A Practitioner's Guide to

# Planning and Design of Wildlife Crossings in Florida

Version 1.0

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Photo credit: Florida Panther Posse.

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# Foreword

“Nothing is worse for wildlife than roads.” I’ve heard versions of this statement from wildlife ecologists and conservationists for decades, and it still rings true. I’ve said and written it myself many times, beginning with a review article I published on the ecological effects of roads back in 1990. Of the various threats to wildlife—habitat destruction and fragmentation, habitat degradation from fire exclusion, invasive species, poaching, overhunting, pollution—none is more insidious and far-reaching in its effects than roads. The building and use of roads facilitates and exacerbates virtually all other threats to wildlife, ecosystems, and biodiversity generally.

When we build a road, we destroy the land under it and immediately around it. The road construction increases sedimentation and pollution of nearby waterbodies. During and after construction, the road serves as a movement barrier to many animals, fragmenting populations and restricting gene flow. Traffic on the road is a direct cause of mortality from wildlife-vehicle collisions (roadkill). Birds and anurans breeding near the road often must alter their behaviors in an attempt to attract mates, and yet still suffer reproductive declines in response to traffic noise. Vehicles on the road spew out pollutants, affecting the health of humans and other animals, as well as sensitive plants. And the more growth and the more vehicles, the more barrier effects and roadkill.

Roads, once built, inevitably fuel additional development—indeed they are often built to serve and even generate new developments. These developments, and the roads themselves, hinder the ability of land managers to employ prescribed burning, due to concerns about smoke limiting highway visibility and impacting human health. Roads built into wildlands compromise roadless areas and wilderness character and lead to increased hunting, harassment, persecution, and population declines of animals sensitive to humans, such as large carnivores and snakes. Road expansion is also strongly linked to forest loss and degradation because of the access roads provide to loggers. About the only good thing that can be said about roads is that they help us get to where we’re going in our foolishly vehicle-dependent society.

Fortunately, not all the news about roads is bad news. Over the last few decades, a new subdiscipline of ecology—road ecology—has developed and grown rapidly. The science of road ecology is helping us find ways to reduce, sometimes radically, the ecological impacts of roads. Using various empirical and modeling methods, road ecologists are figuring out what stretches of roads, usually curving or sloping portions, pose greatest threats of roadkill. They have designed and implemented a variety of context-specific wildlife crossing structures and associated fencing to funnel animals into the crossings and then safely under or over the road. Various animal detection systems have been developed to alert drivers to large animals that are either on or are approaching a road.

These road mitigation measures are being implemented virtually worldwide and are increasing most rapidly in regions where ambitious conservation plans are being implemented. For example, in the Yellowstone to Yukon (Y2Y) region of the U.S. and Canadian Rockies, very few wildlife-crossing structures existed on roads in 1993, when Y2Y was founded, but today the region has at least 130 designated wildlife underpasses and overpasses and associated fencing. Florida, which is a national and even global leader in large landscape conservation, is also in the forefront of the science and application of road ecology. The ambitious Florida Wildlife Corridor cannot succeed without a tremendous investment in wildlife crossings and other road mitigation.

This guide by wildlife and landscape ecologist Dr. Dan Smith, my colleague for the last two decades, exemplifies the status of Florida as a global leader in road ecology and road mitigation for wildlife. There are many, many papers and even a few books on road ecology, but until now there has not been a practical guide for agencies, land managers, and conservationists on how to mitigate the impact of roads by use of crossing structures and other methods. This guide addresses both the direct and indirect effects of roads on wildlife. Direct effects, such as roadkill, habitat loss, spread of invasive species, and barrier effects, are relatively easy for the public and road engineers to understand. Indirect effects are more subtle and often involve a lag time, but they are no less pernicious. The isolation of animal populations by road networks, for example, often leads to population instability and loss of genetic diversity, which in turn can cause local extinctions, which can cumulatively result in regional extinctions of wildlife species. Negative edge effects such as noise, artificial light, and soil and water contaminants, can markedly reduce the suitability of habitat within hundreds of feet of busy roads, in turn leading to population declines.

The heart of this report is practical guidance for how to avoid, reduce, and mitigate deleterious impacts of roads on animals, and by extension on plants and ecosystems, as all things in Nature are interdependent. It is highly advised that planning for wildlife crossings begin prior to road construction and include identification of stretches of roads where conflicts with wildlife are most likely—for example, those areas where, due to landscape configuration and vegetation structure, road-sensitive animals are likely to try to cross. Surveys of roadkill and animal tracks, hair snares, camera traps, capture-mark-recapture, and radiotelemetry of individual animals, followed by GIS analysis to make spatially explicit sense of the field data, are all useful. Such critical "preconstruction planning" was almost never done in the past but is now becoming more common.

After identification of crossing needs and preferred locations, the next step is the design of the crossing structures, and this guide provides many principles and specific recommendations for crossing design. In many cases, existing structures such as culverts can be modified to enhance their potential for wildlife movement. Post-construction monitoring and adaptive management is another phase that is often omitted; however, it is essential to determine whether a crossing structure is functioning as intended, and if not, to modify the structure and its surroundings or, if possible, add additional crossings to create and maintain functional connectivity for wildlife across the road. This guide is replete with case studies that demonstrate how all these phases can be, and have been, implemented in real-world settings.

The maturation of road ecology and the abundant experience gained from many applications of wildlife crossing structures offer a strong basis for optimism. Although the many devastating impacts of roads on wildlife cannot be entirely eliminated by wildlife crossings, if implemented intelligently crossings can greatly reduce road mortality and facilitate the natural movements of animals across landscapes. That's about the best we can hope for in a state, such as Florida, with such overwhelming human population growth. Dan Smith has provided us with a practical and comprehensive guide for how to plan, design, implement, and monitor wildlife crossings. The focus is on Florida, but the potential application of this knowledge is universal.

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*University of Florida Center for Landscape Conservation Planning*

# Executive Summary

The Practitioner's Guide includes seven separate sections briefly described below:

## Section 1. Background and Focus

This section provides a concise summary of the primary effects of roads on wildlife and wildlife habitat. It also outlines the purpose and objectives for the guide and discusses the identification of representative target species or groups.

## Section 2. Preconstruction Planning

Important concepts and steps for studies conducted in the preconstruction planning phase are presented. This includes identifying the need and locations for wildlife crossings to avoid or alleviate wildlife-vehicle conflicts. Subjects covered include field data collection techniques, data analysis and GIS, and environmental assessments.

## Section 3. Site and Structural Design

Here, we explore the wide array of wildlife crossing types and designs and general site design principles. Discussion includes use and installation of wildlife fencing and landscaping parameters (including native plant materials and natural topographic features). Finally, alternative measures to wildlife crossing structures that can also improve the permeability of roads for wildlife are explored.

## Section 4. Post-construction Monitoring, Maintenance, and Adaptive Management

This section discusses parameters for monitoring studies to evaluate usage or avoidance by target and common species, basic maintenance considerations that assure high functionality for wildlife use and traffic safety, and adaptive management practices that evaluate effectiveness and examine need for enhancements to improve function.

## Section 5. Case Studies and Quick Takes

The case studies represent key examples of in-practice crossing designs in Florida and pre- and post-construction monitoring activities. Discussion includes lessons learned and adaptive management measures. Quick takes include examples of noteworthy wildlife crossing projects and specific issues that aid in addressing common problems and executing effective solutions.

## Section 6. References

In addition to the list of articles cited in the guide, the reference section presents a broad selection of suggested readings (books and articles). It also includes a Florida-based bibliography of published papers and reports on wildlife and roads.

## Section 7. Appendices

The appendices include the FDOT Wildlife Crossing Guidelines and additional examples (mostly in Florida) of the three categories of wildlife crossing structures: overpasses, underpasses and multi-purpose structures.

# Section 1: Background and Focus

In section one we provide a brief review of the subject in a Florida context and set up the underlying framework for the rest of the guide. This section is divided into the following subsections:

- Introduction and background
- Purpose and objectives
- Target species and functional groups

## 1.1. Introduction and Background

The effects of roads on wildlife and wildlife habitat are varied and include both direct and indirect impacts (fig. 1-1):

Direct impacts

- wildlife-vehicle collisions
- habitat loss
- spread of invasive species
- filters or barriers to species movement and migration

Indirect impacts

- habitat fragmentation and isolation effects (leading to reductions in population stability and genetic health, and potential extirpation)
- human disturbance and habitat degradation (e.g., altering individual and social behavior and species composition, negative edge effects such as noise and artificial light, and runoff of soil and water contaminants)

Significant research examining these effects and developing solutions has occurred over the past 30 years (Forman et al. 2003, Huijser et al. 2008, Clevenger and Huijser 2011, Andrews et al. 2015, van der Ree et al. 2015). Two significant road-wildlife conflicts addressed in this handbook are wildlife-vehicle collisions (WVCs) and barriers to species movement and migration. This is well illustrated in an example from Sweden that demonstrates how

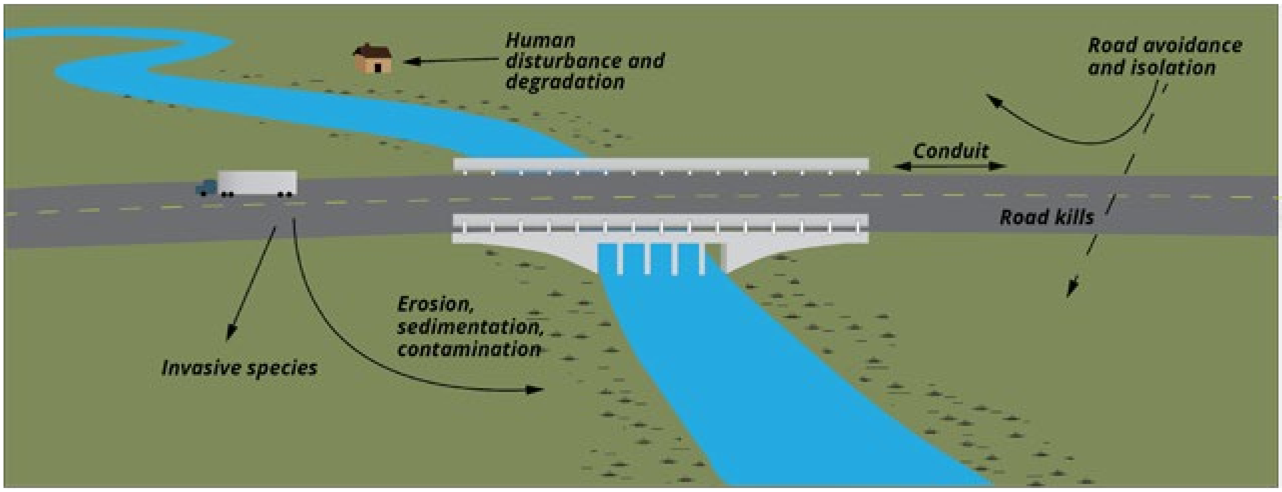
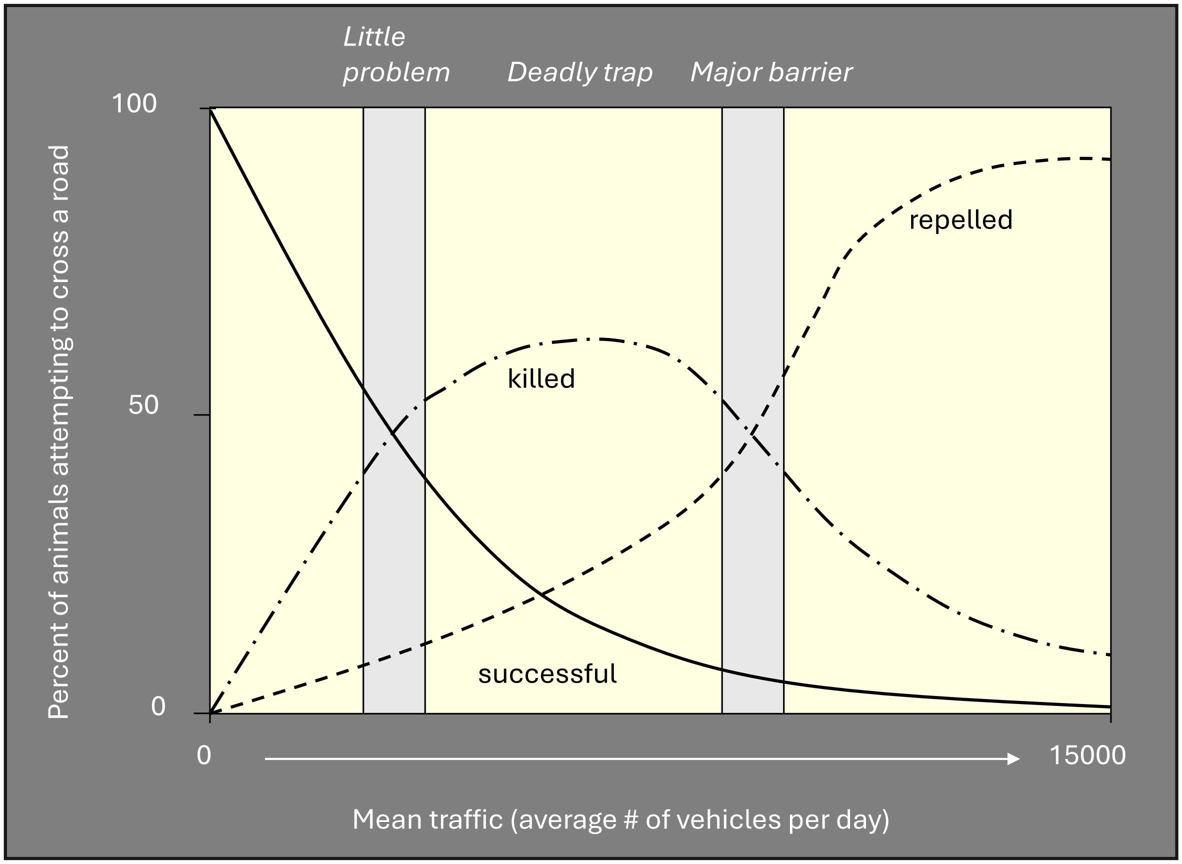


**Figure 1-1 An illustration of the different ecological effects of roads on landscapes and wildlife.** (modified from Dramstad et al. 1996)

increasing traffic influences wildlife movement across a road (fig. 1-2; Seiler 2003). The first change occurs at a threshold of traffic where WVCs become greater than successful crossings. A second change occurs at yet higher traffic levels when crossing attempts become rare and the road becomes a significant barrier to wildlife movement. The traffic-level thresholds that determine whether the road is a deadly trap or a major barrier will vary depending on the species.

Florida is one of the fastest growing states in the nation and has the third highest population (over 21.5 million people; 2020 US Census). The tremendous growth over the past 40+ years has led to more roads, more traffic and urban development, and a collection of smaller, fragmented natural areas for wildlife. A consequence of this growth is greater numbers of WVCs annually on Florida roads. Increased WVCs are driven by individual animals traversing roads to access other patches of habitat in search of food and other resources as populations outgrow shrinking habitat areas. Two species especially impacted, due to their wide-ranging behaviors, have been the Florida panther (figs. 1-3a and 1-3b) and black bear (over the last 10 years, annual vehicle collision mortalities have averaged 23 [panthers] and 250 [bears]). Two state conservation programs (Florida Forever and the Florida Wildlife Corridor Act) have sought to



modified from Seiler (2003)

**Figure 1-2 The effects of increased traffic on permeability of roads for wildlife.** Essentially, there are two traffic level thresholds that influence (1) the number of WVCs and (2) the number of crossing attempts (modified from Seiler 2003).

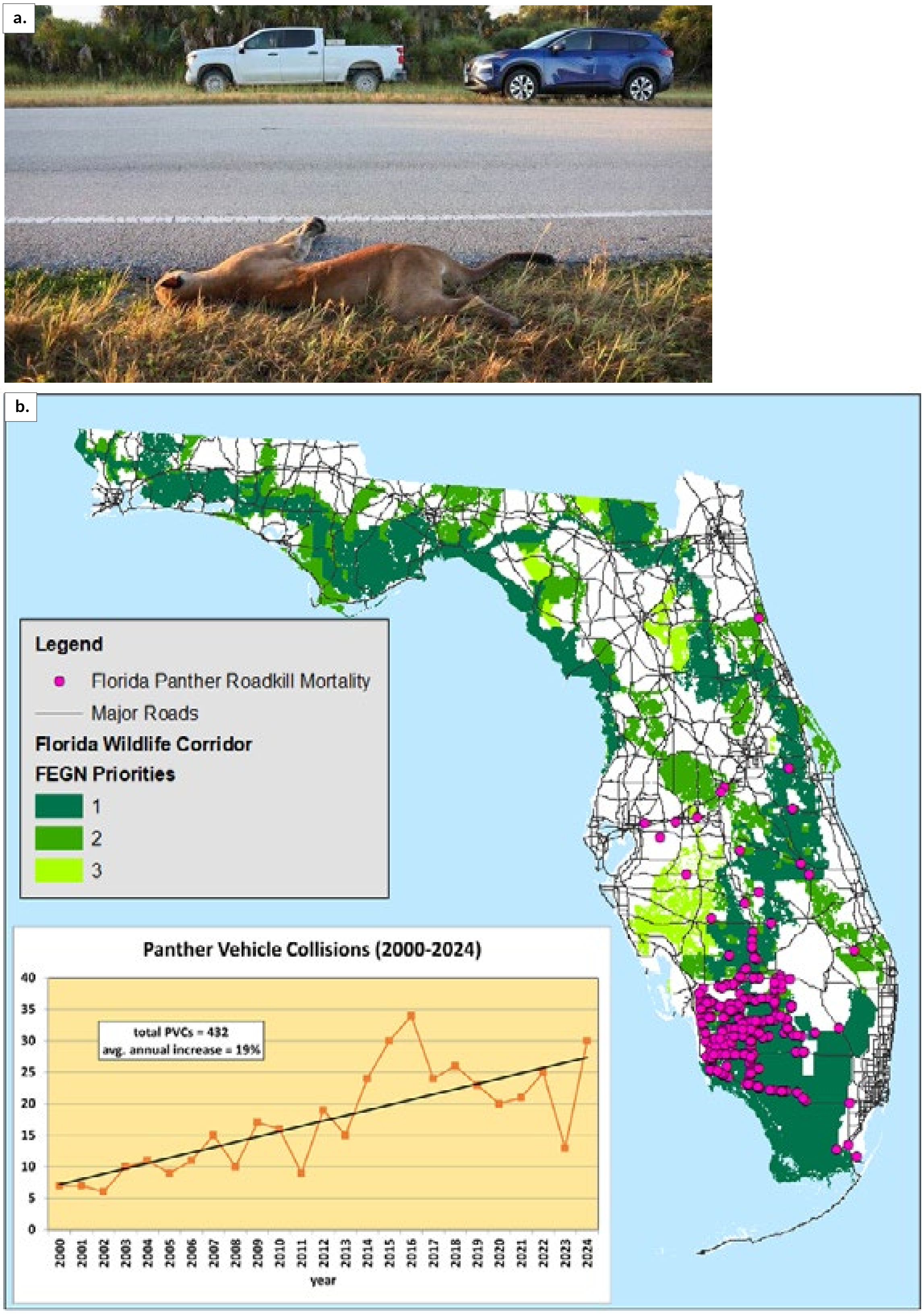


**Figure 1-3 Florida Panther roadkill (a) and locations and trends in Florida panther-vehicle collisions from 1998 to 2024 (b)** (data source: FWC).

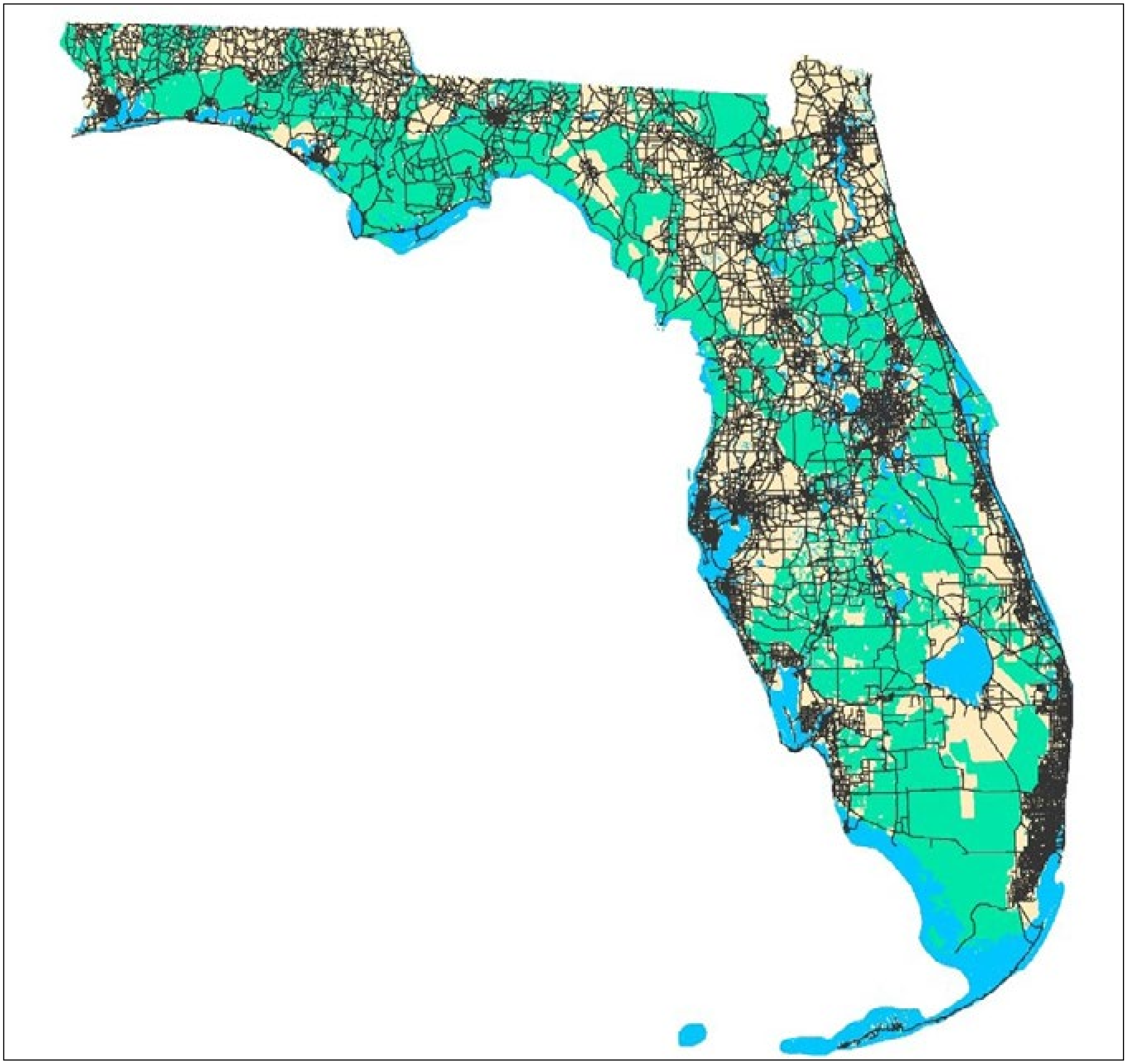


**Figure 1-4 The Florida Wildlife Corridor and Florida's major roads** (data sources: CLCP and FDOT).

balance urban growth and natural heritage by protecting a statewide network of connected conservation areas. Creating a network of conservation hubs and functional habitat corridors requires integrated planning with the state transportation network. Where these networks intersect are locations where solutions are needed to improve road permeability for wildlife and improve highway safety (fig. 1-4).

Solutions devised to reduce road-wildlife conflicts include warning signage and wildlife detection systems, speed restrictions, wildlife exclusion fencing and barriers, and wildlife crossing structures. Wildlife crossing structures combined with fencing are currently the most effective means of reducing WVCs and improving permeability of roads for wildlife movement, reconnecting habitat and wildlife populations (Clevenger 2005, Huijser et al. 2008).

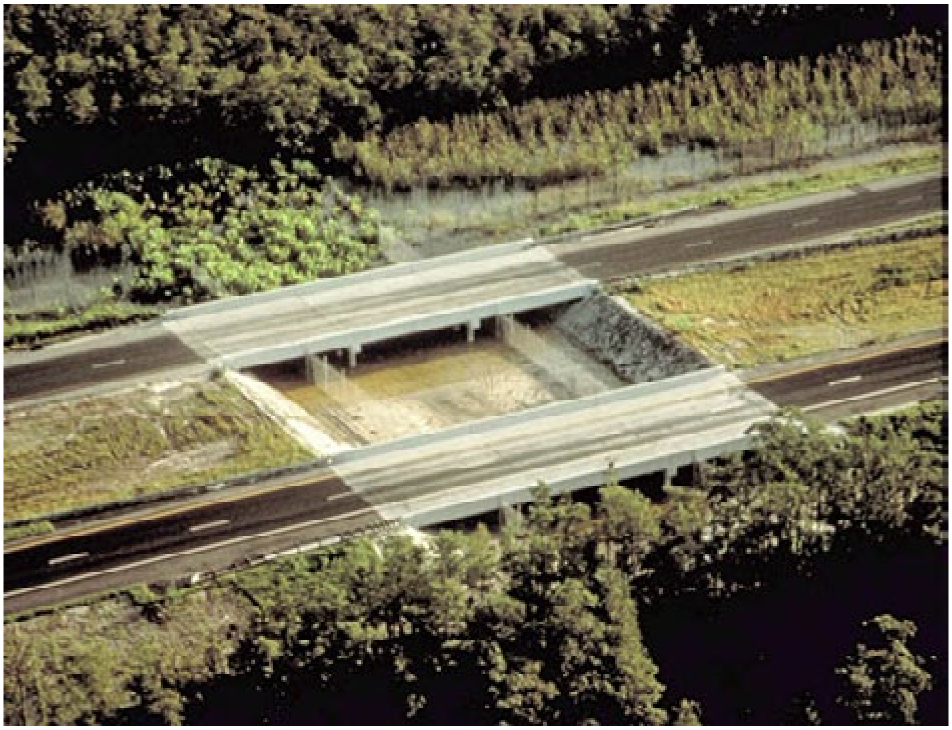


**Figure 1-5 One of the 36 underpasses constructed on I-75 (Alligator Alley).** The structures were intended to restore wildlife and hydrologic connectivity in Big Cypress NP and Everglades NP.

Florida has a significant history regarding wildlife crossings. The first purpose-built wildlife crossing structures in the state were constructed on I-75 (Alligator Alley; fig. 1-5) in the early 1990s (Foster and Humphrey 1995). Although not originally intended as wildlife crossings, a handful of ranch land access tunnels were constructed in the 1960s in South-Central Florida on the Florida Turnpike and I-95 to connect portions of properties that were separated by the limited access highways. Two of these structures are now located within state conservation lands and act as functional habitat connections for wildlife. Over the past 35 years the Florida Department of Transportation (FDOT) has constructed over 125 wildlife crossings on more than 25 roads across the state. Additionally, a few counties have funded and installed crossings on local roads.

Requests for more wildlife crossing structures continue to increase and funding is limited. This places pressure on FDOT to evaluate and prioritize these needs as well as moderate costs. In 2015, FDOT created a set of wildlife crossing guidelines to establish criteria and appropriateness of wildlife crossing applications that could be used within the road project planning process (see FDOT Wildlife Crossing Guidelines in Appendix I). In 2021-22, FDOT sponsored a project to identify and prioritize wildlife-vehicle collision hotspots on all state and major county roads. This Practitioner's Guide to Planning and Design of Wildlife Crossings is another tool created to assist decisionmakers on wildlife crossings.

The Practitioner's Guide is a resource for planning, design, construction, and maintenance of wildlife crossings in Florida landscapes. It includes information on 1) pre-construction data collection, analytical methods, planning and assessments, 2) site and structural designs, and 3) post-construction maintenance, effectiveness monitoring, and adaptive management. Practical examples and case studies are also included to illustrate applications in various contexts and offer lessons learned.

## 1.2. Purpose and Objectives

The purpose is to provide informed guidance to local, state, and federal agencies, other interested organizations and the public on wildlife crossing structure needs and implementation within the road project planning process.

Chief objectives include:

- Describing the most current methods to identify and prioritize road-wildlife conflict areas
- Elucidating alternatives for site and structural designs by functional species groups
- Outlining best management practices (post-construction) that include methods for maintenance and effectiveness monitoring and evaluation
- Providing examples/case studies of successful/unsuccessful applications

## 1.3. Target Species and Functional Groups

A sound and manageable approach to address the impacts of roads on Florida's wildlife should include establishing a set of target species with broad representation. Target species should include those that would benefit from using typical wildlife crossing structures to traverse roads and are either state or federally listed, key management indicators, wide ranging, or otherwise of special conservation interest, and those that pose substantial risks to highway safety (FWC 2019). Below are useful criteria to identify representative target species:

- Pose risk to highway safety
- State and federally protected species
- Other identified at-risk species (e.g., Florida Natural Areas Inventory species tracking list) and candidate listings
- Representation by habitat types (e.g., wetland or upland dependent)
- Habitat specialists or isolated/disjunct populations
- Match representative species by crossing structure size/type
- Other focal species (e.g., keystone and umbrella species)

The objective remains to establish a short list of species (from each taxonomic group) that represent the needs of the species listed in Table 4b of the State Wildlife Action Plan (FWC 2019) that are susceptible to road impacts. Representative species were organized by taxonomic group and Florida habitat types/plant communities. The consensus list provided below (Table 1-1) was produced following consultation and discussion with a Technical Advisory Group (TAG) of agency representatives and other stakeholders.

Target species organized by functional groups in association with wildlife crossing structure size (large, small) can be useful in simplifying structure type/size selection and can aid in assessing suitability by species size and habitat requirements (see Table 1-2 below). An important factor when considering size is the perception of openness. Some species are more averse than others when faced with "closed-in" spaces, low light or poor visibility conditions. These factors are discussed in more detail in Section 3.

Sections 2 through 5 include practical examples using target species and representative groups to help explain road ecology concepts, streamline the process, and make better, more informed decisions in planning, design and adaptive management of wildlife crossings.

**Table 1-1 Representative groupings of target species.**

| Generalist Orientation | Upland-oriented | Wetland-oriented |
|---|---|---|
| Florida black bear | Florida mouse | River otter |
| Florida panther | Wild turkey | American alligator |
| Bobcat | Northern bobwhite | Florida gopher frog* |
| White-tailed deer | Gopher tortoise | Flatwoods salamander* |
| Eastern diamondback rattlesnake | Florida pine snake | Striped newt* |
| Eastern indigo snake | Southern hognose snake | Tiger salamander* |
| Florida box turtle | Southern fox squirrel | |

**these species also have an upland habitat requirement.*

**Table 1-2 A sample list of crossing structure size needs by various target species.**

| Large Structures | Large or Small Structures |
|---|---|
| Florida panther | Bobcat |
| Florida black bear | River otter |
| White-tailed deer | Florida mouse |
| Southern fox squirrel | Gopher tortoise |
| Wild turkey | Florida box turtle |
| Northern bobwhite | Eastern diamondback rattle snake |
| | Eastern indigo snake |
| | Florida pine snake |
| | Southern hognose snake |
| | American alligator |
| | Florida gopher frog |
| | Flatwoods slamander |
| | Striped newt |
| | Tiger salamander |

**Note:** *Certain smaller species may be hesitant to use small structures (e.g., southern fox squirrel, sand skink, wild turkey), and therefore large structures would need to be considered when planning for these species. Typically, many smaller species can be accommodated when also planning for larger species such as black bear or white-tail deer (an "umbrella" effect).*

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# Section 2: Preconstruction Planning

## 2.1 Introduction

The aim of this section is to highlight important concepts, steps, and studies necessary in the preconstruction planning phase to identify the need and locations for wildlife crossings or other measures to avoid or alleviate wildlife-vehicle collisions (WVCs) or other road conflicts (e.g., road avoidance, habitat fragmentation effects). We outline the current types of data collected, study methods, techniques, and data analysis used to help agencies and practitioners select the best methods and analytical techniques to effectively inform decisionmakers. We summarize and discuss the pros and cons of different field data collection and monitoring techniques, data analysis methods and tools, and environmental impact assessments. This section is split into three subsections with practical examples to help explain the basic concepts:

- Field data collection and monitoring techniques
- Data analysis and GIS techniques
- Environmental assessments

## 2.2 Field Data Collection and Monitoring Techniques

Monitoring and data collection are essential to avoiding, minimizing, mitigating, and offsetting the negative environmental effects of roads and traffic. The scale of studies is broad, and can range from short to long term, single or multiple roads, and may occur on old, new, or proposed roads. In all cases, success is enhanced when a structured process is followed: (i) formulate appropriate research questions and study objectives; (ii) locate and use valid and reliable existing data; (iii) construct an effective study design and identify target species; and (iv) select best methods for collection of new or supplemental data.

There are two broad categories of field study that are related to either (a) existing or proposed road construction projects, or (b) general ecological research on the impacts of roads and traffic – although the distinction between these two categories is often blurred. The research conducted for existing or proposed road construction projects is typically focused on:

- Identifying the target species or group of species (see Section 1) likely to be impacted by a road project, often as part of an Environmental Impact Assessment.
- Utilizing existing data and collecting new data on existing or potential road impacts to the target species or groups.
- Analyzing data to identify spatial and temporal patterns of wildlife activity, movements, road crossings, road avoidance, and WVC hotspots.
- Designing the mitigation strategy, including the type and location of mitigation required (Section 3).
- Quantifying the performance of mitigation (Section 4).

General ecological research is often broader than that associated with proposed road projects and includes:

- A broad range of species, not necessarily rare, threatened, or high profile.

- Multiple sites spread over large geographic areas.
- A greater focus on testing ecological theories and hypothesized regularities.
- Sometimes manipulative/experimental.

Once the type of study to be conducted is identified, a set of research questions can be outlined. Questions should be phrased as measurable or testable objectives or hypotheses. The next step should be to identify the potential target species and/or natural communities/ ecosystems associated with the study area. Existing data layers on physical, ecological, and biological features (e.g., roads and traffic, topography, land cover, species locations) and GIS analysis tools are useful resources in the evaluation. Identifying the knowns and unknowns within the study area can help narrow the focus of the study and streamline data collection and analysis. Finally, using this background information and considering logistics of the study (such as scope, duration, and funding), the most appropriate survey methods can be selected. The following subsections provide a summary of field techniques.

### 2.2.1. Roadkill Surveys

Collecting roadkill data is a standard method to identify locations of WVCs (fig. 2-1). The objective of a roadkill survey is to identify spatial and temporal patterns associated with WVCs on existing roads (fig. 2-2). Data collected includes species type, date, and location coordinates. Many roadkill apps are now available to assist with recording of the field data (fig. 2-3). Considerations in planning a roadkill survey include personnel and operations. Safety and training are important to both protect survey crews and to ensure consistency and accuracy of data

**Figure 2-1 A field biologist recording data of a roadkill specimen.**

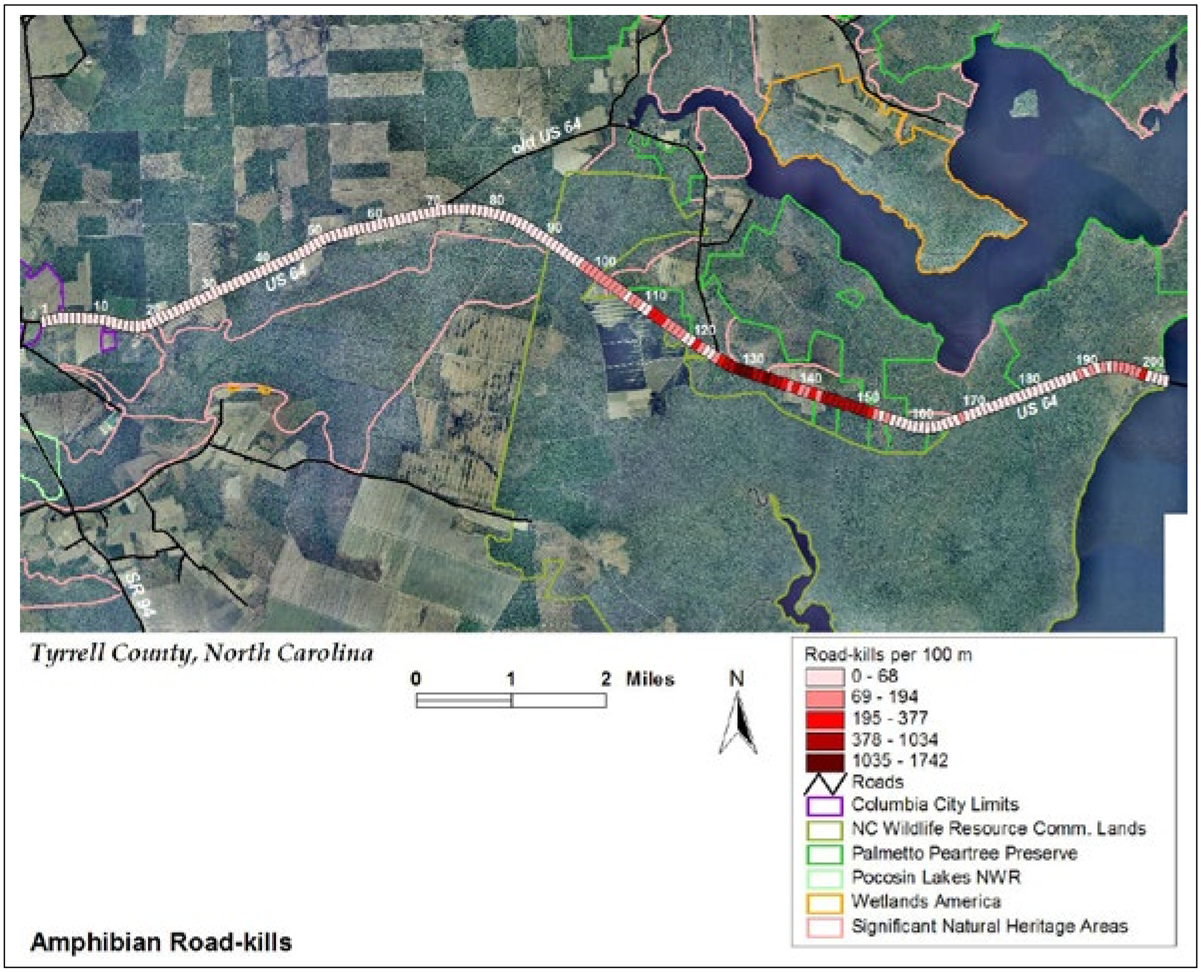
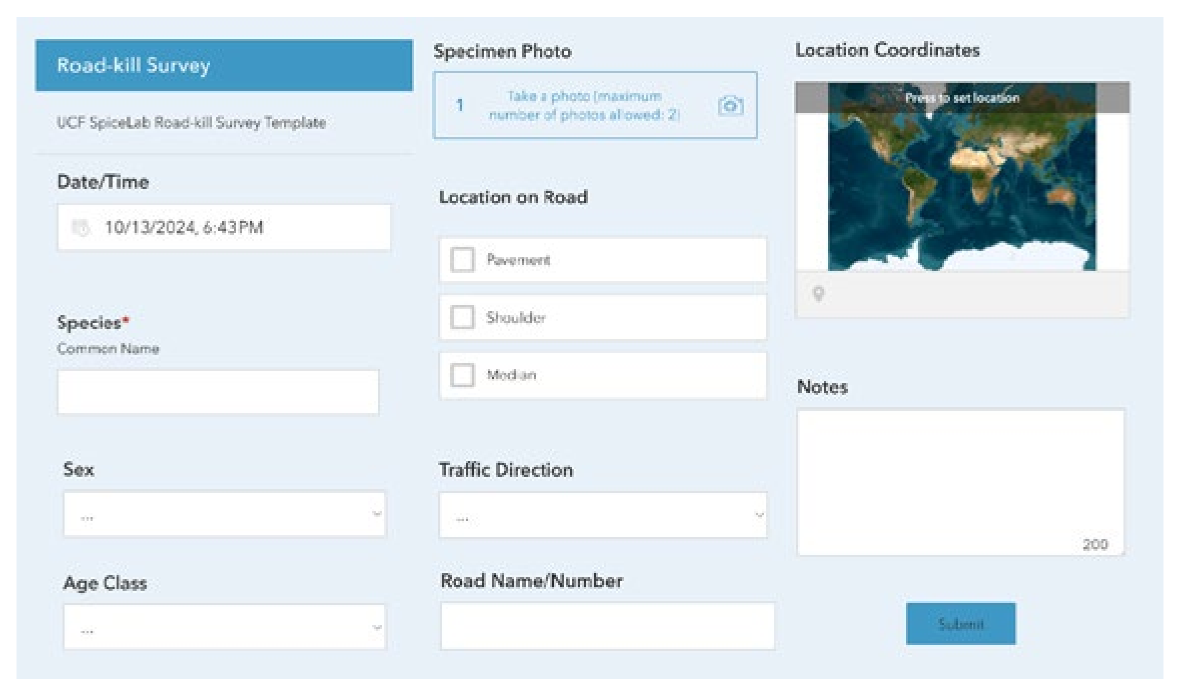


**Figure 2-2 An example showing the spatial distribution of roadkill data collected.**


Road-kill Survey

UCF SpiceLab Road-kill Survey Template

Date/Time

10/13/2024, 6:43PM

Species*

Common Name

Sex

...

Age Class

...

Specimen Photo

1 Take a photo (maximum number of photos allowed: 2)

Location on Road

☐ Pavement

☐ Shoulder

☐ Median

Traffic Direction

...

Road Name/Number

Location Coordinates

Press to set location

Notes

200

**Figure 2-3 An example of a cell phone roadkill data collection application** (ESRI: Survey123).

collected. Basic training in highway worker safety and species identification of local fauna is essential. Key operational aspects include the mode, frequency, and duration of the survey. The mode refers to driving vs. walking. Driving surveys can cover more distance, but walking surveys are more thorough, particularly when counting small animals. This is because small animals are harder to see from a vehicle and are frequently thrown clear of the road after collisions, often winding up in the grass shoulders (fig. 2-4). Factors that influence the decision to perform walking or driving surveys include logistics, funding and duration of the study, target species or species and the areal extent of the study (number of roads and total centerline mileage). If driving surveys are preferred, it is important to choose a consistent speed applicable to all observers participating in the study. Detection rates of small specimens increase with slower speed. A rate of speed of 10 mph or less is recommended, but many studies have been conducted at 25 mph or greater. If higher speeds are chosen, it must be acknowledged that roadkill abundance estimates (particularly of small animals) may be smaller due to lower detection rates.

Frequency refers to how often surveys are conducted on a consistent basis. Estimates of abundance and spatial and temporal patterns are more accurate the more frequent the surveys can be performed. This is partly because roadkill can be removed by carrion scavengers and pulverized by continuous vehicle traffic (fig. 2-5). Consistent sampling frequency by week and over the course of the study is important to produce statistically valid and defensible results. The preference is to conduct surveys multiple days per week (at a minimum) in the early morning hours to minimize losses attributed to scavengers and vehicle traffic. It is worth noting that identification becomes more difficult as specimens decompose with time and are further disintegrated by vehicle tires. Once specimens are recorded, they should be marked (typically with spray paint) or removed so they are not counted again on subsequent surveys (fig. 2-6). Duration refers to how long the survey will be conducted. To effectively evaluate environmental effects on roadkill frequency and abundance, the study design should incorporate both seasonal and interannual variation (e.g., wet and dry years) as animal movement can be driven by these factors (see example in Section 5). Consideration of environmental variation would mean that roadkill surveys should be conducted for 2 or more years. There are a couple different ways to incorporate environmental variation into the study depending on

**Figure 2-4 Location of a roadkill in the grass shoulder of the road.**

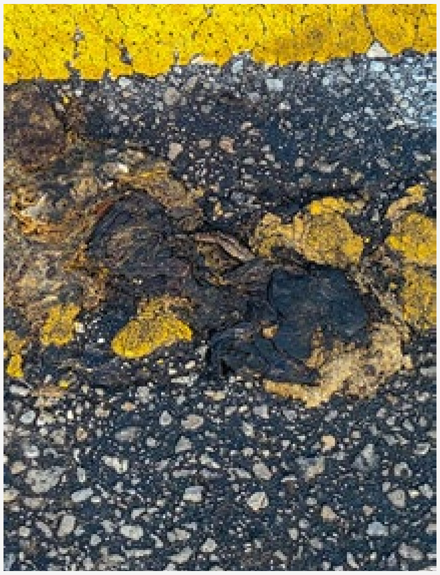


**Figure 2-5 An unrecognizable roadkill;** flattened and repeatedly pulverized by vehicle tires.

**Figure 2-6 Marking roadkill specimen with paint after recording data** (to avoid double counting on subsequent surveys).

the funding and workforce available. One example would be to conduct surveys 2 or 3 days over a 5-day work week (e.g., every other day or every third day, respectively) consistently each week over a minimum 2-year period. Another example might include surveys 3 days per week (every other day) for 6-7 straight weeks each season over the course of at least two years. Variations to these examples could also be applicable.

### 2.2.2. Track Surveys

Track or footprint studies are designed with similar considerations to those in roadkill surveys. They can be performed either by walking or driving (in this case usually on an ATV). Track surveys, however, require establishing suitable substrate to detect tracks. Most often track surveys are conducted on sand or soft soils, or on snow. An ATV is valuable in creating and maintaining track paths in sandy soils along roadsides (fig. 2-7). The same frequency and duration factors described for roadkill surveys also apply here. Removal of tracks occurs from precipitation and wind effects; therefore, it is preferable to perform these at least 2-3 days per week to assure enough data is collected on a consistent basis. In locations where soft soils or sand is present, these can be maintained using an ATV and a harrow or drag (to essentially erase the tracks after recording them to "reset" the track path). Due to maintenance of the track path, it may be beneficial to perform these surveys in consecutive days (e.g., 3-4 days in a row; the first day the path would be dragged and then checked the following three days). Smaller scale, track surveys can be conducted by establishing suitable substrate where animal trails emerging from the adjacent habitat intersect the clear zone of the road. In this case it is best to perform reconnaissance at the beginning of the study to identify trails of different size animals for a more pointed approach to track surveys. This approach is easier to manage, particularly if an ATV or other equipment is not available.

Track identification can be difficult with certain species and may require detail-oriented training (e.g., similarity of different Canidae footprints; fig. 2-8). It should be noted that some species (e.g., whitetail deer) use roadsides to browse and presence of tracks may only indicate that it is an area of high foraging activity, not necessarily road crossing locations. Other species like coyote and fox are known to parallel roads in search of prey, again their intent is not to cross the road but to use the verges for hunting. Track data is more useful when paired with roadkill data to predict probable areas where deer are most likely to cross the road based on unsuccessful attempts (roadkill data) and where clusters of activity (tracks) occur. Refer to Section 2-2 for more information on combining multiple data types for analyzing spatial and temporal patterns of wildlife movement and road crossings.

### 2.2.3. Landscape Genetics (hair snares)

Hair snares installed along roadsides to detect road crossings by medium to large mammals is a relatively new method. Modern genetic analysis techniques afford precise identification of individuals as well as sex ratios and offer relatively high resolution of road crossing locations. This method is somewhat labor-intensive requiring installation of multiple strands of barbed wire

**Figure 2-7 Track bed preparation and maintenance.** Field technicians (left) preparing roadside track path and (right) checking for tracks and maintaining track path with ATV and harrow.

**Figure 2-8 A comparison of different Canidae tracks** (left to right: red wolf, coyote, domestic dog).

and then establishing a schedule to collect hair samples. The barbed wire can be attached to trees, fence posts and guardrail (fig. 2-9). Vertical height and spacing of barbed wire strands are based on the target species. This method is more effective on species that prefer to step between the wires as opposed to jumping over them. Vertical spacing and clearance height is crucial. Wires that more easily allow animals to step through will be more effective, but too wide of spacing may allow individuals to pass through without leaving a hair sample. This method was tested successfully for all age classes of black bears (samples were also obtained of wild pig, coyote, bobcat and gray fox) using two wires at 25 cm and 50 cm heights (fig. 2-10). Hair snares should be checked when wildlife is most active (e.g., seasonal timing associated with mating, dispersal or migration). There are many approaches to frequency and timing of collecting hair samples. One example would be once per week for 4-6 weeks in each season. Each sample should be placed in an individual, labeled envelope and kept in a cool, dry location until submitted to the lab for analysis. There are many labs available that can process samples and conduct DNA analysis. The lab process is not discussed here, but other resources are available for this information.

### 2.2.4. Camera Trapping

Camera traps along roadsides are also effective in detecting road crossing attempts by medium to large wildlife mostly (although some smaller animals can also be detected at reliable rates). They can be programmed to record single or multiple-burst images or short videos for 24 hours daily or alternative selected periods. The interval between successive image captures can also

**Figure 2-9 Barbed wire hair snare application.** Here it is attached to the top of continuous guardrail along a road adjacent to Alligator River National Wildlife Refuge in North Carolina.

**Figure 2-10 Another example of barbed wire hair snare placement.** In this case, it is attached to trees along the roadside in Ocala National Forest (see collection of hair samples [inset]).

be set. Using video or image burst modes is helpful in revealing brief behavioral responses of animals approaching the road. No-glow or low-glow infrared illuminator cameras are preferable to reduce disturbance of animals during nighttime. Performing short tests of these settings before deployment can help in optimizing image/video capture. Motion blur related to glare or low light can be an issue with some cameras. Some cameras can transmit the image data over wireless networks, and some have solar power capabilities. The brands, types, and options of trail cameras are quite broad, and we recommend checking performance reviews and running cost comparisons before choosing a specific camera. Image quality (night and day), sensor range and reliability, and battery life are key issues to consider.

Suitably wide, clear zones are required to set up cameras far enough from the pavement to allow vehicles to safely pull off the road in an emergency. Cameras can be mounted on posts or attached to fence posts, trees, or guardrails (fig. 2-11). Theft and vandalism are possible and security boxes and cable locks are available to deter such actions. Camera traps can be set up in continuous arrays along the roadside when the habitat type adjacent to the road is homogeneous and no identifiable, intersecting animal-trails are

**Figure 2-11**

**Cameras mounted on guardrail, enclosed in security boxes;** on US 41 in Big Cypress National Preserve (BCNP).

evident (fig. 2-12). If the road segment is too long, it may not be fiscally practical to deploy cameras along its entire length. In such a case, multiple, shorter, sample monitoring-sections could be randomly established to estimate the probable number of animal movement events along the entire road segment. Alternatively, if there are distinct animal trails emerging from the adjacent habitat that intersect the clear zone of the road, camera traps can be set up to monitor wildlife moving to and from the road corridor on these trails (fig. 2-13). Detection distance varies depending on the camera model (typically 50 – 75 ft), and spacing intervals should be slightly below this threshold in continuous camera arrays as detection distance will diminish as battery strength wanes. Data collected from images can be compiled and analyzed by species or species groups regarding roadside habitat preferences and locations and number of successful and unsuccessful road crossing attempts. Later (Section 2.2.2) we discuss automated methods for processing images that greatly reduce processing time.

**Figure 2-12 A continuous camera trap array along US 41 in BCNP.**

**Figure 2-13 Trail camera and track bed to monitor an animal trail** (abutting US 41 in BCNP).

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## 2.2.5. Capture-Mark-Recapture Trapping

Capture-mark-recapture trap arrays are often used to estimate diversity and abundance of small animal populations on roadsides and in adjacent habitats. Roadside trap arrays installed on opposite sides of the road and control arrays located in adjacent habitats are used for comparison of species richness and abundance and to detect potential road-related edge effects, such as road attraction or avoidance. The roadside trap arrays can also provide estimates of road crossing frequency. These trap arrays can also be used to obtain small animal subjects to use in telemetry studies of small animal use of roadside habitat and potential road crossings (see next section). Different types of traps and drift fencing have been used to create small animal trap arrays. Aluminum flashing once was common, but the material is expensive and difficult to work with. A suitable, less expensive replacement is woven plastic, silt-fencing, which is typically used to control runoff and erosion at road construction sites. It comes in 4 ft wide, 100 ft long rolls and is easy to work with when trenching. These fences are typically paired with several traps placed on each side of the fence. Some traps work better on various species than others, so a combination of trap types can be beneficial. Two types frequently used are 5-gal plastic buckets (pitfalls) and aluminum screen funnel traps. With a 100-ft silt fence, 4 buckets and 4 funnels (2 each on either side of the fence) equally spaced is effective at capturing small mammals, snakes, lizards, small turtles, amphibians and other small organisms (fig. 2-14). To evaluate the impact of the road on small animal populations, trap arrays should be replicated in each different habitat type at both roadside and control locations. Control sites should be far enough from the road so that noise, artificial light, and other negative edge effects are minimal. A capture-mark-recapture study requires use of different marking techniques to identify individual recaptures (see wildlife techniques references regarding marking methods). This method, though effective, is labor intensive and involves training in animal handling, use of marking methods, collecting morphometrics, and species identification. Labor costs can be significant, but supply costs are relatively low.

**Figure 2-14 Example of installation and trap array design;** positioned along the edge of the clear zone of the road right-of-way.

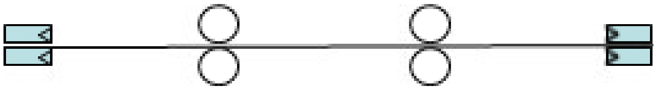

Diagram of drift fence trap array; circles=pitfalls, rectangles=screen funnels.

### 2.2.6. Radiotelemetry Studies

Radiotelemetry is useful to evaluate effects of roads on wildlife movement and habitat use. Radiotelemetry involves trapping and handling of animals to fit them with tracking devices. This results in more stress and risk for the animal. Because of higher labor and equipment costs and added risk to animals from trapping activity, radiotelemetry is used less often in road impact studies than other methods. When it is employed, target species are typically management indicators, wide-ranging, and/or highly susceptible to vehicle-related road mortality, habitat fragmentation and isolation. Trapping methods to capture radiotelemetry subjects are not discussed here, several accessible references are available on that subject.

GPS transmitters are more costly, but popular because they are programmable (relatively unlimited options for collection frequency and duration; only constrained by battery life), collect substantial amounts of location data at high resolution, and do not require field labor for tracking (fig. 2-15). VHF transmitters are vastly cheaper but require manual field tracking and triangulation to obtain location fixes (fig. 2-16). Capabilities of GPS telemetry on smaller organisms are still limited because of greater power demands and battery size/weight. As microtechnology continues to improve, applications for small organisms will shift more toward GPS transmitters. Analysis of radiotelemetry data is valuable for identifying spatial and temporal patterns associated with road crossings and avoidance. Specifically, high resolution, frequently collected GPS locations can help in assessing behavioral responses to roads and other landscape features and micro-habitat characteristics. GPS collars equipped with cameras can increase the ability to evaluate behavioral responses to natural and human-related stimuli.

**Figure 2-15 Example of a GPS collar fitted on a black bear.**

The six data collection methods described above have different positives and negatives associated with small vs. large animal evaluations and vary on costs, labor, highway safety concerns, and in road crossing identification (Table 2-1). The target species and the site characteristics should be considered before selecting one or more methods to employ. For broad species impacts or ecosystem-level examinations, combining multiple methods is strongly recommended for effectively identifying overall temporal and spatial patterns of wildlife-road interactions (see Sections 2-2, 4 and 5 for examples and more discussion).

One innovation in field studies not discussed here but deserves consideration is the collection and processing of environmental DNA (eDNA). New technology has enabled the potential for broad application in this frontier and could greatly benefit the intersection of ecology and transportation.

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**Figure 2-16 An example of radiotelemetry equipment;** a glue-on VHF radiotransmitter on a Florida box turtle (left) and field biologist tracking its location (right).

**Table 2-1 Comparison of different field data collection methods.**

| Method | highway safety risk | equipment cost | processing cost | labor intensive | medium to large animals | small animals | Road crossing identification | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | general | unsuccessful attempts | successful attempts |
| roadkill counts | medium | low | low | high | yes | yes | | yes | no |
| track counts* | medium | medium | low | high | yes | yes | yes | | |
| hair snares (genetics) | low | low | high | medium | yes | no | | | yes |
| camera traps | low | medium | medium | low | yes | no | | | yes |
| capture-mark-recapture | low | low | low | high | no | yes | | | yes |
| radio-telemetry (GPS)** | low | high | low | low | yes | no | yes | | |
| radio-telemetry (VHF)*** | low | medium | low | high | yes | yes | yes | | |

*Notes:*

**detection accuracy varies with species and quality of prints—dependent on substrate type and moisture content (i.e., ratio of sand, clay, organic); moist sandy soil with some clay and minimal organic mix is best.*

***road crossing location precision increases with higher location fix frequency (e.g., lower <– 60 min, 30 min, 15 min –> higher).*

****can identify road crossings, but location accuracy is unreliable due to infrequency of location fixes; this method would not be recommended for identifying frequency of road crossings or in identifying specific locations.*

## 2.3 Data Analysis and GIS Techniques

The approach to data analysis presented in this section focuses on the most common methods used to identify locations of highway-wildlife conflict and assess relative severity. For a broader account, consult one of the many references on current data analysis techniques and statistics. Presentation and analysis of data can be simple or complex. A simple study may only involve plotting abundance and distribution of roadkill or track data to denote spatial proportion of WVCs or wildlife activity along a road transect (see fig. 2-2). A more complex assessment would combine the field data with landscape and/or other environmental variables to investigate why certain locations are WVC hotspots or high concentrations of wildlife activity (see example in fig. 2-17).

### 2.3.1. Analysis of Roadkill, Track, and Hair Snare Data

Roadkill, track, and hair snare samples signify locations where animals approached a road. Roadkill represents unsuccessful attempts to cross a road. Track and hair snare sample locations may indicate either the location of a successful attempt to cross the road or simply where certain species are browsing or hunting along the roadside. An understanding of the behavioral characteristics of the species in question is necessary to answer that question. For example, white-tailed deer are frequent roadside browsers, while black bears do not forage on the grassy road shoulders. Although track and hair snare data from certain species may not indicate actual road crossing locations, it is valuable for locating clusters of high activity and indicating where road crossings are more probable.

Location data from roadkill, track, and hair-snare sampling surveys are useful in determining relative distribution and activity hotspots, and can also be combined with landscape, roadway, and environmental characteristics to evaluate spatial patterns over time. Besides establishing basic metrics of species abundance and richness, common statistical methods employed to perform spatial pattern analysis include frequency distribution and clustering techniques (e.g., Poisson distribution, kernel density estimate, Getis ord gi* hot and cold spots; see fig. 2-18).

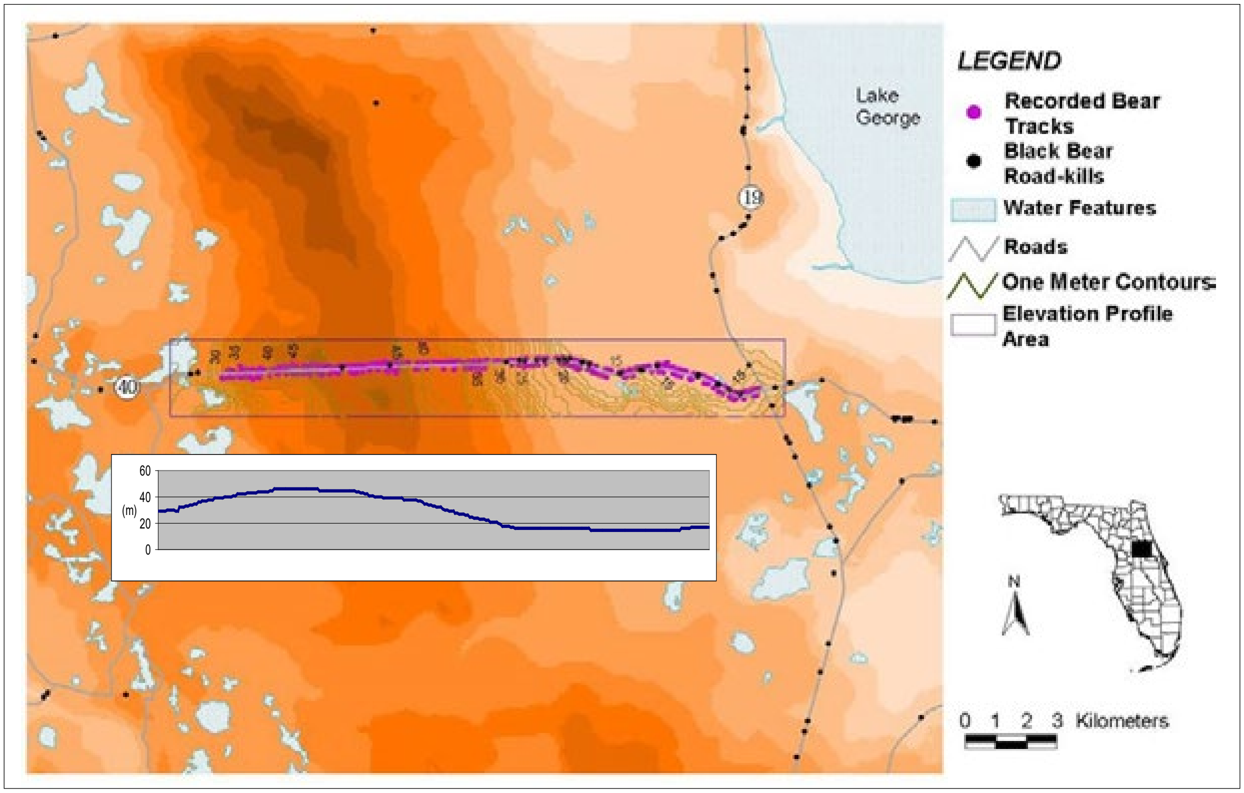


**Figure 2-17 Landform, road alignment and black bear roadkill trends.** Track data show that bear road crossings are continuous throughout this transect, but roadkill is concentrated at curved and sloped sections of State Road 40. These road conditions reduce driver sight-line visibility and increase risk and incidence of collisions with bears.

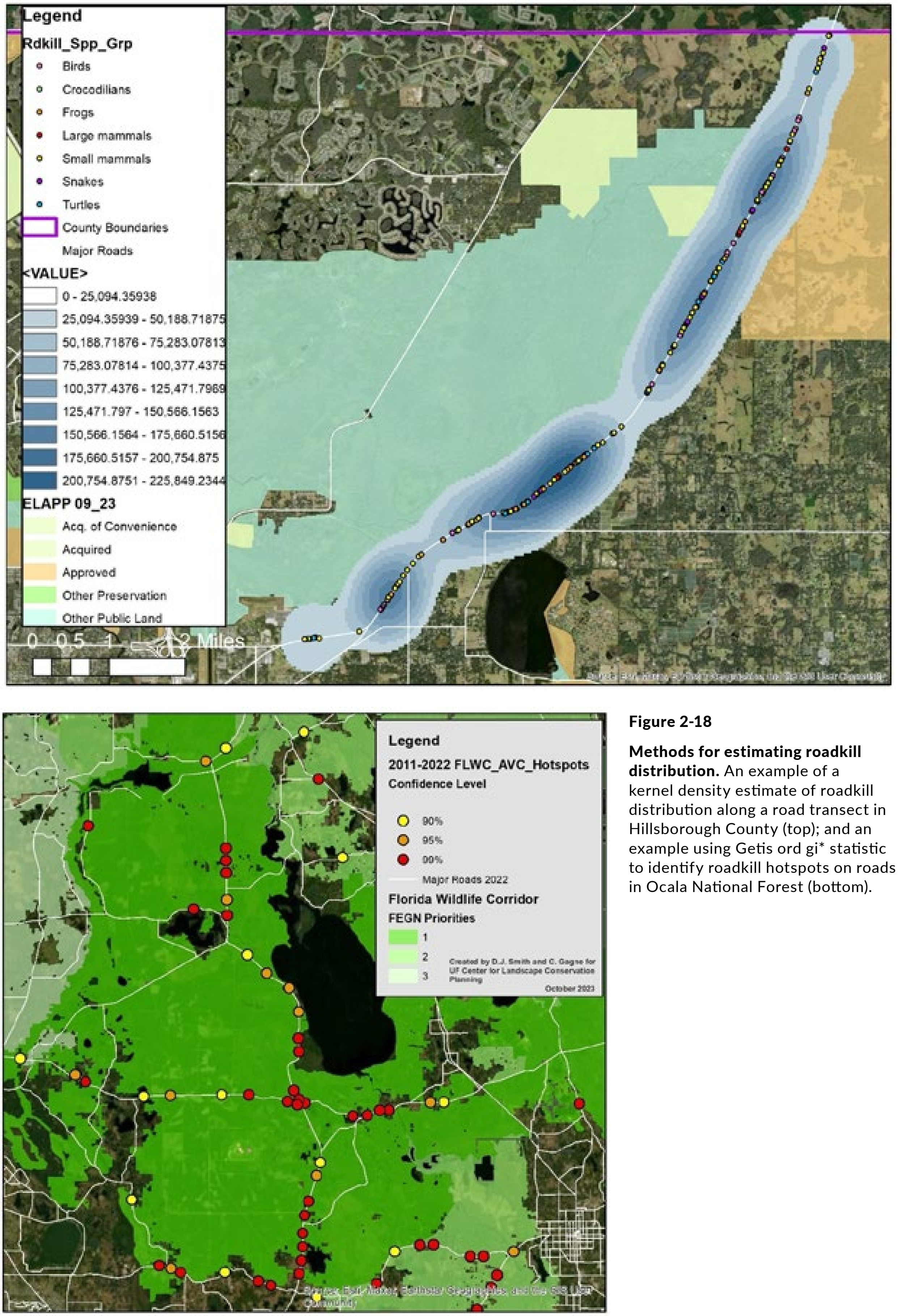


**Figure 2-18**

**Methods for estimating roadkill distribution.** An example of a kernel density estimate of roadkill distribution along a road transect in Hillsborough County (top); and an example using Getis ord gi* statistic to identify roadkill hotspots on roads in Ocala National Forest (bottom).

## 2.3.2. Analysis of Camera and Capture-Mark-Recapture Trapping Data

Digital camera traps as a survey method have dramatically expanded our ability to conduct reliable presence/absence and population census studies on medium to large animals. They also allow for effective 24/7 observations. This translates into enormous amounts of data (typically 10s to 100s of thousands of images to process). Machine learning program development is rapidly improving to help reduce time and labor necessary to process the image data for analysis. Types of analysis from camera data associated with wildlife-road interactions include identifying presence/absence within roadsides and estimating activity levels and road crossing frequency by medium to large animals (fig. 2-19). The variability in relative abundance and diversity of species adjacent to roads and attempting road crossings can be evaluated according to factors such as land cover type, clearance zone width, roadside tree and shrub cover, number of traffic lanes, and traffic volume.

Capture-mark-recapture trapping data are valuable for assessing small animal abundance and diversity at roadside-habitat edges and frequency of successful road crossing attempts (fig. 2-20). Adjacent land cover type, clearance zone width, roadside vegetation type and coverage, number of traffic lanes, and traffic volume can affect variance in species occupancy at roadside edge habitat and road crossing attempts.

## 2.3.3. Analysis of Movement Data (telemetry)

Analytical techniques for telemetry data emphasize locations of individuals in space and time. Typically, these techniques are used to identify habitat use preferences and estimate home range size and extent (fig. 2-21). They are also useful in identifying movement patterns and potentially road crossing locations and frequency. Identifying relatively precise road-crossing locations and movement pathways requires frequent position fixes (e.g., 15 min or less is best, but not always practical due to battery consumption of transmitters) (fig. 2-22). Telemetry can also inform about road avoidance (fig. 2-21) and failed crossing attempts (fig. 2-23). Analysis of telemetry data can provide insight into differential behavioral responses by gender and age of individuals to roads, for example road avoidance and road crossing frequency and location (e.g., in relation to habitat type, road and traffic characteristics, and physical features).

Other methods for analyzing animal movements include step-selection functions and individual-based movement models. These methods can also evaluate the significance of multiple environmental and anthropogenic covariates (e.g., distance to forest edge, forest cover, land cover type, number of lanes, traffic volume, season, and time of day).

**Figure 2-19**
**A trail camera image of a Florida panther crossing US 41** at night in BCNP.

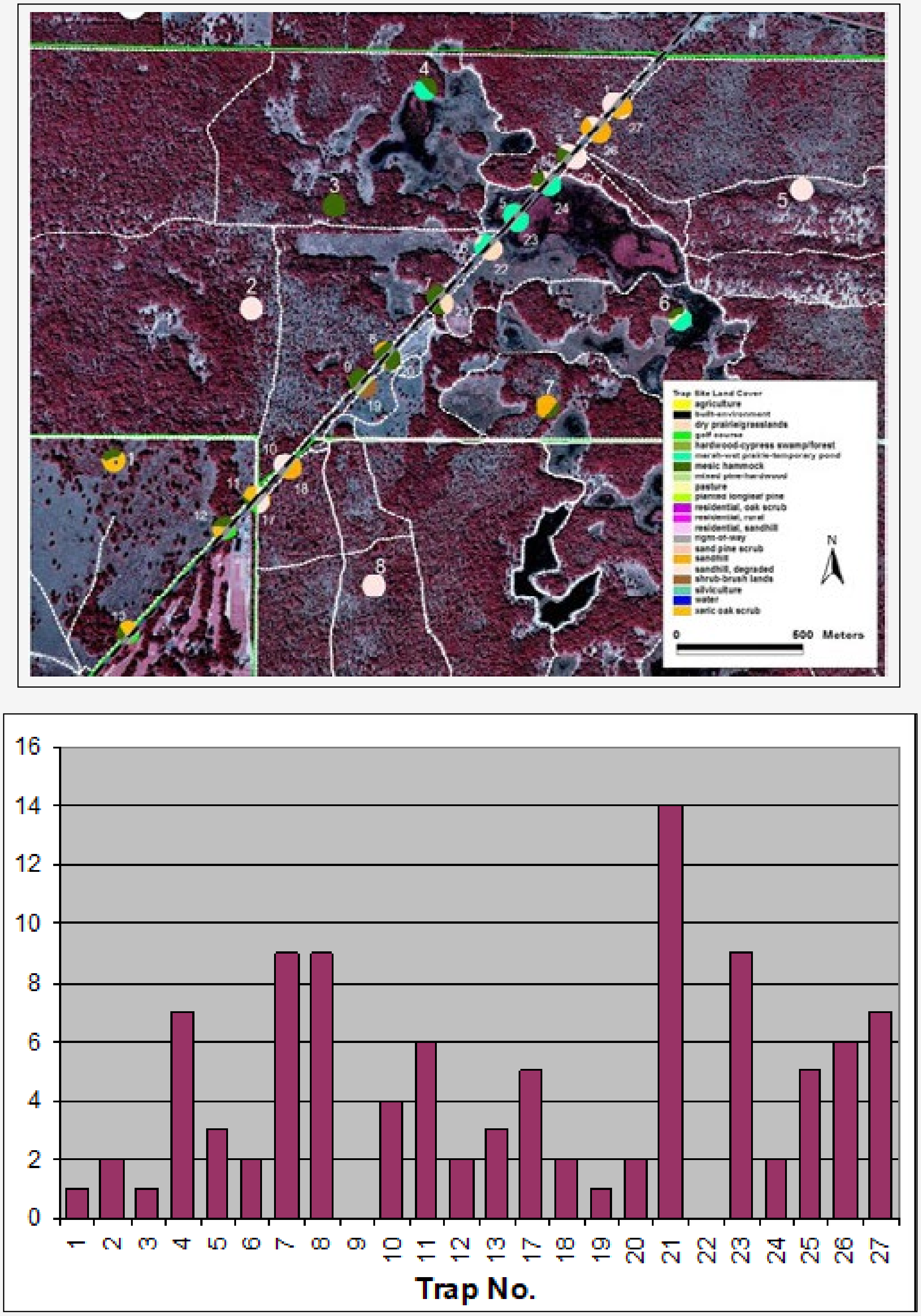
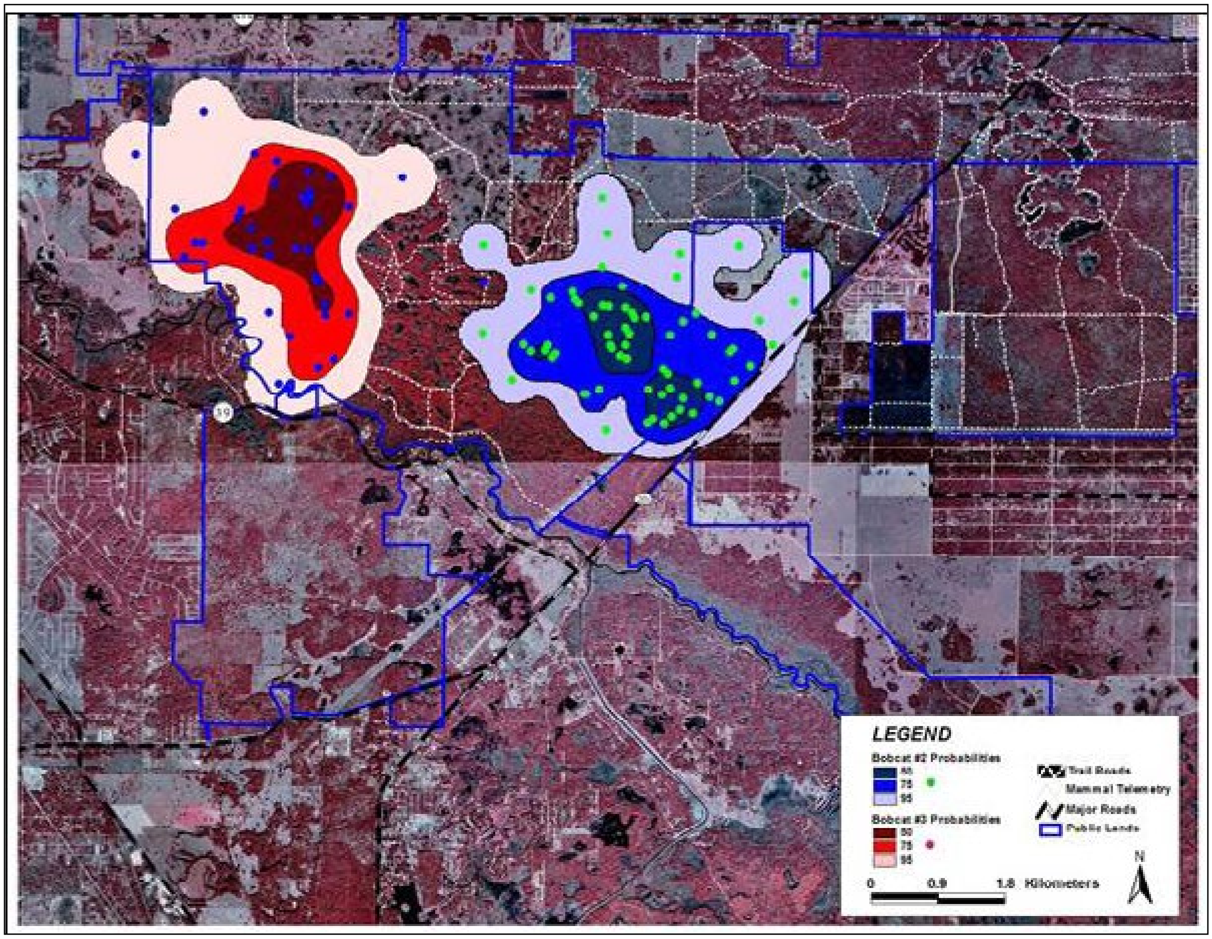


**Figure 2-20** **An example of drift fence trap arrays;** opposing locations along a road transect with replicates placed in representative land cover types (based on a 50m radius) (top). Spatial distribution of Florida mice captured in drift fence trap arrays (bottom).



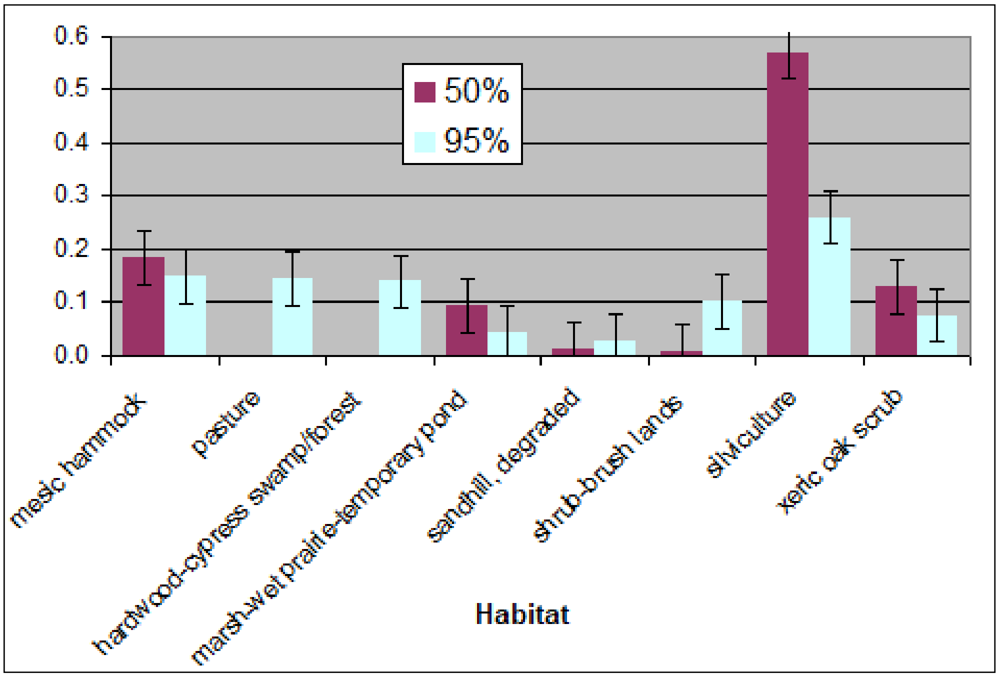


**Figure 2-21**

**Home range and habitat composition calculations**. Bobcat fixed kernel home ranges at 95%, 75%, and 50% (top), and percent habitat composition (bottom) near SR 200 in Halpata Tastanaki Preserve, Marion County. Note that Bobcat #2 likely uses the road as a home range boundary (no recorded crossing attempts).

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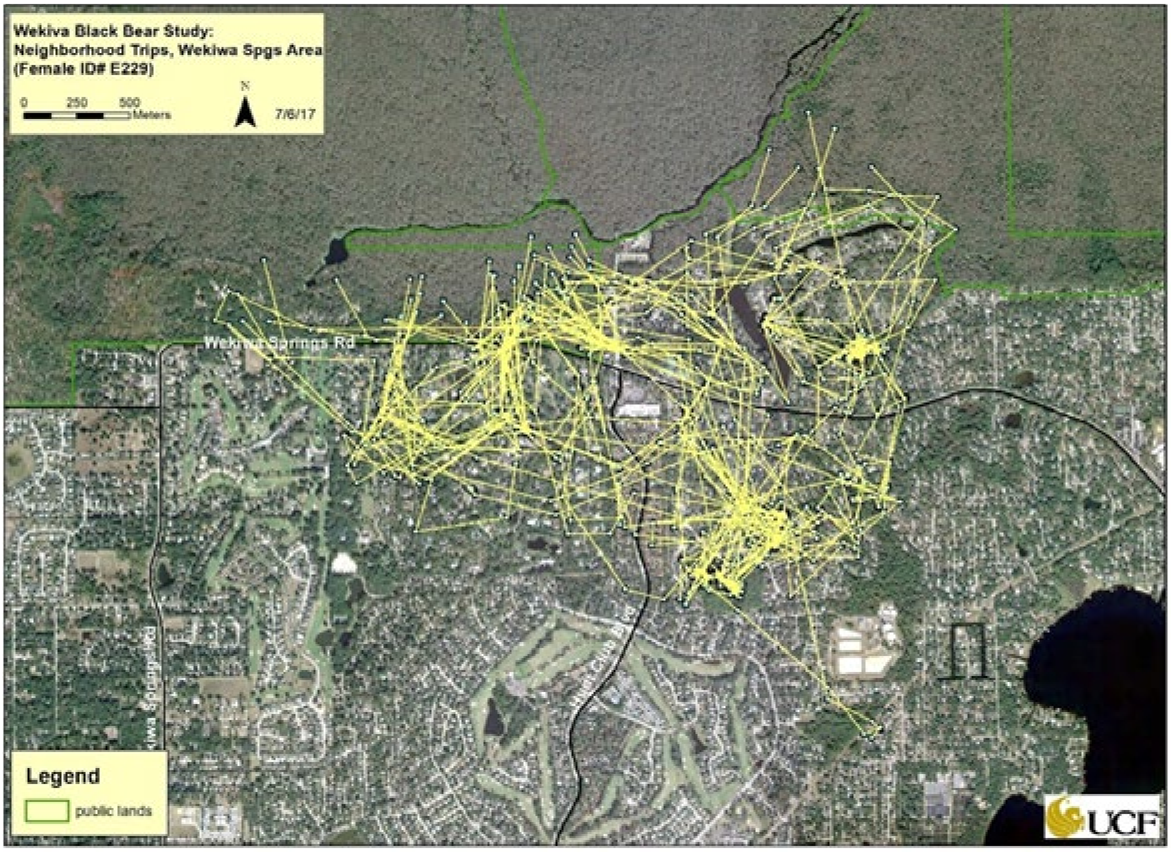


**Figure 2-22 An example of multiple road crossings by a black bear in the Wekiva River Basin.**

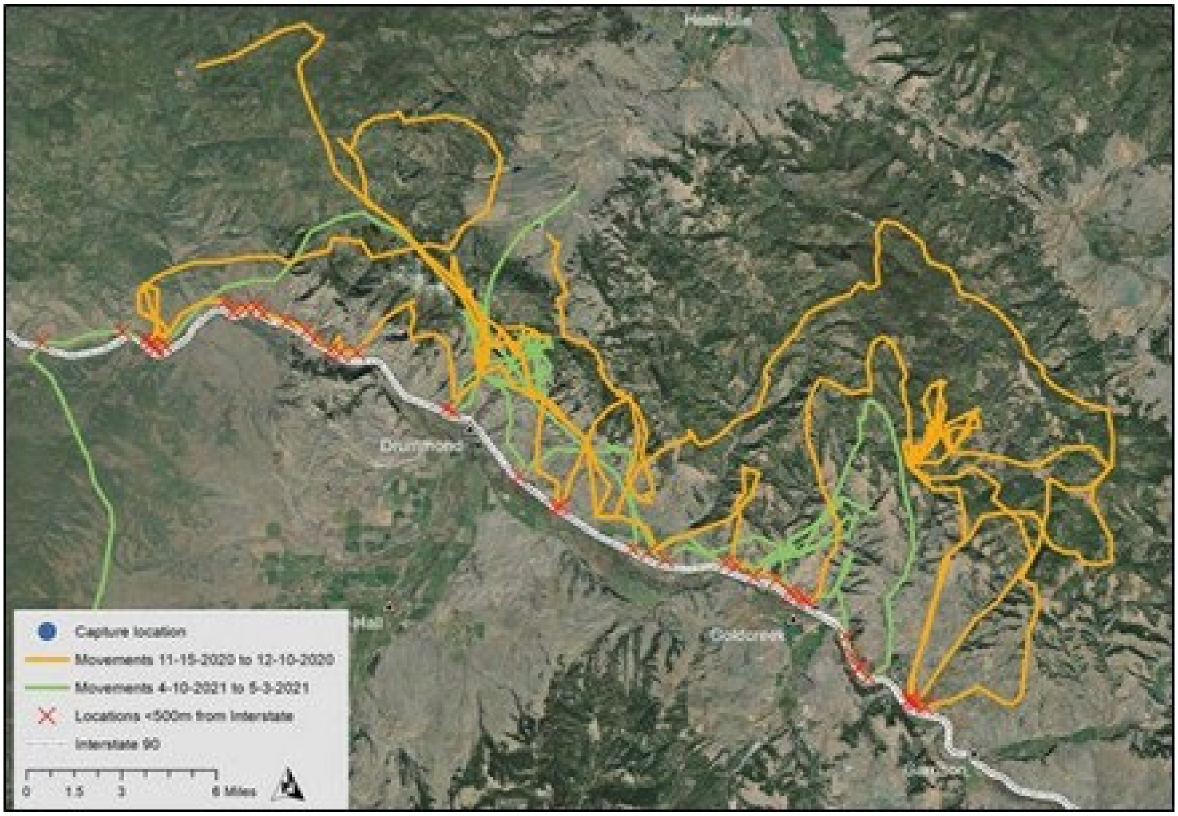
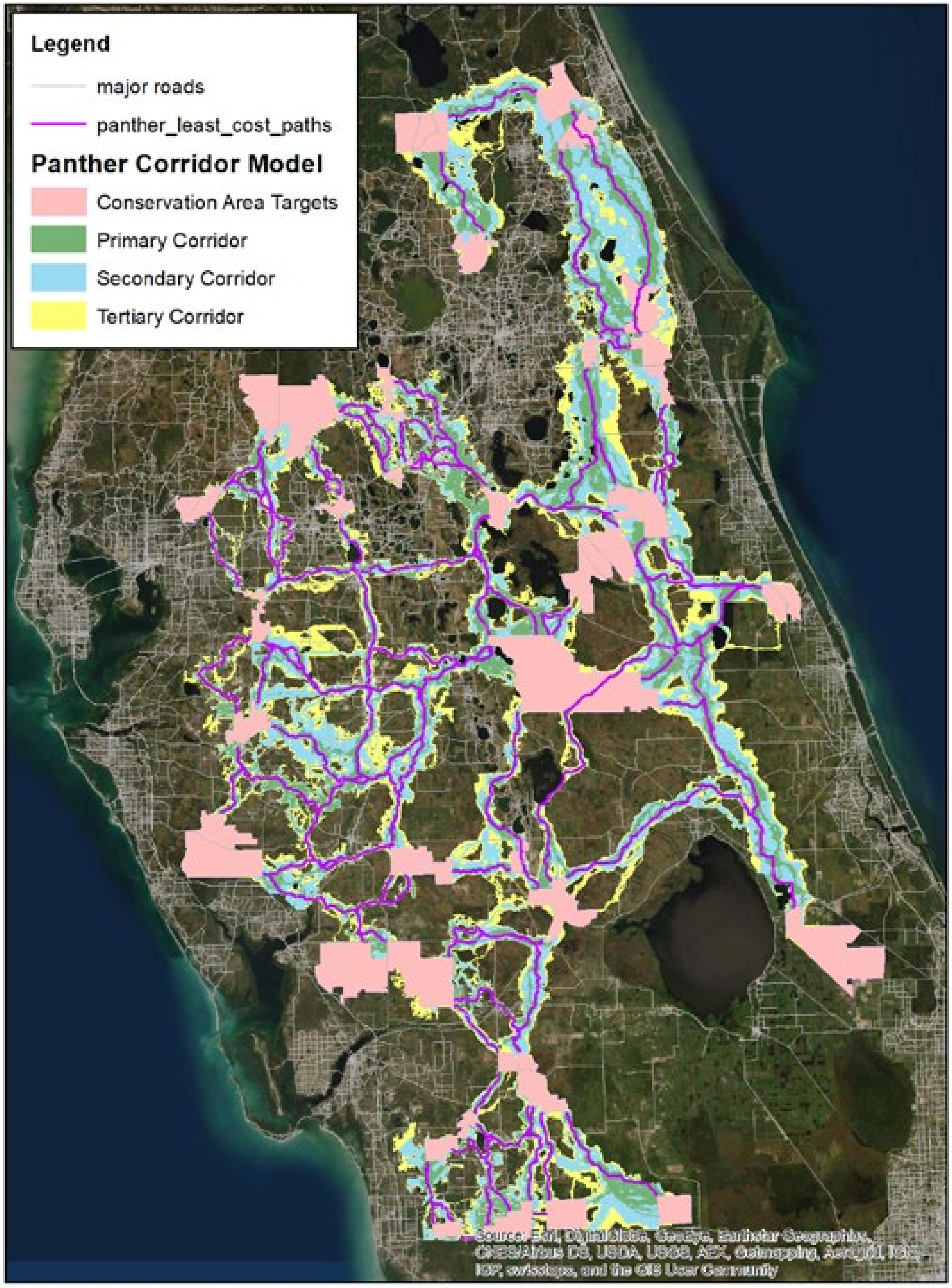


**Figure 2-23 Example of a grizzly bear making multiple attempts, unsuccessfully, to cross a major road in Montana** (source: Montana Fish, Wildlife and Parks).

### 2.3.4. Putting it all together: GIS and Modeling

Using GIS tools to model landscape, road and traffic, and wildlife data can help provide a complete picture of existing and potential road impacts at broad scales. One example used species-habitat preferences identified from GPS collar data of Florida panthers to construct a movement model to predict potential road-wildlife conflict locations (fig. 2-24). GIS is also a valuable tool at smaller scales, for example combining and analyzing the interrelationship between the various data types discussed above (fig. 2-25). Other examples of using GIS and spatial models are included in Section 5.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

**Figure 2-24 Results of least cost path and corridor modeling in ArcGIS.** The model identifies road segments that intersect predicted movement paths and corridors used by Florida panthers in south-central Florida.

**Figure 2-25 Combining multiple data types (roadkill, tracks, and hair snags)**. In this example, the spatial distribution of road crossing locations by black bears on SR 40 in Ocala National Forest is evaluated. Using multiple data derived from different methods can strengthen overall results and confirm or refute patterns from a lone source.

## 2.3.5. Assessing Effects of Roads on Wildlife Populations

The techniques described above generally identify the impacts of roads on individual animals but do not address the broader effects on animal population persistence and survival. Few studies include research into the latter, even though we are aware many thousands of animals are killed on roads every year in Florida. More research is needed on local population level effects including genetic diversity and integrity. To address the impacts to animal populations, it is necessary to obtain population density and abundance estimates. With these estimates, the relative impact of roads can be evaluated, for example the percentage of overall mortality due to roads in relation to population size. In other words, does roadkill contribute to a net decrease in local population size, and if so at what proportion and at what rate?

Population-level analyses can evaluate the relative impact of the many contributing sources of mortality and threats to population persistence. Understanding the effects of roads on the population can help in assessing urgency and need for mitigation. Other studies have evaluated the impact of roads on population-level genetics. For instance, with certain species, roads act as a significant barrier to movement and over time this can result in isolated and genetically distinct populations on either side of a road.

## 2.4 Environmental Impact Assessments

Environmental Impact Assessments (EIAs) typically involve data collection during the pre-construction phase to assess potential ecological impacts of proposed new roads or improvements to existing roads. The duration and emphasis of EIAs are highly variable, but they are generally brief (less than 1 year) and focused on one or more listed species. Assessments involving listed species, and state or federal lands may be required for compliance with state and federal law. Less typical are more comprehensive, research-related monitoring projects that quantify the impacts of existing roads or the success of mitigation over longer periods involving entire species assemblages. In situations involving certain environmentally sensitive locations and protected conservation areas, more comprehensive studies may be mandated as a special condition for approval of a project. In some cases, they are initiated and conducted more independently (such as by academics, citizen scientists, or governments), but outside the approval process for a major project. Impact studies encompass a range of methods and approaches, including (i) roadkill surveys; (ii) analyses of animal movements, such as road avoidance, barrier effects, and increased overlapping of home ranges; (iii) population-level studies that assess population size or density, survival rates, sex ratios, and reproductive output; and (iv) species occurrence and distribution. These studies occur at a range of spatial scales, from a single section of road to many roads. Most typically address effects on individual animals and occasionally populations, and recent reviews have recommended that studies need to be broadened to encompass communities, ecosystems, and ecosystem processes.

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# Section 3: Site and Structural Design

## 3.1 Introduction

In this section we explore the wide array of wildlife crossing types and designs, general site design principles, use of wildlife fencing, and alternative mitigation measures that improve the permeability of roads for wildlife. The section is split into several subsections that include basic concepts and practical examples.

- Site design considerations
- Structural types and preferences
- Fencing and other barriers
- Landscape parameters
- Alternative solutions

## 3.2 Site Design Considerations

Most wildlife impact studies and models (e.g., WVC hotspots analysis) only identify approximate locations where wildlife crossings are needed. Depending on the resolution of the analysis, these estimates may range from 10s to 100s of feet to a mile or more. Therefore, a contextual analysis should be conducted within the bounds of the approximate location before deciding the exact placement of the wildlife crossing. The contextual analysis includes documentation and mapping of existing roadway corridor configuration and adjacent natural features to inform decisions on appropriate placement and site design alternatives. Characteristics to consider include right-of-way and clearance zone widths, traffic volume, road geometry (curvature), pavement width, roadside terrain (ruggedness), drainage features, topographic relief (slope), adjacent land cover/land use, and secondary roads, driveways, and buildings. These factors can be used to identify constraints to siting of wildlife crossing structures or use of wildlife fencing, as well as identify the best opportunities to enhance ecological function. A contextual analysis increases our ability to optimize placement typically resulting in lower construction and maintenance costs, higher functionality for wildlife movement, and more effective habitat reintegration. There are several key considerations for site design that can lead to higher functionality and greater acceptance by a wide array of species. Overall wildlife use can be enhanced by including these favorable qualities:

- incorporate habitat preferences of the target species or groups, when possible;
- plantings in the crossing approach areas should be consistent with adjacent native plant communities (discussed in more detail in Section 3.5);
- use native soil types, consistent with adjacent habitat areas (discussed in more detail in Section 3.5);
- employ natural designs that take advantage of available topographic relief (fig. 3-1) to minimize need for fill or excavation (e.g., minimize slope of underpass/overpass approaches; improve wildlife and motorist visibility);
- use vegetative screening, berms, and/or walls to block headlights, diminish traffic noise and provide cover (fig. 3-2);
- roadside swales and drainage conveyances should not impede free movement of terrestrial species to and from the crossing (e.g., culverts should be used to create an even surface in the crossing approach areas (fig. 3-3));

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- when present, maintain or restore historic surface water features, flows and floodplain function (as part of the site and crossing structure design); this may require replacing an existing culvert with a bridge or replacing an existing, flowway-only bridge with a longer bridge that can accommodate dynamic floodplain functions (fig. 3-4);
- use wildlife fencing to funnel wildlife through the passage and away from the road surface (discussed in more detail in Section 3.4) and
- minimize human access that may deter use by sensitive wildlife.

**Figure 3-1 An example of a constructed overpass that takes advantage of natural topography (B38, Birkenau, Germany).** This reduces the need for fill and provides minimally sloped approaches for wildlife. Photo source: Berkshire Environmental Action Team (BEAT).

**Figure 3-2 Examples of the use of vegetative screening and walls.** Such measures reduce the effects of lights and noise from approaching traffic. Photo source: Siebe Swart Aerial Photography Luchtfotografie (left). Skyward Kick Productions (right).

**Figure 3-3 An example of engineering smooth, unimpeded approach areas**. Preferred when roadside swales are present for the transport of highway stormwater runoff.

**Figure 3-4 An example of wildlife fencing**. Designed to direct animals toward crossings and away from traffic lanes.

## 3.3 Structural Types and Preferences

Bridge and culvert designs must adhere to accepted industry standards and approved FDOT and FHWA engineering specifications. This document is meant to provide general guidance and does not explore detailed structural specifications and standards. We will discuss general types of structures, and their potential applications based on existing examples in Florida and elsewhere.

Crossing structures can be divided into three primary categories: overpasses, underpasses and multipurpose. Overpasses have also been described as land bridges or green bridges but are basically "safe passages" for wildlife over roadways. Underpasses are connections for wildlife under the road and can be in the form of culverts or bridges. Multipurpose structures can be overpasses or underpasses but also possess features associated with human use (e.g., trails, primitive forest or farm roads, water conveyance).

There are a couple basic rules of thumb when planning and designing wildlife crossing structures. For improving connectivity at a landscape scale (i.e., multi-species considerations), they include "bigger is better" and "more is preferable to less" regarding size and number of structures proposed in an area known for numerous wildlife crossings. The main argument against using these rules of thumb, however, is cost effectiveness. Planners and engineers are interested in promoting protection for wildlife and public safety but at optimum efficiency, which involves minimizing costs. The following table (Table 3-1) provides a general guide by structure type with advantages and disadvantages.

### 3.3.1. Species preferences

Preferences for types and characteristics of wildlife crossing structures differ between species and individuals within species. All species have certain habitat preferences, but some are generalists and others are specialists. Similar principles apply to crossing structure characteristics, but species such as raccoon and Virginia opossum will use nearly all structure types and sizes, whereas others may require special features. For example, smaller prey species (such as small rodents) may not use larger, open crossings that do not provide sufficient cover or concealment from avian and mammalian predators. Similarly, white-tailed deer may require clear sightlines from one side to the other to enter and move through crossings frequented by predators like Florida panther and bobcat. Intra- and inter-specific competition and predator-prey dynamics are applicable with wildlife crossings. Considering that wildlife crossings act as bottlenecks or pinchpoints of connectivity in the landscape, the presence of superior competitors or predators may reduce access by less competitive or vulnerable prey species. To overcome these constraints, designs

**Table 3-1 A general comparison of structure types.**

| | | | | | Traffic disturbance effects | |
|---|---|---|---|---|---|---|
| | Openess | Cost | Species diversity | Design flexibility | Noise/vibration | Headlights |
| **Larger Crossing Structures (widlife bridges)** | **High** | **High** | **High** | **High** | **Medium to high** | **Medium to high** |
| **Smaller Crossing Structures (culverts)** | **Low to medium** | **Low to medium** | **Medium** | **Medium** | **Low** | **Low to medium** |
| **Amphibian Tunnels (smalls specialty pipes)** | **Low** | **Low** | **Low** | **Low** | **Variable** | **Variable** |

must provide elements that accommodate prey, predators, and competitors. Reducing spacing intervals between crossing structures can also address these community interactions. In the absence of adequate species location data, spacing of crossings should be a distance comparable to the average female home range diameter and/or dispersal distance of the target species, though spatial extent and configuration of preferred habitat should also be a factor in the decision.

The key is to identify habitat features preferred by the target species and include them in the crossing design when possible. Consider Florida pine snake or southeastern pocket gopher, fossorial species that would prefer soft, sandy soils as opposed to denser, compacted soil types within the crossing structure and approach areas. Key elements associated with species preferences include landscape materials, soils and substrate, moisture, lighting conditions, temperature, and openness. More discussion on qualities associated with wildlife crossing preferences and their evaluation is included in Subsection 3.5 and in Section 4, respectively.

**Figure 3-5 Examples of different overpass types and sizes. Photo source:** Michielap/ Board Panda (top). Wageningen University & Research (bottom).

**Figure 3-6**

**A typical, rectangular style wildlife overpass.** Photo source: Obiektyw1855/Reddit.

**Figure 3-7**

**An example of the hourglass design for a wildlife overpass. Photo source:** 2010 Aerodata International Sruveys Google maps.

## 3.3.2. Overpasses

Overpasses provide continuous, suitable, native vegetative cover and soils consistent with the adjacent plant communities. They essentially form a landscape connection that mimics adjacent habitat and enhances wildlife use (fig. 3-5). These characteristics are the greatest advantage of an overpass. Disadvantages include potential land acquisition necessary outside the ROW to accommodate the space required for the landings of bridge approaches and the cost may be higher when compared to underpasses at the same location (largely influenced by site-specific characteristics and constraints—also see discussion above on contextual analysis).

Many sizes and shapes of wildlife overpasses have been constructed, most in Europe and Canada. Two basic deck shapes have been used, rectangular and hourglass (figs. 3-6 and 3-7). The hourglass shape is meant to reduce construction cost while increasing the range of full-length sightlines from one end to the other and to widen the approach capture area. Length and width of overpasses are highly variable, and no standard or minimums have been established. They range in width from 20 ft in Utah to 164 ft in Holland (112 ft on average, worldwide). Length is determined mostly by the width of the highway it crosses over. Recommendations seem consistent, with FHWA recommending widths from 165-230 ft and a recent synthesis paper that reviewed overpasses around the world finding that 164 ft average width and a width to length ratio of 0.8 were most ecologically sound and cost-effective.

A key factor to consider with an overpass is its load-bearing capacity. Typically overpasses contain soil and live plants, so the structural design must consider the weight of these components, which includes the potential amount of water contained in the soil. Two examples of bridge substructure designs employed to tackle this issue include heavy steel I-beams and steel-reinforced, precast concrete arches (figs. 3-8 and 3-9).

**Figure 3-8 An example of an overpass with typical beams and column supports.**

**Figure 3-9 An example of an overpass of pre-cast arch sections. Photo source:** Wildlife overpass in Banff National Park Photo: Parks Canada / Allie Banting / 2014.

There are several design considerations associated with the bridge deck and approach areas. These include the following:

- Soils should be of suitable quality and depth to sustain selected ground cover, shrubs, and small trees.
- Plant materials should be consistent with adjacent plant communities at the site.
- Soil depth should also be sufficient to enhance use by fossorial species (i.e., subterranean species like moles, shrews, snakes, legless lizards) that may be present at the site.
- Appropriate soil moisture level for plant health is important and may require special drainage considerations like percent slope and gravity flow rates, and special features such as gravel base treatments and drainage pipes.
- If the site is more xeric in nature and vegetation growth limited, use of "furniture" elements can be used to provide cover for smaller prey species, e.g., logs, brush piles, rocks (fig. 3-10).
- Approaches should include a gradual rather than a steep slope to reduce erosion potential and to provide more beneficial sight lines and visibility for wildlife.

A conceptual overpass design is shown in fig. 3-11 to illustrate the basic elements required to optimize function and minimize disturbance. Additional examples of overpass designs are included in Appendix II. More discussion of fencing and landscaping provisions is provided in subsections 3-4 and 3-5.

**Figure 3-10 An example of using rocks and logs on an overpass.** These materials provide shelter areas on the surface when establishing vegetation is difficult (note: these same materials can be used inside underpasses to provide cover under low light conditions). Photo source: Utah Division of Wildlife Resources.

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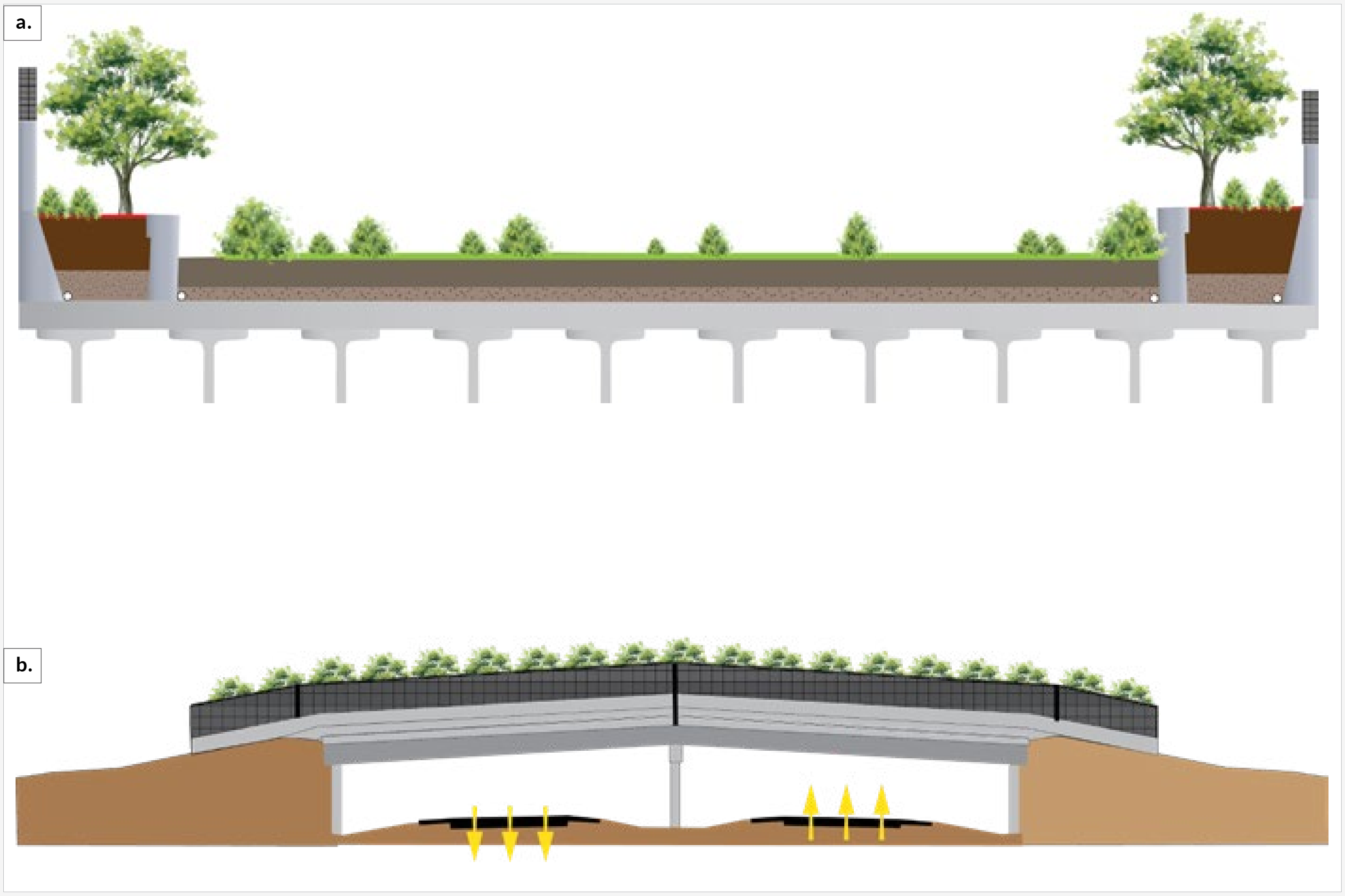

**Figure 3-11 A conceptual illustration of a cross-section (a) and highway view (b) for a functional overpass design.**

*Note the soil profile and depth (about 2 ft, above gravel base and drainage piping) and configuration of vegetation (provides continuous shrub cover along the sides and sporadic shrub cover patches in the center, but also clear sightlines across the structure); the planter boxes function to reduce traffic noise and light. This example generally represents a functioning crossing area of about 60 ft in width. Compare with examples in Figures 3-2, 3-6 & 3-7.*

### 3.3.3. Underpasses

Underpasses have two structural categories (bridges and culverts) that differ in size, shape, material, design and construction. The two basic applications of underpasses in Florida include those associated with primary conveyance of rivers, streams, and artificial waterways or drainage flows and those associated with uplands (fig. 3-12). In the former case, the underpass includes shelves or earthen ledges for passage of terrestrial species adjacent to the watercourse (fig. 3-13). For resilience planning, a conceptual design of an underpass that accommodates a river or stream would allow for a shifting channel and floodplain dynamics, and include provision for long term, terrestrial passage (fig. 3-14). Basic types and design alternatives for bridges and culverts are discussed below, accompanied by examples in illustrations and images (also see Appendix II).

Typical underpass bridge designs include those with open, single spans (fig. 3-15) and those with single or multiple support pilings or columns (fig. 3-16). Open, single spans provide unobstructed, clear views through the crossing but are limited in length, unlike bridges with supporting columns. It is unknown if either type limits use by any species of wildlife. Cost and site-specifics may play a role in selecting the most appropriate design type. Another variation in bridge type includes flat-slab and I-beam construction (fig. 3-17). This is important because bridge types differ in their ability to reduce traffic noise and vibration inside the wildlife crossing. For instance, I-beam bridges seem more effective at dampening vibrations and reducing noise from vehicle tires than flat-slab bridges. Clearance height can also influence vibration effects, e.g., the higher the bridge, the lower the impact of noise and vibrations at ground level.

**Figure 3-12 An example of a wildlife underpass typical in upland locations** (I-75, Alligator Alley in Collier County).

**Figure 3-13 An example of a wildlife underpass associated with water features** (US 192, Crabgrass Creek in Osceola County). In this case broad, earthen ledges were provided on each side of the creek for use by terrestrial species.

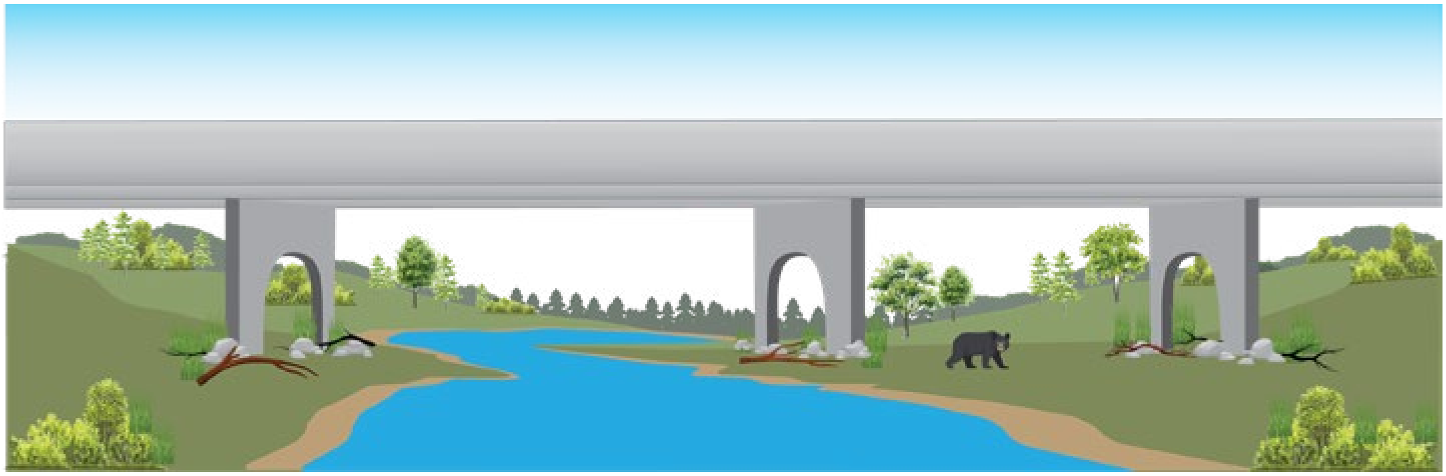

**Figure 3-14 A conceptual illustration of an underpass that considers long-term resilience and climate change adaptation**; broader, it incorporates changing stream and floodplain dynamics and provision for long-term terrestrial wildlife passage.

**Figure 3-15 An open, single span wildlife underpass design** (Wekiva Parkway).

**Figure 3-16 A wildlife crossing bridge design with typical support columns** (SR 46, Rock Springs Run SP).

**Figure 3-17 Examples of wildlife underpasses of flat slab (left) and I-beam (right) construction.**

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### 3.3.4. Culverts

Culverts come in several shapes and sizes but are limited in maximum height and width when compared to bridges. The wider ones (20 ft or more) are considered bridge culverts. Figure 3-18 provides a set of concept drawings of basic culvert designs used in Florida for wildlife passage purposes. Culverts can be rectangular, round, elliptical or oval, and arch shaped (fig. 3-19), and are constructed of concrete or corrugated steel (curved shapes only). Culverts are generally a more economical alternative to bridges and suitable to multiple site conditions. Culverts also function better at minimizing traffic-related vibrations and noise. This is because the construction includes a substantial layer of soil between the structure and the pavement layers that effectively captures and dissipates most vibrations and noise.

There are several internal qualities for both bridge and culvert underpasses that can affect wildlife use. Among these are lighting, surface soils or substrate, cover/concealment for prey species, and adaptation to environmental variability, as explained below. Finally, additional examples of the broad range of underpass designs are included in Appendix II.

- A frequently used metric to evaluate species acceptance of different sized underpasses is openness value (height*width/length). Higher openness values enhance use by a broader range of species by providing more natural light penetration, particularly those deterred by a long, dark "tunnel" effect (mostly applies to culverts). The tunnel effect can be further reduced by providing light penetration through openings in medians of divided highways (fig. 3-20).

- Conditions within the crossing structure should include natural light characteristics across normal diel periods. Some studies have investigated the use of solar tubes and artificial lighting to more closely emulate daytime light levels in culverts where lighting is more challenging. More investigation into these measures is needed to evaluate the effect on wildlife use of crossings.

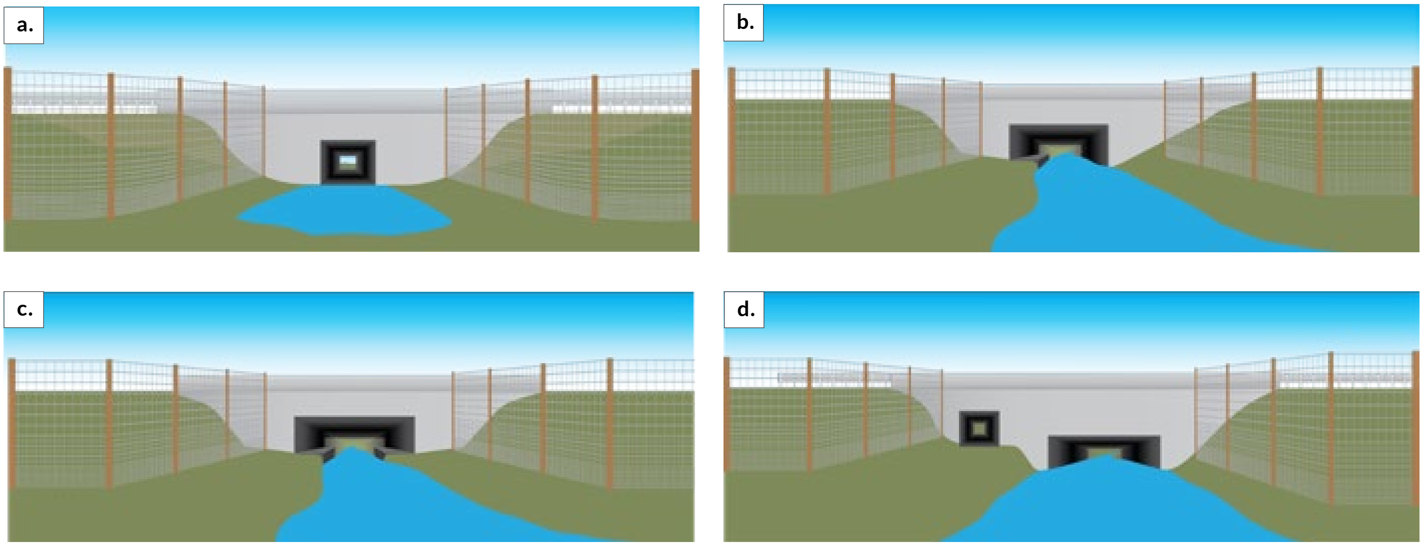

**Figure 3-18 Conceptual illustrations of basic culvert designs for wildlife passage**: a) standard, provides intermittent passage for terrestrial wildlife when water levels are low, b) includes a single, raised shelf, c) includes twin raised shelves, and d) includes a separate culvert at a higher elevation for terrestrial passage (one on each side is recommended).

- Like overpasses, native soil substrates should be used to satisfy needs of most species (depth should be sufficient to enhance use by fossorial species) in cases where this isn't practical other surface materials used include raised beds of soil/pea gravel mixture, blocks filled with pea gravel, cement sandbags, etc. (fig. 3-21).
- Where vegetation is not practical, improving cover for concealment of vulnerable small prey species in underpasses can be accomplished by installing "furniture", e.g., logs, brush piles, rock walls (fig. 3-22).
- Underpass designs should be adaptable to environmental variability. Those associated with surface waters and wetlands should provide terrestrial passage during periods of high-water levels (fig. 3-23).

**Figure 3-20** **An example of a steel grate**; installed to allow light penetration in the center of the culvert tunnel.

**Figure 3-19** **Examples of the different types of wildlife crossing culvert designs** (a and d, uplands; b and c, streams). Also see others in fig. 3-28 and the Appendix. Photo source (c): Ryan Haggerty (USFWS).

**Figure 3-21**

**Examples of using manufactured surface materials for wildlife pathways adjacent to water features**, e.g., blocks filled with pea gravel, cement sandbags, and raised beds of soil/pea gravel mixture. See the Appendix for more variations.

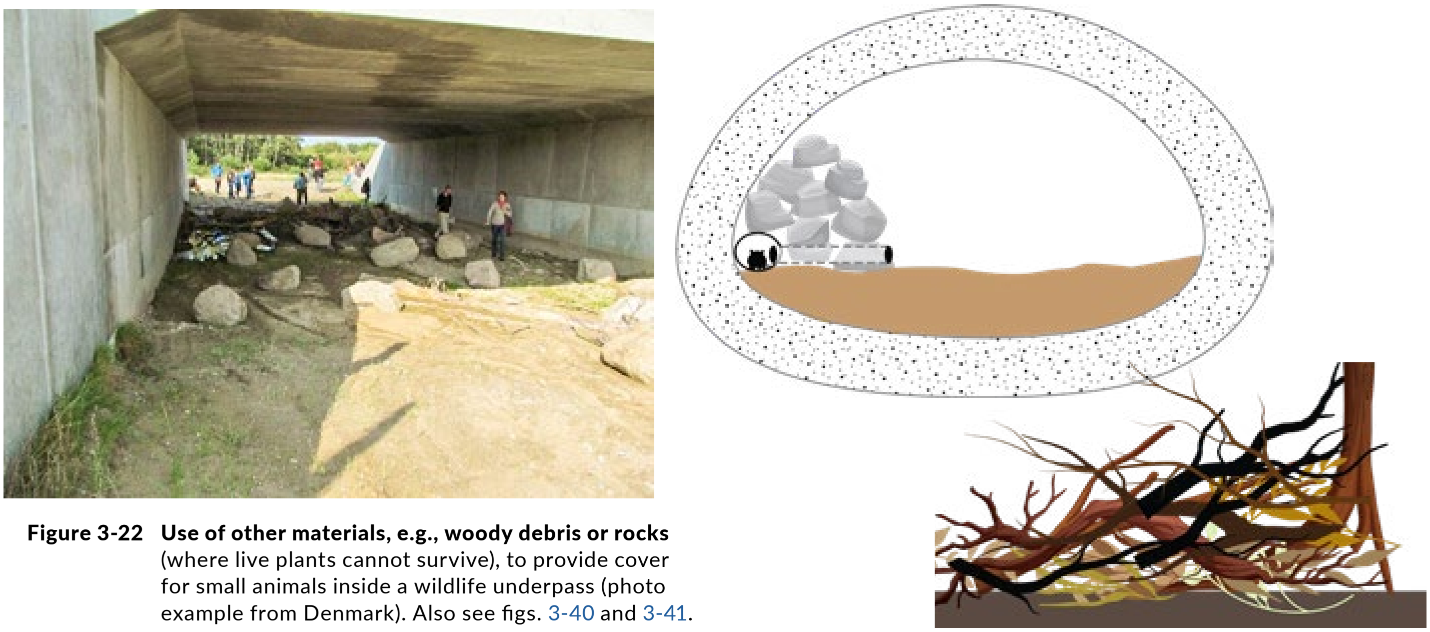

**Figure 3-22 Use of other materials, e.g., woody debris or rocks** (where live plants cannot survive), to provide cover for small animals inside a wildlife underpass (photo example from Denmark). Also see figs. 3-40 and 3-41.

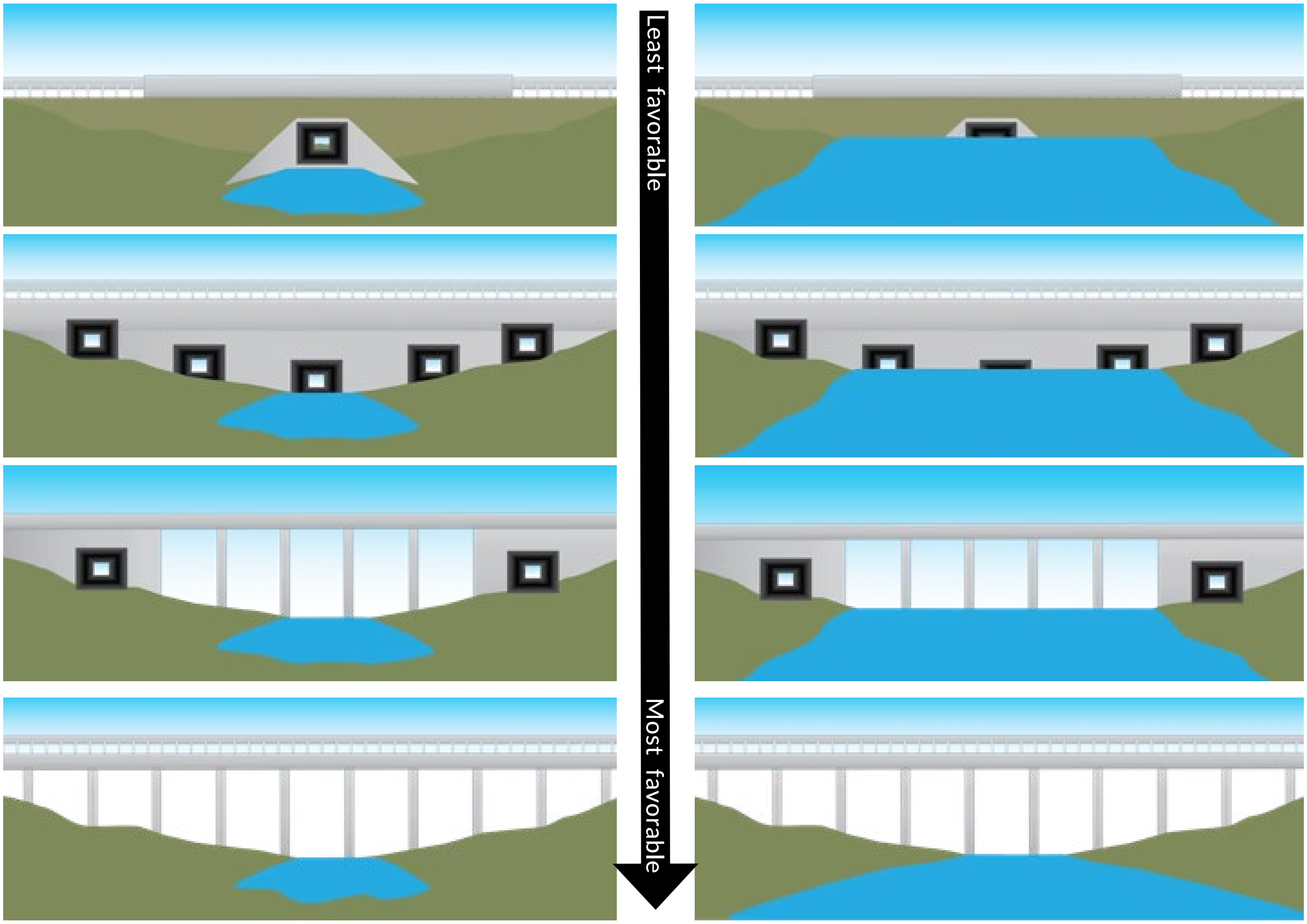

**Figure 3-23 Alternative bridge and culvert design adaptations for water features.** While the top two panels do not facilitate safe passage of terrestrial species, the lower three panels illustrate various configurations to accommodate terrestrial species during low (left) and relatively high-water (right) periods.

### 3.3.5. Multi-purpose crossing structures

Multi-purpose crossing structures accommodate people and/or vehicles and wildlife and can be overpasses or underpasses. The most common combinations are 1) nature trail and wildlife and 2) limited access forest, farm, or rural unpaved road and wildlife. Multi-purpose overpasses have been constructed in many European countries, but only a few exist in the United States and Canada. A cross-section of a conceptual design for a multi-purpose overpass is provided in Figure 3-24. The illustrated example highlights key design elements, and the placement and separation of human use areas intended to minimize disturbance to the wildlife use area. An in-practice example of a similar design is shown in Figure 3-25. There are potential opportunities (e.g., urban-rural interfaces) in Florida where multi-purpose crossing structures could be the best option to improve landscape connectivity. Additional multi-purpose crossing examples are included in Appendix II.

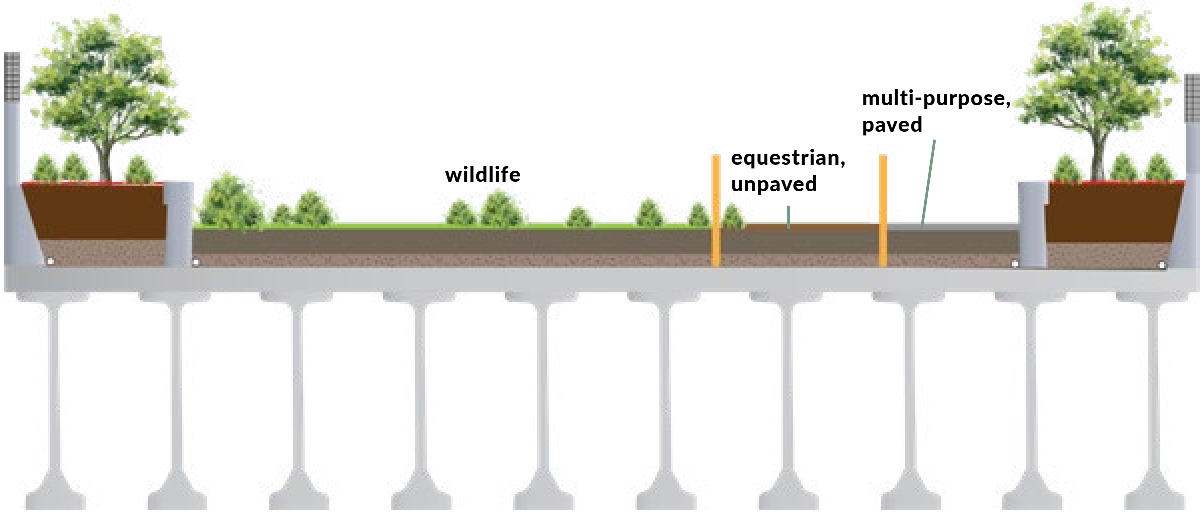

**Figure 3-24 This illustration is a conceptual design for a multi-purpose crossing.** It includes separate sections for wildlife, horseback, and general paved-trail users. Each section is separated by a 4-5 ft high, 4-rail wooden fence. A vegetative screen is included between the trail and wildlife zones. The basic characteristics of the crossing are like those shown in Figure 3-11.

**Figure 3-25 An example of a multi-purpose overpass from Europe. It includes variably landscaped wildlife and paved trail sections. Photo source:** GLF Media.

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## 3.4 Wildlife Fencing and other Barriers

Wildlife fencing provides two primary functions: reducing collisions and facilitating use of crossing structures. In many cases, wildlife fencing has been used as a relatively low-cost, primary measure to reduce WVCs, yet when not combined with crossing structures a recognized negative effect is greater habitat fragmentation, and potential separation and isolation of wildlife sub-populations. When combined with wildlife crossing structures, fragmentation effects of fencing can be alleviated. Contrarily, without fencing, reduction rates of WVCs associated with wildlife crossing structures can drop significantly. Therefore, wildlife fencing is a key element in increasing the effectiveness of crossing structures and together they are reported to reduce WVCs by 87% or higher.

The design aspects for fencing are important to maximize the function of wildlife crossing structures. There are several types of fencing specific to large and small animals. Below is a list of the most common options. There is wide variation, and each has advantages and disadvantages.

- wire fencing
- electrified fencing
- barrier walls
- mesh, hardware cloth
- temporary (silt fences, aluminum flashing)

### 3.4.1. Fencing for large wildlife

The most common wire fencing used for wildlife includes field or farm fencing and chain-link. The most effective farm or field fences for wildlife are 2" x 4" vertically oriented, welded, rectangle style and the graduated, welded rectangle style (smaller openings at the bottom to larger at the top) (fig. 3-26). Both styles reduce the ability of medium-to-large animals to penetrate the fence but are not effective for small animals. Chain-link has smaller, diamond-oriented squares that are more difficult for larger animals to climb (fig. 3-26) yet is considered less appealing aesthetically. Chain-link is more expensive than field fence.

Based on observed performance from several projects, the preferred height to prevent trespass

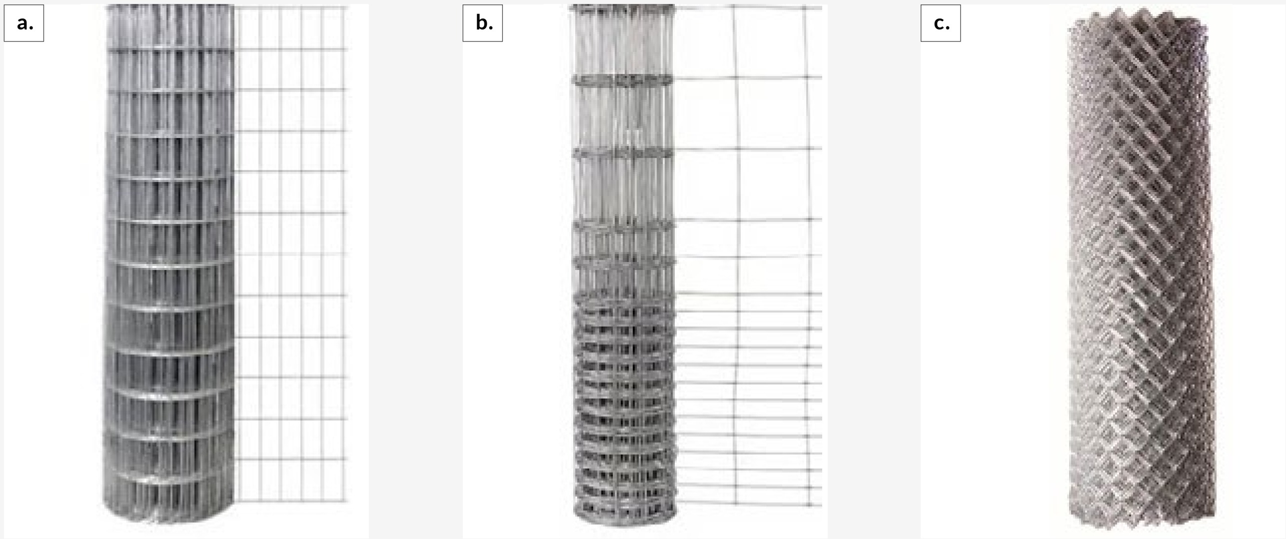

**Figure 3-26** **Typical large-species wildlife fencing**. Depicted in a and b above are vertically oriented and horizontally oriented (and graduated in size from bottom to top) rectangle-shaped, welded, galvanized material. Panel c displays standard, galvanized chain-link fencing. Fencing is typically zinc-coated and corrosion resistant but can also be purchased with naturally colored vinyl coating. The vinyl coating lengthens the fence life but is not recommended in areas where prescribed fire is used. For natural looking wire in fire prone areas, there is a commercially available galvanized metal with stain coating.

by white-tailed deer is 8 ft, and for Florida panther and black bear the recommended height is 10 ft (fig. 3-27). These applications typically include the addition of barbed-wire strands along the top. For medium-sized wildlife, a standard 6-ft high, field fence would be sufficient to prevent intrusion.

Electrified fencing is not commonly used for wildlife, but there have been specialty applications that use this technology for medium to large animals. One example in Volusia County, Florida paired field fencing with *Electrobraid* copper wire strands above the standard field fence height (fig. 3-28).

Retaining walls and wing walls are commonly employed as part of the wildlife crossing structure and sometimes used in approach areas in place of earthen slopes (see figs. 3-17 and 3-19). These are effective in directing medium-to-large wildlife toward the structure but are generally cost prohibitive to use for any lengthy stretch of the road. Most often wire fencing is used instead for that purpose.

**Figure 3-27 An example of large animal, wildlife fencing**; installed on SR 29 to prevent intrusion by Florida panther (specs: 10 ft height, chain-link with 3-strand, barbed-wire outrigger at the top).

**Figure 3-28 Use of Electrobraid strand fencing to deter climbing and jumping by large animals**. Standard 4.5 ft field fence is included at the base for small-medium sized, wildlife species.

## 3.4.2. Wildlife fencing for small animals

Concrete retaining walls have been used in a special context as barriers to keep climbing and jumping reptiles and amphibians off roads (fig. 3-29). Paired with crossing culverts, these make a highly effective system to reduce roadkill and improve highway permeability for small animals. Appropriate at wetland and semi-aquatic sites, two have been constructed (near Gainesville and Tallahassee) and a third is planned in Marion County, Florida. A conceptual example was provided in Figure 3-22. A disadvantage is a significant cost disparity; and though more expensive, the walls have greater longevity and less maintenance needs than other small animal fencing materials.

Another experimental solid barrier, thrie beam guardrail was used in Paynes Prairie adjacent to primarily upland, privately owned land (fig. 3-30). Its effectiveness in preventing trespass by various species of herpetofauna and small mammals was poor, but more due to failure of hardware cloth used to fill the gap between the guardrail and the ground. A more sturdy and durable material may improve overall effectiveness.

The most common material used for small animals is mesh fencing. It is more economical and comes in vinyl and metal forms. The most durable is a galvanized mesh (hardware cloth) that is commercially available. It comes in different sizes, but a ¼-inch cell size is most effective in preventing penetration by most small vertebrates (fig. 3-31). Aluminum and vinyl options are also available in this mesh size. Each type of material has its strengths and weaknesses, and cost is variable. The project location and potential exposure to inundation, natural corrosives (e.g., salinity), and sunlight should

**Figure 3-29 An image of the Paynes Prairie State Preserve herpetofauna barrier wall on US 441**. On average the wall is 4 ft above grade and includes an overhanging lip to help prevent climbing.

**Figure 3-30 Installation of thrie-beam guardrail (in the background)** used as a barrier to prevent trespass by small mammals and herpetofauna in Paynes Prairie State Preserve.

be carefully considered in conjunction with the qualities of each material type before selection. The recommended minimum height from ground level is 4 ft to prevent climbing by most large snakes. A height of 3 ft will prevent climbing by most medium-size snakes and jumping by most frog species (note: this material is not effective for tree frogs). There have been reports of stress in desert tortoise (Gopherus agassizii) in response to transparent fences. Opaque barriers were shown not to generate an adverse response. Similar responses may occur with other species. In multi-species applications, the small and large animal fencing is typically paired during installation (fig. 3-32). There are other fence materials that have been used as a temporary measure and for research that are effective at preventing intrusion by many small wildlife species. The two most common fences for this purpose are silt fences (commonly used in the construction industry) and aluminum flashing. The silt fence is an inexpensive alternative, but it typically only lasts 1-2 years due to ultraviolet light exposure. Aluminum flashing is durable, strong, and corrosion resistant, however it is expensive, physically difficult to work with (too rigid and sharp), and is not compatible with stormwater management.

### 3.4.3. Installation

There are a few key issues associated with installation that can influence effectiveness, increase durability and reduce the need for continual maintenance and repairs. All wildlife fencing should be buried at least 1 ft below the surface of the ground to deter digging by various wildlife. For larger wildlife, the fence posts and the fasteners used to attach the fence to the posts should be strong enough to withstand heavy leaning, pushing, pulling, and attempted climbs by very strong, individual animals (e.g., adult black bears). Wildlife fence placement is typically set at the right-of-way property boundary, but often this is too close to denser, adjacent habitat vegetation (thick ground cover, vines, and shrubs). This vegetation can allow many smaller animals to climb up the vegetation and get over fences. Placing the wildlife fencing a few feet inside the right-of-way may allow for easier management of vegetation on both sides of the fence.

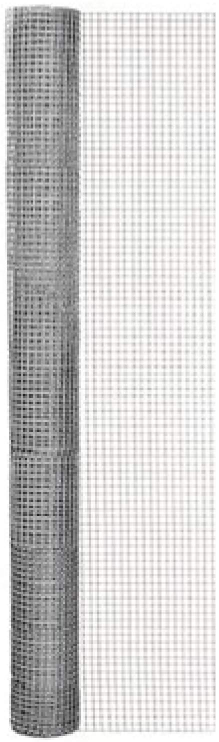

**Figure 3-31 Galvanized ¼ in mesh hardware cloth.** Useful as a barrier fence for most small mammals and herpetofauna. Also available in vinyl.

**Figure 3-32 Combining fence materials to address small and large wildlife species**. At the base is a 3 ft high ¼ mesh attached to an 8 ft high field fence and a 3 ft section of barbed wire with outrigger on top (the fences are also buried 1 ft to discourage digging).

Another issue to pay attention to with installation is the attachment to wildlife crossing structures. In several cases, fences not securely attached to the structure provide gaps for animals to intrude into the highway side of the fence enclosure creating a potential collision hazard. End posts need to be secured to the side of a culvert or bridge abutment in a location that precludes jumping or climbing (fig. 3-33).

The distance that fencing should extend beyond the crossing structure is largely dependent on spatial distribution of road mortality data and the movement ecology and habitat preferences of the target species or species groups. In absence of road mortality data, three parameters have been used to determine an appropriate length of wildlife fencing (i.e., target species averages of home range diameter and dispersal distance, and extent and configuration of preferred habitat type). Several constraints like intersecting roads and driveways, and access to private lands may result in fence gaps. Fence gaps are addressed in the next section.

### 3.4.4. Specialized devices

Several specialized measures have been developed to address unavoidable fence gaps like intersections and other vehicle access points where gates are not practical. Examples include specialized livestock guards

**Figure 3-33 Examples of fence gaps that potentially allow wildlife to access the road.** End posts need to be placed directly against the structure and the fence needs to be continuous across corner and median gaps where animals can traverse slopes and hop over short barrier walls.

(designed for wildlife), electromats, and electrified pavement (fig. 3-34). These devices allow free movement of traffic but deter trespass by wildlife. Their effectiveness can be variable depending on the animal's ability to leap more than 6-8 ft forward or maneuver along the outer edges of a modified cattle guard frame. The electrified measures are typically solar powered.

Specialized mechanisms have also been designed to assist animals accidentally trapped on the highway side of a fenced section to escape safely and avoid potential collisions. Examples of these include jumpouts, one-way gates, and in-fence chutes (fig. 3-35). Jumpouts have been constructed on a few roads in association with wildlife crossing projects (e.g., Wekiva Parkway, I-4, SR 415). While jumpouts have a proven record of success for ungulates in western states and Canada, we do not have any data on their use or effectiveness in preventing collisions in Florida. Most one-way gates have produced inconsistent results. More research and development are needed to improve these solutions. One recent experiment involved the design of alternative escape mechanisms installed in roadside wildlife fencing for ocelots in Texas (fig. 3-36).

**Figure 3-34 Wildlife trespass deterrents at access roads that intersect fenced road sections.** An electromat device installed on an access road that intersects SR 415 in Volusia County (left), and a double-sized wildlife guard in Arizona (right).

**Figure 3-35 An example of a jumpout and a one-way gate;** on SR 415 in Volusia County and in California, respectively.

**Figure 3-36 Experimental escape chute design alternatives installed in a highway wildlife exclusion fence**. This device was designed for ocelots in Texas (photo credits: John Young, TxDOT).

## 3.5 Landscape Parameters

Landscaping of wildlife crossing sites is important to promote use by most species and essential for prey species and others sensitive to exposure. The three main zones of wildlife crossing structure projects for which to develop landscape plans include approaches, overpass deck areas and underpass interiors. General landscape design components and guidelines include:

- Terrain
- Use native soils
- Contouring should gradually slope away from the structure to allow natural drainage and prevent internal flooding and erosion
- Vegetation
- Use native tree, shrub, and ground-cover species to provide cover and shelter
- Mimic adjacent plant community composition, diversity and density
- Incorporate clear sight-line paths in landscape planting plans
- Special features (sometime referred to as "crossing furniture")
- If underpass light levels are too low to establish vegetation in the interior, use rock ledges, brush piles, or other elements to provide cover for small prey species
- Incorporate special attractants, such as water features (when appropriate)

### 3.5.1. Approach areas

The approach areas should be consistent with adjacent habitat to bring normal wildlife activity closer and facilitate movement toward the crossing structure. To achieve the latter, it is not only important to use native ground cover, shrub, and tree layers (fig. 3-37), but to also provide screening from the roadway to minimize visual disturbance from vehicle traffic as well as light and noise intrusion. It may be necessary to combine vegetative screening with berms, fencing, or walls (fig. 3-2). Mimicking the adjacent habitat would also include the use of logs, stumps, and woody debris, and perhaps some rock outcroppings (in karst locations). These elements all provide cover for smaller prey species.

### 3.5.2. Overpass deck areas

Landscaping strategies were previously discussed in subsection 3.3.2, and in this subsection, a basic, conceptual landscape plan is presented (fig. 3-38). The plan uses zones to prescribe different planting densities with the intent of providing cover for species that prefer concealment along the outer edges and clear sightlines in the interior for predator-wary species such as white-tailed deer that like to see what might be at the other end of the crossing. The same strategy is appropriate in approach areas also. Sporadic use of logs, stumps, and woody debris on the overpass would also be beneficial to provide microhabitat for smaller vertebrates and invertebrates using the crossing.

### 3.5.3. Underpass interiors

Unlike approach areas or overpasses, light penetration in underpass interiors is typically too low for plant growth (except within a few feet under the edge of a bridge, the median of divided highway bridges, or at the culvert entrance). For the interiors, it is therefore important to focus on alternative cover features. Scattered logs, stumps, woody debris piles, and rocks can serve as "stepping stones" for movement by smaller species that require cover from predators (see figs. 3-10, 3-22, and 3-39). Other artificial materials like PVC tubes have been used for movement passages for small mammals and herpetofauna. They provide cover and opportunities to escape from larger predators (fig. 3-40). Within underpass bridges over streams or rivers, riprap is often used to prevent scouring bridge abutments and support pilings (fig. 3-41). These rocks can serve as cover for many smaller wildlife species. If wide enough, median areas between divided highway bridges should be landscaped using the same design considerations prescribed for approach areas.

**Figure 3-37 Typical plantings in an approach area to a wildlife crossing structure.**

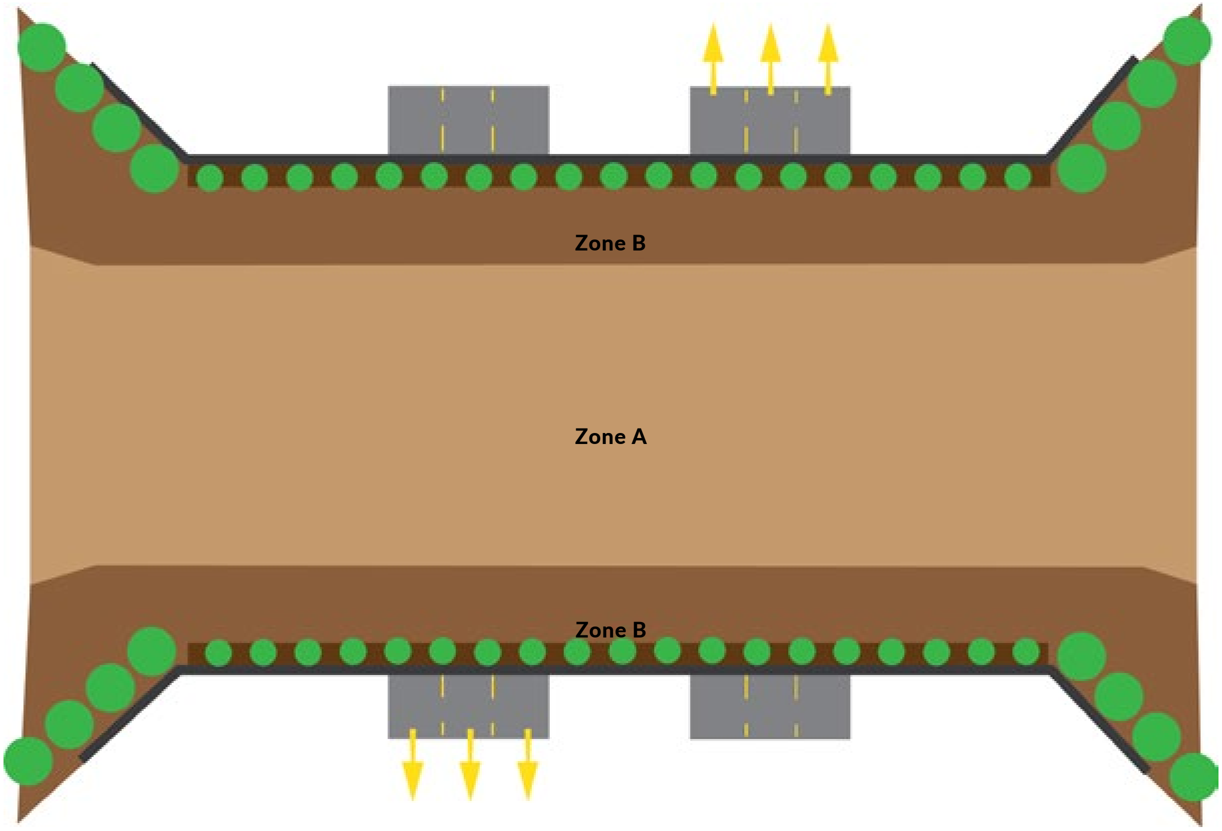

**Figure 3-38** **A conceptual landscape plan for an overpass.** Zone A includes randomly planted small to large native shrubs, clustered in low densities and native ground cover (consisting of a mix of grasses and forbs). Zone B includes small to large shrubs in higher density to provide continuous cover across the span of the structure. In the planter boxes are small native trees, and small to medium sized shrubs in densities sufficient to provide visual screening from oncoming traffic.

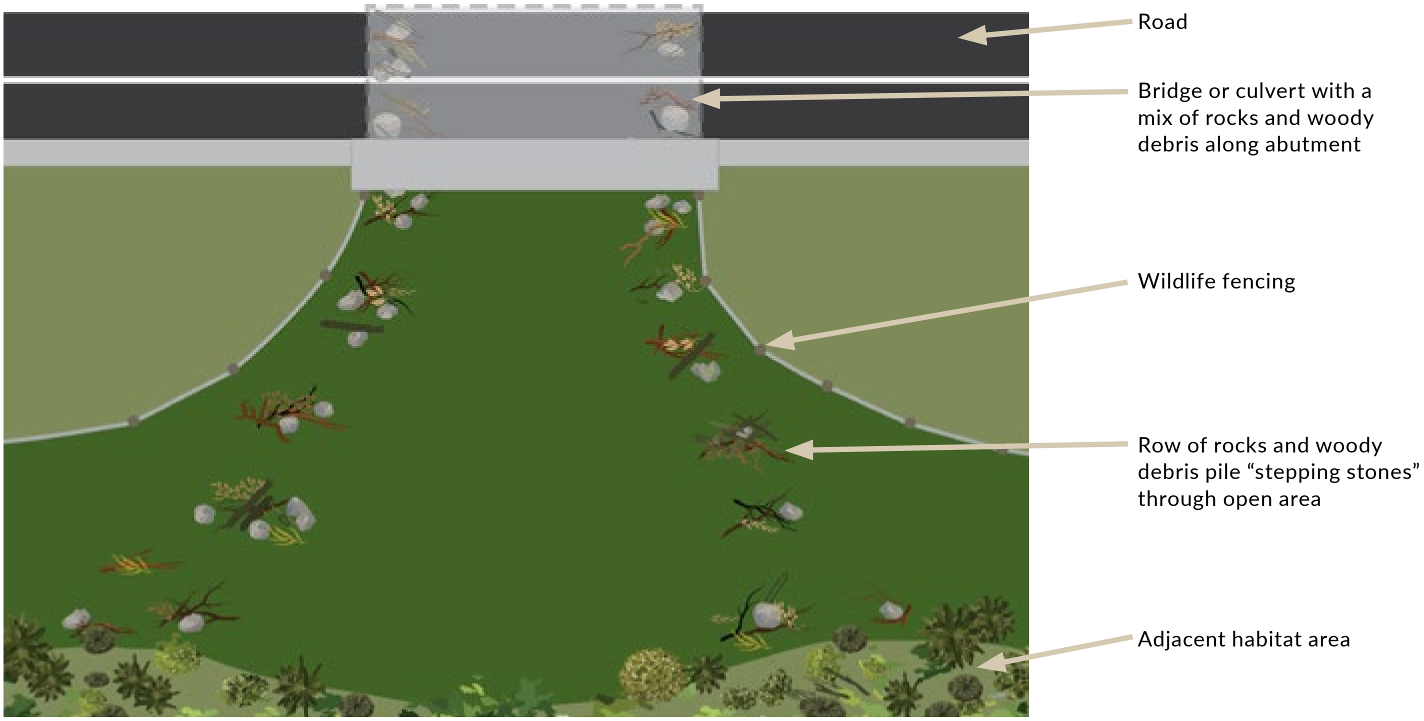

**Figure 3-39** **Illustration of the use of "stepping stone" cover materials.** This functions to lead small prey species to and through bridge and culvert under-crossings (also see fig. 3-22).

**Figure 3-40** **A close-up showing the use of artificial means to provide cover in underpass interiors.** The 4" dia. PVC tubing is typically imbedded among the rocks or covered with woody debris and the t-joints provide escape opportunities for small prey species from larger predators (see fig. 3-22 also).

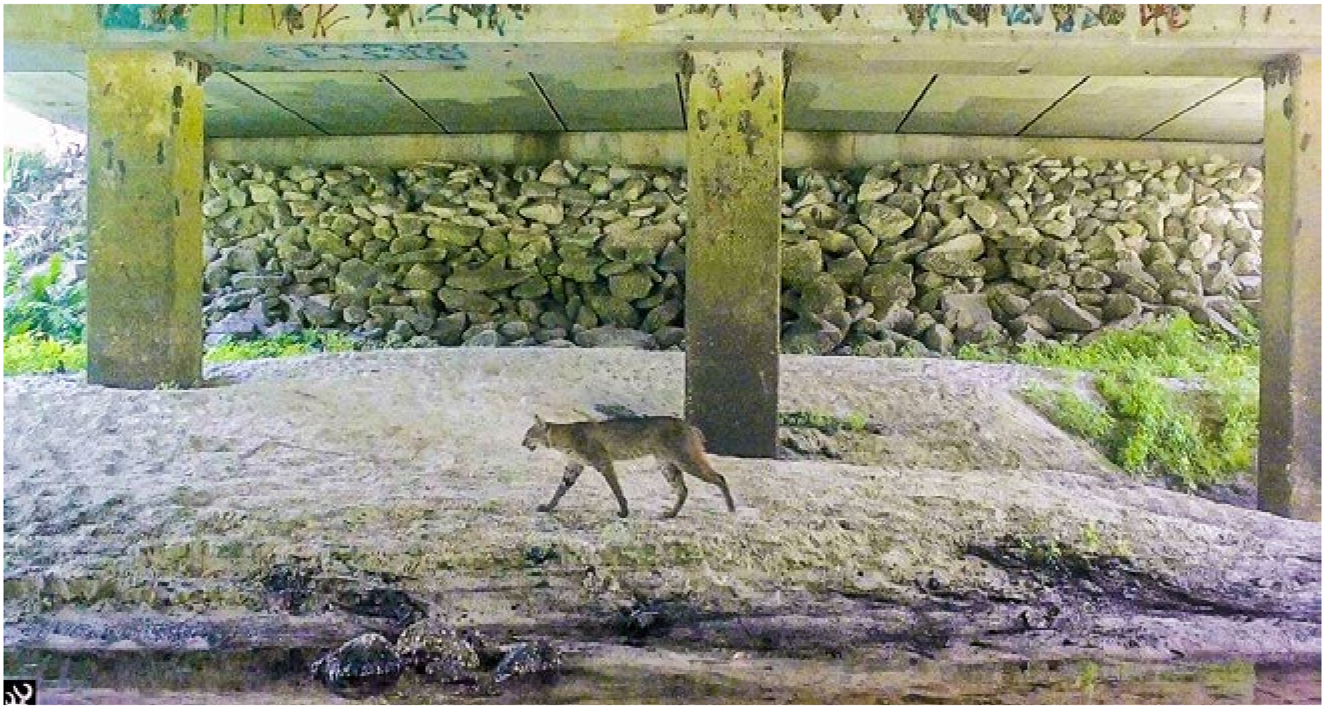

**Figure 3-41** **An example of the utility of riprap as wildlife cover.** This underpass with a stream (in the foreground) shows use of riprap to prevent scouring and erosion along the bridge abutment (in the background). These rock ledges can serve as cover for many small wildlife species moving through the crossing (see fig. 3-22 also).

## 3.6 Other Wildlife Crossing Opportunities and Alternative Solutions

To this point the discussion has focused on planning and design of new crossing structures. However, it is important to also recognize the value of existing structures in offering opportunities for wildlife passage. Later, this subsection will explore alternatives to standard bridge and culvert structures in providing safe passage of wildlife across roads.

### 3.6.1. Existing bridges and culverts

Despite not being designed for the purpose of wildlife passage, can existing bridges and culverts serve in that capacity? The short answer is yes, but it depends on the structure and its location. A study performed from 2001-03, inventoried 1,232 ecological hotspot locations on roads throughout Florida that included 375 bridges and 536 culverts. Upon evaluation, several were found suitable for wildlife passage in their existing condition and many others, if modified somewhat (e.g., adding shelves, fencing, or landscaping) could also act as wildlife crossings. Adapting many existing structures can offer:

- significant cost savings/benefits over construction of new structures
- many only require minimum modifications or re-construction measures
- certain existing structures (e.g., abandoned railroad bridges, river-floodplain bridges) represent potentially significant landscape connections that facilitate broad-scale species movement and dispersal and adaptation to climate change effects (fig. 3-42)

A noteworthy example included two canal bridges along a section of I-75 (Alligator Alley) that were retrofitted to provide safe passage for Florida panther as part of a wildlife fencing project to prevent panther-vehicle collisions. For both bridges, the riprap on the slopes supporting the bridge abutments was rearranged to create clear animal pathways. Subsequent monitoring has documented use of the pathways by panthers and other species (fig. 3-43).

At a broader scale, FWC identified existing bridges near black bear roadkill hotspots and performed field evaluations on suitability of the structures for bear use. They recommended installing wildlife fencing at several locations to help direct bears to the bridges and away from the road surface. Another example involves placement of metal shelves inside existing culverts that do not require replacement or reconstruction. These structures have been used in other states to provide passage for smaller

**Figure 3-42 Broad floodplain and overflow bridges** (top– Santa Fe River, US 301, bottom – Waccasassa River, US 19).

terrestrial fauna (fig. 3-44). The shelves do not restrict the hydraulic capacity of the culvert and are securely attached to the side and the top of the structure. Bridges have a typical lifespan of around 75 years and must be routinely inspected for safety and maintenance needs. As such, FDOT has a bridge replacement program for outdated and failing structures. In the 1990s, FWC recognized this as an opportunity to incorporate wildlife passage features in bridge replacement designs. Through their coordination with FDOT, all bridge replacement projects in ecologically sensitive areas are now evaluated for potential wildlife connectivity.

**Figure 3-43 Addition of an animal pathway imbedded into rip-rap slopes under a bridge;** used by a Florida panther (photo credit: FDOT).

**Figure 3-44 A commercially available metal shelf design that can be installed inside of drainage culverts**. It provides passageways for small terrestrial wildlife (see inset for example of use). Photo credit: K. R. Foresman.

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## 3.6.2. Alternative solutions

Several specialized measures have been developed to aid species that are particularly challenged in crossing roads. Among these are arboreal species and amphibians. Devices such as canopy rope bridges and glider poles have been used in Australia and Africa to provide safe means for crossing the roads without traversing at ground level (fig. 3-45). These have shown success for various marsupials and smaller primates. Amphibians such as frogs and salamanders seasonally migrate in large numbers to and from breeding ponds. If they encounter roads along their migration, the resulting mortality can be in the thousands of individuals. Studies in Florida and the southeast US have recorded amphibian deaths from road traffic in the tens of thousands on single sections of roadways over periods of 2 yrs or less. The high level of carnage globally has led to the development of special amphibian tunnel and fence systems that have been deployed across Europe and in North America (mostly NE US). There are several types of amphibian tunnels in practice, from standard culverts to specially designed, load-bearing surface structures with grating to allow moisture and light penetration (fig. 3-46). The accompanying barriers designed to guide amphibians to the tunnels are made of various materials, e.g., concrete, metal, or vinyl. There are a handful of companies that specialize in design, manufacturing, and installation of amphibian tunnels and barrier fencing.

**Figure 3-45** A canopy rope bridge installed over a roadway in Australia. Photo source: Fauna Crossings: Kempsey to Kundabung in NSW Fauna Crossings.

Another unique measure was used at Sebastian Inlet in Brevard County, Florida to reduce bird strikes on the A1A Bridge. Sebastian Inlet State Park is known as a nesting area and overwintering site for Royal Terns. Many terns and other birds were being killed in vehicle collisions on the bridge. To reduce the bird strikes, silver-colored metal poles 10 ft high and 2 in in diameter were installed at 12 ft intervals to encourage flight paths above the traffic (fig. 3-47). The poles have been moderately successful in reducing mortalities. The alternative solution that provides the greatest promise in reducing large animal-vehicle collisions involves smart technology in vehicles and on roadsides. Roadside animal detection systems (RADS) have been experimented with in the United States since the early to mid-2000s and for about 10 years longer in Europe. The earlier systems produced mixed results, due in part to limitations in technology and environmental, site, and installation constraints. The sophistication and precision of sensor technology has improved significantly in

**Figure 3-46** **Examples of amphibian tunnels and barrier walls**; left (a) of a manufactured tunnel and directional fence; middle (b and right c) of a concrete tunnel and barrier, the curved design deters climbing and guides migrating individuals to the structure. Photo source (a): Froglife.org.

the last 20 years as has our understanding of wildlife movement behavior (associated with roads) and site planning and installation specifications. The recent RADS installations that use radar technology and/or high-resolution thermal cameras have performed with much greater effectiveness. One of the most successful is a wildlife "crosswalk" in Arizona on SR 260 designed primarily for elk (fig. 3-48). A recent application that combines the use of radar detection and thermal camera validation is being installed on SR 29 in Collier County.

Most of the major automakers have also been developing sophisticated motion and heat sensor arrays on vehicles to successfully detect potential hazards in proximity to vehicles including pedestrians, cyclists, and animals. One of the greatest challenges is accurately detecting moving animals at a distance, while at high speeds, within the time needed to prevent collisions. Integrated smart vehicle-road systems would connect vehicles to roadside sensors in known, high-incident, wildlife-collision zones to provide the necessary advanced warning to avoid an accident. The vehicle computer system could first warn the driver and secondly enable driver-assistance technology.

**Figure 3-47** **Metal poles installed on the A1A bridge over Sebastian Inlet.** They encourage flight paths above oncoming traffic (although Royal Terns were the subject of this measure, it has positively influenced other species too).

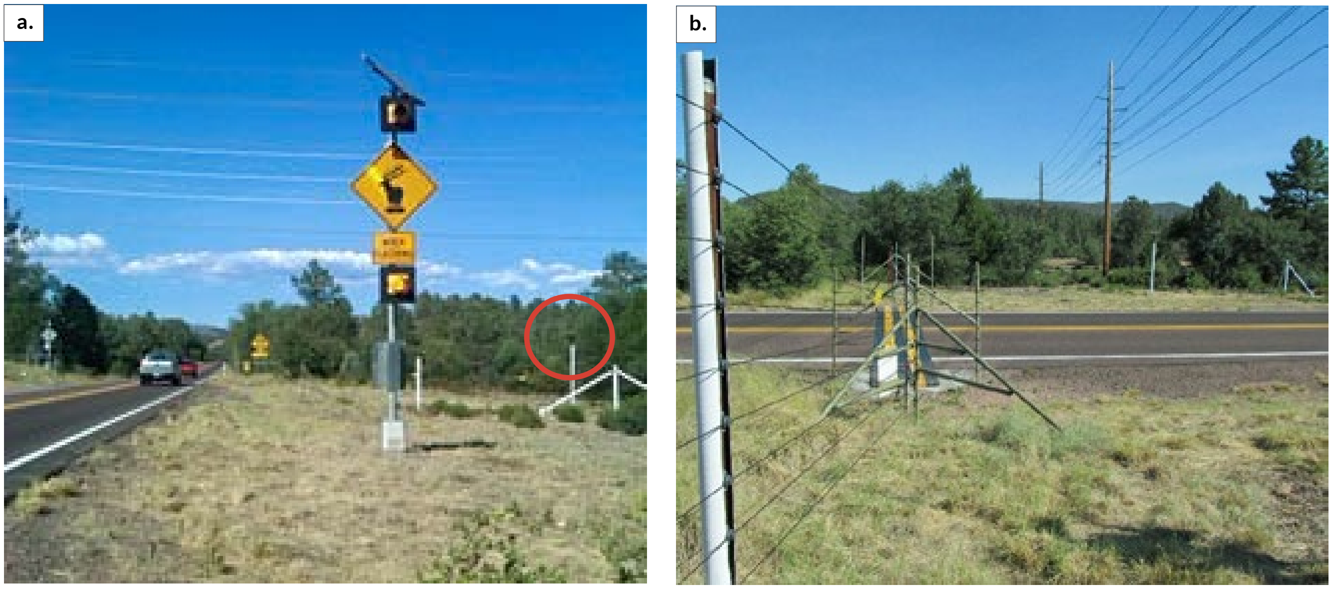


**Figure 3-48** **The Arizona SR 260 roadside animal detection system "crosswalk design"**; uses high-resolution thermal cameras (a, in red) to detect presence of medium to large animals. The animal's viewpoint (b) shows an electromat used to keep animals within the crosswalk area.

# Section 4.0: Post-construction Monitoring, Maintenance and Adaptive Management

## 4.1 Introduction

In most wildlife crossing structure projects, the primary focus tends to be on planning and construction, while less emphasis is placed on evaluating effectiveness, ongoing maintenance, and long-term management. However, these post-construction elements are critical to ensuring that mitigation measures continue to function as intended over time.

Here, we highlight the importance and value of monitoring and adaptive management, emphasizing how lessons learned from completed projects can improve future efforts. Monitoring can reveal how well structures are performing for target species, help clarify the costs and benefits of assorted designs, and support more effective, cost-efficient planning going forward. This section explores three key components that support long-term project success:

- Monitoring and Evaluation
- Maintenance and Best Management Practices
- Adaptive Management

Affording greater attention to these areas enables practitioners to build on past experience to improve the performance, sustainability, and impact of future wildlife crossing projects.

## 4.2 Monitoring and Evaluation

Monitoring is essential for evaluating the performance of mitigation measures intended to reduce WVCs and provide safe passage for wildlife. Whether it is a short- or long-term monitoring program, success is enhanced by establishing an organized planning approach. It should include (1) a set of goals and objectives, including whether to assess road mortality, habitat connectivity, or both; and (2) an effective study design suitable for pre- and post-construction phases, as well as during construction where feasible (see also Section 2). The study design should (a) address the scope, timing, and duration of the monitoring project; (b) include achievable methods for data collection and statistical analysis; and (c) incorporate mechanisms for adaptive management. The goal of any mitigation measure, no matter the level of sophistication or cost, is to function at its optimal performance level. Monitoring can increase our knowledge of the type and extent of road and traffic effects on wildlife, as well as the performance of various mitigation measures.

### 4.2.1 Goals and objectives

Setting goals (end points) and objectives (tasks necessary to achieve each goal) is essential to any successful monitoring effort. The goals and objectives should be attainable and measurable and should guide the expected outcomes of the study. An important aspect of monitoring is to evaluate the performance of the mitigation measure in achieving the goal of the project (e.g., reducing vehicle-related mortality, restoring habitat connectivity for wildlife populations, and ideally, improving population viability).

### 4.2.2 When funding is limited

Funding is a key factor in the types of monitoring methods that can be employed and the frequency with which data are collected. Goals and objectives must reflect the available funding and level of effort that can be expected in the monitoring plan. When funding and time are limited, Rapid Assessments can be performed (also see Section 2). Rapid Assessments generally include short periods of field data collection and employ pre-existing data or expert opinion. If the amount of time for collecting field data is limited, it should coincide with periods when effects are expected to be greatest (e.g., temperature or rainfall induced species movement). This alternative can save money in relation to long-term, labor-intensive field data collection.

### 4.2.3 Key elements of a monitoring program

There are many important considerations in the design of a monitoring plan for evaluating effectiveness of wildlife crossings. These are applicable whether it is a long-term monitoring program involving several roads or a single road, or whether it involves complex solutions involving multiple mitigation measures or simple solutions that require few mitigation measures.

1. **Identify and coordinate with stakeholders.**
   Stakeholders are important in obtaining support for the project, including community (public or private), management, and financial support. Stakeholders also can provide valuable information on the study location or affected fauna and flora (from previous or current studies).

2. **Scope of the monitoring project.**
   The scope of a monitoring project is defined by the roadway and traffic characteristics, the wildlife crossing(s), and the ecological infrastructure (i.e., connections among habitat components that are potentially affected by the road). One of the greatest challenges in determining the scope is the number and complexity of parameters related to both transportation elements and ecological infrastructure. For example, considerations for ecological infrastructure could include a broad spectrum of biodiversity; endangered, threatened, or rare species; or a single species of conservation interest. Because it is difficult to monitor for all faunal diversity, typically a target species, or a representative species list is selected.

3. **Identify the most effective methods for monitoring the target species.**
   Many monitoring methods have been employed in wildlife crossing evaluation studies (see below in sub-section 4.2.8, and also Sections 2 and 6).

4. **Establish treatment and control sites.**
   Reliance on a single site can limit the value of study results. Selecting two or three additional control (i.e., reference) sites for monitoring allows for scientific comparison and analysis; the control sites must be ecologically similar to the treatment site(s). Comparison to a single reference site can cause problems if the reference site turns out to be different from the treatment site (e.g., in habitat character or population densities). Although monitoring a single site provides information about what is occurring right there, monitoring multiple sites can provide a broader picture of whether the mitigation strategy is effective overall, across sites. In addition, where different structures or sites vary in efficacy, comparisons among multiple sites can reveal the factors that explain why some structures function better than others.

5. **Document site conditions.**
   Many external factors can affect the results of a monitoring study. These include physical, biological, and environmental variables, such as topography, microclimate, soil characteristics, water quality and quantity, vegetation composition, artificial light, and noise. Relevant factors should be quantified to analyze their effects.

6. **Acquire pre-existing data on the study site(s).**
   Based on the identified species and habitat factors, it is important to obtain valid and available preexisting data, such as previous scientific reports and records on the species of interest and on the adjacent habitats. Specific characteristics of the road, such as features of the ROW, road width, number of lanes, traffic volume, structure type and dimensions, and structure approach features, should be recorded (see Section 2).

7. **Minimize collection bias.**
   Ideally, from a biological standpoint, monitoring should occur over multiple generations of the target species. As such, monitoring programs should be designed so that data can be collected in a standardized manner by multiple surveyors, thus minimizing bias.

8. **Schedule appropriate timelines and data collection efforts.**
   A single, short-term survey is rarely sufficient. Repeated surveys help capture seasonal variation, detect trends, and provide statistically meaningful

results. The sampling intensity and duration should increase with increasing levels of natural variability and complexity of the scientific question or the targeted ecosystem. If variation is moderate to high, power analysis or computer simulation can then be used to determine the optimal number and seasonal timing of surveys. In practice, trade-offs in the frequency of data collection can depend as much on resource availability (i.e., both time and money) as on statistical defensibility requirements.

9. **Create a uniform data entry and management system.**
   Standardized data entry forms and centralized databases should be used to avoid inconsistencies and errors that can occur when multiple people are collecting and entering data. This uniformity improves transferability of data and reduces time needed to prepare data for analysis.

10. **Identify personnel and equipment needs.**
    The number and type of personnel needed, and amount of training and oversight required depends on the project tasks and the qualifications and experience of available recruits. Along with personnel and administration needs, the costs of equipment and supplies should be projected for the duration of the study.

11. **Establish an operating budget.**
    In practical terms, the project objectives and activities must be aligned with available funding. When funding is limited, crafting a budget to meet project requirements within the resources available may require prioritizing data collection efforts and scaling back less essential monitoring activities.

12. **Contingency planning and adaptability.**
    Many unexpected circumstances can occur over the course of a monitoring project. For this reason, it is important to build flexibility and adaptation into the budget and timeline to address any uncertainties that may occur during the life cycle of the project.

### 4.2.4 Spatial and temporal variation

Characterizing how road effects vary among locations (i.e., spatially) and across time (i.e., temporally) is important. For many species, habitat use and movement patterns are governed by environmental factors (e.g., temperature, rainfall, water levels; Section 2) that change by season and by year. As a result, the frequency at which animals encounter roads may vary significantly over space and time.

### 4.2.5 Pre-construction data

To evaluate performance of wildlife crossings effectively, pre-construction data must be collected to establish baseline conditions (see Section 2). Pre-construction data allows for the quantification of changes in road effects post-construction. For a scientifically defensible evaluation, it is imperative to standardize data collection protocols and methods used in both monitoring phases. Further, in many situations, anthropogenic effects, or alterations to ecological infrastructure (e.g., land use changes) have already occurred before the road is built or widened. Without pre-construction monitoring, and with only post-construction monitoring, certain effects may be attributed to the road, even though the existing alterations to the landscape may have contribute to impacts before construction of the wildlife crossing.

### 4.2.6 When pre-construction data are unavailable

While post-construction monitoring may have been included in the project budget, in many cases comparable pre-construction data are either not collected or are temporally insufficient. Without baseline data, measuring changes resulting from construction and mitigation efforts is impossible. In the absence of baseline data, the focus of analysis must shift to the function of the wildlife crossing structure over time, and in relation to reference locations without crossing structures. Meaningful insights to this end include identifying trends and factors affecting the use or avoidance of a particular wildlife crossing by various species over time.

### 4.2.7 Implementing post-construction monitoring

Post-construction monitoring should be an essential component of wildlife crossing projects beginning in the planning phase and continuing after construction. A well-designed monitoring plan selects methods that best meet the project's primary objectives.

For example, if the goal is reduction of WVCs, the monitoring protocols should include measuring roadkill rates and wildlife movement patterns near the roadway and wildlife fencing. If the goal is to enhance habitat connectivity, the methods would include measuring rate of use of crossing structures and assessing wildlife movement between habitat areas. Ideally, the wildlife crossing project should address both safety and connectivity using appropriate, scientifically sound methods designed to meet each of these goals.

1. **Evaluating reductions in road mortality.** At the most basic level, collecting road mortality data simply consists of identifying and counting animals killed by vehicles. A typical procedure for collecting mortality counts is to walk (or drive) relevant stretches of road and count carcasses on the pavement and the road shoulder. If counts are standardized (see Section 2), the resulting data can serve as the basis for evaluating the effects of mitigation on mortality. Numbers of dead animals per unit of time and road length for each species can then be compared, pre- and post-construction. Alternatively, if pre-construction road mortality data are not available, mortality counts can be compared between mitigation (i.e., wildlife crossing treatment) sites and reference (i.e., control) sites. Broadly, such comparisons on various mitigation measures (e.g., types of crossing structures and wildlife fencing) are useful in identifying relative performance and can guide future design and placement decisions.

   Animal movement patterns and consequently road mortality fluctuate significantly due to seasonal and interannual changes in temperature, precipitation, and other environmental factors (see Section 2). Ensuring that surveys are carried out evenly across all monitoring periods eliminates data irregularities, making mitigation efficacy easier to quantify. Understanding movement patterns of varied species (e.g., seasonality of breeding, migration, or juvenile dispersal) is also crucial in planning effective surveys (see Section 1, target species preferences). Surveys should be repeated multiple times within each seasonal movement period. The required number of surveys will depend on variability in counts from one survey to the next (i.e., greater variability will require more surveys). In most cases, a minimum of three to five surveys per seasonal movement period will provide sufficient data to assess how counts are changing over time.

2. **Evaluating improvements to habitat connectivity.** Assessing the ability of crossing structures to reconnect fragmented wildlife habitat and populations can be complex. Such an evaluation requires at a minimum documentation of crossing attempts, crossing success, and avoidance rates at treatment and control sites. Certain species may avoid roads completely or may be unable to successfully cross roads in the absence of suitable crossing structures. Thus, determining the efficacy of a crossing structure requires measuring the change in animal crossing rates before and after the mitigation measure is implemented. Where pre-construction data are not available, crossing rates can be compared between the mitigation site (i.e., wildlife crossing treatment) and comparable sites where no mitigation was implemented (i.e., controls).

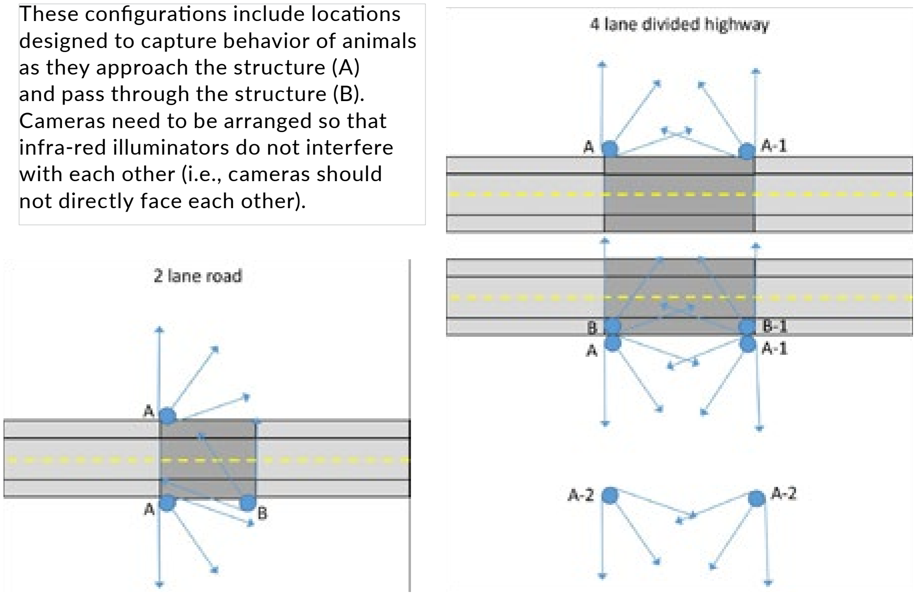
   Monitoring crossing structure use at the species level is relatively simple, but measuring population effects is far more complex. For many common species, occasional crossings can suffice to reconnect former habitats or sustain genetic diversity. In contrast, species that rarely cross can be challenging to monitor, potentially difficult to detect, and standard monitoring methods might not reliably separate low activity from none. Over time, effective mitigation can support recolonization and restoration of genetic variation, but these outcomes may take decades to emerge and are difficult to measure directly. Some techniques do allow for retrospective, population-level assessments, but as with mortality studies, the most straightforward way to assess connectivity is through pre- and post-construction comparisons of crossing rates.

### 4.2.8 Field techniques

Many active and passive monitoring techniques may be appropriate in assessing effectiveness of mitigation measures (see Section 2). They not only evaluate effectiveness for varied species but also reveal deficiencies that may require adjustment through maintenance or adaptive management (see Sections 4.3 and 4.4). Certain techniques (as described in Section 2) may be more appropriate for evaluating the effectiveness of a crossing structure as opposed to other mitigation measures (e.g., barrier fencing).

Camera and track surveys are the most common methods used to monitor wildlife use and avoidance of crossing structures. These survey techniques can provide data on multiple taxa simultaneously, along with assessments of relative movement frequency.

1. **Camera traps.** Motion-activated cameras record images or videos of wildlife as they near and pass through crossing structures. For best results, position multiple cameras at different angles to observe both entry and exit points of the crossing structure, ensuring behaviors like hesitation, avoidance, and successful passage are clearly recorded (fig. 4-1). When positioned correctly, these cameras enable identification of species or species groups and provide data on how often animals utilize or avoid the crossing.
2. **Track surveys.** Track stations involve preparing a surface—such as gypsum powder, sand, clay, or cleared soil—to make animal footprints more visible (fig. 4-2). These stations help record species' presence and movement direction. They are also useful in identifying smaller species not typically detected by cameras (e.g., amphibians, lizards, snakes, certain small mammals). When placed strategically, they can address targeted questions, such as whether animals are trying to bypass or breach a fence.
3. **Camera/track survey combination.** Combining cameras with track stations at the same site provides a fuller understanding of animal activity. Cameras offer visual confirmation of animal behavior at the site, while track stations can reveal entry and exit points. Together they identify patterns of use over time for a variety of species (large and small).
4. **Other methods.** Other less common methods used at crossing structures include hair snares for medium-large mammals and drift fence arrays to target small mammals and herpetofauna. Hair snare studies in this instance usually target a single species or group of species, e.g., black bears or large carnivores. More information on hair snares and genetic analysis and drift fence arrays and capture-mark-recapture techniques is available in Section 2.



These configurations include locations designed to capture behavior of animals as they approach the structure (A) and pass through the structure (B). Cameras need to be arranged so that infra-red illuminators do not interfere with each other (i.e., cameras should not directly face each other).

Camera detections are generally good to 50 or 60' – for long bridges, dual cameras may need to be installed that span the entire structure (see A-1 and B-1; e.g., crossing areas wider than 120').

If the clear zone on each side of the road is wider than 50', then additional cameras may be needed to capture animals near the habitat edge as they approach the structure (see A-2).

**Figure 4-1 Camera configurations for monitoring crossings on 2-lane and 4-lane divided highways.** Note: Cameras can be mounted on posts or trees. Site specifics will determine height, but when vegetation is absent, cameras should be placed approximately 18" to 24" above grade.

**Figure 4-2**

**Location of cleared track beds to record animals crossing an overpass** (Trans-Canada Highway, Banff National Park).

### 4.2.9 Benefits of long-term monitoring

Long-term monitoring is required to achieve a broad understanding of the effects of road mitigation measures on wildlife and ecosystems. While short-term monitoring (typically one to two years) can provide valuable insight into immediate impacts, such as reductions in wildlife-vehicle collisions (WVCs) or early indications of improved habitat connectivity, it often falls short of capturing larger, more complex or longer-term ecological responses.

Long-term monitoring generally equates to multiple years (at least five [time for acclimation], or ideally many more) to assess the adaptation of species or populations to mitigation features. It involves discerning differences in wildlife behavior, movement patterns, and population dynamics that may vary across seasons, weather cycles (e.g., drought vs. wet years), or even generations. For example, if monitoring were conducted during a single drought year, it could potentially omit significant movements by amphibian populations in the study area.

The benefits of long-term monitoring apply equally to pre- and post-construction. Multiple years of pre-construction monitoring provides a more solid foundation in comparison with post-mitigation conditions. In post-construction, monitoring efforts should evaluate if mitigation features, such as wildlife crossings and fencing, are functioning effectively and consistently over time.

Other issues captured through long-term monitoring include future changes to infrastructure and land use (e.g., increases in traffic volume, site conditions and, structural integrity, or shifts in local land use or habitat management), which may influence mitigation performance. Finally, another advantage is that long-term monitoring supports and informs adaptive management strategies (see Section 4.4). By identifying issues early, project managers can make targeted adjustments to improve outcomes, reduce long-term costs, and avoid more serious problems later.

General knowledge advantages associated with long-term monitoring include:

- There is a longer acclimation period for certain species to adapt to using wildlife crossings; short-term monitoring may underestimate effectiveness.
- Roadkill hotspots and wildlife crossing activity can shift locations over time; long-term monitoring helps track these changes.
- Preferences to wildlife crossing structure types and designs are species-specific.
- Human presence at wildlife crossings deters wildlife use.
- Wildlife crossing structures coupled with fencing significantly reduce WVCs.

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- Trail cameras are as effective as track pads in monitoring crossing structures for large mammal use and are more cost-effective over the long term.
- Few documented cases exist of crossing structures serving as prey traps by large carnivores.
- Drainage culverts can act as passages for many small and medium-sized mammals.
- Guidelines for monitoring and measuring performance of wildlife crossings should include a wide range of temporal and spatial considerations and ecological goals.

Long-term performance of mitigation measures is most effective when adaptive management frameworks are used to identify deficiencies and opportunities for improvement. Adaptive management is a process of using knowledge gained from research and monitoring to make adjustments and changes necessary to ensure and improve future performance (see Section 4.4 for more information).

## 4.3 Maintenance and Best Management Practices

Roadway maintenance is an essential program of public transportation agencies. Effective maintenance is necessary to ensure public safety, reliability, and efficiency of transportation infrastructure. Routine maintenance and repairs can maximize or extend the life of facilities, improve performance, and reduce long-term costs. Standard maintenance practices are typically managed through maintenance operations departments or through contracts with external service providers. In most cases, certain tasks are handled internally for practical reasons or out of necessity, while others are more cost-efficiently handled by outside contractors. In this subsection, we will discuss maintenance practices as they relate to maintaining or improving effective performance of wildlife crossing structures and associated features.

### 4.3.1. General Maintenance

Wildlife mitigation measures such as crossing structures, advanced warning systems, and fencing have special functions that distinguish them from typical roadway facilities. As such, standard maintenance and inspection practices need to be modified to ensure that they not only remain structurally sound but also function as intended. For example, typical roadside mowing practices are primarily designed to support and maintain turfgrass and prevent encroachment of trees and shrubs into the "clear zone." Vegetated areas associated with crossing structures need to be managed differently, and specifically with the intent to support and maintain a more diverse plant community consistent with the adjacent habitat areas and the needs of the wildlife that will be using it.

The maintenance approach discussed above appropriately requires establishing new practices and additional training for maintenance crews attending to wildlife mitigation features. It may be a case where the specialized knowledge and atypical techniques needed could be more cost-effective and appropriately contracted out to a landscaping or habitat management firm already possessing the necessary expertise. Similarly, inspection of wildlife mitigation features may require special knowledge. While evaluating structural integrity may not differ from that associated with standard road facilities, the functional integrity of the wildlife mitigation feature would require different skills to evaluate. This situation suggests the need for wildlife ecologists and maintenance engineers to review the various maintenance and inspection requirements and work together to develop an integrated management plan with an appropriate schedule and set of procedures. Finally, identifying and providing sufficient funding for maintenance should be considered and included as part of the wildlife crossing project.

The following set of examples represent characteristic maintenance activities associated with wildlife crossing features. These include structural, fence, and site considerations to include in a management plan.

- Wildlife crossing structures function better with soil substrates (particularly of local origin); when performing maintenance, care should be taken to maintain the prescribed depth of soil.
- Excessive water flows and drainage can lead to flushing of culverts or erosion along stream banks under a bridge

crossing negatively affecting the stability of the adjacent shelves; if washed out or removed, the soil should be replaced.

- At upland crossings, stormwater runoff can result in depressions within the structure that remain flooded over time; periodic grading and filling of depressions may be necessary to ensure that after rain events, runoff flows away from rather than towards the structure.
- Crossing "furniture" (e.g., brush and rocks) can improve use by certain species that require cover/concealment; periodic flooding or excessive water flows can shift the furniture, cause blockage, and reduce accessibility that requires periodic attention to maintain the appropriate amount and arrangement of furniture.
- Fence integrity is crucial to direct wildlife to crossing structures and prevent access to the roadway; periodic inspections—such as walking the length of a fence or examining the area around a crossing—can uncover issues like gaps in fencing, structural damage, or signs of wildlife avoidance.
- Certain animals may burrow under fencing; this may indicate that the fence needs to be buried deeper, constructed from more robust materials, or repositioned to prevent access.
- Amphibian and reptile fencing, constructed of lightweight metal or polymer mesh can be easily damaged by grass cutting equipment and vehicles; care should be taken to avoid damaging the fence or consider using herbicides along the fenceline as an alternative. Herbicides should be carefully selected to minimize adverse effects.
- In approach areas and medians of underpasses, native shrub and groundcover species should be maintained at the appropriate densities and spatial arrangement to provide cover for smaller prey species yet simultaneously provide clear sight lines through the passage area for larger prey species (e.g., white-tailed deer).
- For wildlife crossing locations in Florida, control of invasive plant species is imperative; many plants like Brazilian Pepper and Cogon Grass can easily outcompete native species, alter accessibility to the crossing, and decrease use by various species of wildlife.
- Vegetation screening used on multi-use structures should be maintained to provide safe, sufficiently broad, and open trails or pathways for people (high visibility implied), yet sufficiently dense to minimize disturbance and encourage use by wildlife on the other side of the screen.

### 4.3.2 Best Management Practices

Best management practices (BMPs) can be created to establish consistent guidelines for maintenance of wildlife crossing features. Underlying concepts for the development of BMPS might include the following:

- Identify a set of basic considerations that will maintain high functionality for wildlife use and traffic safety.
- Target species preferences by structure type, site characteristics, and location can assist in selecting certain management practices that enhance use.
- Landscape designs and management practices should promote maintenance or restoration of historic water flows and floodplain functions—hydrologic integrity enhances habitat value and wildlife use.
- Maintaining natural slope and terrain characteristics in approach areas is beneficial and can enhance wildlife access to crossing structures.
- Native habitat management practices should be followed in wildlife crossing feature applications.

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- Important wildlife crossing site design and management factors to consider include adjacent vegetation, topography, soils, hydrology, and water features.

### 4.3.3 Green Highways and Green Stormwater Programs

When developing an ecologically sustainable maintenance program for wildlife crossing features, there are two other ecologically based initiatives that could offer useful insights: the Green Highways Partnership and Green Stormwater Infrastructure. The Green Highways Partnership is an initiative to promote sustainable highways. It relies on partnership development and integration of public and private interests to advance Green Highways goals centered around themes such as watershed-based stormwater management, recycling and reuse, and conservation and ecosystem management.

Green Stormwater Infrastructure (GSI) focuses on ecological principles and sustainable management approaches to stormwater treatment and ecosystem protection (Bean et al. undated). Briefly, GSI uses innovative techniques that integrate natural and engineered systems to effectively manage and treat stormwater. It stresses the use of native plant materials, treatment at the source, improving water quality, and functional solutions such as bioretention and bioswales (fig. 4-3). A major emphasis is placed on system maintenance which is critical to long-term performance and preserving function

Though these initiatives focus on somewhat different topics than wildlife crossings, developing partnerships and a systematic and ecological approach to management and maintenance is parallel. For instance, a wildlife crossing structure that features a linear water feature could enhance wildlife use when designed to function more sustainably using native plants and materials that improve water quality. Applying conservation and ecosystem management principles can only help to improve functionality and reduce maintenance needs and costs.

## 4.4 Adaptive Management

The basic concept of adaptive management is simple: a management action is taken, the results are monitored, and the management action is re-evaluated based on results of the monitoring. As our understanding of ecological and social dynamics grows, adaptive management enables continuous refinement of strategies, enhancing their effectiveness and long-term resilience.

Combined with science-based monitoring, an adaptive management strategy reduces the risk and uncertainty inherent in restoration (or mitigation) projects. It advances proactive learning and flexibility, helping decisionmakers improve management plans, maintenance schedules, and infrastructure designs based on relevant performance data. Effective adaptive management links science and conservation by applying lessons learned to achieve intended outcomes – making wildlife crossings, fencing, or

**Figure 4-3**

**An example of a bioswale** (photo credit: IFAS).

other mitigation features more effective over time. In addition, because the life cycle of a road project includes several phases, there are multiple opportunities to learn, adjust, and adapt. Flexibility in each phase improves decisions and ensures successful mitigation.

### 4.4.1. The application of adaptive management

Adaptive management stresses the need to adjust and change as research and monitoring, or even multiple observations over time, provide added information about the performance of the mitigation feature (e.g., wildlife crossing structure). Two guiding principles are generally acknowledged: (1) there is uncertainty associated with ecosystem-level restoration (e.g., reducing wildlife mortality and restoring habitat connectivity are influenced by many complex, variable factors); and (2) the best way to reduce uncertainty is by learning from the outcomes of actual management actions. Simply stated, we improve understanding not just through planning or theory, but by observing how actual interventions perform over time (e.g., installation of wildlife crossings, modifying approach areas, or addition of barrier or guide fencing).

### 4.4.2. Integrating adaptive management into project development

Identifying target species, selecting suitable locations for wildlife crossings, and designing effective structural features are key steps early in the project planning process. These initial tasks establish the foundation for effective implementation and ensure the long-term success of mitigation measures. Once the mitigation features are installed, they should be evaluated through a rigorous, science-based monitoring plan. Many monitoring tasks can be incorporated into routine maintenance activities (see Section 4.4), though some issues—such as species-specific use or avoidance of a crossing—may require targeted monitoring efforts. Monitoring results should guide timely adjustments and improvements to ensure mitigation measures are performing as intended (fig. 4-4; also see example in Section 5). The core principle of adaptive management is learning from the project in real time and applying that knowledge to enhance outcomes.

Recognizing the importance of wildlife connectivity early in the planning phase is critical, even though detailed design features and cost estimates may not be finalized until later in the preliminary engineering and design stages. In the planning stage, project documents should include explicit recommendations

**Figure 4-4**

**An adjacent swale prevented terrestrial access from the north end and on occasion flooded into the crossing structure** (a). Many smaller non-aquatic species could not traverse the swale. To improve connectivity for species such as gopher tortoise, the swale was piped and covered (b). This now allows passage by species that could not previously use the crossing. This includes certain smaller terrestrial species like the turkey poults shown in (c) accompanied by the hen.

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and commitments for a comprehensive long-term monitoring program. Funding for monitoring and adaptive management should be included in the initial cost estimates to ensure these efforts are fully supported throughout the project's life cycle.

### 4.4.3 Establishing successful partnerships

Collaborative partnerships are essential for the success of monitoring programs and adaptive management. Partners not only help secure funding but also provide valuable in-kind contributions such as technical expertise, field personnel, and equipment. Effective monitoring programs, particularly those covering both pre- and post-construction periods—depend on strong collaboration among key stakeholders. These typically include:

- **Transportation agencies**, project leaders for infrastructure development;
- **Wildlife and land management agencies**, oversight of natural resource protection; and
- **Nongovernmental organizations (NGOs)** focused on conservation of species and natural communities potentially affected by the project.

Public engagement and community support often are cited as vital components of successful projects. Community members can contribute by volunteering for data collection, advocating for the project, and helping build public and political support for its goals. When integrated into an adaptive management framework, strong partnerships can deliver critical benefits such as:

- Reducing potential conflicts among stakeholders;
- Improving coordination and communication;
- Supporting permit acquisition and compliance;
- Streamlining the implementation of monitoring and mitigation;
- Strengthening credibility and buy-in for study recommendations.

True collaboration builds shared responsibility, promotes transparency, and strengthens the effectiveness and sustainability of mitigation efforts.

### 4.4.4. Applying Lessons Learned from Monitoring

To make monitoring efforts practical and impactful, it is essential to define clear, transportation-focused research questions from the start. This helps ensure that the data collected are directly relevant and useful to transportation planners, engineers, and ecologists involved in project development and implementation. Resources like this guide aim to build a shared understanding of wildlife crossings—their function, planning, design, and long-term management. Well-designed monitoring studies that align with project objectives can significantly expand our knowledge base and inform future improvements. This, in turn, leads to two major benefits:

1. **Targeted adaptations** that improve the performance and effectiveness of mitigation measures.

2. **More cost-efficient designs and applications** for future projects.

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# Section 5.0: Case Studies and Quick Takes

## 5.1 Introduction

This section provides key in-practice learning examples from Florida and elsewhere. Two types of examples are included:

- In-depth case studies on crossing structure site selection and monitoring
- Quick takes that highlight specific issues of certain projects

Prior to exploring the case studies, it is beneficial to reiterate the basic framework, approaches, and key concepts covered in this guide. First, consider the primary steps for conducting a wildlife crossing project:

1. Identify purpose and objectives,
2. Identify target species or taxonomic groups,
3. Obtain existing information or collect new data to assess wildlife crossing needs and potential locations for mitigation,
4. Use a landscape-level, contextual approach (e.g., careful consideration of physical and ecological characteristics) and consider target species in the site design and in selecting the most appropriate mitigation measure (e.g., size and type of crossing structure), and
5. Perform pre- and post-construction effectiveness monitoring and use the lessons learned in an adaptive management approach to adjust and improve function and for enhanced future designs, and finally practice routine, best management techniques to maintain high functionality.

Second, the approach to wildlife crossing studies and mitigation can vary between local, regional and state scales. As the size and complexity of the project increases it is necessary to establish a team of experts to consider data, evaluate alternatives, and make decisions throughout the process. Categories of projects can be described as follows:

1. Single location and structure design project,
2. Single road, multiple structures as part of an ecosystem-level mitigation project, and
3. Regional approaches (i.e., multiple roads and ecosystems) to mitigation of road impacts on wildlife.

Third, fundamental principles and considerations that lead to a successful project include:

1. Using data-driven models to identify likely wildlife crossing hotspots,
2. Performing consistent pre- and post-construction monitoring (overall effort can vary depending on budget; 2-3 yrs recommended to address environmental variability but if budget is limited use staggered, multiple seasonal evaluations),
3. Selecting structures (and fencing) that best meet the chief principles of reducing WVCs and improving habitat connectivity for the target species (a multiple species approach is recommended),
4. Site design and landscaping that mimics adjacent vegetation, soils, native plant community types, and hydrologic variability, and
5. Considerations that address economy and efficacy, e.g., many small-medium vs single large structure to potentially expand

the ecological scope and address the broader need of multiple species for the least cost.

Even though we only provide a few representative examples here, there are numerous projects in and out of state that provide valuable lessons in addressing road impacts to wildlife movement and population reintegration. We cannot cover all the possibilities and therefore intend to broaden the available information on the topic through an online resource with additional case studies and quick takes on a variety of challenges and opportunities for wildlife crossing structures and monitoring projects.

## 5.2 Case Studies (Assessing Wildlife Crossing Needs through Monitoring and Data Analysis)

There are several common threads among the projects discussed in this subsection. Among these include: 1) the use of different methods to collect data on multiple species (representing different taxonomic groups) potentially impacted or involving a wide-ranging, umbrella species that would potentially address the needs of several species of more limited range. 2) the monitoring occurred over at least 2 years and multiple seasons. These studies were generally comprehensive, focused on representative target species, and included several project collaborators. Recommendations for mitigation included multiple, wildlife-crossing features across different ecosystem types, and in the case of subsection 5.2.3, multiple roads with a regional connectivity scope.

### 5.2.1. SR 200 in the Ross Prairie Ecosystem (Smith and Voigt 2005)

Ross Prairie is a 6,500-ha reserve and an important habitat node in the Marjorie Harris Carr Cross-Florida Greenway (fig. 5-1). This diverse ecosystem is a mosaic of several plant community types that supports many rare and listed species. It is bisected by SR 200, a major two-lane state highway with average annual daily traffic in 2024 of 15,600 vehicles. Suburbanization in western Marion County necessitated widening of the road to four lanes. From 2002 to 2004, a comprehensive, multi-species approach employing several methods was used to assess current and potential impacts on presence/absence and movement behavior for suites of wildlife (primarily carnivores, selected herptiles, and small mammals). Successful and unsuccessful wildlife crossing locations were identified by roadkill and track surveys. A capture-mark-recapture study targeting small mammals and various herptiles was conducted to determine species presence, habitat use, and movement behavior. Radio-telemetry targeted wide-ranging species (e.g., bobcat and eastern indigo snake) and key indicator species (e.g.,

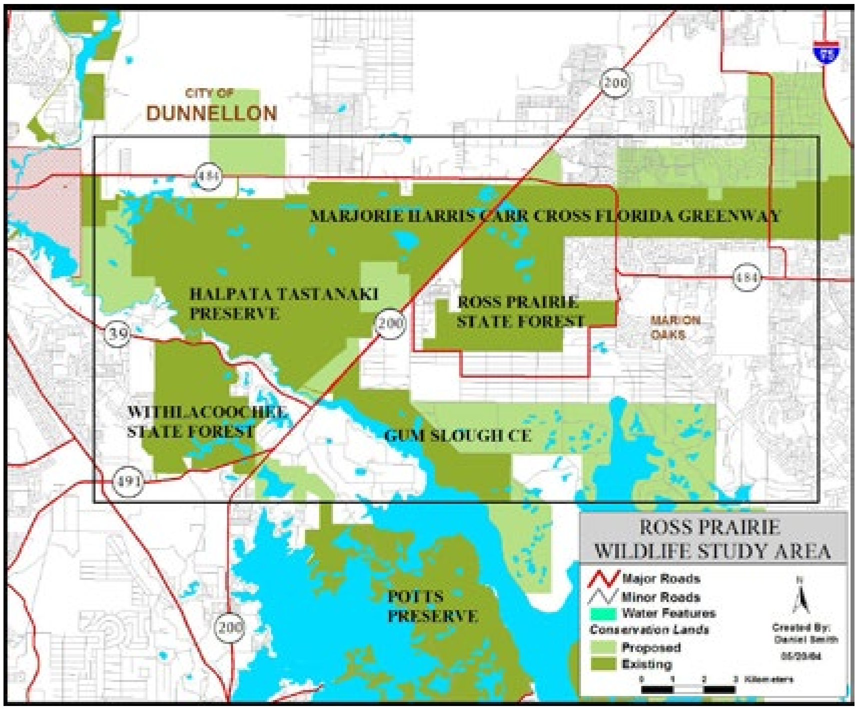


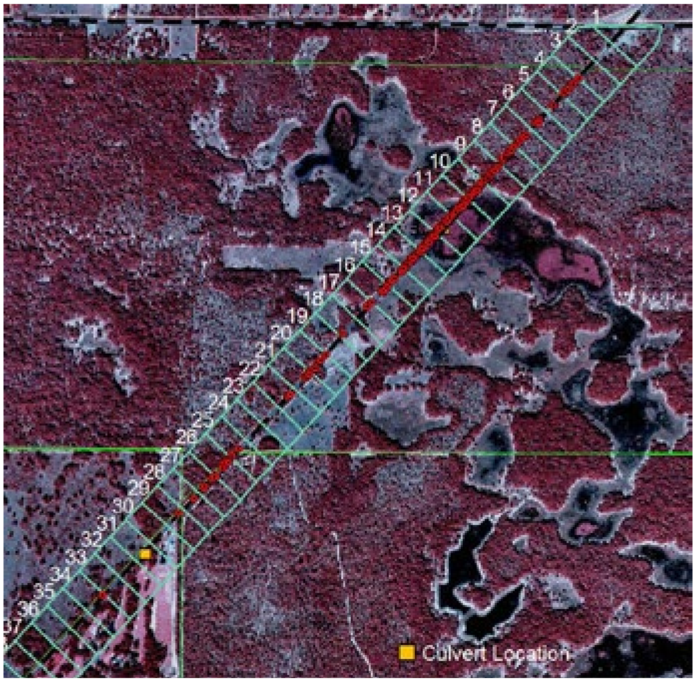
**Figure 5-1**

**Ross Prairie Study Area.**

**Figure 5-2 Gopher Tortoise pitfall trap** with Shade Cover (left) and with Glue-on Radio-transmitter (right).

gopher tortoise [fig. 5-2], and eastern diamondback rattlesnake). GIS data layers were used in conjunction with results of telemetry, track, capture-mark-recapture and roadkill studies to conduct analyses and predict wildlife response to the expansion of SR 200.

Road-kill surveys yielded 759 individual animals from 57 identifiable species. The majority were anurans followed by meso-mammals. Hotspots of road-kills by taxa and rare species were identified (fig. 5-3). Track site hotspots were identified for snakes, white-tailed deer, and carnivores. In most instances they corresponded to the same locations identified as road-kill hotspots. A total of 1,777 herptiles were captured in right-of-way drift fence traps. Individuals of several species of snakes, frogs, and lizards were recorded crossing the road in the two sandhill crossing sections and moving to/from the Ross Prairie wetland basin. Of 342 small mammals captured, one cotton mouse was recorded crossing the road; only six were found as road-kills. The road forms a relatively significant barrier to small mammal movement. Fifty gopher tortoises were captured and marked. Three attempted crossings of SR 200 were recorded, and only two were successful. Tortoises used habitat as close as 10-20 m from the pavement. For gopher tortoise, the road is a semi-permeable barrier. Successful crossings are possible; however, their poor mobility and response behavior increases the risk of collisions with vehicles. We captured 24 eastern indigo snakes over the entire



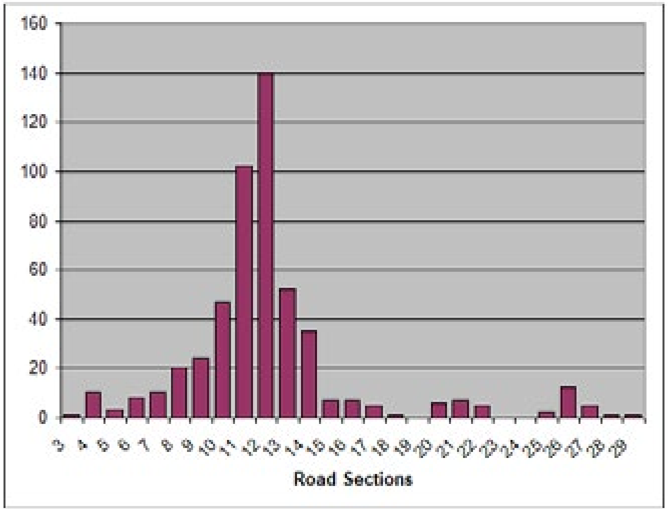


**Figure 5-3 Amphibian roadkill distribution at Ross Prairie**.

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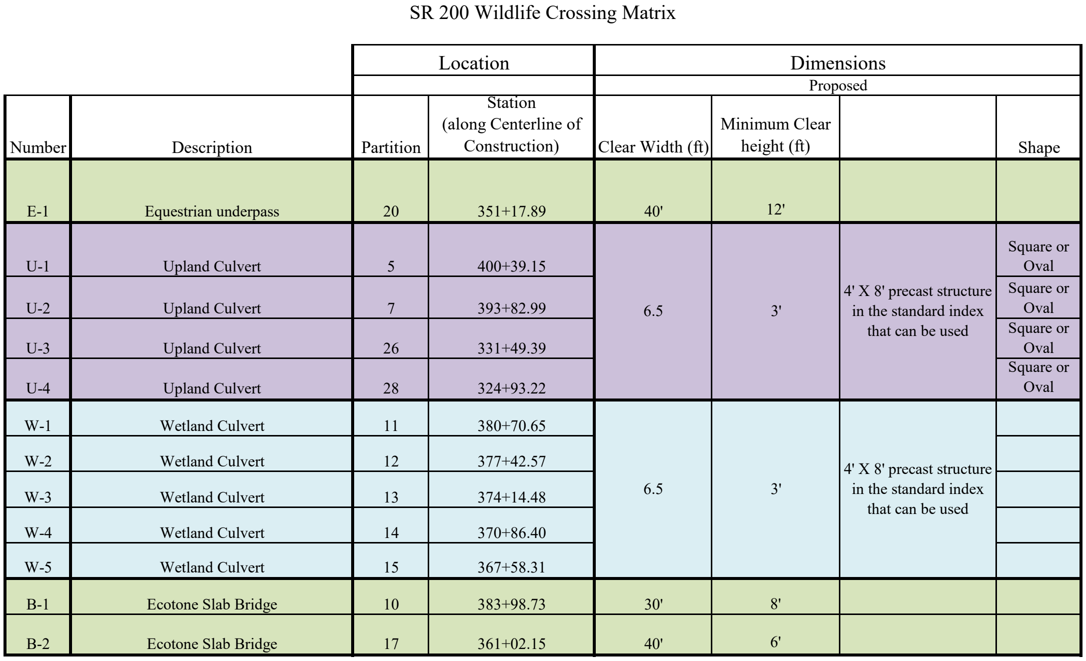
study area, observed 2 others and encountered 5 road-kills. The areas of highest density of eastern indigo snakes coincided with gopher tortoise burrow clusters and sandhill communities. The individuals we tracked seemed to use the road as a home range boundary. Nevertheless, the road-killed individuals confirm that road crossing attempts do occur. Only 5 bobcats, 2 coyotes, and 1 gray fox were captured and monitored in the carnivore telemetry study. Yet observations, track, and scat evidence suggest that a significantly higher number of these animals were present. Known human-related mortality for those captured was high (50%). Most radio-collared felids avoided SR 200 or used the road as a home range boundary, whereas the radio-collared canids commonly crossed major roads.

The multi-year study yielded results from wet and dry years revealing significant changes in behavior and movement patterns across varying environmental conditions. To improve habitat connectivity and eliminate road mortality, a system of culverts, bridges, and barrier fences was proposed (fig. 5-4). Four box culverts were recommended in the upland sandhill areas, bridges at each ecotone between the wetland basin and adjacent uplands, a series of five culverts within the basin adjoined by a herptile exclusion wall, and an equestrian underpass across from the trailhead. Wildlife fencing (2m in height) with herptile excluding mesh (minimum 1 m high) at the base of the fence was recommended to prevent trespass between all structures.

## 5.2.2 SR 40 in the Greater Ocala National Forest Ecosystem (Smith et al. 2015)

In preparation for the planning and design of the multi-lane expansion of SR 40 in Marion County from just east of Silver Springs to CR 314a, the Florida Department of Transportation (FDOT) conducted a PD&E study. The study included assessment of the effects of potentially increased habitat fragmentation and barrier effects on persistence of wildlife populations, habitat use, and successful dispersal and other movements by individuals. The following is a summary of an evaluation of the current impacts to wildlife associated with the existing 2-lane configuration and potential adverse effects related to the proposed widening to 4-lanes.

A comprehensive approach was employed that integrated several methods designed to evaluate pre- and post-construction differences in mortality and movement of wildlife in Project Planning Areas A/B and F. This summary concerns phase 1 of this project, collection of baseline pre-construction data for later comparison to post-construction data (phase 2). Roadkill,



SR 200 Wildlife Crossing Matrix

| | | Location | | Dimensions | | | |
|---|---|---|---|---|---|---|---|
| | | | | Proposed | | | |
| Number | Description | Partition | Station (along Centerline of Construction) | Clear Width (ft) | Minimum Clear height (ft) | | Shape |
| E-1 | Equestrian underpass | 20 | 351+17.89 | 40' | 12' | | |
| U-1 | Upland Culvert | 5 | 400+39.15 | 6.5 | 3' | 4' X 8' precast structure in the standard index that can be used | Square or Oval |
| U-2 | Upland Culvert | 7 | 393+82.99 | | | | Square or Oval |
| U-3 | Upland Culvert | 26 | 331+49.39 | | | | Square or Oval |
| U-4 | Upland Culvert | 28 | 324+93.22 | | | | Square or Oval |
| W-1 | Wetland Culvert | 11 | 380+70.65 | 6.5 | 3' | 4' X 8' precast structure in the standard index that can be used | |
| W-2 | Wetland Culvert | 12 | 377+42.57 | | | | |
| W-3 | Wetland Culvert | 13 | 374+14.48 | | | | |
| W-4 | Wetland Culvert | 14 | 370+86.40 | | | | |
| W-5 | Wetland Culvert | 15 | 367+58.31 | | | | |
| B-1 | Ecotone Slab Bridge | 10 | 383+98.73 | 30' | 8' | | |
| B-2 | Ecotone Slab Bridge | 17 | 361+02.15 | 40' | 6' | | |

**Figure 5-4** **Wildlife crossing matrix with structure type and location** (partitions correspond to sections in fig. 5-3).

**Figure 5-5**

**Example of drift fence array (right) and animals captured and marked (above).**

track, telemetry, capture-mark-recapture (fig. 5-5), and landscape genetics were techniques used to evaluate presence-absence, habitat use, movement behavior, roadway interactions, and mortality of multiple taxa. An extensive amount of information was generated from 2011 to 2014 in this study—63,000+ road-kill observations, 27,000+ track counts, and 164 hair samples covering 1.6 mi of roadway. This was pared down to what was primarily pertinent to the widening of SR 40 and the location and design of the proposed wildlife crossings. A convergence of high densities of roadkill, track, and hair snare data indicated significant hotspots on SR 40 (fig. 5-6); locations where focal species were impacted were also identified. Large and small vertebrate data were compared to proposed locations of wildlife crossing structures. Results showed significant and widely dispersed impacts, especially for herpetofauna and managed species (e.g., Florida black bear and white-tailed deer). The study evaluated road avoidance effects by monitoring key species using radio-telemetry and by conducting comprehensive capture-mark-recapture surveys in control and roadside areas. Road avoidance was not detected from tracking 28 telemetry subjects (over 1,800 locations); in fact, roadside areas were used on a consistent basis. We recorded nearly 14,000 captures of small mammals,

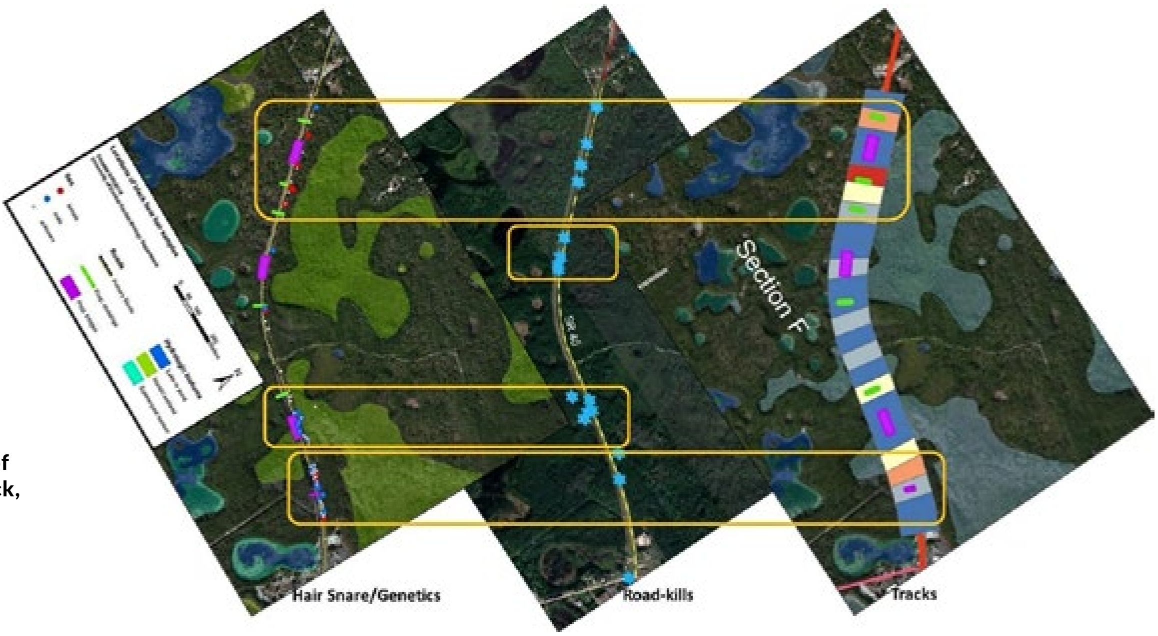


**Figure 5-6**

**Locations of overlap of recorded roadkill, track, and hair snare data.**

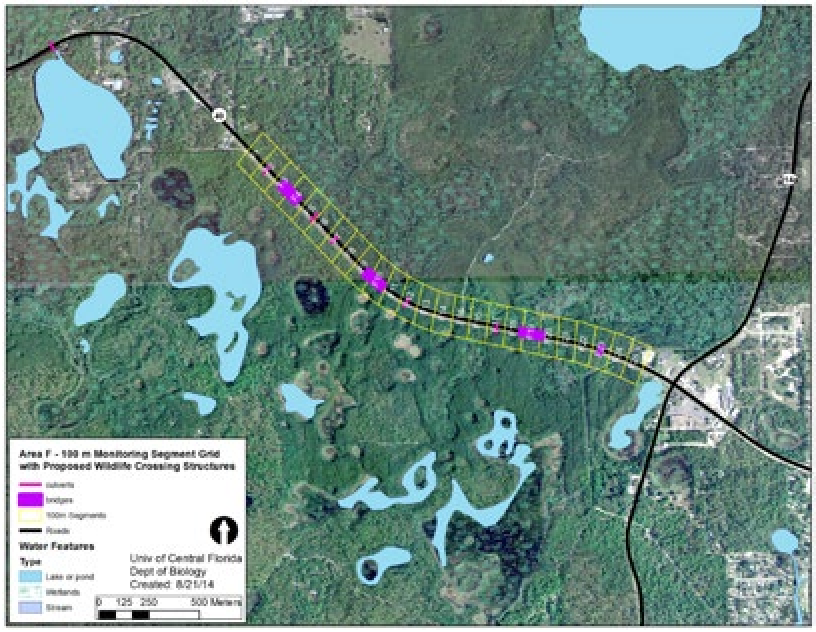


**Figure 5-7**

**SR 40 Project Area F with planned locations for wildlife crossings.**

amphibians and reptiles. Of all these captures, very few species found at controls were not found at roadsides. These data indicate there was not a significant road avoidance effect among the vertebrates we observed. The effect of the multi-lane widening project design will dramatically reduce the current impacts, improve roadside habitat quality, and provide safe passage for wildlife (fig. 5-7). The number and types of crossing structures proposed and their location and arrangement together with the wildlife fencing is sufficient to improve landscape connectivity and the health of wildlife populations in these areas over the current 2-lane configuration of SR 40. From the process of conducting field monitoring work, we identified certain limitations and complications with some methods that affected performance and quality of data. Recommendations were provided to improve performance of similar field monitoring efforts in phase 2 (post-construction monitoring).

### 5.2.3 Keri and Corkscrew Roads: Identifying Priorities for Safe Crossing Measures for Florida Panthers (Smith et al. 2019, Smith et al. 2022)

This two-year study examined movement patterns and potential road crossing locations of Florida panthers and other wildlife on two county roads. Keri Road essentially subdivides the Okaloacoochee Slough State Forest into two separate habitat areas and supports an average of about 450 vehicles per day. Seven panthers died from vehicle collisions since 2004. Corkscrew Road passes through two distinct study areas characterized by public conservation lands on one side of the road and commercial agriculture and rural residential on the opposite side of the road. Traffic ranges from about 4,000 to 8,000 vehicles per day. Five panther deaths have occurred on Corkscrew Road since 2009. Traffic volume and the rate of conversion of agricultural to residential development are increasing in the area.

The objectives of the study were to: 1) evaluate the importance of local movement pathways within key panther habitat areas, their deficiencies and road conflicts, and, 2) identify specific need for safe road-crossing measures and provide recommendations to improve habitat connectivity and reduce panther-vehicle conflicts.

We deployed a total of 99 cameras along 29 road segments on Keri and Corkscrew roads (fig. 5-8). We recorded a total of 6,199 and 2,259 photo events of wildlife adjacent to Keri and Corkscrew roads, respectively, between December 2017 and May 2019. Photo event count data (for target species: FL panther, black bear, bobcat, and whitetail deer) were assessed using R by fitting an N- mixture model using the package "unmarked" which fits hierarchical models to models of measures of wildlife occurrence and abundance. The number of active camera days at each site was a significant factor in the detection process and affected relative

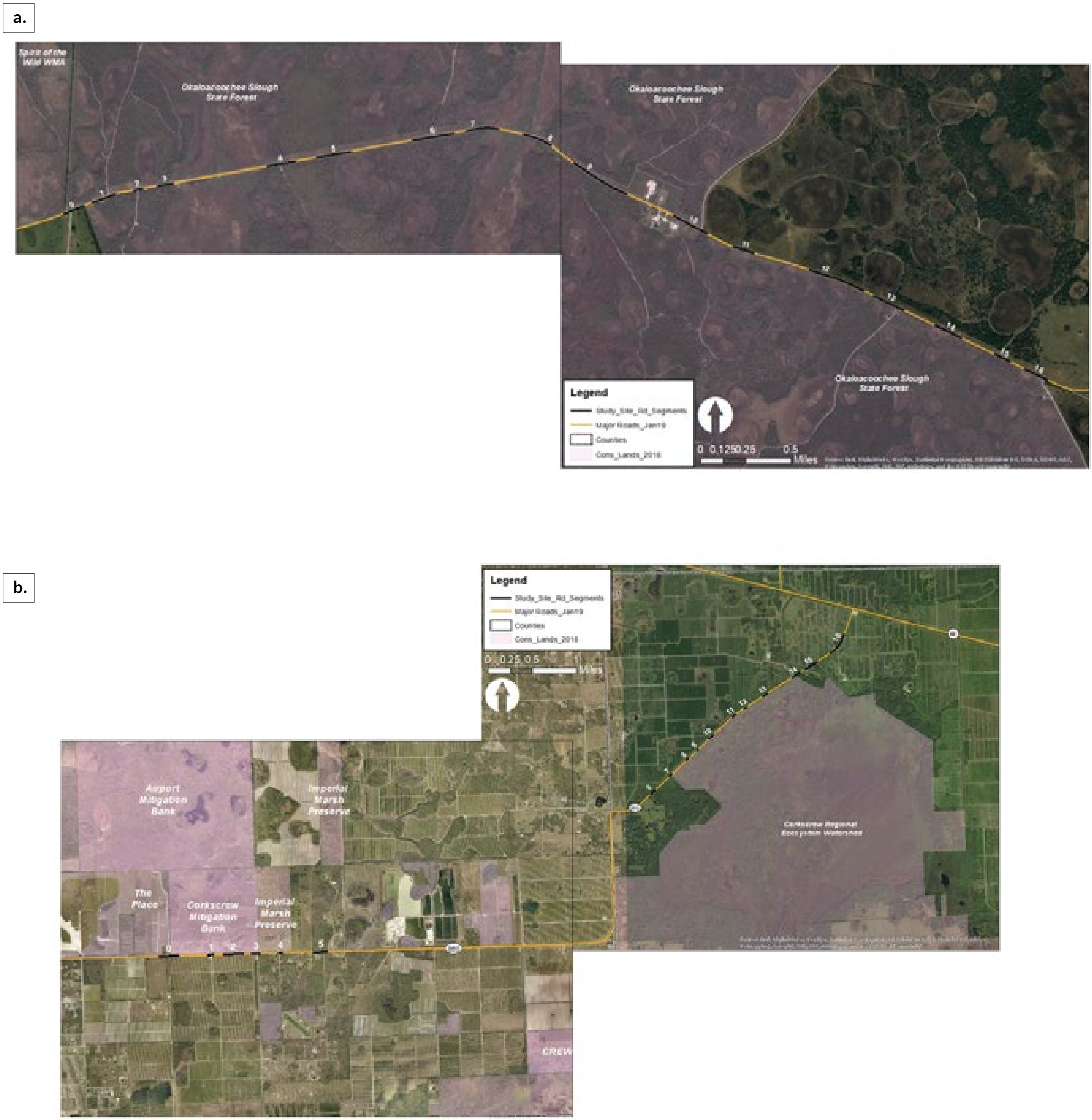


**Figure 5-8 Study area trail camera monitoring locations**, Keri Road (a) and Corkscrew Road (b).

abundance estimates. Eight state process covariates (4 numerical and 4 categorical) were also evaluated.

The road segments on Keri Road where the target species were most abundant (in relative terms only) as measured by Bayesian posterior abundance estimates differed (fig. 5-9); abundance estimates for FL panthers and bobcats were highest in road segments 1, 4 and 9, black bear abundance was greatest in road segments 0, 1 and 4, while estimates for whitetail deer were highest in road segments 2, 3, and 10. On Corkscrew Road, the top two measures of relative abundance for panthers and bobcats were both associated with road segments 11 and 14. Black

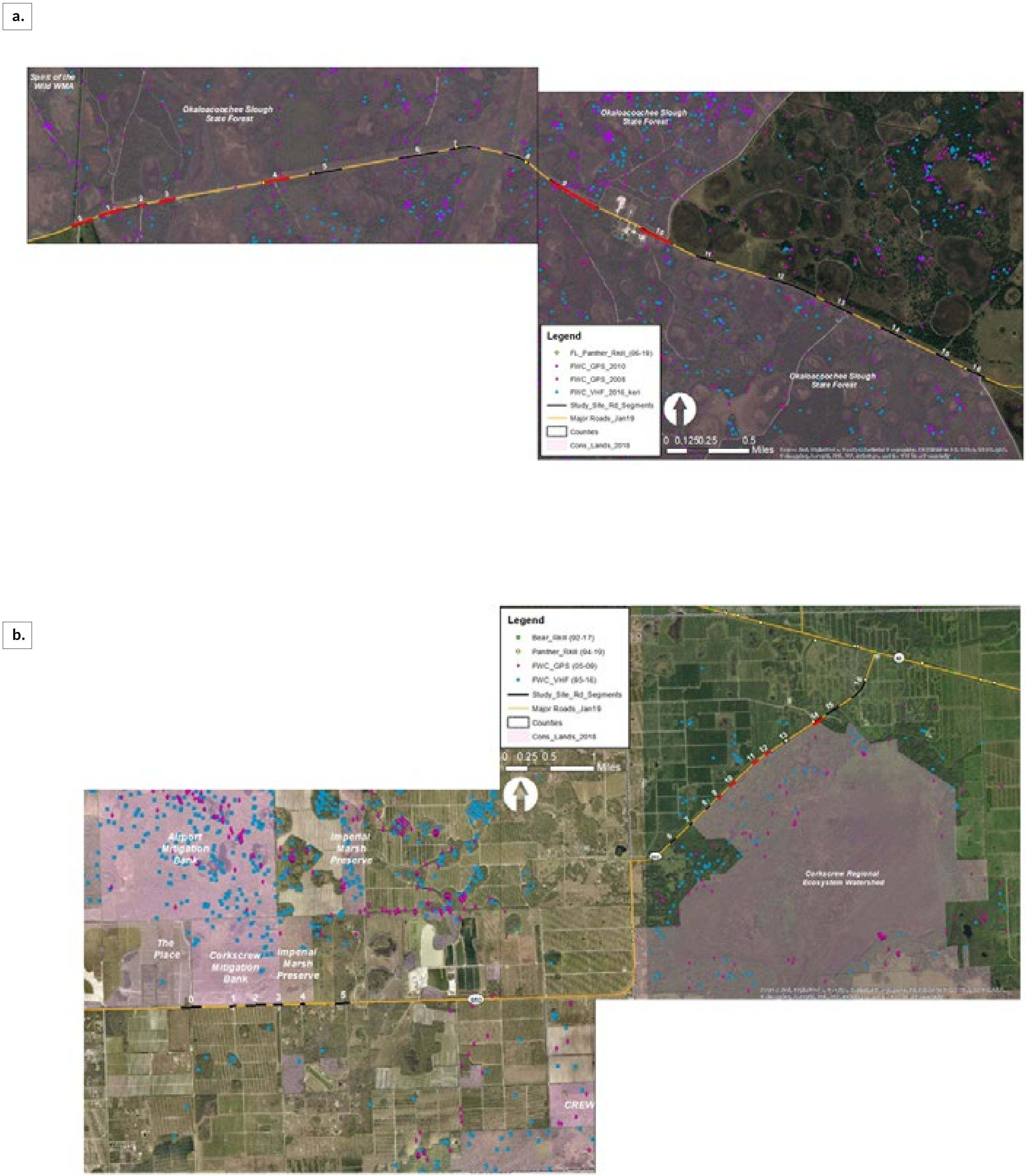


**Figure 5-9 Significant locations of target species activity,** Keri Road (a) and Corkscrew Road (b).

bears were highest in road segment 14. Deer were most abundant in road segments 9, 10 and 12.

Recommendations regarding need and type of mitigation to address wildlife-vehicle conflicts were discussed for each individual road segment for both Keri and Corkscrew roads. Types of mitigation discussed included lighted warning signage, enhanced speed enforcement, wildlife fencing, "crosswalk" animal detection/warning systems, and wildlife underpasses and fencing.

**Figure 5-10**

**Tyrell County Study Area along US Hwy 64** (shaded area).

## 5.2.4 Using Monitoring to Guide the Placement and Design of Mitigation Measures along US 64, North Carolina (Smith 2011)

During the summer months, the Outer Banks of coastal North Carolina, is a primary tourist destination for residents of the Mid-Atlantic states and is also a frequent site for landfall of hurricanes. US Highway 64 represents one of two coastal evacuation routes and has been targeted for widening from two to four lanes to improve traffic flow during emergencies (fig. 5-10). The road bisects a network of federal, state, and privately managed conservation areas that provide habitat for black bears (Ursus americanus), red wolves (Canis rufus, a federally endangered species), migratory birds, a diverse assemblage of herpetofauna, and numerous other species. Comprehensive wildlife surveys were conducted in 2009 and 2010 to assess potential impacts and to make recommendations for crossing structures and other measures to reduce adverse effects on key sections of US 64 proposed for widening in Tyrell and Dare counties. Surveys consisted of road cruising three times per week, recording tracks in sand beds (fig 5-11) twice a week, and camera traps checked weekly (Vaughan et al. 2011). This use of complementary techniques provided data on successful and unsuccessful road crossings. To determine species presence and potential road avoidance, capture-mark-recapture studies for small mammals and herpetofauna were performed at roadside and control locations in differing habitat

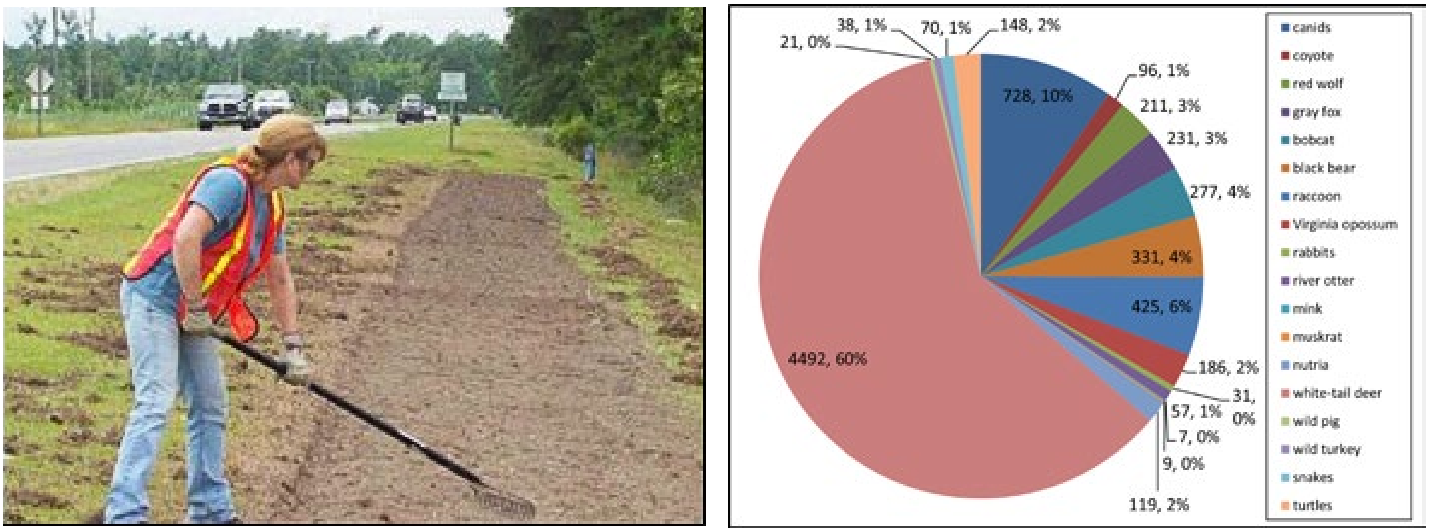


**Figure 5-11 Example of track bed preparation (left) and track counts (right)**.

types adjacent to the highway corridor. Lastly, existing telemetry data were available on red wolf movements in proximity to the road (Vaughan et al. 2011). Roadkill surveys produced 27,877 records involving 113 different species. From 31 track bed stations, 18 different species or taxa were recorded from 7,477 sets of animal tracks. From the trapping arrays, 362 individuals were captured in control arrays, including 13 amphibian species (720 total captures), while the roadside traps captured 1,094 individuals including 19 amphibian species (767 total captures). For reptiles, 16 species were detected in both control and roadside sites, and the abundance (number of captures) was also similar. For small mammals, we captured 9 mice and rats and 47 shrews and moles at control sites and 31 mice and rats and 33 shrews and moles at roadside arrays. Spatial analysis of field data revealed 15 areas (ranging in road length from 100 m to 2,800 m) of significant wildlife activity (fig 5-12). Results of field surveys and landscape analysis were used to determine candidate locations, structure types, and design specifications for wildlife crossings based on site characteristics and target species requirements. Specifically, recommendations included construction of 8 large animal crossing structures and 13 small animal crossing structures. Planning for road improvements for US Hwy 64 also included the analysis of potential ecological effects of projected sea-level rise based on recent climate change models. As such, the improvements will include elevation of the road, which, along with the planned crossing structures, will allow for movement of species assemblages as the area transitions from freshwater wetlands to estuarine systems. This project was successful due to active participation and review by a diverse group of stakeholders representing multiple levels of government, private industry, and environmental advocates. It serves as an excellent example of comprehensive monitoring and successful integration of long-term transportation and conservation planning.

## 5.3 Case Studies (Assessing Effectiveness of Wildlife Crossings from Pre- and Post-construction Monitoring Data and Analysis)

There are similarities and differences to discuss among the case studies in this subsection. Suncoast Parkway (subsection 5.3.1) and Paynes Prairie (subsection 5.3.3) involved a single roadway and ecosystem, whereas the East-Central Florida project (subsection 5.3.2) included multiple roads across a multi-county region consisting of varying landscapes and ecosystems. Suncoast Parkway and Paynes Prairie included both pre- and post-construction monitoring of about 12-18 months duration for each phase. The East-Central Florida Project only had 2-3 months of pre-construction monitoring, insufficient to compare to the post-

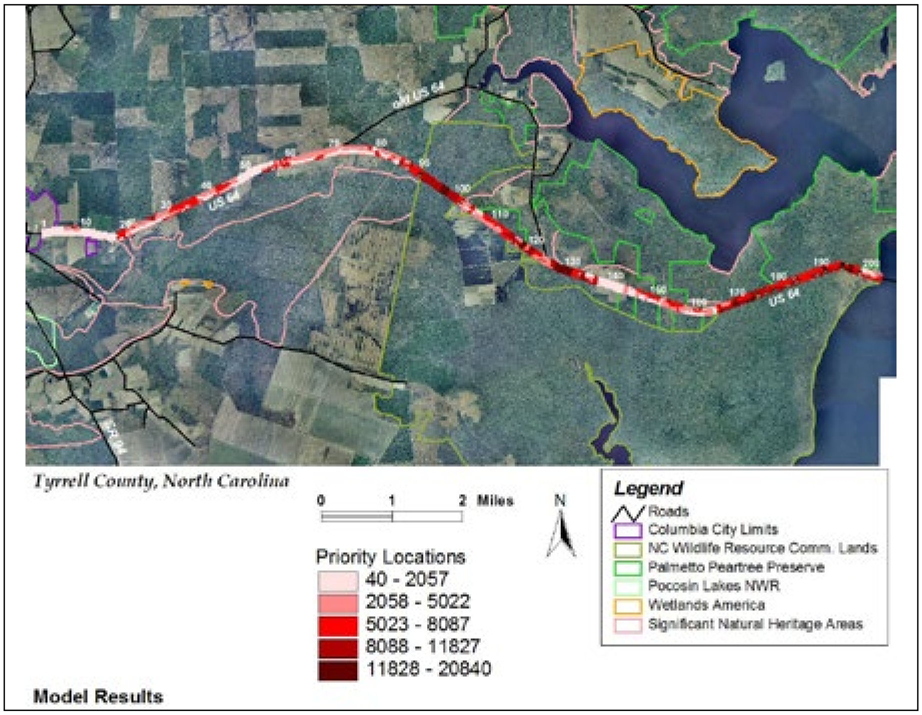


**Figure 5-12**

**Prioritized locations for mitigation along US Hwy 64.**

A Practitioner's Guide to Planning and Design of Wildlife Crossings
Section 5 5.3 Case Studies (Assessing Effectiveness of Wildlife Crossings from Pre- and Post-construction Monitoring Data and Analysis)
5.3.1 Suncoast Parkway Phase II Wildlife Crossing Effectiveness Study (Smith and Parks 2023)
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construction monitoring that occurred for 6 years. The Suncoast Parkway only consisted of upland community types, whereas Paynes Prairie focused mostly on wetland-dependent species. All studies were similar in that they included multiple methods to evaluate the effects of fencing or barriers and wildlife crossings to reduce WVCs and improve connectivity, respectively for multiple species of different taxonomic groups.

These studies were generally comprehensive, focused on representative target species, and included multiple project collaborators. Paynes Prairie only included culvert wildlife passages, whereas the other two projects included both culvert and bridge crossings. In all cases, there were weaknesses associated with the duration of the monitoring to fully compare pre- to post-construction effects. While the East-Central Florida project included sufficient time post-construction, it didn't include sufficient time pre-construction. Paynes Prairie and Suncoast had at least one-year pre and post, yet two years minimum for each phase would have been better. Subsequently, a more substantial evaluation of these two could be obtained with an additional follow-up monitoring study ideally after the 5-year mark, long enough to evaluate change over time and acclimation by local wildlife populations.

Fencing and barriers were also an issue in all three case studies allowing opportunities for either 1) road surface trespass by wildlife and road mortality associated with inadequate maintenance or design flaws that allowed gaps in fences or insufficient fence lengths, or 2) human access and increased disturbance. These are issues easily addressed through more consistent maintenance, and fence extensions or adjustments to fence ends and bridge/culvert attachments.

### 5.3.1 Suncoast Parkway Phase II Wildlife Crossing Effectiveness Study (Smith and Parks 2023)

Wildlife crossing structures and fencing are proven to reduce animal-vehicle collisions, thereby reducing wildlife mortality as well as human injury and damage to vehicles. To be effective, wildlife crossing structures must be properly located, designed, monitored, and maintained. This report presents the post-construction phase of the wildlife monitoring efforts necessary to evaluate the effectiveness of wildlife crossings constructed on the Suncoast Parkway Phase 2 Project in Hernando and Citrus counties.

Monitoring was conducted in the Sugarmill Woods Tract of Withlacoochee State Forest between US 98 and CR 480 along and adjacent to the Suncoast Parkway (fig. 5-13). The focus of the study was on select groups of mammals and herptiles. Methods primarily included capture-mark-recapture and camera traps. Treatment sites included the two wildlife crossings. Control sites were included to evaluate potential effects 500 m or more from the wildlife crossings and the highway. The wildlife surveys conducted in 2022-23 (along with the 2015-16 surveys) provided nominal pre- and post-construction baseline data to evaluate the effectiveness of the wildlife crossings in maintaining habitat connectivity. Our recommendation was to collect more post-construction data to assess the true population-level effects of the parkway and the effectiveness of crossing structures to provide passage for species dispersal and home range extension.

The wildlife crossings were used readily by white-tail deer, bobcat, coyote and raccoon (fig. 5-14).

**Figure 5-13** **Study area design for monitoring wildlife crossing effectiveness.**

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Other species using the crossings were recorded in much lower numbers. It is noteworthy that none of the small species involved in the capture-mark-recapture study were recorded using the crossings. Listed species (except gopher tortoise) were not observed, though other relatively rare species were recorded in this and/or past studies, e.g., bobcat, southern fox squirrel, Florida mouse, peninsular mole skink, central Florida crowned snake, southern hognose snake and least shrew. Of these species, only bobcat was recorded using the wildlife crossings. Abundance of many species was higher in 2022-23 than in 2015-16. This may be a result of seasonal differences in activity by certain species. The 2022-23 study was conducted in winter and spring; the 2015-16 study was conducted in summer and fall.

To improve wildlife use of the crossings, we highly recommended: 1) installing a suitable barrier, such as a wildlife-permeable, cable fence to prevent disturbance by unauthorized motorized off-road vehicles, and 2) re-landscaping both the underpass and the culvert approach on the west side using native groundcover and shrub species. The latter will encourage use by smaller wildlife species (specifically small mammals, reptiles and amphibians) that are more sensitive to native habitat qualities including soils, vegetation, leaf-litter, and woody debris suitable for foraging and to serve as cover from predators.

### 5.3.2 East-central Florida Wildlife Crossing Structure Study (Smith and Noss 2011)

This case study presents information on research conducted on the use of several bridges and culverts, many upgraded with wildlife crossing features (such as shelves) and built as alternatives to more expensive, dedicated wildlife crossing structures. The East-Central Florida study (FDOT – District 5) included thirteen sites located on SR 40, SR 46, SR 520, SR 415 and US 192 (fig. 5-15).

The effectiveness of crossing structures was evaluated by monitoring successful and unsuccessful wildlife movements at each study site. Multiple methods were utilized to evaluate activity by different species including trail cameras and track plates for medium to large species, and drift fences/pitfall traps for small mammals and herpetofauna. Roadkill and track surveys were conducted at all 13 field sites. Capture-mark-recapture surveys (including treatments and controls) were performed at four locations for small mammals and herpetofauna to evaluate species presence-absence, avoidance behavior, and potential crossing use (fig. 5-16). Data was collected from 2004 to 2010. Experiments were also conducted on effectiveness of different barrier fence materials for small mammals and herpetofauna. For all study locations we documented 176 different species. This included 17 state and federally listed species and 9 other species of conservation interest. Data included a total of 39,993 roadkills and 13,686 tracks within wildlife crossings for all the study sites. Results of mark-recapture studies of small mammals and herpetofauna included

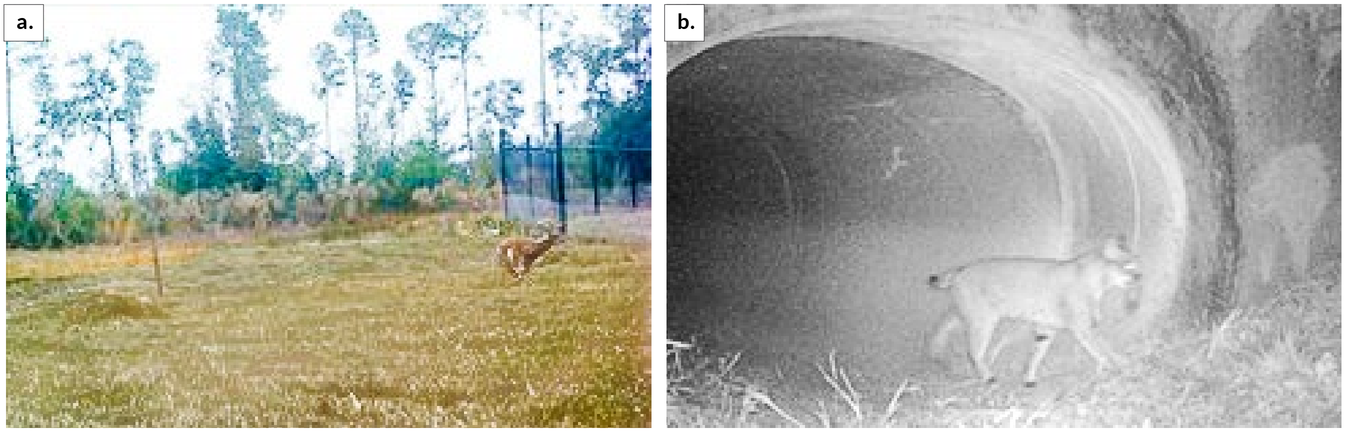

**Figure 5-14** Images of a white-tailed deer running toward the underpass (a) and a bobcat emerging from the large culvert crossing (b).

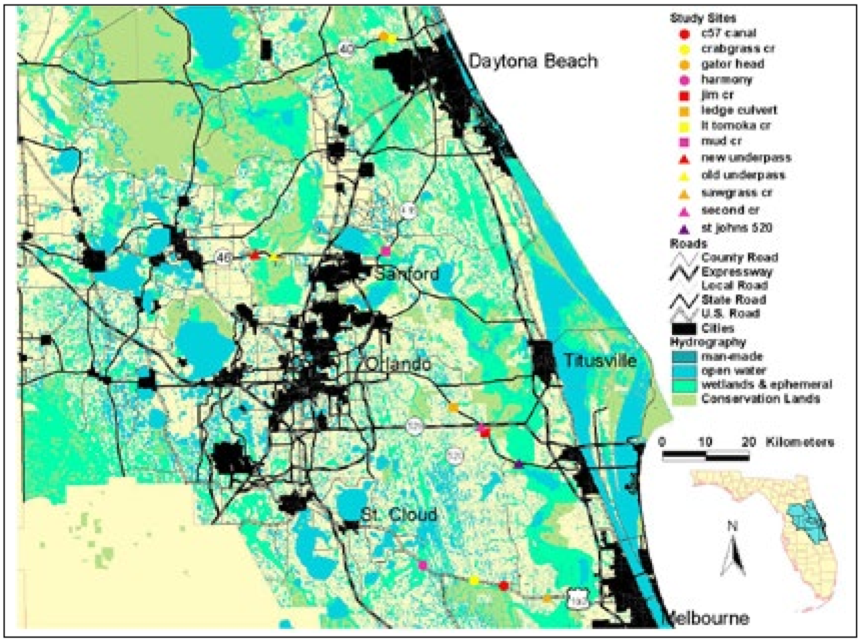

**Figure 5-15**

**East-Central Florida region study sites.**

1,250 individuals at wildlife crossing treatments and 5,799 individuals at control locations.

A wide diversity of avian species was negatively affected by vehicle strikes. Most could be reduced by using appropriate fencing to reduce the amount of small prey species killed on the pavement and altering flight trajectories into traffic. Numerous rodent, frog, lizard, and snake tracks were recorded in the larger wildlife crossings. Large numbers of road-killed frogs and snakes were also observed at nearly all study sites; this was attributed to inadequate fencing, not avoidance of the wildlife crossings. Other than gopher tortoise, few turtle species were recorded as road-kills or using the wildlife crossings. Several factors may contribute to this lack of data: effectiveness of fencing, low population levels, road avoidance, and habitat selection. Few road-kills of carnivores were recorded at the study sites except at Rock Springs Run State Preserve (RSSP). Carnivores used most of the crossing structures. State

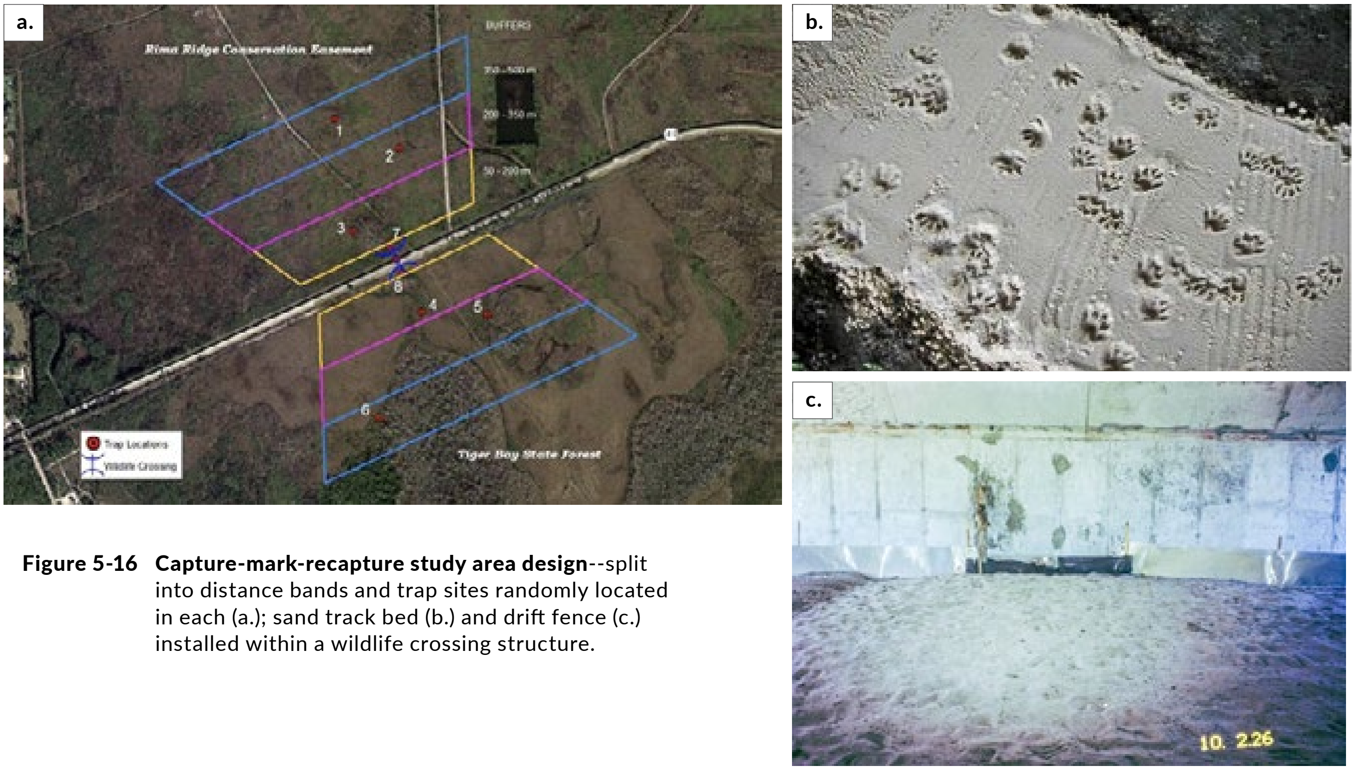

**Figure 5-16 Capture-mark-recapture study area design**--split into distance bands and trap sites randomly located in each (a.); sand track bed (b.) and drift fence (c.) installed within a wildlife crossing structure.

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Road 46 at RSSP still had a few chronic roadkill sites of black bears; these occurred beyond the existing wildlife fences. White-tailed deer were documented at all study sites. Road-kill numbers were highest at the SR 40, SR 46, and C-57 Canal sites and associated with attempts to circumvent the existing wildlife fencing. White-tailed deer were regularly recorded using the wildlife crossings at SR 40 and SR 46. Examples of wildlife crossing use are shown in fig. 5-17.

Detailed results for each site including species diversity and abundance and wildlife crossing use and avoidance were included in the study report. Problems and proposed corrective measures at each wildlife-crossing location were also discussed; categories for corrective measures included: structural, approaches, substrate, fencing, and vegetation and cover. Based on performance in field experiments, recommendations were provided on the application of different barrier fence materials for small mammals and herpetofauna.

**Figure 5-17**

**Images of wildlife crossing use** (a.-SR 46, b.-SR 40, c.-SR 415).

### 5.3.3 US 441 Ecopassage Study at Payne's Prairie State Preserve (Dodd et al. 2004)

The Paynes Prairie Basin in North-Central Florida is best described as a large freshwater marsh contained within a limestone basin. The prairie basin exists in a complex of surrounding ecosystems that include forested riverine wetlands (cypress, black gum, etc.), bayheads, pine flatwoods, live oak hammocks, mixed upland forest, managed pasture, and urban lands. The basin is transected (separated) into three sections by two major north-south, multi-lane highways, US 441 and I-75. Paynes Prairie was known as a haven for snake populations going back to the 1930s. US 441, which was built essentially at the same elevation as the prairie, has had tremendous impacts on snake populations as well as other wetland-dependent species as documented through roadkill surveys in the 1970s and 1990s.
In response to elevated wildlife mortality on US 441, in 2001, at Paynes Prairie State Preserve in Alachua County, Florida, FDOT constructed a barrier wall–culvert system designed to reduce roadkill while enhancing cross-highway connectivity with wildlife passages (fig. 5-18). A one-year post-construction evaluation demonstrated a substantial reduction in mortality, with only 158 animals recorded killed in the treated area (excluding hylid treefrogs), compared to 2,411 individuals documented during the year preceding construction. Within the prairie basin, mortality declined by 65% when hylid treefrogs were included and by 93.5% when they were excluded. The 24-hr kill rate declined from 13.5 to 4.9. Despite these improvements, most post-construction mortalities were concentrated at maintenance access points and along sections of fencing adjacent to private property, and the majority of non-hylid road kills occurred beyond the system's spatial extent.

Culvert effectiveness improved markedly, with species use increasing from 28 vertebrate species to 51 species (including fish) from pre-to post-construction, respectively. By constructing the barrier wall and expanding the number of ecopassages (adding four additional pipe culverts to the four pre-existing box culverts), capture success increased tenfold. Identified performance limitations—such as vegetation-related barrier breaches, siltation, and human access—highlight opportunities for targeted design refinements and routine maintenance to further enhance system effectiveness.

As alluded to above, a limitation of the Paynes Prairie application involved the inability to extend the mitigation measures into the transitional zones between the wetland basin and adjacent uplands. Such ecotones are known to exhibit high levels of wildlife activity but could not be addressed because of private land ownership. Other examples of barrier wall/culvert systems implemented or planned in Florida wetland and aquatic ecosystems where this limitation was addressed include Lake Jackson in 2010 and Ross Prairie (see subsection 5.2.1.)

**Figure 5-18**

**Images of the US 441 culvert and barrier wall system at Paynes Prairie.**

## 5.4 Quick Takes

Quick takes are brief project summaries that represent unique examples ranging from ideal approaches in restoring landscape connectivity to smaller, specific problem-solving measures associated with wildlife crossing projects that can enhance the overall objectives to improve permeability of roads for wildlife and/or reduce WVCs.

### 5.4.1 The Wekiva Parkway and SR 46

The Wekiva Parkway project was conceived over several decades of planning, research, and public meetings and deliberations involving the local community and government leaders. The Parkway was needed because of the tremendous demand to improve traffic flow around the rapidly growing Orlando metropolitan area. The unique challenge was that the Wekiva River Basin (fig. 5-19), north of Orlando, was designated a special planning district (Wekiva River Protection Area) imposing more stringent regulations on development and landuse practices to protect the fragile and valuable natural resources that includes springs, important surface waters, and aquifer recharge areas, and a diverse mosaic of native wildlife habitat types. The Wekiva River is one of only two National Wild and Scenic Rivers in Florida. How do you construct a limited access, multi-lane expressway through this area while simultaneously protecting and enhancing the sensitive ecological resources?

The existing SR 46 was a two-lane highway supporting over 20,000 vehicle trips per day in the 2000s. It was a significant barrier to wildlife movement and in the early 1990s had the highest recorded number of black bear vehicle collisions among all roads in the state.

To address the impacts, two wildlife crossings and an extended bridge over the river that included terrestrial wildlife crossings were constructed (fig. 5-20).

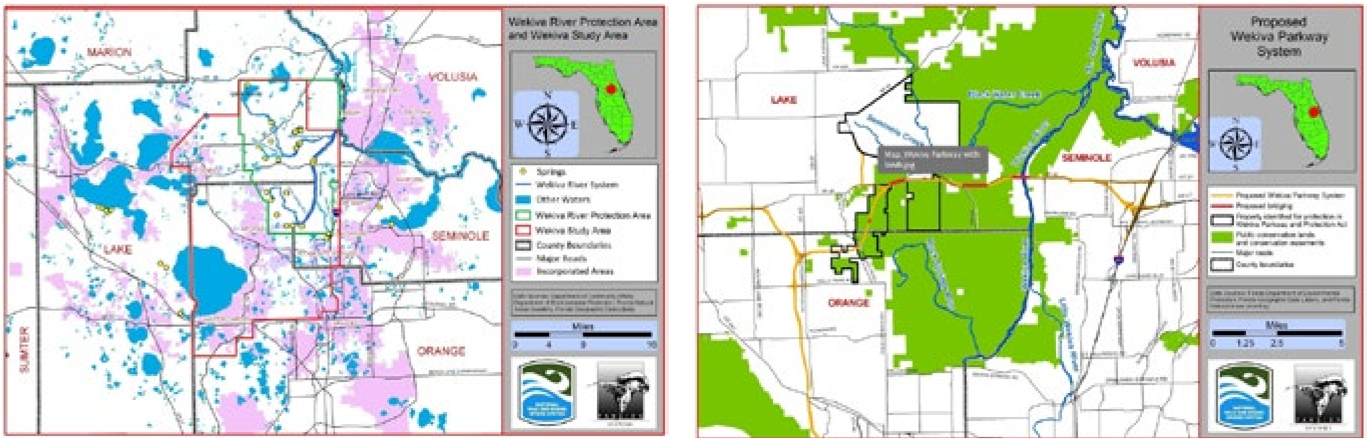

**Figure 5-19 Maps of the Wekiva River Basin Study Area** (courtesy of wekivawildandscenicriversystem.com).

**Figure 5-20 The wildlife crossings constructed on SR 46 in the 1990s and early 2000s prior to replacement by the Wekiva Parkway.**

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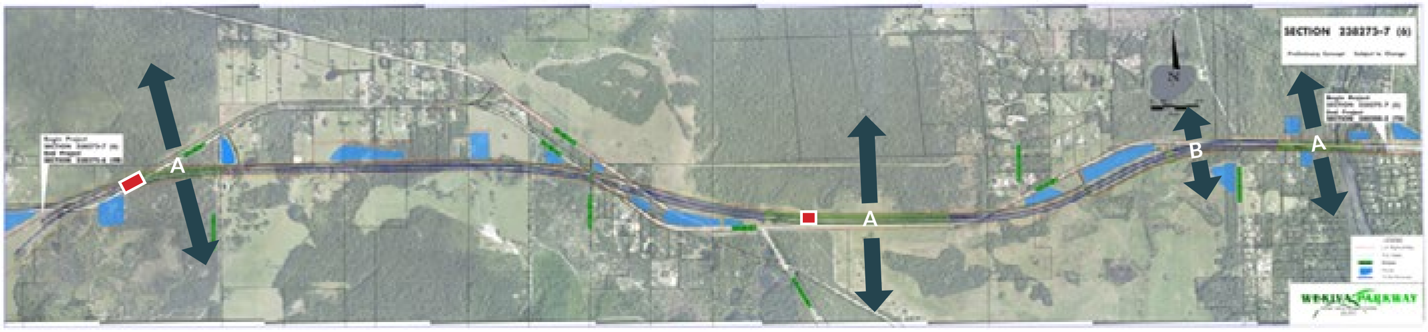

**Figure 5-21** **A map depicting the plan for Section 6 of the Wekiva Parkway Project.** It included three primary landscape bridges (A) of approximately 1,800, 4,000 and 2,000 ft lengths (from left to right). An additional equestrian crossing (B) of 100 ft length was also added.

*Research Studies.* Research efforts occurred on and along the original SR 46, the road the Parkway was designed to replace. Types of research included habitat and highway hotspots (using WVC data) modeling and subsequent field assessments of different types (e.g., roadkill and track surveys, radio-telemetry, and capture-mark-recapture studies) to address impacts on different taxonomic groups. These studies took place over nearly 15 years from the mid-1990s through the 2000s (Roof and Wooding 1996, Smith 2003, Hoctor et al. 2008, Smith and Noss 2011). In summary, considerable data were collected and analyzed to support the need for a system of wildlife crossings to restore landscape connectivity between the Wekiva River Basin state parks and the Ocala National Forest to the north.

*The Design Process.* Planning and design were led by FDOT and a team of consultants and involved the National Park Service and a large collaborative of participants from all levels of government, environmental NGOs, and the local community (fig. 5-21). Design charrettes were held and research findings consulted with the outcome incorporating several elements such as:

- Realignment and elevation of the new road
- Removal of the old SR 46 alignment
- Limited access and provision for a local service road
- Extension of the current wildlife crossing structures
- The primary crossings represent landscape–level connections
- Aesthetic and scenic qualities incorporated into the river bridge design
- Restoration of adjacent disturbed habitat areas

The construction was completed and the Wekiva Parkway opened in 2024. Examples of the Parkway bridges (figs. 5-22 and 8-6) display the scale and features included in the project.

### 5.4.2 Wildlife Crossing Shelf Design Associated with Linear Water Features

Interstate 4 in central Florida is an east-west coast connector that links the two north-south interstate highways in Florida, I-75 and I-95. Associated with I-4 is one of the state's major growth corridors with over 6.36 million people, including Tampa and Orlando that are top 20 cities in the U.S. Including Daytona Beach at the east end of the corridor and infill from smaller cities, the urban development along the I-4 corridor has essentially divided the natural resource areas in the peninsula into north and south halves (fig. 5-23). The barrier effects of this road to wildlife are exacerbated by nearly impenetrable annual average daily traffic volume (in 2024) of up to 161,000 near the largest urban areas and ranging from 69,500 to 104,000 in the rural context.

Because of the increasing barrier effects associated with I-4, it became imperative to construct wildlife crossing features to improve permeability for wildlife, a primary goal of establishing the Florida Wildlife Corridor. Efforts led by FDOT and other partners have resulted in construction of several wildlife crossings to address this problem. It's quite probable these are the most important wildlife crossings in Florida from

**Figure 5-22**

**Image of the Wekiva River Bridge,** designed to aesthetically fit the surroundings of the National Wild and Scenic River.

a statewide and regional landscape connectivity perspective. They facilitate reconnecting South and North Florida conservation lands, improving accessibility and reintegration of terrestrial wildlife populations and allowing for geographic adaptation to long-term climate change effects in the peninsula. Figure 5-24 provides examples of the standard, effective wildlife crossing types for large and small animals that were constructed on Interstate 4.

These examples include broad, upland-oriented structures as well as one that includes earthen shelves and a linear water feature. Other installations include elliptical pipes for small mammals, reptiles, and amphibians (see example in fig. 3-19a) and Florida's first dedicated wildlife overpass (under construction). The wildlife bridges include the use of locally native soil substrates creating a more ecologically uniform and accessible habitat linkage for wildlife like fossorial species that prefer to move under the soil surface. These are relatively new

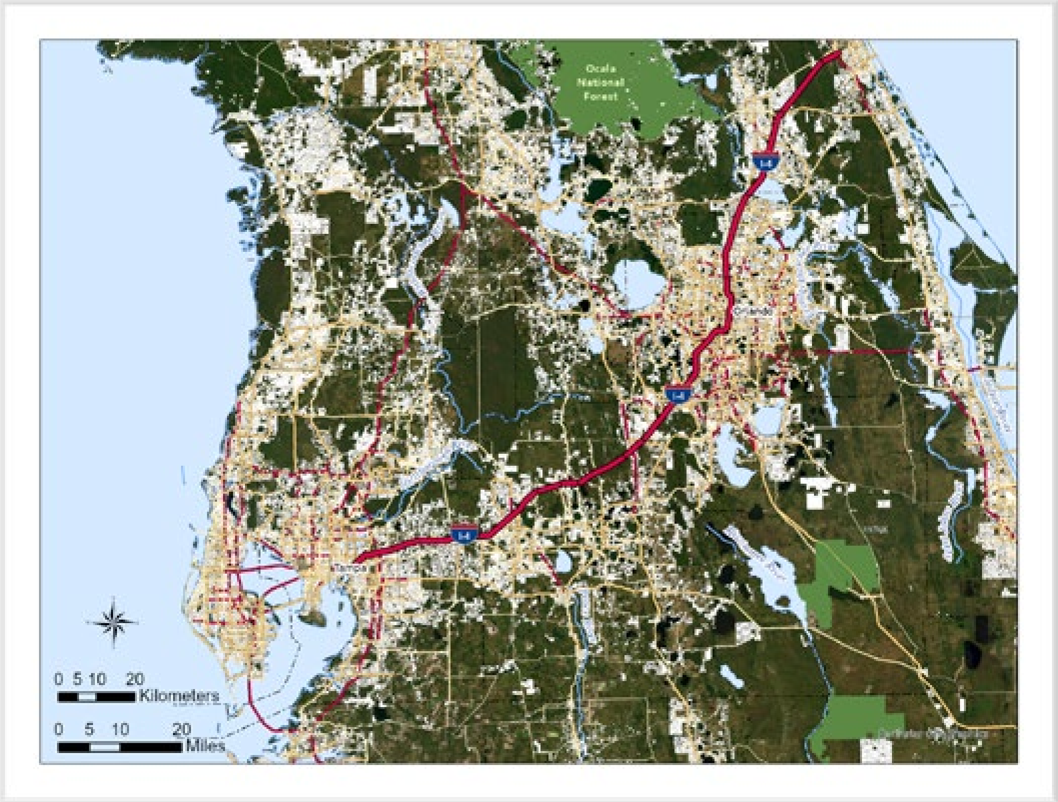

**Figure 5-23**

**Urban Growth along the Interstate 4 Corridor in Central Florida.**

**Figure 5-24** **Images of the two types of wildlife underpasses constructed on Interstate 4 upland-oriented** (left) and earthen shelves adjacent to a linear water feature (right); also see fig. 5-13.

structures and the addition of native shrubs and groundcover in the approaches and the median areas of the structure would enhance wildlife use.

### 5.4.3 Retrofits on Alligator Alley (I-75) Designed to Improve Wildlife Connectivity

Alligator Alley (I-75) is another east-west connector between the metropolitan areas of Miami/Ft. Lauderdale and Naples/Ft. Meyers. It passes through vast areas of wetlands including the Everglades and Big Cypress, both are National Parks/Preserves (fig. 5-25). A diverse assemblage of wildlife occurs in this area (of over 2.4 million acres of conservation lands) and 36 underpasses were constructed to ensure wildlife connectivity (fig. 5-25; also see example in fig. 3-12). The primary driver for this accomplishment was the endangered Florida panther, but these structures serve many other species that have been documented using them. Some of the structures are upland-oriented and others are wetland or aquatic passages. This was a significant and successful endeavor to maintain a connected natural landscape in this globally unique ecosystem.

An integral aspect that improves the effectiveness of the underpasses and reduces WVCs is the 40+ continuous miles of 10 ft high chain-link, wildlife fencing that accompany the wildlife underpasses (fig. 5-25; also see example in fig. 3-27). The original fencing only extended to the Faka-Union Canal primarily abutting existing conservation lands at the time of construction in the early 1990s (see fig. 5-25). The remaining 9 miles of Alligator Alley to the west toll booth, bordering private lands, only included a standard, 4.5 ft high, field fence. The same private lands bordering the southside of Alligator Alley became part of the Picayune State Forest in 1995.

While the wildlife-fenced section was effective in preventing WVCs, the section without wildlife fencing steadily showed increasing numbers of WVCs over a decade including many involving Florida panthers (14 from mid-May of 2004 to March of 2015). Many of the panthers were attempting to access private lands north of Alligator Alley in an area called North Belle Meade that remains suitable habitat yet is only partially protected for conservation. Wildlife crossings were absent in this section of the highway as well though two existing canal bridges and a series of large cross-drainage culverts were present.

Beginning in 2015, actions were taken by FDOT, FWC, USFWS and other involved parties that led to retrofit projects on the two bridges (Faka-Union and Miller canals), and at five large cross-drainage culverts that could function as seasonal crossings. In addition, a project was set in motion to extend the wildlife fencing to west of the toll booth near SR 951 (Collier Boulevard).

The two canal bridge retrofits and the extended wildlife fencing project were completed early 2017.

The culvert site modifications were performed in 2023 and 2025 (see fig. 3-43). The culvert site modification included installing pole bridges over canals at each end of the structure to allow for a continuous path (figs. 5-26 and 5-27). The culvert periodically floods and is connected to the canals that hold water for most of the year, and providing dry passage over the canals improves access for wildlife movement. When water levels are low the culvert has demonstrated occasional to frequent use by various species (fig. 5-28).

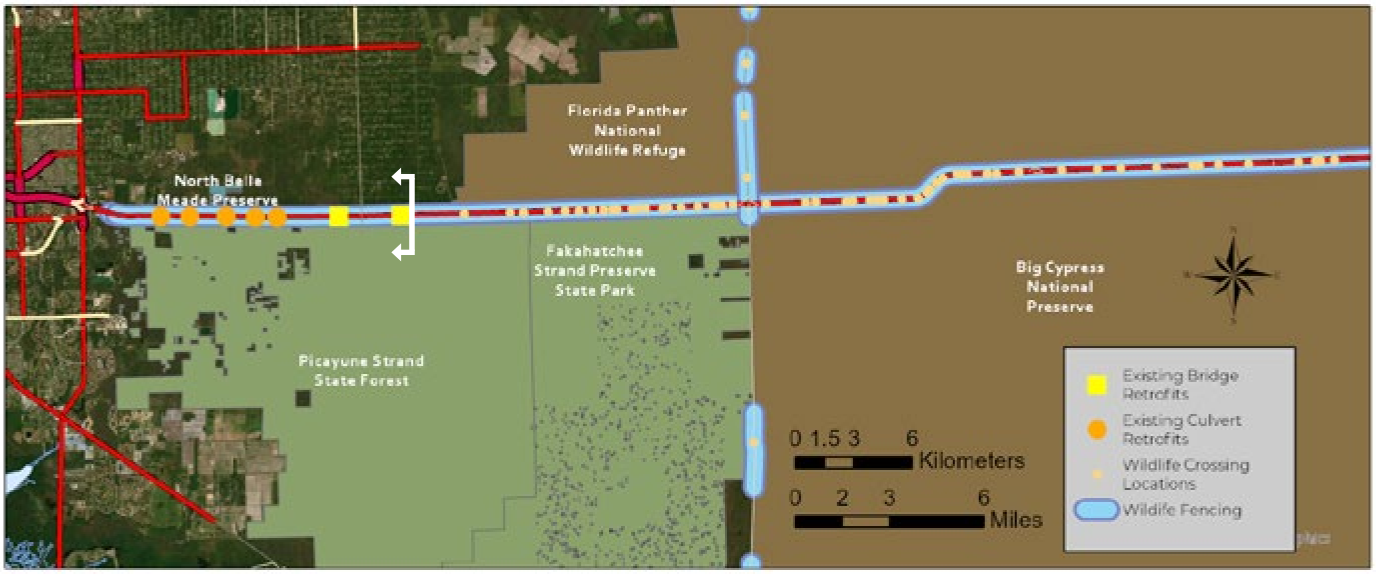

**Figure 5-25** **A map showing Alligator Alley (I-75)** and the surrounding conservation lands, with locations of wildlife underpasses and fencing. (Arrow direction indicates where new fencing was installed in 2017; all other fencing was installed in 1990.)

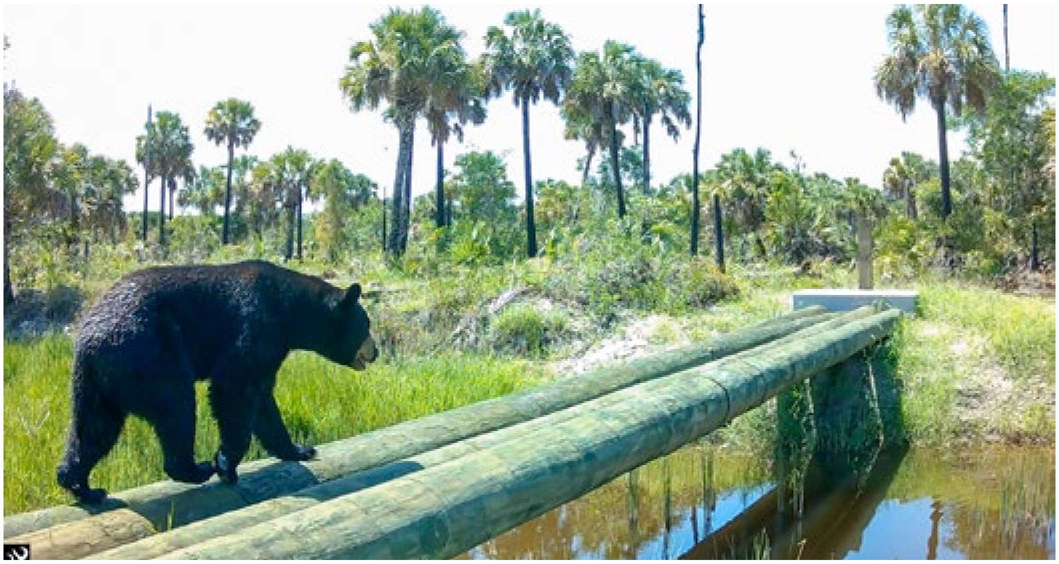

**Figure 5-26**

**Image of a black bear using the wood pole bridge over the canal leading from the cross-drain culvert.** Photo credit: fStop.

**Figure 5-27 Image of a raccoon using the cement pole bridge over the northside canal leading into the cross-drain culvert.** Photo credit: fStop.

**Figure 5-28 Image of an alligator moving through the cross-drain.** Photo credit: fStop.

# Section 6.0: References

## 6.1 Cited Literature

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Photo credit: Florida Panther Posse.

# Section 7: Appendix 1

## Florida Department of Transportation Wildlife Crossing Guidelines (2023)

### Introduction

These guidelines have been developed for use by the Florida Department of Transportation (FDOT) to evaluate the appropriateness of including wildlife crossings (upland or wetland) for proposed projects on the State Highway System (SHS) or as possible stand-alone retrofit projects on the SHS when warranted. These guidelines also establish criteria that must be considered during design of wildlife crossings. These guidelines have been developed in coordination with the United States Fish and Wildlife Service (USFWS) and Florida Fish and Wildlife Conservation Commission (FWC), which have regulatory authority and are the recognized experts for wildlife within the State of Florida.

The Florida Wildlife Corridor Act (259.1055, Florida Statutes) was established in 2021 and these guidelines adopt the definitions therein for the following terms:

- Conserved lands – federal, state, and local lands owned or managed for conservation purposes, including, but not limited to, federal, state, and local parks; federal and state forests; wildlife management areas; wildlife refuges; military bases and airports with conservation lands; properties owned by land trusts and managed for conservation; and privately owned land with a conservation easement, including, but not limited to, ranches, forestry operations, and groves.
- Florida wildlife corridor – the conserved lands and opportunity areas defined by the Florida Department of Environmental Protection as priority one, two, and three categories of the Florida Ecological Greenways Network.
- Opportunity area – those lands and waters within the Florida wildlife corridor which are not conserved lands and the green spaces within the Florida wildlife corridor which lack conservation status, are contiguous to or between conserved lands, and provide an opportunity to develop the Florida wildlife corridor into a statewide conservation network.
- Wildlife – the same meaning as in Article II of the Wildlife Violator Compact Act, s. 379.2255 which reads in part: all species of animals, including, but not limited to, mammals, birds, fish, reptiles, amphibians, mollusks, and crustaceans, which are defined as "wildlife" and are protected or otherwise regulated by statute, law, regulation, ordinance, or administrative rule.
- Wildlife corridor – means a network of connected wildlife habitats required for the long term survival of and genetic exchange amongst regional wildlife populations which serves to prevent fragmentation by providing ecological connectivity of the lands needed to furnish adequate habitats and allow safe movement and dispersal.
- Wildlife crossing – a landscape design element that connects two or more patches of wildlife habitat and that is meat to function as a safe conduit for wildlife

> over or beneath roads, waters, and other barriers to wildlife movement and that is designed to protect Florida panther and other critical wildlife habitat corridor connections and to reduce motor vehicle collisions with wildlife, to reduce the likelihood of injuries and mortalities to humans and wildlife from such collisions, and to reduce the potential for damage to motor vehicles from such collisions.

Wildlife crossings are designed based on site specific needs and constraints, but generally include one or more of the follow elements:

- new or modified structures (e.g., bridges, bridges with shelves1, or wildlife overpasses)
- specially designed culverts
- directional or barrier fencing (with jump outs if appropriate), walls, or embankments

**This structure modification includes a shelf at the toe of the riprap slope protection area under a bridge. This modification can be used to provide a raised alternative for wildlife accommodations when flooding limits wildlife passage at the ground level.*

Other design elements such as reduced nighttime speed limits, species crossing signs, and roadside animal detection may also be incorporated into wildlife crossing locations. Wildlife crossings may coincide with other uses such as greenways and trails (e.g., hiking, equestrian, paddling) or cattle and farm crossings when these uses are compatible. Wildlife crossing locations should be identified as early as possible in the project development processes, and prior to project design.

## Timing to Identify Wildlife Crossing Opportunities

During project development the FDOT District offices, in coordination with USFWS and/or FWC, will determine if a wildlife crossing is appropriate. The FDOT also considers input from other stakeholders, including local governments, non-governmental organizations, and the public. Although opportunities for input exist throughout the process, the FDOT has two phases where early coordination and input are most effective in addressing wildlife connectivity: the Planning phase and the Project Development and Environment (PD&E) phase. The processes used for review and input during these phases include:

1. In the Planning Phase, Efficient Transportation Decision Making (ETDM) is the process used to screen qualifying projects (refer to ETDM manual) during which wildlife agencies, land acquisition and management agencies, and other stakeholder input is solicited to provide early scoping information regarding potential effects and resources of concern in the project area. During a screening event, FDOT uses available habitat, land use, and wildlife information in the Environmental Screening Tool (EST), including the Wildlife Crossing Considerations data layers, to identify initial wildlife crossing opportunities. The District will also use other methods and information such as field reviews and local knowledge to supplement the GIS information. Resource agencies and stakeholders are requested to review and comment on wildlife crossing opportunities or other wildlife impact minimization measures and potential mitigation strategies as well as identify opportunity areas/ gaps in conservation lands where land acquisition may be needed to support wildlife crossings.
2. In the PD&E Phase the PD&E Study is the process by which the FDOT develops the project alternative(s) and analyzes project impacts. It is important for resource agencies and stakeholders to be involved during this phase since this is when preliminary design, constructability, financial needs, and resource agency/stakeholder considerations are balanced to develop the preferred alternative and conceptual design. During this phase it is critical for FDOT to understand the timing of when resources agencies will address opportunity areas/ gaps in conservation lands needed to support wildlife crossings. This is also the phase where project commitments are initially developed.

## Guidelines

In evaluating a project for a potential wildlife crossing the following guidelines should be observed:

For a proposed FDOT project: Wildlife crossings are typically considered when the project is a new alignment, capacity improvement, roadway reconstruction or bridge replacement. However, if FDOT finds that a wildlife crossing may be beneficial on other projects (e.g., resurfacing projects with drainage improvements) the District can review the project/site specific circumstances to consider inclusion of a crossing in the project.

For a requested retrofit project: Districts should require entities requesting a wildlife crossing to provide scientifically based documentation or studies to substantiate their requests. Funding for acceptable, substantiated requests could result from financial partnerships with requesting entities. In support of these efforts, requesting entities can work with other stakeholders to facilitate funding, to meet coordination requirements with property owners /other stakeholders, and identify right of way and maintenance requirements. Retrofit projects may require the requesting entity to agree to maintain and/or fund the maintenance of the wildlife crossing. It is important to advise the requesting entity that appropriate agreements (i.e., Local Funds Agreements/Maintenance Agreements) would need to be executed consistent with FDOT requirements and related Work Program approvals would be needed in order to design and construct a retrofit project.

The following list should be used as a guide in evaluating whether a wildlife crossing is appropriate. The list below is not exhaustive and should not be considered a checklist, but simply a guide for coordination, consultation and decision making:

- Is there a documented or science-based need for a wildlife crossing that is supported by USFWS and/or FWC and other resource agencies (as applicable) such as: o Are there wildlife documented within the project area? o
- Are there documented road kills of wildlife with high conservation value (as determined by the USFWS/FWC)? If not, this should not be construed as a requirement for FDOT to conduct a roadkill survey.
- Does wildlife traversing the roadway create a potential hazard to motorists and/or wildlife?
- Is the project within the documented range of the Florida panther and/or Florida black bear?
- Does the project cross or fragment designated critical habitat or a documented landscape level habitat linkage, ecological greenway, the Florida Wildlife Corridor, or a Florida Forever project area? This may be especially important when a median barrier is proposed that could create entrapment of the species within the roadway.
- Are the future land use and development patterns compatible with wildlife needs or ecosystem viability?
- Does the project involve locations of critical conservation need as determined by USFWS or FWC?
- Are conserved lands needed to achieve successful use of a wildlife crossing? If so, are conserved lands present in sufficient amounts on both sides of the road (adjoining and contiguous), where a wildlife crossing may be located, including the ability to provide adequate fencing (where appropriate) to guide wildlife for a sufficient distance to achieve successful use of the crossing?

Generally, these questions would apply to large, new or retrofit wildlife crossings that target wildlife with a large home range as compared to smaller wildlife crossings where a shelf is being added to an existing structure. These questions should be discussed and needs agreed upon with USFWS or FWC during the ETDM Screening and/or the PD&E Study. If one of these conditions required to achieve successful use of the crossing does not exist prior to the design phase but is reasonably certain to occur no later than the beginning of the 60% project design phase (when environmental permit applications are typically submitted), the wildlife crossing can be considered. Should the conditions agreed upon by the FDOT and resource agencies not exist at the beginning of the 60% design phase, the FDOT may decide not to move forward with the inclusion of the wildlife crossing in the project. In cases where a project achieves 60% design but is not funded for right of way acquisition or construction and is put on "hold", the FDOT may consider moving forward with the inclusion of the wildlife crossing if the conditions have been satisfied by the time the project design is resumed and if the schedule and budget allow.

Answers to the above questions should serve as a guide to determine whether a wildlife crossing is appropriate. In addition, this information should support the selection of an appropriate wildlife crossing design that would promote wildlife movement or ecosystem viability. The District should consult with USFWS or FWC when alternative measures and technology are considered.

In cases where a documented need or science-based data does not exist to adequately support a proposed crossing, it may be necessary to perform studies or additional research to obtain the data. Generally, the party requesting the wildlife crossing is expected to perform the study or conduct the needed research. The USFWS and/or FWC should have an active role in the review and development of relevant studies and in the evaluation of the results, including meeting with the appropriate District about the final recommendations. This effort needs to be done in a timely manner so as not to slow the progress of the project development process.

The specific design (type, size, and location) of the wildlife crossing should be determined by the District through coordination with the USFWS and/or FWC and other resource agencies as appropriate. The District may also consider input from other interested stakeholders.

A wildlife crossing design must take the following criteria into consideration:

- The wildlife crossing cannot compromise any state or federal highway safety criteria.
- The wildlife crossing cannot compromise FDOT design requirements. Should roadway or bridge design variations or exceptions be needed for the proposed wildlife crossing proper and timely review by the Districts and Central Office (as applicable) would be required. If not 4 approved, the wildlife crossing would require redesign and further coordination with the agencies to determine whether it is feasible to provide the crossing.
- The wildlife crossing cannot cut off an adjacent property owner's only practicable route of ingress/egress to their property. Coordination with adjacent property owners may be needed for addressing access related issues. Results of this coordination could affect structure locations and/or fencing lengths.
- The wildlife crossing cannot negatively impact adjacent properties (e.g., provide access for people and/or wildlife to private properties where none presently exist).
- The wildlife crossing cannot negatively impact existing drainage patterns or flood off-site properties.
- The placement of the wildlife crossing is usually associated with wildlife mortality hotspots; however, the ultimate placement may be based on the most cost efficient and ecologically effective design that meets the needs identified by USFWS and/or FWC and regulatory agencies as appropriate.
- Upland and wetland habitat impacts should be avoided and minimized to the extent practicable by proper design.
- Lighting at the wildlife crossing should be minimized to the greatest extent practical. Refer to Section 231.2.1 Environmental Lighting in the FDOT Design Manual.

- The wildlife crossing must be accessible for proper maintenance to ensure the structure remains viable. Considerations should include maintenance of fence and gates, vegetation management, "skylight" or other small features supporting the crossing, and sediment or erosion issues. Coordination with maintenance prior to final design and construction is strongly encouraged.

- When various types of wildlife crossings could be applied to a location, a cost-benefit analysis should be considered. The costs of each wildlife crossing type should be compared to the anticipated benefit of reduced risks of collisions for both motorists and wildlife. Costs for the wildlife crossing should include design, permitting, right-of-way, construction, and long-term maintenance (e.g., fencing, gates and maintaining wildlife access to the wildlife crossing when applicable). Costs for collision reductions should be coordinated with the Traffic Operations Office and be based on the anticipated number of reduced collisions using the data supporting the need for the wildlife crossing. The Wildlife Crossing Calculator developed by UC Davis may be used to develop this cost benefit analysis. Contact OEM for access and support.

- Should post-construction monitoring be requested by a regulatory agency, USFWS and/or FWC should have an active role in the review and development of the monitoring plan. Any post-construction monitoring should be for data collection and information only and will only be conducted for a limited period of time. FDOT may also implement long-term monitoring at broad intervals (e.g., semiannually, bi-annually) to look for any maintenance issues (e.g., vegetation removal, erosion issues, fence repairs) that may need to be addressed.

Photo credit: Florida Panther Posse.

# Section 8: Appendix II

## 8.1 Introduction

This appendix presents additional examples (mostly in Florida) of the three major categories of wildlife crossing structures.

## 8.2 Overpasses

There are currently no wildlife overpasses in Florida, though there is one under construction on Interstate 4, and it is expected that opportunities to build others will occur in the future. Below is a conceptual design for a landscaped wildlife overpass (fig. 8-1) and a couple examples of existing ones from outside Florida (fig. 8-2). One design guideline for plantings intended to provide

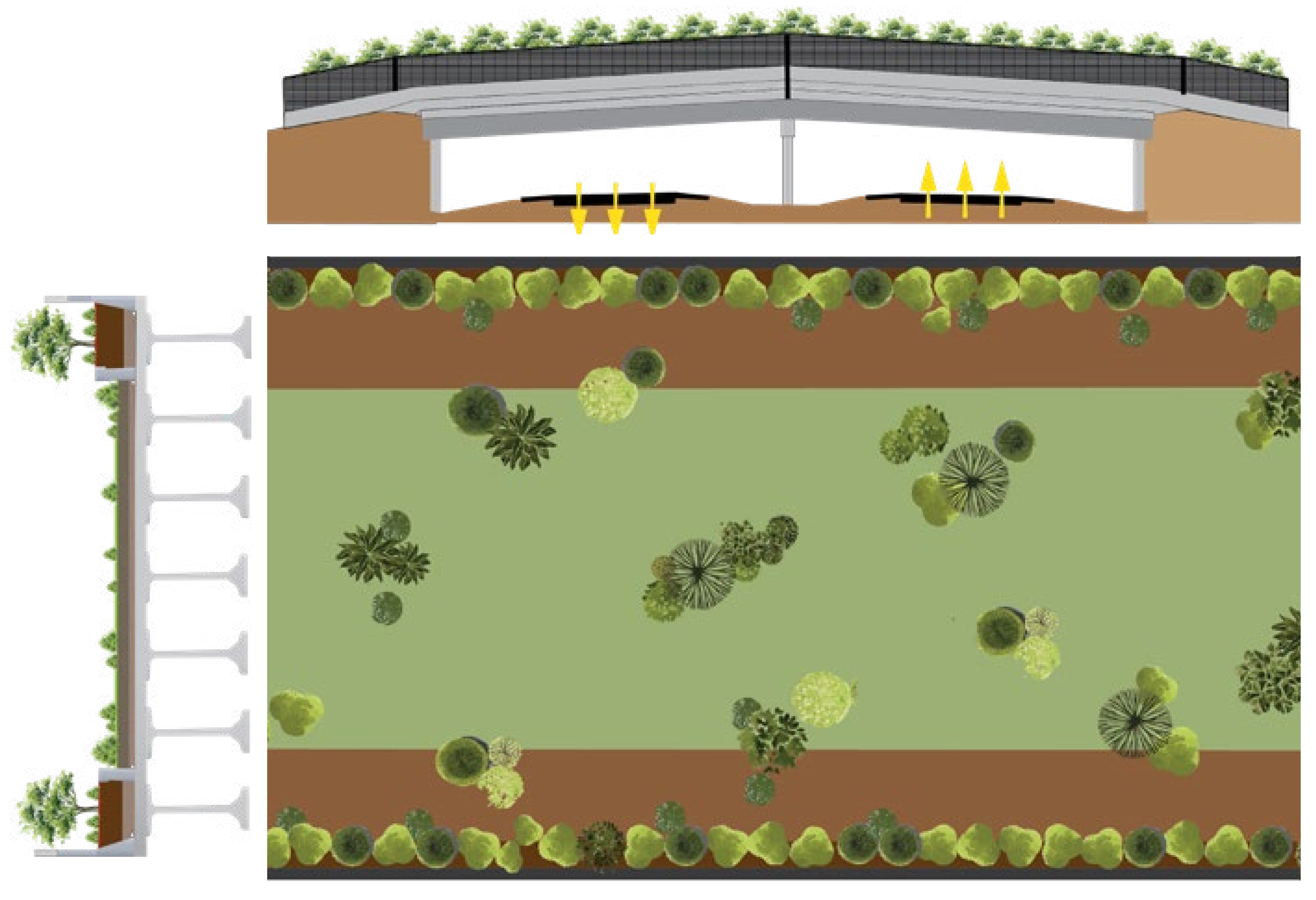

**Figure 8-1 Multiple views of a conceptual wildlife overpass.** This example generally represents a functioning crossing area of 100 ft in width with two planting zones, denser cover on the outside and more variable density in the interior.

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**Figure 8-2** **Additional examples of wildlife overpasses** (in Washington [left] and Europe [right]); note the use of landscaping to provide cover, clear zones in the center on the left and more dense plantings across the structure on the right. Also see figs. 3-1, 3-2 and 3-5 to 3-10. Photo source: WSDOT, left.

functional connectivity for a wide diversity of small and large wildlife is to maintain continuous, medium density shrub cover in the outer zones and low shrub density in the inner zone (with inclusion of randomly scattered boulder rocks, logs, stumps, and woody debris piles).

## 8.3 Underpasses

Underpasses, both bridges and culverts, are common, and a wide variety have been constructed in Florida. At many locations, considerable effort and creativity went into adapting standard structures into alternative underpass designs to improve permeability for wildlife on Florida roads.

### 8.3.1. Upland-adapted underpasses

Conceptual designs for upland culverts and bridges should include plantings to reduce noise and light disturbance along the perimeter, clear sightlines in the interior of approaches, and wildlife fencing to direct animals toward the structure (see fig. 8.3). The variety of examples of upland crossings include round or elliptical (fig. 3-19), box (fig. 8-4), and arch culverts (fig. 8-5), and bridges (fig. 8-6).

### 8.3.2. Underpasses linked to water features

Examples of crossings associated with a water feature include culverts with built-in shelves (fig. 8-7 and 8-8), culverts with separate aquatic and terrestrial passage (fig. 8-9 and 8-10), bridges with shelves (fig. 8-11 and 8-12), and bridges with seasonal-flow features (fig. 8-13). In each case the terrestrial passage area is at a higher elevation than the aquatic flowway when at the mean high-water level. Size of the target species dictates how much vertical clearance is needed inside the terrestrial passage. Capacity for how high above the mean high-water line the terrestrial passage can be placed depends on site topography and fill needs. The more fill required, the greater the cost. The latter example of seasonal-flow features (fig. 8-13) is a novel approach when contending with ephemeral water conveyance and provides adequate separation and protection of the wildlife crossing area.

There are two existing trail bridges in Florida that wildlife use has been observed. Though not designed to include specific wildlife features, they do provide landscape connectivity for some species (fig. 3-8 and 8-14). To convey more functional design options (in concept and in-practice elsewhere), other examples are provided of different combined -wildlife and -trail crossings from North America and Europe (figs. 8-15 to 8-18; and compare with fig. 3-25).

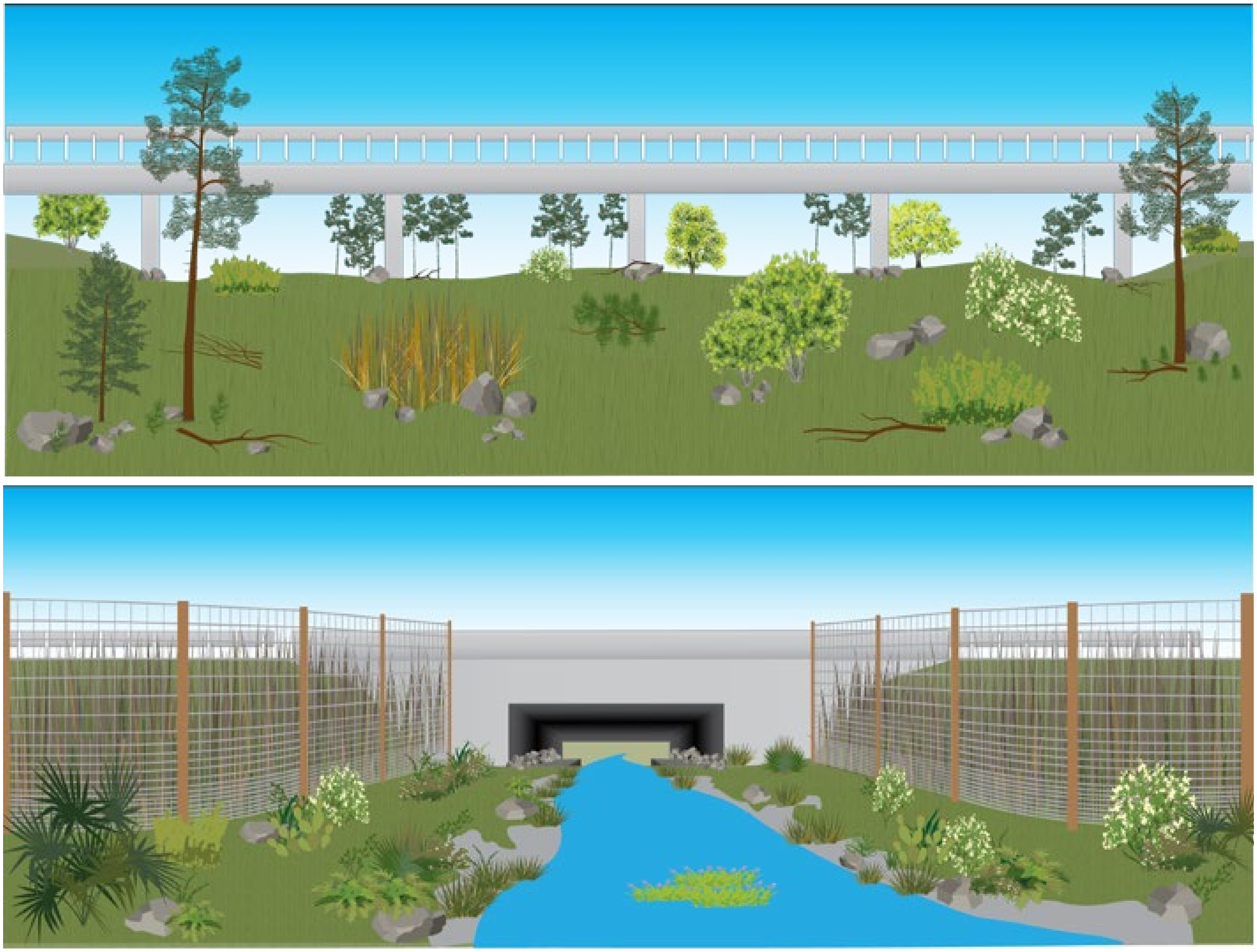

**Figure 8-3** **Conceptual design of a bridge (top) and a culvert (bottom) in dry, upland communities**; the illustrations represent native plantings and wildlife fencing to direct animals toward the crossing.

**Figure 8-4** **Small (<5 ft) and large (> 5 ft) box culverts in upland communities** (left, SR 60 in Indian River County; right, SR 46 in Lake County). Also see fig. 3-19d.

**Figure 8-5** **Examples of large arch culverts in upland communities** (left, Immokalee Road in Collier County; right, California). The Immokalee Road crossing includes angled wing walls.

**Figure 8-6** **Example of underpass bridges at upland sites** (left, Wekiva Parkway in Lake County; right, SR 29 in Collier County). Also see figs. 3-12 and 3-15 to 3-17.

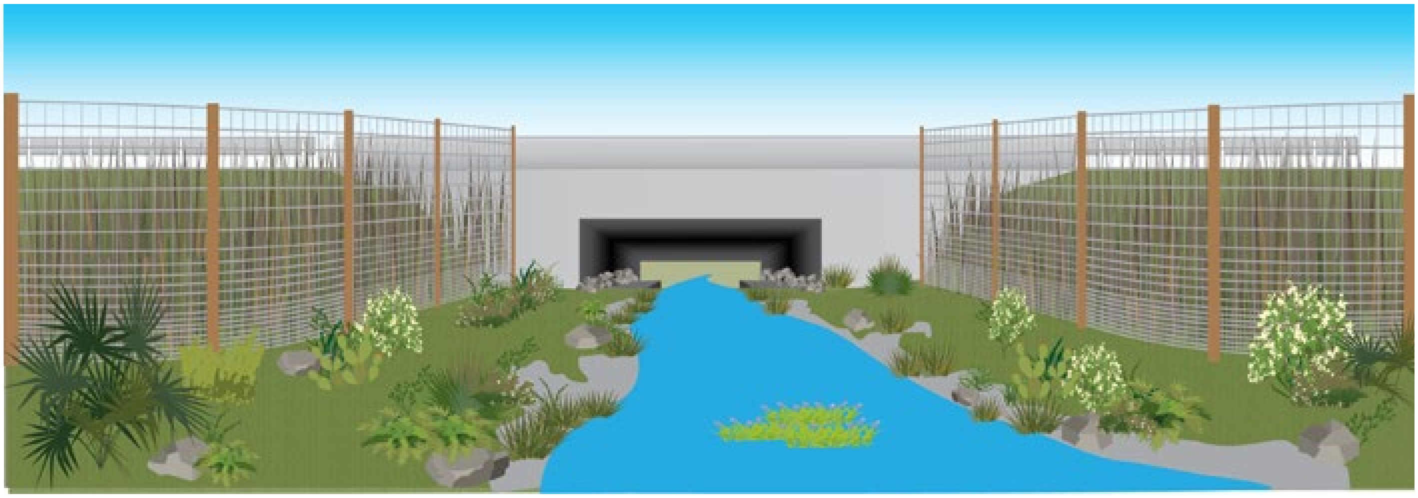

**Figure 8-7** **Conceptual design of a culvert with raised shelves.** The shelves are postioned above the mean high-water line to provide consistent terrestrial passage opportunities.

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**Figure 8-8** **Culvert with built-in shelf adjacent to flow-way feature** (US 192 in Osceola County below). It is preferable to add shelves on both sides of the water feature. Also see fig. 3-19b and 3-19c.

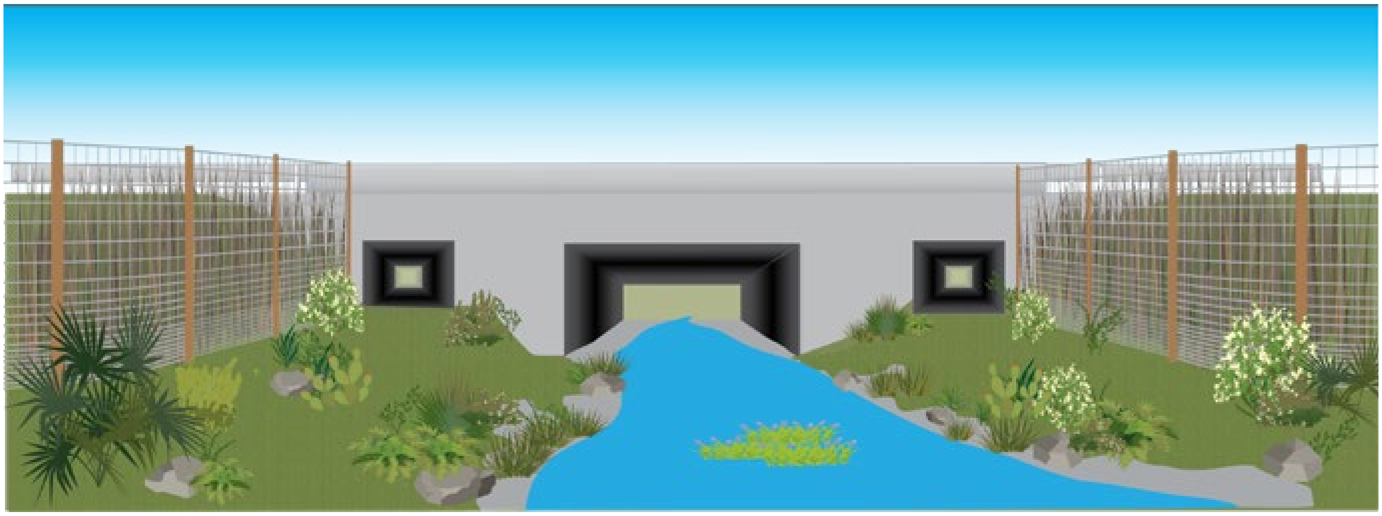

**Figure 8-9** **A conceptual representation of separate culverts for water flow and for terrestrial passage**. Note the differential elevation during mean high water level.

**Figure 8-10**

**Culvert design with separate aquatic and terrestrial passage** (Nokuse Plantation, Walton County).

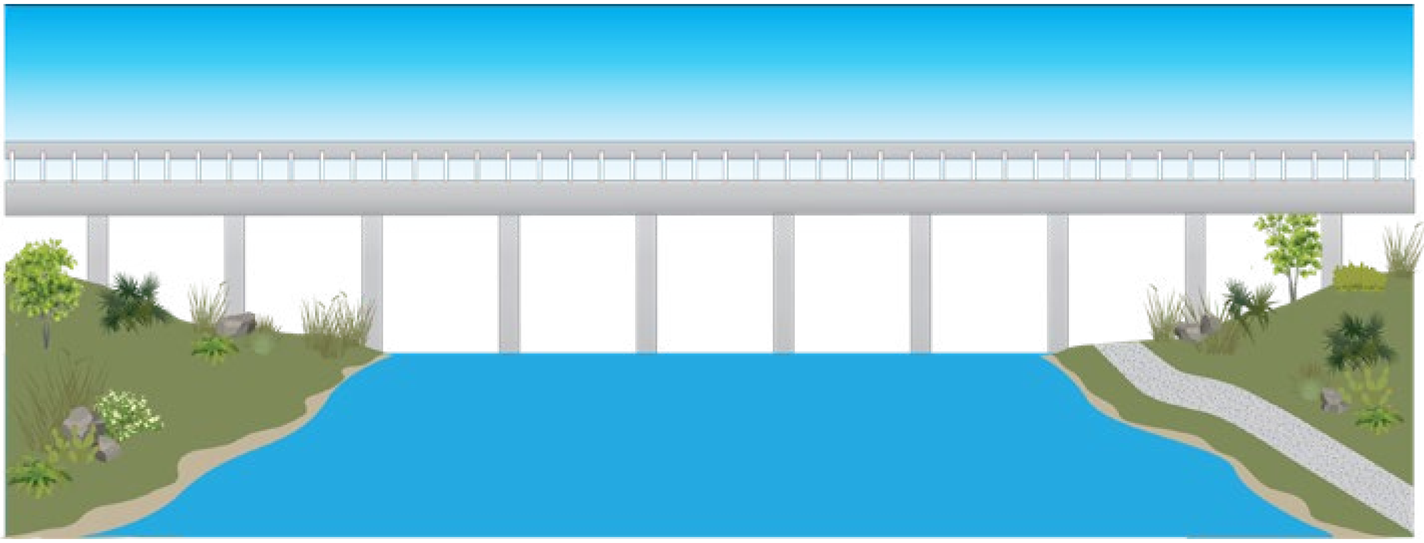

**Figure 8-11** **The bridge design depicts gradually sloping shelves adjacent to the flowway.** The aim is to maintain consistent openings for terrestrial species to traverse as water levels rise.

**Figure 8-12** **Examples of bridges with shelves** (left-SR 520 and right-US 192 in Brevard County), see also figs. 3-13, 3-21, 3-41 and 3-43.

**Figure 8-13** **Bridges with special, seasonal-flow features** (left, SR 29 in Collier County includes channel created from rip-rap; SR 40 in Volusia County includes a pipe culvert that extends through the crossing).

**Figure 8-14** **Overhead view of the Marjorie Harris Carr Cross-Florida Greenway trail crossing of I-75**. Note the paved trail and the wide, inaccessible planter boxes; this leaves only about 8 ft of unpaved pathway, or nearly half the width of the accessible space of the crossing with a more natural substrate for wildlife use.

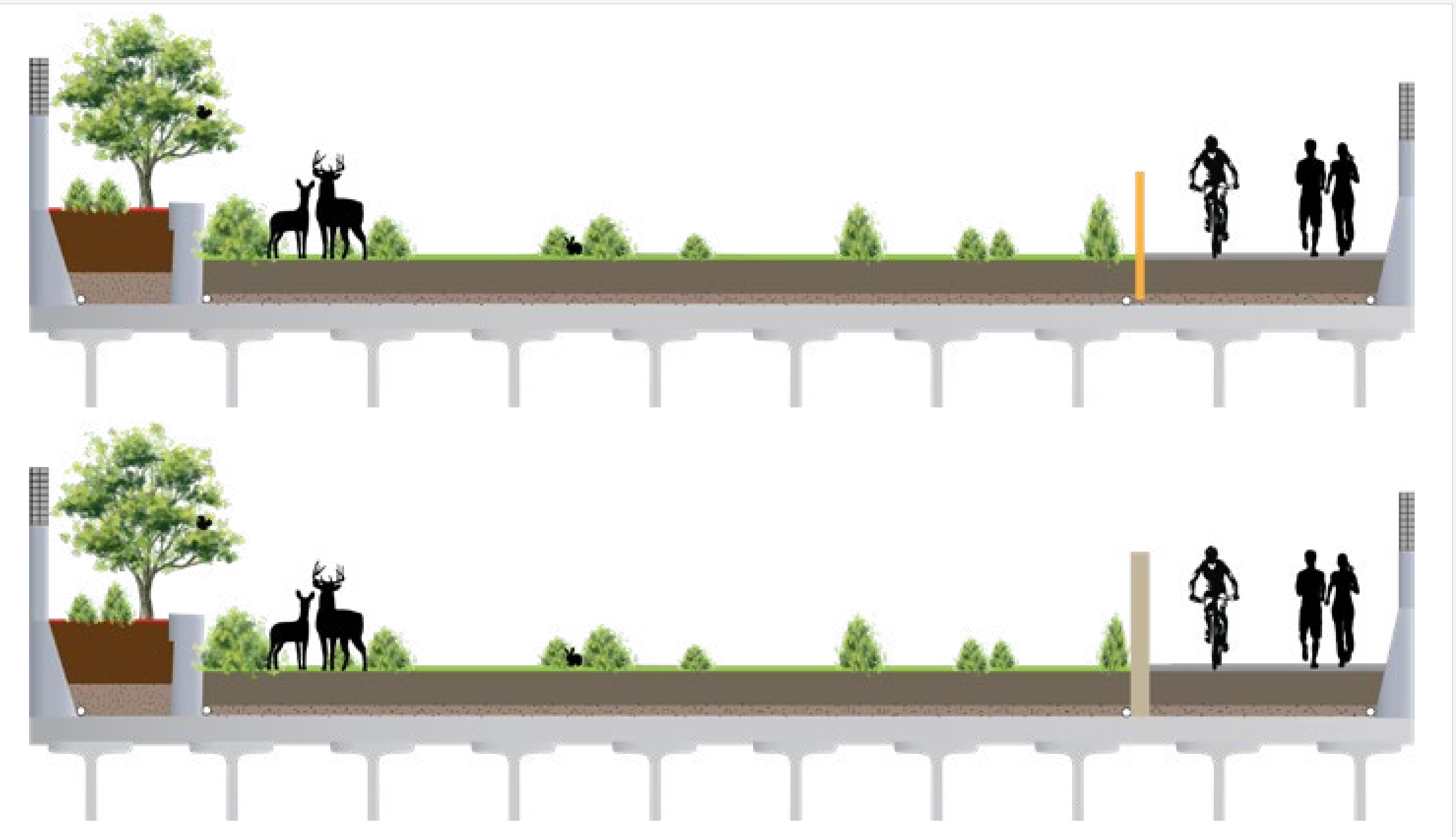

**Figure 8-15** **Conceptual designs of a multi-purpose crossing with recreational trail**. This includes separate sections for wildlife and paved-trail users; dividers include a fence (top) or a wall (bottom). The design concept is proportional and not to scale, wildlife section is recommended as 100 ft wide.

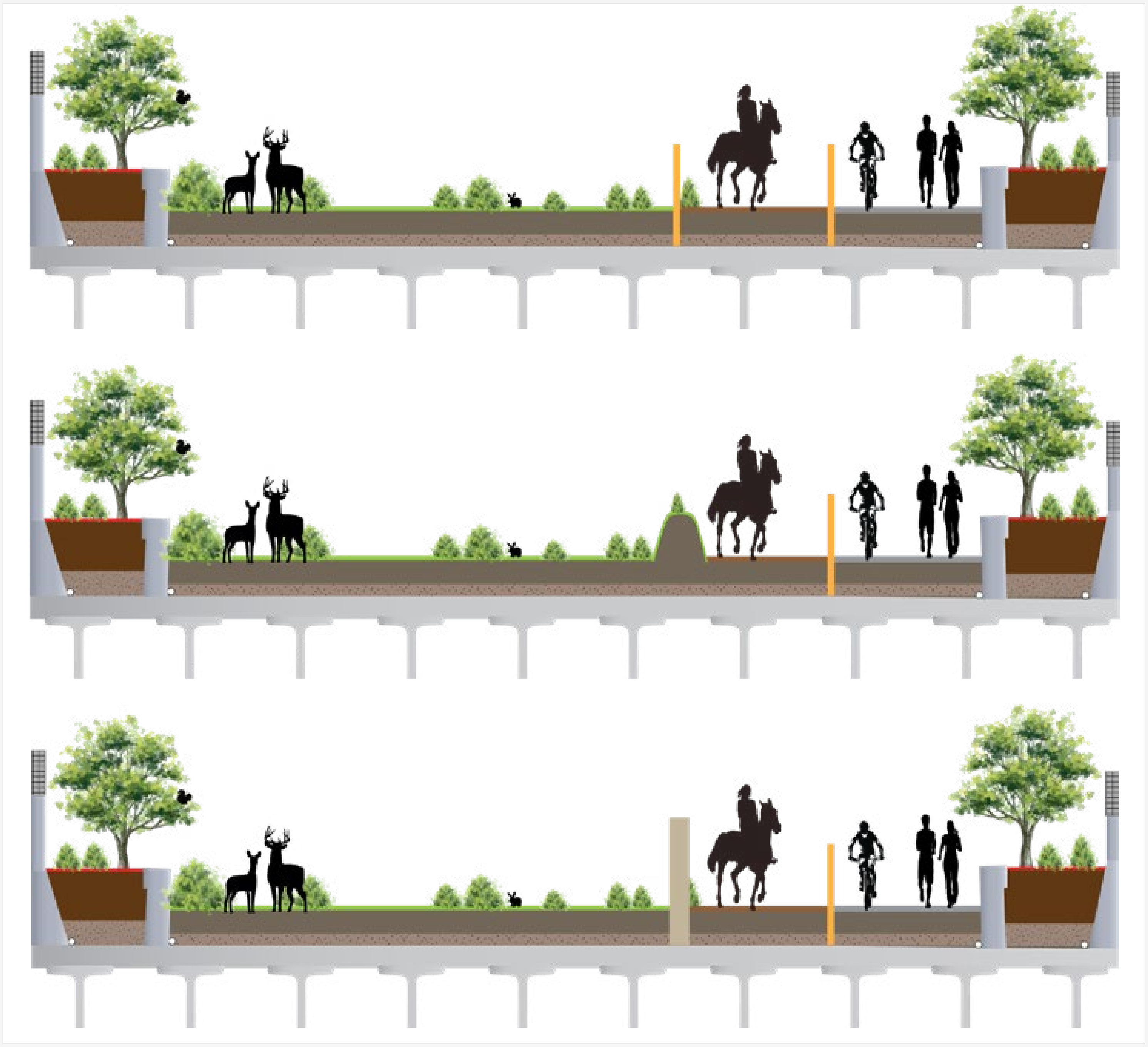

**Figure 8-16** **Conceptual design of a multi-purpose crossing with equestrian use.** It includes separate sections for wildlife, horseback and general paved-trail users. Dividers include wood-rail fence (top), berm (center), and wall (bottom). The design concept approximates 75 ft in width of useable space. berm  and wall (bottom).

**Figure 8-17** **Examples of multi-purpose overpasses** (Texas, upper left and Europe, center and lower right). Note the broad natural design in the upper left with an unobtrusive, imbedded trail, while in the center is a minimal design focusing centrally on the trail and nature along the margins, and finally the example in the lower right provides separate structures for trail and wildlife uses. A cost comparison would likely reveal significant differences between the three. Photo source: Phil Hardberger Park Conservancy org / STIMPSON Landscape Architects, top left. Graeme Paton, top right. ZJA Architectural Studio, right.

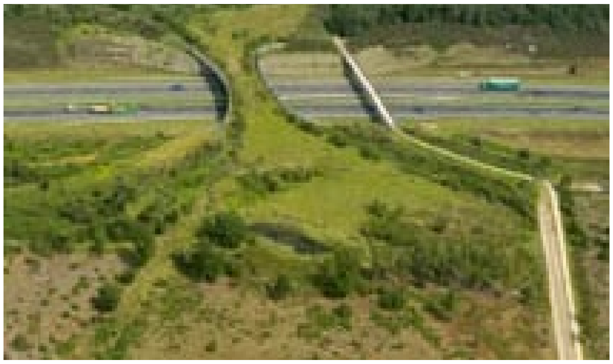

**Figure 8-18** **Examples of combined wildlife and multi-purpose trail underpasses in central Florida.** Note the height, designed to accommodate equestrian use. Addition of native shrub and tree plantings in approach areas could improve appearance and use by wildlife.

# Concluding Remarks

This guide was crafted to provide readers with a better overall understanding of the challenges that wildlife faces when encountering roads and what measures are being taken to reduce conflicts between vehicles and wildlife and simultaneously improving landscape connectivity between Florida's natural areas. The primary focus is on planning and design of wildlife crossing structures.

The field of road ecology is a growing subdiscipline of landscape ecology that focuses on the role that roads play in landscapes and society. Road effects on landscapes and wildlife are varied and many. The Reference section of this guide provides a bibliography that includes general and Florida-oriented resources including formative books and journal articles on the subject. This resource serves as an introduction to current issues that practitioners are conducting scientific research on and applying this knowledge to develop practical solutions.

Please visit the website at the University of Florida, Center for Landscape Conservation Planning for updates and other resources we are developing on the subject.

https://conservation.dcp.ufl.edu/

*Daniel Smith*

Photo credit: fStop.