thus, the distribution of site characteristics was limited. Sites were chosen based on their location within Blanding's conservation priority areas and to provide a somewhat even distribution of model risk classification.

The research effort was designed with a mixed-methods approach to enhance understanding of wildlife movement (Pagnucco et al. 2011, Buxton et al. 2018, Read and Thompson 2021). Though cameras have become an oft-used method for monitoring eco-passage use by turtles, some projects have had varying degrees of success (Taylor et al. 2014, Baxter-Gilbert et al. 2015, McCann 2017, Markle et al. 2017, Read and Thompson 2021, Baker 2022), and the culvert-facing cameras captured insufficient data. Future investigations into turtle road mortality across sites with greater ranges of site characteristics may identify additional correlations, but the results here support a simple model to identify high-risk crossings that can be prioritized for improved management.

Wetland Crossing Design

Key management implications to reduce turtle road mortality based on field data gathered during this study include the following: 1) Reduce road accessibility, 2) increase the opening of eco-passage

structures, 3) strategically restrict AADT (at least during high turtle movement periods), and 4) include community involvement in road morality mitigation projects. These strategies were used in a conceptual design of an anonymized site classified as high risk by the road mortality model (Fig. 5). In this design, the turtle road accessibility was restricted by installing a turtle-proof fence that met the previously listed recommendations, including curving the ends back towards the wetland and spanning the entire length of the wetland. In this scenario, a new wildlife passage was suggested to establish an openness ratio > 0.25 m^2, which would be met with a 3.05 m x 1.2 m box culvert. Increasing the height of the opening at the existing culvert was impractical due to the existing small cover depth of the road — to increase the road cover here would require raising the road for a long distance on either side of the crossing. It is improbable that AADT would be restricted via road closures during peak migration periods, but encouraging a reduction in vehicle speed may lessen vehicle-animal collisions, so turtle crossing signs and speed reduction signs facing both directions were indicated on the plans.

Conclusions

Our field research and ground-truthing effort demonstrates that the road mortality risk model derived from assessments of road accessibility and wetland-road crossing structure characteristics can function as a tool to manage turtle road mortality by identifying and prioritizing high-risk sites. Additionally, results suggest eco-passages be designed to limit road accessibility while increasing the structure opening. The findings from the roadkill and road activity monitoring efforts should be acted on with urgency to avoid population quasi-extinction for Blanding's and possibly spotted turtles. Gathering data for long-term studies, while a worthwhile scientific endeavor, will not reduce road mortality on its own; action must be taken to mitigate the turtle mortality rate. Deadly road-crossing locations in New Hampshire have been identified through the 2023 monitoring process, and eco-passages and fencing should be designed, funded, and constructed, beginning with the highest risk sites, to protect local turtle populations. Implementation of an expanded replacement culvert is underway at one of our high-priority sites.

Declarations

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All authors contributed to the conception and design of the study. Data collection, analysis, and the first draft of the manuscript were performed and written by Lauren White. Conceptual engineering plans were designed by Lauren White and Thomas Ballestero. All authors commented on the manuscript. All authors read and approved the final manuscript.

Datasets generated by this study are available upon reasonable request from the corresponding author.

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Figures

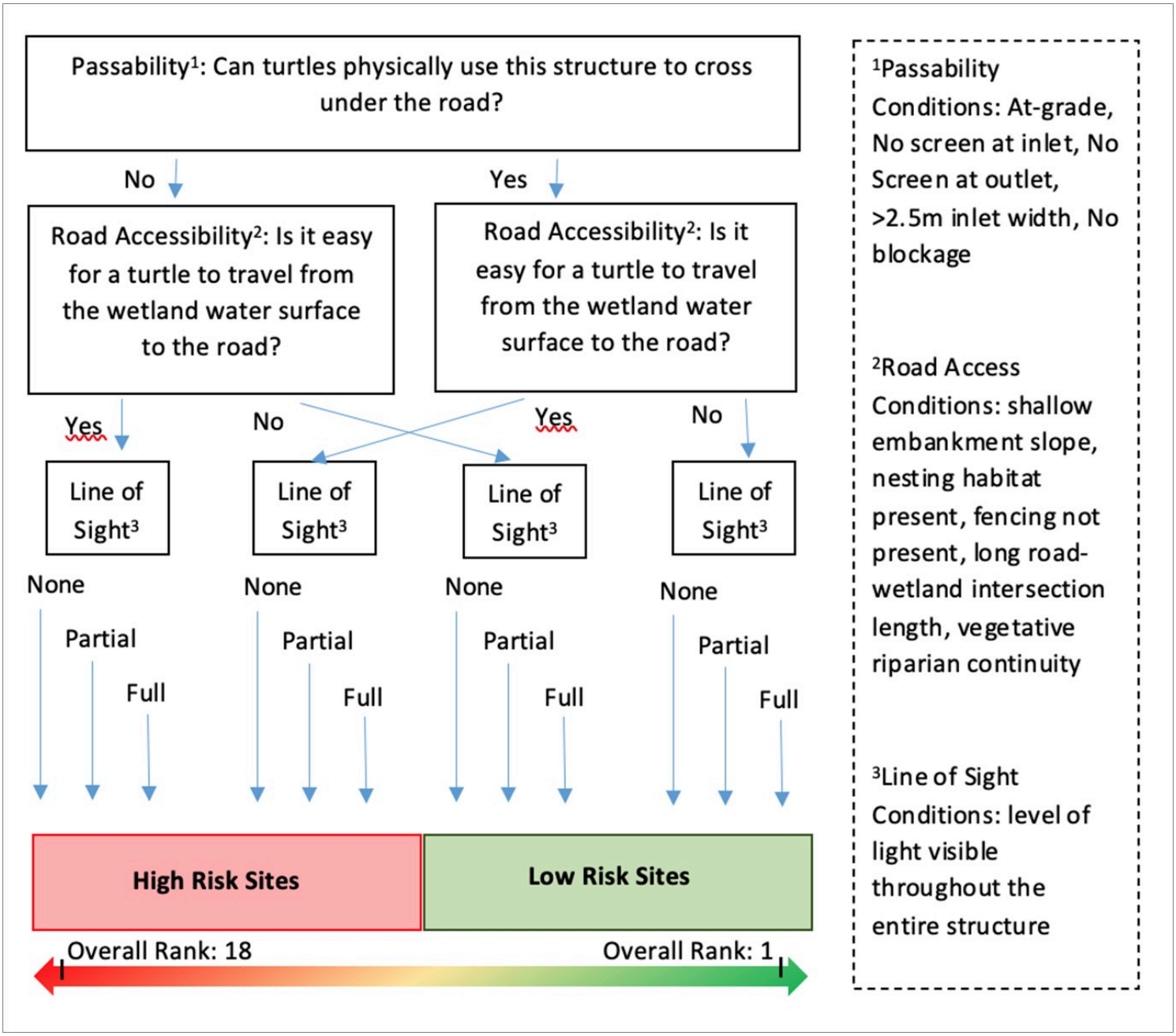


Figure 1

This turtle road mortality risk model was informed by a literature review on turtle eco-passage and landscape use, and was built on the following statements: If any of the conditions for structure passability[1] are not met, then the hydraulic structure is deemed physically impassable and the site has a higher risk of turtles crossing the road. If the site's road accessibility score[2] is higher than the median score (calculated with points assigned for each road access condition, see Ballestero et al. 2023), the site has a higher risk of turtle road mortality due to the relative ease in accessing the road from the water surface. The visible line of sight[3] through the structure is described as either full, partial, or none: with less light, there is a decreased chance that a turtle will use the structure as a passage point and instead cross over the road. Figure adapted from Ballestero et al. (2023).

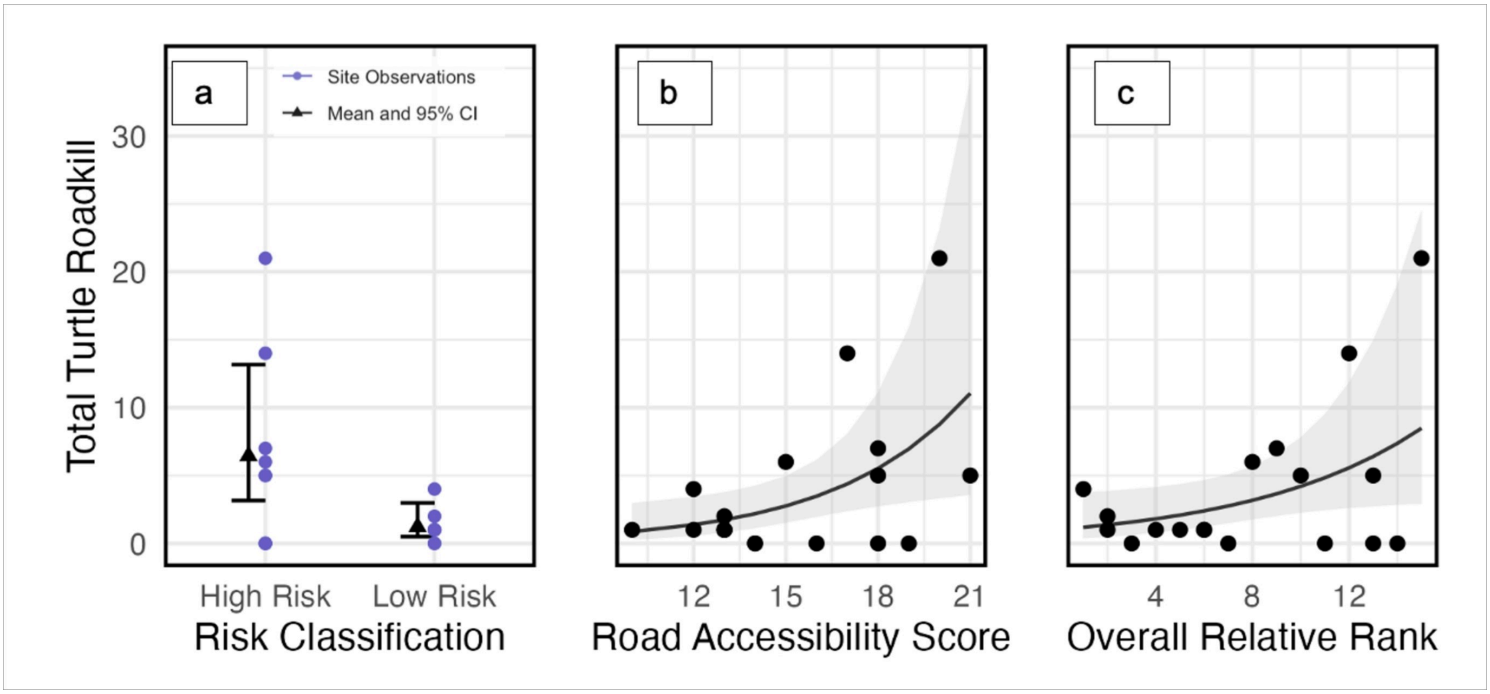


Figure 2

The three turtle road mortality risk model outputs all have significant correlations to observed turtle road mortality. (a) Sites classified as High Risk have greater total counts of turtle roadkill than sites classified as Low Risk ($p < 0.01$). (b) Sites with a higher road accessibility score, indicating that road access is easier at these sites, have greater total counts of turtle roadkill than lower-scored sites, on average ($p = 0.02$). (c) Sites with a higher overall relative risk have greater total roadkill counts than lower overall relative risk sites ($p = 0.04$). Panels (b) and (c) show negative binomial regressions with 95% confidence intervals.

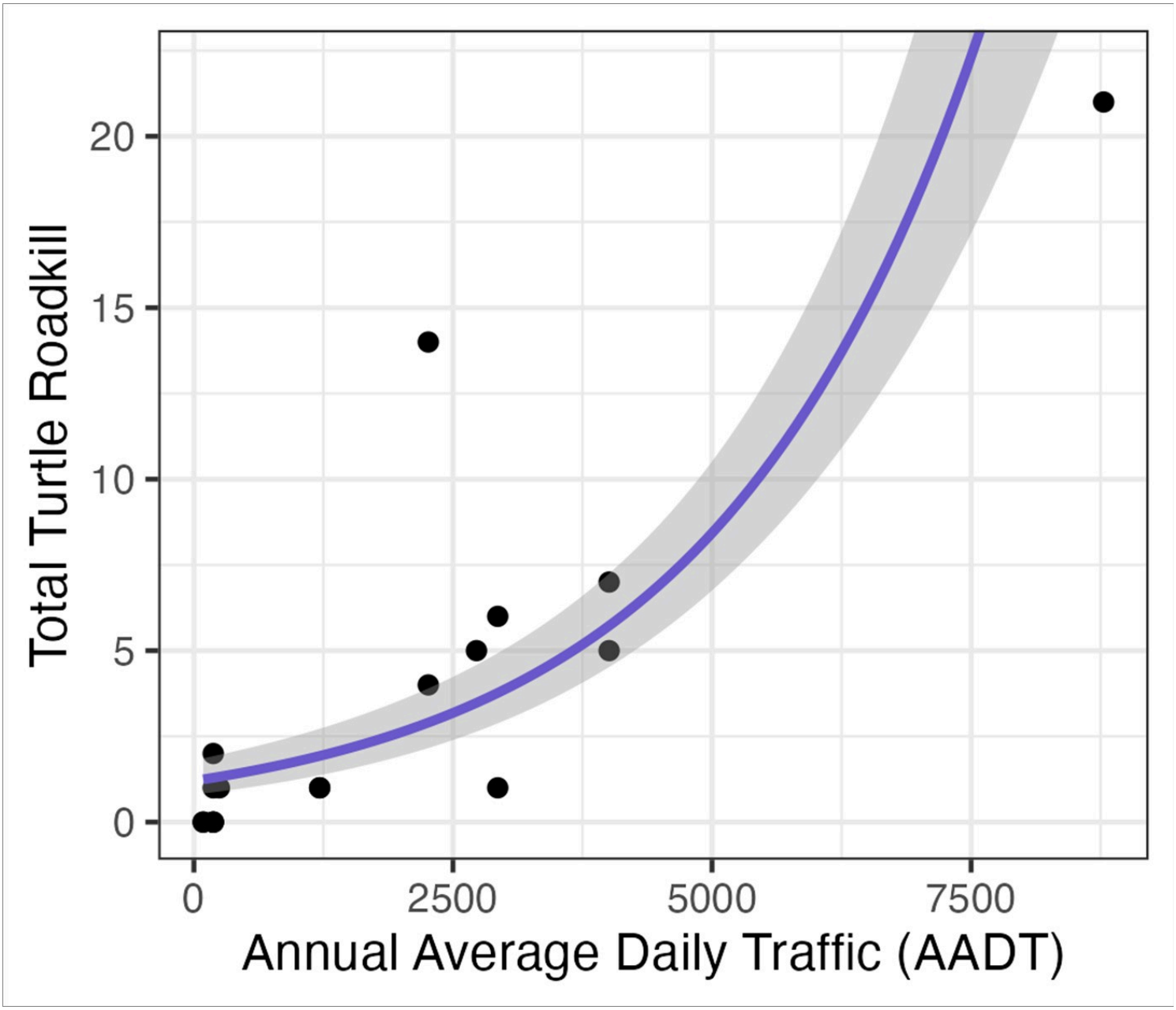


Figure 3

Annual average daily traffic (AADT) and road curve varied with total turtle roadkill observed via road surveys at 18 sites during the 2023 field season (negative binomial regression with a 95% confidence interval). An increase in AADT significantly correlates with greater turtle roadkill ($p<0.01$) while a decrease in road curve trends towards lower roadkill ($p=0.18$).

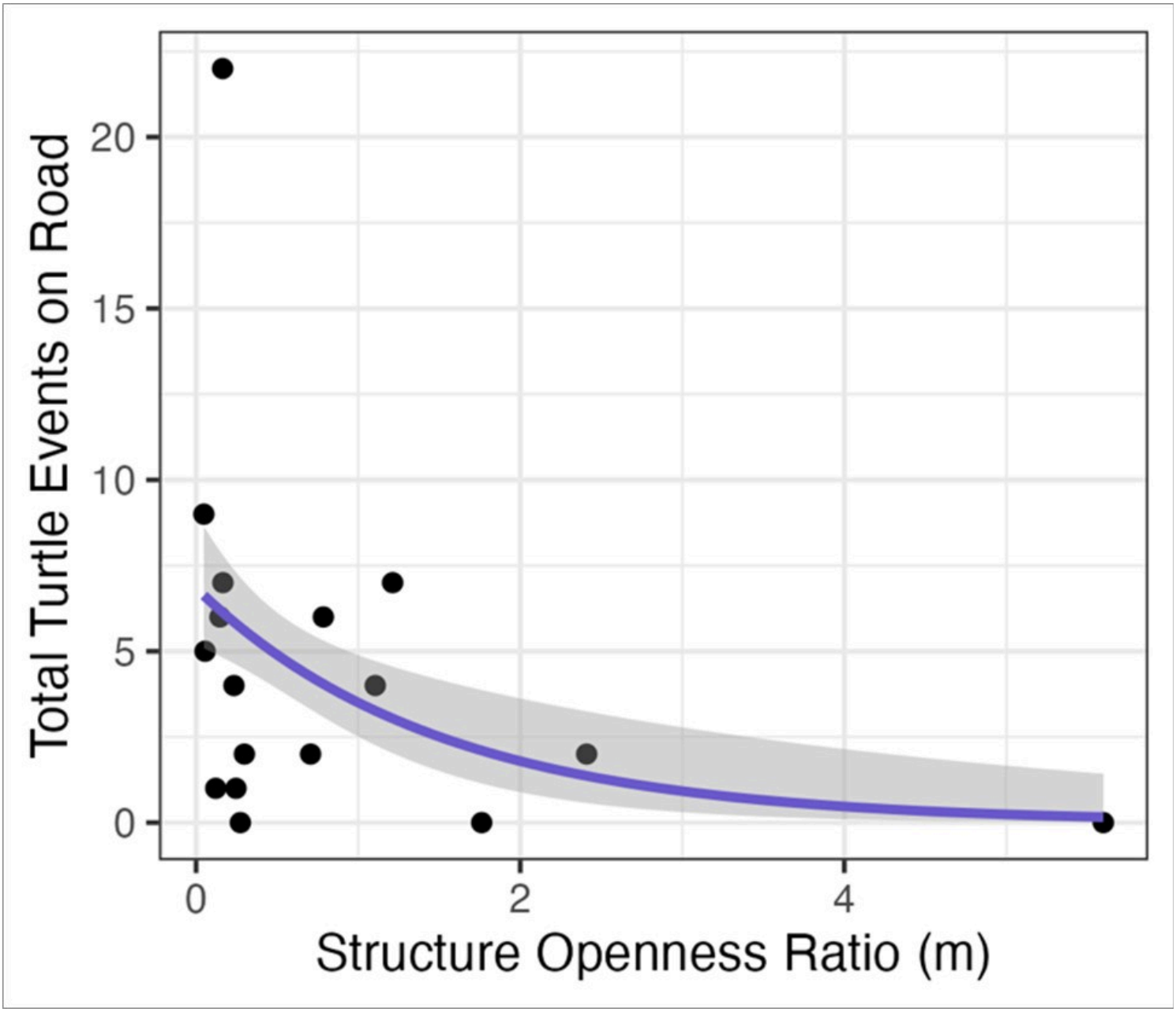


Figure 4

During the 2023 field season, the number of turtles observed on the road above a wetland crossing structure tended to be less at sites with a greater openness ratio (total cross-sectional area of inlet/structure length) (p=0.06). Negative binomial regression with a 95% confidence interval.

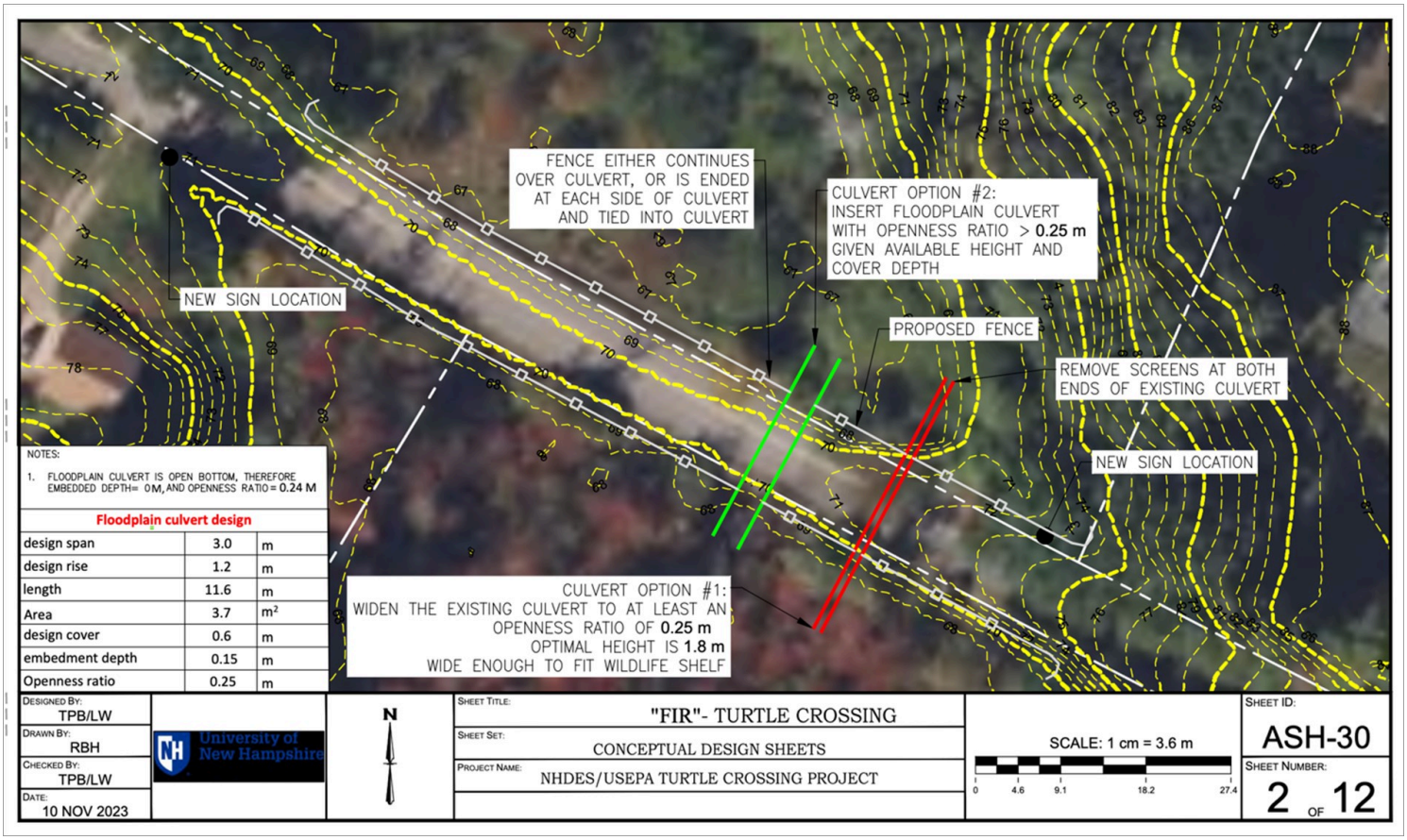


Figure 5

Conceptual engineering plans of a high-risk turtle crossing site designed to reduce Blanding's and other freshwater turtle road mortality. AutoCAD prints assembled by TPB and Robert Hopkinson; designed by TPB and LEW.