ECOLOGICAL EFFECTS OF ROADS: THEORY, ANALYSIS, MANAGEMENT, AND PLANNING CONSIDERATIONS

By

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Human population growth and land development over the last century has resulted in widespread habitat loss, fragmentation, and increased wildlife mortality on highways. Since 1936, growth in Florida has resulted in the loss of 54% of herbaceous wetlands and 22% of forested lands. Concurrent with increased land development, hard-surface roads are being constructed at the rate of 8.8 km per day. Interagency coordination in the 1990s toward establishing a statewide greenways and trails network prompted State transportation officials to look at greenway-highway interfaces where conflicts are likely to occur.

First, a computer algorithm was developed to evaluate and prioritize the need for wildlife crossing structures or underpasses on state roads. A rule-based decision-support model was developed using geographic information systems (GIS). Of 15,644 road segments prioritized by the model, 81% were located in designated greenways. Chronic road-kill sites, focal species hotspots, greenway linkages, listed species presence, and

strategic habitat conservation areas strongly influenced results. Ninety-five scheduled road construction projects coincided with high-priority road segments.

Second, field inventories were conducted to determine mitigation needed at 1,232 highly ranked, ecological hotspots on highways. Features documented included parameters of existing bridges and culverts, characteristics of roadways, description of surrounding landscape features, and signs of present animal use. Mitigation measures recommended ranged from installation of underpasses or culverts to minor measures such as fencing, landscaping, signage, and speed restriction.

Third, a 2-year monitoring study was conducted to determine the capacity of existing highway drainage-structure designs to function as wildlife passages. Fifty-five different organisms were identified from 47,955 records at 290 field sites. Twenty structural, environmental, and ecological factors affecting use or avoidance of highway-crossing structures by six faunal groups (birds, carnivores, herpetofauna, mesomammals, small mammals, and ungulates) were evaluated through logistic regression analysis. Significance of factors varied by faunal group.

Lastly, landscape ecology principles applied to conservation and transportation planning are discussed. Gradients such as topographic relief can be used to design and situate underpasses that conform to on-site ecological flows and landscape patterns. Road-corridor design should include sufficient right-of-way clearance and reduced curve severity and slope steepness to increase driver visibility. Appropriate native vegetation at entry points to underpasses protects species either intolerant of open areas or subject to ambush predators. Fencing or other barriers should be used to direct wildlife toward the crossings and away from the road surface; and to restrict human access.

CHAPTER 1
LAND DEVELOPMENT IN FLORIDA AND EFFORTS TO REDUCE ROAD-RELATED WILDLIFE MORTALITY

Roads are an important element for human mobility and the transport of goods and services. Before 1900, an extensive system of trails and simple roads already existed in the United States; of these, only 4% had improved surfaces (FHA 1979). As mass production of the automobile began in 1906 (FHA 1979), paved road construction became an important step in expanding commerce and land development of the United States. The Federal Aid Road Act of 1916 was the first major State-Federal cooperative funding program instituted for road improvement and expansion. In 1914, of 413,601 km of rural roads, only 22,531 km were paved (FHA 1979); yet by 1930, there were 1,116,885 km of paved rural roads (ODOT 2003). Currently, there are over 4,828,032 km of paved rural roads in the coterminous United States (FHWA 1996).

The timeline for road construction in Florida was much the same as for the rest of the country. Construction of the first transcontinental highway in America (the Spanish Trail) began in Florida in the early 17th century (McDonald 1937). Today the Spanish Trail is a major highway (US 90) connecting Florida to California, a distance of approximately 3,921 km. Yet in 1923, only 189 km of US 90 (total length in Florida, 764 km) was hard-surfaced, located primarily around Pensacola and between Jacksonville and Lake City. Without exception, few roads in Florida were hard-surfaced in 1923 (Figure 1-1). More recent growth trends for roads in Florida include construction of hard-surface roads at a rate of 8.8 km per day (FDOT 1998); and increase in road density from 0.28 km/km^2 in 1947 to 1.31 km/km^2 in 1995 (FHWA 1996).

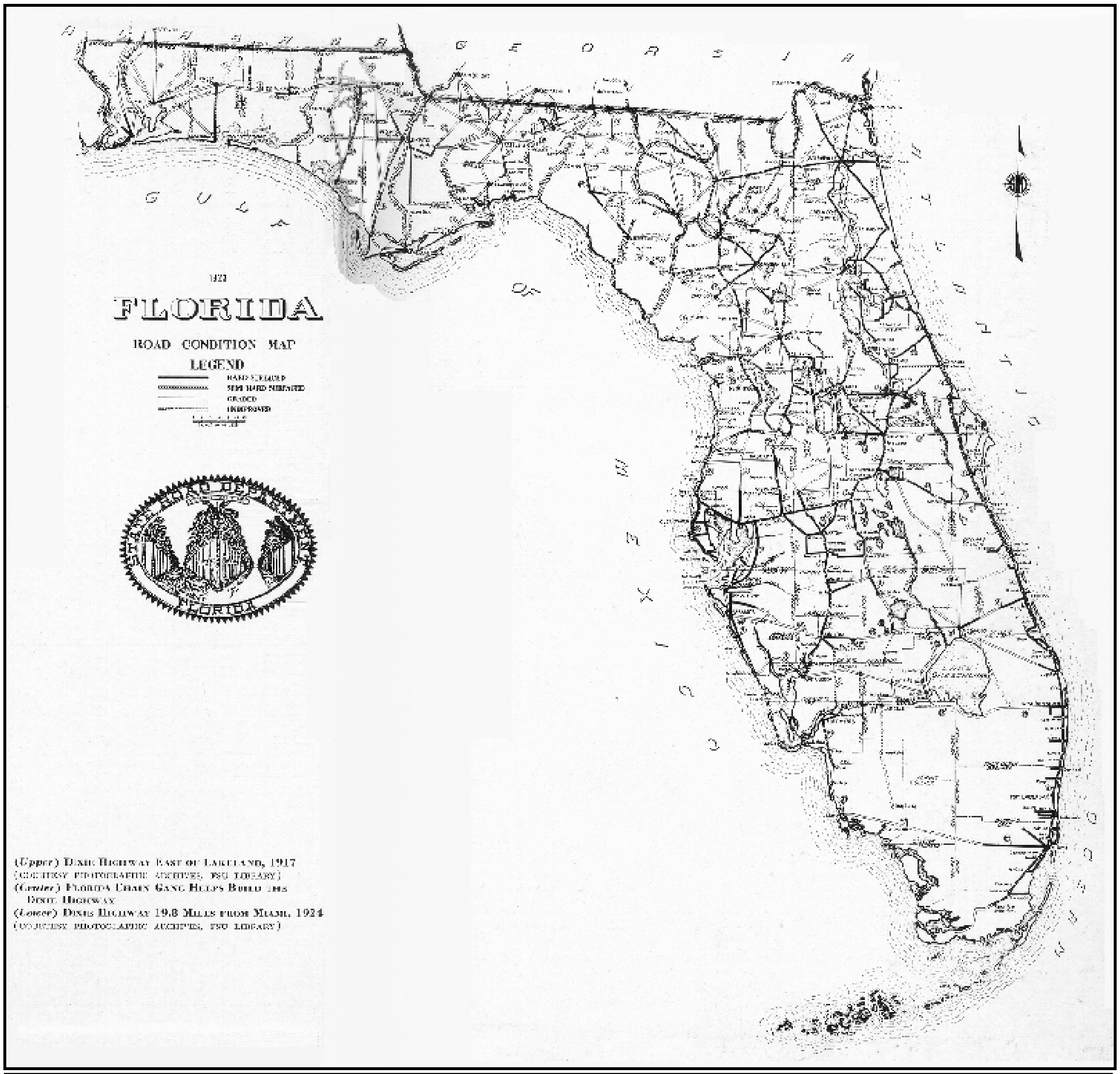


Figure 1-1. Florida road network in 1923. Four classes of road surfaces existed in 1923, hard-surfaced, semi-hard-surfaced, graded, and ungraded. As shown, most hard-surfaced roads occurred in and around towns and cities, few rural roads were paved. In 1918 there were less than 13 km paved; yet by 1936 over 11,690 km were paved (McDonald 1937).

The driving factor affecting land-use change and development is human population increase. According to the American Planning Association (APA 1995), Florida population growth has been increasing, on average, at 3.2% per year since 1950 (approx. 245,000/yr). As the population burgeons, the number and size of urban centers expand. Poorly planned urban sprawl erodes and threatens remaining natural areas through conversion to urban and intense agricultural uses. Human population growth and land development over the last century has resulted in widespread habitat loss (Kautz 1992), fragmentation (Harris and Silva-Lopez 1992), and increased wildlife mortality on highways (Gilbert 1996, Smith 1996). The consequence of these impacts to native species diversity can be staggering. In most cases, species more adaptable to human change in the landscape (habitat generalists, midsize carnivores, and omnivores) flourish, while habitat specialists and larger, carnivorous forms decline (Crooks and Soule 1999, Rogers and Caro 1998, and Harris and Gallagher 1989).

One approach that mitigates the negative effects of expanding human development is the creation of greenways or ecological networks consisting of an integrated system of habitat corridors, core habitat reserves and naturally isolated areas. Such "green" infrastructure can maintain or restore necessary ecological processes (e.g., animal and plant migration and dispersal, hydrologic flows, fire management regimes) to once-contiguous natural landscapes (Bennett 1999, Dobson et al. 1998, Csuti 1991, Harris and Scheck 1991, Harris and Gallagher 1989, Eisenberg 1986, and Forman 1983). Creative use of linear parks and greenways (open space) can also restore natural amenities to urban areas and provide buffers to protect surrounding natural systems (Smith and Hellmund 1993, and Little 1990).

While greenways provide a means to restore ecological function to large-scale habitat conservation systems, roads that act as significant barriers to most ecological processes intersect most. Proper management of these greenway-highway interfaces is necessary for maintaining the integrity of an ecological network. The Florida

Department of Transportation (FDOT) recognized the importance of these interfaces and funded a 7-yr research program to identify and prioritize needs; and to develop programs and policies to counter the negative ecological impacts of roads.

Infrastructure and Population Growth in Florida

Origin of Road Networks and Opportunities for Development

Major expansion of settlements in Florida began with the transfer of the peninsula from Spain to the United States in 1821. One of the primary reasons for acquiring control of the territory was to regulate Seminole Indian attacks on American colonists (McDonald 1937). This brought about the construction of an integrated road system by the military during the Seminole Indian Wars. Several forts (that were forerunners to current Florida cities) were constructed across the State at various nodes of the military road network (McDonald 1937). During the U.S. Civil War, Florida (with its many seaports) served as a transportation hub for food and supplies for the Confederate Army (McDonald 1937).

Many of Florida's roads and railroads were left in a condition of disrepair following the civil war. A period of reconstruction led by Henry Flagler and H.B. Plant occurred (in the late 1800s and early 1900s) that resulted in the widespread expansion of existing railroads (McDonald 1937). Construction of roads for automobiles began in earnest in 1915, with the creation of the first State Road Department (Kendrick 1964). By 1935, the population in Florida had reached 1,602,268 (McDonald 1937). In 1918 there were 7,598 km of improved state highways, yet only 13 km were paved. By 1936, 19,312 km of state roads existed and 11,690 km were hard-surfaced (McDonald 1937). The increase in construction of hard-surface roads during this period was due largely to depression-era public programs designed to create jobs for the unemployed (Sautter 1986).

Recent Population Growth and Infrastructure Needs

Population growth and land development have produced steady and increasing concerns about the declining quality of the environment and natural resources of Florida. Florida is the 4th most populous state (behind California, Texas, and New York) (BEBR 1998). Population growth between 1990 and 2000 was 24% (USCB 2000).
Twenty-eight new residents move to Florida every hour; the 3rd highest growth rate in the U.S. The population rose from 13 to 16 million between 1990 and 2000; and is projected to reach 18.5 million by 2015 (USCB 2000). Additionally, Florida receives an estimated 59 million tourists annually (FDOT 2000). Fifty percent of the tourists visiting Florida arrive by automobile (FDOT 1994). Population density in Florida is approximately 103 persons/km^2, the 10th highest in the U.S. (BEBR 1998).

The intensity of our dependence on automobiles is illustrated by the following demographic facts: the average Florida household has 2.74 persons (BEBR 1998) and 2.15 vehicles (FHWA 1996). With 12 million private registrations, nearly all adult-aged residents own an automobile (3rd most in the U.S.) (FHWA 1996). The impact of the large number of vehicles traveling on Florida's roads manifests itself through increased traffic density. Vehicle kilometers driven on State roads in Florida increased some 90% between 1980 and 1997, nearly doubling from 194.8 million km to 372.1 million km, respectively (FDOT 1998). Florida's traffic volume is the 3rd highest in the U.S. (FHWA 1996).

Highway Construction

Corresponding to increases in traffic are increases in highway construction to meet demand. From 1980 to 1997, centerline km of State-maintained roads increased from 18,251 to 19,315 (5.2%) and lane km increased from 52,170 to 62,793 (20.4%) (FDOT 1998). Over this period, lane km have increased at a rate 14.4 times greater than centerline km (Figure 1-2), indicating more expansion of existing roads to multi-lane highways than construction of new roads.

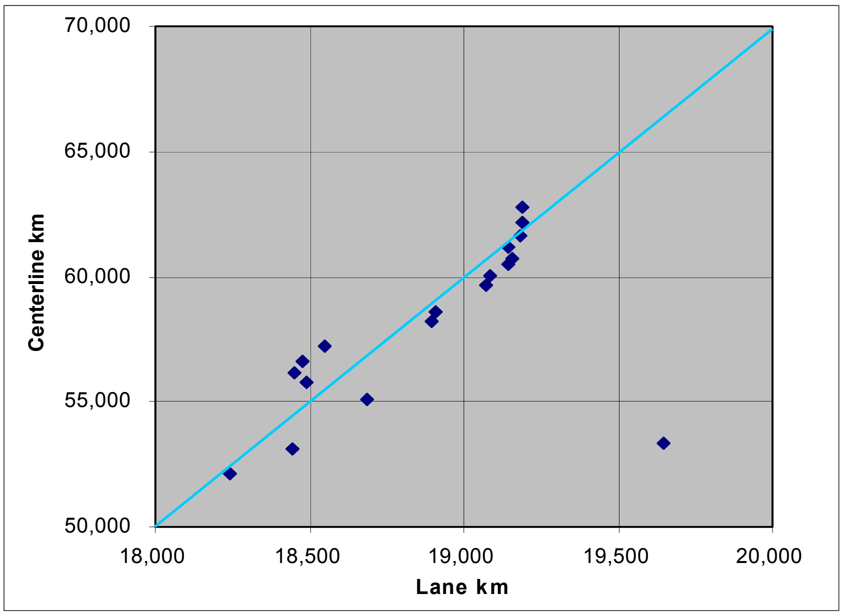


Figure 1-2. Lane km and centerline km for State-maintained roads in Florida, 1980 - 1997. Lane km represent the construction of additional lanes to existing highways. Centerline km represent new highway construction. The graph depicts a greater increase in expansion of existing roads over the construction of new roads. (Data source: Florida Department of Transportation 1998)

Kilometers of paved roads in Florida have increased 5-fold since 1947 (Figure 1-3). Florida ranks 10th and 13th in the U.S. for total length of roads (182,735 km) and road density (1.31 km/km^2), respectively (FHWA 1996). Urban roads have increased from a share of 16% in 1947 to 43% in 1995, whereas rural roads have declined from 84% in 1947 to 57% in 1995. In actual kilometers, both categories nearly doubled from

1964 to 1976, though subsequently rural roads have declined (-3,542 km) while urban roads continue to rise (+29,463 km).

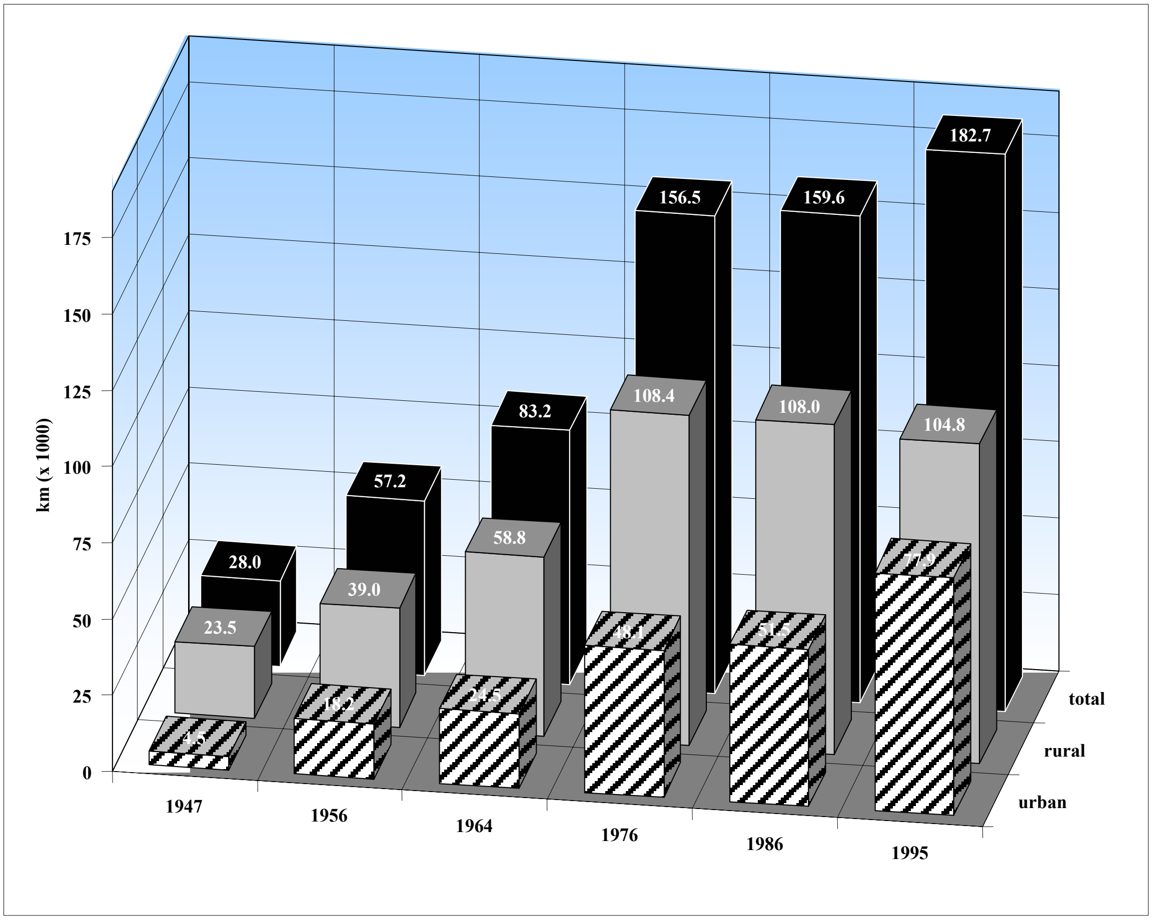


Figure 1-3. Kilometers of paved roads in Florida from 1947 to 1995. Overall highway construction has increased five-fold since 1947. Urban roads in 1995 are 16 times greater than that of 1947. Kilometers of rural roads have also increased since 1947, but have remained relatively constant since 1976. These trends reflect early agricultural development and later the rapid transformation of rural areas to urban land-uses. (Data sources: Florida Statistical Abstracts (1976, 1988, 1996) and Federal Highway Administration (1947, 1964)

Two causal factors are at work here. First, the chart does not reflect the amount of rural land that has been converted to urban land-uses over this period; resulting in rural roads being reclassified as urban roads. Therefore kilometers of urban roads are increasing because of construction of new urban roads and land-use conversion. Secondly, it would suggest that for total rural-road kilometers to remain the same, new rural-road construction is occurring despite urban land-use conversion. Urban and rural hard-surface roads were constructed at rates of 4.45 and 5.98 km/day respectively, between 1947 and 1995. Over the 48-yr interval, rural roads increased by 81,300 km and urban increased by 43,600 km (Figure 1-3). As a result, roadless areas have decreased dramatically in size and amount.

Land-Use Change

Florida has a total land area of 139,697 km^2 (making it the 26th largest state). Although 30% of this area (38,000 km^2) is protected as public parks, recreation, and preserve lands, the threat of development to key areas and linkages of Florida's statewide habitat system remains. Overall, growth in the state has resulted in the loss of 54% of herbaceous wetlands and 22% of forests (Figure 1-4; Kautz 1992, Florida Water Management Districts unpublished data 1995). According to Kautz (1992), Florida has lost the equivalent of eight Apalachicola National Forests since 1950 (an area of approximately 2,400 km^2). This land has largely been converted to urban and agricultural lands. From 1936 to 1994, urban lands have increased from 2,800 to 19,700 km^2, a change of approximately 600% in the last 58 years (Kautz 1992, Florida Water Management Districts unpublished data 1995). Land conversion to agriculture had reached 44,000 km^2 in 1980, but now appears to be declining; another victim of urban-development pressure. Furthermore, more than 13% of Florida has been covered by pavement (Florida Water Management Districts unpublished data 1995). In summary, over 43% of Florida's original forest and wetland habitats have been converted to human-oriented land-uses (Kautz 1992).

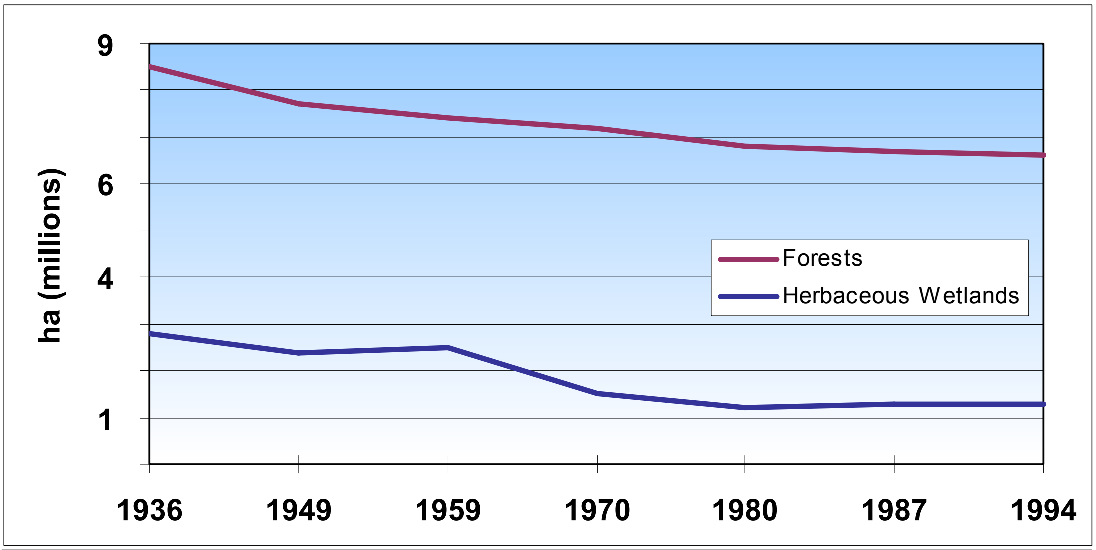


Figure 1-4. Florida's forests and wetlands from 1936-94. Forested lands declined by 22% between 1936 and 1994. Longleaf pine, accounting for 3.1 million ha (37%) of Florida's forests in 1936, has been reduced to 0.1 million ha. Marshlands accounted for 20% of the land area in 1936; there are now less than 1.3 million ha (8.8%). About 60% of the original wetland habitats have been drained for urban and agricultural uses or water management. (Modified from Kautz (1992) with Florida Water Management Districts unpublished data 1995)

There are now only eight remaining areas greater than 1,000 km^2 in Florida where paved roads are absent. There are 18 additional areas greater than 500 km^2. Combined, these areas comprise 12 separate but contiguous regions (Figure 1-5). The largest is the greater Everglades–Big Cypress region (13,900 km^2) that consists of nine adjacent habitat blocks separated by major paved roads, canals, and flood-control structures. Seven of the 12 regions consist of public forest, park, preserve, wildlife refuge, or military lands; the remaining five are in part targeted for public acquisition. The state presently looks like a jigsaw puzzle divided into various-sized pieces of land separated by an extensive road network. This configuration jeopardizes the ability of wide-ranging wildlife (such as the Florida panther *Puma concolor coryi*, Florida black bear *Ursus americanus floridanus*, and river otter *Lutra canadensis*) to successfully disperse and colonize adjacent habitat areas.

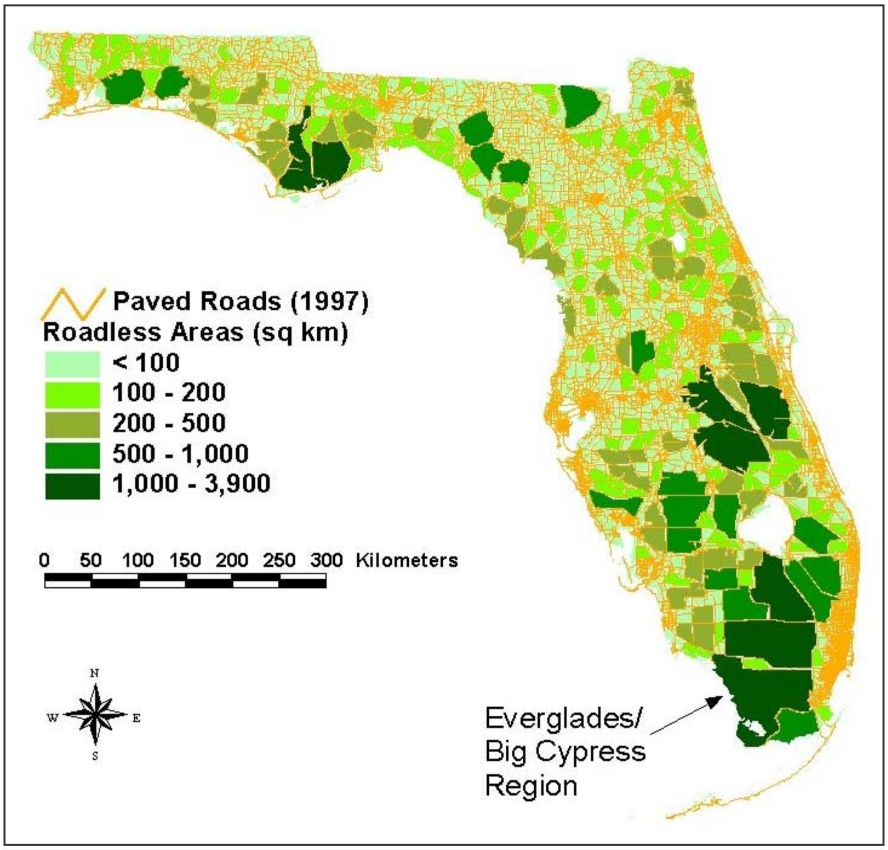


Figure 1-5. Roadless areas in Florida (includes paved roads only). Only three regions remain that have areas greater than 1,000 sq km without paved roads, the Everglades, Three Lakes Wildlife Management Area, and Appalachicola National Forest.

Projects Designed to Increase Permeability of Roads in Florida

This discussion will focus on case studies of road projects designed to restore landscape connectivity to fragmented ecosystems in Florida. Over the last 15 years the FDOT constructed crossing structures designed to address public concerns about automobile passenger safety, property loss, and wildlife and floodplain management (Smith and Dodd 1999, Roof and Wooding 1996, Evink 1990, and LoBuono 1988).

The Everglades, Alligator Alley, and the Florida Panther

Since 1917, population growth, land conversion to agriculture and urban uses, and damaging flood events resulted in construction of over 2,400 km of canals and levees for flood control and water supply in the Everglades (SFWMD 1992). In many instances, roads were built on levees next to the canals constructed throughout the Everglades system. These roads compound habitat alteration, fragmentation, and barrier effects caused by the canals. Interstate-75 (Alligator Alley) is one such road that fits this characterization (Figure 1-6).

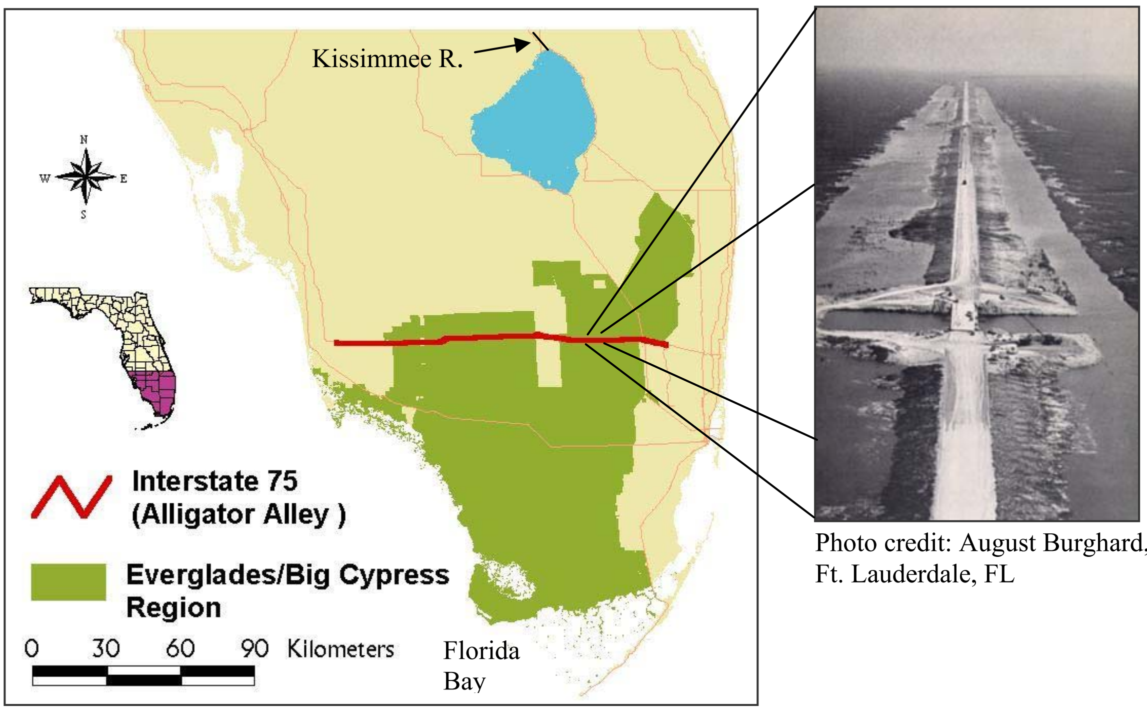


Photo credit: August Burghard, Ft. Lauderdale, FL

Figure 1-6. Location of the I-75 (Alligator Alley) road corridor through south Florida. Inset–residual effects, canals left during dredging for construction of the original highway, ca. 1960s.

Alligator Alley, a 125 km highway traversing the Florida Everglades and Big Cypress Swamp (FEBCP), was constructed in the late 1960s. Not only did the route bisect and fragment the FEBCP, but borrow canals were excavated for fill dirt and for drainage purposes to control flooding of the road (Figure 1-6). These actions further altered natural hydrologic flow patterns. As Florida's population grew in the 1970s, the traffic volume on Alligator Alley increased; and FDOT proposed four-laning the highway in the 1980s.

Also, significant road-kills were recorded including several collisions with the endangered Florida Panther (17 deaths from 1979 to 1989). With a total population estimated at 46 to 74 individuals, the loss of one to two animals per year to automobile collisions was a significant mortality factor that could not be ignored (Maehr 1997b). The Florida panther recovery plan identified road mitigation as a necessary step for the restoration of a viable population (USFWS 1995). Specific prescriptions included wildlife underpasses, warning signs, reflectors, and nighttime speed restrictions.

In the late 1980s, the FDOT installed 36 underpasses on I-75 through the FEBCP. Twenty-four of these were designed and located specifically to facilitate safe travel for the Florida panther (Figure 1-7) (Villano 1993). Locations of most crossing structures were determined from telemetry data, where repeated road crossings of 18 radio-collared cats occurred; or other significant evidence (typically vegetated corridors of high ground) where repeated Florida panther presence was found (Logan and Evink 1985). All remaining underpasses were located at 1.6 km intervals; a distance thought to minimize travel distance for Florida panthers between crossings. Thirteen bridges were also constructed that provide 12.2 m wide strips of land over canals (parallel to the road) to facilitate movement by terrestrial organisms at underpass locations (Evink 1990).

After 4-lane construction was completed in 1990, the road project modifications resulted in the elimination of vehicle collisions with the Florida panther on Interstate-75 (Gary Evink, FDOT; personal communication). Foster and Humphrey (1995) recorded underpass use by Florida panther, Florida black bear, bobcat *Lynx rufus*, white-tailed deer *Odocoileus virginianus*, raccoon *Procyon lotor*, alligator *Alligator mississippiensis*, and various wading birds.

Figure 1-7. One of the functional underpasses constructed on I-75 (Alligator Alley) in the Big Cypress National Preserve in south Florida. Bridge dimensions are 36.6 m wide and 2.4 m high. (Photo credit: David Maehr, University of Kentucky, Lexington, KY)

The amount of preplanning and research for the design and locations was credited for the effectiveness of the underpasses. Openness of the structure (openness ratio > 0.92), 3 m tall barrier fencing that runs the length of the project boundary (64 km), and native vegetation were important aspects of the underpass design (Figure 1-7) (Foster and Humphrey 1995, and Evink 1990). The success of the Interstate-75 underpasses has led to construction of six, additional, wildlife-crossing tunnels on SR 29 (a north-south arterial highway) that also crosses through primary habitat for the Florida panther.

Habitat Connectivity in Central Florida for the Florida Black Bear

The pattern of intensified development and road construction in Florida has forced the threatened Florida black bear into several segregated subpopulations (Figure 1-8). This isolation has created concern regarding potential inbreeding depression, founder effects, and greater impacts by natural and unnatural disasters (Maehr 1984).

Potentially increasing numbers of Florida black bears coupled with increasing habitat loss to development leads to greater dispersal distances for males and subadult females (in search of new home range territories). In Florida, an individual 2.5 yr old male was reported traveling 126 km over large areas of non-forested land (Maehr et al. 1988). Dispersal events in and between dwindling core habitat reserves lead to increased encounters with highways, thus increasing the probability for collisions with vehicles. Concurrently, increasing traffic volumes add to the risk of collisions. Even though roads pose a serious threat to a bear's success in moving between large habitat areas, their wide-ranging behavior indicates that widely spaced populations can maintain genetic connections (if suitable habitat-corridors are present).

Figure 1-8. Current distribution of the Florida black bear. Habitat loss and fragmentation have reduced the former statewide range of the black bear to seven areas of concentration. (Adapted from Florida Fish and Wildlife Conservation Commission 2000)

An area of great concern for black-bear conservation is preserving the landscape linkages between the Wekiva River Basin (north of Orlando) and the Okefenokee Swamp National Wildlife Refuge in southern Georgia (a distance of approximately 250 km; encompassing over 750 thousand km^2 of existing and proposed conservation-lands) (Figure 1-9). Twenty-one major roads pose serious threats to the integrity of this network (as barriers to movement, and as development facilitators that can result in additional habitat loss and fragmentation).

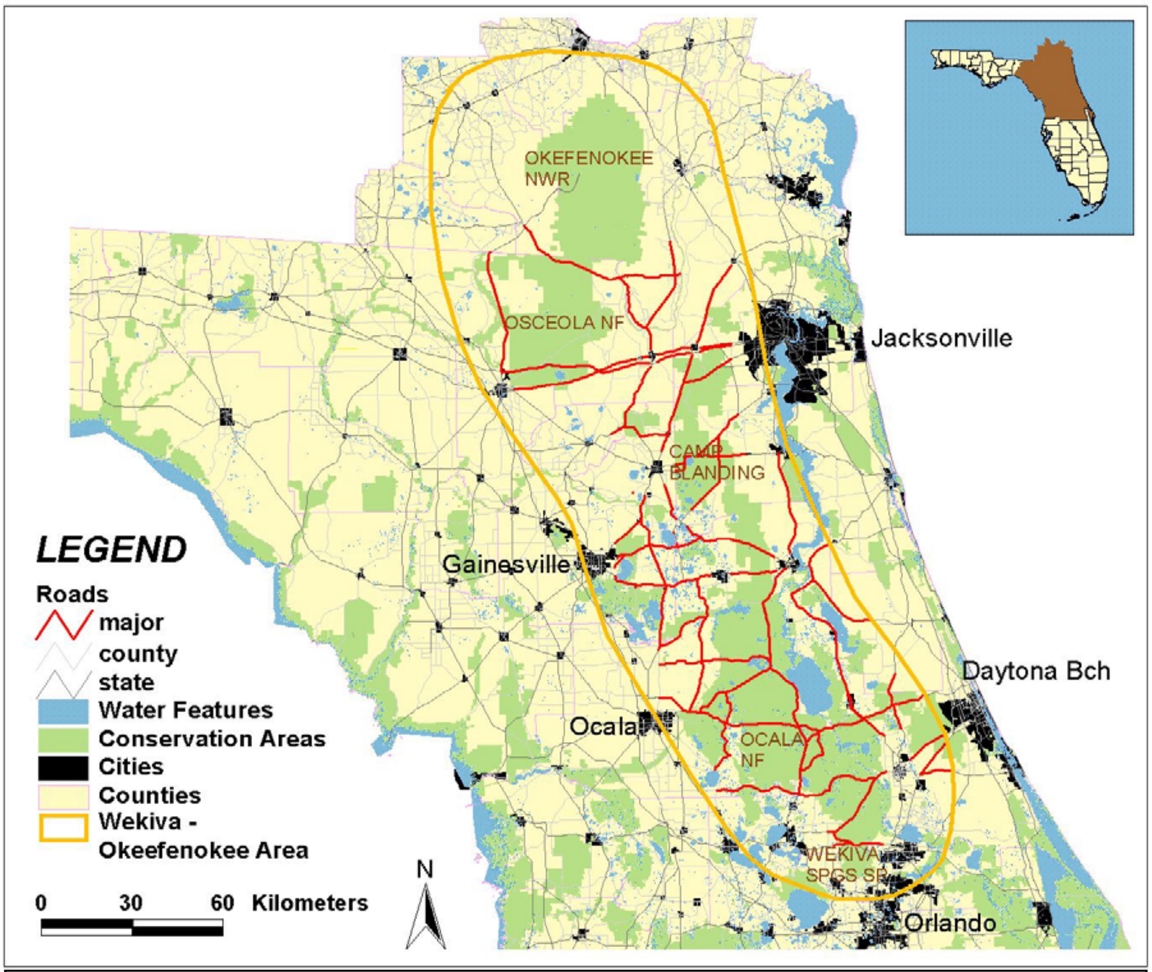


Figure 1-9. Wekiva Basin GeoPark – Okefenokee Swamp National Wildlife Refuge corridor. The area within the orange border represents a major landscape linkage for black bear conservation stretching from central Florida to southern Georgia. Several major roads (shown in red) function as barriers (of variable permeability) to wildlife movement and other ecological processes. From 1976 to 1999, 275 black bear road-kills were recorded on these roads (FFWCC 2000).

Five of these roads (all located in the Ocala National Forest (ONF) or the Wekiva River Basin; Figure 1-10) account for the majority of these deaths—SR 46 (48), SR 40 (69), SR 19 (58), SR 44 (26) and CR 42 (21). The FDOT (in 1994) constructed an experimental box culvert (Figure 1-11) under SR 46 (Roof and Wooding 1996) as a prototype underpass to address the problem. In addition, a 3 m tall barrier fence extending 0.6 km west and 1.1 km east of the underpass was erected (Roof and Wooding 1996).

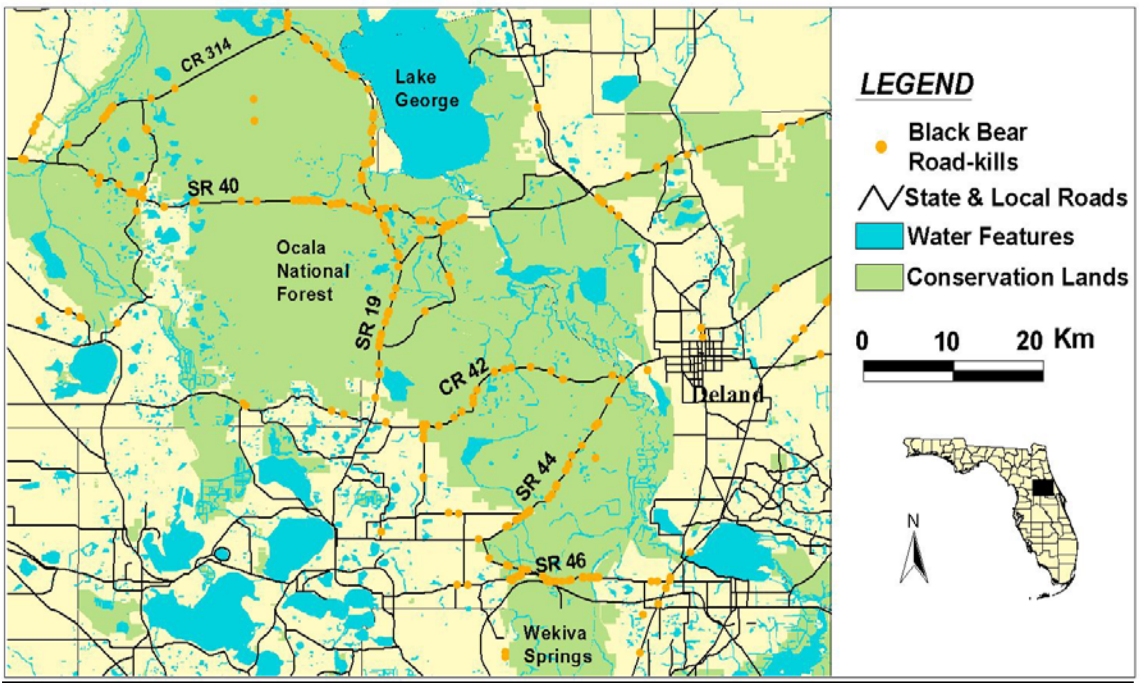


Figure 1-10. Ocala National Forest region including location of black bear road-kills on major highways in central Florida. From 1976 to 1999 over 200 road-kills have been documented on these five major roads (FFWCC 2000).

The aim of the project (according to Gilbert and Wooding 1994) was to reduce the number of road-kills occurring along a 4.5 km section of SR 46 (20 fatalities from 1981 to 1994); and to establish an unobstructed connection between the isolated Wekiva River population and the larger, ONF population (that consists of more than 500 individual black bears; Eason 2000).

The first year following construction, Roof and Wooding (1996) only recorded five black bears crossing through the underpass. Just one of the 50 black bears that encountered the barrier fence found and crossed through the underpass; another crossed the road at the end of the fence; and the remainder turned around and returned to the forest (Roof and Wooding 1996). Subsequently, three vehicle collisions with black bears have occurred at the end of the barrier fencing. Vegetative cover was added near the underpass openings to increase use. Now that black bears have become acclimated to the structure, movement through the underpass occurs frequently (87 crossings from 2001 to 2002).

Figure 1-11. Precast concrete culvert constructed on SR 46 between Wekiva River State Park and Seminole State Forest in central Florida. Placement coincides with high incidence of black bear road-kills (16 from 1981 to 1998) (FFWCC 2000). Dimensions are 2.4 m high, 7.3 m wide, and 14.6 m long.

Fourteen additional black bears have died in vehicle collisions (from 1988 to 1998) in four distinct clusters beyond the fencing, associated with the SR 46 underpass

(FFWCC 2000). Construction of additional underpasses and barrier fencing are planned to effectively retrofit the remainder of this section of highway (to reduce future road-kills and increase permeability).

In 1994, plans to increase SR 40 from 2-lanes to 4-lanes through the ONF led to a comprehensive black-bear movement study. Preliminary results (1999 to 2001) of movements of 77 radio-collared individuals revealed 324 crossings of SR 40. Track studies performed on a 17.7 km section of SR 40 revealed 752 sets of bear tracks (McCown and Eason 2001). The final results of the movement study (1999 to 2003) should provide evidence for the need to increase the permeability of the major roads that currently cross through the ONF.

Speculation based on previous studies (Ariza 1998, Gilbert and Wooding 1994, Wooding and Maddrey 1994, Wooding and Hardisky 1994, Brody and Pelton 1989, and Wooding and Brady 1987) suggests that increasing SR 40 to four lanes of traffic will further fragment the ONF black-bear population; by acting as an aversion zone or barrier to movement, and increasing road-kills on side roads due to increased traffic (Gilbert 1996). Population effects that may result from avoidance of the 4-lane highway include the potential creation of subpopulations with reduced gene flow; based on research conducted in North Carolina (Brody and Pelton, 1989, and Carr and Pelton 1984).

Road Mortality of Herpetofauna in Payne's Prairie State Preserve

Payne's Prairie (in north-central Florida) is a wet prairie trisected by two major multi-lane highways (Figure 1-12). Since the 1930s, it has been known as a significant population reservoir for many amphibians and aquatic snakes (Kauffeld 1957, Auffenberg 1956, Hellman and Telford 1956, and Carr 1937).

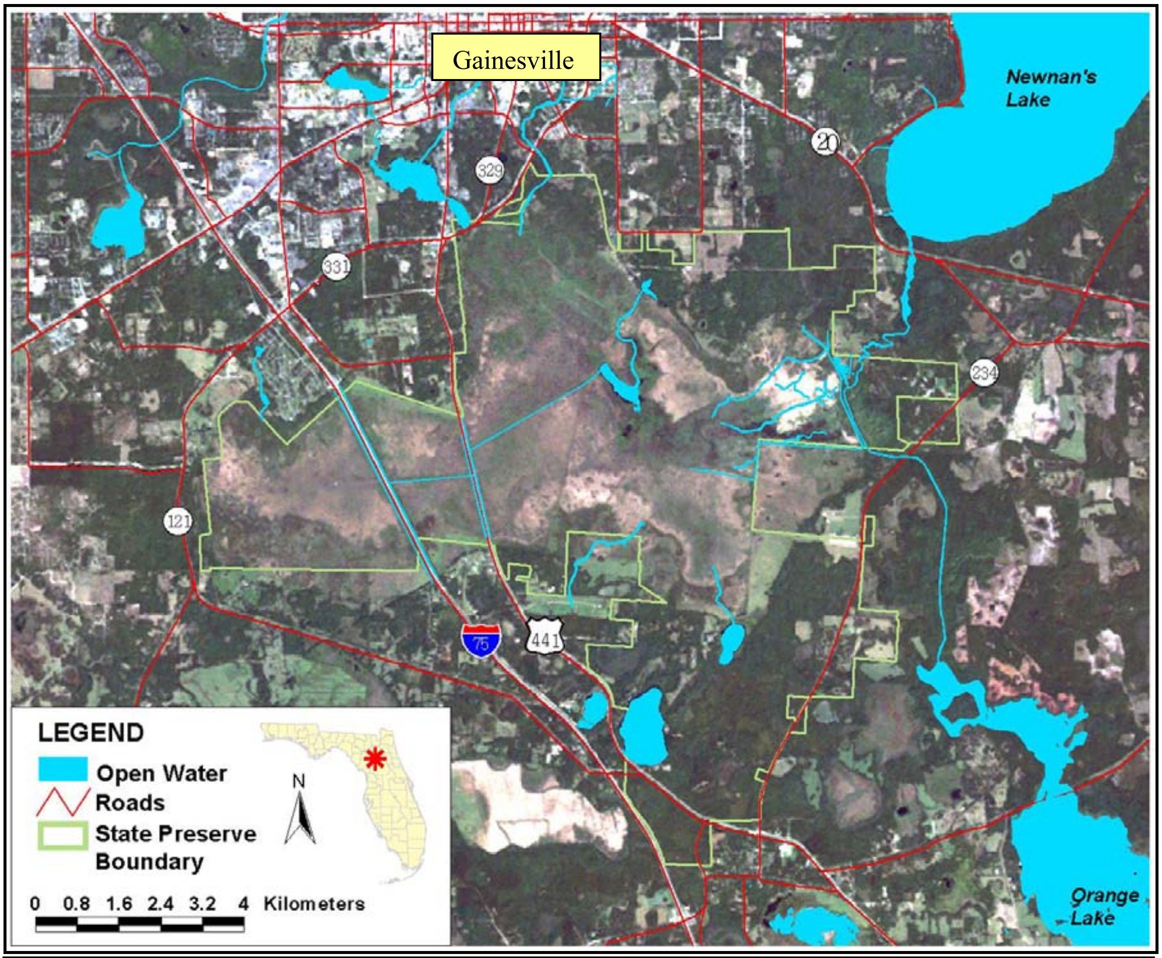


Figure 1-12. Payne's Prairie location map. Payne's Prairie, a Florida state preserve near Gainesville, Florida, encompasses approximately 7,300 ha. Several inflows occur from surrounding urban and agricultural lands. The two major roads that impact the preserve are I-75 and U.S. 441 that subdivide the prairie into three large fragments. Drainage canals and spoil areas parallel to these roads cause significant disturbance to adjacent habitat.

From data collected in the 1970s, an estimated 2,753 (predominantly aquatic) snakes were being killed annually on a 3.38 km stretch of 4-lane highway (Smith 1996). Estimates from data collected in the early 1990s revealed similar mortality levels. Public concern led to the construction of a 1.1 m high barrier wall in 2000 designed to eliminate road-kills (Figure 1-13). The FDOT also installed four new round pipe culverts as an addition to the four existing box culverts to allow for faunal movement from one side of the road to the other.

Figure 1-13. Concrete barrier wall along U.S. 441 in Payne's Prairie State Preserve. The 1.1 m high barrier is fitted with 2–1.83 m and 2–2.4 m box culverts, and 4–0.91 m round pipe culverts to allow wildlife movement and water flow between prairie fragments.

Monitoring of these culverts was conducted pre and post construction; to determine the effectiveness of the culvert-barrier system to eliminate road-kills, yet maintain habitat connectedness. Pre (1998 to 1999) and post (2001 to 2002) construction monitoring of organisms killed on the highway resulted in counts of 3,365 and 1,992, respectively (Barichovich and Dodd 2002, Smith and Dodd 1999). Significant reductions occurred for all taxa, except frogs and mammals. Excluding hylid treefrogs (that readily climb the barrier wall), 65% of post-construction road-kills occurred beyond the extent of the barrier wall (Barichovich and Dodd 2002).

Prior to construction, 25 terrestrial or semi-aquatic vertebrate species were recorded from track surveys and funnel traps using the (2–1.83 m) dry culverts (Smith and Dodd 1999). An additional 18 different terrestrial or semi-aquatic vertebrate species were recorded using the two existing dry culverts following construction (Barichovich and Dodd 2002). Only one additional terrestrial vertebrate (ring-necked snake *Diadophis punctatus*) was found using the new (4–0.91 m) round culverts and not the existing (2–1.83 m) dry culverts. The new culverts (located at lower elevations along the basin) were periodically flooded, and provided passage for (8) aquatic-based organisms as well as (17) terrestrial or semi-aquatic species during dry periods (Barichovich and Dodd 2002). Post-construction use of the existing (2–2.4 m) aquatic box culverts included (8) aquatic and (4) semi-aquatic species (Barichovich and Dodd 2002).

Total diversity of terrestrial/semi-aquatic, and aquatic species found using all culverts was 43 and 18, respectively (Barichovich and Dodd 2002, Smith and Dodd 1999). Ten species (birds excluded) were found as road-kill and not encountered using culverts (1 lizard, 3 turtles, 5 snakes, and 1 mammal). This could indicate that either: these culvert designs are unsuitable for certain species; some species may occur in much lower densities (resulting in fewer opportunities to encounter culverts); or a longer sampling period is required.

The culvert/barrier wall system installed on U.S. 441 across Payne's Prairie has eliminated 59% of highway road-kills and provided safe passage between prairie fragments for at least 61 species (as determined from two years of monitoring, pre and post construction) (Barichovich and Dodd 2002, Smith and Dodd 1999).

Several measures are recommended to improve future designs. First, to prevent species from circumventing the barrier, the wall or a substitute structure should be extended a sufficient length beyond the target area (along the right-of-way). Second, increased culvert usage might be achieved by using a sinusoid-shaped barrier wall (parallel to the highway) that funnels animals into the culverts. Third, to increase permeability for all species, the number and type of passages should be increased; different tolerances (including structural parameters) and modes of mobility must be considered (multiple culvert designs and placements may be necessary in the same area to accommodate all species, e.g., a gradient of fossorial, terrestrial, semi-aquatic, and aquatic organisms). Original research supporting these suggestions is presented in Chapter 3 and 4.

Culverts and underpasses serve as connections between landscapes divided by highways; and play a critical role in decreasing the barrier effect of roadways by increasing permeability for wildlife. Increased permeability results in consequent decreases in mortality (Yanes et al. 1995). These underpasses can facilitate corridors that connect spatially separated habitats and enhance the efficacy of wildlife movement throughout the landscape (Forman 1983).

CHAPTER 2
PRIORITIZATION OF ECOLOGICAL HOTSPOTS ON FLORIDA HIGHWAYS

Introduction

Underpasses, referred to internationally as ecopassages, can reduce transportation-related wildlife mortality and restore connectivity to the landscape. With increasing requests for these projects, it has become apparent that mitigation is needed throughout the state (in conjunction with road improvement and development projects). Government efforts and public support in the 1990s for ecologically based greenways in Florida has prompted FDOT to look at highway-greenway interfaces; and the potential for implementing a wildlife underpass construction program designed to restore landscape connectivity and ecological processes at regional and statewide scales. The ability to coordinate needs for ecopassages with future highway construction projects would prove valuable toward effective and efficient use of funds for highway construction. A necessary step in this effort is the identification and prioritization of ecological hotspots on highways. This chapter represents phase I of an FDOT-sponsored research program, designed to integrate transportation planning with statewide conservation objectives.

Methods

Priority of roads was determined from their relative ecological impact. Ecological impact was ascertained by ranking roads according to various, existing ecological and planning criteria. The criteria were selected to identify road segments with the greatest impact on existing and proposed conservation-lands—their ecological integrity, the species that utilize them, their connectedness to adjacent habitat areas, and their attributes regarding sustainability and restoration (Smith et al. 1998).

Important environmental factors (for prioritizing relative impact of roads on lands with conservation value) were derived from a survey conducted at the FDOT-sponsored "Transportation-Related Wildlife Mortality Seminar" in Orlando, Florida in 1996 (Appendix A). Respondents were asked to rank various criteria associated with prioritizing sites for the location of underpasses on Florida roads. Eleven elements were identified and ranked as follows:

1. Chronic road-kill sites
2. Known migration/movement routes
3. Identified hotspots of focal species
4. Landscape linkages (designated greenways)
5. Presence of listed species
6. Identified strategic habitat conservation areas
7. Riparian corridors (with potential for retrofitting existing structures)
8. Core conservation areas
9. Presence of separated required ecological resources (e.g., a forest patch and ephemeral wetland breeding area for amphibians that is separated by a highway) for a species or set of species
10. Public ownership (or in public land acquisition program) as opposed to private lands
11. Potential to be included in proposed road improvement project

Note that No. 2 (known migration/movement routes), which pertains to large-scale animal-movement events such as migrating caribou, does not occur in Florida. Therefore, this criterion was modified to apply to wildlife movement patterns typical for this region (i.e., juvenile dispersal, breeding season movement, and normal home range activity). This was estimated by focusing on landscape features that typically represent likely travel routes including topographic gradients, riparian corridors, and habitat ecotones (Forman 1995, Ims 1995, Noss et al. 1994, Cross et al. 1991, Harris et al. 1991, Johnson et al. 1991, Noss et al. 1990, and Harris et al. 1989). Criteria No. 8 (core conservation areas) was divided between two other overlapping criteria—public lands and strategic habitat conservation areas. In this case, the core portions of large conservation areas in Florida are either publicly owned or part of state-sponsored programs for conservation land acquisition. Lastly, No. 9 (presence of separated required ecological resources) was dropped from the analysis due to lack of available data.

Criteria were evaluated according to large-scale priorities including the plan for an ecological greenways network in Florida. Forman (1995) and Noss et al. (1994) described an approach to reserve design based on principles of landscape ecology. Using this philosophy, several statewide planning datasets were obtained.

Available data corresponding to these criteria included: habitat/land cover and habitat ecotones, hydrology, topography, ecological hotspots, known-species occurrence sites, known road-kill locations for Florida black bear and Florida panther, road-kill data for state and federal parks and preserves, existing public conservation-lands, strategic habitat conservation areas, areas of conservation interest, proposed public conservation-lands, proposed ecological greenways, and future road projects.

An appropriate value was given to each attribute from a dataset relative to the importance of other attributes in the set. Datasets were grouped into six categories: biological features, landscape features, road-kills, planning, infrastructure, and public conservation lands. An example of the process is shown (Figure 2-1) for the biological features category. The use of data categories reduced redundancy. Table 2-1 displays the categories, the criteria, and associated attributes with assigned base values. The survey rank and multipliers reflect priority rankings from the questionnaire (Appendix A).

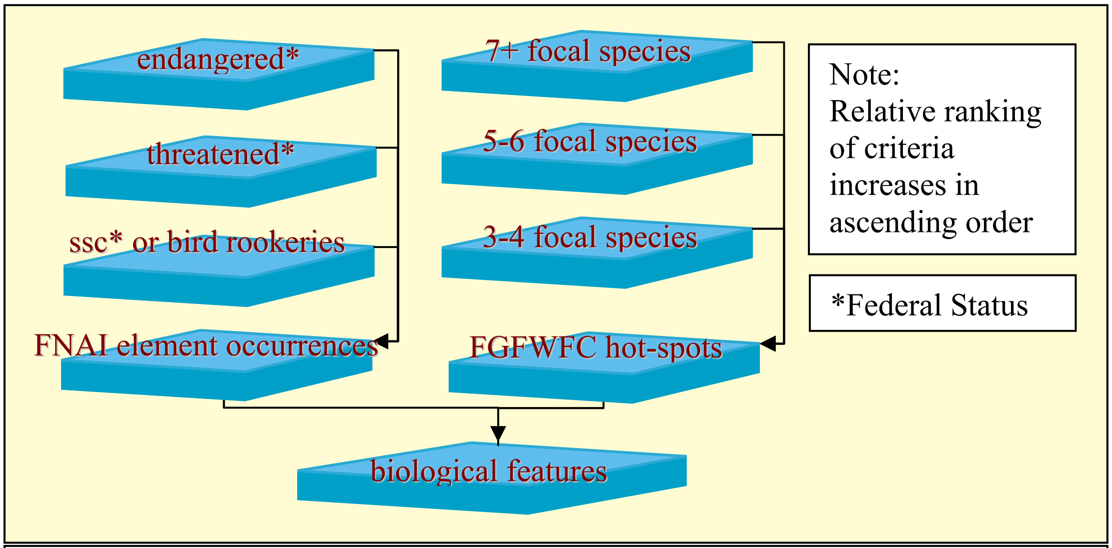


Figure 2-1. Components of biological features dataset. This flow chart provides a graphic display of construction of the biological features grid and relative importance of attribute values.

Cell-based (raster) modeling (Arcview© Spatial Analyst; Environmental Systems Research Institute, Inc., Redlands, California) was used to analyze and combine datasets and determine priority rankings. The resolution (cell size) used in the analysis was 100 m. Although certain data were available at higher resolution (30 m), 100 m was used to accommodate limited data storage capability and microprocessor speed. This resolution and scale was satisfactory to meet United States Geological Survey (USGS) national mapping and data accuracy standards.

State roads were buffered on each side by 600 m; consistent with the distance determined by other studies as the primary negative edge-effect-zone of highways (Fagan et al. 1999, Yahner et al. 1997, Forman 1995, Rodgers et al. 1995, Brody et al. 1989, Harris 1988a, Yahner 1988, Kroodsma 1987, Wilcove et al. 1986, Wilcove 1985, Carr et al. 1984, and Ferris 1979). The road buffer also serves as an analysis mask to eliminate unnecessary data that would slow computer processing.

Table 2-1. Grid values for FDOT priority model

Category	Criteria	Base value	Survey rank	Multi-plier
Landscape Features	**Gradients**		2	8
	Topography: slopes and ridges (greater than 36m elevation)	2		
	Ecotones (natural lands greater than 40ha)	2		
	Riparian		7	4
	Streams/Lakes in natural habitats	4		
	Canals in natural habitats	3		
	Streams/Lakes/Canals in urban/agriculture lands	2		
	GFC Habitat/Land Cover		n/a*	3
	Xeric Habitats	4		
	Wetland Habitats/Hardwood Hammocks	3		
	Silvicultural/Mixed Pine and Hardwoods	2		
Biological Features	**GFC Hotspots**		3	7
	7+ species	4		
	5 – 6 species	3		
	3 – 4 species	2		
	FL Element Occurrence (listed species locations)		5	5
	Endangered	4		
	Threatened	3		
	Species Special Concern/Bird Rookery	2		
Road-kill	**Road-kill**		1	9
	Listed Species (black bears, panther, key deer)	4		
	State Parks	2		
Planning	**Strategic Habitat Conservation Areas**		5	5
	High (Clan98{proposed}, FWC-SHCA{proposed}, FNAI{A,B}, TNCERC{Priority})	4		
	Low (FNAI{C}, TNCERC{Interest})	2		
	Greenway Final Rankings (linkages)		4	6
	High Priority	4		
	Medium Priority	3		
	3 – 7 Final Rankings	2		
Public	**Public Lands**		9	2
	Clan98 (existing)	4		
Infrastructure	**Road Projects**		10	1
	Proposed, Bridge Replacements	4		
	Existing	2		

* This criterion was not identified in the survey

Configuration of Data

Original data sources were manipulated to conform to the criteria specified by responses to the questionnaire. Nominal and ratio data types that represent ranked criteria were converted to interval data measurements so that basic calculations could be performed in the GIS model. Carr et al. (1999) described this process; where individual data layers, with descriptive attributes, are transformed into values on an interval scale to provide a measure of utility (utility assignment). Specific conversions are explained below for each criterion; and assigned base values, as mentioned previously, are shown in Table 2-1.

Landscape gradients

Potential wildlife movement, travel, or dispersal routes were based on topographic relief and ecotonal-habitat movement-corridors (Forman 1995). USGS digital elevation models (floating-point grids based on 1-m contours; spatial resolution—90 m) were used to determine topographic ridges or plateaus. In Florida, low-elevation areas were considered equivalent to aquatic features including wetlands; and were therefore identified through those criteria. A floating range of elevation was used to determine significant topographic zones for each FDOT district; based on the differential change in elevation from district to district across the state (Figure 2-2). Range of elevation (m) for each district is shown below:

- District 1—0 to 88
- District 2—0 to 76
- District 3—0 to 117
- District 4—0 to 24
- District 5—0 to 68
- District 6—0 to 5
- District 7—0 to 91

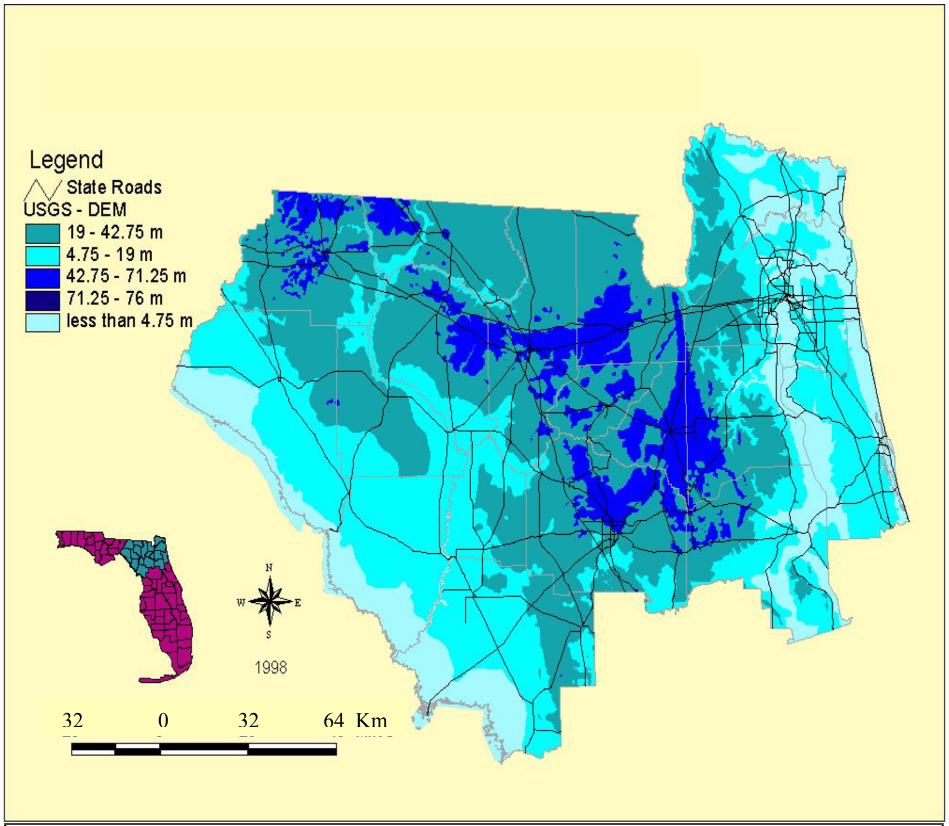


Figure 2-2. Digital elevation model (USGS 90 m) for FDOT District 2. Topographic ridges for this district were defined as 36 m or greater.

Topographic ridges for each District were assigned as follows:

- District 1-3, 7—greater than 36 m
- District 5—greater than 30 m
- District 4, 6—n/a, insignificant

Ecotones were derived from the Florida Fish and Wildlife Conservation Commission (FFWCC) land cover/habitat dataset. This dataset was based on Landsat satellite imagery at 30 m resolution, and included 22 basic types that were consolidated into the following 9 categories:

- Coastal resources
- Agriculture, grasslands, open prairie, and shrub and brushlands
- Pinelands, and mixed hardwood and pine forests
- Xeric habitats
- Hardwood hammocks and forests
- Open wetlands, and shrub wetlands

- Forested wetlands
- Open water
- Barren, urban, and exotic communities

These habitat types were reclassified to reduce variety (noise) in the data, and to limit ecotones to transitions between major land-cover types. Six basic types were created:

- Urban, open water, and coastal resources
- Agricultural classes
- Pinelands, and mixed hardwood-pine forests
- Xeric habitats
- Forested wetlands, and hardwood hammocks
- Open wetlands, and shrub swamps

After the reclassification process, neighborhood statistics were conducted. By executing a focal majority test (5x5 cell neighborhood) increased grouping was achieved that eliminated outlier cells. After which, a focal variety function (3x3-cell neighborhood) was performed to find margins between adjacent differing, habitat types. The resulting grid represented primary habitat ecotones. All areas with a value of one, indicating like adjacent habitat, were eliminated; the remaining values represent those areas where differing habitat types meet. The grid was then converted to a shapefile to define the relative size (area) of identified ecotones. Since the focus was on large-scale movement, anything smaller than 40 ha (approximately 100 acres) was deleted. The remaining areas were converted to grid format for use in analysis.

In many cases, ecotones coincide with the location of riparian corridors; the other significant landscape feature used for dispersal, travel, or movement by wildlife. This landscape feature was determined from USGS hydrography.

Riparian systems

The USGS 1:24,000 scale hydrography database (line and polygon coverages converted to grids and combined) was used to identify certain hydrologic features including streams, lakes, and canals (Figure 2-3). These features were considered important as potential travel corridors or destinations. Base values were assigned according to importance as travel corridors and quality of habitat (Table 2-1).

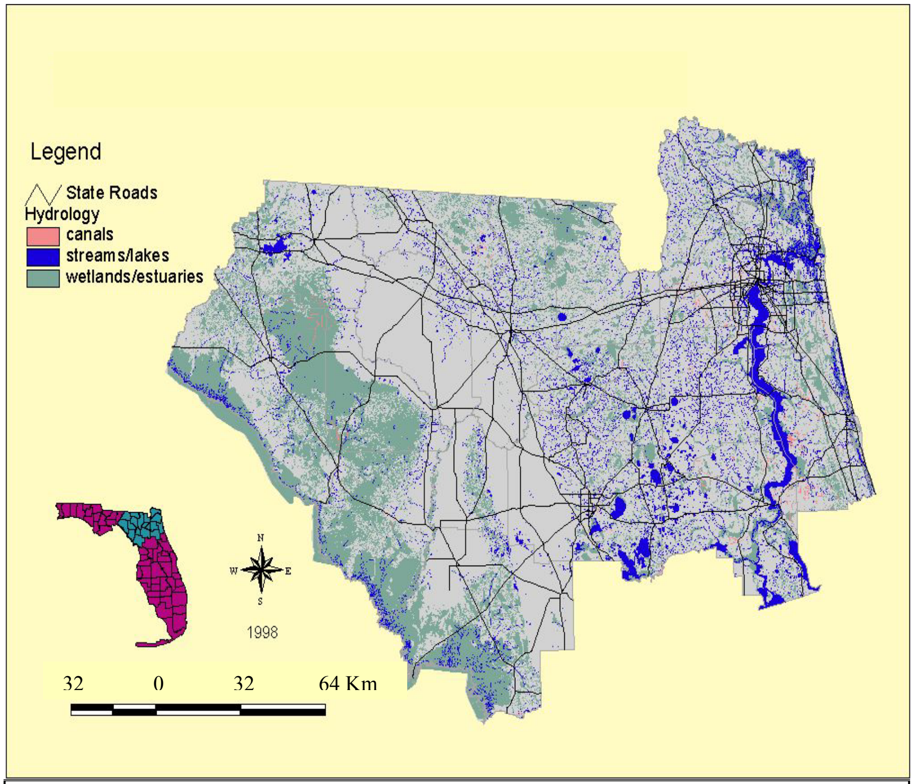


Figure 2-3. Hydrography (USGS 1:24,000) for FDOT District 2. Open water features (e.g., lakes, streams, canals) were used from this dataset; wetlands were derived from water management district 1995 land-cover data.

Habitat/land cover

The FFWCC land cover/habitat dataset was based on Landsat satellite imagery at 30 m resolution and included 22 basic types that were consolidated into the following 4 categories (Figure 2-4):

1) Urban, barren, exotic communities, shrub and brushlands, and agricultural classes
2) Pinelands, and mixed hardwood-pine forests
3) Hardwood and tropical hammocks, forested, open and shrub wetlands, open water, and coastal resources
4) Xeric habitats—dry prairie, sandhill, and scrub

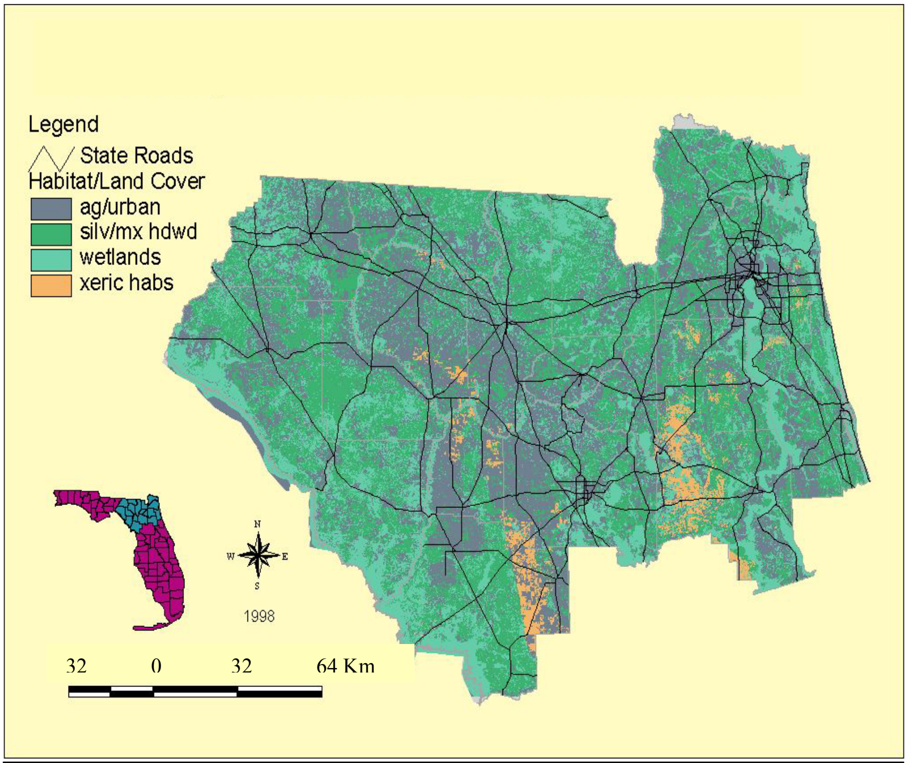


Figure 2-4. Reclassified land cover/land use for FDOT District 2. Categories of development threat in descending order: xeric – 4, wetlands – 3, silviculture/mixed hardwood-pine forests – 2, agriculture/urban – 1. (Data source: Water Management Districts 1995)

Category four, xeric habitats, was ranked the highest due to scarcity and high rate of conversion to development. The classes in category three were next highest due to presence of high biodiversity levels and use as wildlife refuge and travel corridors. Category two contains areas with good habitat value or potential for restoration; and was therefore ranked third. Category one includes all other land-cover types, considered to be low priority areas for wildlife habitat.

Identified hotspots

Hotspots were determined by the FFWCC. This is a data set (grid) representing biological diversity; created by aggregation of predictive habitat maps for wading birds, important natural communities, and 44 focal species (Figure 2-5). Categories of values that were used include:

- 3 – 4 focal species present
- 5 – 6 focal species present
- 7 + focal species present

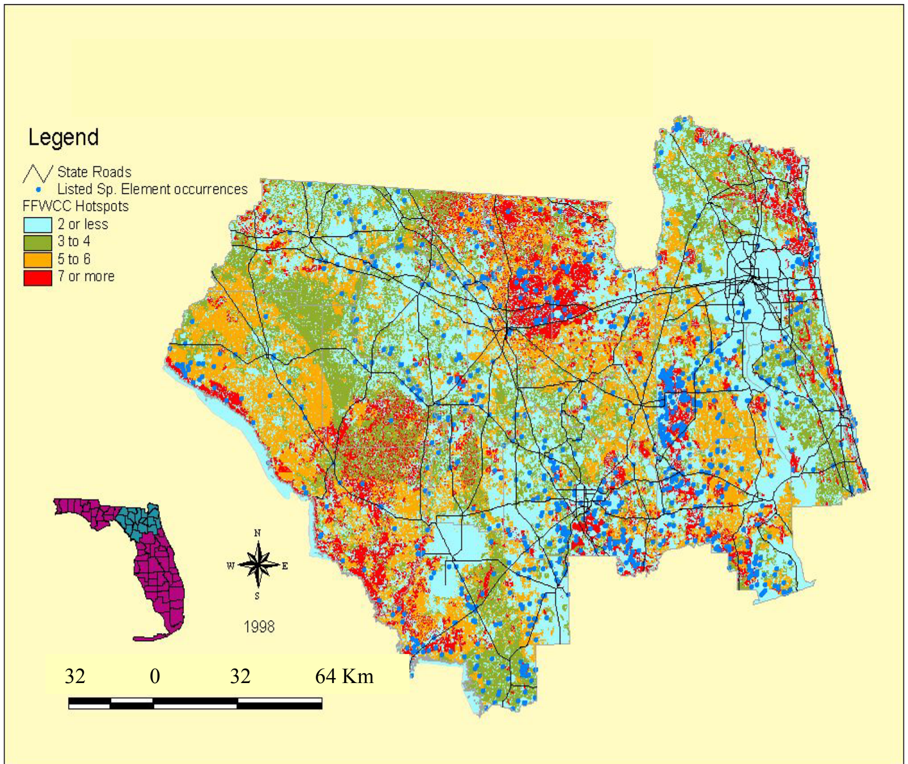


Figure 2-5. Element occurrences (FNAI)/hotspots (FFWCC) for FDOT District 2. Element occurrences include federal and state listed species, bird rookeries and migratory bird congregations; hotspots are shown in four categories according to number of focal species present.

Base values were assigned according to the number of focal species present (Table 2-1). For more information on the determination of hotspots, refer to Cox et al. (1994).

Known locations of listed species

State and federally listed species, bird rookeries, and migratory bird congregation areas were extracted from the Florida Natural Areas Inventory (FNAI) element occurrence database (Figure 2-5). Only records precise to 1,850 m or less were included in the analysis. Base values were set consistent with designated protection levels (Table 2-1). Each species location was buffered according to home range distances documented in the Florida Gap Analysis Project bibliography (FGAP 1998). The home range of the closest related species was used in cases where home range information was not available. A minimum home range of 100 m^2 was used consistent with the model's minimum cell resolution. Many bird species were buffered in line with documented negative edge-effect-distance (when home range information was unavailable).

Chronic road-kill sites

Road-kill locations of two focal species (Florida black bear and Florida panther) were buffered by 150 m; requisite to perform analysis at the minimum 100 m cell resolution. Segments of state roads, passing through or adjacent to state parks, with documented road-kill problems were also buffered by 150 m (Crocodile Lake and Florida Key Deer National Wildlife Refuges in District 6 received the highest base value because of the presence of endangered species). Figure 2-6 displays these features for FDOT District 2. Base values were assigned according to relative significance (Table 2-1).

Road projects

Road projects identified in FDOT 5-Year Work Programs (1996 to 2000, 1999 to 2004) included the following categories (Figure 2-6):

- New construction, and bridge replacement
- Road widening, reconstruction, and additional lanes

Road project locations were buffered by 150 m. Base values were applied according to significance and opportunity for mitigation. New roads and bridge replacements provide greater opportunity to reduce environmental impact through appropriate planning and the absence of constraints from existing facilities; and were therefore ranked higher than existing road projects.

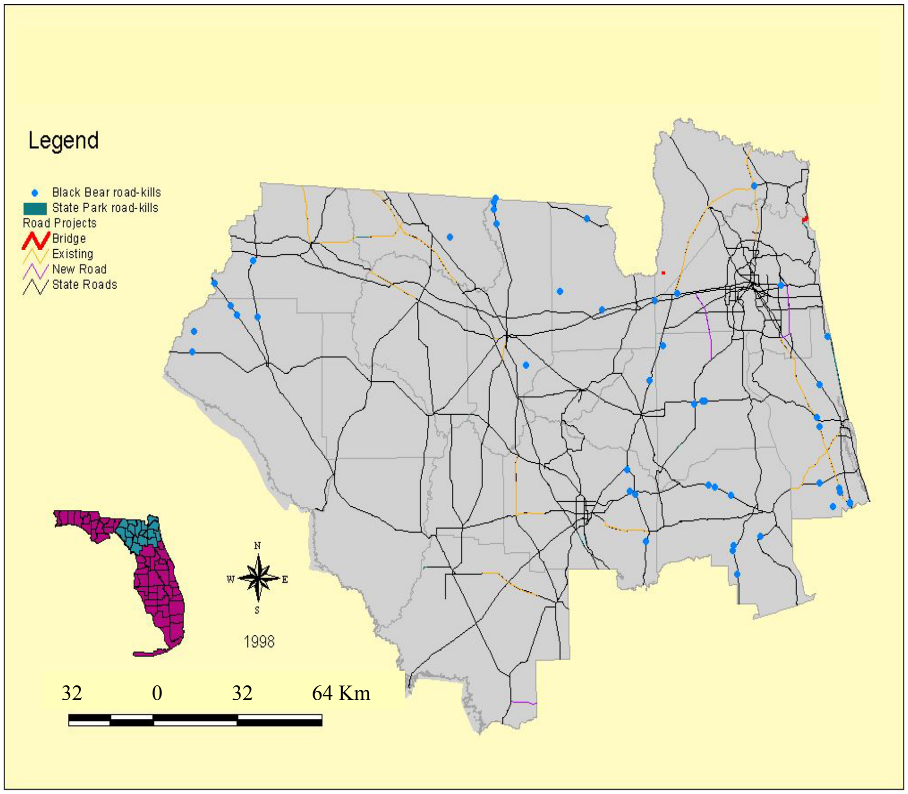


Figure 2-6. Documented road-kills/road projects for FDOT District 2. Road-kill data include that recorded by the FFWCC and state park personnel; Road projects are those scheduled from 1999 – 2004.

Public conservation lands

Public conservation lands were selected from the 1998 Florida Department of Environmental Protection (FDEP), Conservation and Recreation Lands-Preservation 2000 (CARL/P2000) conservation-lands database. All jurisdictions were combined into one data layer; and assigned one base value reflecting public ownership (Figure 2-7).

Strategic habitat conservation areas (SHCA)

SHCAs were derived from various datasets including CARL/P2000, FFWCC proposed SHCAs, FNAI areas of conservation interest (ACI) categories—A, B, and C, and the Nature Conservancy (TNC) ecological-resource-charette results. These datasets all reflect efforts from different groups to identify unprotected natural resource areas that warrant some level of protection.

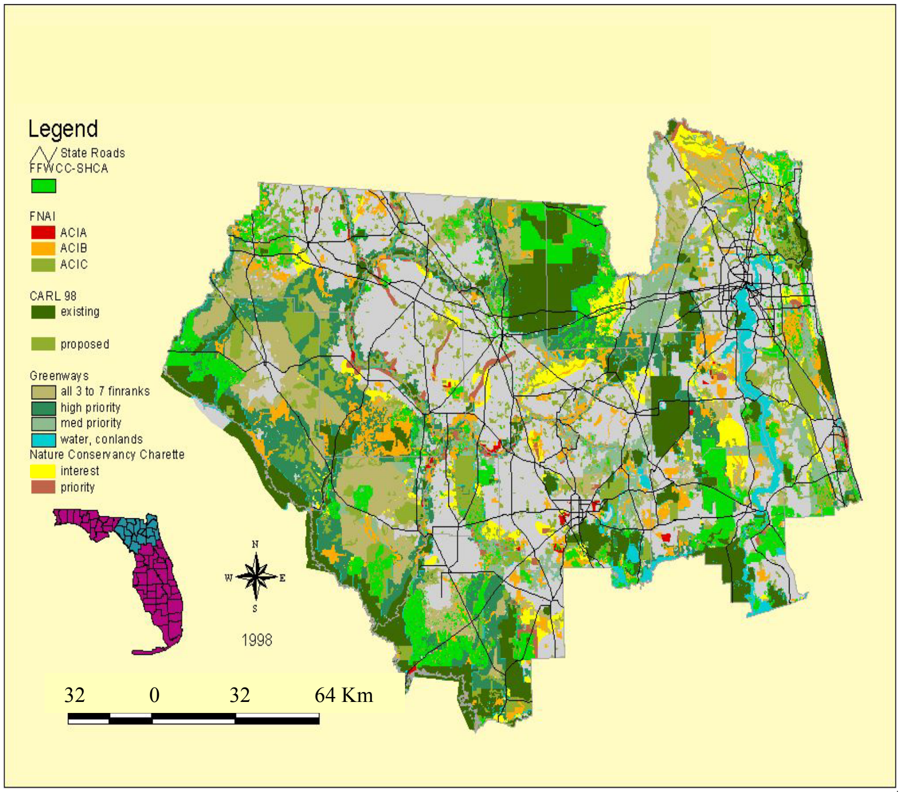


Figure 2-7. Conservation planning programs for FDOT District 2. These include FFWCC strategic habitat conservation areas, FNAI areas of conservation interest, CARL/P2000 existing and proposed conservation-lands, Florida statewide greenways planning project, and the Nature Conservancy planning charette.

Base values were divided into two categories—high and low priority. The "high" category includes CARL/P2000 proposed conservation lands, FFWCC proposed SHCAs, FNAI: ACI categories A and B, and TNC priority conservation areas. The "low" category includes FNAI-ACI category C and TNC conservation interest areas. These datasets possessed considerable overlap; and therefore were combined into one dataset to reduce redundancy (Figure 2-7). Base values are shown in Table 2-1.

Greenway linkages

Greenway linkages came from the FDEP, Florida greenway network, final priority rankings (Figure 2-7). Priority reflects the relative value to provide regional- or local-scale connections, and need for significant restoration. Regional-scale linkages included those connecting areas of national or statewide ecological significance. Local linkages were considered secondary connections that link local conservation areas with regional conservation areas. Base values for each type of linkage were derived from final priority rankings (Table 2-1):

- High priority
- Medium priority
- Category 3 – 7 final rankings (low priority)

Modeling Process

A rule-based model that applies user-determined weights to input-data-layers to generate suitability surfaces (Aspinall 1993) was developed in Arcview© Spatial Analyst (refer to Appendix B for specific model parameters and development). Datasets were grouped into categories; weights for each category were averaged values (rounded up) of individual criteria from the questionnaire (Table 2-1; Appendix A):

- Biological features – 7
- Landscape features – 6
- Infrastructure – 1
- Public lands – 3 (includes ranking of core conservation areas, multiplier = 3)
- Planning – 5
- Road-kill – 9

The algorithm combines, sorts, assigns weights, and calculates information associated with each criterion (Figure 2-8). The result is a final priority layer based on user-input weights and base values for each criterion.

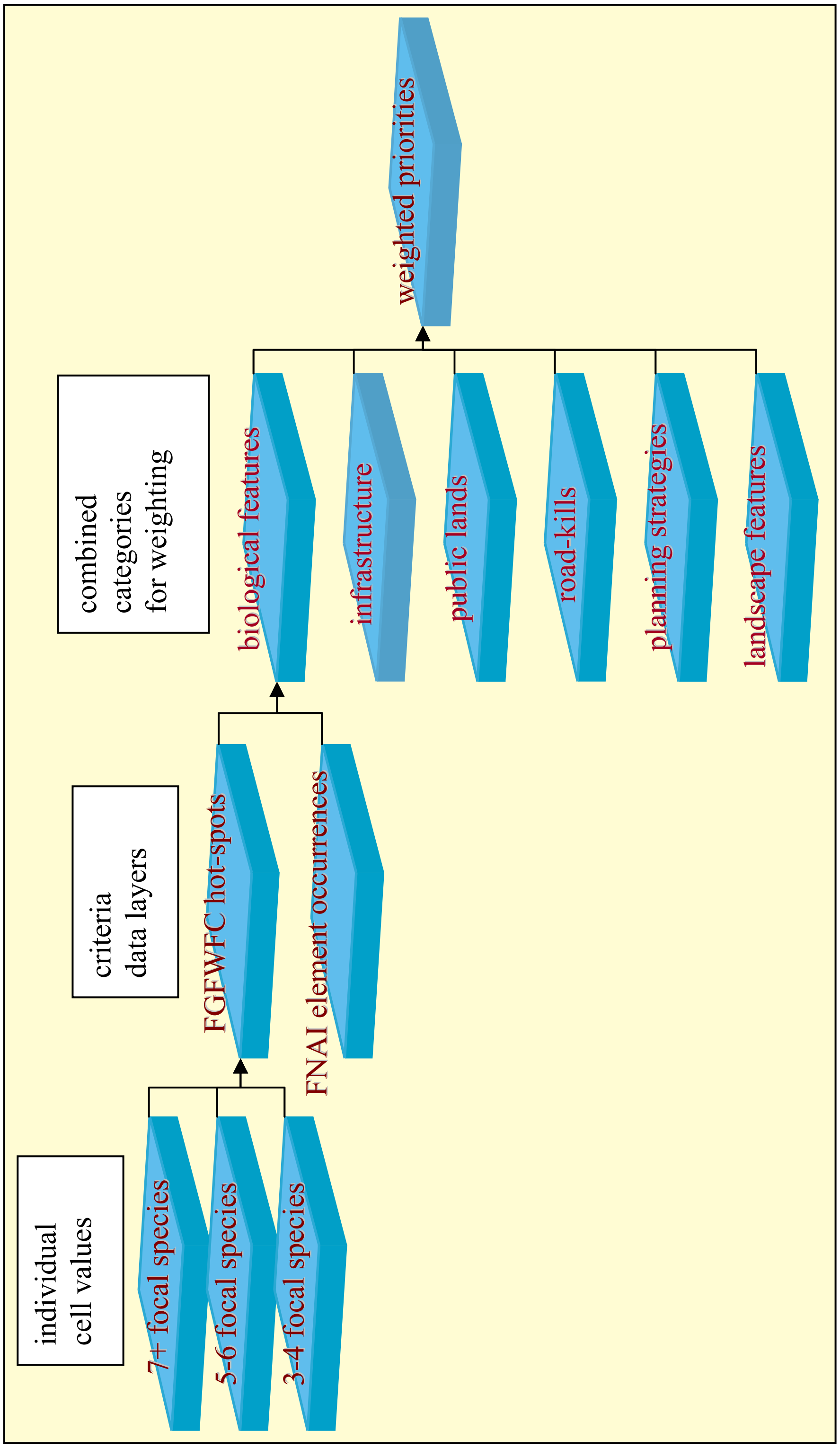


Figure 2-8. Flow chart of analysis algorithm. Individual cell attributes for each data layer are assigned relative values. Like category data layers are combined and assigned appropriate weights. Weighted priority layer is the result of individual cell calculations for each data layer multiplied by its associated weighting and added to the other layers.

State road-project programming and scheduling in Florida is divided into seven districts within the state. State road-project budgeting is also apportioned according to these seven FDOT districts. As a matter of logistics, it was appropriate to perform the analyses according to these districts (Figure 2-9). Therefore, results of this analysis will reflect rankings or priorities by individual FDOT districts, not the State as a whole.

Calculated priority layers for each FDOT district exhibited different value ranges. Reclassifying each cell value from one to seven (one being the highest value and seven being the lowest value) standardized final priority layers for each district. Priorities were assigned by dividing the total score by equal 20 unit intervals (i.e., the highest 20 values = 1, second highest 20 values = 2, third highest 20 values = 3...). Cells with scores of one to three were considered highly ranked.

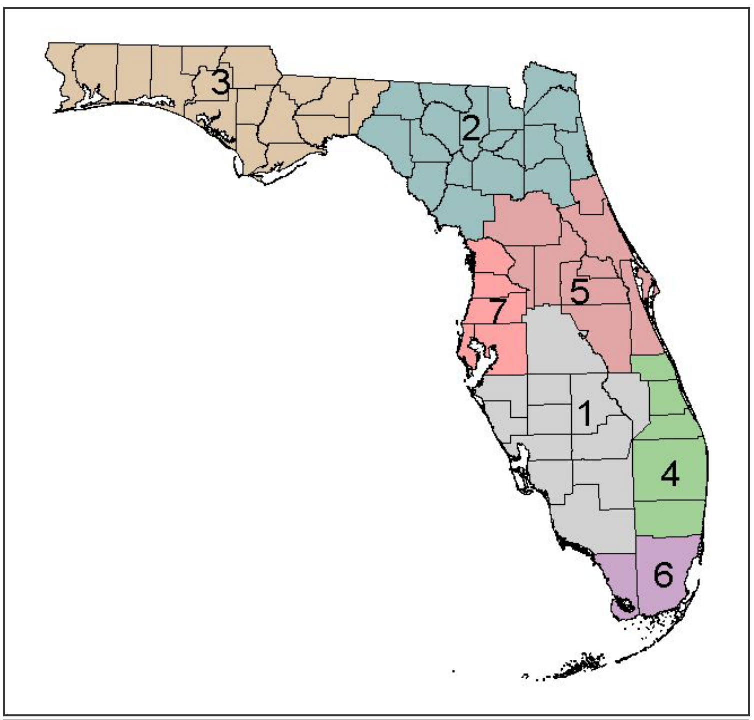


Figure 2-9. Florida Department of Transportation maintenance districts.

Results

The priorities determined by the model indicate significant focus on nationally and regionally significant conservation areas and riparian corridors. The number of road segments identified as priority areas varies between districts. In this study, a road segment is any continuous section of road that contains the same cell values from the analysis results. Identified priority road segments are displayed in Figures 2-10a through 2-10g, according to relative ranking for each FDOT district.

Table 2-2 contains the number of road segments in each district for priority levels one to five. Total overall scores ranged from 84 to 320. The district with the greatest range of values (89 – 300) was District 6; the district with the smallest range in values (84 – 203) was District 4. District 6 had the fewest priority one road segments (3) and District 4 had the most (22). The district with the most sites ranked three or higher was District 4; the district with the fewest sites ranked three or higher was District 6.

Table 2-2. Number of contiguous prioritized road segments by FDOT district

FDOT district	**Priority 1**	**Priority 2**	**Priority 3**	**Priority 4**	**Priority 5**	**Total**
One	10	46	81	161	697	995
Two	4	7	25	156	1,402	1,594
Three	19	39	59	475	2,230	2,822
Four	22	190	653	1,386	2,193	4,444
Five	7	53	127	236	1,653	2,076
Six	3	8	25	50	57	143
Seven	7	6	48	539	1,904	2,504
Total	**72**	**349**	**1,018**	**4,069**	**10,136**	**15,644**

Table 2-3 contains the most significant sites in each district including the criteria that contributed their ranking. Roads that contain the most significant priority sites (scores of 1 – 5) are shown in Figure 2-11. Additional detail can be found in the final project report (Smith et al. 1998).

Figure 2-10a. Road segment priorities in FDOT District 1. Rankings increase from low to high as red shading becomes darkest.

Figure 2-10b. Road segment priorities in FDOT District 2. Rankings increase from low to high as red shading becomes darkest

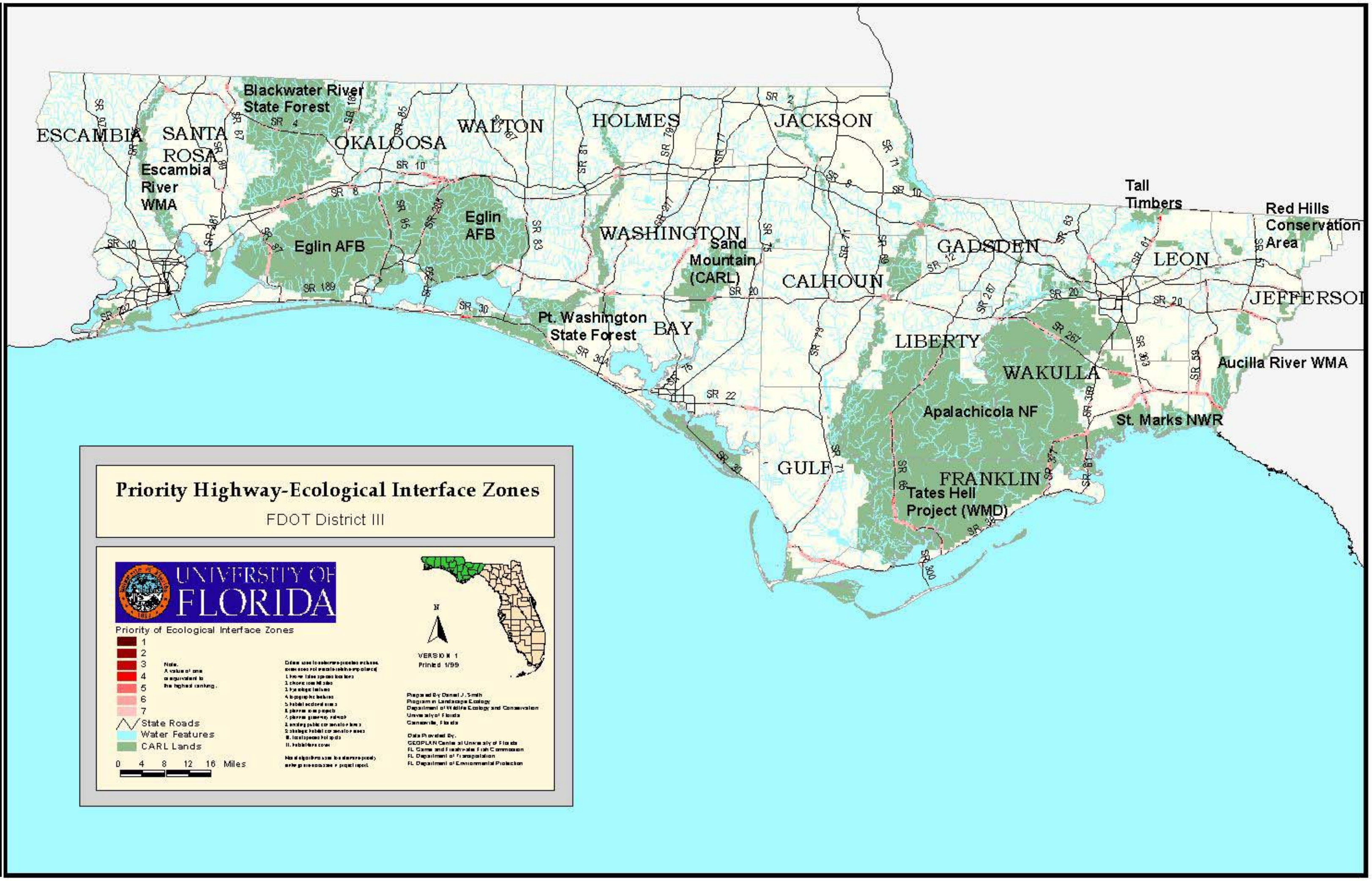


Figure 2-10c. Road segment priorities in FDOT District 3. Rankings increase from low to high as red shading becomes darkest

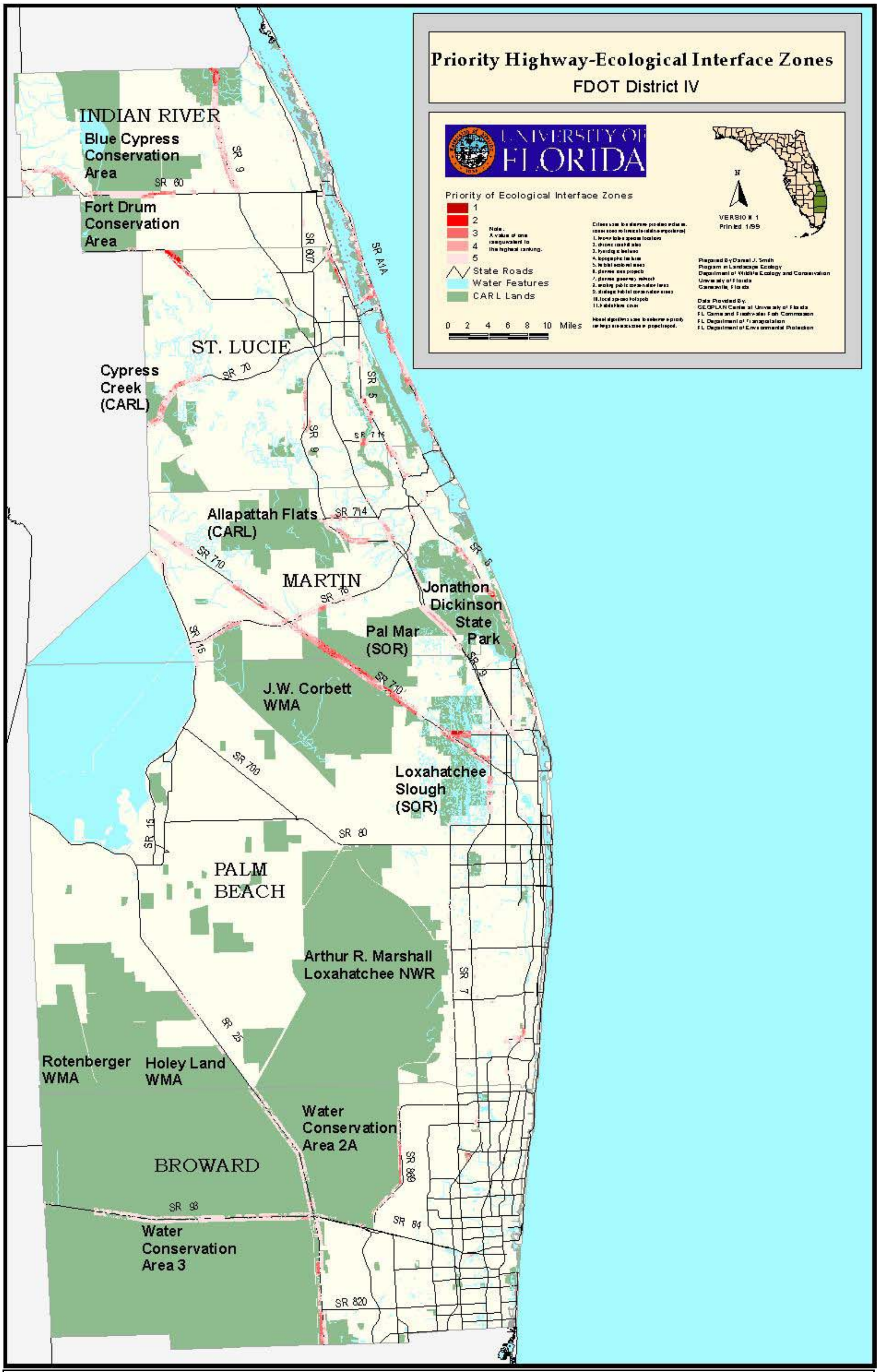


Figure 2-10d. Road segment priorities in FDOT District 4. Rankings increase from low to high as red shading becomes darkest.

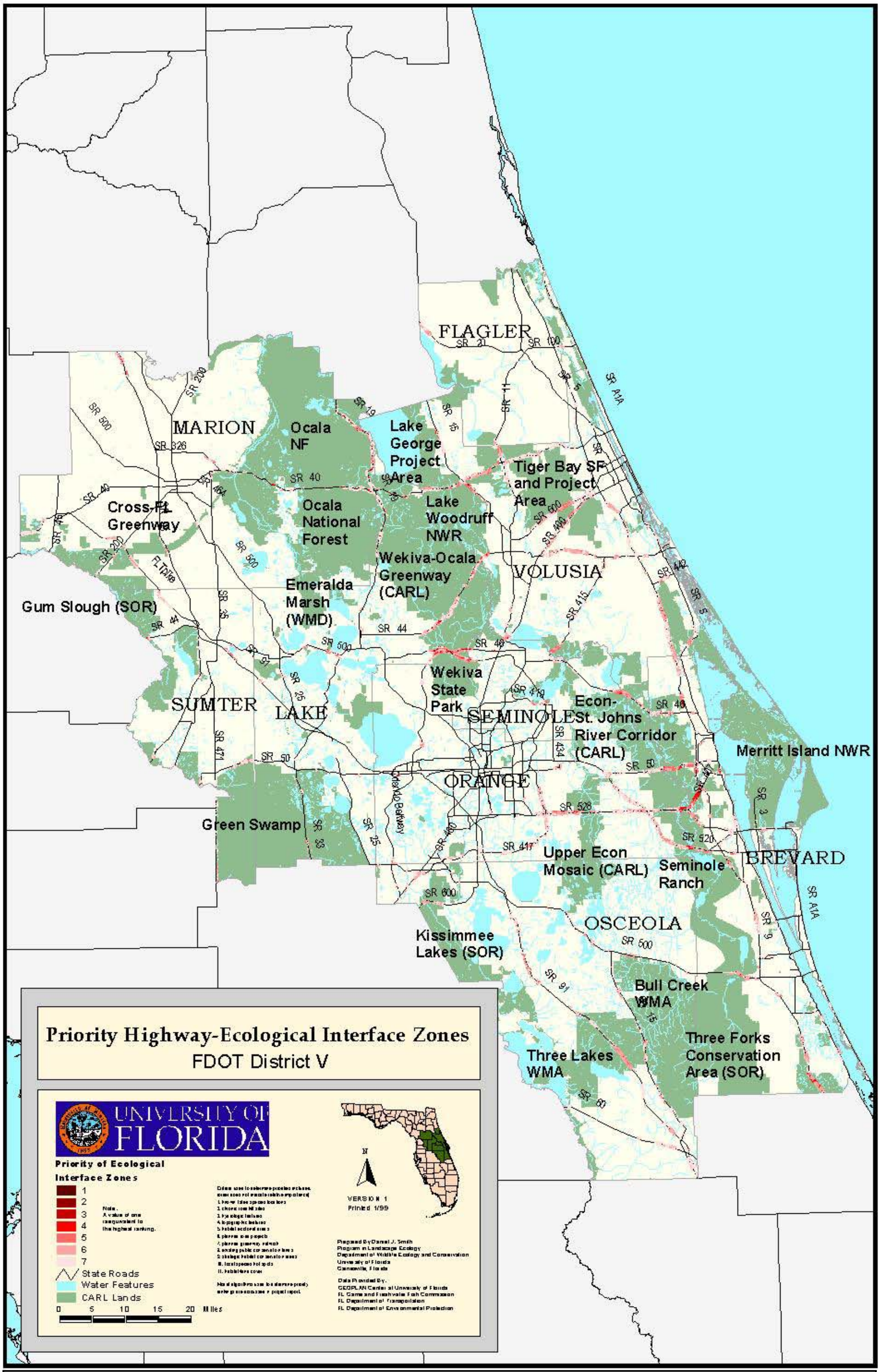


Figure 2-10e. Road segment priorities in FDOT District 5. Rankings increase from low to high as red shading becomes darkest.

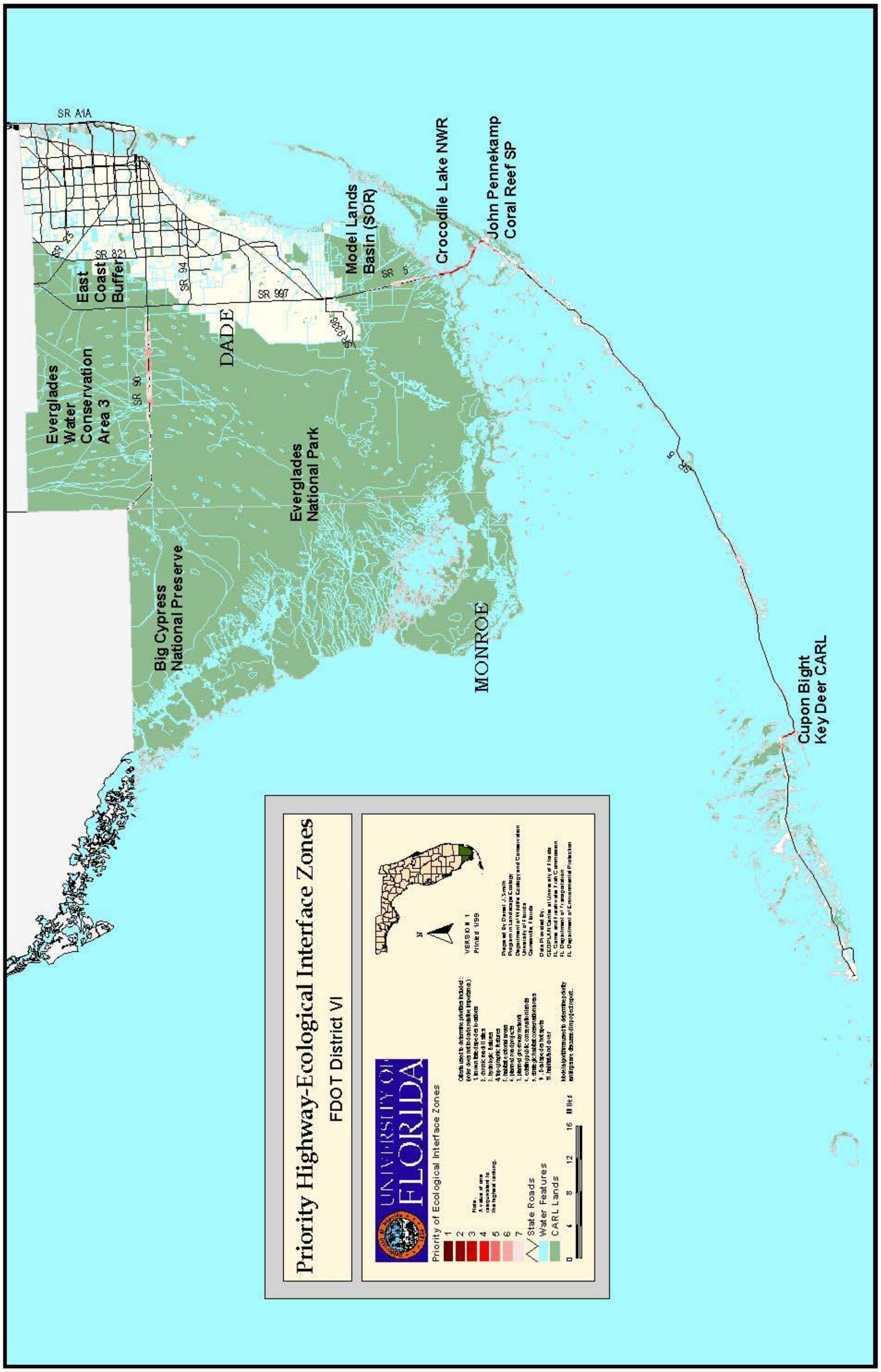


Figure 2-10f. Road segment priorities in FDOT District 6. Rankings increase from low to high as red shading becomes darkest

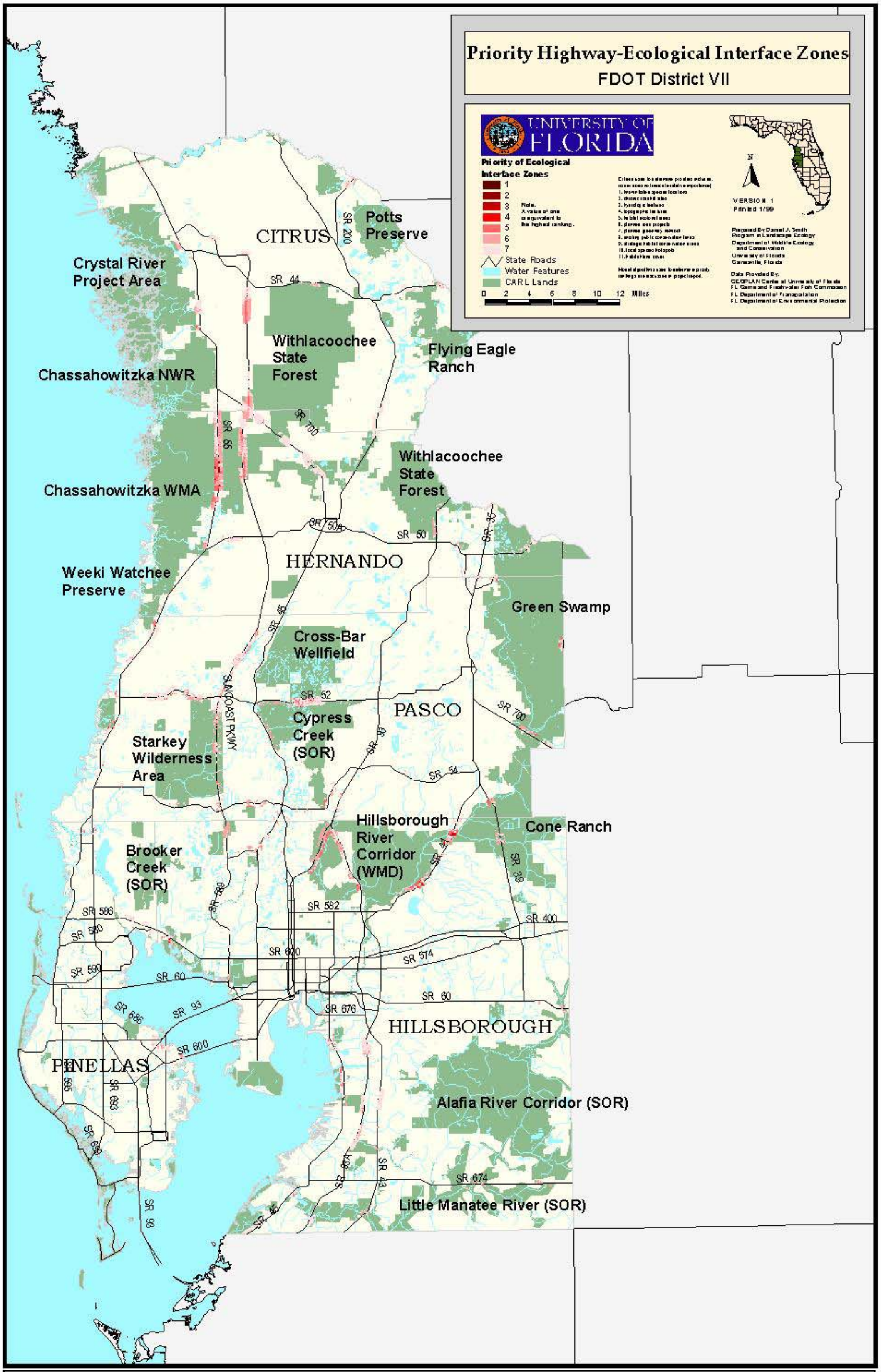


Figure 2-10g. Road segment priorities in FDOT District 7. Rankings increase from low to high as red shading becomes darkest.

Table 2-3. Significant prioritized road segments by FDOT district

FDOT district	Highways	Conservation areas	Contributing criteria
One	SR 29, US 41	Everglades NP/Big Cypress NP	flp, blb, rdkl, lsp, hsp, pub, hab
	US 27	from SR 70 south to Fisheating Creek	blb, rdkl, lsp, hsp, shca, grn, flp
	I-75, US 41, SR 72, SR 776	Myakka River conservation area	rdkl, lsp, hsp
	SR 60, SR 70, SR 700	Lake Wales Ridge and Kissimmee R SOR	lsp, hsp
	I-75, US 41, SR 31	CM Webb WMA	hab, pub, shca
Two	SR 19	Ocala NF at the Oklawaha River	rdkl, rip, hab, pub
	SR 20, SR 100	Etonia Creek Carl	rip, grn, shca, hsp
	SR 21, SR 16, SR 230	Camp Blanding	pub, grn, lsp, hsp
	SR 121	Lake Butler WMA	pub, grn, lsp, hsp
	SR 2, US 441, I-10, US 90	surrounding Osceola NF	pub, hsp, lsp, rdkl
	US 441, I-75, SR 20, US 301	Paynes Prairie and Prairie, Orange and Lochloosa creeks	rdkl, rip, shca, grn, pub, rdpr
	SR 105, SR 107, SR A1A, US 1, SR 301	Timuacan National Preserve	pub, rip
	Florida Turnpike Extension	Goethe State Forest	rdpr, rcw, lsp, pub, hab
	SR 24	Cedar Key Scrub State Preserve	hsp, lsp, hab, pub
	SR 20, SR 55, US 27	Aucilla, Wacissa and Econfina rivers	rip, rdkl
Three	SR 20, SR 65, SR 377, SR 61, SR 267, SR 71, US 98	Apalachicola National Forest/St. Marks NWR and Aucilla WMA area	rcw, rdkl, pub, rip, hsp, lsp
	SR 83, SR 85, SR 87, SR 189, SR 4, US 90, I-10	Eglin AFB/Blackwater Creek SF area	rdkl, lsp, hsp
	US 98	Topsail Hill and Henderson SRA	pub, hsp, lsp, hab
Four	US 27, I-75, SR 710, SR 786, SR 70, SR 76	within the WCAs, Dupuis Reserve, Cypress Creek CARL, East Coast Buffer SOR, JW Corbett WMA and Pal Mar CARL areas	grn, pub, shca, lsp, hsp
	SR 60, SR 91	Blue Cypress and Fort Drum conservation areas	grn, pub, shca
	I-95, US 1, SR A1A	St. Sebastian River Buffer SP, N. Fork of St. Lucie River, and Indian River Lagoon Blueway	lsp, grn, rip
Five	SR 19, SR 40, US 17	Ocala National Forest area and Lake George WMD project	blb, rdkl, lsp, pub, hsp, rdpr
	US 92, I-4	Tiger Bay State Forest	grn, pub
	SR 46, SR 44, SR 417	Wekiva River Basin – Ocala greenway, Little Econlockhatchee and St. Johns River	grn, rip, rdkl, shca, rdpr
	I-95, SR 46, SR 407, SR 50, SR 520, SR 528	Seminole Ranch/Tosahatchee SR	pub, grn, rip, hsp, shca
	SR 44, I-75, SR 50	Withlacoochee R. and Green Swamp	rip, grn
	I-95	St. Sebastian River Buffer SP and Indian River Lagoon Blueway	rip, pub, shca, lsp
Six	US 1	between Key Largo and the Everglades	lsp, rdkl, hsp, pub, amcr, rdpr
	US 1	Prop. addition to the Florida Key Deer NWR on Big Pine Key	rdkl, flkd, lsp, shca, rdpr
Seven	US 19	adjacent to the Chassahowitzka NWR and Annutteliga Hammock	rdkl, hsp, lsp, pub, shca
	the Suncoast Parkway	adjacent to the Chassahowitzka NWR and Annutteliga Hammock	hsp, lsp, pub, shca, rdpr

Table 2-3 continued

FDOT District	Highways	Conservation Areas	Contributing Criteria
Seven	I-75, I-275, SR 54, US 41	through the Cypress Creek and Hillsborough River corridors	rip, grn, pub
	I-75, SR 43	Little Manatee and Alafia Rivers SOR	rip, grn

Note: Abbreviations for criteria are as follows: American crocodile (amcr), black bear (blb), Florida key deer (flkd), Florida panther (flp), habitat/land cover (hab), hotspots (hsp), greenway linkages (grn), listed species locations (lsp), public lands (pub), red-cockaded woodpecker (rcw), riparian system (rip), road-kills (rdkl), road projects (rdpr), and SHCAs (shca).

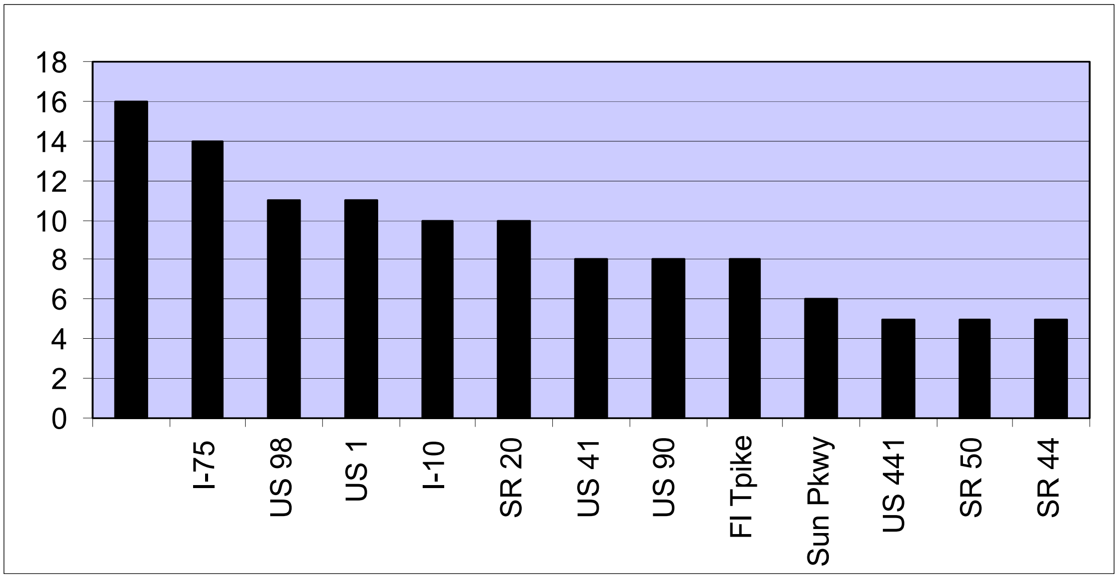


Figure 2-11. Number of significant priority sites by route number.

Explanation of results is most revealing with reference to the major contributing criteria used in the analysis. Regional greenways within the State that are intersected by high priority road segments (Figure 2-12a and 2-12b) include:

- The south Florida ecosystem – upper St. Johns River basin greenway,
- The middle St. Johns River basin –Ocala National Forest greenway system,
- Ocala National Forest –Osceola National Forest/Pinhook Swamp/Okefenokee Swamp greenway,
- Osceola National Forest –Apalachicola National Forest greenway system,
- Green Swamp/Withlacoochee State Forest — Big Bend conservation area greenway system,
- The south Florida ecosystem –Green Swamp greenway system, and
- Eglin AFB – Blackwater Creek State Forest greenway.

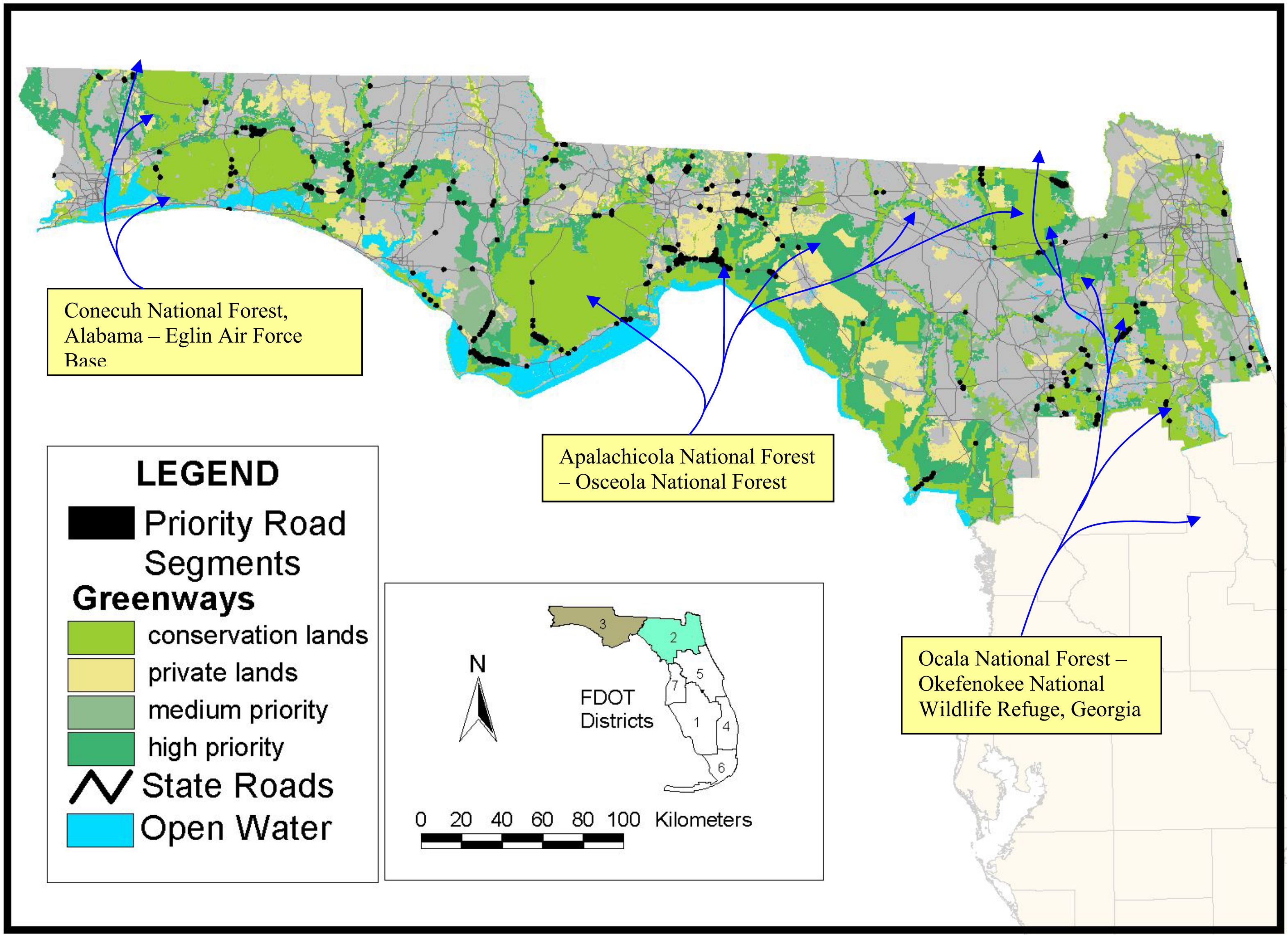


Figure 2-12a. Road segment priorities and greenways in panhandle Florida. Prioritized ecological hotspots are shown in black for FDOT districts 2 and 3. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

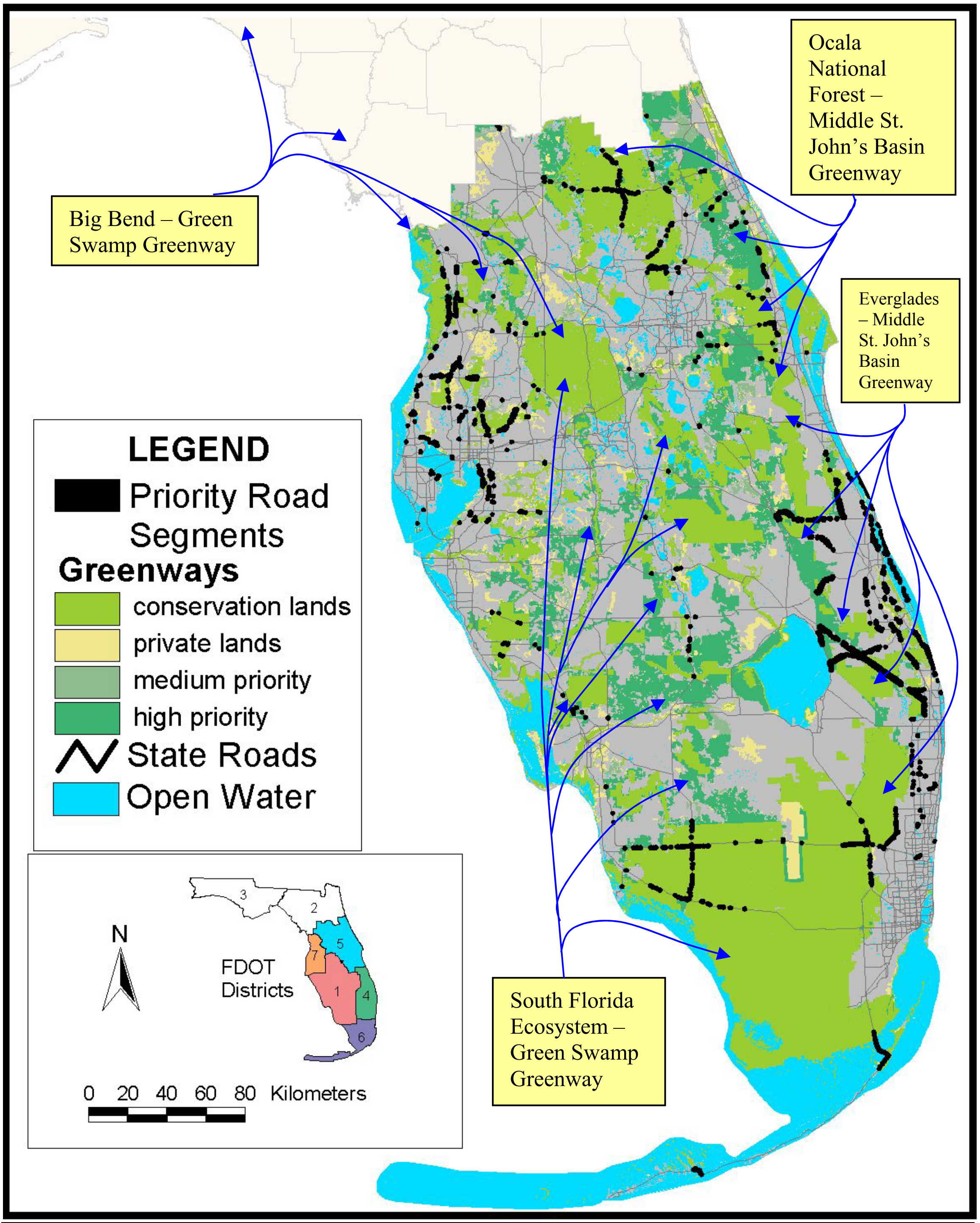


Figure 2-12b. Road segment priorities and greenways in peninsular Florida. Prioritized ecological hotspots are shown in black for FDOT districts 1, 4, 5, 6 and 7. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

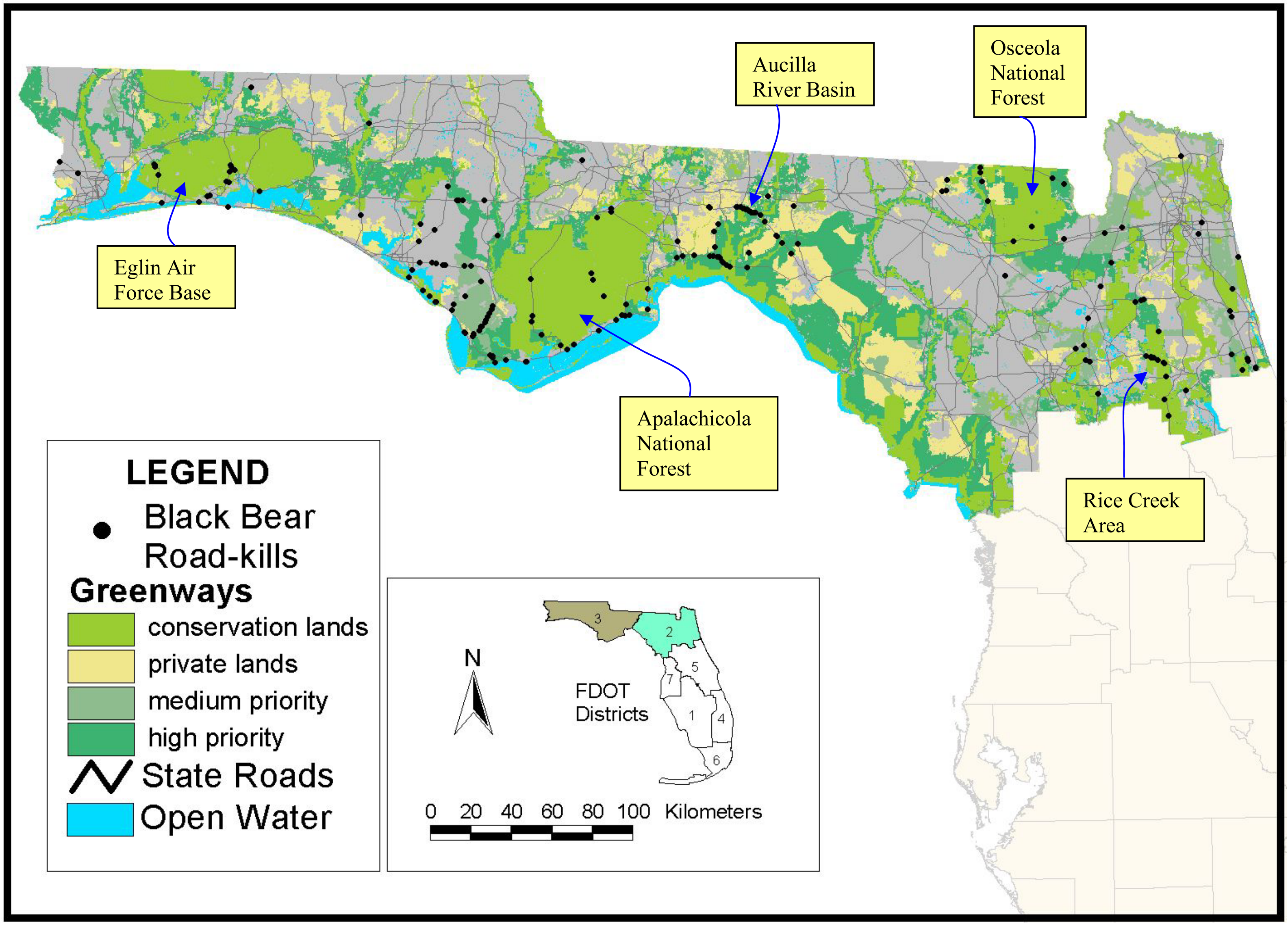


Figure 2-13a. Black bear road-kills and greenways in panhandle Florida. Black bear road-kills, 1976-1999, are shown in black for FDOT districts 2 and 3. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

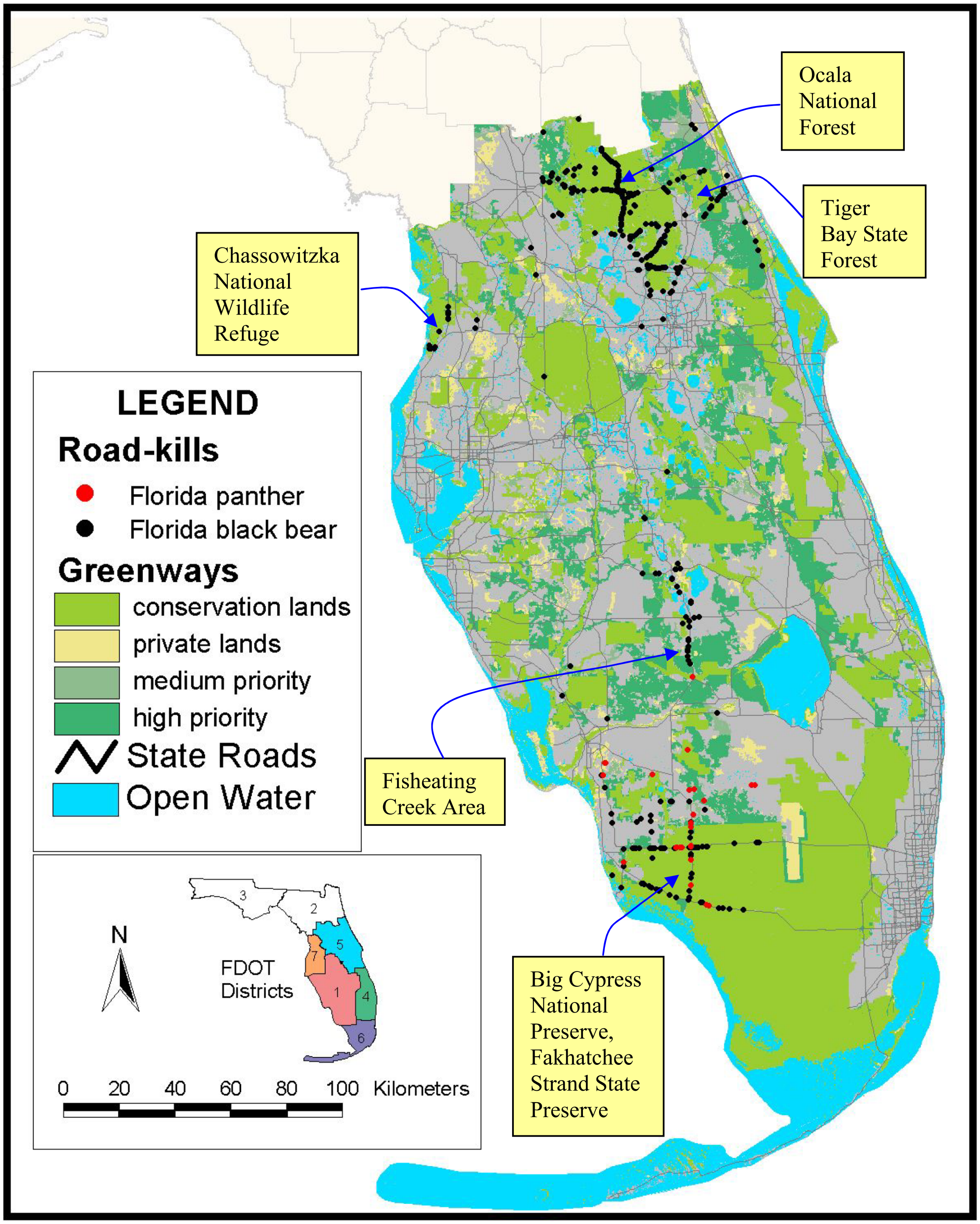


Figure 2-13b. Black bear and Florida panther road-kills and greenways in peninsular Florida. Black bear, 1976-1999 (in black), and Florida panther, 1973-1996 (in red), road-kills are shown in for FDOT districts 1, 4, 5, 6 and 7. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

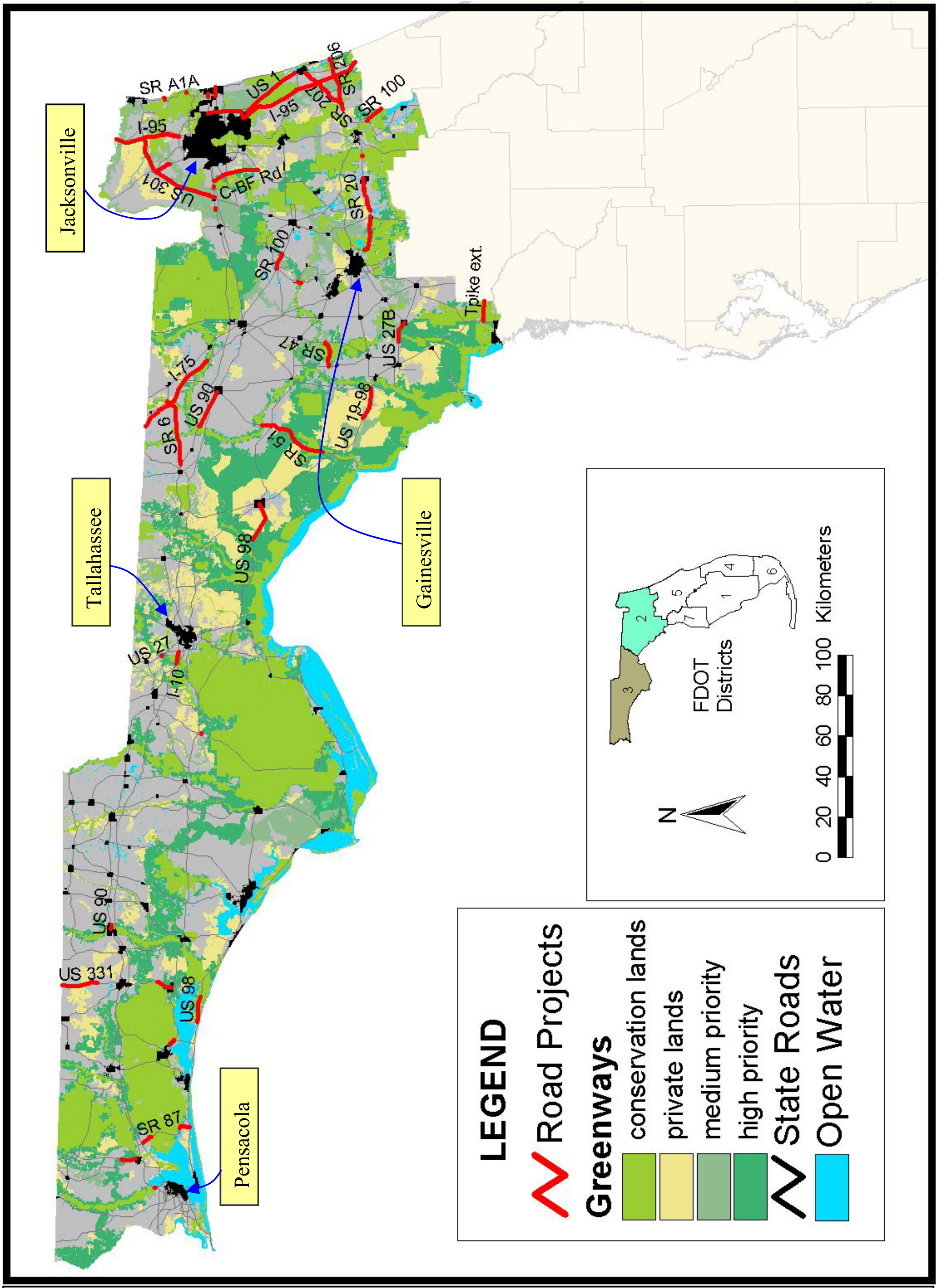


Figure 2-14a. Road projects and greenways in panhandle Florida. State-funded road projects through 2004 are shown in red for FDOT districts 2 and 3. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

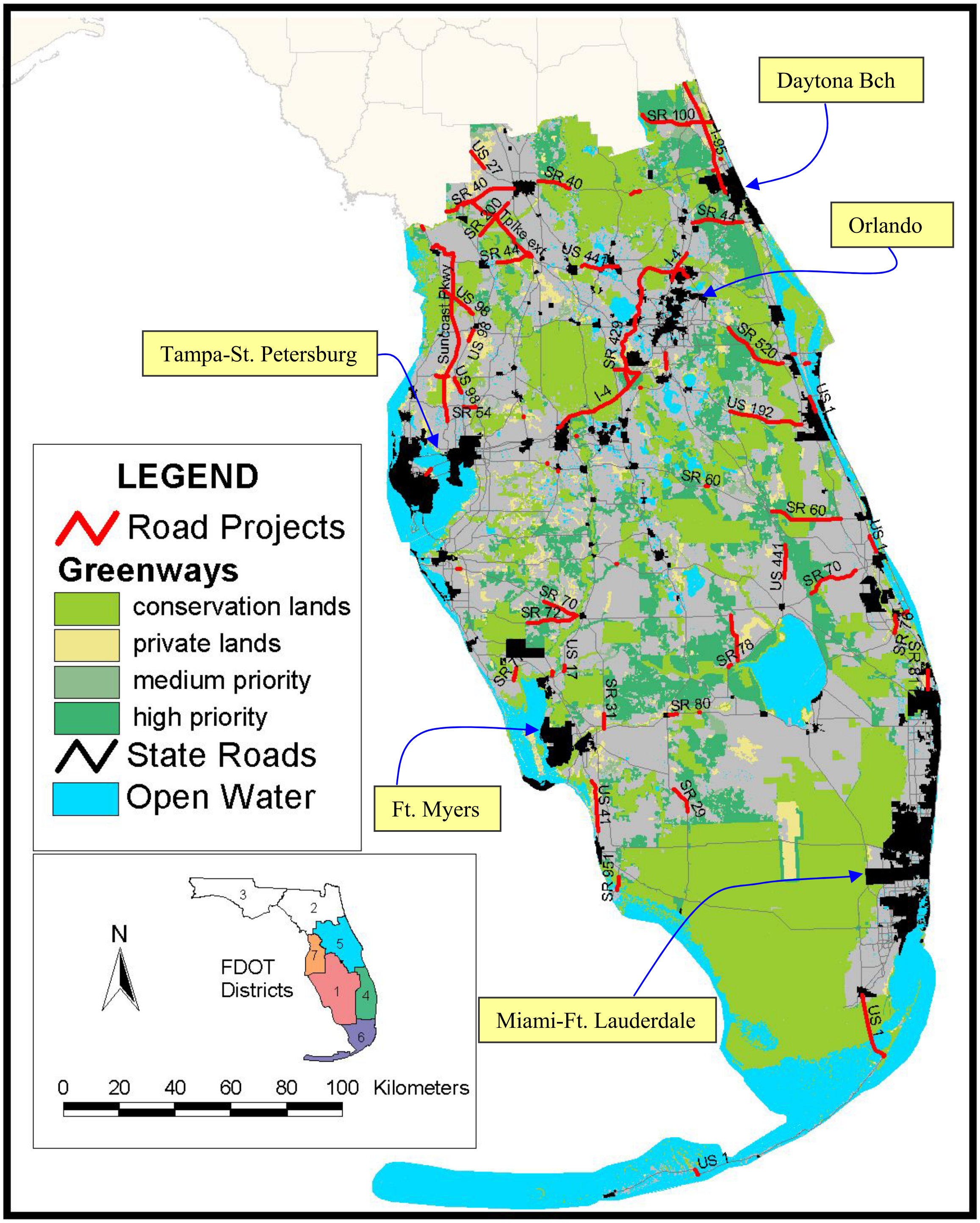


Figure 2-14b. Road projects and greenways in peninsular Florida. State-funded road projects through 2004 are shown in red for FDOT districts 1, 4, 5, 6 and 7. These are overlaid upon existing and proposed state conservation-lands and priority greenway linkages.

Of 15,644 road segments identified with priorities one to five, 12,828 (82%) were associated with identified greenways; and 4,019 (26%) were located within existing conservation lands. Of these road segments, 27 were ranked 1st, 150 were ranked 2nd, and 389 were ranked 3rd. On proposed CARL project lands there were 2,469 (16%) prioritized road segments. Numbers of significantly ranked, road segments on proposed conservation lands include: 13 (1st), 63 (2nd), and 181 (3rd).

Major riparian systems where multiple priority ecological hotspots on road segments were identified include the following rivers and their tributaries:

- St. Johns
- Suwannee
- Aucilla/Wacissa
- Withlacoochee
- Peace
- Myakka
- Kissimmee
- Apalachicola
- Choctawatchee
- Escambia
- Yellow
- St. Marks

Black-bear road-kills significantly influenced results at the statewide level. This was due to the high weight placed on the criterion and the wide distribution of the species. The most significant priority sites where Florida black-bear road-kills were located (Figure 2-13a and 2-13b) included:

- SR 19 and SR 40 in Ocala National Forest (NF)
- SR 44 and SR 46 crossing the Ocala – Wekiva habitat corridor
- US 441 adjacent to Osceola NF
- US 41, I-75 and SR 29 in Big Cypress National Preserve
- US 19 adjacent to Chassahowitzka NWR
- US 27, SR 59 and US 98 in Jefferson and Wakulla counties
- US 27 in Highlands county
- SR 85 and SR 87 in Eglin AFB

- SR 65 and US 319 in Apalachicola NF
- SR 71 in Gulf county

Ninety-five major, state-sponsored, road projects coincide with highly ranked ecological hotspots on highways (Figures 2-14a and 2-14b; Table 2-4). These projects were identified from FDOT district workplans for 1996 – 2000 and 1999 – 2004; and include 46 bridge replacements/new construction, 43 road expansions/reconstruction, and 6 new roads (FDOT 1999, 1996).

Table 2-4. Road projects identified at highly ranked, ecological hotspots on highways

FDOT District	Route No.	Ecological Feature	Project Type
1	I-4	Green Swamp	Multi-lane Reconstruction
1	SR 29	Big Cypress NP, Fakahatchee Strand SP	Install Box Culvert Wildlife Underpasses
1	SR 29	Canal, S of Fisheating Creek SOR	Bridge Replacement
1	SR 29	Canal, S of Fisheating Creek SOR	Bridge Replacement
1	SR 29	Canal, S of Fisheating Creek SOR	Bridge Replacement
1	SR 29	Canal, S of Fisheating Creek SOR	Bridge Replacement
1	SR 29	south of CR 847, Corkscrew Regional Ecosystem	Bridge Replacement, Road Reconstruction
1	SR 60	Kissimmee River SOR	Bridge Replacement
1	SR 70	Horse Creek	Bridge Replacement
1	SR 70	Horse Creek	Bridge Replacement
1	SR 776	Myakka River Corridor	Add Lanes/Reconstruction
1	SR 951	Rookery Bay	Add Lanes, New Bridge
1	US 41	Big Cypress NP	Bridge Replacement
2	Chaffee-Branen Field Rd	Jennings SF, Black Creek Area	New Road Construction
2	FL Turnpike Ext.	Goethe SF	New Road Construction
2	I-95	Julington/Durbin CARL,12-mile Swamp, Fish Swamp, Pellicer Creek	Add Lanes/Resurfacing
2	I-95	Timucuan EP, Nassau River Corridor	Add Lanes/Reconstruction
2	SR 105/SR AIA	Ft. George Inlet, Timucuan EP	Bridge Replacement
2	SR 121	Santa Fe River Corridor	Bridge Replacement
2	SR 20	Fowler's Prairie	Add Lanes, PD & E / EMO Study
2	SR 20	Lochloosa Creek, Prairie Creek, Newnans Lake CARL	Add Lanes/Reconstruction
2	SR 20	Rice Creek, Etonia Creek CARL	Bridge Replacement
2	SR 207	Deep Creek CARL, Fish Swamp, Moultrie Creek, Trestle Bay Swamp	Add Lanes/Reconstruction
2	SR 47	Santa Fe River Corridor	Bridge Replacement
2	SR 500	Devils Hammock WMA to Watermelon Pond	Add Lanes/Reconstruction
2	SR 9A	Gum Swamp, Big Island Swamp	New Road Construction

Table 2-4. continued

FDOT District		Ecological Feature	Project Type
2	US 17	Lofton Creek	Bridge Replacement
2	US 17	Nassau River Salt Marsh	Bridge Replacement
2	US 17	Nassau River Salt Marsh	Bridge Replacement
2	US 301	Timucuan EP, Cary SF	Add Lanes/Reconstruction
2	US 90	Intra-coastal Waterway	Bridge Replacement
2	US 90	Pablo Creek	Add Lanes/Reconstruction
3	SR 71	Cypress Creek	Bridge Replacement
3	SR 71	West Arm Creek	Bridge Replacement
3	SR 83	Eglin AFB	Add Lanes/Reconstruction
3	SR 87	Clear Creek	Add Lanes/Reconstruction
3	SR 87	Eglin AFB, Yellow River	Add Lanes/Reconstruction
3	US 27	Ochlocknee River	Bridge Replacement
3	US 27	Ochlocknee River Corridor	Bridge Replacement
3	US 90	Choctowatchee River	Bridge Replacement
3	US 98	St. Marks River	Bridge Replacement
3	US 98	Topsail Hill SP, Pt. Washington SF	Add Lanes/Reconstruction
4	SR 60	Blue Cypress Conservation Area	Add Lanes/Reconstruction
4	SR 70	Cypress Creek Branch	Bridge Replacement
4	SR 70	Cypress Creek CARL	Bridge Replacement
4	SR 70	Cypress Creek CARL	Add Lanes/Reconstruction
4	SR 70	Cypress Creek CARL	Bridge Replacement
4	SR 70	Relief Canal, Cypress Creek CARL	Bridge Replacement
4	SR 70	Relief Canal, Cypress Creek CARL	Bridge Replacement
4	SR 76	South Fork St. Lucie River	Add Lanes/Reconstruction
4	SR 811	Lake Worth Creek	Add Lanes/Reconstruction
4	US 1	North Savannas, Indian River Blueway	Add Lanes/Reconstruction
5	FL Turnpike Ext.	Marion/Levy 1 SOR, Cross-FL Greenway, Gum Slough	New Road Construction
5	I-4	Reedy Creek	Add Lanes
5	I-4	St. Johns River AP	Bridge Replacement
5	I-4	St. Johns River AP	Add Lanes
5	I-4	Tomoka River Area	Add Lanes
5	I-95	Pellicer Creek AP, Graham Swamp	Add Lanes
5	SR 100	Creek to Crescent Lake	Bridge Replacement
5	SR 100	Flagler County Greenway, Black Point Swamp	Add Lanes
5	SR 11	Middle Haw Creek	Bridge Replacement
5	SR 19	Palatlakaha Creek, Lake County WCA	Bridge Replacement
5	SR 40	Ocala NF	Add Lanes
5	SR 40	Silver River SP, Ocala NF	Add Lanes
5	SR 429	Wekiva Basin GeoPark	New Road Construction
5	SR 44	CSX RR, Spruce Creek	Bridge Replacement
5	SR 44	Deep Creek Swamp, Tiger Bay, Spruce Creek Swamp, Bicentennial Conservation Park	Add Lanes

Table 2-4. continued

FDOT District	Route No.	Ecological Feature	Project Type
5	SR 44	Lake Panasoffkee SOR, Gum Slough SOR, Withlacoochee River	Add Lanes
5	SR 46	Lake Jessup	Bridge Replacement
5	SR 520	St. Johns River, Jim Creek, Tosahatchee Creek/SP, Seminole Ranch	Add Lanes
5	SR 60	C-54 Canal, Ft. Drum Conservation Area	Bridge Replacement
5	SR 60	Kissimmee River SOR	Bridge Replacement
5	US 1	Korona Canal, Tomoka River Area	Bridge Replacement
5	US 1	Tomoka River Area	Bridge Replacement
5	US 17/92	Reedy Creek	Bridge Replacement
5	US 192	Reedy Creek	Add Lanes
5	US 192	Three Forks SOR Conservation Area, St. Johns River, Crabgrass Creek	Add Lanes
5	US 441	Lake County WCA, Lake Harris, Lake Eustis	Add Lanes
6	US 1	Big Pine Key, Coupon Bight	Add Lanes
6	US 1	Everglades NP, Crocodile Lake NWR, Jewfish Creek	Add Lanes, Bridge Replacement, Multi-lane Reconstruction
7	I-275	Big island Gap, Tampa Bay	Add Lanes/Reconstruction
7	SR 200	Jordan Ranch, Withlacoochee River	Add Lanes/Reconstruction
7	SR 39	Blackwater Creek SOR	Bridge Replacement
7	SR 44	Moccosin Slough, Withlacoochee River	Add Lanes/Reconstruction, Bridge Replacement
7	SR 50	Withlacoochee River	Bridge Replacement
7	SR 52	Starkey WMA, Pithlachascotee River	Add Lanes/Reconstruction
7	SR 54	Cypress Creek	Add Lanes/Reconstruction
7	Suncoast Pwy	Annuteliga Hammock	New Road Construction
7	US 19/98	Cross-FL Greenway	New Bridge
7	US 41	Pasco 1 SOR, Five-mile Creek	Add Lanes/Reconstruction
7	US 98	Annuteliga Hammock	Add Lanes/Reconstruction

Discussion

Determinants of Model Priorities

Five primary factors were instrumental in the model. The following discussion highlights their importance and explains their role in statewide conservation planning.

Greenways

The Florida Statewide Greenways Planning Project (Carr et al. 1999) was based on several criteria used in this model (e.g., riparian linkages, core areas of conservation, existing and proposed public conservation-lands, SHCAs, and land cover/land use).

When priorities one to five from each district are compared to the greenways final priority results (Figure 2-12a and 2-12b; also see Smith et al. 1998), it is apparent that ecological greenways were an important element in identifying road segments in areas of high ecological value.

Roads intersect most ecological greenways. As part of the design of a functionally integrated ecological network, many of these intersections will require some type of mitigation measures such as wildlife underpasses. Many of these sites are identified as high priorities in this analysis (Table 2-3; Figure 2-12a and 2-12b). Much discussion surrounding costs to construct underpasses has occurred. The common conclusion being that too few monetary resources exist to install underpasses at all of these sites. The purpose of this research was to formulate a prioritization method to determine those sites in greatest need (so that limited resources could be used most efficiently). Even with prioritization, the multiple sites selected probably require more funding than is available to construct the number of wildlife underpasses needed; and that keeps up with land acquisition proposals and encroaching development.

As much as 2.28 million acres have been proposed for purchase under various state land acquisition programs (FGP 1999). FDOT is reluctant to provide funding for construction of wildlife underpasses on private lands when future land-use is uncertain. In these cases, costs for construction of mitigation structures (such as wildlife underpasses) should be included as part of the total purchase costs; as part of the ecological network plan for Florida. This could expand construction costs across multiple funding sources. For example, FDOT could focus on existing public conservation-lands and riparian corridors when allocating their resources for underpass construction. Whereas, FDEP could schedule funds for underpasses on acquired CARL lands in conjunction with the purchase of the property. Such an approach could help facilitate a quicker realization of the greenways vision—an interconnected ecological network that serves as a statewide conservation system for Florida.

Riparian systems

Riparian systems were considered important movement corridors in this project. Several studies have investigated and described the function of riparian systems as habitat and movement corridors (Rosenberg et al. 1997, Baschak et al. 1994, Malanson 1993, Noss 1993, van Buuren et al. 1993, Schaefer et al. 1992, Harris 1985, and Forman 1983). In the Netherlands, riparian corridors are considered vital ecological linkages for movement of species (Lammers et al. 1996). In Florida, the Wekiva and Suwannee Rivers have been identified as critical greenway linkages by multiple authors (Noss 1993, Smith 1993, and Harris 1988b). Riparian corridors are natural features that provide functional connectivity between landscape elements. Sufficiently wide riparian systems contain gradients of ecosystems (from aquatic to xeric habitat types) that can facilitate movement by various habitat dependent species (Harris et al. 1996).

Riparian systems are represented in four individual criteria used in the analysis: riparian, habitat/land cover, SHCAs, and greenway linkages. As is the case with the greenway criterion, riparian systems are an integral part of Florida’s statewide conservation system. They act as refuges and travel corridors, and provide sources of food and shelter for various mammals, herpetofauna, fish, and birds (Darveau et al. 1995, Spackman et al. 1995, van Zadelhoff and Lammers 1995, Noss 1993, Smith 1993, Schaefer et al. 1992, and Dodd 1990).

Terrestrial connections along these river corridors are essential at road intersections (to provide connectivity for terrestrial vertebrates). It is imperative that bridge replacements be programmed to include accommodations for terrestrial connections adjacent and parallel to the watercourse. These connections should include native vegetation consistent with the present community type.

The St. Johns, Suwannee, Peace, Withlacoochee, and Apalachicola river systems are part of major statewide greenway linkages. Functional terrestrial underpasses are necessary where roads intersect these. Some already have adequate structures that serve as underpasses; examples include I-10 at the Suwannee River, I-10 at the Apalachicola River, SR 40 and SR 19 at the Ocklawaha River, US 90 and I-10 at the Little St. Mary's River, US 129 at the Suwannee River, and US 301 at the Santa Fe River. Others may require expansion or other minor modifications to the structure; examples include I-75, US 441, and US 27 at the Santa Fe River, US 301 at Orange Creek, and US 19 at the Suwannee River.

Hotspots

Location of focal species hotspots and listed species element occurrences typically signify high priority wildlife conservation areas. The hotspots dataset also acts as the basis for the FFWCC SHCAs used in this analysis.

The hotspots dataset was created by overlaying habitat maps of 44 focal species and subdividing the composite map into three broad categories: 1) 3 – 4 species, 2) 5 – 6 species, and 3) 7 + species (Cox et al. 1994). These categories represent areas where existing habitat conditions can support the aforementioned number of focal species. Cox et al. (1994) described category one as typical of large forested habitat areas that serve many large-scale landscape functions (such as maintenance of air and water quality, and faunal movement between preserves). Category two and three serve as habitat areas for generalists as well as habitat-specific species. According to Cox et al. (1994), the latter two categories require special attention in conservation planning, since many of these areas are critical for the survival of certain rare species.

Biodiversity hotspots played a major role in final rankings of road segments. Presence of hotspots and/or inclusion in SHCAs coincides with the location of most major core conservation areas. Thus, most of these locations are either in public ownership or proposed for acquisition. Updated versions of the hotspots and land-cover datasets that were recently released, were not available at the time this research was conducted.

Road-kills

Road-kill was included in the analysis as an independent category. It was originally included in the biological features category, and only showed a strong presence when combined in certain cells with hotspots and listed species element occurrences; therefore diminishing the significance of the road-kill data. Being the highest ranked criterion, it was decided that chronic road-kill sites should be separated from other biological data.

When road-kill sites are clustered or contain multiple kills, they deserve extra consideration relating to their potential importance as travel routes for listed species. This dataset needs to be expanded to include more listed and non-listed species. The quality and accuracy of the existing data was good regarding the three listed species available—Florida black bear, Florida panther, and Florida key deer.

Road projects

It is important to identify significant ecological hotspots that correspond with planned road projects. Through these opportunities, construction of wildlife underpasses or other mitigation measures can be facilitated. Such pre-planning can reduce costs incurred when engineers must retrofit existing roads. Road projects are conducted over a series of phases: 1) environmental assessment, 2) planning, design, and engineering, 3) right–of–way development, 3) road construction, and 4) maintenance. Ideally, information from this study would be most useful if provided prior to phase two, when mitigation measures could be included as part of the original highway design. With this in mind, time is a critical factor for implementation. Road projects used in this analysis (completed in 1999) were identified from FDOT workplans from 1996 – 2004 (Table 2-4), and are therefore almost all completed at this writing. This means that the process must be updated repeatedly to maintain a current listing of proposed road projects.

Data Limitations and Development of other Criteria

Certain limitations of available data affected the capability of the model to derive more accurate results. For instance:

- Accuracy of listed species locations could be improved with new inventories
- Land-cover data were from 1994 satellite data; a more current version that is being compiled was not complete at the time of this study
- With availability of more recent land-cover data the SHCAs, hotspots, and habitat ecotones (based on the 1994 land-cover data) could be updated
- Road-kill databases could be expanded to include other species such as white-tailed deer and certain listed species not currently available

Future iterations of this application should include a few additional criteria that might be developed from existing and new data sources to further refine results. Two potential new criteria utilize previously unavailable census and land-use data to identify at-risk, high-growth areas and high-intensity land-uses. Three other improvements might include additional components to existing criteria. These improvements include:

- Establishing a new criterion that utilizes 1990 and 2000 census-block data to identify high-growth areas (Figure 2-15) and future land-use to determine areas at greatest risk for habitat loss
- Establishing a new criterion that identifies and demotes areas consisting of high-intensity land-uses (Figure 2-16) from three indicators—2000 census (housing-unit density), updated land cover (urban, mining, intense agriculture, and exotic plant communities) and USGS 1:24,000 roads (high road densities)
- Utilizing 1:24,000 hydrography and updated land cover to identify ephemeral areas in high quality habitat areas, adjacent to road right-of-ways, to apply criterion no. 9 for herpetofauna
- Identifying severe slope and ravine areas, typical of northwest Florida creek systems, and other critical features from USGS topography, DEMs, hydrography, and updated land-cover data (Figure 2-17)
- Conducting more in-depth application of topographic and habitat gradient information (e.g., slope/aspect and habitat juxtaposition) to improve the ability to predict likely movement corridors; in the current analysis its application was limited to two parameters (topographic highs and lows and large-scale habitat ecotones)

Model Priorities

The process used in this model reduces variance in final scores by combining criteria into categories. Final scores were slanted toward road-kill, planning, biological and landscape features. This was due to higher weightings for road-kill (listed species road-kill sites), planning (SHCAs and greenways), biological features (hotspots, road-kill and listed species locations), and landscape features (gradients, riparian, and habitat/land cover); and lower weightings for public (public lands), and infrastructure (road projects). As a decision-support model, these preferences were cognizantly made. Although the latter two categories may have had some bearing on final results, most highly ranked cells are due to high values from the former four categories. Since the intent was to focus on biological components of natural landscapes, the process seemed to work as expected.

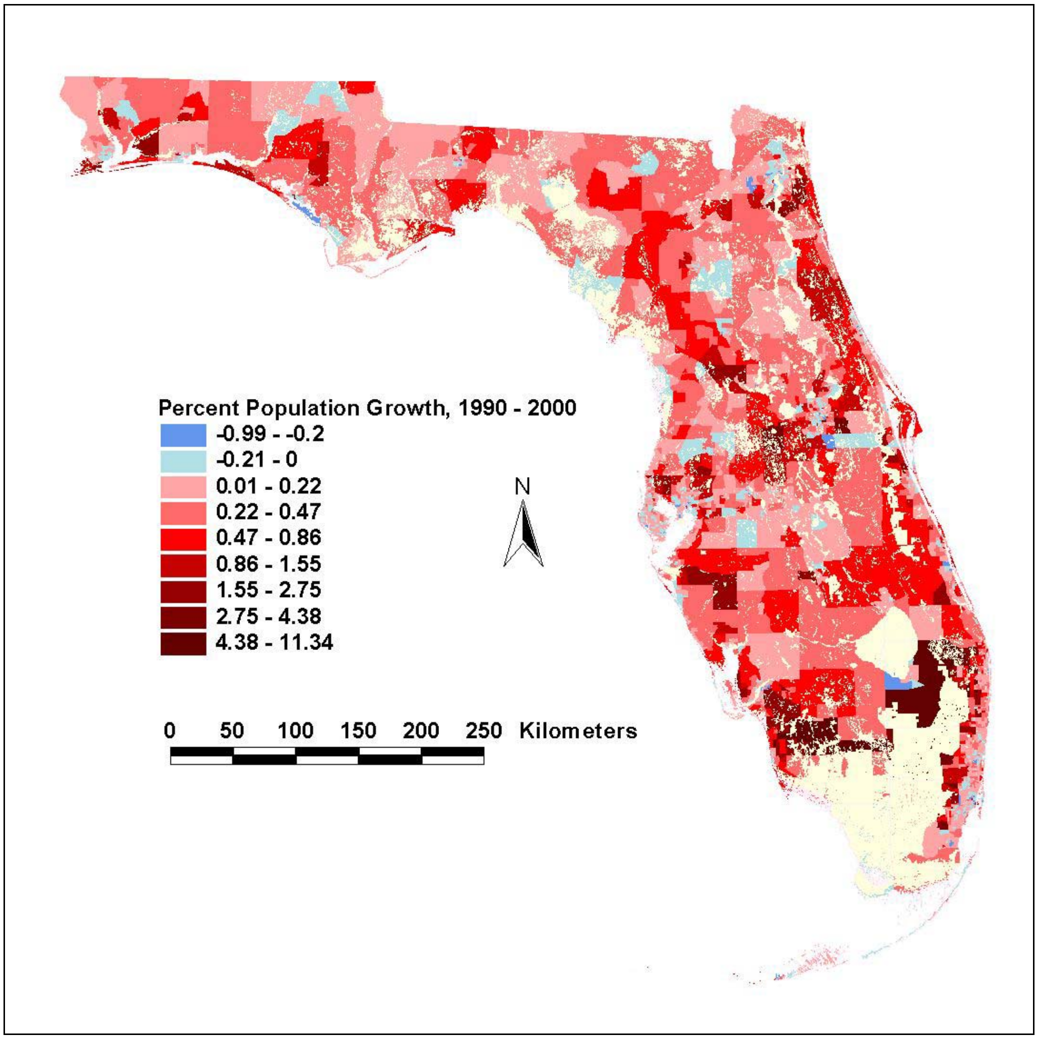


Figure 2-15. Human population growth rates in Florida from 1990 – 2000. Census tract boundaries from the 1990 and 2000 U.S. Census were normalized so that population growth for the decade could be determined at the census tract level. To identify areas at high risk to development, it is suggested that future land-use data from local comprehensive plans (currently unavailable post 2000) be combined with census information.

However, certain limitations are of interest. By combining criteria, a reduction in variance occurs and the intonation caused by individual criteria from each category is lost. In other words, the impact of each individual criterion is tempered by the other criteria within the respective group.

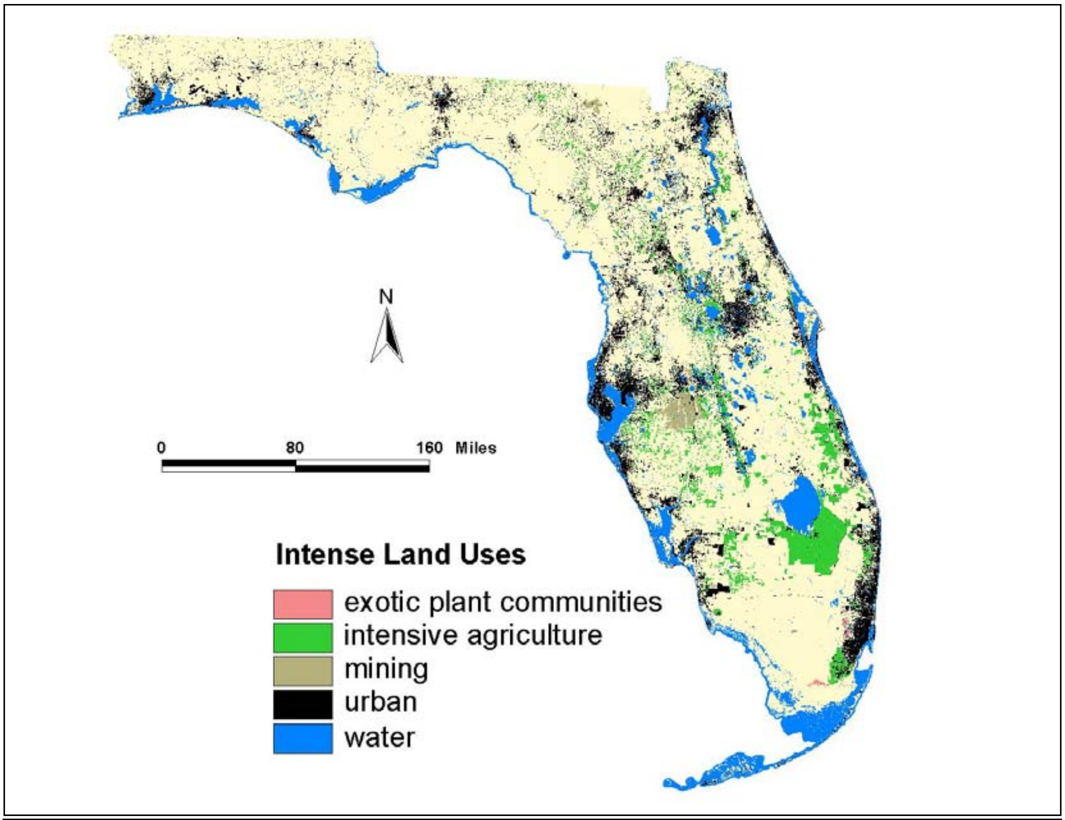


Figure 2-16. Identification of intense land-uses. Land uses shown here consist of four categories that include all urban lands, intensive agriculture lands (e.g., vegetable crops, sugar cane, citrus), and mining lands. This figure displays 1994 Water Management District (WMD) land-use, this data is currently being updated to 1999 by individual WMDs. Housing unit data from the U.S. Census and road densities from the USGS 1:24,000 roads should be combined to create a development intensity data layer that could serve as a criterion to reduce the priority of these areas for road mitigation for conservation purposes.

For example, each criterion was weighted individually for the initial trials of the model; the consequence that results were skewed to whichever criterion had the highest weighting. The original test run resulted in high values for road-kill sites because they were ranked the highest in the survey questionnaire. Contrarily, the effect of a single criterion on site rankings is diminished in the grouped version of the model (presented here). This was most appropriate, since the goal was to design the model so that one criterion could not overshadow all others. As a result, the model has greater balance and selects and ranks road segments with the highest ecological significance.

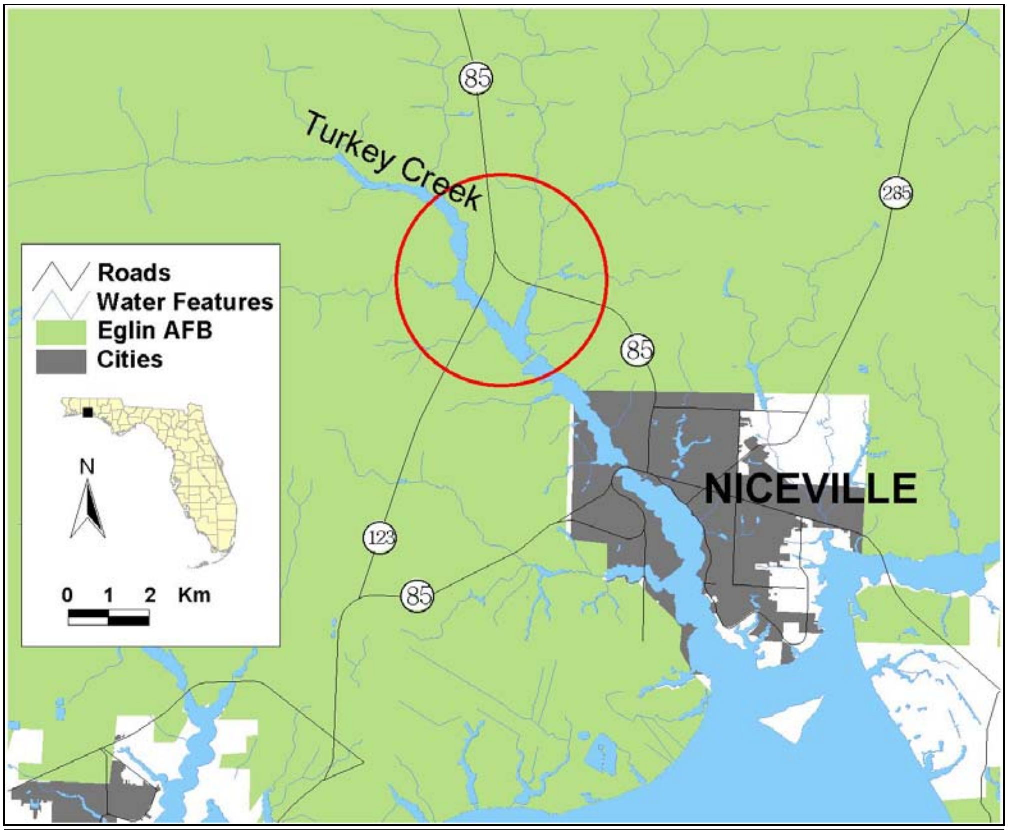


Figure 2-17. Identification of severe slope/ravine areas typical of northwest Florida creek systems. Natural isolation of steephead creek corridors was created from erosion over geologic time. Construction of certain road designs (using fill instead of bridging ravines) in this area may result in range severance of local salamander populations that travel along these creek corridors.

Exceptions to the groupings were public lands, road projects, and road-kills that still function independently. Public lands and road projects did not fit into the other group classifications; and therefore were placed in independent categories. The justification for an independent road-kill category was explained above.

Conclusion

The results pinpoint efforts to alleviate the impacts of highways and highway traffic by targeting adjacent, environmentally sensitive areas at specific highway locations. Through identification and prioritization of ecological hotspots on highways, the FDOT can program mitigation measures to counter negative impacts on wildlife and wildlife habitat.

Potential for more accurate results exist with future refinements to the priority algorithm and updates to existing data layers. The interactive Arcview© scripts provide a simple platform (Appendix B) for end users (e.g., transportation planners) to update the findings and focus on specific areas of interest. Special attention should be given to those priority sites identified that include proposed road projects and suitable existing structures.

CHAPTER 3
EXISTING INFRASTRUCTURE IN FLORIDA

Introduction

The information presented here represents phase II of the research conducted for FDOT (designed to integrate transportation planning with statewide conservation objectives). Phase I (Chapter 2) began with the development of the aforementioned algorithm that identified and prioritized ecological hotspots on roads. Tasks performed for phase II included: 1) field verification of the computer model results; 2) inventory and ecological characterization of roadway segments identified in the prioritization model (levels 1 – 3; and in special cases, levels 4 – 5); and 3) evaluation of wildlife-passage functions of existing structures and recommendations for mitigation/restoration.

Parameters for Field Site Evaluation and Infrastructure Inventory

Site characterization provides valuable information that enhances efforts to implement greenway projects, by evaluating the need for underpass connectors or other less intensive retrofits. It increases FDOT's ability to quickly address mitigation measures needed at high-priority, ecological hotspots on highways. Ground-truth surveys identified several features that included presence of existing structures (bridges, culverts, etc.), their dimensions and composition, roadway characteristics (ROW width, number of lanes, width of paved surface, etc.), description of surrounding landscape features, identity of associated aquatic features, and signs of present animal use.

Determining Appropriate Measures for Mitigation

Inventory and evaluation of specific ecological characteristics of prioritized highway segments was used to provide general recommendations, for the appropriate type and location of mitigation measures (e.g., wildlife underpasses, fencing, bridge widening, culvert designs, special r-o-w designs, plantings, signs, and speed controls). At many sites, suitable bridges or culverts already exist that require only minor directional fencing or vegetative plantings (to enhance use by wildlife and to provide connectivity between adjacent areas). Examples include the existence of wide, floodplain bridges constructed at stream intersections and abandoned, railway bridges within existing conservation areas.

Several factors should be considered in the design of roadways and wildlife crossing structures. Topographic relief can be used toward enhanced design and placement of underpasses that follow ecological flows and landscape patterns. Proper management of right-of-way and adjacent vegetation is an important factor in the design of wildlife crossing sites (Clevenger and Waltho 2000, Hewitt et.al. 1998, Tewes and Blanton 1998, Friedman 1997, Land and Lotz 1996, Roof and Wooding 1996, and Singer and Doherty 1985). Right-of-way and road corridor design should include sufficient clearance distance from the roadway, and reduction in severity of curves and slopes of hills, to increase driver visibility. Appropriate native vegetation at entry points to underpasses provides cover for species intolerant of open areas, and safety to species susceptible to ambush predators. Clevenger and Waltho (2000) identified proximity to human activity or influence, as the most critical factor in determining species performance ratios at wildlife underpasses in Banff National Park, Alberta, Canada.

Site Inventories, Assessments and Recommendations

Each field site was identified through previous GIS modeling (Chapter 2) as high priority interfaces (ecological hotspots) between state highways and critical state and regional conservation resources. The field study involved visits to 1,232 sites statewide. Recommendations for improvements were provided for 140 separate road segments containing prioritized sites.

Measures of Model Accuracy, Site Inventory and Ecological Characterization

A qualitative assessment was performed that compares land-cover characteristics collected from field surveys to satellite land-cover data (Water Management Districts 1995) used in the modeling process. Accuracy of the data used in the prioritization process (Chapter 2) was evaluated to assess the frequency that the model correctly predicted locations of ecological hotspots on highways.

State level

For the entire state, 15,644 road segments were prioritized (Chapter 4); field surveys included 989 sites (sample size equal to 6% of those sites ranked 1 – 5) from 65 of 67 counties. An additional 243 sites visited were unranked in the model, but included significant physical features (e.g., bridges or other potential wildlife crossing structures) that were not considered in the prioritization process.

Land cover, derived from 1994 Landsat satellite data, was compared with recorded landscape characteristics for the 989 field sites statewide. Site verification revealed 115 misclassifications in the development classes. Sixty sites should have included urban (15) and exotic communities (46). Another 55 sites did not include rural residential; however, building density was likely too low, in most cases (e.g., single buildings sparsely arranged), to be detected at the 30 m resolution of the satellite data, or were simply classified as agriculture (that includes the farmhouse and associated buildings, etc.). Because of limitations in resolution these latter discrepancies were not included in the data assessment. Therefore 61 misclassifications from 989 sites represent a 6% error rate in land-use representation. Further analysis was conducted to determine the potential effect of this error rate on the prioritization process.

A comparison matrix (comprised of site rankings and scores for nine land-use features) that reflects extent of human disturbance and habitat degradation was created to measure accuracy of those sites selected as priorities. Land-use features considered and their respective scores include: man-made canals (Figure 3-1), railroads, power-lines, fences, access roads (Figure 3-2), or trails (1); presence of invasive plants (Figure 3-3), local human-use parks (Figure 3-4), low-intensity agriculture—pasture and pine plantation (3); low-density development—sparse residential, single retail buildings, etc. (5); high-intensity agriculture—mining operations, row crops, citrus, etc. (7); and high-density development—strip commercial, planned unit developments, industrial parks, etc. (10).

For purposes of this analysis, any disturbance value of 4 or less was considered minor; and therefore was an acceptable error level in the prioritization process. Percentage-of-disturbance scores equal-to or less-than 4, for each priority level, are shown below:

- priority-one—90% (n = 49)
- priority-two—89% (n = 96)
- priority-three—81% (n = 144)
- priority-four—86% (n = 222)
- priority-five—88% (n = 478)

Figure 3-1. One of the many canals adjacent to roadways in south Florida. Primary function of these canals is water management and flood control. They also compound the barrier and edge effects caused by roads for many species of wildlife.

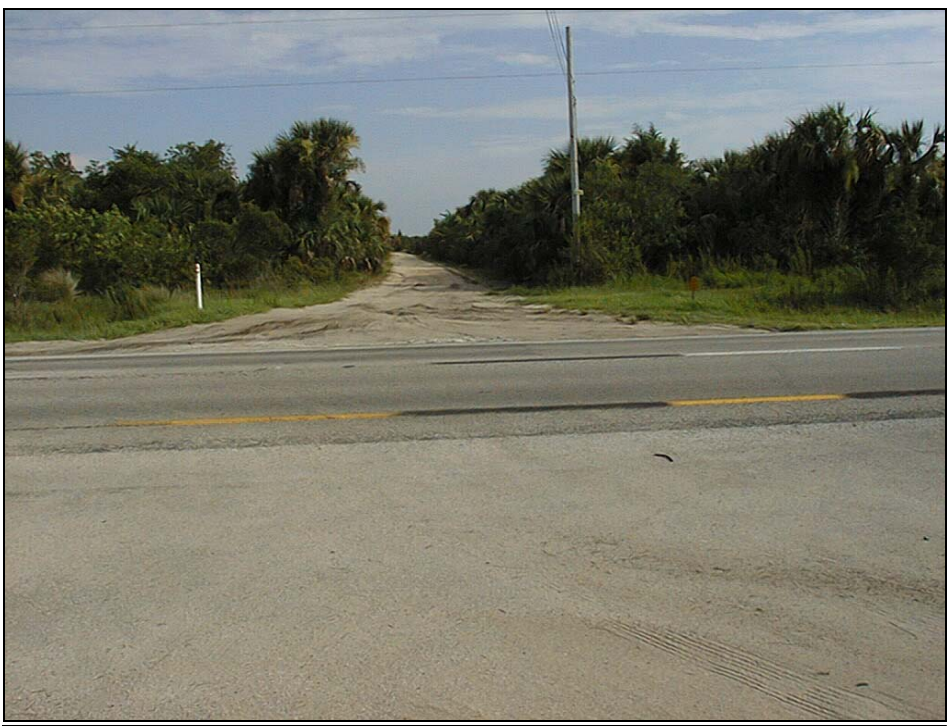


Figure 3-2. One of the many off-road access points. Throughout the state many primitive and substandard roads are present that provide access to public and private conservation areas. Some of these roads are managed for, but many are not. These elements add to potential disturbance for wildlife and ecological processes.

Figure 3-3. Spread of invasive plants. Roads are commonly known to advance the spread of invasive plants. In south Florida, three species are now quite common, Brazilian pepper (shown above), Melaleuca and Australian pine.

Figure 3-4. Active recreation in resource areas. In many conservation areas, public access parks are provided for outdoor recreation. Many of these are located near roads to provide boat access. Depending on intensity of human use allowed, disturbance to adjacent area can be substantial.

Figure 3-5 displays percent of the mean number of field sites measured on a scale of human disturbance (from 17 to 0; higher to lesser disturbance), for all model priority rankings of one to five. Based on field site disturbance scores of 4 or less, the prioritization process would, on average, accurately identify ecological hotspots on highways 87% of the time, with a 95% confidence level.

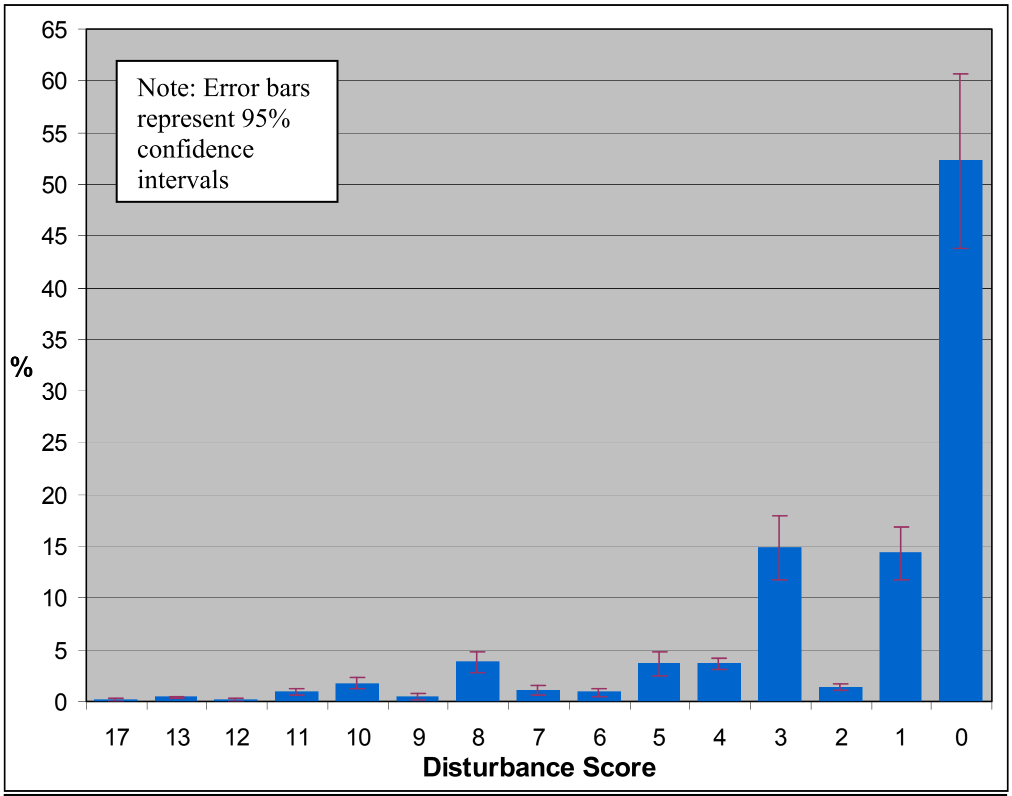


Figure 3-5. Percent of the mean number of field sites measured on a scale of human disturbance (17 = highest disturbance, 0 = lowest disturbance). A disturbance score of four or lower would be considered minor. As expected little difference in disturbance scores is evident between priority rankings for field sites. Of 989 total sites, on average, 10% (97) had scores greater than 5 and 87% (856) had scores less than 5.

The statewide field inventory and characterization of ecological hotspots on highways (Schaefer and Smith 1999) is presented according to FDOT districts (Figure 2-9).

District one

An inventory of 222 sites on 22 different highways was conducted in District 1 (Figure 3-6). Of the locations surveyed, 6 were priority-one sites, 25 were priority-two sites, 13 were priority-three sites, 43 were priority-four sites, and 82 were priority-five sites. Fifty-three of the sites inventoried were not ranked. Existing structures found among these sites included 5 ecopassages, 78 bridges, 37 concrete box culverts, 35 concrete pipes, and 4 corrugated steel pipes. Sixty-three sites did not have any drainage-control structures.

Of all sites checked, 59 were associated with the Big Cypress Area (includes the Big Cypress National Preserve, Florida Panther National Wildlife Refuge, Fakahatchee Strand State Preserve and Golden Gate Estates CARL), 29 cross the Peace River or its tributaries, 26 were within existing or proposed conservation-lands associated with the Myakka River, 14 were associated with C.M. Webb Wildlife Management Area, 10 were within the Lake Wales Ridge conservation area, 6 were adjacent to Collier-Seminole State Park, 6 were found within Charlotte Harbor Flatwoods CARL area, and 3 each were adjacent to Highlands Hammock State Park, Fisheating Creek, and the Kissimmee River.

The 6 priority-one sites surveyed contained the following adverse characteristics: 5 of 6 sites had adjacent man-made canals, one site exhibited invasive Brazilian pepper *Schinus terebinthefolius*, and another was adjacent to some strip development and a golf course. It should be noted that the canals were water control structures within Big Cypress National Preserve and Florida Panther National Wildlife Refuge. Signs of animal activity included multiple black-bear road-kills at 2 sites, 6 sites had single black-bear road-kills, and another site had one Florida panther and one black-bear road-kill.

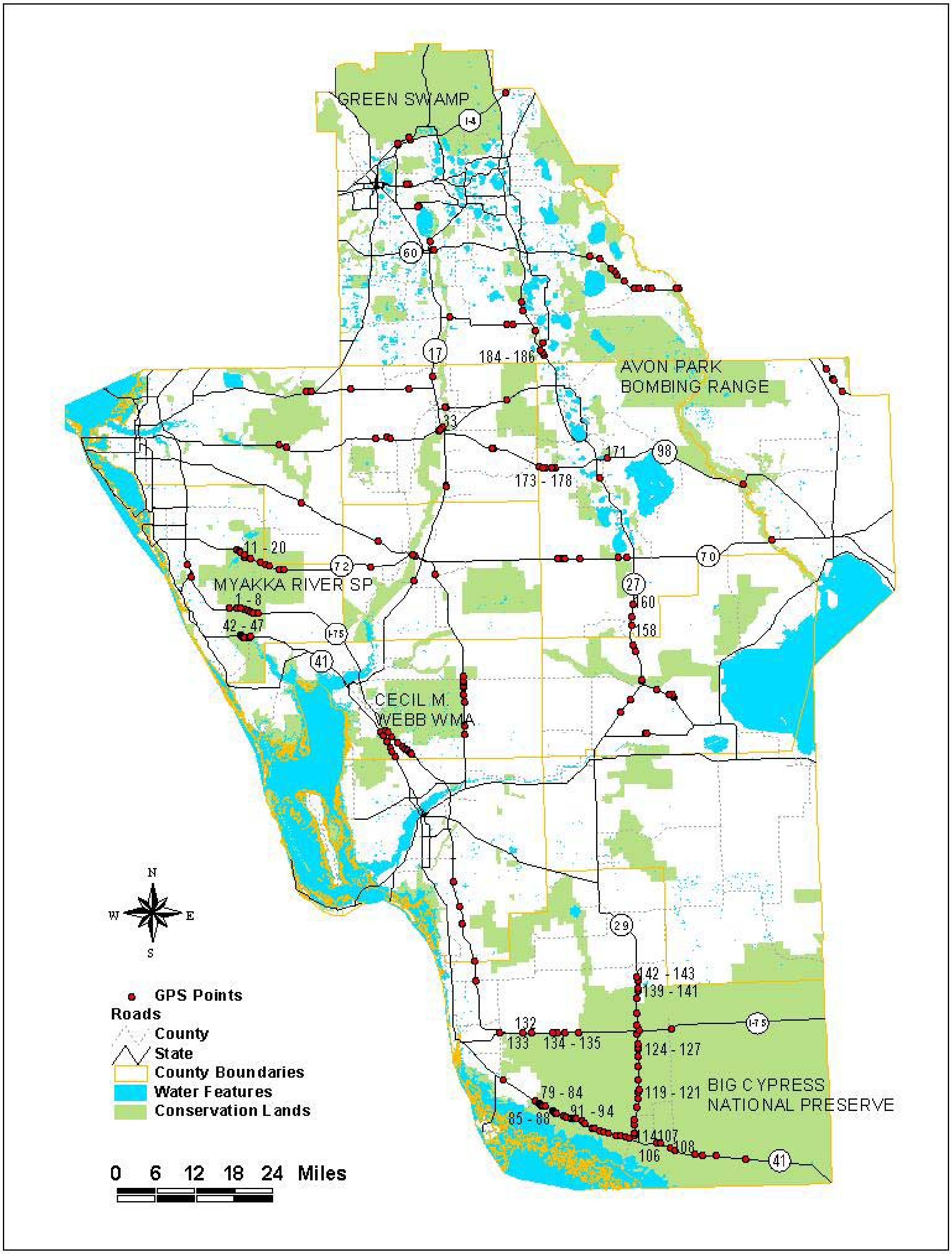


Figure 3-6. District 1 field verification sites. Of the 995 ecological hotspots on roads identified in the priority modeling process, 222 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

Characteristics negatively influencing ecological conditions at the 25 priority-two sites included: adjacent man-made canals at 18 sites, substantial development at one site, some low-intensity grazing lands at another site, presence of Brazilian pepper or Melaleuca *Melaleuca quinquinervia* at 5 sites, off-road vehicle access at 4 sites, and open trash receptacles at one site that has a road-side picnic area. Three sites had multiple black-bear road-kills, 15 had single black-bear road-kills, and another 3 sites had records of Florida panther road-kills. Habitat quality, other than the exceptions mentioned above, was quite good. Twenty-one of 25 sites are within the Big Cypress area.

On-site factors counterproductive to conservation efforts at the 13 priority-three sites include: presence of parallel canals at 8 sites, Brazilian pepper or other invasive plants at 2 sites, access roads at 3 sites, scattered rural-development at 3 sites, minor pasture lands at 2 sites and citrus at one other site. Two sites contained multiple black-bear road-kills, 7 had single bear road deaths, one site had 2 road-killed Florida panthers, and an unidentified dead snake was found at another.

The 43 priority-four sites visited contained the following adverse characteristics: 18 sites had adjacent man-made canals, 9 sites exhibited presence of invasive plant species, 5 sites had substantial residential and/or commercial development, 2 sites had single, combined business-residences nearby, and 4 sites had off-road vehicle access. Twelve sites had single, black-bear road-kills, one site had three bears killed, and another site had an unidentified dead turtle on the road.

The 82 priority-five sites included the following negative influences: 13 sites had adjacent man-made canals, 7 sites contained the invasive plants Brazilian pepper and Melaleuca, 12 sites had some low-intensity pasture, 1 site had citrus development and 3 sites had pine plantations, 8 sites had significant development adjacent or nearby including 2 housing developments, 3 mining operations and a prison, 5 sites had minor development sites including a marina, 2 local parks, a cemetery and a tourist shop, and 3 sites had off-road vehicle access. Seven sites had black-bear road-kills, 1 site had two dead alligators and one dead aquatic turtle, a dead gopher tortoise was found on the road at another site, 2 sites had road-killed snakes; one was identified as a red rat snake.

District two

Two hundred and eighty-eight sites were surveyed on 35 different roads (Figure 3-7). Number of field sites visited by model priorities of one to five in District 2 was 5, 5, 15, 51 and 143 respectively. An additional 69 significant, but unranked sites were also inventoried. Structures of various size, present at these sites include: 110 bridges, 89 concrete box culverts, 33 concrete pipes, 2 corrugated steel pipes, and 1 highway overpass. Fifty-three sites surveyed did not have any structures.

Majority of those sites inventoried were associated with conservation lands or riparian systems. A list of field sites by conservation area would include Alapaha and Withlacoochee Rivers (8), Aucilla River (7), Camp Blanding Military Training Site and Black Creek (13), Ocala National Forest and Cross Florida Greenway (8), Osceola National Forest (11), Jennings State Forest (6), Cedar Key Scrub State Preserve (6), Etonia Creek conservation area (7), Timucuan National Preserve area (9), Suwannee River Buffers (26), Pumpkin Swamp, Waccasassa River, Devil's and Gulf Hammock area (19), Lochloosa Wildlife Management Area, Newnan's Lake and Payne's Prairie State Preserve (39), Santa Fe River system (15), and the Steinhatchee River system (16).

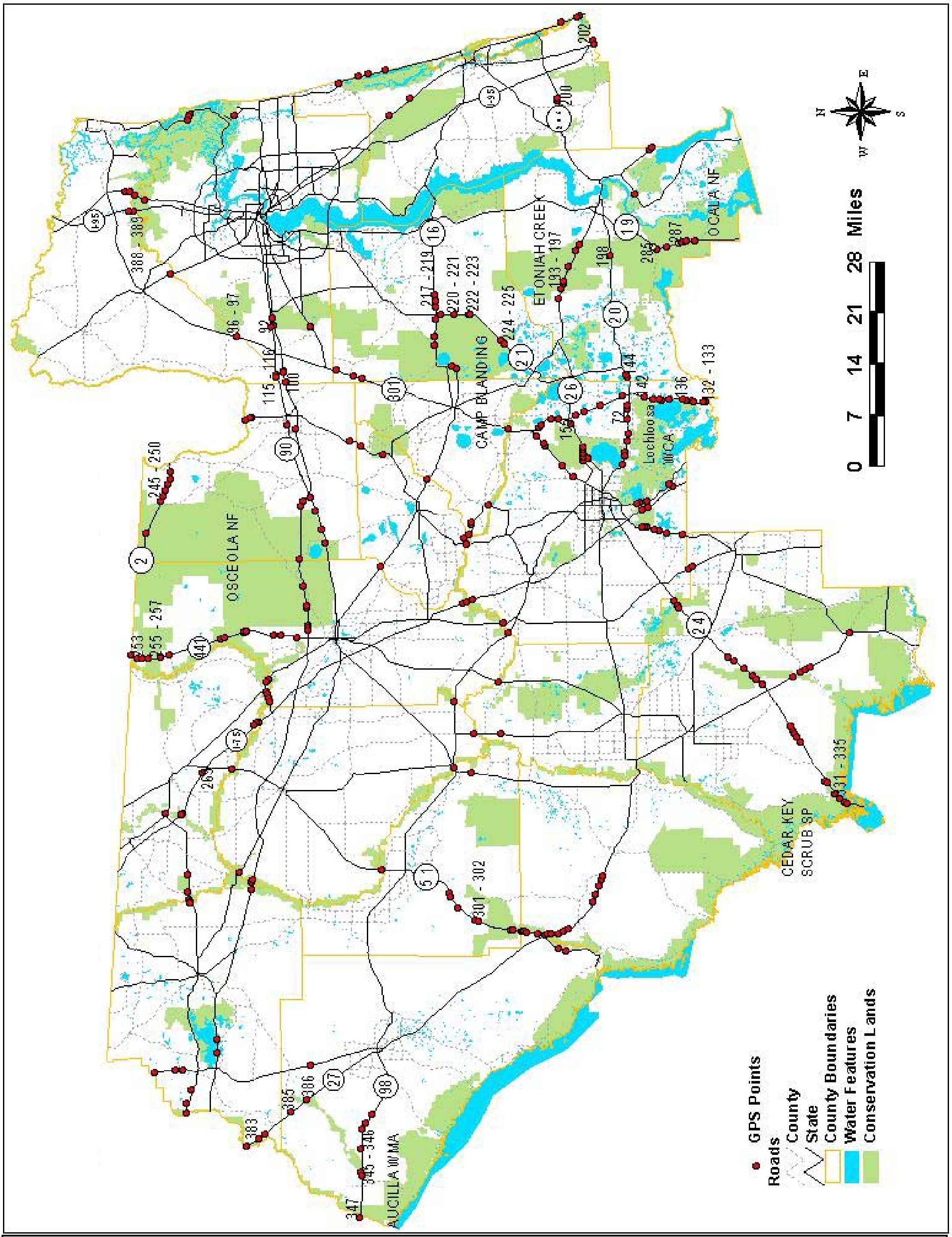


Figure 3-7. District 2 field verification sites. Of the 1,594 road segments identified in the priority modeling process, 288 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

Characteristics negatively influencing ecological conditions at the 5 priority-one sites were minimal. Some planted-pine areas were identified at all 5 sites and off-road vehicle access at 1 site. Each of the 5 sites included records of black-bear road-kills. Hardwood, cypress swamp and pine flatwood communities dominated all of these sites.

The 5 priority-two sites visited contained the following adverse characteristics: 1 site had a steep-walled canal (Cross-Florida Barge Canal), 1 site had a single residence, 3 sites had patches of planted pine, and 1 site had off-road vehicle access. Each of these sites included black-bear road-kill records.

The 14 priority-three sites surveyed contained the following adverse characteristics: 6 sites had parcels of pine plantation, 2 sites had scattered rural-residential, and another had a government-facilities building and a microwave tower. Habitat was high quality and certain sites consisted of sandhill and hardwood and cypress swamp communities. Eleven sites had black-bear road-deaths and one site had a dead, striped mud turtle.

For the 52 sites in category four, on-site factors contrary to conservation efforts include: 5 sites disturbed by access trails or dirt roads, railroad tracks at 3 sites, a powerline corridor at another site, scattered rural-development at 4 sites, 16 sites contained some planted pine, and minor pasture or crop lands at 4 sites. Ten black-bear road-kills occurred at 10 sites, one cottonmouth *Agkistrodon piscivorous* was sighted at another site, and multiple species of herpetofauna and small mammals were recorded in a research project at 2 other sites.

The 147 priority-five sites included the following negative influences: 3 sites had adjacent man-made canals, 1 site had an adjacent active railroad, 2 sites had some low-intensity pasture, 38 sites consisted partially of pine plantations, 5 sites have significant development adjacent or nearby (e.g., 1 housing development, 1 mobile home park, 2 marinas / fish camps, and 1 quarry), 15 sites have minor development (e.g., sparse rural-residential, 3 local parks, and a motel), and 5 sites have off-road vehicle access. One site had a black-bear death, an alligator was sighted at another site, and hog and deer bones were found at 2 other sites. Lastly, multiple species of herpetofauna and small mammals were sighted at 2 other sites.

District three

An inventory of 304 sites on 24 different highways was conducted in District 3 (Figure 3-8). Of the locations surveyed, 15 were priority-one sites, 13 were priority-two sites, 29 were priority-three sites, 64 were priority-four sites, and 107 were priority-five sites. Seventy-six additional sites surveyed were not ranked. Existing structures found among these sites included: 70 bridges, 49 concrete box culverts, 90 concrete pipes, and 5 corrugated steel pipes. Ninety sites did not have any drainage-control structures.

Of all sites checked, 52 were associated with the Apalachicola River system (includes the Apalachicola National Forest, Tates Hell State Forest, and Apalachicola River and tributaries), 11 were located in the Aucilla River Wildlife Management Area, 18 were in Blackwater River State Forest, 13 cross the Choctawatchee River or its tributaries, 4 were in existing or proposed conservation-lands associated with the Econfina River aquifer recharge area, 54 were located in Eglin AFB and the Yellow River area, 14 are along the Ochlockonee River corridor, 5 are in the Tall Timbers – Red Hills area, 15 were associated with Pt. Washington and Topsail Hill, 15 were within the Wakulla Springs – St. Marks National Wildlife Refuge area, and 5 were in Tyndall AFB.

Figure 3-8. District 3 field verification sites. Of the 2,822 road segments identified in the priority modeling process, 304 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

The 15 priority-one sites surveyed contained the following adverse characteristics: 4 sites had off-road vehicle access, 3 sites had clearcuts on pine plantations, and another was adjacent to a ranch and a tourist curio shop. Ecological communities included longleaf pine-turkey oak, hardwood forest, cypress swamp, and bottomland hardwoods. Recorded animal activity included multiple black-bear road-kills at 4 sites; and 10 sites had single black-bear road-kills.

Characteristics negatively influencing ecological conditions at the 13 priority-two sites were minimal. Some planted-pine areas were identified at 7 sites, off-road vehicle access was found at 4 sites, one site had a fire tower, and another had a single house. Each of the 13 sites included records of black-bear road-kills. Hardwood and cypress swamp, and pine flatwoods were the dominant communities.

The 29 priority-three sites included the following negative influences: 1 site had an adjacent active railroad, 12 sites consisted at least partially of commercial silviculture, 3 sites had minor development (e.g., one house, a boat ramp, and a shooting range), and 8 sites had off-road vehicle access. Typical native communities included sandhill, pine flatwoods, bottomland hardwoods, and several other wetland types. Two sites had multiple black-bear deaths; 22 others were sites of single mortalities from vehicle collisions.

The 64 priority-four sites visited contained the following adverse characteristics: 3 sites had railroads, 5 sites had boat ramps and/or small parks, 13 sites had parcels of planted pine, 1 site had a borrow pit, 2 sites had significant development (e.g., a shopping center and residential areas), 3 other sites had scattered rural-residential, and 5 sites had off-road vehicle access. Ecological communities include hardwood and cypress swamp, hardwood hammock, and longleaf pine forest. Thirteen sites had black-bear mortalities from vehicle collisions; 2 of these contain multiple deaths. Other road-kills found include a black vulture and a cottonmouth.

Characteristics negatively influencing ecological conditions at the 107 priority-five sites included: an adjacent man-made canal at 1 site, active railroads at 6 sites, scattered rural-development at 10 sites, pine plantations at 8 sites, off-road vehicle access at 13 sites, and boat ramps and / or recreation areas at 7 sites. Many of these land uses occurred at the same sites. Five sites had black-bear road-kills, and one site had a river otter road-kill.

District four

Characteristics of 77 field sites were documented on 11 different roads in District 4 (Figure 3-9). Number of field sites evaluated by model priorities (in parentheses) included 7(1), 18(2), 26(3), 13(4), and 10(5). Three additional but unranked sites were also inventoried. Structures of various size present at these sites included: 28 bridges, 27 concrete box culverts, 9 concrete pipes, and 1 corrugated steel pipe. Thirteen sites surveyed did not have any structures.

The number of field sites by conservation area are as follows: Blue Cypress conservation area (4), Cypress Creek SOR and Loxahatchee River—CARL, Preserve, and National Wildlife Refuge (15), Everglades buffer area (3), Ft. Drum conservation area (4), Indian River County Preserve and Padgett Marsh (4), Jonathon Dickinson State Preserve (4), Pal Mar, J.W. Corbett and Pratt-Whitney conservation areas (18), water conservation areas 2a and 3a (10), St. Sebastian River State Preserve (4).

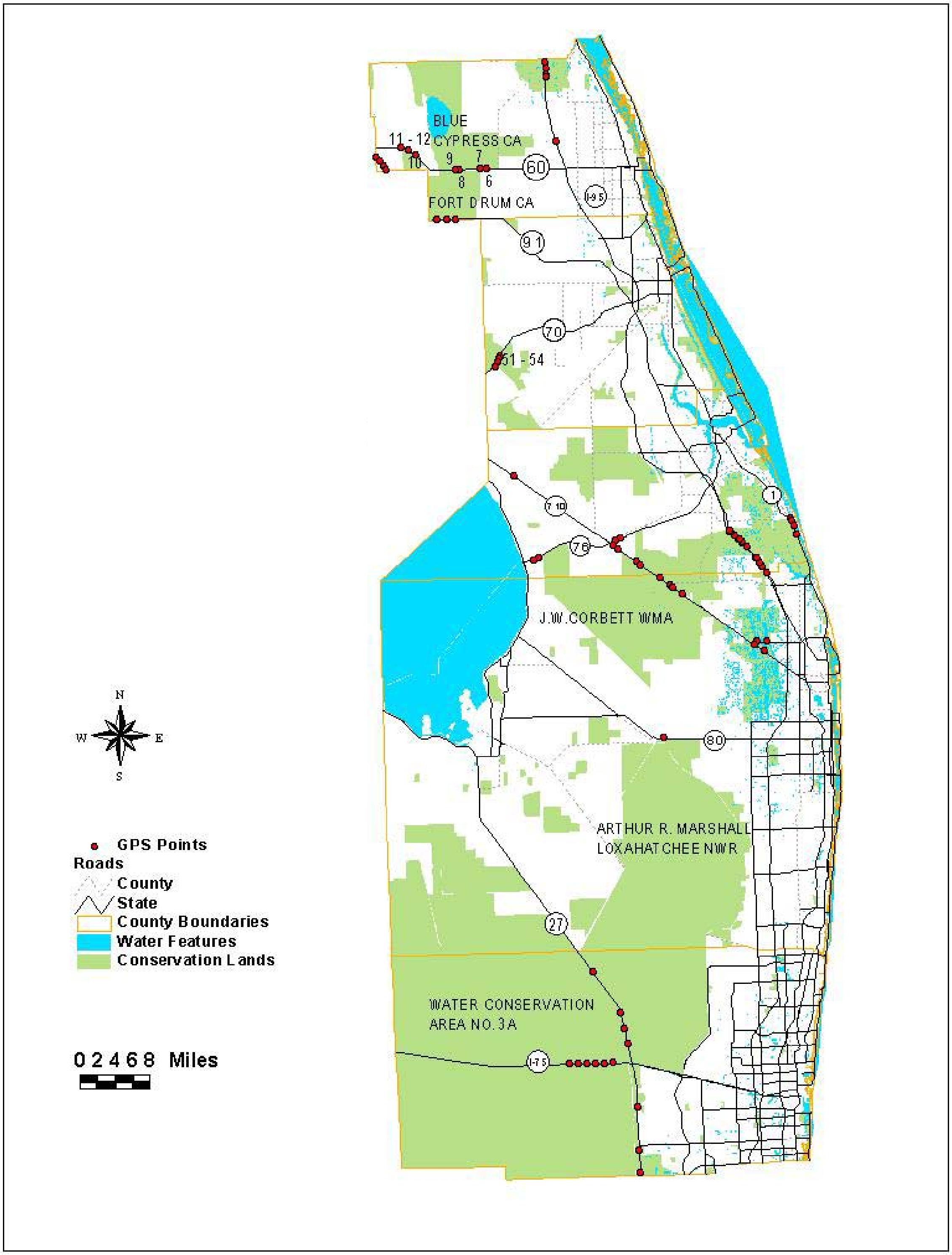


Figure 3-9. District 4 field verification sites. Of the 4,444 road segments identified in the priority modeling process, 77 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

The 7 priority-one sites included the following negative influences: 1 site had an adjacent man-made canal, 1 site had an adjacent active railroad, and 4 sites had invasive Melaleuca patches. Ecological communities present at these sites included sand pine scrub, coastal dunes, sawgrass marsh, cypress and hardwood swamp, hardwood hammock, and pine flatwoods. No signs of animal presence were found during visits to these sites.

The 18 priority-two sites visited contained the following adverse characteristics: 3 sites had adjacent man-made canals, 3 sites exhibited presence of invasive plant species (Melaleuca or Brazilian pepper), 1 site had substantial residential and improved pasture, 1 site was partially composed of citrus, and 4 sites had active railroad lines. One unidentified dead snake was found at one field site.

For the 26 sites in category three, on-site factors contrary to conservation efforts included: 11 sites disturbed by canals, some residential development and a local park at 1 site, 10 sites contained citrus groves, invasive Melaleuca was evident at 1 site, and another site had cattle grazing. Primary habitat at these sites was pine flatwoods, and flatwoods prairie with isolated cypress and hardwood swamps, and wet prairie.

The 13 priority-four sites visited contained the following adverse characteristics: 8 sites had canals, 1 site had an airboat marina, 3 sites had patches of invasive plants (i.e., Melaleuca, Brazilian pepper, and Australian pine), and 3 sites had cattle grazing. Ecological communities include hardwood and cypress swamp, hardwood hammock, and sawgrass marsh.

Characteristics negatively influencing ecological conditions at the 10 priority-five sites included: citrus development at 3 sites; man-made canals associated with all 10 sites; one site had a construction-debris landfill, an aggregate mine, and a turfgrass farm; invasive plants at 2 sites; and another had a boat ramp and local park. One site in Blue Cypress conservation area had multiple road-killed turtles; and another site had a road-killed bobcat.

District five

An inventory of 278 sites on 24 different highways was conducted in District 5 (Figure 3-10). Of the locations surveyed, 9 were priority-one sites, 28 were priority-two sites, 44 were priority-three sites, 30 were priority-four sites, and 120 were priority-five sites. Forty-seven of the sites inventoried were not ranked. Existing structures found among these sites included 66 bridges, 90 concrete box culverts, 47 concrete pipes, and 2 corrugated steel pipes. Seventy-four sites did not have any drainage-control structures.

Major conservation areas associated with field sites included: Three-Lakes Wildlife Management Area (19), Lake George CARL, Haw Creeks and Deep Creek (21), Econ-St. Johns Ecosystem including Seminole Ranch and Tosohatchee State Preserve (35), Micco Scrub (8), N. Indian River CARL (9), Ocala National Forest (47), Tiger Bay and Tomoka River (16), and the Wekiva River area (16).

The 9 priority-one sites surveyed contained few adverse characteristics: 3 sites had off-road vehicle access and 1 site had a local park. Ecological communities included sand pine-xeric oak scrub, hardwood forest, and cypress swamp. Recorded animal activity included multiple black-bear road-kills at 7 sites and 2 sites had single black-bear road-kills.

The 28 priority-two sites surveyed contained the following adverse characteristics: 6 sites had parcels of pine plantation, 2 sites had scattered

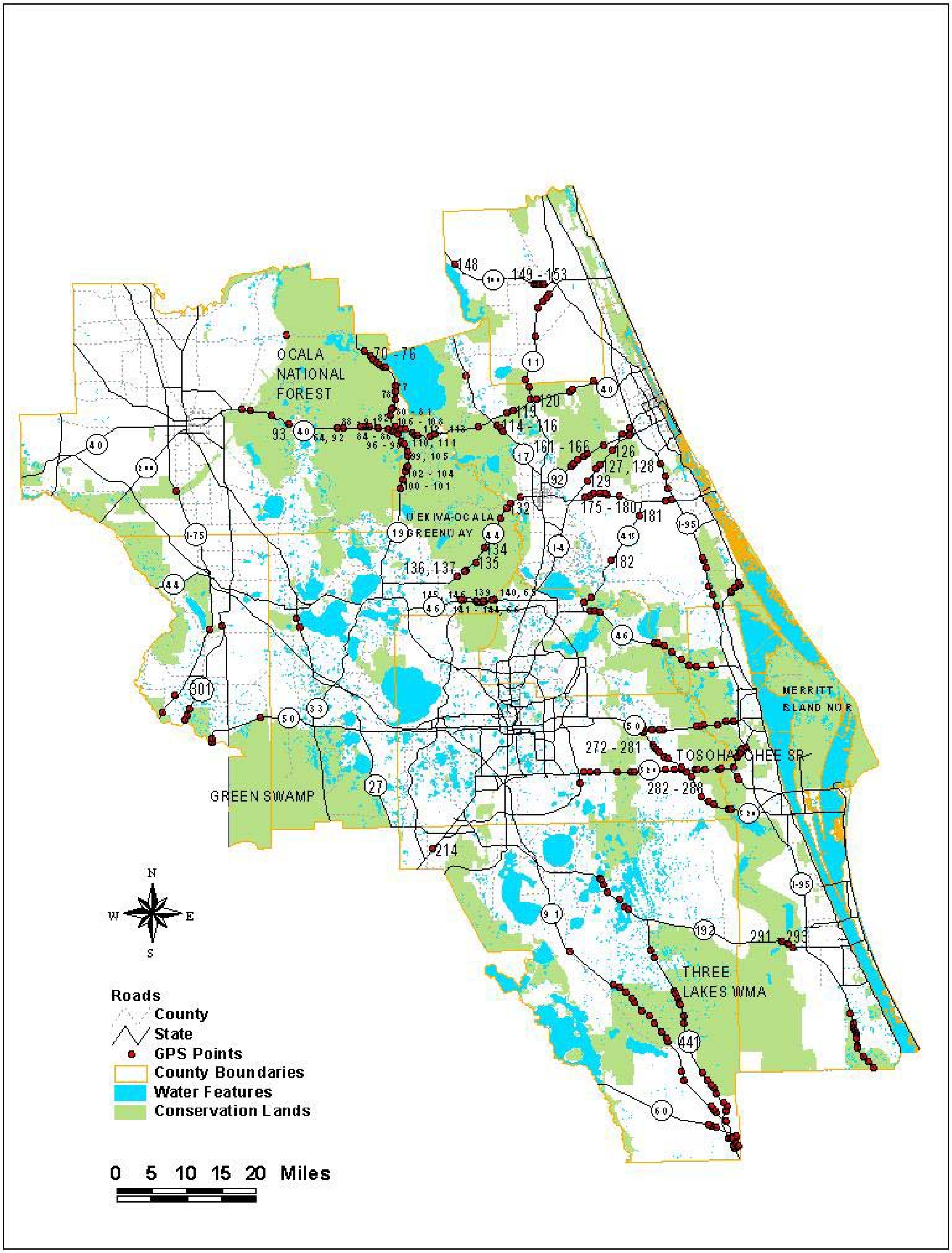


Figure 3-10. District 5 field verification sites. Of the 2,076 road segments identified in the priority modeling process, 278 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

rural-residential, one had some pasture, 4 sites had access roads, and 2 sites had railroad lines. Habitat was high quality and certain sites consisted of sandhill, xeric oak and sand pine scrub, and hardwood and cypress swamp communities. Twenty-seven sites had black-bear road-deaths, 19 of them had multiple deaths; and one site had a dead corn snake.

The 44 priority-three sites included the following negative influences: 2 sites had adjacent active railroads, 2 sites consisted at least partially of agricultural fields, 4 sites had minor development (e.g., scattered residential, one horse farm, and one small business), and 15 sites had off-road vehicle access, mostly forest-service roads. Eighteen sites had multiple black-bear deaths; 17 others were sites of single mortalities from vehicle collisions. One site had multiple snake road-kills.

For the 30 sites in category four, on-site factors contrary to conservation efforts included: 3 sites each disturbed by access roads and canals, powerlines at 1 site, 3 sites had minor development (e.g., a toll booth, scattered rural-residential, and a fish camp), 1 site each contained some planted pine and minor pasture. Multiple black-bear road-kills occurred at 1 site and single deaths occurred at 2 sites; and one unidentified turtle was found at another site.

The 120 priority-five sites visited contained the following adverse characteristics: 1 site each had an adjacent man-made canal or powerline corridor, 4 sites had active railroads, 2 sites exhibited presence of Brazilian pepper, 2 sites had substantial residential and/or commercial development, 3 sites had rural residential, one site had a single house, 2 sites had marinas, one site each had a rail-trail and a local park, and 7 sites had off-road vehicle access. Agriculture present at field sites included 7 with pasture, 4 agricultural fields, and 1 pine plantation. Three sites had single black-bear road-kills, 1 site had a road-killed bobcat, and 3 sites had multiple species road mortalities that included meso-mammals, snakes, a Black Vulture and a Barred Owl. At one site a river otter crossed the road; and 2 other sites had alligators in adjacent ditches. Swallowtail Kites, Wood Storks, and Caracara were also sighted at three sites.

District six

Eighteen sites were surveyed on U.S. Highway 1 (Figure 3-11). Number of field sites visited, by model priorities of one to five, was 1, 5, 5, 3, and 2 respectively. Two other significant but unranked sites were also inventoried. Structures present at these sites included 2 drawbridges and 2 corrugated steel pipes. Fourteen sites surveyed did not have any structures. Conservation areas where all field sites were located include Everglades National Park, Crocodile Lake National Wildlife Refuge, Key Deer National Wildlife Refuge – Cupon Bight CARL, and the Southern Glades SOR.

The 18 prioritized sites included the following negative influences: 1 site had an adjacent man-made canal, 1 site had an access road, 2 sites had adjacent intensive development (e.g., a hotel and marina, and other strip commercial businesses), and 5 sites had invasive Brazilian pepper and/or Australian pine. Ecological communities present at these sites included mangrove, salt marsh and tropical hardwood hammock. Signs of wildlife found included road-kills at separate sites: 3 juvenile alligators, 1 juvenile crocodile, and recorded occurrence of multiple key-deer deaths from vehicle collisions.

District seven

Characteristics of 46 field sites were documented on 12 different roads in District 7 (Figure 3-12). Number of field sites evaluated by model priorities (in parentheses)

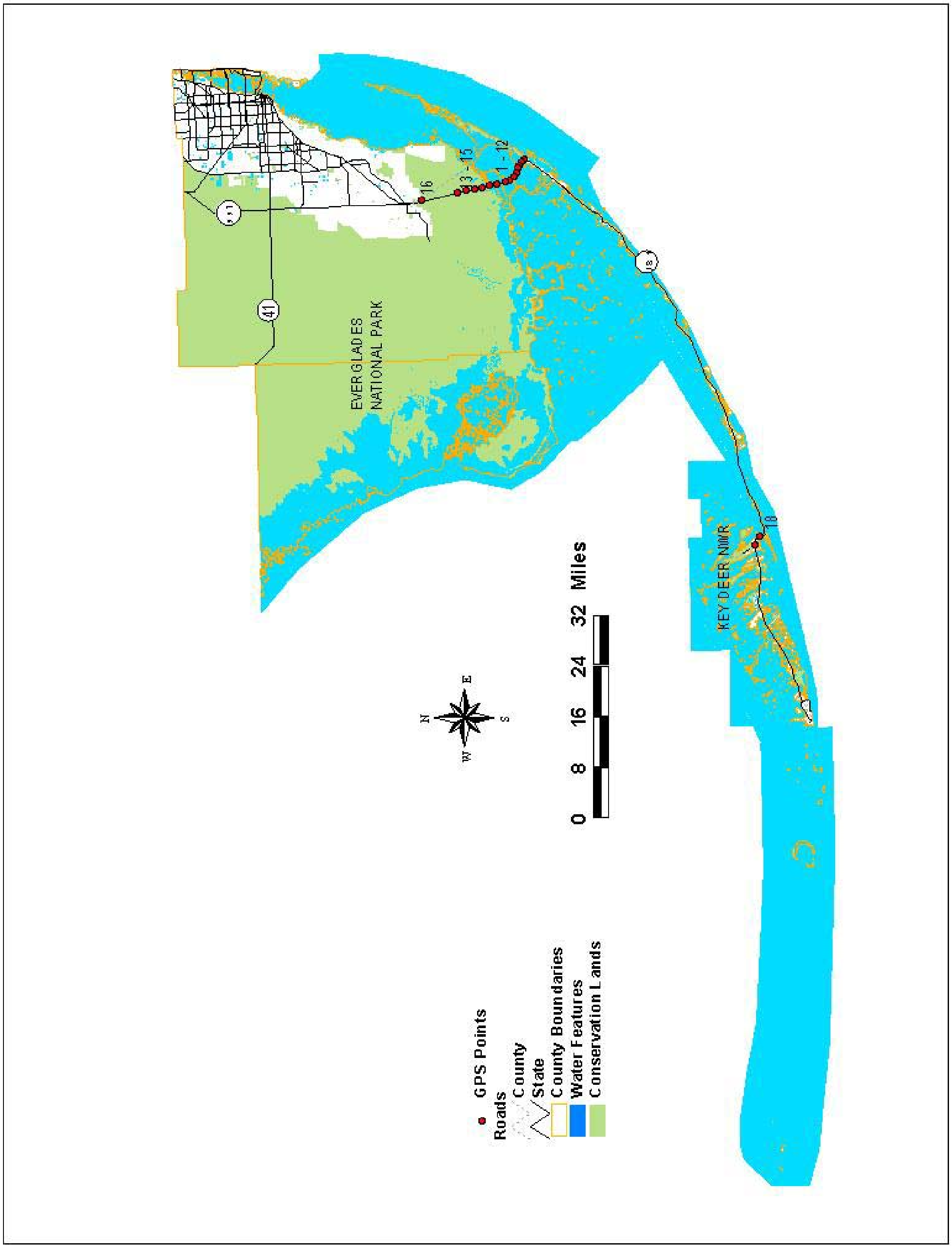


Figure 3-11. District 6 field verification sites. Of the 143 road segments identified in the priority modeling process, 18 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed Appendix C).

included 6(1), 1(2), 12(3), 17(4), and 9(5). One additional but unranked site was also inventoried. Structures of various size present at these sites included 21 bridges, 4 concrete box culverts, 9 concrete pipes, and 1 corrugated steel pipe. Eleven sites surveyed did not have any structures.

A list of field sites by conservation area would include Annutteliga Hammock CARL and Chassahowitzka Wildlife Management Area (9), Withlacoochee River and tributaries and Withlacoochee State Forest (10), Hillsborough River State Park and Green Swamp SOR (7), and Little Manatee River SOR (5).

The 7 priority-one and priority-two sites surveyed contained the following adverse characteristics: 1 site had a junkyard, 1 site had an abandoned house, and 5 sites had access roads. Habitat was high quality and most sites consisted of longleaf pine sandhill or hardwood hammock and swamp. No signs of wildlife activity were found.

For the 12 sites in category three, on-site factors contrary to conservation efforts included: 2 sites each disturbed by access roads and railroads, 2 sites had scattered rural-residential, 2 sites had substantial development (e.g., a racetrack and a golf club), and 3 sites contained some planted pine. Typical native-plant communities included wet and dry prairie, and hardwood hammock and swamp. Multiple hog road-kills occurred at 1 field site.

The 17 priority-four sites included the following negative influences: 1 site consisted partially of citrus groves, 2 sites had significant urban development, 2 sites had minor development (e.g., a park and canoe launch, and one house and a small business), and 2 sites had recreational trail access. Dominant habitat types were mixed hardwood and cypress swamp. A road-killed turkey vulture was found at one site.

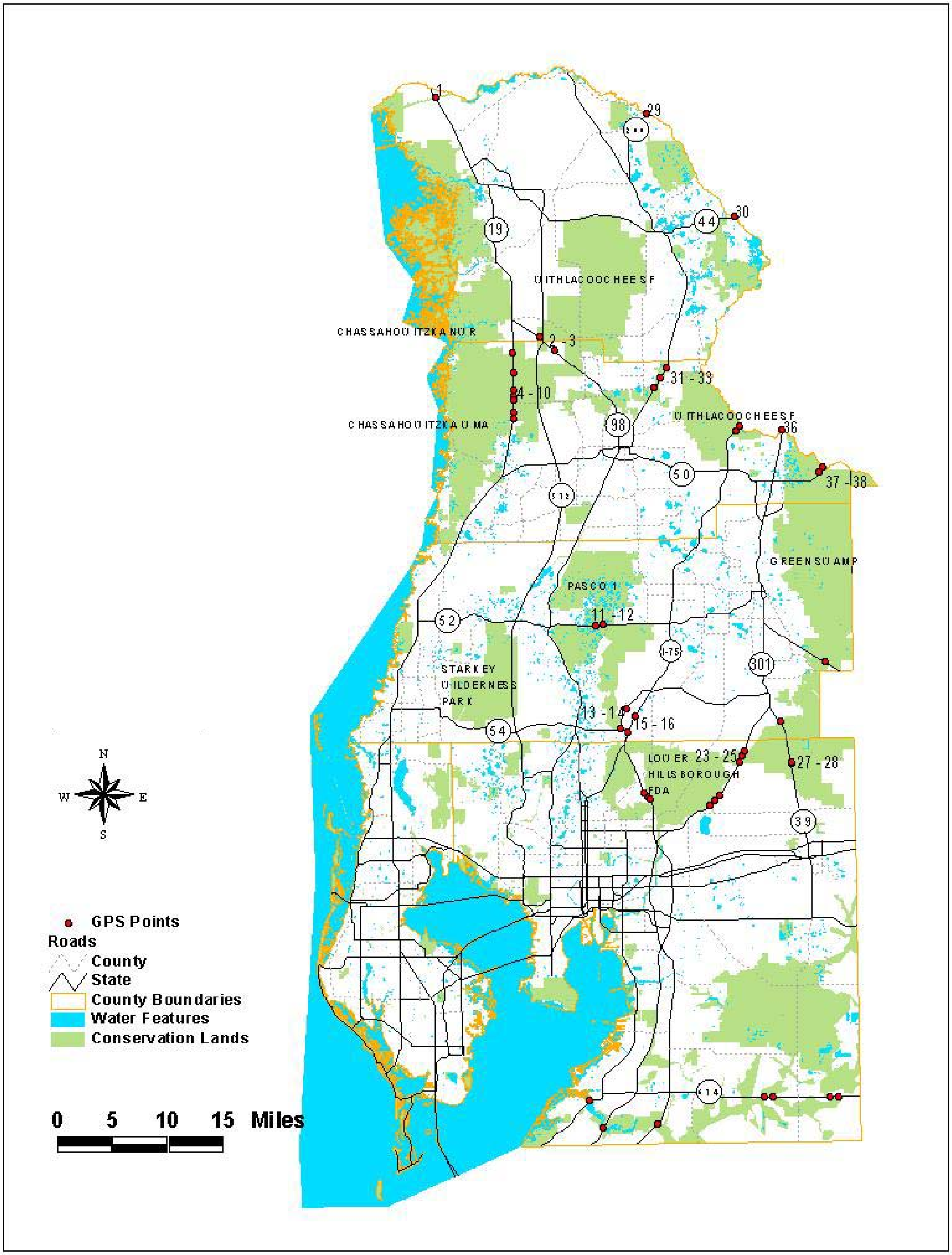


Figure 3-12. District 7 field verification sites. Of the 2,504 road segments identified in the priority modeling process, 46 field sites were inventoried and landscape characterization performed. Recommendations for corrective measures necessary to maximize permeability for wildlife were provided on the numbered locations displayed (Appendix C).

Characteristics negatively influencing ecological conditions at the 9 priority-five sites included: urban development at 1 site, access roads associated with 4 sites, one site had a man-made canal, and another site had scattered residential. Dominant habitat types were pine flatwoods, hardwood hammock, and hardwood and cypress swamp. Wood storks were seen at one site.

Recommended Actions to Improve Functional Habitat Connectivity: Retrofitting "Highway Hotspots"

The data presented below includes those road segments from each FDOT district with the greatest need for on-site mitigation. The locations discussed are not in any rank order of importance. Further ranking of these sites is recommended through discussion with various state agency officials, researchers, and other parties with expertise on highway-wildlife issues. Such discussion must address factors associated with species-specific needs, large-scale conservation objectives, and economic limitations; and be able to weigh any such factors that conflict. The sites identified herein are generally associated with large-scale or regional, conservation objectives. As such, there may be localized situations beyond the scope of this research that require greater immediate attention.

District one

Seventy-two sites on ten different highways were evaluated in District 1 (Appendix C, Figure 3-6). Existing structures found among these sites included 21 bridges, 11 concrete box culverts, 12 concrete pipes and 2 steel corrugated pipes. Twenty-six sites did not have any drainage-control passageways.

Of all sites evaluated, 32 were associated with the Big Cypress Area (includes the Big Cypress National Preserve, Florida Panther National Wildlife Refuge, Fakahatchee Strand State Preserve, Collier-Seminole State Park and Golden Gate Estates CARL).

Appendix C lists recommendations for 11 locations on three roads: US 41, SR 29, and I-75. Suggested measures include expansion of existing bridges (Figures 3-13a and 3-13b), construction of new ecopassages, installation of barrier fencing, (Figures 3-14 and 3-15) and straightening blind curves to increase driver visibility (Figure 3-16 displays one such instance).

Figure 3-13a. Bridge over stream on US 41 near Collier-Seminole State Park. This is an example of an old "floodway" bridge that only allows for water flow. When scheduled for replacement, retrofits should include an extension with an adjacent terrestrial connection along the stream under the bridge. Black bear – vehicle collisions have been recorded at this particular site. Lengthening this bridge could correct the conflict.

Twelve sites were located along the Lake Wales Ridge and Fisheating Creek on US 27, US 98, and SR 66 (Appendix C). Critical needs for this area were associated with the local black-bear population, and included recommendations to secure protected habitat-corridors and construct underpasses.

Figure 3-13b. New bridge on SR 72 over Horse Creek, a tributary of the Peace River. This recent bridge replacement includes a wide terrestrial connection adjacent to the stream; and allows for wildlife movement under the bridge that reduces opportunities for vehicle collisions.

Twenty-four sites were within existing or proposed conservation-lands associated with the Myakka River (Appendix C). Recommendations for improvements on I-75, US 41, and SR 72 included purchase of adjacent resource areas and expansion of existing structures. Appendix C details scheduled bridge replacements and recommends enhancements for wildlife use.

Regarding the Peace and Kissimmee rivers, work programs should include longer bridge spans when replacements are scheduled; examples include the bridges on U.S. 17 over the Peace River at Zolfo Springs (Figure 3-6, Site No. 33) and SR 60 over the Kissimmee River (Figure 3-6, Site No. 196). Bridge replacements within these riparian corridors should include terrestrial linkages above the high water mark that accommodate movement by wildlife restricted to dry habitats.

Figure 3-14. One of the wildlife underpasses constructed on I-75 in the Big Cypress National Preserve. The directional / barrier fence is 3 m high chain link with barbed wire. The native vegetation provides open character and good visibility for larger wildlife and lower protective cover for smaller organisms.

Development along the Lake Hancock – Saddle Creek – Green Swamp greenway severely threatens remaining habitat areas. To realize the objective of the Statewide Greenways Project to provide linkages across Interstate 4, immediate action is necessary to secure protection for the corridor. FDOT should consider constructing new wildlife underpasses and incorporating wildlife considerations along creek bridges on I–4 if this linkage is established.

District two

Fifty-eight sites on 18 different highways were evaluated in District 2 (Appendix C, Figure 3-7). Existing structures found at these sites included 23 bridges, 14 concrete box culverts, and 7 concrete pipes. Fourteen sites had no drainage-control passageways.

Figure 3-15. Wildlife Exclusion Fence on SR 29 in Collier County. The 3 m high chain link barrier fencing with barbed wire was designed to prevent Florida panthers from entering the roadway. The fence runs parallel to the roadway for the entire section of road between two wildlife underpasses.

Figure 3-16. Blind curve on State Road 29 in Collier County. These elements in road corridor design present special risks to wildlife attempting to cross the road. The inability of motorists to see what is around the curve on high-speed rural roads lead to many vehicle – wildlife collisions.

The Ocala National Forest – Cross-Florida Greenway – Etonia Creek CARL region contained 9 sites on 3 roads (SR 19, SR 20, and SR 100) evaluated for retrofits (Appendix C). Suggested measures include lengthening existing bridges, replacing small pipes with larger box culverts (Figures 3-17a, 3-17b and 3-17c), constructing new ecopassages, permeating bridge approaches (berms) with additional culverts (Figure 3-18), and installing barrier fencing.

Figure 3-17a. Depression site on SR 100 in the Etonia Creek CARL area in Putnam County. This site has approximately 2.5 m clearance between the road surface and the floor of the existing pipe culvert. Opportunity exists to retrofit this site with a larger structure to accommodate safe travel for larger wildlife such as black bear and deer.

Appendix C provides information on a priority-one site on SR 206 in the Fish Swamp WMA and Twelve Mile Swamp CARL area. A small culvert at the site provides insufficient permeability for a high incidence wetland corridor (Figure 3-19a and 3-19b). Road-kills included black bear and multiple herpetofauna. Recommended corrective measures include a large animal ecopassage and exclusionary barrier system.

Figure 3-17b. Side view of existing culvert. Dimensions of this concrete pipe are 0.6 m wide x 21.6 m long. Situated at the bottom of the depression shown in Figure 3-17a, erosion has partially blocked the structure; and combined with the small size leaves little opportunity for movement by wildlife.

Figure 3-17c. Box culvert at ephemeral creek site on SR 100 in the Etonia Creek CARL area in Putnam County. This site has similar topographic relief to that shown in Figure 3-17a; only in this case a three cell concrete box culvert (each cell is 2.1 m wide x 1.8 m tall x 21.6 m long) was installed. Most times this structure is at least partially dry and allows for movement by larger wildlife species.

Figure 3-18. Bridge approach on State Road 100 at Palmetto Branch in Putnam County. When construction of longer bridge spans is not possible, approaches such as the one shown here, consisting of fill, should be perforated with smaller culverts to increase landscape connectivity and provide greater opportunity for safe movement by wildlife.

Four sites on US 90 and I-10 were located in the St. Mary's River corridor – Cary and Jennings State forests area (Appendix C). Two bridges scheduled for replacement need to accommodate passage by black bears, and barrier fencing needs to be erected at two other sites.

Camp Blanding Military Training Site is the location of 7 sites on SR 21 and SR 16 (Appendix C). Addition of two wildlife passages for black bears on SR 16 west of Black Creek and wildlife fencing; sites on SR 21 need retrofits with larger ecopassages. Appendix C contains recommendations for 6 sites on SR 20, SR 26, and US 301, located in the Lochloosa Forest conservation easement – Newnan's Lake CARL – Cross Florida Greenway area. Suggested improvements include replacing the Lochloosa and Orange Creek bridges with longer and higher spans (similar to that constructed on SR 46 at

Wekiva River). Other measures needed include elimination of a blind curve and retrofitting small box culverts with larger ecopassages.

Figure 3-19a. State Road 206 crossing through the Fish Swamp CARL area. This highway – greenway interface was the highest ranked site in St. Johns County, it forms the linkage between Twelve-mile Swamp to the north, St. John's River to the west, and Pellicer Creek and the Flagler County Greenway to the south. It is a known movement corridor for black bears, as documented by collisions with vehicles.

On SR 24 in Cedar Key Scrub State Preserve, a 6.5 km road segment requires investigation on road mortality and barrier effects to scrub fauna and elimination of off-road vehicle disturbance (Appendix C, Figure 3-20). Six sites were located on US 98 and US 27 in the area from the Aucilla River WMA to the Econfina River corridor (Appendix C). Corrective measures recommended include retrofitting ineffective existing structures with more permeable designs and adding wildlife fencing. The Pinhook Swamp – Osceola National Forest – Suwannee River area contains 11 sites on three roads, US 441, SR 2, and I-10 (Appendix C). Suggestions to increase permeability at these sites include bridge replacements with designed ecopassages and installation of new underpasses and fencing to prevent black-bear road-kills. Appendix C contains recommendations for scheduled bridge replacements on SR 51 and US 301.

Figure 3-19b. Concrete Box Culvert Present at Unknown Creek at the Fish Swamp Site. This small aquatic cross drain is obviously inadequate to accommodate large species such as black bear and white-tailed deer.

Other road projects that require investigation for wildlife retrofits include: 1) Interstate 95 (add lanes) over the Nassau River corridor (Figure 3-7, Site Nos. 388 and 389), Twelve Mile Swamp and Pellicer Creek (Figure 3-7, Site No. 202), 2) U.S. 17, St. Mary's River bridge replacement, 3) ALT U.S. 27 (add lanes) crossing through the Devil’s Hammock – Waccasassa Flats Greenway, and 4) the Florida Turnpike extension adjacent to Goethe State Forest.

District three

In District 3, 73 sites on 12 different highways were evaluated (Appendix C, Figure 3-8). Existing structures found among these sites included 6 bridges, 9 concrete box culverts, and 25 concrete pipes. Drainage-control structures were not present at 33 sites.

Figure 3-20. State Road 24 crossing through the Cedar Key Scrub State Preserve. Damage to adjacent habitat occurs from all terrain vehicles that access the preserve area from the highway.

Fourteen sites were located in the Aucilla Wildlife and Water Management Area on US 27 and US 98 (Appendix C). Corrective measures recommended include replacing existing substandard structures with underpasses (accompanied by high-level fencing for black bears). The Wakulla Springs State Park – St. Marks NWR area has 7 sites on two roads, SR 267 and US 98 (Appendix C). Suggested improvements include purchase of adjacent CARL lands (to establish a protected corridor) and installation of underpasses. Appendix C contains recommendations for improvements to 23 sites on US 98, SR 71, and SR 65 in the Apalachicola National Forest – Tates Hell SF / CARL – Apalachicola River WMD project areas. Three separate measures are suggested for these sites: realign roads to reduce severity of curves, close certain access roads, and install underpass/high-level fence systems. Tyndall AFB has one site on US 98 where multiple black-bear deaths have occurred (Appendix C). Considerations include side road removal and improvements to increase driver visibility (Figure 3-21).

Figure 3-21. U.S. Highway 98 crossing through Tyndall Air Force Base in Bay County. Multiple black bear road-kills have occurred at this site. Although exact circumstances of the collisions are unknown, probable causes are high speed, reduced driver visibility (due to proximity of dense vegetation in the verge and the curve in the road), and increased traffic from the intersection.

Eglin Air Force Base contains 19 sites on SR 85, SR 87, SR 123, and I-10 (Appendix C). Primary measures needed to improve permeability at these sites include reducing curve severity, perforating high roadbeds with box culverts, and constructing wildlife underpasses on I-10 along the Yellow River Ravines CARL corridor. Appendix C contains recommendations for improvements at other greenway linkages and scheduled road projects on SR 20, SR 22, US 98 and US 331.

District four

Eleven sites on 2 different highways were reviewed in District 4 (Appendix C, Figure 3-9). Existing structures found among these sites included 6 bridges and 2concrete box culverts. Three sites did not have any drainage-control passageways.

Seven sites, located on SR 60, are associated with the Blue Cypress SOR, Kissimmee River SOR, and Ft. Drum Marsh WMD lands (Appendix C). Corrective measures needed at these sites include perforating high roadbed areas with box culverts, lengthening existing bridges scheduled for replacement, and construction of new underpasses. Appendix C contains data on 4 sites within the Cypress Creek CARL area. Recommendations include scheduled replacement of existing low-level bridges and box culverts with underpasses and exclusionary fencing for wildlife.

District five

Evaluations were performed on 104 sites on 11 different highways in District 5 (Appendix C, Figure 3-10). Existing structures included 12 bridges, 31 concrete box culverts, 17 concrete pipes, and 1 corrugated steel pipe. Forty-four sites did not have any drainage-control passageways.

Thirty-nine sites are in the Ocala National Forest on SR 19, SR 40, and CR 42 (Appendix C). Primary impacts to address are chronic road-kill sites of black bears due to blind spots for drivers created by hills and curves (Figure 3-22). Corrections include straightening and leveling the road alignment and installing wildlife underpass/fence systems.

Appendix C contains information on 5 sites on SR 44 within the Lake Woodruff NWR, Hontoon Island State Park, and Wekiva River Basin – Ocala greenway SOR lands.

Figure 3-22. State Road 40 crossing through Ocala National Forest. Multiple black bear road-kills have occurred at this site. Although precise circumstances of the collisions are unknown, probable causes are high speed, reduced driver visibility (due to hills and curves in the road), and increased traffic levels near the entrance to Juniper Springs Recreation Area.

Recommendations include securing conservation easements and adding underpasses in strategic locations to maintain the connection between Ocala NF and the Wekiva River Basin. State Road 46 that bisects the Wekiva River State Park and Seminole State Forest has 10 sites where retrofits are suggested (Appendix C). Purchasing lands, or securing conservation easements south of SR 46 on the western side of the Wekiva River is essential to preserve linkages along the river (Figure 3-23). Other measures include eliminating "S" curves, constructing additional underpasses, and extending high-level fences.

Appendix C provides data for 5 sites on US 17 and SR 40 in the Lake George State Forest and Haw Creek WMD project area. Corrective measures, such as purchasing development rights and replacing small culverts with large mammal underpasses, are needed to maintain connection to the Ocala National Forest and St. John’s River.

Figure 3-23. Wekiva River conservation lands for sale. Probably more critical than retrofitting roads is the need to secure valuable conservation linkages before they are developed. This river frontage is one corner of the recently constructed black bear passage on SR 46. If developed it could render the road mitigation meaningless and a waste of approximately $1 million in taxpayer dollars.

Appendix C includes 18 sites on I-4, US 92, SR 44, and SR 415 in Tiger Bay State Forest, Deep Creek Swamp, and other proposed greenway lands north of the St. John's River. Existing small culverts (at these sites) need to be replaced with large underpasses to increase functional connectivity for wildlife, especially regarding Interstate 4. Establishing conservation corridors is critical in the rapidly developing SR 415 area. Several programmed road projects in District 5 should include retrofits for wildlife along important riparian corridors.

District six

Seventeen sites on U.S. Highway 1 were evaluated in District 6 (Appendix C, Figure 3-11). Existing structures found among these sites included 2 draw bridges and 2 corrugated steel pipes. Fourteen sites did not have any drainage-control structures.

Sixteen of these sites are within Everglades National Park, Model Lands Basin and Southern Glades SOR, or the Crocodile Lake NWR (Appendix C). Recommendations include perforating the roadbed and installing several aquatic culverts to accommodate movement by the endangered American crocodile (Figure 3-24a and 3-24b).

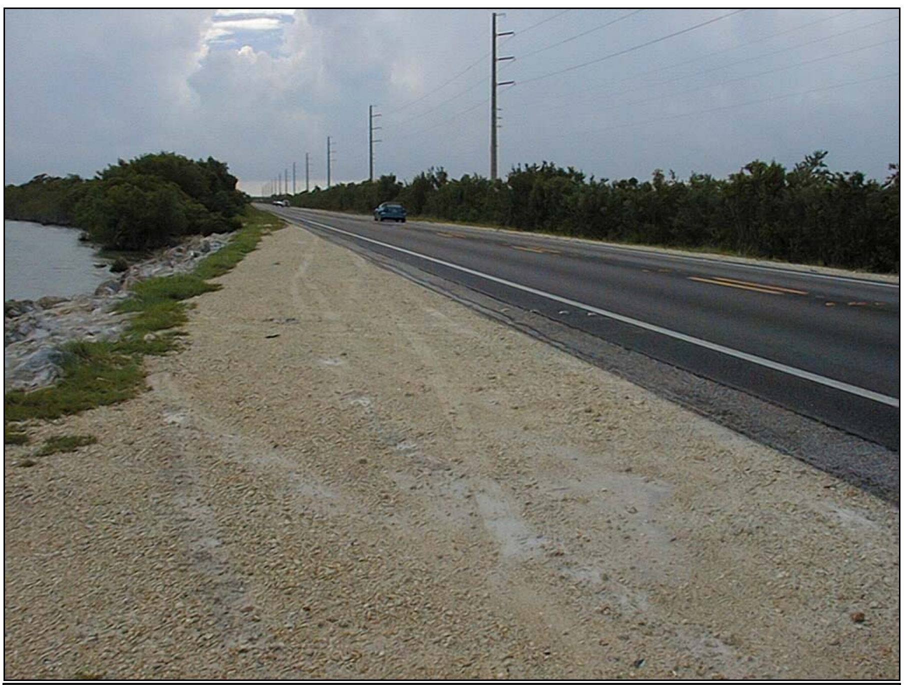


Figure 3-24a. U.S. Highway 1 crossing through Crocodile Lake National Wildlife Refuge. The highway bisects critical mangrove and tidal salt flats and marshes used by the endangered American crocodile. Only two 1.5 m wide corrugated steel pipe culverts exist along the 10 km of highway between the mainland and the Jewfish Creek Bridge on Key Largo.

Appendix C contains information on the other sites on US 1, which are associated with one of the following: Big Pine Key, Key Deer National Wildlife Refuge, Cupon

Bight CARL project, Bahia Honda-, Long Key-, and John Pennekamp- State Parks. Top priority is acquisition of the Cupon Bight habitat area (for the endangered Florida Key deer) and retrofits to US 1 (to eliminate the road mortality problem) (Figure 3-25).

Figure 3-24b. A juvenile American crocodile encountered during field surveys. A consequence of the road barrier is collisions with vehicles when the crocodilians attempt to cross from one side to the other.

District seven

In District 7, 29 sites on 11 different highways were assessed (Appendix C, Figure 3-12). Existing structures at these sites included 9 bridges, 3 concrete box culverts, 6 concrete pipes, and 1 corrugated steel pipe. Ten sites did not have any drainage-control passageways.

Appendix C includes field sites on three roads (US 19, US 98, and the Suncoast Parkway) that cross through the Chassahowitzka NWR / WMA and Annuteliga Hammock CARL project. Suggested improvements include increasing driver visibility (either through vegetation management near intersections, or removal of access roads and curves in highways) and installation of wildlife passages designed for black bears.

Figure 3-25. U.S. 1 passing between Cupon Bight and Big Pine Key. This is a critical section of road that the Florida key deer use to move between the two remaining primary habitat areas. Over 50 individuals die annually on this 3 km section of road from collisions with vehicles.

The Withlacoochee State Forest provides the setting for 6 sites on 3 roads: US 41, SR 50, and US 301 (Appendix C). Two issues to be addressed include securing habitat connections and fragments that remain unprotected (between existing forest lands and the Chassahowitzka NWR), and replacement of existing culverts with larger suitable wildlife underpasses. Appendix C lists 6 sites on SR 52, SR 54, and I-75 within the Cypress

Creek corridor, Pasco SOR lands, and lower Hillsborough River WMD lands. Suggested improvements include installation of larger box culverts (to increase permeability at wetland sites), and coordinating wildlife considerations with scheduled bridge replacements. Five sites of concern in the Hillsborough State Park, Hillsborough River corridor (SOR), and Blackwater Creek area are located on US 301 and SR 39 (Appendix C). Corrective measures needed include a new wildlife underpass and a longer span installed at one scheduled bridge replacement location.

Other suggested highway improvements for District 7 sites on US 19, SR 200, SR 44, SR 52, US 41, and the Suncoast Parkway are summarized in Appendix C. These sites are associated either with the Withlacoochee River or the Starkey Wilderness Area.

Value of Existing Infrastructure

Certain existing highway structures can serve as ecopassages and provide significant benefits over new structures including:

- Minimum modifications or construction necessary
- New construction cost savings
- Many existing structures are effective for facilitating wildlife movements/dispersal (Chapter 4)

Value of existing bridges that function as wildlife ecopassages and costs to retrofit those structures that require expansion (to provide the same ecological benefits) can be quantified. Recent bridge replacement costs were compiled to establish baseline values for construction materials. The average rates were then used to estimate costs to implement wildlife retrofits.

Determining Bridge Replacement Costs

An analysis was performed for 15 bridges recently constructed or bidded out. Structure variation for calculations included 2- and 4- lane highways and single- and twin- span construction. Bridge replacements generally include six project components: 1) temporary traffic control measures during construction, 2) bridge approach construction, 3) old structure removal, 4) earthwork and site preparation, 5) new bridge construction, and 6) permanent traffic control and safety measures.

Costs for traffic control measures can vary widely, depending upon the traffic volume and adjacent land use. Bridge approach costs also have high variability, depending on specific site needs associated with topography and adjacent land use. Old structure removal is considered a fixed cost in project estimates (i.e., demolition), and varies depending on the volume of material to be removed. For the other two components, earthwork and the new structure, standardized values could be determined.

The objective was to provide approximate costs of the structure sections that enable existing bridges to serve as wildlife ecopassages; therefore many of the project components with high variability (previously discussed) were omitted. Costs for removal of fill and the new structure addition were separated to generate a standard cost/m^2 (to determine an estimate for bridges inventoried during field surveys; as part of the statewide ecological hotspots on highways analysis).

Table 3-1 provides information on costs generated from new bridge construction and earthwork for 15 previous projects. Calculations reveal an average of \$7.54/m^3 for fill removal/addition on 15 typical bridge replacement projects. Construction costs for the bridge structures were split according to high- and low- level structure types. Examples of high-level bridges encountered for this research included railroad bridges and navigable river bridges. Low-level bridges are most typical for aquatic features where vertical clearance is primarily designed to accommodate flood stages. Costs differ because of different structural configuration. Substructure support is much greater for high-level bridges thus costs are generally higher. FDOT officials have estimated average construction costs as follows: low-level bridge spanning river floodplain: $484/m^2, and high-level railroad bridge: $700/m^2 (Keith Campbell-FDOT, Personal Communication 2000). Since no high-level structure replacements were identified, they were not included in calculations shown in Table 3-1. An average cost of $702.19/m^2 was calculated for low-level bridges. This calculation is significantly higher than the verbal estimate provided by FDOT for low-level bridges. Table 3-2 provides information on estimated costs to add extensions (to provide terrestrial linkages for wildlife movement) to the existing bridges from Table 3-1.

Calculations made in these tables are explained with the following examples: US 90 crossing the Little St. Mary's River (Figure 3-26), and SR 46 crossing the Wekiva River (Figure 3-27). The dimensions of the new structure over the L. St. Mary's River on US 90 were 120 m x 27 m with a clearance of approximately 3 m. Construction bids (n = 7 bidders) for this structure averaged $545/m^2, a total cost of approximately $1.77 million (FDOT 1997). The original bridge replaced had dimensions of 102 m x 9 m. Thus length and width each increased by 18 m; width was increased to accommodate two additional lanes of traffic. Given the topographic configuration of the site, the fill removed for the new bridge would have been transported in from off-site to build the original elevated approaches. Unit costs multiplied by the area of the bridge extension segment (162 m^2) results in added costs of approximately $113,755.

Table 3-1. Typical bridge replacement construction costs

Road (configuration)	Feature	Year	Bids (#)/ Actual	Fill Amount (m^3)	Total Fill Cost	Fill Cost/m^3	Length	Width	Height	Area (m^2)	Structure Cost	Structure Cost/m^2	Structure Cost by Height ($m\text{-}m^2$)
US 1 (4 lane, 2 spans)	Tomoka River	1999	a	9,850	89,151	9.05	107	30	5	3,210	1,757,192	547.41	109.48
US 1 (4 lane, 1 span)	Turkey Creek	1997	a	14,400	132,700	9.22	67	37	7	2,479	1,562,624	630.34	90.05
US 1 (4 lane, 2 spans)	Goat Creek	2001	b (9)	5,779	76,172	13.18	42	25	6	1,034	1,084,068	1,048.26	174.71
US 90 (4 lane, 1 span)	Little St. Mary's Creek	1998	b (7)	276,327	625,868	2.26	120	27	3	3,240	1,766,449	545.20	181.73
SR 20 (4 lane, 2 spans)	Lochloosa Creek	2002	a	557,983	2,260,779	4.05	73	26	2.8	1,898	819,866	431.96	154.27
SR 20 (2 lane)	Rice Creek	2000	a	52,138	552,766	10.60	152	13	2.3	1,976	999,219	505.68	219.86
SR 46 (2 lane)	Wekiva River	1997	a	15,194	70,453	4.64	171	14	3	2,445	919,904	376.19	125.40
SR 40 (2 lane)	Tomoka River	1998	a	109,430	576,507	5.27	110	13	5	1,430	1,098,700	768.32	153.66
US 192 (2 lane)	Reedy Creek (3)	1999	a	82,722	597,836	7.23	680	14	7	9,520	4,940,323	518.94	74.13
US 301 (2 lane)	Shady Brook	1999	a	783	8,294	10.59	36	14	7	504	368,700	731.55	104.51
US 301 (2 lane)	Jumper Creek	1999	a	623	4,933	7.92	23	14	3	322	260,574	809.24	323.69
SR 19 (2 lane)	Palatlakaha Cr.	2000	a	10,696	95,068	8.89	44	13	3	592	421,082	710.95	284.38
SR 11 (2 lane)	Haw Creeks (3)	2000	b (7)	23,442	225,502	9.62	172	14	4	2,477	1,850,583	747.17	186.79
SR 60 (2 lane)	Kissimmee R.	2001	b (5)	259,797	1,146,036	4.41	182	16	6	2,912	2,776,482	953.46	158.91
SR 520 (2 lane)	St. John's River	1999	a	133,390	821,989	6.16	108	14	4	1,512	1,826,660	1,208.11	302.03
			Average Cost—fill work			**$7.54**			**Average Cost—structure**			**$702.19**	**$176.24**

Figure 3-26. Construction of replacement bridge. New bridge built over the Little St. Mary's River, on US Highway 90 near MacClenny in 1999.

Figure 3-27. Wildlife bridge extension on SR 46 over the Wekiva River in central Florida. Structure design includes a 74 m terrestrial linkage along the river to facilitate safe movement for the Florida black bear. (T. Gilbert, Florida Fish and Wildlife Conservation Commission - 1999, Personal Communication.)

Table 3-2. Old bridge dimensions and costs for extension

Road (configuration)	Feature	Length	Width	Area (m^2)	Added Length	Cost/m^2	Cost for Added Length
US 1 (4 lane, 2 spans)	Tomoka River	91.5	9.6	878	16	547.41	81,455
US 1 (4 lane, 2 spans)	Turkey Creek	47	19.4	912	20	630.34	244,574
US 1 (4 lane, 2 spans)	Goat Creek	23.8	19.1	455	18	1048.26	358,389
US 90 (2lane)	L. St. Mary's Cr.	102	9	918	18	545.20	88,322
SR 20 (2 lane)	Lochloosa Cr.	38	14	532	35	431.96	211,660
SR 20 (2 lane)	Rice Creek	32	8	256	120	505.68	485,453
SR 46 (2 lane)	Wekiva River	78	9	702	93	376.19	314,873
SR 40 (2 lane)	Tomoka River	n/a	n/a	n/a	n/a	768.32	n/a
US 192 (2 lane)	Reedy Creek (3)	114	12	1,368	566	518.94	3,524,651
US 301 (2 lane)	Shady Brook	31	7.2	223	5	731.55	26,336
US 301 (2 lane)	Jumper Creek	23	7.2	166	0	809.24	-
SR 19 (2 lane)	Palatlakaha Cr.	30	9	270	14	710.95	90,860
SR 11 (2 lane)	Haw Creeks (3)	138	7.7	1,063	34	747.17	195,608
SR 60 (2 lane)	Kissimmee R.	182	10	1,820	0	953.46	-
SR 520 (2 lane)	St. John's River	85	9	765	23	1208.11	250,078
Average Cost—structure						**$702.19**	

Another cost comparison was performed on the low-level bridge replacement project on SR 46 over the Wekiva River in central Florida. This bridge was extended to incorporate a terrestrial wildlife underpass adjacent to the watercourse, primarily for use by black bears. The dimensions of the new structure are 171 m x 14.3 m with a clearance height of approximately 3 m. Bridge construction costs totaled $919,904 or $376/$m^2$ (FDOT 2000). Portions of the original bridge approaches had to be removed to allow clearance for the wildlife underpass. Expenditures for earth removal (quantity of fill = 15,194 m^3) associated with these approaches totaled $70,453 or $4.6/$m^3$ (FDOT 2000). The original bridge that this structure replaced measured 78 m x 9 m. Given the topographic configuration of the site, the fill removed for the new bridge would have been transported in from off-site to build the original elevated approaches. Therefore, assuming similar costs for the earthwork, the total costs to build the original bridge (based on the known cost for the new bridge, $376/$m^2$) would be approximately

$264,000. Cost differential between constructing the shorter floodway bridge at this site and the extended bridge would be around $315,000.

If this type of investment is being considered for each underpass, the location and modification of existing structures (at identified priority road segments) could result in substantial savings to the State for retrofits on roadways (to restore landscape connectivity between adjacent conservation lands).

Infrastructure Investments for Wildlife

Value of existing bridges (that function as wildlife ecopassages) was calculated from the field inventory conducted as part of the site verification and recommendation phase of the statewide prioritization process of highway – greenway interfaces, a.k.a. ecological hotspots on highways. Many structures that require retrofits (to provide terrestrial linkages under the structure for wildlife movement) were also identified in the inventory. As part of this analysis, bridge extensions are proposed and approximate construction costs estimated.

Table 3-3 summarizes calculations of fixed capital for the bridges listed in the field inventory. For each bridge to provide suitable permeability for terrestrial wildlife, differing corrective measures are needed (dependent on context and structural dimensions). The five categories of retrofits include: 1) bridges over canals within sawgrass marsh; 2) bridges that are suitable in their existing condition, provided that a percentage of the rip-rap is replaced by other scour preventing measures conducive to wildlife movement; 3) bridges that need extensions to provide a terrestrial linkage; 4) bridges with low clearance that require replacement by higher structures to accommodate larger wildlife; and 5) bridges that are suitable in their existing condition. Parameters include estimated value of existing structures and added costs for proposed retrofits, including cost for fill and excavation work and added structural work.

Table 3-3. Summary of existing bridges evaluated for corrective measures

Structure-Retrofit Type	No.	Existing Structure Surface Area (m^2)	Estimated Existing Value	Fill Amount (m^3)	Fill Cost	Added Surface Area (m^2)	Structure Cost	Total Added Cost
canals in marsh	12	13,335	$ 9,363,431		$ -		$ -	$ -
length extension	102	117,190	$ 82,289,991	435,975	$3,287,251	44,889	$31,520,598	$34,807,850
rubble removal/replacement	5	4,633	$ 3,253,442		$ -		$ -	$ -
replacement/height addition	52	24,037	$ 16,878,730	27,175	$ 204,897	55,320	$38,844,885	$51,346,820
suitable in existing condition	201	573,641	$401,434,758		$ -		$ -	$ -
Total	**372**	**732,836**	**$513,220,353**	**463,150**	**$3,492,149**	**100,209**	**$70,365,484**	**$86,154,669**

Values for Calculations: Existing Structure Cost $702.19/m^2, Fill Cost $7.54/m^3, Increased Length (25m) and Height (minimum 3m), Added Structure Height Cost $176.24/m-m^2.
Note: One suspension bridge was included in the "suitable in existing condition" category, although surface area was included, value information was not available.

Capital investment in existing structures currently suitable as wildlife ecopassages (201) was estimated at $401.4 million. This estimate includes the value for the surface area of the bridge only. Calculations were performed for 102 bridges that require extensions to provide terrestrial passage. Estimated existing value of these structures was $82.3 million. Approximate cost to construct 25 m extensions for the 102 bridges was $34.8 million. The cost to extend each bridge was determined by estimating: 1) the cubic meters of approach fill to remove, and 2) the square meters of surface structure to add for 25 m of additional length. These amounts were multiplied by the estimated cost for structure work of $702.19/m^2 and fill work of $7.54/m^3. Additional expenses would be expected for traffic control and approach reconstruction.

There were 52 bridges valued at $16.9 million identified that require increased height to provide for passage by larger wildlife. Costs for this work include replacement value and estimated cost for structure and fill work to increase the length by 25 m and the clearance height to 3 m. Cost for each square meter in surface area per added meter in height ($176.24/m-m^2) was the averaged value from the known bridge costs shown in Table 3-1. The sum of the replacement value, cost for fill work, and construction cost for increased length and height give the approximate cost to increase each bridge by 25 m in length and to 3 m in clearance height. Total cost to retrofit the 52 bridges is estimated at $51.3 million. Again, additional expenses would be expected for traffic control, old structure removal, and approach reconstruction.

Twelve bridges were constructed over canals located in sawgrass marsh. These structures were entirely surrounded by aquatic habitat. Calculating modification cost for providing terrestrial linkages was therefore unnecessary. Approximate investment value of these bridges was $9.4 million (structure and fill work only). Five bridges were of sufficient length and height to act as ecopassages; however, substrate under these structures consisted of coarse rip-rap (heavy rock and rubble) used to prevent scouring around pilings. Rip-rap renders the area impassable for many species, especially ungulates and other large wildlife. Existing capital investment (structure and fill work only) in these five bridges was estimated at $3.3 million. The process necessary to improve the functionality of these bridges as wildlife underpasses involves removal of the riprap and replacement with other material (e.g., concrete or tiles). Cost to perform this work was unavailable, but considered here to be minor compared to replacement and retrofit costs previously discussed.

In summary, approximate construction costs to retrofit the 154 bridges identified in the field inventory would be $86 million. Additional expenses associated with these projects would include traffic control measures and approach reconstruction. Fencing and landscape work is needed at all terrestrial sites identified (360) to improve their function as wildlife underpasses.

A subset of the bridges evaluated for corrective measures above are those bridges located at priority sites included in the prior section, "Recommended Actions to Improve Functional Habitat Connectivity: Retrofitting Highway Hotspots". Table 3-4 contains a summary of the 79 bridges from priority locations evaluated in the inventory. Of the 79 bridges, 24 existing structures (with an estimated value of $29 million) were considered functional in their existing condition as ecopassages. Seventeen bridge replacements were identified to increase clearance for larger wildlife present at each location. Structure replacement was estimated at $13.8 million, excluding traffic control measures and approach reconstruction. Bridge extensions were recommended for 34 of these bridges. Existing value of these structures was estimated at $23.1 million and added cost to extend the length of the bridges 25 m was estimated at $9.4 million. Two bridges require removal and replacement of coarse rubble with more permeable anti-scouring materials. Finally, two other bridges were identified in sawgrass marsh context.

Table 3-4. Summary of existing bridges on priority list evaluated for corrective measures

Structure-Retrofit Type	**No.**	**Existing Structure Surface Area (m^2)**	**Estimated Existing Value**	**Fill Amount (m^3)**	**Fill Cost**	**Added Surface Area (m^2)**	**Structure Cost**	**Total Added Cost**
canals in marsh	2	1,084	$ 760,911		$ -		$ -	$ -
rubble removal/replacement	2	1,171	$ 821,972		$ -		$ -	$ -
length extension	34	32,222	$ 23,096,032	115,396	$ 870,088	12,146	$ 8,529,013	$ 9,399,101
replacement/height addition	17	6,568	$ 4,611,652	7,724	$ 58,242	16,705	$11,730,064	$13,754,971
existing condition suitable	24	41,247	$ 28,963,475		$ -		$ -	$ -
Total	**79**	**82,292**	**$ 58,254,042**	**123,121**	**$ 928,330**	**28,851**	**$20,259,077**	**$23,154,072**

Values for Calculations: Existing Structure Cost $702.19/m^2, Fill Cost $7.54/m^3, Increased Length (25m) and Height (minimum 3m), Added Structure Height Cost $176.24/m-m^2.
Note: One suspension bridge was included in the "suitable in existing condition" category, although surface area was included, value information was not available.

Of the 372 bridges evaluated in field surveys, 21% (79) were located at high priority locations. Capital investment for provision of functional wildlife underpasses at these sites is approximately $58.3 million; an additional $23.2 million is needed to retrofit those structures below functional standards. Existing bridges represent only 22% (79 of 364) of those sites identified for corrective measures. Although this assessment only considered bridges, similar cost analyses need to be performed for smaller structures such as pipe and box culverts; and other measures needed to prevent wildlife – vehicle conflicts and increase highway permeability to wildlife.

Statewide Bridge Expansion Program

Over the last few years, the FDOT has been conducting an unofficial program to restore connectivity of riparian systems in conjunction with scheduled bridge replacements and upgrades. Through consultation with the Florida Fish and Wildlife Conservation Commission, existing bridges scheduled for replacement are examined to assess their present impact on floodplain and riparian habitat connectivity (Terry Gilbert-FFWCC, Personal Communication). Replacement structures within valuable riparian habitat areas are then designed to include terrestrial or floodplain linkages under the structure, not just provide for the floodway of the watercourse.

This is a valuable approach that can help restore habitat connectivity to wildlife, such as the river otter and Florida black bear. Roads have been documented as an impediment to movements of river otters, usually resulting in highway mortality (Kruuk and Conroy 1991, D. Smith unpublished data). The first reported construction of a bridge in Florida, which included provisions for terrestrial wildlife movement along a stream corridor, was the replacement and expansion of the SR 46 bridge over the Wekiva River in 1997 (T. Gilbert-FFWCC, Personal Communication). The original bridge (consisting of a narrow passage for the floodway of the river) was replaced and expanded to a 171 m span that includes a 74 m terrestrial corridor, to accommodate movement by the Florida black bear (Figure 3-27).

One hundred and three bridge construction projects were identified in existing and proposed conservation areas (Table 3-5). Many of these sites were ranked in the prioritization process and several were not. These projects were expected to cost approximately $414 million and include new bridges, replacements, and widenings (FDOT 1999). A key to mitigation of impacts of highways and automobile traffic on wildlife populations and ecologically sensitive areas is the programming of road projects and identification of existing structures. It is important to identify ecological hotspots on highways that correspond with planned road projects. Through these opportunities, construction of wildlife underpasses or other mitigation measures can be programmed into the proposed road project. Such pre-planning can reduce costs incurred when engineers must retrofit existing roads.

Table 3-5. Scheduled bridge replacement construction projects, 1999-2004

FDOT District	County	Route No.	Project Type	Highest Rank	Let Date	Length (m)	Environmental Feature
1	Charlotte	I-75	Widen Bridge	nr	00-01	2411	Peace River Corridor
1	Collier	SR 951	New Bridge	3	97-?	488	Rookery Bay
1	Collier	SR 951	Bridge Replacement	nr	03-?	2313	Rookery Bay
1	Collier	US 41	Bridge Replacement	3	00-?	67	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	00-?	13	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	96-99	13	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	00-?	10	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	00-?	10	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	00-?	18	Big Cypress NP
1	Collier	US 41	Bridge Replacement	nr	00-?	10	Big Cypress NP
1	DeSoto	SR 31	Bridge Replacement	nr	96-99	79	Prairie Creek
1	DeSoto	SR 70	Bridge Replacement	nr	98-99	69	Horse Creek
1	DeSoto	SR 70	Bridge Replacement	5	98-99	69	Horse Creek
1	DeSoto	SR 70	Bridge Replacement	5	98-99	106	Horse Creek
1	DeSoto	US 17	Bridge Replacement	nr	98-99	28	Thornton Branch
1	Glades	SR 29	Bridge Replacement	5	96-99	10	Canal, S of Fisheating Creek SOR
1	Glades	SR 29	Bridge Replacement	5	96-99	13	Canal, S of Fisheating Creek SOR
1	Glades	SR 29	Bridge Replacement	5	96-99	45	Canal, S of Fisheating Creek SOR

Table 3-5. continued

FDOT District	County	Route No.	Project Type	Highest Rank	Let Date	Length (m)	Environmental Feature
1	Glades	SR 29	Bridge Replacement	5	96-99	15	Canal, S of Fisheating Creek SOR
1	Hardee	SR 636	Bridge Replacement	nr	96-99	31	Peace River Corridor
1	Hardee	SR 636	Bridge Replacement	nr	96-99	66	Peace River Corridor
1	Hardee	SR 64	Bridge Replacement	nr	96-99	76	Charlie Creek
1	Hardee	SR 66	Widen Bridge	nr	96-99	37	Charlie Creek
1	Hardee	SR 66	Widen Bridge	nr	96-99	61	Charlie Creek
1	Hardee	US 17	Bridge Replacement	nr	96-00	92	Peace River Corridor
1	Hardee	US 17	Bridge Replacement	nr	96-99	50	Charlie Creek
1	Hendry	SR 80	Bridge Replacement	nr	98-99	37	Caloosahatchee Ecoscape, Long Hammock Cr.
1	Highlands	SR 70	Widen Bridge	3	98-99	48	Fisheating Creek
1	Manatee	SR 64	Bridge Replacement	nr	99-00	132	Palma Sola Bay
1	Manatee	SR 64	Bridge Replacement	nr	99-00	43	Perico Bay
1	Manatee	US 41	Widen Bridge	nr	96-00	115	Terra Ceia Bay
1	Polk	SR 60	Bridge Replacement	nr	96-99	55	Alafia River
1	Polk	SR 60	Bridge Replacement	nr	96-99	69	Peace Creek
1	Polk	SR 60	Bridge Replacement	nr	96-99	27	Poley Creek
1	Polk	SR 60	Bridge Replacement	5	00-01	963	Kissimmee River SOR
1	Polk	US 92	Widen Bridge	5	96-00	50	Saddle Creek
1	Polk	US 92	Widen Bridge	5	96-00	44	Lake Parker Drainage
2	Alachua	SR 121	Bridge Replacement	5	00-01	1439	Santa Fe River Corridor
2	Duval	SR 105	Bridge Replacement	5	00-03	410	Ft. George Inlet, Timucuan EP
2	Duval	US 90	Bridge Replacement	5	00	1659	Intra-coastal Waterway
2	Duval	US 90	Bridge Replacement	nr	00-01	206	Brandy Branch
2	Gilchrist	SR 47	Bridge Replacement	5	00	92	Santa Fe River Corridor
2	Lafayette	CR 53	Bridge Replacement	n/a	96-00	96	Mill Creek
2	Lafayette	CR 53	Bridge Replacement	n/a	00	216	4-mile Creek
2	Madison	CR 150	Bridge Replacement	n/a	96-99	39	Little Aucilla River
2	Madison	US 90	Bridge Replacement	nr	00	29	Suwannee Greenway
2	Nassau	CR 121	Bridge Replacement	n/a	96-00	202	Brandy Branch
2	Nassau	CR 121	Bridge Replacement	n/a	96-00	11	Mill Creek
2	Nassau	US 17	Bridge Replacement	nr	96-03	173	St. Mary's River
2	Nassau	US 17	Bridge Replacement	5	00	62	Nassau River Salt Marsh
2	Nassau	US 17	Bridge Replacement	5	00	41	Nassau River Salt Marsh
2	Nassau	US 17	Bridge Replacement	5	00	10	Lofton Creek
2	Nassau	US 17	Bridge Replacement	nr	00	19	McQueen Creek
2	Nassau	US 17	Bridge Replacement	nr	00	16	McQueen Swamp
2	Nassau	US 90	Bridge Replacement	nr	00	153	Deep Creek
2	Nassau	US 90	Bridge Replacement	nr	00	162	SCLRR Bridge
2	Putnam	SR 20	Bridge Replacement	nr	00	223	Sweetwater Creek
2	Putnam	SR 20	Bridge Replacement	5	00	296	Rice Creek, Etonia CARL
2	St. Johns	CR 13	Bridge Replacement	n/a	00-04	127	Deep Creek
3	Escambia	US 90	Bridge Replacement	nr	96-01	499	Escambia River
3	Gadsden	US 27	Bridge Replacement	4	98-99	199	Ochlocknee River Corridor
3	Gadsden	US 27	Bridge Replacement	4	98-99	394	Ochlocknee River
3	Gulf	SR 71	Bridge Replacement	4	96-01	77	Cypress Creek
3	Gulf	SR 71	Bridge Replacement	5	96-01	66	West Arm Creek
3	Jackson	SR 166	Bridge Replacement	nr	96-01	169	Chipola River
3	Liberty	CR 2224	Bridge Replacement	n/a	99-00	247	Big Creek, North of Apalachicola NF
3	Okaloosa	SR 85	Bridge Replacement	nr	98-99	91	Eglin AFB, Boggy Bayou
3	Santa Rosa	US 90	Bridge Replacement	nr	96-01	82	Macavis Bayou
3	Santa Rosa	US 90	Bridge Replacement	nr	96-01	59	CSXRR Bridge
3	Wakulla	US 98	Bridge Replacement	5	96-99	98	St. Marks River
3	Washington	US 90	Bridge Replacement	4	98-99	764	Choctowatchee River
3	Washington	US 90	Bridge Replacement	nr	96-99	123	Cypress Slough
4	Brevard	SR 520	Bridge Replacement	nr	00-04	1444	Banana River

Table 3-5. continued

FDOT District	County	Route No.	Project Type	Highest Rank	Let Date	Length (m)	Environmental Feature
4	Brevard	SR 528	Bridge Replacement	nr	00-04	1449	Indian River
4	Martin	SR A1A	New Bridge	nr	98-99	809	St. Lucie River
4	Martin	SR A1A	Bridge Replacement	nr	96-03	496	Indian River
4	St. Lucie	SR 70	Bridge Replacement	5	97-01	10	Cypress Creek
4	St. Lucie	SR 70	Bridge Replacement	5	97-01	18	Cypress Creek Branch
4	St. Lucie	SR 70	Bridge Replacement	3	97-01	10	Relief Canal
4	St. Lucie	SR 70	Bridge Replacement	3	97-01	10	Relief Canal
4	St. Lucie	SR 70	Bridge Replacement	1	97-01	15	Cypress Creek
5	Flagler	SR 100	Bridge Replacement	5	00-01	322	Creek to Crescent Lake
5	Flagler	SR 11	Bridge Replacement	nr	96-00	31	Sweetwater Branch
5	Flagler	SR 11	Bridge Replacement	nr	96-00	22	Canal
5	Flagler	SR 11	Bridge Replacement	nr	00	30	Black Branch
5	Flagler	SR 11	Bridge Replacement	5	00	37	Middle Haw Creek
5	Lake	SR 19	Bridge Replacement	5	98-00	28	Palatlakaha Creek
5	Lake	US 27	Bridge Replacement	nr	96-01	28	Lake Denham - Lake Harris
5	Osceola	SR 60	Bridge Replacement	5	96-01	148	Kissimmee River SOR
5	Osceola	SR 60	Bridge Replacement	nr	96-99	19	Blanket Bay Slough
5	Osceola	SR 60	Bridge Replacement	5	96-99	40	C-54 Canal
5	Osceola	US 17/92	Bridge Replacement	5	97-01	47	Reedy Creek
5	Osceola	US 17/92	Bridge Replacement	nr	97-01	35	Reedy Creek
5	Osceola	US 17/92	Bridge Replacement	nr	97-01	42	Reedy Creek
5	Seminole	SR 46	Bridge Replacement	5	98-?	129	Lake Jessup
5	Volusia	I-4	Bridge Replacement	3	00-04	5635	St. Johns River
5	Volusia	SR 415	Widen Bridge	5	98-99	13	Alamana Canal
5	Volusia	SR 44	Bridge Replacement	5	97-?	27	CSX RR, Spruce Creek
5	Volusia	US 1	Bridge Replacement	5	96-00	103	Tomoka River Area
5	Volusia	US 1	Bridge Replacement	5	96-00	79	Korona Canal
6	Monroe	US 1	Bridge Replacement	4	97-02	66	Jewfish Creek
7	Citrus	US 19/98	New Bridge	5	96-01	1910	Cross-FL Greenway
7	Hillsborough	SR 39	Bridge Replacement	3	96-01	439	Blackwater Creek

CHAPTER 4
MONITORING WILDLIFE USE AND DETERMINING STANDARDS FOR CULVERT DESIGN

Introduction

The FDOT has recently taken a proactive approach to construction of wildlife underpasses (e.g., Alligator Alley for Florida panthers, SR 46 for black bears). Certain issues need to be addressed prior to implementation of a statewide program designed to incorporate these provisions in all FDOT highway projects.

One of these is the fact that little empirical research has been performed to correlate what species will use what type of crossing structure. Another issue involves cost of implementation. Design of new structures specifically for wildlife use is expensive and not cost effective. A preferred approach would be to use existing designs oriented toward hydraulic function, but serve dual purposes as wildlife passages and drainage structures (potential examples are provided in Figure 4-1).

Study Description and Design

Structural characteristics that may affect use by various faunal classes include composition, shape, texture, light penetration, moisture, and dimension (width, length, and height). Certain studies (Krikowski 1989, and Langton 1989) have shown importance of light and moisture on use by amphibian species. Size of structures has also been evaluated (Clevenger et al. 2001, Rodriguez et al. 1996, Yanes et al. 1995, and Hunt et al. 1987).

Figure 4-1. Variety of existing structures that may function as wildlife underpasses.

Some general rules of thumb have been proposed by landscape ecologists (i.e., "bigger is better", and "more is preferable to less") with regard to size and number of culverts per distance interval, in areas known for wildlife crossings. The biggest argument against using these rules of thumb, however, is cost effectiveness. Transportation engineers are interested in promoting protection for wildlife and public safety but at optimum efficiency, which involves minimizing costs. With this point in mind, it is therefore necessary to set standards based on the structural characteristics outlined above. The following research provides one approach to classification based on structural characteristics and suitability of use by various wildlife taxa. Objectives of this study include:

1) Identifying specific structure characteristics that enhance or detract from their suitability as wildlife crossing structures

2) Developing standards for culvert design based on relationships between criteria such as culvert type and configuration, landscape context (including species-habitat associations), and species preference

This experiment evaluated culvert use by wildlife as a function of body size and environmental preference. Field data was analyzed by aquatic or terrestrial habitat preferences of each taxon or body size group. A conceptual list of faunal categories found in Florida by environmental preference is presented below (Table 4-1).

Table 4-1. Faunal orders predicted to use culverts

Aquatic (moist conditions)	**Terrestrial (dry conditions)**
Urodela (salamanders)	Testudinata (gopher tortoise & box turtle)
Anura (frogs)	Squamata (lizards & snakes)
Testudinata (aquatic turtles)	Insectivora (moles & shrews)
Crocodilia	Rodentia
Squamata (aquatic snakes)	Carnivora
Carnivora (river otters)	Artiodactyla (deer)

Alternatively groups could be established by the following body weight categories (Table 4-2).

Table 4-2. Mammal body weight categories

Body weight	Smallest	Largest
3 – 1000 g	Southwest shrew	Fox squirrel
1000 – 6000 g	Swamp rabbit	Red fox
6000 – 15,000 g	Otter	Nutria
15,000 – 30,000 g	Bobcat	Beaver
30,000 – 179,500 g	Florida panther	Black bear

Note: A listing of herpetofaunal body weights was not available; however, the same approach would apply as with mammals above).

Individuals from the faunal classes above (that were monitored using culverts) were also evaluated to determine preference according to structural characteristics. Three shapes of culverts exist—round, oval, and rectangular. Length of culverts is dependent on roadway width that most commonly varies from 8 m (2 lane) to 60 m (6 lane). Round and oval culvert width ranges from 30 cm to 3.8 m (FDOT 1989). Box culverts have great variability in dimension ranging from 0.30 m to 2.4 m (tall) and 0.30 to 7.3 m (wide); and can be constructed with single or multiple openings or cells (FDOT 1989).

Width, length, and height are likely correlated in association with the "tunnel effect" that inhibits animals from passing through culverts. This results from an animal's inability to sufficiently see a substantial area or destination at the other end of the culvert. As length increases, width must be increased to reduce the tunnel effect. Others have attempted to evaluate the impact of tunnel effect by developing an "openness" index (W x H)/L (Rodriguez et al. 1996, and Yanes et al. 1995).

Methods and Study Area

The study design included selection of replicates of two structure types (culverts and bridges) from 7 different land-cover classes. Using bridge and culvert categories reduced variance for explanatory structural variables. Study sites were randomly selected (using *SAS* software, SAS Institute, Cary, N.C.) from a database of previously surveyed structures (Chapter 3) that included information on structural and contextual parameters. A minimum of five replicates each of bridges and culverts were selected from each habitat/land-cover class (Table 4-3) at the 210 m^2 level. In some cases, randomly selected sites had to be substituted because of flooding, construction, restricted access, or other uncontrollable factors.

Table 4-3. Land-cover classes

Category	Description
1	urban mining
2	dry prairie sand pine scrub/forest sandhill xeric oak scrub/forest
3	pinelands
4	cypress swamp hardwood swamp bay swamp shrub swamp cutover wetland forest bottomland hardwood forest freshwater marsh & wet prairie open water
5	grassland/pasture/agriculture intensive agriculture bare soil/clearcut
6	shrub/brush (range) land
7	mixed pine-hardwood forest hardwood hammock & forest

Structures were monitored either twice weekly using track beds, or on a continual basis using remote, infrared-camera equipment. The area surrounding culvert entrances was also monitored. This design afforded the ability to evaluate culvert avoidance by particular species or faunal groups. Road-kills were also recorded at each study site. All species were recorded 50 m in each direction from crossing structures, while large mammals and alligators were recorded beyond 50 m. General soil moisture (5-point Likert response scale: very wet, wet, moist, dry, very dry) within each culvert was recorded during each visit. Height of right-of-way vegetation was recorded once monthly. Weekly rainfall and minimum and maximum temperatures for each site were acquired from National Climate Data Center (NCDC) weather stations closest to each monitoring site (maximum distance of 57 km). Benefits of the design included:

1) monitoring in the natural setting of those species present,
2) documenting simultaneously the effect of structural, environmental and habitat variables on effectiveness as wildlife passageways,
3) evaluating overlapping species-habitat associations to develop generalizations of culvert sizes needed in particular habitat types (e.g., Florida black bear's use of multiple habitat types would overlap many smaller species that exist within the black bear's range—"umbrella effect"),
4) identifying certain sites containing small culverts that are nonfunctional for larger species present in the area, and
5) identifying species that are "culvert avoiders".

Track beds were prepared by clearing vegetation and debris (Figure 4-2), tilling and loosening existing soil, and when necessary applying substrate additives (e.g., builder's sand) to ensure readable tracks. Problems encountered at various sites included vegetation overgrowth and mowing, rain, flooding, erosion, and washouts (that in some cases interrupted monitoring efforts or required repeated site preparation).

Remote infrared-camera equipment used at camera sites included Trailmaster© Models 550 and 1500, and the Camtrakker™ Wildlife-Pro Model. The Model 1500 is an active-sensor device that has a transmitter and a receiver. The Model 1500 system works by orienting the single infrared-beam, emitted by the transmitter, directly toward the receiver. When the path of the beam is obstructed, the camera is triggered and a photograph is taken. The range of the Model 1500 is approximately 33 m.

before

after

Figure 4-2. Site preparation at track monitoring stations. Steps consisted of 1) Clearing vegetation, 2) Preparing soil (e.g., tilling and loosening), and 3) Applying soil additives (e.g., builder's sand) when needed to ensure readable tracks. Frequent problems included flooding, erosion, and washouts.

The Model 550 and the Wildlife-Pro are passive-sensor devices. The Model 550 emits an infrared array that consists of several beams, directed outward at equal interval angles that form a semicircle. The range of the infrared array is approximately 20 m. When an object interrupts two or more of the infrared rays, the camera is triggered and a photograph is taken. The Wildlife-Pro emits a cone-shaped infrared-beam with a range of approximately 20 m. When an object enters the path of the infrared beam, the camera is triggered and a photograph is taken. Timers on the sensors were set to function on a 24 hour cycle whenever possible. For sites where human activity was prevalent during the day, timers were set for nighttime hours only. Film and batteries were checked every two to three weeks depending on the amount of wildlife traffic at each site.

To protect the equipment from the elements and to prevent theft, custom lock boxes were constructed out of military ammunition boxes. Figure 4-3 displays the remote-camera system attached to a bridge. Each lock box was fastened to bridge pilings by Tapcon™ concrete screws and steel cables to deter theft. The Model 1500 system was aligned approximately 30 to 35 cm above ground level. The other models were setup at various positions and angled toward the target area, depending on site characteristics.

Statistics were performed (using *SAS*) on numeric variables for each monitoring site. These included basic-univariate-statistical measures, tests for normality, and distribution tables and plots. Multiple-logistic regression was performed to determine significance of numeric and class variables governing species use, recorded at each monitoring location. Logistic discrimination performs a logistic regression on the categorical variable, and assigns population membership to observations based on the associated explanatory variables (Khatree and Naik 2000). Frequency distributions for significant explanatory variables identified in logistic regression models, and thresholds for use by each faunal group were generated.

Figure 4-3. Remote infrared camera system fastened to bridge pilings. This particular example is a Trailmaster 1500 active sensor; above is the transmitter unit, and to the right is the receiver unit and camera inside a customized security box.

Independent variables used in the analyses included 34 factors: number of traffic lanes, right-of-way clearance, right-of-way gap, median width (on divided highways), AADT (annual-average-daily traffic), structure—type, composition, substrate, shape, size, and "openness", distance to next nearest culvert, habitat—diversity and dominant types (primary and secondary) at 30, 210, 1020, and 2040 m^2, presence of humans and domestic predators, soil moisture, right-of-way vegetation type and height, rainfall, and minimum and maximum temperatures. The dependent variable measured for each taxon was whether animals that approached culvert entrances, passed through or not.

Study sites were established in three regions in the state: central Florida (District 5), northeast Florida (District 2), and panhandle Florida (District 3). Culvert monitoring was conducted from March 2001 to December 2001 and July 2002 to March 2003. For the first study period, 22 camera sites and 247 track sites were monitored (Figure 4-4);

during the second study period, 19 camera sites and 85 track sites were monitored (Figure 4-5). Of these, 61 sites were monitored during both study periods.

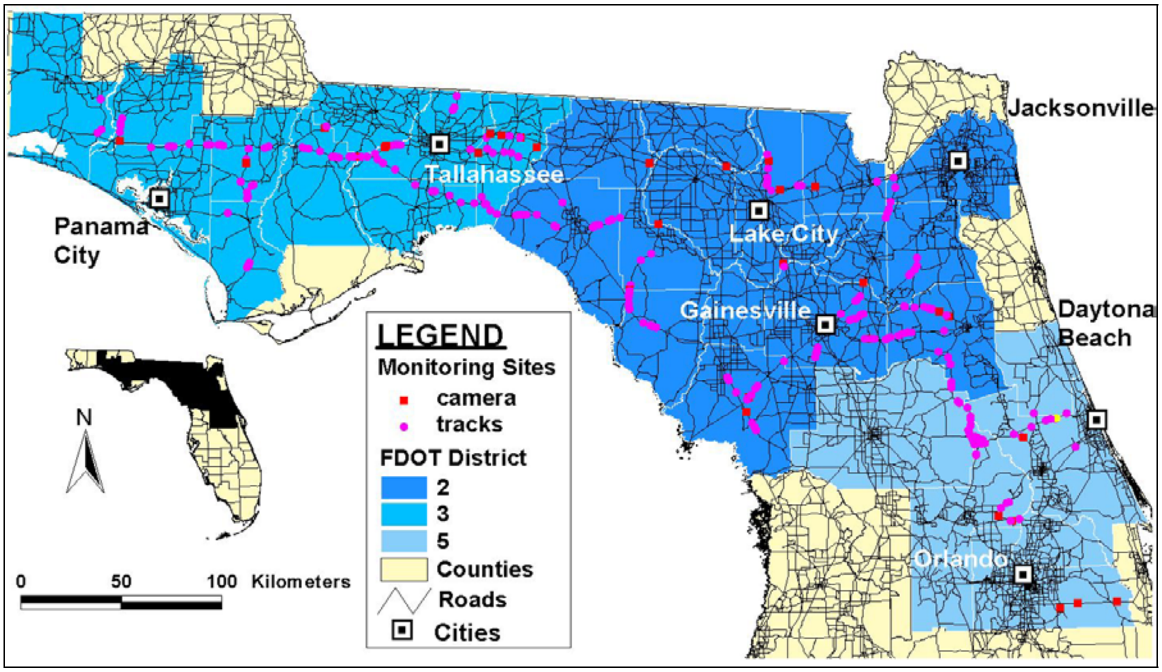


Figure 4-4. Bridges and culverts monitored for wildlife use (March to December 2001). Sites were checked for tracks or monitored by infrared remote cameras on 37 roads in 32 counties.

Results

Results from field data collection and statistical analyses include three separate components. First, the selection of site replicates is presented, including univariate measures for each site and associated explanatory variables. Second, general findings and trends are discussed. Third, data reduction using multivariate-logistic regression and frequency distribution analysis are performed on field data.

Assumptions for Multivariate Logistic Regression Analysis

Four assumptions were addressed for discriminant multivariate-logistic regression: independent random sampling, multivariate normality, equality of variance-covariance matrices, and singularity and multicollinearity of explanatory variables.

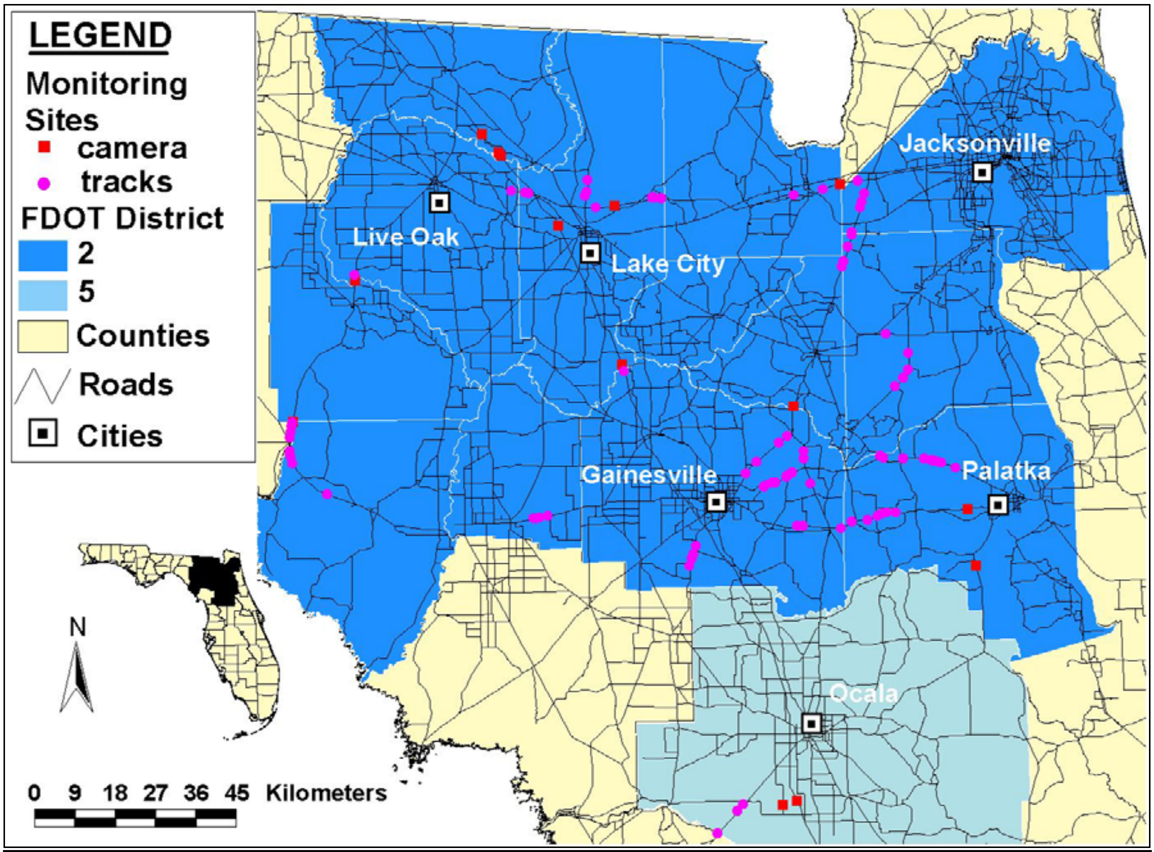


Figure 4-5. Bridges and culverts monitored for wildlife use (July 2002 to April 2003). Sites were checked for tracks or monitored by infrared remote cameras on 17 roads in 14 counties.

Suitable replicates were randomly drawn from a sample of 1,232 field sites (Chapter 3) from across the State. Logistics (e.g., level of funding and staffing for the project) reduced the study area to north-central Florida and the eastern half of the panhandle (Figures 4-4 and 4-5). Coordinating driving time with twice-weekly site visits narrowed the sites available to routes that were efficient for timely and consistent data collection. The result included 290 bridge and culvert sites from the various land-cover types (Table 4-4).

Enough culvert sites were found to provide more than the minimum 5 replicates for each primary land-cover class at the 210 m^2 scale, and included a total of 223 culvert monitoring sites. For bridge sites, suitable replicates were found for all primary land-cover classes except for classes 1 (urban/mining) and 2 (xeric-based land-covers).

To obtain sufficient bridge replicates in these land-cover classes, secondary land-cover was included; and resulted in 12 additional sites for class 1, and 2 additional sites for class 2.

Table 4-4. Replicates found for each structure type by land-cover class

Structure type	Primary land-cover at the 210 m^2 scale							
	1	2	3	4	6	7	8	Total
Culverts	12	18	77	27	24	52	13	**223**
Bridges	1	3	17	24	6	9	7	**67**
Total	13	21	94	51	30	61	20	**290**

Notes: 1) shaded cells indicate insufficient replicates for the primary land-cover class, secondary land-cover was included to provide 12 additional sites suitable as replicates for bridges in class 1. Two additional sites had the same secondary land-cover for bridges in class 2 that resulted in availability of five replicates for this category.
2) Table 4-3 provides land-cover descriptions.

Sample size, mean, standard deviation, and normality of numerical structural, environmental, and ecological explanatory variables for the 290 monitoring sites are shown in Table 4-5. The variables in the table represent 14 static and 4 dynamic factors. The 14 static measures had the same value for the duration of the study. Normality curves were not generated for number of lanes, structure number, and the 4 habitat diversity factors that consisted of integer values; mean and standard deviation was rounded to the nearest whole number. The 4 dynamic variables that were measured throughout the study included—rainfall, minimum and maximum temperature, and right-of-way vegetation height. The other 16 explanatory variables included were non-numeric—primary and secondary habitat (30, 210, 1020, 2040 m^2), water feature type, vegetation type, soil moisture, and other structural characteristics (i.e., type, composition, shape, substrate, and number).

Table 4-5. Univariate measures and distributions of explanatory variables

Explanatory variable	***n***	**Mean**	**Standard deviation**	**Goodness-of-fit test for normality** (Kolmogorov-Smirnov)
All sites (n = 290)				
Number of lanes	290	3	1	-
Road clearance width, m	290	39.07	20.80	$p < 0.01$
Gap width, m	269	6.87	4.84	$p = 0.058$*
Median width, m	290	14.08	5.57	$p < 0.01$
AADT	275	7165	6916	$p > 0.014$*
Distance between structures, m	278	921.23	580.11	$p > 0.15$*
Habitat diversity 30 m^2	290	3	1	-
Habitat diversity 210 m^2	290	3	1	-
Habitat diversity 1020 m^2	290	6	1	-
Habitat diversity 2040 m^2	290	6	1	-
R-o-w vegetation height, cm	13,060	48.47	31.02	$p < 0.01$
Average minimum temperature, C	15,548	15.18	6.08	$p < 0.01$
Average maximum temperature, C	15,558	27.47	4.74	$p < 0.01$
Rainfall, ml	15,671	2.65	4.07	$p < 0.01$
Bridges (n = 67)				
Openness index (w x h / l)	67	12.95	12.07	$p > 0.15$*
Width (w), m	67	61.94	41.99	$p > 0.15$*
Length (l), m	67	20.11	13.79	$p > 0.15$**
Height (h), m	67	3.77	2.79	$p = 0.117$**
Culverts (n = 223)				
Structure number	223	1	1	-
Openness index (w x h / l)	223	0.077	0.12	$p < 0.01$
Width (w), m	223	1.39	0.99	$p < 0.01$
Length (l), m	223	25.23	13.21	$p < 0.01$
Height (h), m	223	0.93	0.48	$p < 0.01$

* lognormal data conversion ** exponential data conversion

Note the significant difference in the means of openness index, width, and height for bridges and culverts (Table 4-5). This high variability explains why the two structure types were evaluated separately. Plots and goodness-of-fit tests for univariate normality of explanatory variables for bridges (n = 67) and culverts (n = 223) revealed skewed or peaked distributions. Lognormal and exponential data transformation and removal of extreme observations was used to fit normal data curves. Goodness-of-fit was corrected following data transformation for openness index, width, length, and height on bridge sites and AADT, gap width, and distance for all sites (Table 4-5).

Although goodness-of-fit values (Kolmogorov-Smirnov Test) were not significantly changed from data transformation, lognormal curves were the closest approximation for culvert—openness, width, length, and height. Rainfall most closely fit an exponential curve, whereas right-of-way vegetation height was most similar to a lognormal distribution. Distribution curves of temperature parameters were not significantly improved through data transformation and/or removal of extreme observations, so original values were used. Although these did not strictly meet univariate normal requirements, they did not grossly violate them either (e.g., minimally elevated skewness and kurtosis values). They were therefore included in the model using the most appropriate data transformation method. Logistic regression still provides a robust method when multivariate distributions are nonnormal (McGarigal et al. 2000).

Levene's test of homogeneity generated in SAS from one-way ANOVA performed on explanatory variables revealed equality for within-group variance for all groups (F statistic, all groups—$p < 0.0001$, ungulates—$p < 0.004$) except the alligator-aquatic mammal group.

Significant overlap was evident between certain explanatory variables. To adhere to singularity and multicollinearity rules for use of logistic regression, and to improve fit of models, it was necessary to remove these. Elements of right-of-way width were expressed in three different variables—number of lanes, median width, clearance, and gap width (pairwise analysis—Pearson's correlation coefficient, $p < 0.0001$). The first three were removed from the analysis, as focus was most appropriately placed on gap width (the distance wildlife must traverse between adjacent habitat and the entrance of the crossing structure). Multicollinearity (Pearson's correlation coefficient, $p = 0.0002$) was also apparent between the openness index and individual structural measurements (i.e., width, length, and height). Recent studies (Bertwhistle 2003, and Garrett and Gordon 2003) reveal that the openness index may overlook the importance of specific structural dimensions to use by certain wildlife; as the mathematical function (width x height / length) can be manipulated in each of the three dimensions to derive the same index value. Due to this, the openness index was not included in the regressions; even so, its significance was included in the discussion. Concern for potential correlation between soil moisture (categorical) and rainfall (continuous) variables resulted in removal of soil moisture (the least precise of the two variables) from the analysis.

Logistic regression models were optimized using backward stepwise processing to select the number of independent factors (determined by Akaike's Information Criterion (AIC) and -2 *log* L model fit criteria in *SAS*). Additional explanatory variables were removed following initial iterations of the regressions because of insignificance. These included: structure composition, water feature, habitat diversity (1020 and 2040 m^2 resolution), and dominant habitat types (primary and secondary at 1020 and 2040 m^2 resolution, and secondary at 30, 210, 1020, and 2040 m^2 resolution). This reduced the number of explanatory variables used in logistic regression models to 20.

General Findings

Over the course of 10 months in 2001 and 9 months in 2002-03, nearly 48,000 records were collected from monitoring sites (Table 4-6). These data were divided into three categories: events, nonevents, and road-kills. Events include records of wildlife movement, either through or in proximity to culverts and bridges (evidenced either by photographs or tracks). Among these events, certain records could not be identified and were classified as such. Nonevents include three different types of records: 1) none (refers to site visits when no tracks were present), 2) washouts (site encounters with washed-out track-beds or flooding following rain events), and 3) vehicle downtimes, thunderstorms, or other circumstances when data collection could not conducted (these are not reported here).

Table 4-6. Events, nonevents and road-kills recorded at culverts and bridges

	Total	**Events**	Tracks	Photographs	Unidentified	**Nonevents**	Washouts	None	**Road-kills**
Total	47,955	36,870	33,678	852	2,340	10,822	3,835	6,987	263
Percent		77	70	2	5	23	8	15	0.5
# sites	290		278	39	211		127	243	125
Yr 02-03	21,400	18,607	17,557	515	535	2,650	2,523	127	143
Percent		87	82	2	3	13	12	1	0.3
# sites	97		67	18	43		81	31	44
Yr 01	26,555	18,263	16,121	337	1,805	8,172	1,312	6,860	120
Percent		69	61	1	7	31	5	26	0.25
# sites	254		211	21	168		46	212	81

Overall, track records (n = 33,678) accounted for 70% of data collected (Figure 4-6); photographs accounted for only 2% of the data (Figure 4-7), and more or less served as a verification method for identification of tracks at certain sites. Five percent of records collected could not be identified (Figure 4-8) and were not used in statistical analyses. No tracks were found at monitoring sites 6,987 times (Figure 4-9), and washouts occurred 3,835 times (Figure 4-10). Road-kills recorded included 263 individual vertebrates, accounting for less than one percent of the data collected (Figure 4-11). The routine for field site visits (twice per week) proved inadequate to effectively estimate road-kill counts on road segments (where structures were monitored for tracks). This limited the ability to evaluate culvert avoidance by specific wildlife.

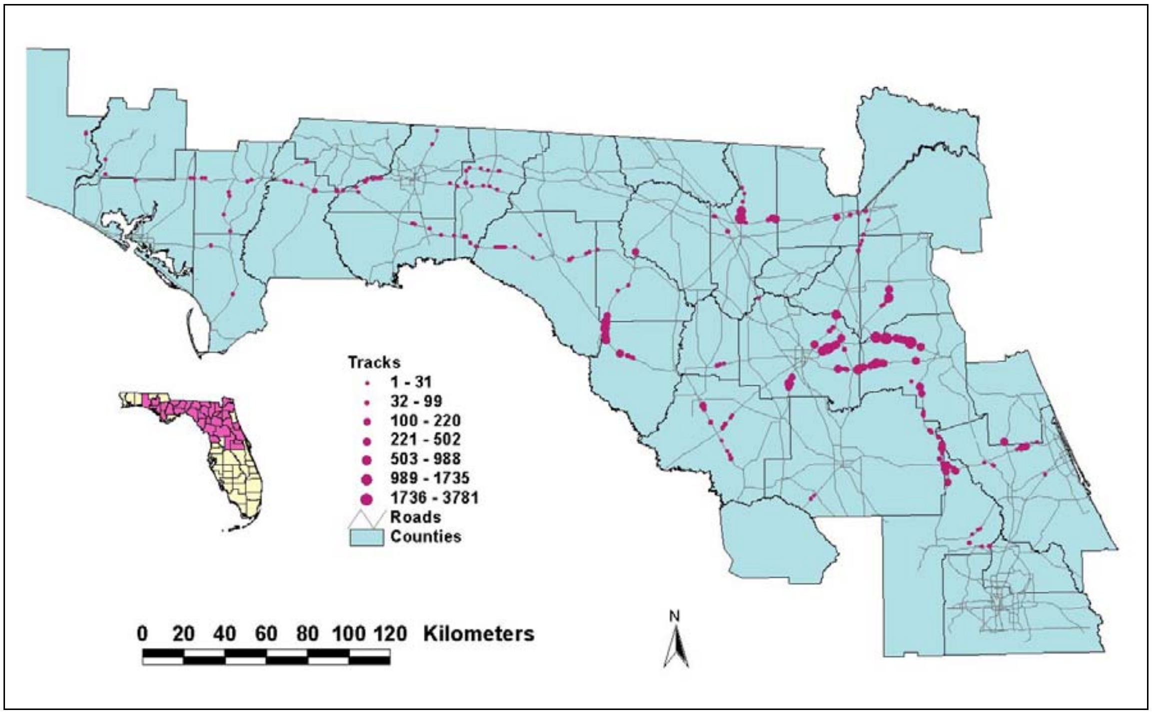


Figure 4-6. Number of tracks recorded at culverts and bridges (3/01 to 12/01 and 7/02 to 4/03). Sites where larger dots are shown had more records for two possible reasons—most were included in both study periods, and some correspond to bridge locations that consistently had more wildlife use.

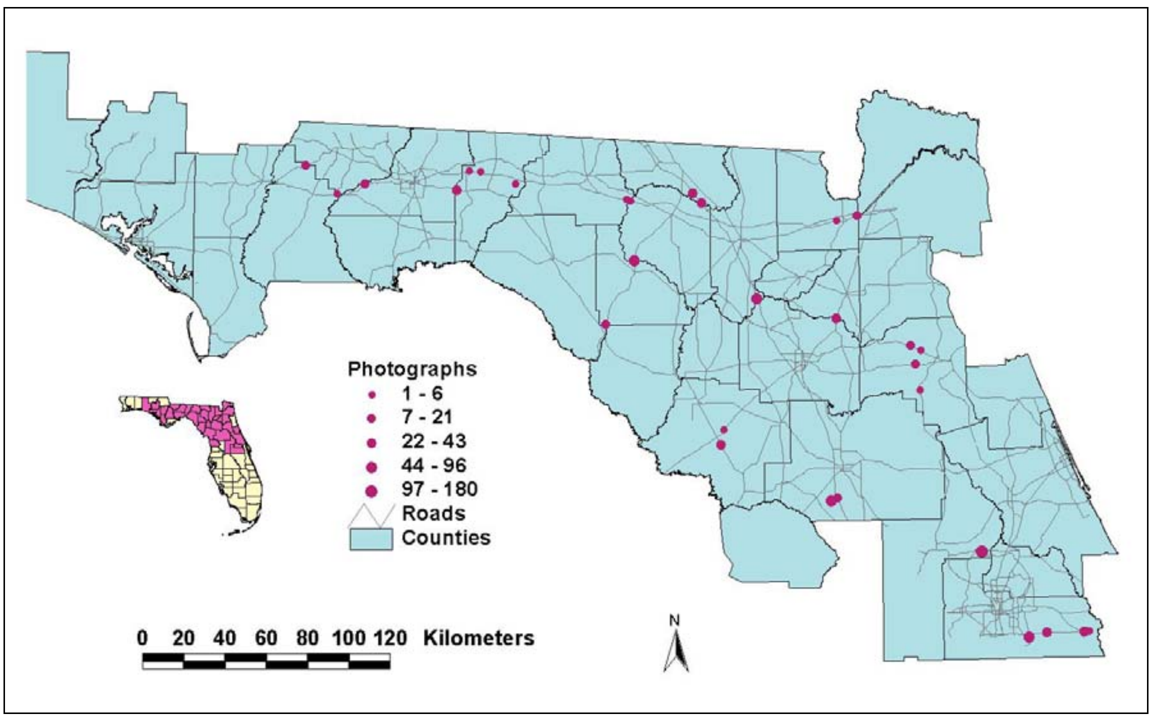


Figure 4-7. Number of photographs taken at culverts and bridges (3/01 to 12/01 and 7/02 to 4/03). Numbers displayed only represent photographs positively identified.

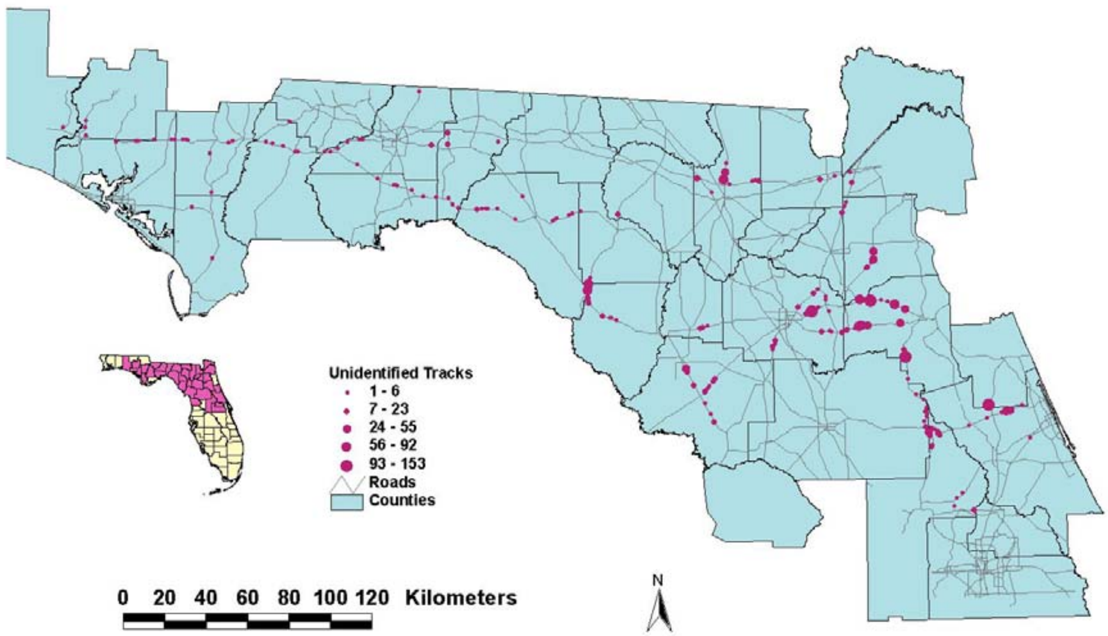


Figure 4-8. Unidentified tracks recorded at culverts and bridges (3/01 to 12/01 and 7/02 to 4/03). Sites where larger dots are shown had more records for two possible reasons—most were included in both study periods, and some correspond to bridge locations that consistently had more wildlife use.

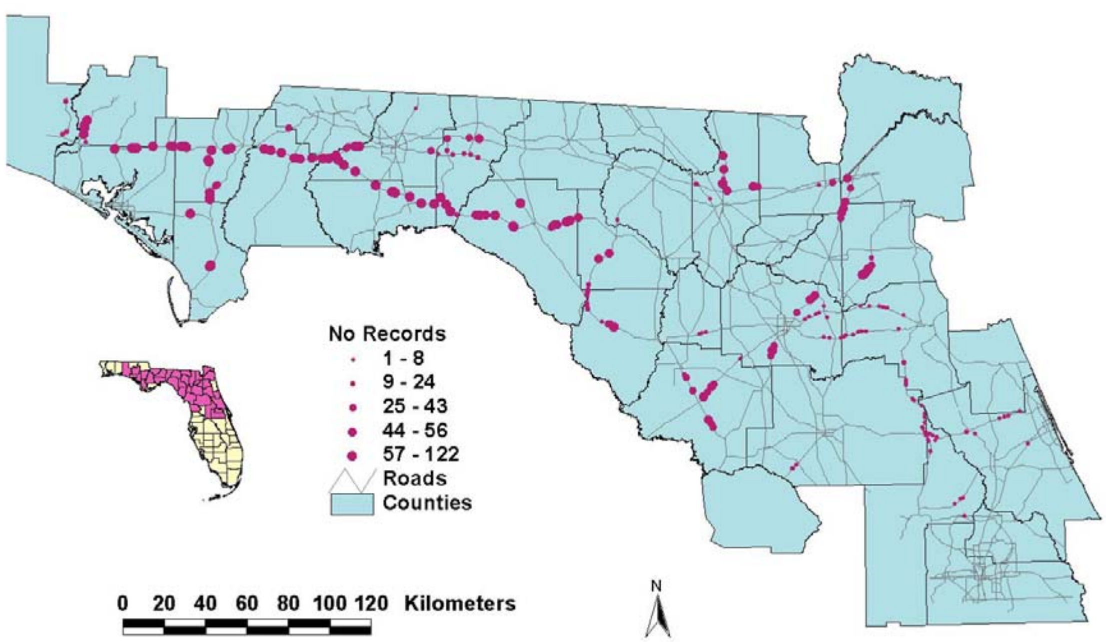


Figure 4-9. Number of visits when no tracks were found at culverts and bridges (3/01 to 12/01 and 7/02 to 4/03). The central peninsula and panhandle were only monitored during the first study period.

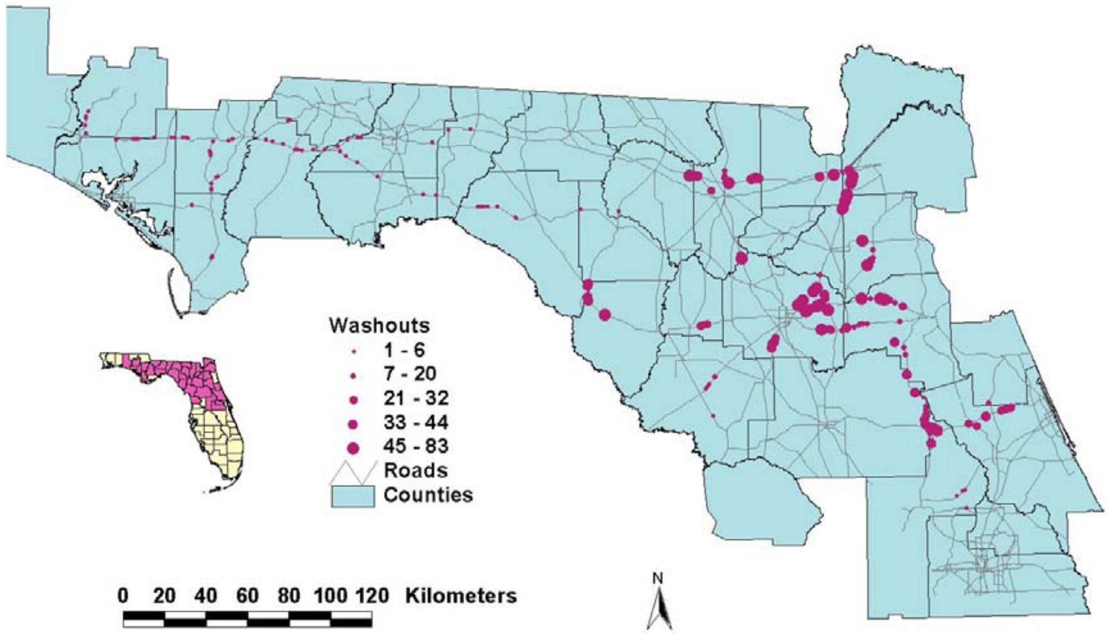


Figure 4-10. Number of visits when sites were flooded or washed out (3/01 to 12/01 and 7/02 to 4/03). The central peninsula and panhandle were only monitored during the first study period. Annual-average rainfall was higher during the second monitoring period and corresponds to the location and number of flood events shown. Most flooded sites contained surface water features.

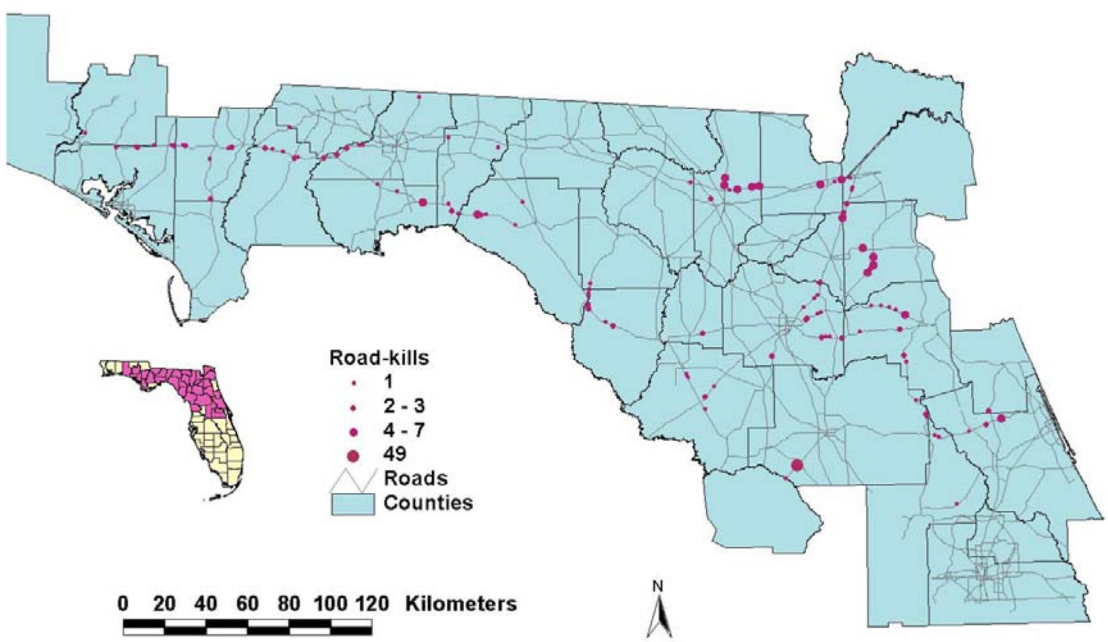


Figure 4-11. Road-kills recorded from 3/01 to 12/01 and 7/02 to 4/03. On average, less than two road-kills were recorded at each site. The central peninsula and panhandle were only monitored during the first study period.

Certain field sites produced exceptional results. Nine sites were flooded and impassable on average for 58% (42 of 72) of site visits, and only included road-kill records (n = 19). No tracks or photographs were recorded at 24 separate sites.

In 2001 and 2002-03, 16,458 (48%) and 18,072 (52%) tracks and photographs, respectively were recorded. A total of 14,751 track records were recorded from 55 bridge sites, an average of 268 per site. Culvert sites produced 18,927 track records from 222 sites (site average = 85).

Findings by Faunal Groups

For all monitoring sites, 41 different organisms or categories were recorded. To perform statistical analysis, these were consolidated into 14 general groups (Table 4-7). Faunal groups were determined according to taxa and body size (discussed previously), mode of movement, and environmental preference. Logistics of monitoring and resource availability restricted the focus of the study to terrestrial organisms, the exception being those aquatic dependents (e.g., river otter, alligator) that used terrestrial areas for movement (either adjacent to aquatic systems or to get from one water source to the next). Faunal groups of interest included: meso-mammal, carnivore, bird, ungulate, herpetofauna, and small mammal. Statistics regarding use or avoidance of culverts and bridges were performed on these six categories.

The other eight categories recorded were either discarded or used in the analysis of the other categories of interest. The category "none" referred to site visits when no tracks were detected; and were not applicable to the analysis unless a particular site revealed no movement for the course of the study. These were reviewed separately to examine why no movement was evident. The category "alligator" and "aquatic mammal" did not produce enough samples (n = 25 and n = 41, respectively) to perform multivariate statistics. Recording tracks in the category "arthropod" proved too intensive a task at the scale of the study and frequency of site visits. The importance of this group's use of connecting structures along roads is recognized; however, a separate study would be necessary to properly evaluate this faunal group. Records of presence and use by "domestics" and "humans" were applied as explanatory variables for the other categories. The category "other" represented those that could not be identified, and therefore could not be included in the regression analysis; additionally "n/a" represents failed attempts to perform monitoring duties and were also ignored in the analysis.

Table 4-7. Faunal groups

Group name	Group code
none	0
alligator	1
meso-mammal	2
arthropod	3
carnivore	4
bird	5
ungulate	6
domestic	7
herpetofauna	8
human	9
small mammal	10
aquatic mammal	11
other	12
n/a	30

The different organisms recorded and their respective group assignments are shown in Table 4-8. Forty-four were identified to the species level, two to the family level, five to the order/suborder level, four to the class level, and 4 other types. Results are presented for each faunal group by structure type (bridge or culvert) and the three groups of explanatory variables—structural, environmental, and ecological.

Table 4-8. Species recorded and group assignments

Group name	**Code**	**Common name**	**Scientific name**
none	0	none	
alligator	1	alligator	*Alligator mississippiensis*
meso-mammal	2	armadillo	*Dasypus novemcinctus*
meso-mammal	2	opossum	*Didelphis marsupialis*
meso-mammal	2	raccoon	*Procyon lotor*
meso-mammal	2	skunk	*Mephitis sp., Spilogale sp.*
arthropod	3	insect	Insecta
arthropod	3	spider	Arachnida
arthropod	3	centipede	Chilopoda
carnivore	4	bear	*Ursus americanus*
carnivore	4	bobcat	*Lynx rufus*
carnivore	4	coyote	*Canis latrans*
carnivore	4	fox	*Urocyon sp., Vulpes sp.*
bird	5	wild turkey	*Meleagris gallopavo*
bird	5	great blue heron	*Ardea herodias*
bird	5	common bobwhite	*Colinus virginianus*
bird	5	wading bird	Ardeidae
bird	5	perching bird	Passeriformes
ungulate	6	white-tailed deer	*Odocoileus virginianus*
ungulate	6	wild pig / hog	*Sus scrofa*
domestic	7	domestic cat	*Felis catus*
domestic	7	domestic dog	*Canis familiaris*
herpetofauna	8	frog / toad	Anura
herpetofauna	8	s. leopard frog	*Rana utricularia*
herpetofauna	8	southern toad	*Bufo terrestris*
herpetofauna	8	green tree frog	*Hyla cinerea*
herpetofauna	8	Cuban tree frog	*Osteopilus septentrionalis*
herpetofauna	8	lizard	Squamata: Lacertilia
herpetofauna	8	6-lined racerunner	*Cnemidophorus sexlineatus*
herpetofauna	8	5-lined skink	*Eumeces spp.*
herpetofauna	8	anole	*Anolis spp.*
herpetofauna	8	fence lizard	*Sceloporus undulatus*
herpetofauna	8	snake	Squamata: Serpentes
herpetofauna	8	cottonmouth	*Agkistrodon piscivorus*
herpetofauna	8	timber rattlesnake	*Crotalus horridus*
herpetofauna	8	s. black racer	*Coluber constrictor*
herpetofauna	8	yellow rat snake	*Elaphe obsoleta*
herpetofauna	8	e. garter snake	*Thamnophis sirtalis*
herpetofauna	8	turtle / tortoise	Testudines
herpetofauna	8	snapping turtle	*Chelydra serpentina*
herpetofauna	8	alligator snapper	*Macroclemys temminckii*

Table 4-8. continued

Group name	Code	Common name	Scientific name
herpetofauna	8	Florida cooter	*Pseudemys floridana*
herpetofauna	8	striped mud turtle	*Kinosternon baurii*
herpetofauna	8	box turtle	*Terrapene carolina*
human	9	human	*Homo sapiens*
sm mammal	10	rabbit	*Sylvilagus spp.*
sm mammal	10	eastern cottontail	*Sylvilagus floridana*
sm mammal	10	mouse	Cricetidae
sm mammal	10	rat	Cricetidae
sm mammal	10	Fl. water rat	*Neofiber alleni*
sm mammal	10	mole	*Scalopus aquaticus*
sm mammal	10	gray squirrel	*Sciuris carolinensis*
aquatic mammal	11	river otter	*Lutra canadensis*
aquatic mammal	11	beaver	*Castor canadensis*
other	12	livestock	Bovidae
other	12	mammal	Mammalia
other	12	other	
other	12	unknown	
n/a	30	n/a	

Note: Table excludes recorded road-kill species that are discussed separately.

Meso-mammal use of bridges

Meso-mammal presence at 58 bridge sites included records (n = 6,480) of five different species: armadillo *Dasypus novemcinctus*, Virginia opossum *Didelphis marsupialis*, raccoon *Procyon lotor*, and skunk *Mephitis sp*. or *Spilogale sp.*

Logistic regression model. The model was significant in predicting use of bridges by meso-mammals: Wald X^2: 390.01 (df—18, p <.0001), Nagelkerke's R^2 (0.4005), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 14.52 (df—8, p = 0.0014). Eleven of 21 factors were found significant (p < 0.03) by the model in predicting use of bridges by meso-mammals. Percentage of movement under bridges correctly predicted by the model was 91.1%.

Response to structural characteristics. Six structural parameters—gap width (distance between bridge entrance and adjacent habitat), annual-average-daily traffic (annual-average of number of vehicles-per-day), bridge width (width of bridge opening), bridge length (distance that organisms had to travel to pass through the structure), bridge height, and distance to next nearest crossing structure—were significant in the logistic regression model for meso-mammal use of bridges.

The majority of meso-mammals using bridges (75.76%, n = 4,687 of 6,186) were recorded when gap width was 8.5 m or less; presence but not passage (84.69%, n = 249 of 294) was also associated with gap widths of 8.5 m or less. Gap width (distance from adjacent habitat to bridge entrance) ranged from 0 – 31.1 m.

When AADT was greater than 7,500, passage under bridges by meso-mammals (n = 6,179) occurred only 13.9% during the period monitored. The highest percentage of passages by meso-mammals (28.39%) were recorded when AADT was at 250 vehicles-per-day. Presence recorded near bridges, but not crossing from one side to the other, primarily occurred (61.56%, 181 of 294) when AADT was 3,000. Range of AADT on roads where meso-mammals were recorded was 250 to 69,374. Of 6,186 records of meso-mammals using bridges, three peaks occurred when bridge width (width of bridge opening) was 19 – 60 m (89.09%).

Sixty-two percent of records of presence but not passage (n = 182 of 294) occurred at two bridge widths, 41 and 60 m. Where meso-mammals were recorded, bridge widths ranged from 7.3 – 200 m. Of 6,186 records of meso-mammals using bridges, most occurred (75.45%) when bridge length was less than 15 m. Presence but not passage (n = 294) was also associated predominantly with bridge lengths less than 15 m (84.69%). Bridge length used by meso-mammals ranged from 6.4 – 80 m. Of 6,186 records of meso-mammals using bridges, most occurred (92.65%) when bridge height was between 1.5 to 3.7 m. Presence but not passage (n = 294) was associated primarily (75.17%) with bridge heights of 3.1 – 3.7 m. Bridge height ranged from 1.2 – 15 m.

When distance between structures was greater than 1,000 m, presence (but not passage under) bridges by meso-mammals (n = 294) occurred 76.53% during the period monitored. Records of passage under bridges (n = 6,174) were relatively even across all distances. Range of distance between structures was 130 to 3,450 m.

Response to environmental characteristics. Recorded passage under bridges (n = 6,186) occurred 73.68% of the time during fall and summer months. High passage rates occurred for all seasons for meso-mammals (minimum of 88.85% in winter). Of 6,480 that approached bridge entrances, 6,186 passed through to the other side.

When average maximum weekly temperature was 20 degrees C or higher, meso-mammals passing under bridges occurred 91.12% (n = 5,637 of 6,186) of the time recorded. Presence at (but not passage under) bridges showed an opposite trend regarding high temperatures; 88.44% of these records occurred when temperatures were 27 degrees C or less. Average maximum weekly temperature at bridges used by meso-mammals ranged between 12 and 34 degrees C.

Response to ecological characteristics. Four ecological characteristics—habitat diversity at 30 m^2 resolution, primary habitat type at 210 m^2 resolution, right-of-way vegetation height, and presence of domestic predators—were significant in the logistic regression model for meso-mammal use of bridges.

Meso-mammals recorded using (n = 6,186) and present at (n = 294) bridges were greatest (80.71% and 90.14%, respectively) when 3 land-cover types existed at the 30 m^2 cell resolution. Habitat diversity ranged from 1 to 4 land-cover types at the 30 m^2 scale.

Passage under bridges by meso-mammals (n = 6,186) was the highest for 210 m^2 scale land-cover classes 3 (pinelands, 18.96%), 4 (wetlands, 50.74%), and 6 (shrub and brushlands, 16.86%). Presence at (but not passage under) bridges (n = 294) was greatest for land-cover classes 4 (58.84%) and 5 (grasslands and agriculture, 23.47%). Passage rates were high (minimum of 86.71%) for all classes (n = 7).

Meso-mammal movement under bridges (n = 585) was recorded most frequently (86.67%) when vegetation height was between 30 and 61 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 150 cm.

Use by meso-mammals was greatest (n = 4,841 of 6,186, 78.25%) when recorded presence of domestic predators was 3 or less. Contrary to this observation, use and occurrence of meso-mammals was high when number of domestic predators recorded was 32 and 104 (32—21.77% and 6.66%, and 104—39.80% and 10.05%, respectively). This demonstrates an anomaly to the general downward trend in meso-mammal use as a result of increased presence of domestic predators. Presence of domestic predators ranged from 0 – 104 records at bridges used by meso-mammals.

Meso-mammal use of culverts

Presence of meso-mammals at 162 culvert sites included records (n = 5,957) of five different species: armadillo *Dasypus novemcinctus*, Virginia opossum *Didelphis marsupialis*, raccoon *Procyon lotor*, and skunk *Mephitis sp*. or *Spilogale sp.*

Logistic regression model. The model was significant in predicting use of culverts by meso-mammals: Wald X^2: 577.04 (df—17, p <.0001), Nagelkerke's R^2 (0.3447), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 61.55 (df—8, p < 0.0001). Note that R^2 is less significant for meso-mammals using culverts, than for meso-mammals using bridges. Ten of 21 factors were found significant ($p < 0.03$) by the model in predicting use of culverts by meso-mammals. Percentage of movement through culverts correctly predicted by the model was 82.4%.

Response to structural characteristics. Five structural characteristics were significant in multiple logistic regression analysis. The majority of meso-mammals using culverts (77.44%, n = 4,271 of 5,515) were recorded when gap width was 7.5 m or less; presence but not passage (52.72%, n = 232 of 442) was frequently associated with gap widths of 8.5 m or more. Gap width (distance from adjacent habitat to culvert entrance) ranged from 0 – 39.3 m.

When AADT was from 3,200 to 8,400, records of passage through culverts by meso-mammals (n = 5,472) occurred 76.9% of the time. Presence recorded near culverts, but not crossing from one side to the other, was primarily recorded (76.02%) when AADT was 6,400 or higher. Range of AADT on roads where meso-mammals were recorded was 250 to 42,500.

For meso-mammals using culverts (n = 5,515), most occurred (93.36%) when culvert width was between the range of 0.5 to 3.5 m. Highest percentage of passage (19.37%) occurred at 3.1 m width. Presence but not passage (n = 442) was also associated predominantly (98.64%) with culvert widths of 0.5 to 3.5 m. Highest percentage of presence but not passage (42.08%) occurred at 0.9 m width. Width of culverts used by meso-mammals ranged from 0.3 – 4.3 m. Seventeen meso-mammals were recorded passing through culverts at the minimum width monitored of 0.3 m. Of 5,515 records of meso-mammals using culverts, most occurred (87.86%) when culvert height was between 0.6 to 1.5 m. Presence but not passage (n = 442) was also associated (89.83%) with culvert heights of 0.6 m to 1.5 m. Culvert height ranged from 0.3 – 3.7 m.

Passage (n = 5,515) by meso-mammals through culverts occurred relatively even across all distance intervals between crossing structures, with the exception of 950 m (16.77%). Presence (n = 442) by meso-mammals at culvert entrances was also recorded evenly, with one peak at 1,330 m (18.78%). Range of distance between structures was 110 to 5,750 m.

Response to environmental characteristics. Effects of three environmental measures identified from the logistic process are reported. Recorded passage through culverts (n = 5,515) was high during spring (26.24%), summer (33.42%) and fall (26.59%) months. Presence at (but not passage through) culverts (n = 442) was recorded mostly in fall and summer months (81.67%).

Of meso-mammals passing through culverts (n = 5,489) and present at culvert entrances (n = 440), most occurred (83.41% and 65.22%, respectively) when average maximum weekly temperature was 24 degrees C or higher. When average maximum weekly temperature was from 26 to 33 degrees C, 70.91% of movement through culverts was recorded. Average maximum weekly temperature at monitoring sites used by meso-mammals ranged between 12 and 35 degrees C.

Of 5,492 records of meso-mammals using culverts, most occurred (92.43%) when rainfall was 6 ml or less; and presence but not passage was also recorded predominantly (90.23%, n = 398 of 441) when rainfall was 6 ml or less. Average weekly rainfall at monitoring sites used by meso-mammals ranged between 0 and 25 ml.

Response to ecological characteristics. Primary habitat type at 210 m^2 scale and influence of presence of humans and domestic predators were identified as significant factors regarding culvert use by meso-mammals.

Passage through culverts (n = 5,515) by meso-mammals was the highest for 210 m^2 scale land-cover class 3 (pinelands, 22.41%) and lowest for class 2 (hardwood forests, 4.1%). Presence at (but not passage through) culverts (n = 442) was greatest for land-cover classes 3 (52.26%) and 4 (16.06%). Passage rates were high (minimum of 84.25%) for all classes (n = 7).

Use by meso-mammals decreased, when presence of humans increased at monitored sites. When no humans were recorded, use of culverts (n = 5,515) occurred 90.79% of the time. Presence at (but no passage through) the culvert also was greatest (90.95%, n = 402 of 442) when no human presence was recorded. Presence of humans ranged from 0 – 4 records at sites used by meso-mammals.

When presence of domestic predators increased at monitored sites, use by meso-mammals also decreased. Use of culverts (n = 5,515) occurred 76.28% of the time when one or less domestic predators were recorded. Similarly, presence at (but no passage through) the culvert was greatest (95.25%, n = 421 of 442) when recorded domestic predator presence was less than 2. Presence of domestic predators ranged from 0 – 4 records at culverts frequented by meso-mammals.

Carnivore use of bridges

Carnivore presence at 34 bridge sites included records (n = 384) of five species: black bear *Ursus americanus*, coyote *Canis latrans*, bobcat *Lynx rufus*, and fox *Urocyon sp.* or *Vulpes sp*.

Logistic regression model. The model was significant in two of three tests for predicting use of bridges by carnivores: Wald X^2: 45.30 (df—8, p <.0001), Nagelkerke's R^2 (0.5375), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 12.79 (df—8, p = 0.1193). Other combinations of explanatory variables were used in model simulations without improvement to the score for goodness-of-fit test. Partitions created for the goodness-of-fit test encountered too many zeros (for observed values in the nonuse category) and predicted 26% false negatives. Thus the model fit is questionable. Only 31 records were documented for nonuse of bridges, likely accounting for the weak score for the goodness-of-fit test. Only 6 of 21 factors were found significant ($p < 0.05$) by the model in predicting use of bridges by carnivores. Percentage of movement under bridges correctly predicted by the model was 90.9%.

Response to structural characteristics. Two significant structural parameters are described here that were identified by the regression model. Records of carnivores using bridges (n = 353) occurred most often (92.91%) when bridge height was less than 4 m. Presence but not passage (n = 31) was also associated predominantly (83.88%) with bridge heights less than 4 m. Height of monitored bridges used by carnivores ranged from 1.5 – 15 m.

Of 353 records of carnivores using bridges, two peaks occurred when distance to next nearest crossing structure was either 575 – 600 m (41.77%), or greater than 1,500 m (34.81%). Presence but not passage (n = 31) was notable regarding one distance, 1,050 m (53.33% of occurrences). Where carnivores were found, distance between structures ranged from 200 – 3,450 m.

Response to environmental characteristics. Season, temperature, and rainfall were all identified as significant factors associated with carnivore activity recorded near bridges. Carnivore passage under bridges (n = 353) occurred mostly during summer (25.21%), fall (36.83%), and winter (23.23%) months. Upon approach to bridge entrances carnivore passage rates were high for all seasons, 353 of 384 (91.93%). Presence at (but not passage under) bridges (n = 31) was recorded most frequently in fall and winter (80.64%).

Of 341 records of carnivores passing under bridges, most occurred (72.14%) when average, maximum, weekly temperature was 24 degrees C or higher. Presence at, (but not passage under) bridges (n = 31) showed a reverse trend where most movement (80.63%) was recorded when average, maximum, weekly temperature was 25 degrees C or less. Average, maximum, weekly temperature at these sites ranged between 12 and 34 degrees C.

Of 341 records of carnivores using bridges, most occurred (87.38%) when rainfall was 5 ml or less; and presence but not passage was also recorded predominantly (96.77%, n = 30 of 31) when rainfall was 5 ml or less. Average weekly rainfall at monitoring sites where carnivores were recorded ranged between 0 and 18 ml.

Response to ecological characteristics. Only domestic predators were identified in the regression analysis as a significant factor. When presence of domestic predators increased at monitored sites, use by carnivores decreased. Passage by carnivores (n = 302 of 353, 85.55%) coincided with 6 or less records of domestic predators. Approximately 51% of carnivores, that approached but did not pass under bridges, were recorded at sites where 104 domestic predators had been recorded. Presence of domestic predators ranged from 0 – 104 records at sites monitored.

Carnivore use of culverts

Records (n = 315) of carnivores at 51 culvert sites included five species: black bear *Ursus americanus*, coyote *Canis latrans*, bobcat *Lynx rufus*, and fox *Urocyon sp.* or *Vulpes sp*.

Logistic regression model. The model was significant in two of three tests for predicting use of culverts by carnivores: Wald X^2: 59.95 (df—5, p <.0001), Nagelkerke's R^2 (0.6462), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 12.74 (df—8, p = 0.1211). Other combinations of explanatory variables were used in model simulations without improvement to the score for goodness-of-fit test. Partitions created for the goodness-of-fit test encountered too many zeros (for observed values in the nonuse category) and predicted 24% false negatives. Thus the model fit is questionable. Only 57 records were documented for nonuse of bridges, likely accounting for the weak score for the goodness-of-fit test. Only 5 of 21 factors were found significant (p < 0.02) by the model in predicting use of culverts by carnivores. Percentage of movement through culverts correctly predicted by the model was 91.9%.

Response to structural characteristics. Four structural factors were identified in regression analysis. Carnivore movement (n = 258) through culverts was greater the less culvert cells were available (i.e., 1—41.85%, 2—32.55%, 3—25.58%). Carnivore presence (n = 57) at culvert entrances was highest for single and three cell configurations (50.88% and 42.11%, respectively).

When AADT was from 3,200 to 11,000, records of passage through culverts by carnivores (n = 258) occurred 90.32% of the time. Presence recorded near culverts, but not crossing from one side to the other, was primarily recorded (84.23%) when AADT was 6,900 or higher. Range of AADT on roads where carnivores were recorded was 250 to 31,500.

When culvert width was greater than 1 m, most records of carnivores using culverts occurred (n = 217 of 258; 84.3%). Highest percentage of passage (36.78%) occurred at 2.4 m width. Presence but not passage (n = 57) increased as culvert widths decreased (94.43% occurrence at widths less than 2 m). Highest frequency (53.7%) of presence (but not passage) occurred at 0.9 m width. Culvert widths where carnivores were recorded ranged from 0.3 – 3.7 m.

Of 258 records of carnivores using culverts, most occurred (86.03%) when distance to next nearest crossing structure was 875 m or more. Presence but not passage (n = 57) was notable regarding distances from 900 to 1,360 m (65% of occurrences). Where carnivores were found, distance between structures ranged from 125 – 5,750 m.

Response to ecological characteristics. When presence of domestic predators increased at culvert sites, use by carnivores decreased. Most passage by carnivores (92.15%, n = 238 of 258) coincided with 2 or less records of domestic predators. Presence of domestic predators ranged only from 0 – 4 records at culvert sites where carnivores were recorded.

Avian use of bridges

Avian presence at 27 bridge sites included records (n = 208) of three species—wild turkey *Meleagris gallopavo*, common bobwhite *Colinus virginianus*, and great blue heron *Ardea herodias*; one family of wading birds—*Ardeidae* (herons and egrets); and one order—*Passeriformes* (songbirds or perching birds).

Logistic regression model. The model was significant for predicting use of bridges by birds: Wald X^2: 22.27 (df—5, $p < .0001$), Nagelkerke's R^2 (0.5386), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 33.28 (df—7, $p < 0.0001$). Only 5 of 21 factors were found significant ($p < 0.01$) by the model in predicting use of bridges by birds. Percentage of movement under bridges correctly predicted by the model was 91%.

Response to structural characteristics. Three structural factors were identified in regression analysis for birds and bridges. The majority (75.68%) of birds using bridges (n = 177) were recorded when gap width was 8.5 m or less; presence but not passage was also associated mostly (83.87%, n = 26 of 31) with gap widths of 8.5 m or less. Gap width (distance from adjacent habitat to bridge entrance) ranged from 5.3 – 28.4 m.

Records of birds using bridges occurred most often (81.89%) when bridge width was less than 50 m. Presence but not passage (n = 31) was associated principally (80.65%) with bridge widths of 38 to 60 m. Bridge width of sites monitored ranged from 7.3 – 200 m. Of 177 records of birds using bridges, most occurred (92.64%) when bridge height was between 1.5 to 3.7 m. Presence but not passage (n = 31) was associated primarily (16.13%) with bridge heights of 3.1 m (74.19%) and 7.3 to 7.6 m. Bridge height ranged from 1.2 – 7.6 m.

Response to environmental characteristics. Only average, minimum, weekly temperature was a significant factor from logistic regression analysis. Records of birds using bridges (n = 165) were distributed relatively even; average, minimum, weekly temperature at monitoring sites ranged between -2 and 23 degrees C. For birds only recorded at bridge entrances (n = 30), most occurred (86.66%) when average, minimum, weekly temperature was 10 degrees C or lower.

Response to ecological characteristics. Habitat diversity at 30 m^2 resolution was the single significant factor identified in logistic regression. Birds recorded (n = 177) using bridges were greatest (89.93%) when 3 land-cover types were present at the 30 m^2 cell resolution. Similarly, presence of birds (n = 31) near bridge entrances was greatest (93.55%) when 3 land-cover types were present. Only 1 record occurred at sites where the maximum 4 land-cover types existed.

Avian use of culverts

Avian presence from 16 culvert sites included records (n = 115) of one species—wild turkey *Meleagris gallopavo*; one family of wading birds—*Ardeidae* (herons and egrets); and one order—*Passeriformes* (songbirds or perching birds).

Logistic regression model. The model was significant in two of three tests for predicting use of culverts by birds: Wald X^2: 11.59 (df—2, p= 0.003), Nagelkerke's R^2 (0.8582), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 0.51 (df—5, p = 0.99). Large sample sizes are preferred for conducting logistic regression analysis and thus the small sample size (n = 115) likely accounts for the poor score for the goodness-of-fit test. Accuracy of the model is questionable. Only 2 of 21 factors were found significant ($p < 0.01$) by the model in predicting use of culverts by birds. Percentage of movement through culverts correctly predicted by the model was 96.2%.

Response to structural characteristics. Culvert width was the only structural measure of importance in the logistic model for birds and culverts. Of 81 records of birds using culverts, nearly all occurred (98.76%) when culvert width was greater than 2 m. Presence but not passage (n = 34) was more variable (e.g., 0.6 m—32.35% and 2.4 m—47.06%). No birds were recorded passing through culverts less than 1.5 m wide. Culvert width ranged from 0.3 – 3.1 m.

Response to environmental characteristics. Birds passing through culverts (n = 81) occurred most often (75.31%) when average, maximum, weekly temperature was 25 degrees C or lower. Bird presence at culvert entrances (n = 33) frequently occurred (75.75%) when average, maximum, weekly temperature was greater than 20 degrees C. Average, maximum, weekly temperature at monitoring sites ranged between 13 and 34 degrees C.

Ungulate use of bridges

The ungulate group included records (n = 522) of two species—white-tailed deer *Odocoileus virginianus*, and wild pig/hog *Sus scrofa*—from 41 bridge sites.

Logistic regression model. The model was significant in one of three tests for predicting use of bridges by ungulates: Wald X^2: 17.96 (df—4, p =.0013), Nagelkerke's R^2 (0.2610), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 5.42 (df—8, p = 0.71). Large sample sizes are preferred for conducting logistic regression analysis; although we had over 500 records of ungulates crossing under bridges, only 13 records were documented for nonuse of bridges, likely accounting for the poor scores for the goodness-of-fit and R^2 tests. Accuracy of the model is questionable. Only 4 of 21 factors were found significant ($p < 0.04$) by the model in predicting use of bridges by ungulates. Percentage of movement under bridges correctly predicted by the model was 79.6%.

Response to structural characteristics. Bridge height was the only significant structural factor identified in logistic regression analysis. Of 509 records of ungulates using bridges, most occurred (84.87%) when bridge height was between 2.1 and 6.1 m. Presence but not passage (n = 13) occurred mainly (76.92%) with bridge heights of 3.1 to 3.7 m. Bridge height ranged from 1.5 – 9.2 m.

Response to ecological characteristics. Three significant factors were identified from logistic regression analysis: habitat diversity at 30 and 210 m^2 scales and frequency of presence of domestic predators. Ungulates recorded (n = 509) using bridges were greatest (67.39%) when 3 land-cover types were present at the 30 m^2 cell resolution. Bridges with 2 land-cover types had the second highest number of ungulate use (23.18%). Presence of ungulates (n = 13) near bridge entrances was recorded only when 2 – 3 land-cover types were present. Habitat diversity ranged from 1 to 4 land-cover types present at the 30 m^2 scale. Most movement under bridges by ungulates (84.03%) occurred at sites where 4 or less land-cover groups were present at the 210 m^2 level. Presence of ungulates (n = 13) near bridge entrances was recorded when 3 – 6 land-cover types were present. Habitat diversity ranged from 1 to 7 distinct land-cover groups.

When presence of domestic predators increased at monitored sites, use by ungulates decreased. Bridge use (90.17%, n = 459 of 509) coincided with 6 or less records of domestic predators. When 2 or less domestic predators were recorded, predator use and presence was 73.08% and 84.61%, respectively. Records of domestic predators ranged from 0 – 104 records at sites monitored.

Ungulate use of culverts

Two species of ungulates (n = 43)—white-tailed deer *Odocoileus virginianus*, and wild pig/hog *Sus scrofa*—were recorded at 19 culvert sites. Due to small sample size, logistic regression analysis could not be performed for the ungulate-culvert group. Even so, thresholds of culvert use by ungulates are included in the discussion.

Herpetofaunal use of bridges

Herptile presence at 28 bridge sites included records (n = 1,989) of 15 species—southern leopard frog *Rana utricularia*, southern toad *Bufo terrestris*, green tree frog *Hyla cinerea*, Cuban tree frog *Osteopilus septentrionalis*, six-lined racerunner *Cnemidophorus sexlineatus*, anole *Anolis spp*., fence lizard *Sceloporus undulatus*, cottonmouth *Agkistrodon piscivorus*, timber rattlesnake *Crotalus horridus*, southern black racer *Coluber constrictor*, yellow rat snake *Elaphe obsoleta*, alligator snapping turtle *Macroclemys temminckii*, snapping turtle *Chelydra serpentina*, Florida cooter *Pseudemys floridana* and Florida box turtle *Terrapene carolina bauri*; and four orders/suborders—frog/toad *Anura*, lizard *Squamata: Lacertilia*, snake *Squamata: Serpentes*, and turtle/tortoise *Testudines*.

Logistic regression model. The model was highly significant for predicting use of bridges by herpetofauna: Wald X^2: 210.92 (df—12, p <.0001), Nagelkerke's R^2 (0.7472), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 30.62 (df—6, p < 0.0001). Ten of 21 factors were found significant (p < 0.03) by the model in predicting use of bridges by herpetofauna. Percentage of movement under bridges correctly predicted by the model was 92.9%.

Response to structural characteristics. Five structural variables were found significant in the logistic regression: gap width, AADT, bridge width, bridge length, and bridge height. Of 848 records of herpetofauna using bridges, most occurred (82.54%) when gap width was 7.9 to 8.5 m. Records of presence but not passage (94.66%, n = 1,080 of 1,141) were also associated with gap widths of 7.9 to 8.5 m. Passage rate at these gap widths was 64.8%. Gap width (distance from adjacent habitat to bridge entrance) ranged from 4.9 – 16.5 m.

When AADT was greater than 6,400, passage under bridges by herpetofauna (n = 848) occurred only 11.09% during the period monitored. Most passage occurrences by herpetofauna (39.27%, and 34.67%, respectively) were recorded when AADT was at 2 separate levels, 250 and 6,400. Presence recorded near bridges, but not crossing from one side to the other, was primarily recorded (88.96%, 1,015 of 1,141) when AADT was 6,400. At 6,400 AADT, passage rate was only 22.46%. Range of AADT on roads where herptiles were recorded was 250 to 24,000.

Passage under bridges by herptiles occurred largely (82.32%) when bridge width was less than 40 m. Presence but not passage (n = 1,141) was associated chiefly (89%) with 38 m bridge width. Bridge width of sites monitored ranged from 19.2 – 152.5 m. Of 848 records of herpetofauna using bridges, the majority occurred (82.45%) when bridge length (distance that organisms had to travel to pass through the structure) was 8.5 m or less. Presence but not passage (n = 1,141) was also associated predominantly (94.66%) with bridge lengths less than 8.5 m. Bridge lengths at sites used by herptiles ranged from 7.3 – 38.4 m. Of 848 records of herpetofauna using bridges, most occurred when bridge height was between two size ranges, 1.5 to 1.8 m (48.94%) and 3.1 to 3.7 m

(47.52%). Presence but not passage (n = 1,141) was associated primarily (98.25%) with bridge heights of 3.1 to 3.7 m. In this case, bridge height ranged from 1.2 – 7.3 m.

Response to environmental characteristics. Four significant environmental parameters were reported in the logistic regression model and include seasonality, minimum and maximum temperature, and rainfall. Passage under bridges (n = 848) and presence at (but not passage under) bridges (n = 1,141) by herpetofauna occurred 77.6% and 86.59% of the time during spring and summer months. The highest passage rate was recorded in fall (154 of 204, 75.49%), and the highest number of passages occurred in spring (383 of 848, 45.17%).

Of 840 records of herpetofauna passing under bridges most occurred (90.82%) when average, minimum, weekly temperature was 10 degrees C or higher. Presence at (but not passage under) bridges showed the same trend (93.86% occurred at average, minimum, weekly temperatures of 10 degrees C and above). Average, minimum, weekly temperature at monitoring sites ranged between 1 and 24 degrees C. Records (n = 840) of herpetofauna passing under bridges occurred most often (89.17%) when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature was from 26 to 28 degrees C, 45.59% of movement under bridges was recorded. Presence at (but not passage under) bridges (n = 1,141) were similar, as 78.43% occurred when average, maximum, weekly temperature was 25 degrees C or higher. Average, maximum, weekly temperature at monitoring sites ranged between 15 and 34 degrees C.

Of 843 records of herpetofauna using bridges, nearly all occurred (90.75%) when rainfall was 5 ml or less; and presence (but not passage) was also recorded principally

(85.19%, n = 972 of 1,141) when rainfall was 5 ml or less. Average weekly rainfall at monitoring sites ranged between 0 and 14 ml.

Response to ecological characteristics. Three important response variables were identified from logistic regression analysis. These include right-of-way vegetation height, primary habitat at 30 m^2 resolution, and human presence. Herpetofaunal movement under bridges (n = 731) was recorded most frequently (77.98%) when vegetation height was between 31 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 5 to 122 cm.

Bridges where herptiles were recorded occurred in only two 30 m^2 scale primary habitat types, 4 (wetlands) and 7 (hardwood forests). Higher passage rates for herpetofauna were recorded at bridges in habitat type 4 (86.54%) than type 7 (23.58%).

Use of bridges (n = 848) occurred 52.47% of the time when 5 or less humans were recorded. To the contrary, another peak in culvert use (43.04%) occurred when 73 or more humans were recorded. Presence of humans ranged from 0 – 110 records at sites monitored. Similar to the latter, 94.31% (n = 1,076 of 1,141) of records of herptile presence at bridge entrances occurred when 73 or more humans were recorded over the course of the study.

Herpetofaunal use of culverts

Presence of herptiles at 106 culvert sites included records (n = 1,489) of twelve species—southern leopard frog *Rana utricularia*, green tree frog *Hyla cinerea*, six-lined racerunner *Cnemidophorus sexlineatus*, five-lined skink *Eumeces spp.*, anole *Anolis spp*., fence lizard *Sceloporus undulatus*, cottonmouth *Agkistrodon piscivorus*, southern black racer *Coluber constrictor*, eastern garter snake *Thamnophis sirtalis*, striped mud turtle

Kinosternon baurii, snapping turtle *Chelydra serpentina*, and alligator snapping turtle *Macroclemys temminckii*; and four orders/suborders—frog/toad *Anura*, lizard *Squamata*: *Lacertilia*, snake *Squamata*: *Serpentes*, and turtle/tortoise *Testudines*.

Logistic regression model. The model was highly significant for predicting use of culverts by herpetofauna: Wald X^2: 330.78 (df—23, $p < .0001$), Nagelkerke's R^2 (0.7730), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 49.68 (df—8, $p < 0.0001$). Twelve of 21 factors were found significant ($p < 0.05$) by the model in predicting use of culverts by herpetofauna. Percentage of movement through culverts correctly predicted by the model was 94.9%.

Response to structural characteristics. Six structural factors were found significant by the model of logistic regression: gap width, AADT, culvert width, height, and number of cells, and distance to next nearest structure. Of 580 records of herpetofauna using culverts, most occurred (80.84%) when gap width was 3.7 to 7.3 m. Presence but not passage was associated principally (97.8%, n = 889 of 909) with gap widths less than 9 m. Gap width ranged from 0 – 39.3 m.

When AADT was 8,400 or greater, passage through culverts by herpetofauna (n = 580) occurred only 7.91% during the period monitored. Most passage occurrences by herpetofauna were recorded when AADT was at 4 separate levels: 250, 3,900, 6,500 and 8,100 (16.72%, 14.14%, 13.10% and 16.72%, respectively). Presence near culverts, but not crossing from one side to the other, was most frequently recorded when AADT was 3900 (21.35%) and 7,700 (25.06%). Range of AADT on roads at sites monitored was 250 to 42,500.

Herpetofauna were recorded using culverts most frequent (84.15%) when culvert width was 1.5 m or wider. Presence but not passage (n = 909) was associated largely (95.34%) with culvert widths less than 1 m. Culvert width ranged from 0.3 – 3.7 m. Of 580 records of herptiles using culverts, most occurred (95.34%) when culvert height ranged between 0.6 and 1.5 m. Presence but not passage (n = 909) was associated predominantly (83.71%) with culvert heights less than 1 m. Culvert height ranged from 0.3 – 3.4 m. Passage rate (72%) through culverts was greatest when multiples of 2 – 3 cells were present; passage rate at sites with 1 or 4 cells was less than 25%. Presence at (but not passage through) culverts was recorded mostly (82.84%) with single cell culverts.

Records of passage through culverts (n = 580) by herpetofauna coincided most often (72.07%) with distances between structures of 875 to 1,225 m. Range of distance between structures was 125 to 3,150 m.

Response to environmental characteristics. Three environmental factors of significance to herptiles using culverts include seasonality, and minimum and maximum temperature. Recorded passage through culverts (n = 580) was high during spring (43.28%) and summer (41.55%) months. Presence at (but not passage through) culverts (n = 909) was recorded mostly (73.82%) in summer months. Only ten records of herpetofauna were recorded in the winter months.

Regarding herpetofauna passing through culverts (n = 578) or present at culvert entrances (n = 908), most occurred (97.23% and 99.45%, respectively) when average, minimum, weekly temperature was 10 degrees C or higher. Average, minimum, weekly temperature at monitoring sites ranged between 0 and 24 degrees C. Of herpetofauna passing through culverts (n = 578) and present at culvert entrances (n = 908), nearly all occurred (94.29% and 95.71%, respectively) when average, maximum, weekly temperature was 26 degrees C or higher. Average, maximum, weekly temperature at monitoring sites ranged between 15 and 35 degrees C.

Response to ecological characteristics. Three different ecological parameters were significant in logistic regression analysis. These include primary habitat at 210 m^2 scale, and right-of-way vegetation type and height. Passage through culverts (n = 580) by herpetofauna was the highest for 210 m^2 scale land-cover classes 3 (pinelands, 18.28%), 4 (wetlands, 14.31%), 6 (shrub and brushlands, 37.93%), and 7 (hardwood forests, 17.93%). Presence at (but not passage through) culverts (n = 909) was greatest for land-cover classes 2 (xeric lands, 29.70%), 3 (18.81%), 4 (16.94%) and 6 (15.07%). Passage rates were greatest for classes 6 (220 of 357, 61.62%) and 7 (104 of 124, 83.37%).

Movement through culverts (n = 580) occurred 80.69% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at but not movement through culverts (n = 909) was also significant (91.08%), still showing preference for some level of herbaceous groundcover presence. Herpetofaunal movement through culverts (n = 580) was recorded most frequently (86.93%) when vegetation height was greater than 30 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 183 cm.

Small mammal use of bridges

The small mammal group included records (n = 5,142) of three species—rabbit *Sylvilagus spp*., gray squirrel *Sciuris carolinensis*, and eastern mole *Scalopus aquaticus*; and members of one family—*Cricetidae* (mice, rats, voles) from 39 bridge sites.

Logistic regression model. The model was highly significant for predicting use of bridges by small mammals: Wald X^2: 445.43 (df—19, p <.0001), Nagelkerke's R^2 (0.8126), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 43.79 (df—8, p < 0.0001). Twelve of 21 factors were found significant (p < 0.05) by the model in predicting use of bridges by small mammals. Percentage of movement under bridges correctly predicted by the model was 96.8%.

Response to structural characteristics. Six structural variables were identified in the logistic regression model that includes: gap width, AADT, bridge width, length and height, and distance to next nearest structure. Of 618 records of small mammals using bridges, nearly all occurred (90.3%) when gap width was 8.5 m or less; and presence but not passage was also associated predominantly (92.27%, n = 4,174 of 4,524) with gap widths of 8.5 m or less. Gap width ranged from 3.1 – 16.5 m.

When AADT was greater than 6,400, passage under bridges by small mammals occurred only 6.31% (39 of 618) during the period monitored. Most passage occurrences by small mammals were recorded (51.78%, 320 of 618) when AADT was only 250. Presence recorded near bridges, but not crossing from one side to the other, was significantly reduced (12.45%, 563 of 4,255) when AADT was higher than 9,900. Range of AADT on roads at sites monitored was 250 to 42,054.

Of 618 records of small mammals using bridges, most occurred (88.02%) when bridge width was less than 50 m. Presence but not passage (n = 4,524) was associated principally (89%) with bridge widths of 60 m or less. Bridge width of sites monitored ranged from 19.2 – 200 m. Small mammals using bridges were recorded primarily (89.33%) when bridge length was less than 14 m. Almost 70% of bridge use occurred when length was 8.2 m or less. Presence but not passage (n = 4,524) was also associated predominantly (92.29%) with bridge lengths less than 14 m. Bridge length ranged from 7.3 – 41.5 m. Of 618 records of small mammals using bridges, most occurred when bridge height was between two size ranges, 1.5 to 2.4 m (64.56%) and 3.1 to 3.7 m (33.01%). Presence but not passage (n = 4,524) was also associated predominantly with bridge heights of 1.5 to 2.4 m (19.12%) and 3.1 to 3.7 m (80.59%). Bridge height ranged from 3.1 – 7.6 m.

When distance between structures was greater than 1,000 m, passage under bridges by small mammals occurred only 25.56% (158 of 618) during the period monitored. Most passage occurrences by small mammals (55.97%, 346 of 618) were recorded when distance was less than 700 m. Range of distance between structures was 130 to 3,450 m.

Response to environmental characteristics. Three environmental parameters of significance include seasonality, and minimum and maximum temperature. Passage under bridges (n = 618) occurred 86.25% of the time during spring and summer months. Spring months exhibited the highest passage rate, where 375 of 1,231 (30.46%) that approached bridge entrances passed through to the other side. Passage upon approach to bridge entrances for other seasons was less than 13%. Presence at (but not passage under) bridges (n = 4,524) showed no significant seasonal differences.

Of 618 records of small mammals passing under bridges most occurred (95.31%) when average, minimum, weekly temperature was 10 degrees C or higher. Presence at (but not passage under) bridges showed no significant difference regarding low temperature. Average, minimum, weekly temperature at monitoring sites ranged between -1 and 24 degrees C. Small mammal passage under bridges, occurred most often (94.5%) when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature was from 26 to 28 degrees C, 62.31% of movement under the bridge was recorded. Presence at (but not passage under) bridges showed no significant difference regarding high temperature. Average, maximum, weekly temperature at monitoring sites ranged between 12 and 34 degrees C.

Response to ecological characteristics. Four significant factors were found from logistic regression analysis: right-of-way vegetation type and height, and frequency of disturbance from humans and domestic predators. Movement under bridges (n = 618) occurred 95.63% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at (but not movement under) bridges (n = 4,524) was less significant (75.55%); but still showed preference for some level of herbaceous groundcover presence. Small mammal movement under bridges (n = 585) was recorded most frequently (88.54%) when vegetation height was between 30 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 122 cm.

When presence of humans increased at monitored sites, use by small mammals decreased. Use of culverts (n = 618) occurred 55.18% of the time when 1 or less humans were recorded; 68.61% of the time when 5 or less humans were recorded; and 83.66% of the time when 27 or less humans were recorded. Presence of humans ranged from 0 – 110 records at sites monitored. A reverse trend existed with presence at (but no passage under) bridges, where 72.86% (n = 3,296 of 4,524) occurred when 16 or more humans were recorded over the course of the study. When presence of domestic predators increased at monitored sites, use by small mammals decreased. Use (88.9%) and occurrence (82.28%) coincided with 3 or less records of domestic predators. Presence of domestic predators ranged from 0 – 104 records at sites monitored.

Small mammal use of culverts

The small mammal group that used culverts included records (n = 10,656) of four species—eastern cottontail *Sylvilagus floridanus*, rabbit *Sylvilagus spp*., Florida water rat *Neofiber alleni*, and eastern mole *Scalopus aquaticus*; and members of one family—*Cricetidae* (mice, rats, voles) from 108 monitoring sites.

Logistic regression model. The model was highly significant for 2 of 3 tests in predicting use of culverts by small mammals: Wald X^2: 480.74 (df—31, p <.0001), Nagelkerke's R^2 (0.3914), and Hosmer and Lemeshow Goodness-of-Fit Test, X^2: 35.95 (df—8, p < 0.0001). Note that R^2 is less significant for small mammals using culverts than in the previous model for small mammals using bridges. Fifteen of 21 factors were found significant (p < 0.05) by the model in predicting use of culverts by small mammals. Percentage of movement through culverts correctly predicted by the model was 86.6%.

Response to structural characteristics. The four explanatory variables selected by the logistic regression model were AADT, number of culverts cells, culvert width and length. Records of passage through culverts (n = 270) by small mammals occurred primarily (87.05%) at sites where AADT was less than 8,000 vehicles-per-day; and most occurrences without passage through the culvert (69.63%, n = 7,232 of 10,386) were recorded at sites with AADTs of 5,800 to 9,900. Annual-average-daily traffic for sites where small mammals were recorded ranged from 250 to 29,500.

Passage rate (88.89%) through culverts was greatest when multiples of four cells were present; sites with 1 to 3 cells were negligible (approximately 1 – 3%). Presence at (but not passage through) culverts was recorded mostly (50.33%) with single cell culverts. Of 270 records of small mammals using culverts, most occurred (90.73%) when culvert width was from 0.6 to 3.1 m. Presence but not passage (n = 10,386) was associated predominantly with culvert widths of 0.5 to 1.2 m and 2.4 m (50.81% and 32.34%, respectively). Culvert width ranged from 0.3 – 4.3 m. Culvert use by small mammals was primarily recorded (84.8%) when culvert length was 22 m or less. Presence near culvert entrances (n = 10,386) was largely connected (88.4%) with culvert lengths of 14 to 22 m. Culvert length ranged from 9.2 – 49.4 m.

Response to environmental characteristics. Four significant environmental factors include seasonality, minimum and maximum temperature, and rainfall. Passage through culverts (n = 270) occurred 73.7% of the time during spring and summer months. Presence at (but not passage through) culverts (n = 10,386) was recorded mostly (64.46%) in fall and spring months.

Regarding small mammals passing through culverts (n = 270) or present at culvert entrances (n = 10,386), most occurred (90.74% and 90.94%, respectively) when average, minimum, weekly temperature was 5 degrees C or higher. Average, minimum, weekly temperature at monitoring sites ranged between -1 and 24 degrees C. Of small mammals passing through culverts (n = 270) and present at culvert entrances (n = 10,386), most occurred (76.29% and 74.38%, respectively) when average, maximum, weekly temperature was 25 degrees C or higher. When average, maximum, weekly temperature varied from 26 to 32 degrees C, 62.95% of movement through culverts was recorded. Average, maximum, weekly temperature at monitoring sites ranged between 12 and 35 degrees C.

Of 270 records of small mammals using culverts, most occurred (94.82%) when rainfall was 6 ml or less; and presence but not passage was also recorded predominantly (93.88%) when rainfall was 6 ml or less. Average weekly rainfall at monitoring sites ranged between 0 and 22 ml.

Response to ecological characteristics. Seven different ecological variables were significant by logistic regression analysis. These include primary habitat at 30 and 210 m^2 scales, right-of-way vegetation type and height, habitat diversity at 30 and 210 m^2 scales, and frequency of disturbance from human presence and domestic predators. Passage through culverts (n = 270) by small mammals was the highest for 30 m^2 scale land-cover classes 2 (xeric lands, 14.81%), 3 (pinelands, 25.56%), 4 (wetlands, 18.52%), and 7 (hardwood forests, 38.15%). Presence at (but not passage through) culverts (n = 10,386) was also greatest for land-cover classes 2 (17.56%), 3 (21.54%), 4 (27.68%), and 7 (27.65%). Passage through culverts (n = 270) by small mammals was the highest for 210 m^2 scale land-cover classes 3 (22.59%), 4 (17.04%), 5 (grasslands and agriculture, 14.44%), and 6 (shrub and brushlands, 24.81%). Presence at (but not passage through) culverts (n = 10,386) was greatest for land-cover classes 3 (22.33%), 4 (21.26%), and 6 (22.67%).

Movement through culverts (n = 270) occurred 97.41% of the time when herbaceous groundcover (either alone or combined with barren areas or shrubs) was present. Presence at but no movement through culverts (n = 10,386) was also significant (91.28%); still showing preference for some level of herbaceous groundcover presence. Small mammal movement through culverts (n = 260) was recorded most frequently (73.44%) when vegetation height was between 20 and 50 cm. Right-of-way vegetation height at monitoring sites ranged from 0 to 208 cm.

Small mammal use of culverts was highest (65.56%) when habitat diversity comprised 3 different land-covers at the 30 m^2 cell resolution. When 2 land-cover types were present, passage through culverts was recorded 75 times (27.78%). Similar percentages occurred (3—60.79%, 2—33.42%) for those individuals that were present at culvert entrances only. Insufficient records occurred at sites where the maximum 5-land-cover types existed. Small mammals recorded using culverts was highest (40%) with habitat diversity comprised of 3 different land-covers at the 210 m^2 cell resolution. When 2 land-cover types were present, passage through culverts was recorded 75 times (27.78%). Similar percentages occurred (3—48.29%, 2—21.33%) for those individuals that were present at culvert entrances only. Insufficient records occurred at sites where the maximum 6 land-cover types existed.

When presence of humans increased at monitored sites, use by small mammals decreased. Use of culverts (n = 270) occurred 90.37% of the time when no humans were recorded. Similarly, presence at (but no passage through) the culvert was greatest (78.87%, n = 8,191 of 10,386) when no human presence was recorded. Presence of humans ranged from 0 – 4 records at sites monitored where small mammals were recorded. Small mammals preferred sites where domestic predators were absent, whether present at or passing through culverts. Most occurred when domestic predator records were zero (63.97% and 59.26%, respectively) or one (15.97% and 27.04%, respectively). The range of records of domestic predators, where small mammals occurred, was only 0 – 4 at sites monitored.

Alligator and aquatic mammal use of culverts and bridges

A consolidated group of aquatic dependents included three species—alligator *Alligator mississippiensis* (n = 25), river otter *Lutra canadensis* (n = 31), and beaver *Castor canadensis* (n = 5) from 15 culvert and 13 bridge sites. Even when combined into one group, sample size was too small to perform logistic regression.

Discussion

Several studies have demonstrated wildlife movement through culverts and bridges under roadways. Most case studies have shown use by specific species of specific structures, e.g. Florida panther—I-75 bridges, Florida black bear—2.4 x 7.3 m culvert, bobcat and raccoon—1.8 x 1.8 m (Hewitt et al. 1998, Norman et al. 1998, and Boarman et al. 1996). Other studies involved use of wildlife ecopassages designed for large targeted species (Clevenger and Waltho 2000, Foster and Humphrey 1996, and Roof et al. 1996). Yet smaller concrete culverts and tunnels originally designed for drainage under roadways have also been used as wildlife passages by a wide variety of small to medium size mammals (Rodriguez et al. 1996, Yanes et al. 1995, and Hunt et al. 1987) and many species of amphibians (Brehm 1989, Dexel 1989, and Norden 1990). All these studies agree that culverts are useful mitigation measures for movement of animals under roadways; however, none have provided comprehensive evaluations of effectiveness according to a wide distribution of structure sizes and contexts.

The objective of this study was broader; specifically, it was set up to determine design standards for drainage culverts and bridges (to enhance and improve use by a wide variety of wildlife). Yet additionally it addressed larger issues, such as improving overall landscape connectivity of important large-scale ecological linkages. This structure classification system would serve as a reference for transportation agencies when programming mitigation measures for wildlife mortality on highways (based on type of species present and landscape context).

Comparison of Structure Use Among Faunal Groups

Six distinct faunal groups were used for analysis. Similarities and differences regarding use of crossing structures are evident among the groups. Table 4-9 summarizes findings of common parameters for all structures by each faunal group. Three thresholds for each parameter represent liberal to conservative measures of passage success by each faunal group.

Thresholds for contextual parameters

To sustain 90% of crossings made by each faunal group, only 3.7 m of open right-of-way separated the structure entrances from the adjacent habitat (Table 4-9). As the level of sustainability is decreased, differences occur among groups for maximum gap distance. At 75%, the gap width increases to 5.1 and 7.7 m for small mammals and ungulates, respectively. Gap width was statistically significant for the smaller species recorded using crossing structures: meso-mammals, small mammals, herpetofauna, and birds. A distance of 3.7 to 5.1 m from adjacent habitat to structure entrances is recommended to promote high levels of movement for all species.

The gap width can be mitigated in part by right-of-way vegetation type and height. All groups preferred presence of herbaceous vegetation, and in some cases addition of shrubs. Right-of-way vegetation height generally consisted of three minimum thresholds among the faunal groups: 5 cm for birds and ungulates, 10 cm for carnivores, and 20 cm for meso-mammals, herptiles, and small mammals (Table 4-9). Maximum height preferences varied from 50 to 92 cm. Right-of-way vegetation height was a significant factor only for small mammals and herpetofauna. This would coincide with the need for cover from larger mammalian predators and birds of prey. Given specific exceptions, at least 20 cm groundcover should be maintained at all crossing sites; with addition of larger shrubs strategically placed to provide cover for larger, sensitive species, such as white-tailed deer. An example of one exception would include xeric habitats, where open sandy areas are preferred by certain species. The best recommendation regarding type of right-of-way vegetation would be the use of plant species that are the same as those in adjacent habitat, with slightly greater cover near entrances to crossing structures (to provide security for prey species).

Distance between structures was a significant factor regarding use by meso-mammals, carnivores, herpetofauna, and small mammals. A maximum distance of 200 to 250 m between crossing structures was necessary to sustain 90% passage for all groups, except carnivores. The maximum recommended distance is 325 m within core conservation areas and habitat corridors, corresponding to at least 75% use by small mammals. This distance is similar to that recommended by Clevenger et al. (2001).

Table 4-9. Levels of use by faunal groups for common parameters of all study sites

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n = 11,701)	**Carnivores** (n = 611)	**Birds** (n = 258)	**Ungulates** (n = 573)	**Herpeto-fauna** (n = 1,428)	**Small mammals** (n = 888)
gap width (distance to habitat), m	3.7 5.3 5.8	3.7 5.8 7	3.7 6.8 7.9	5.8 7.7 8.1	3.7 6.4 7.8	3.7 5.1 7.9
AADT, annual avg. vehicles / day	250 3,000 5,000	3,200 6,400 6,500	250 3,000 3,200	3,400 6,100 6,709	250 250 3,900	250 250 1,900
distance between structures, m	250 560 775	585 600 875	250 600 775	200 600 670	260 625 875	250 325 585
human presence, no. / year.	4 46 69	3 7 30	3 10 46	3 7 17	3 17 46	1 8 46
domestic predators, no. / year	1 1 20	1 1 3	1 1 1	1 1 4	1 1 1	1 1 20
Preferences						
row vegetation type	herbaceous	herbaceous	herb – shrub	herb – shrub	herb – shrub	herb – shrub
row vegetation height, cm	20 – 70, 82%	10 – 75, 79%	5 – 60, 85%	5 – 91, 78%	20 – 92, 79%	20 – 50, 85%
soil moisture and precipitation	dry – moist	dry – moist	dry	dry – moist	dry	dry
habitat diversity 30m^2	3	3	3	3	3	2 – 3
primary habitat 30m^{2} *	4, 8	4, 7, 8	4, 8	4, 7, 8	4, 8	4, 8
habitat diversity 210m^2	2 – 4	1 – 4	3 – 4	3 – 4	2 – 4	3 – 4
primary habitat 210m^{2} *	3, 4, 7	3, 4, 6	3, 4, 7	3, 6, 7	3, 4, 7	4, 7
season	fall, summer	-	winter	-	spring, summer	spring

Notes: Preferences are based on a minimum of 70% structure use for each faunal group.
* Table 4-3 provides habitat class descriptions.

Crossing structures located in areas with three land-cover types at the 30 and 210 m^2 scales were most frequently used by all groups. All groups used structures most often located in wetlands (4) or hardwood forests (8) at the 30 m^2 scale. Slight differences were apparent at the 210 m^2 scale, with crossing structures in pinelands (3), wetlands (4), and shrub and brushlands (7) most commonly used by five of six faunal groups. Habitat type and diversity (30 m^2) were significant factors in logistic regression for meso-mammals, small mammals, ungulates, and herptiles. This likely corresponds to use of road verges for foraging and the crossing structures as shelter. Surrounding habitat type and diversity (210 m^2) were significant factors for meso-mammals, ungulates, herptiles, and small mammals. Management and mitigation for the species most frequently encountered in this study should generally focus on improving habitat diversity along road right-of-ways and adjacent land-cover classes 4 (wetlands) and 8 (hardwood forests). Specifically, issues regarding habitat should be addressed on a site-by-site basis.

Thresholds for disturbance parameters

Three factors can be considered measures of tolerance by faunal groups to disturbance, specifically AADT (traffic level), human presence, and presence of domestic predators. Meso-mammals, birds, small mammals, and herptiles made 90% of crossings when traffic levels were 250 or fewer vehicles-per-day (Table 4-9). Carnivores and ungulates were more tolerant, with 90% of structure use occurring when over 3,000 vehicles were present per day. While tolerance of traffic increased for 75% structure use by meso-mammals and birds (AADT = 3,000), and carnivores and ungulates (AADT > 6,000); small mammals and herptiles were more sensitive, as 250 vehicles daily was still the maximum traffic level that could sustain measured use of culverts of 75%. Herptiles appear most sensitive to traffic, which is most likely associated with traffic noise; other groups appear more tolerant. Annual-average-daily traffic was statistically significant for all groups, except birds and ungulates. Traffic level was an important factor in culvert avoidance by wildlife in other studies: Banff National Park, Alberta, Canada (Clevenger et al. 2001), and Denali National Park, Alaska (Yost and Wright 2001). Sites where herptiles and small mammals are present require more stringent restrictions or mitigation for traffic and traffic-related noise. Based on the results presented here, none of the groups could sustain more than 60% use of structures when daily traffic levels were over 6,709.

Presence of humans was measured simply as the number of people (or signs of people) recorded over the 19 months of monitoring; therefore, representing the relative human impact that recorded wildlife would tolerate (Table 4-9; values in table were converted to number per year). Greatest number of humans recorded at any single site was 104 over 19 months (1 every 5.5 days). This factor was found significant in regression analysis for meso-mammals, herptiles, and small mammals; however, small mammals, ungulates, and carnivores appeared most sensitive to frequency of human presence (probably reacting to persistence of human scent). Meso-mammals were the least inhibited (75% structure use with 73 total records of human presence, 1 every 8 days). Ninety percent of structure use by all groups, except small mammals, occurred when only 4 – 6 humans were encountered (1 every 95 days; excludes track recorders). This finding echoes that of Clevenger and Waltho (2000), who found that wolves avoided culverts near areas of human activity. Grizzly bears also displayed avoidance of humans associated with logging activities (McClellan and Shackleton 1988). Certainly, the data here indicate that to maximize use by most wildlife, human presence needs to be restricted at crossing sites.

All groups can be considered sensitive to activity by domestic predators near crossing structures (Table 4-9; values in table were converted to number per year). Presence of domestic predators was as high as 110 over 19 months (1 every 5 days).

Ninety percent use of crossing structures by each group occurred when 1 or less domestic predators were present over 19 months. Carnivores, birds, ungulates, and herptiles only used crossing structures at a 60% rate when 2 – 6 domestic predators were encountered during the course of the study. Fencing or other devices should be used to restrict access to crossing sites from the road by domestic predators.

Thresholds for structural parameters

All groups showed a preference for dry soil conditions within structures (Table 4-9), which was statistically significant for meso-mammals, carnivores, herpetofauna, and small mammals; however, caution should be used regarding herpetofauna because some bias in sampling could affect this measure. During rainy periods, tracks were either hard to read or lost from washouts of track-beds, and thunderstorms restricted activities by field technicians. Though commonly found lizard-species seem to prefer dry conditions; intuitively, the movement of amphibian species should increase with wetter conditions.

Although openness was not included in the logistic regression, it is still useful as a reference for general size requirements for each faunal group. Ninety percent of use by meso-mammals, carnivores, ungulates, and small mammals occurred in structures with openness index values of approximately 0.40 (Table 4-10). Birds preferred larger openness values (0.86) and herpetofauna smaller openness values (0.28) for 90% of culvert use recorded. A breakdown of the openness index into its components may be more informative.

Table 4-10. Levels of use by faunal groups for structural parameters of culverts

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n = 5,515)	**Carnivores** (n = 258)	**Birds** (n = 81)	**Ungulates** (n = 32)	**Herpeto-fauna** (n = 580)	**Small mammals** (n = 270)
openness index value (w x h / l)	0.43 0.28 0.18	0.41 0.23 0.23	0.86 0.43 0.23	0.41 0.25 0.25	0.28 0.28 0.23	0.42 0.18 0.08
width, m	3.4 3.1 2.7	3.1 2.7 2.4	3.1 3 > 2.4	3.7 3 3	3.4 3.1 2.7	3.1 2.7 1.5
length, m	11 14 18	12.8 14.5 14.5	11 12 14.6	12.8 13.7 19.2	11.6 14.5 14.5	11.6 13.7 18.3
height, m	1.7 1.5 1.4	1.8 1.5 1.5	3.4 1.5 1.4	3.7 3.7 3.4	1.5 1.4 1.4	1.5 1.4 1.2
Preferences						
structure number, #	▽ trend	▽ trend	△ trend	1 – 2	▽ trend	1
structure shape	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular
structure substrate	dirt	-	-	dirt	dirt	dirt

Response to culvert width was similar for all faunal groups (Table 4-10). All groups exhibited 90% usage when culvert width was 3 m or greater and 60% usage at 2.4 – 2.7 m, except small mammals (1.5 m). Culvert width was a significant factor in all regression models except for ungulates. The low level of variability among groups of differing body size indicates that minimum width may play a role in passage success, but in a general sense. Thus to maintain high passage rates (75%) for all species (especially carnivores) at least 2.7 m width for new structures is encouraged (for comparison, 3 – 5 m was recommended for white-tailed deer by Norman et al. 1998). Note that of 63 Florida black bears recorded, only 5 approached culverts, and only three of these actually crossed through from one side of the road to the other. The culverts used by these individuals had minimum openness index values of 0.23 and heights of 1.5 m.

Culvert height displayed greater variance with regard to use among faunal groups (Table 4-10). Culvert height was a significant factor for meso-mammals, herpetofauna, and small mammals. The latter two groups were more abundant using culverts 1.5 m or lower, presumably because larger predators are more hesitant to use them. All but three individuals in the carnivore group that used culverts either were bobcats, coyotes, or foxes. For areas where only smaller prey are abundant, lower heights should be used. For large carnivores and ungulates, 3 m minimum height should be used. Ungulates did not use culverts with any significant frequency (n = 32 over 19 months). Other studies (Garrett and Gordon 2003) indicate that preference for higher openness values may limit usefulness of standard drainage culverts for deer. Foster and Humphrey (1995) found use of 2.1 m high bridges by ungulates and large carnivores; however, these structures had openness values of 0.92 – 1.12.

Culvert use among groups was similar with regard to culvert length (Table 4-10). Frequency of usage was 90% for all groups if culvert length was 11 m or less. Due to road construction standards, length of culvert is difficult to change; it is entirely dependent on the width of the road itself. Openness index can be used as a mechanism to adjust for length. As a road becomes wider, culvert length increases and openness necessarily goes down. To maintain the same openness value, width and or height of the culvert must be increased.

Other influential factors associated with culverts include number of culverts (e.g., single and multi-cell units), culvert shape, and substrate. Preferences for all groups were for dirt or soil substrate and rectangular shape. Number of structures was more variable among groups; and statistically significant for only carnivores, herptiles, and small mammals. These three groups preferred single to multi-cell configurations.

Influence of structural factors of bridges on faunal groups is shown in Table 4-11. Differences between results for bridges and culverts reflect the significant differences between the two structure types. Bridges were much less limiting on use by faunal groups. All three dimensions (width, length and height) were significant factors for small mammals and meso-mammals, width and height for birds, width for herptiles, and height for ungulates and carnivores.

When comparing bridges to culverts, only bridge height is relatively limiting (because height is similar for the two structure types). Specifically, for locations used by carnivores (especially Florida black bear) and white-tailed deer, a minimum height of 3.5 m is recommended. Predicting use as a result of structure width and length is not as clear. For the groups mentioned above with significant maximum likelihood scores for bridge width, most are likely a result of increased habitat availability.

Table 4-11. Levels of use by faunal groups for structural parameters of bridges

Threshholds: 90% (upper), 75% (middle), 60% (lower)	**Meso-mammals** (n = 6,186)	**Carnivores** (n = 353)	**Birds** (n = 177)	**Ungulates** (n = 541)	**Herpeto-fauna** (n = 848)	**Small mammals** (n = 618)
	17.89	21.35	17.08	25.42	19	17.08
openness index value	14.38	17.08	17.08	16.37	17.08	12.2
(w x h / l)	9.66	15.25	9.66	13.14	17.08	8
	82.4	96.1	60.4	152.5	54.9	54.9
width, m	54.9	60.4	41.2	82.4	38.4	40.3
	41.2	41.2	38.4	58	38.4	32
	7.3	8.2	7.3	8.2	7.3	7.3
length, m	7.3	8.5	7.3	9.2	7.3	7.3
	8.2	12	8.2	11.9	8.2	7.3
	3.7	3.7	3.7	6.1	3.7	3.7
height, m	3.1	3.7	3.7	4.6	3.7	3.1
	3.1	3.1	3.1	3.7	3.1	1.8

Crossing Structures as Primary Habitat Features

Two groups, herpetofauna and small mammals included species that frequented culverts as part of their primary habitat rather than as movement corridors. These included lizards (n = 2,635), primarily six-lined racerunner and five-lined skink; and rodents (n = 15,637), i.e., various mice and rats. Lizards commonly used culvert and bridge faces for sunning areas; and mice used crevices and cracks in the structure for shelter. When controlled for these species, each group's presence is reduced significantly (other herptiles, n = 843, other small mammals, n = 161). Additional analysis that splits these groups into relevant categories is recommended to separate primary habitat needs of local species from species with larger movement requirements (e.g., snakes and turtles).

Meso-mammals, especially raccoons used water collection areas at culvert and bridge sites for foraging areas for amphibians or trash from motorists and fishermen. Specific planning for movement under roads by this group is probably unnecessary because they are already quite successful using existing configurations without need for modification.

Road-kills and Culvert Avoidance

Although frequency of site visits was sufficient for tracks and photographs, twice per week was inadequate to evaluate quantity and types of road-kills occurring on adjacent road segments. Persistence of road-kill depends on factors such as weather, traffic density, frequency of road cleanup or maintenance, and depredation rates by scavengers. Studies of culvert avoidance should include road-kill information; without a complete complement of these data, inferences about avoidance by certain species could not be made. Additionally, surveys of abundance in habitat areas adjacent to monitoring sites may provide evidence of other species present that do not approach structure entrances where track beds were situated. Two studies (Clevenger et al. 2001, and Yanes et al. 1995) performed abundance surveys that provided better information regarding avoidance, and allowed for comparisons between culvert use frequency and total population size.

Effects of Light Penetration and Traffic Noise

Certain characteristics such as light and moisture content have been evaluated for amphibians (Krikowski 1989, and Langton et al. 1989). Amount of light available within culverts can help counter tunnel effects. Certain amphibian species would not enter when sufficient light was not present (Krikowski 1989). Light availability within drainage culverts has tremendous variability based on two factors: size of culvert opening that affects quantity of light and depth of penetration; and the length of the culvert, where quantity of light decreases as distance from the opening increases. Another potential vector affecting light availability occurs on divided highways that incorporate median drainage grates allowing light penetration at the center of the culvert. Although this study did not evaluate the influence of light availability on structure use, visibility is of obvious importance to many species that were recorded. Most specifically, openness index values are related to the amount of light penetration. This was inherently reflected in the results, where most species preferred higher openness values.

Noise is another influential factor that has been investigated by other researchers (Clevenger et al. 2001, and Reijnen et al. 1995). These studies found significant road avoidance associated with the effects of traffic noise, particularly for small carnivores and birds. A direct relationship between traffic noise and traffic volume would indicate a similar relationship between traffic volume and avoidance by species sensitive to noise. This relationship is depicted in this study by the precipitous drop in use of culverts as traffic levels increase beyond 6,000 vehicles-per-day.

Current Research Benefits and Future Directions

Design standards for drainage structures (that promote use by wildlife within certain landscape/habitat contexts) should improve efficiency for retrofitting existing roads, or construction of new roads with appropriate cost-effective ecopassages. Determining the utility of existing structures, within right-of-ways at identified high-priority, highway-greenway interface zones, also provides opportunity for significant cost savings (associated with adapting these sites for optimal connectivity for wildlife). This research should enhance the ability of transportation agencies to effectively address wildlife issues at public hearings; and to quickly implement the appropriate mitigation measures needed at identified high-priority, highway-greenway interface zones.

Future research needs include effects of moisture, temperature and light, and efficacy of drainage culverts to facilitate movement by amphibians in the southeast. Similar research needs to be performed on aquatic culverts; to assess connectivity for fish and other aquatic obligates in the many streams in Florida (potentially obstructed by roads). Significant research in this area has been conducted in the northwest (Ruediger 2001, and Carey 1996).

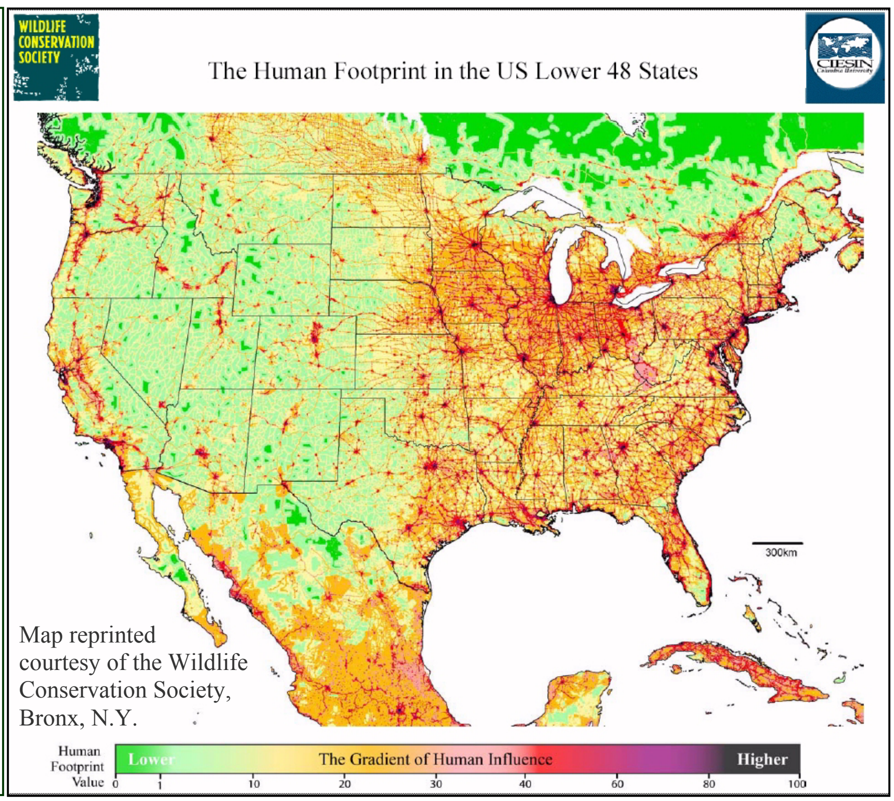
Lastly, wildlife movement, in areas where few drainage structures exist (e.g., sandhill and scrub communities), needs to be investigated to assess impacts of road-kills on population levels (i.e., the need for ecopassages to improve habitat connectivity). Potential study sites include Guana River State Park, Goldhead Branch State Park, Marjorie Carr Cross Florida Greenway – Ross Prairie State Forest, and parts of Ocala National Forest; where park staff has collected significant road-kill data.

CHAPTER 5
INTEGRATING LANDSCAPE ECOLOGY THEORY WITH TRANSPORTATION PLANNING AND POLICY

Theoretical and Conceptual Basis for Infrastructure Ecology

In 2002, the Wildlife Conservation Society presented the results of a study (Sanderson et al. 2002) that explored the extent of human influence over the globe. The project was called 'the human footprint". In the United States, virtually no area has been untouched (Figure 5-1). Large, federally protected lands (Figure 5-2) are the only areas that appear minimally affected. These figures chronologically correspond to clearing of eastern native forests by European settlers in the 1800s and early 1900s for agriculture and urban development (Williams 1990).

Figure 5-1. The human footprint. The human footprint analysis conducted by Sanderson et al. (2002) indicates that the eastern half of the coterminous U.S. is strongly influenced by one or more of the following factors: human population density (> 1 person / km^2), < 15 km from a road or major river, consists of urban or agricultural land-uses, < 2 km from a settlement or railway, and/or produces enough light to be visible from an orbiting satellite at night.



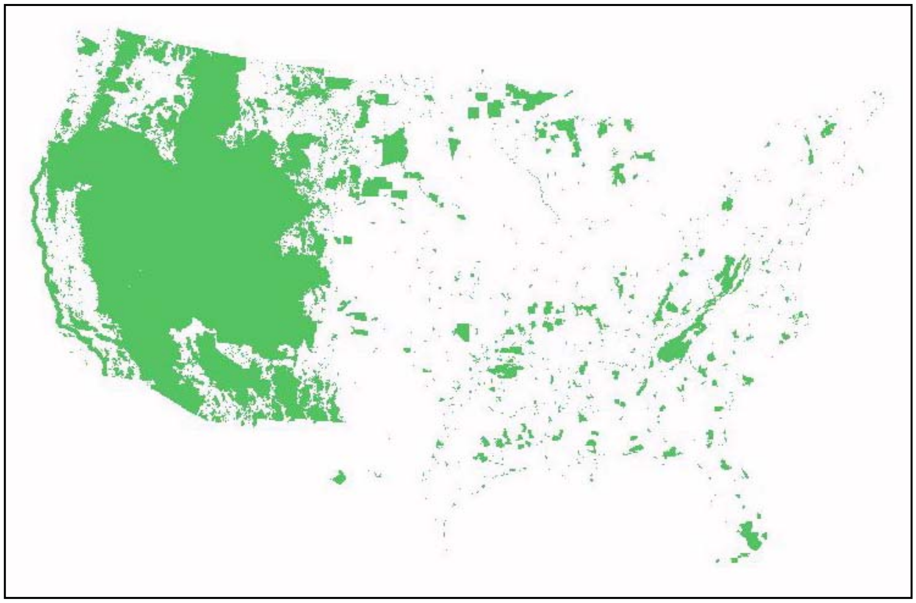


Figure 5-2. Federal lands in the coterminous U.S. Location of the majority of remaining large protected areas mirror the results from the analysis for the human footprint in Figure 5-1; and chronologically correspond to clearing of native forests in the east by European settlers in the 1800s and early 1900s for agriculture and urban development (Williams 1990). (Data source: USGS 2000)

Roads played a significant role during this early period of development, and expanded immensely throughout the 20th century. Paved roads in the U.S. now exceed 6.3 million km (FHWA 2002a; Figure 5-3).

This network of infrastructure has received greater attention in the last two decades regarding the extent of degradation to environmental quality and integrity of ecological systems. Conferences and meetings in the United States and Europe have drawn international attention; with the goal of improving communication between policymakers, engineers, and ecologists to develop scientifically based solutions to the ecological impacts of roads. The National Research Council, Transportation Research Board produced two documents (NRC 1997, 2002) meant to generate interest for scientific research into ecological effects of roads. Two major books on transportation impacts have been published: Environmental Impacts of Railways (Carpenter 1994) and

Road Ecology (Forman et al. 2003). The following discussion offers a theoretical link between road impact studies and landscape-level ecological analysis.

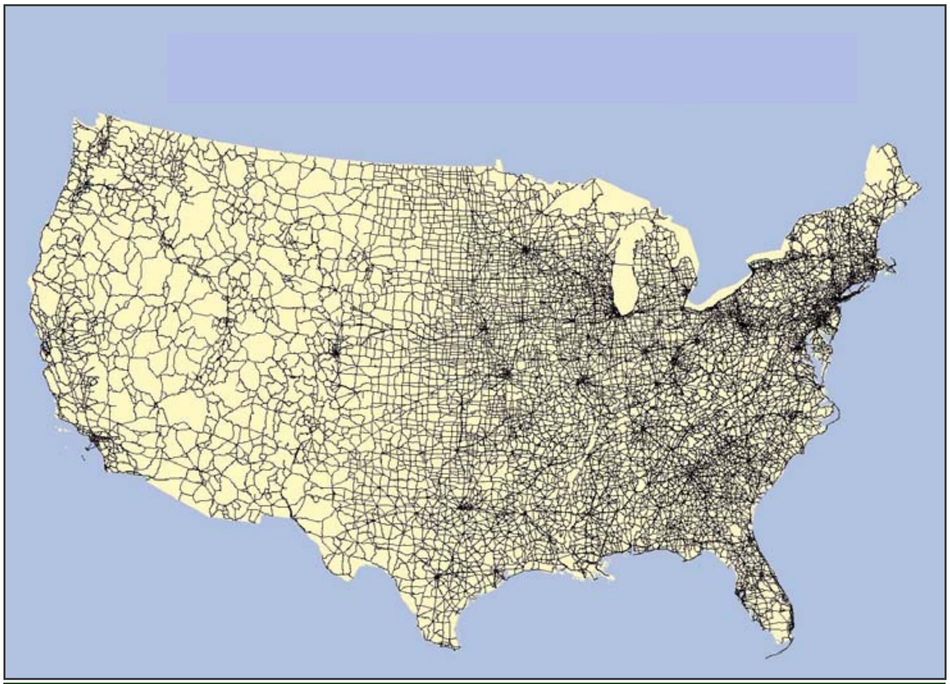


Figure 5-3. Proliferation of roads across the United States. Near the beginning of the 21st century, over 6.3 million km of paved roads have been constructed. (Data source: FHWA 2002, and USGS 1996)

Evolution and Biogeographic Principles

A top-down scientific approach to infrastructure ecology begins with a solid foundation in evolution and biogeographic principles. A brief review of this approach illustrates associations between general ecological principles and road impact studies. Three tiers of interrelated hierarchies are shown in Figure 5-4. Horizontally, the three elements represent system processes, patterns and vectors of stability or change. Vertically, the scale of study decreases from top to bottom. On the top level are evolution, biogeography, and biodiversity conservation. While the theory of evolution provides an explanation of "change…in successive generations of organisms" (Allaby 1994, page 148), biogeography explains the pattern and distribution of organisms in space and time. Though described at large temporal and spatial scales, the patterns at this upper level are determined in large part by the levels below acting on smaller scales, and through interaction among the factors on the same level.

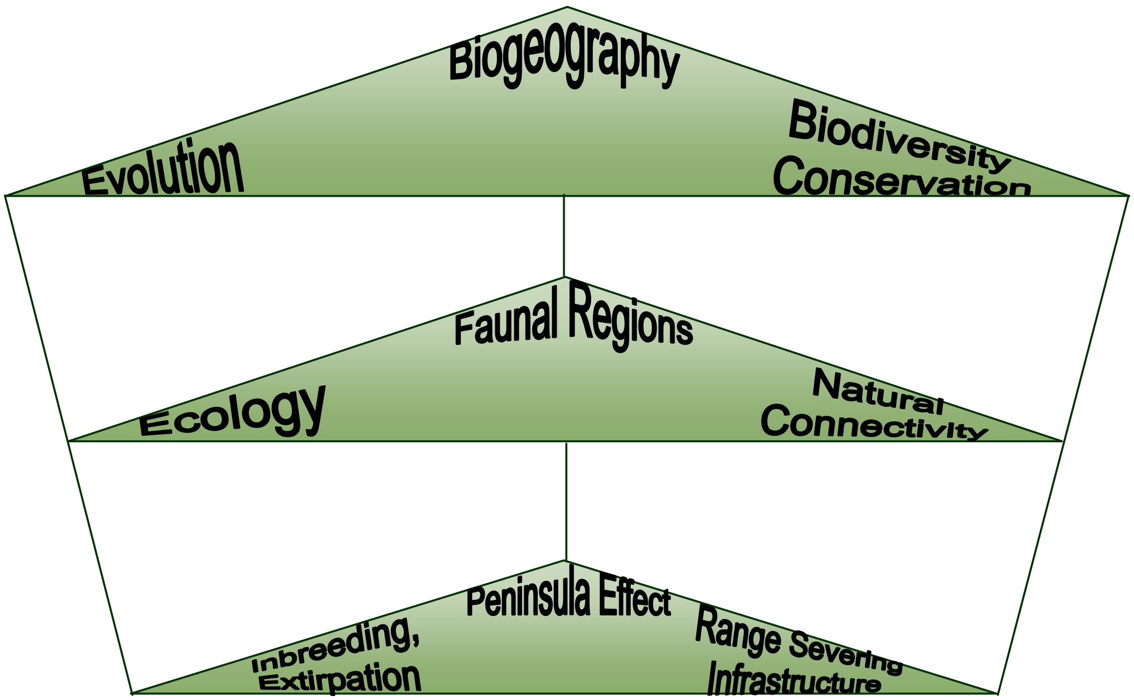


Figure 5-4. Hierarchy of theories/concepts for landscape-level studies.

For example, evolutionary descent or divergence of certain species (e.g., yellow- and red- shafted flicker along the frontal range of the Rockies; Cox and Moore 1980) is brought about by biogeographical phenomena such as physical (e.g., geographical barriers), biological (e.g., competitive exclusion) and climatic (e.g., latitudinal zones) differentiation.

The understanding of evolution is brought about by ecological studies of natural systems, communities, populations, and species that involve internal processes and/or interactions among species and their environment at appropriate biogeographic scales (e.g., among specific faunal groups or plant communities). Roads can affect evolutionary-scale phenomena such as multi-generational movement and migration patterns. Examples include fragmentation of once-contiguous habitat areas used by different stages in the life cycle of amphibian populations (Langton 1989a); or obstruction of stream reaches used by migratory fish (Carey 1996).

Biodiversity conservation, now considered a discipline of its own, asserts to provide measures of protection for organisms and ecological systems across these large scales. In a world where human habitation and development threaten the future existence of many species and unique natural systems, conservation biology incorporates many principles. Such as adaptive and ecosystem management, aimed at protecting ecological components of entire ecosystems; and using techniques that allow for management changes according to response stimuli that indicate ecosystem health. Figure 5-5 provides an illustration of hierarchical linkages between planning and management applications and their respective ecological scale. Note how connections are formed between these levels. Florida can provide a relevant example to the application of these principles.

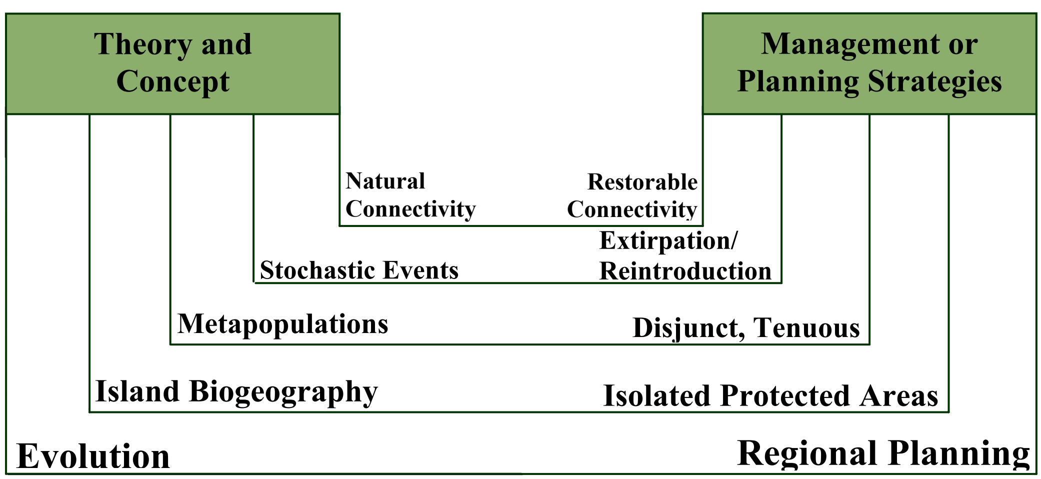


Figure 5-5. Hierarchy of relevant theory and conservation applications. Current theoretical approaches such as island biogeography and metapopulation ecology not only apply to studies of naturally occurring distributions, but management for human induced conditions as well (e.g., forest fragmentation caused by roads and urban development).

Florida is a peninsula characterized by warm latitudes and enriched waters of the Gulf of Mexico and Atlantic Gulf Stream that provide a unique environment, supporting both temperate and subtropical zones (Figure 5-6). A biogeographic, insular phenomenon (caused by the physical dimension or shape of the peninsula) occurs where higher rates of extinction and lower rates of immigration are expected as one proceeds toward the tip of a peninsula (Engstrom 1993). This generally results in a reduction in species richness (Figure 5-7), although Busack and Hedges (1984) found that other local factors also might affect species richness on peninsulas (e.g., latitude, microclimate, and vegetation types).

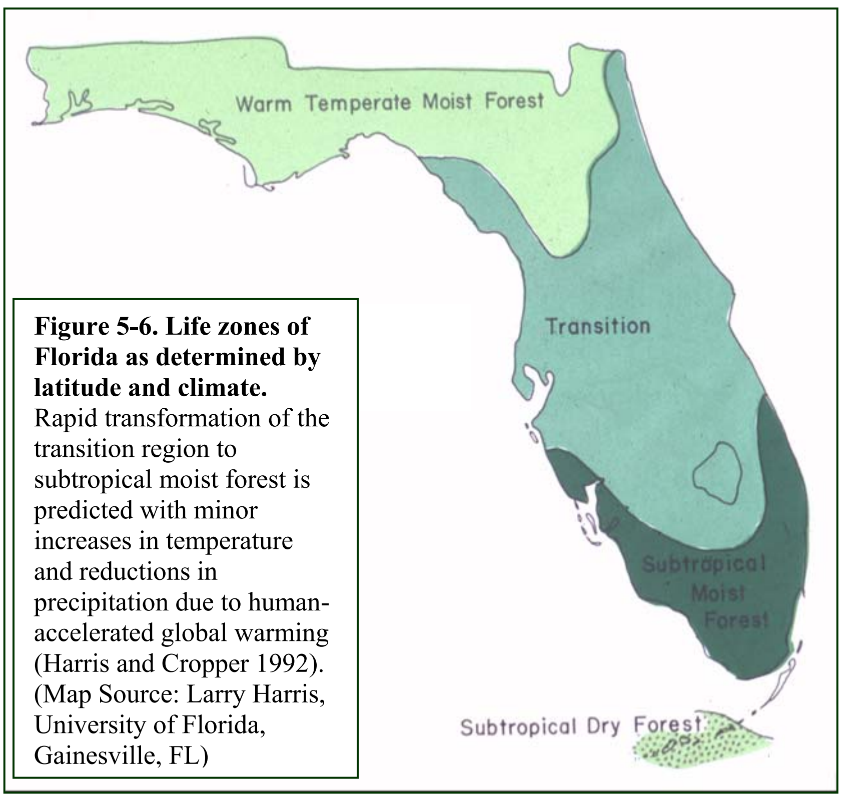


Figure 5-6. Life zones of Florida as determined by latitude and climate. Rapid transformation of the transition region to subtropical moist forest is predicted with minor increases in temperature and reductions in precipitation due to human-accelerated global warming (Harris and Cropper 1992). (Map Source: Larry Harris, University of Florida, Gainesville, FL)

Attention toward human-induced global warming and climate change has pointed to one consequence particularly important in Florida, accelerated sea level rise. A recent study (Williams et al. 1999) conducted on tree islands along the Gulf Coast has determined that advancing sea levels have begun to reduce coastal extent of non salt-tolerant species. The result is an inland shift of non salt-tolerant species. The shift in faunal and floral ranges is a natural biogeographic response to climate change. This has been demonstrated through global climate change models and paleobotany studies that show the latitudinal shifts of dominant plant communities (Iverson and Prasad 1998).

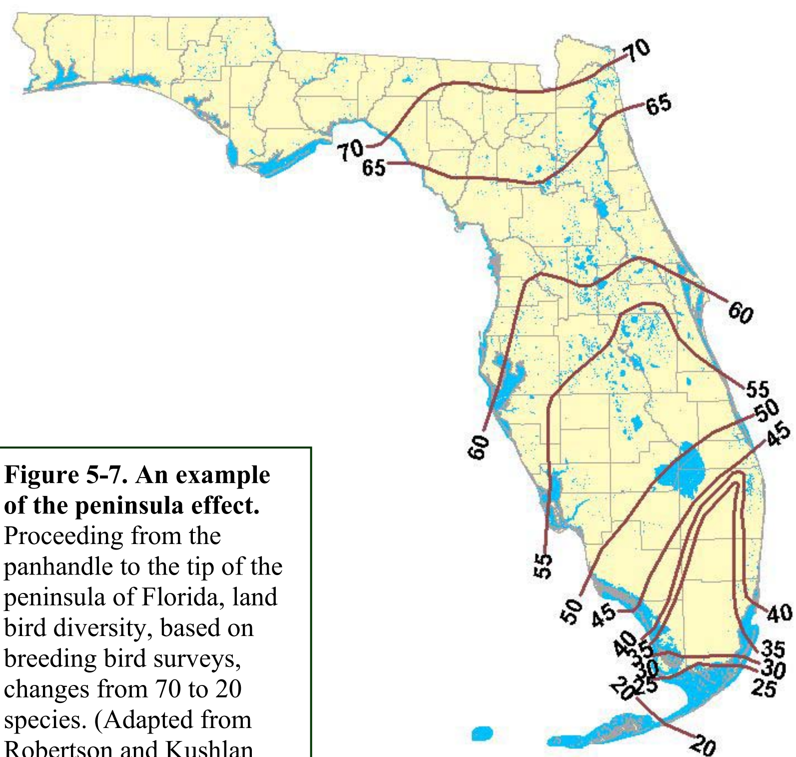


Figure 5-7. An example of the peninsula effect. Proceeding from the panhandle to the tip of the peninsula of Florida, land bird diversity, based on breeding bird surveys, changes from 70 to 20 species. (Adapted from Robertson and Kushlan 1974)

These range shifts would probably proceed uninhibited on an undeveloped peninsula (despite findings by some studies that project human-induced global warming occurring more rapidly than many plant-animal associations can adapt, resulting in multiple extinctions; e.g., Kirtland's Warbler-jack pine forests, see Brown and Lomolino 1998, and Hobbs and Hopkins 1991). In Florida, habitat fragmentation (caused by expanding development and road systems) threatens to sever the network of habitat linkages necessary to allow generational transfer of complete biotas inland and northward (Harris and Cropper 1992, and Hobbs and Hopkins 1991; Figure 5-8).

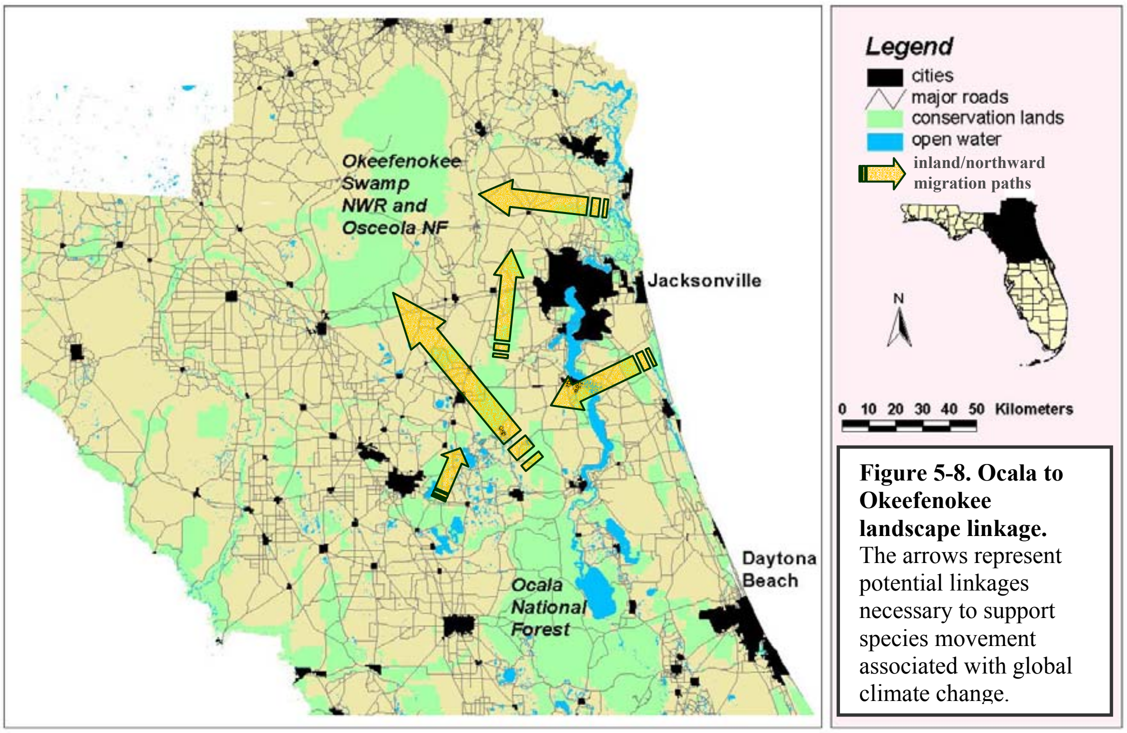


Figure 5-8. Ocala to Okeefenokee landscape linkage. The arrows represent potential linkages necessary to support species movement associated with global climate change.

Landscape Ecology

Landscape ecology provides an approach to ecological research that combines the use of scientific principles from biogeography, geomorphology, community ecology, land-use planning, etc. with GIS, mathematical modeling, and spatial analysis techniques to examine natural phenomena within and across differing temporal and spatial scales. A key feature to this approach is that the role of humans and their impact on ecological systems is considered in the development of scientific solutions to ecological problems and better landscape management practices. Fundamental issues for study include hierarchical arrangement, scale, landscape-level patterns and processes among organisms and ecosystems. Applications of concepts are entwined with reserve design, fragmentation, corridors, and landscape connectivity.

Different approaches to landscape ecology are illustrated by the variation in definitions. One such definition is concerned with the causes and effects of heterogeneity, independent of scale (Pickett et al. 1995); rather than focused at a specific spatial extent, as is the case with Forman (1995, page 13), “a mosaic where the mix of local ecosystems or land uses is repeated in similar form over a kilometers-wide area”.

The larger, landscape approach to the study and protection of ecological systems has gained added acceptance in scientific circles, as well as national-level, land management agencies. A National Research Council committee established conservation priorities for federal agencies, based on the protection of landscape-level ecological processes (NRC 1993). Their approach incorporated provisions for large-scale habitat connectivity and multi-agency coordination for land planning and management. Jerry Franklin (1993, page 202) of the University of Washington, when recalling his experience with the National Forest Service, northern spotted owl, and old growth forests of the northwest, said “…we cannot even come close to attaining our goal of preserving biodiversity…sustainability, if we continue to focus our efforts…on species.” “Larger-scale approaches–at the levels of ecosystems and landscapes–are the only way to conserve the overwhelming mass–the millions of species–of existing biodiversity.”

A conceptual approach to infrastructure ecology based on landscape ecology principles is presented in Figure 5-9. At the top of the diagram are concepts of biogeographic pattern and the bottom of the diagram presents the empirical data that might be associated with road impact studies. Landscape-level applications are scientifically based solutions derived from indices (e.g., Diversity $= f$(topographic relief)) and methods appropriate to evaluate pattern and process from empirical data (applicable to interactions between roads and ecological systems and species).

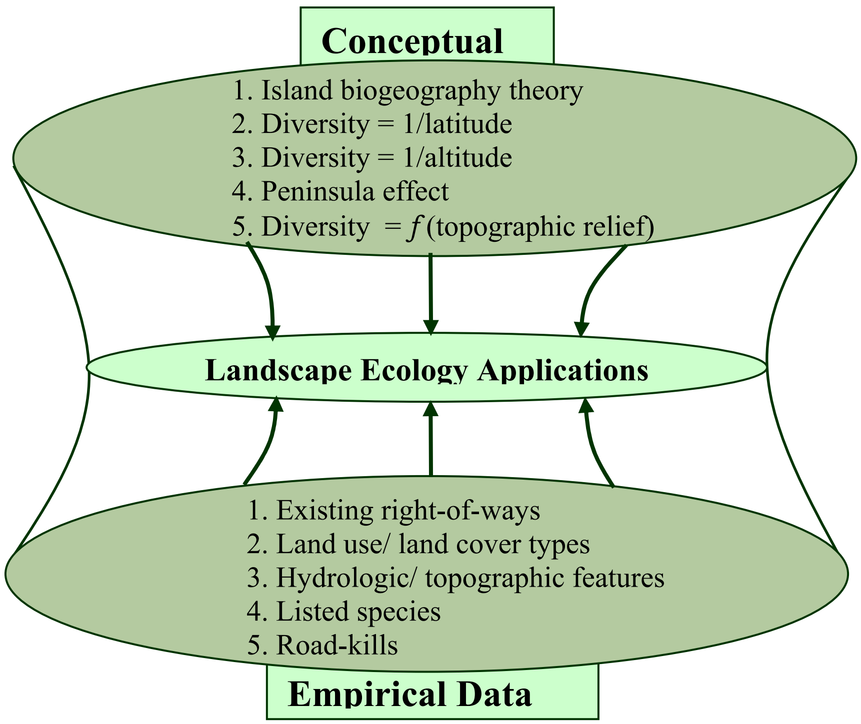


Figure 5-9. A theoretical and conceptual framework for infrastructure ecology.

The Florida black bear in the Ocala National Forest provides an example of a landscape approach to addressing road impacts. A significant impact study (Chapter 1, page 18) was conducted regarding the proposed 4-laning of SR 40 that essentially divides the forest in half. Track data of road crossings by black bears were compared with locations of road-kills. Figure 5-10 displays a uniform distribution of crossing sites, as determined by track counts. No preference is apparent with regard to crossing specific sections of the road along the approximate 20 km length of road checked from 1999 to 2001. Therefore an analysis was conducted to evaluate configuration of the road corridor itself (e.g., topographic relief and curvature). Topographic contours were isolated for this section of road; and an elevational profile was generated. As revealed in Figure 5-10, there appears to be a significant connection between slope of the road and curve severity, and collision sites. This would indicate that driver visibility might be the primary factor in location of collisions with black bears.

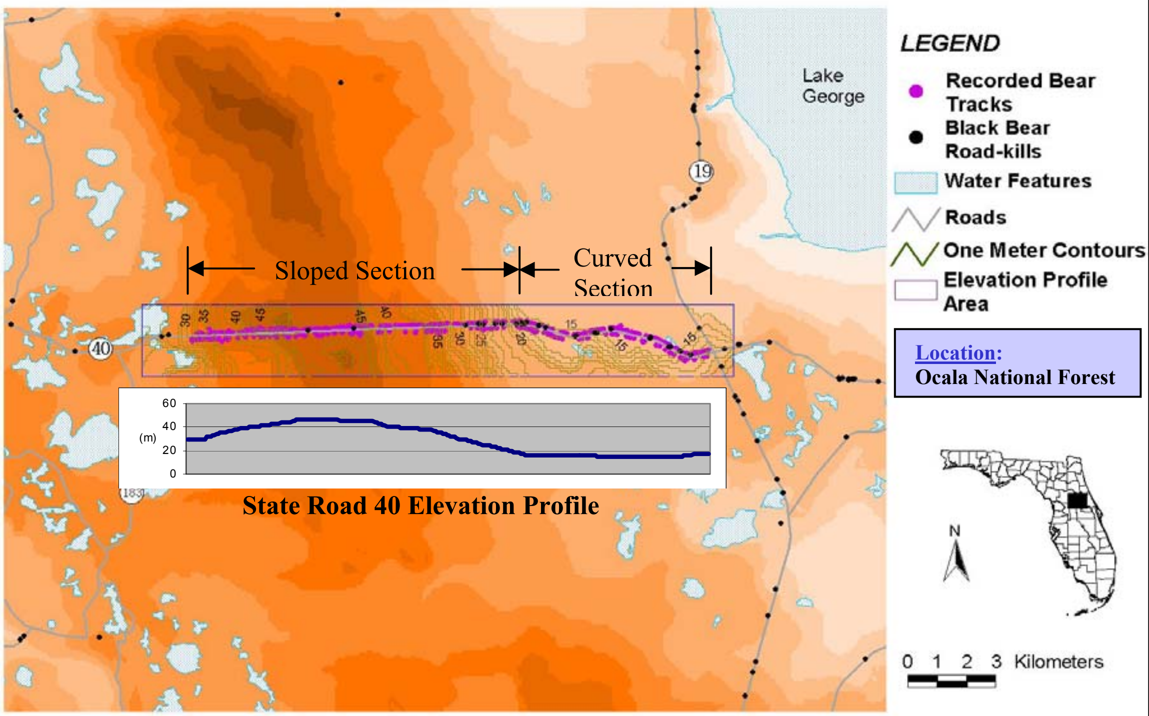


Figure 5-10. Landform, road alignment and black-bear road-kill trends. Road-kills occur more frequently where curves and slopes of the road are more severe. (Data sources: FFWCC 2001, and FDOT 2000)

Before concluding this as the primary cause; however, it may be important to examine potential effects between collision locations and speed limit, traffic density, habitat, land use, and distribution and density of black bears. Figure 5-11 provides an examination of speed limit, traffic density, and intensive land-uses on collision locations. Note that speed limit reductions coincide with intensive land-use areas, where few if any collisions have occurred. Traffic density averaged 12,000 vehicles/day within developed areas and 4,800 in undeveloped areas. It would appear that none of these are factors affecting location of collisions.

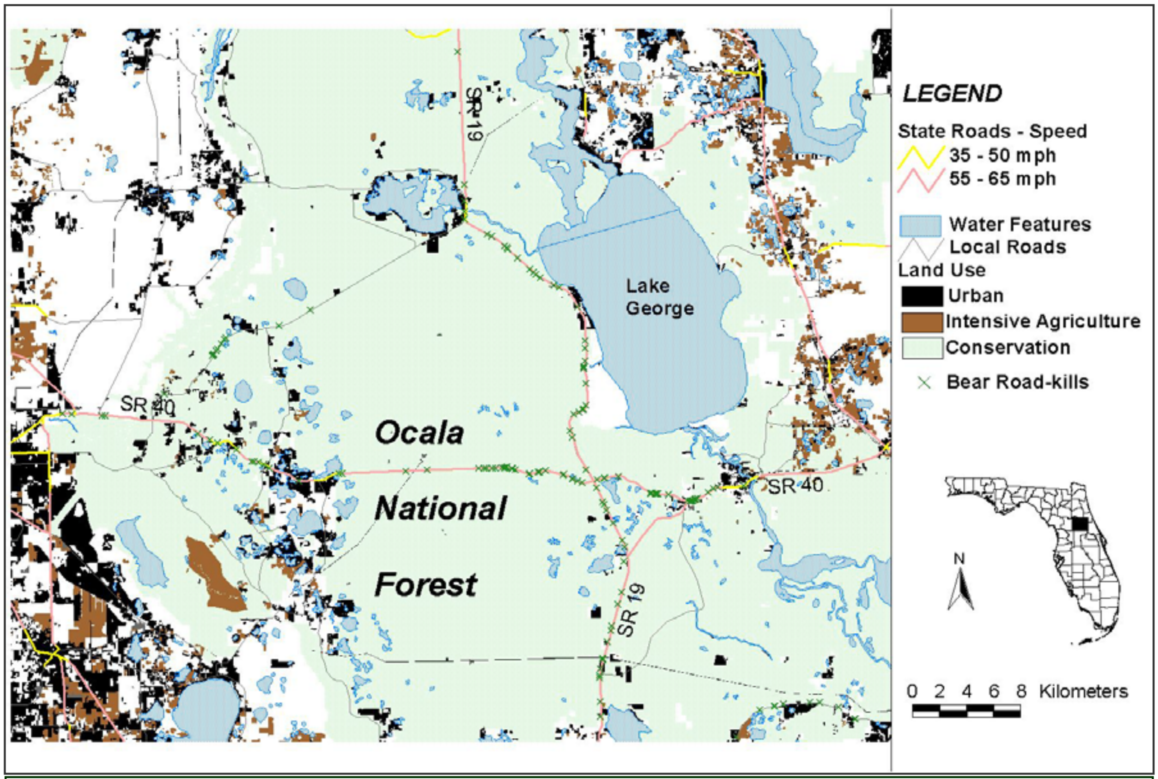


Figure 5-11. Highway speeds, land use and black bear road-kill trends. These factors appear to be unrelated to location of chronic road-kill sites. **(**Data sources: FFWCC 2001, FDOT 2000, and Water Management Districts 1995)

Lastly, a look at habitat use and distribution of black bears (from telemetry data) may reveal some pattern. Figure 5-12 shows that while black bears were located frequently in the area along the section of road where chronic road-kill sites are located; they were also found in equal numbers farther to the west, on the ridge where few road-kills occurred. Thus, from this analysis, the best indicators of chronic road-kill sites are road configuration and topography, which impair driver visibility. While this example was only used to illustrate potential landscape analysis methods, and was descriptive in nature; most of these factors could have been quantified to perform statistical analyses (e.g., slope, extent of curve severity, and location frequencies).

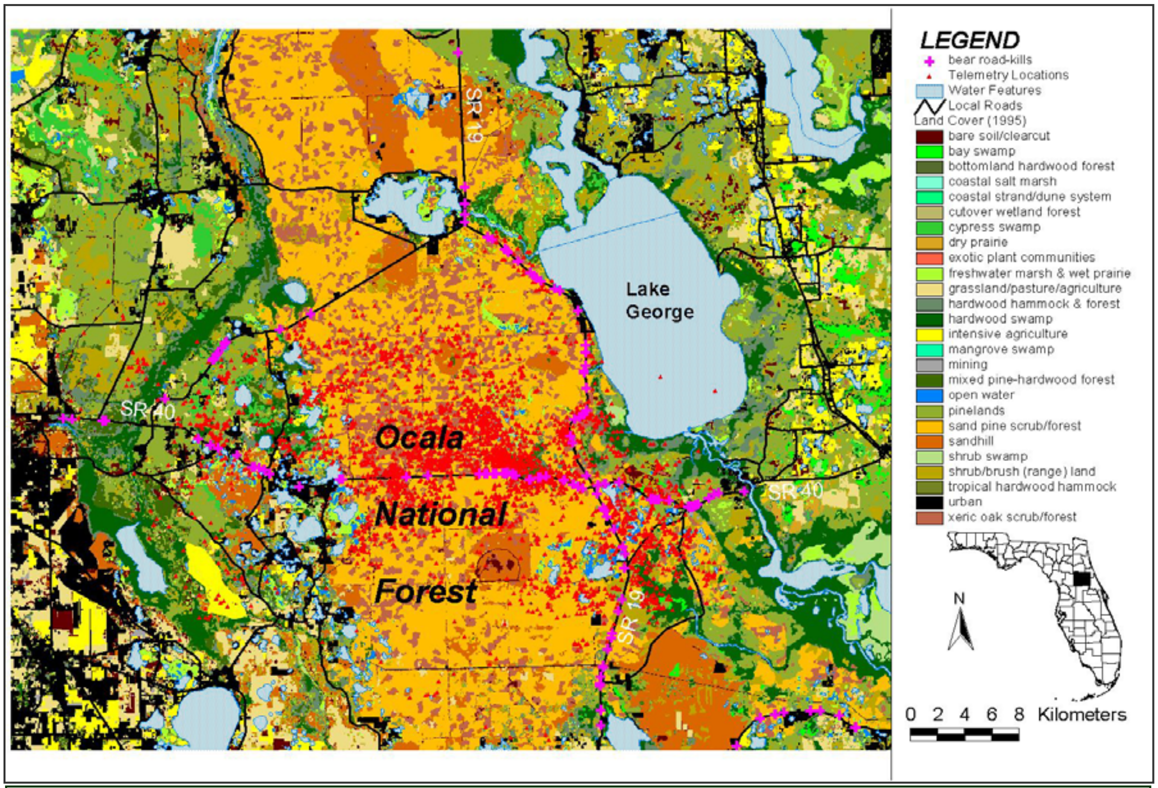


Figure 5-12. Land cover and telemetry locations of radio-collared bears and black bear road-kill trends. Density of radio locations of black bears appear to be unrelated to chronic road-kill locations. (Data sources: FFWCC 2001, and Water Management Districts 1995)

Growth and Roads

In a free-enterprise market economy, growth generates prosperity. Although the merits of this economic system or the inherent disparities in wealth associated with it are not discussed, it is important to recognize how this growth may impact natural systems. Particularly, what is relevant is the real estate industry and government-stimulated economic methods.

Development of land increases the inherent economic value of said property making it more attractive as real estate and as investment capital, thus attracting more development. This is sometimes referred to as “development clustering” or “mutual proximity”, where businesses find it economically beneficial to locate near other like-businesses (Greer and Farrell 1988). Governments conduct public improvement projects to stimulate economic growth in a community; projects that include road building and improvements, and designations of land through zoning or land-use regulations (Chapin and Kaiser 1979). While these measures are meant to increase quality of life and economic prosperity for those that live in a community, when growth is misguided or left unchecked, it can rapidly spiral out of control, resulting in detrimental effects to ecological systems (Stolzenberg 1991).

This continuous cycle, where roads and development in turn promote each other, is illustrated in Figure 5-13. What occurs first is the linear expansion of cities, as new businesses are located outward from central business districts (CBDs) along major arterial streets (Greer and Farrell 1988; Figure 5-14). Second, interstitial areas between these major arterial streets are later filled in by residential and additional commercial development. This is described as a “radial” or “axial” development pattern (Greer and Farrell 1988). The process continues along these vectors as long as it is economically viable (refer to discussion on Von Thunen’s model of land utilization, natural zoning, and bid-rent curves; Greer and Farrell 1988, pages 55 – 62).

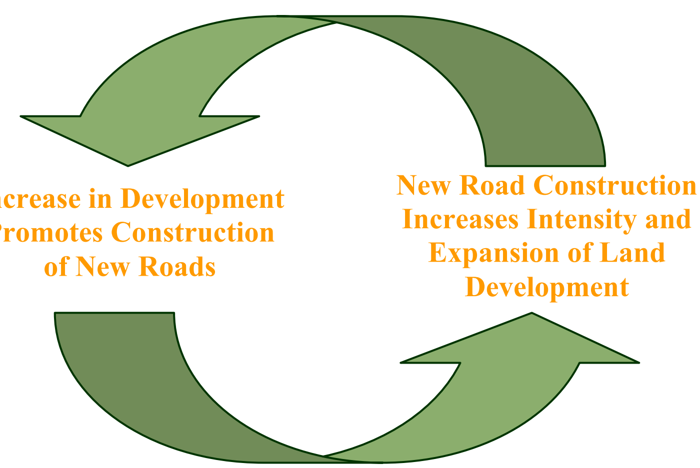


Figure 5-13. The continual cycle of development and road construction.

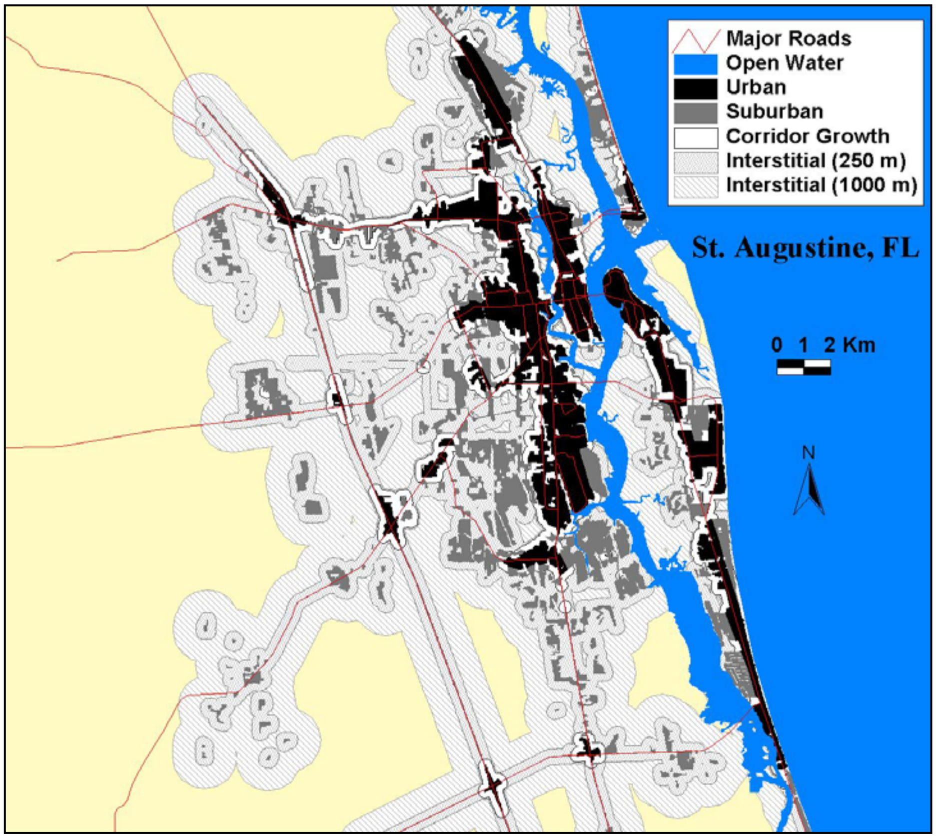


Figure 5-14. Radial or axial development. A linear growth pattern that begins adjacent to the CBD and extends out along major arterial roads (Greer and Farrell 1988). Suburban development later takes place within the interstitial buffer areas.

Negative Ecological Consequences of Roads

The negative ecological consequences of roads are examined from a landscape perspective (for more detail, see Chapter 6). They include: direct and secondary road mortality of wildlife; spread of invasive non-native species; toxic substances and soil erosion; disturbance by humans and domestic predators from increased access to otherwise remote areas; and habitat loss, fragmentation, species aversion, genetic isolation, population and species loss. A relation can be depicted for the extent of each of these impacts in space and time (Figure 5-15). The distance into adjacent natural areas affected by these and other ecological effects have been estimated (Forman 1995).

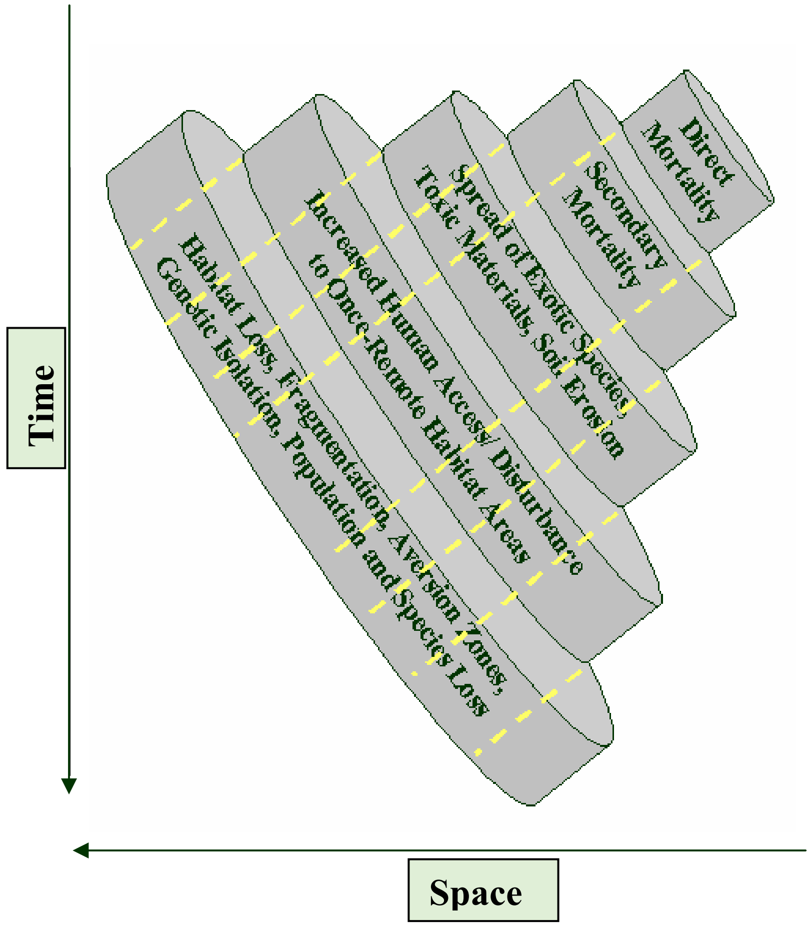


Figure 5-15. Cumulative impacts of roads on wildlife and wildlands. Severity in extent and cumulative nature of impacts become magnified with increased time and space.

Few studies have determined impacts of road mortality on wildlife population persistence. Certain conditions may allow wildlife to sustain their population levels despite significant road mortality. An example is the Florida Key deer, geographically restricted to Big Pine Key and adjacent islands. Road mortality exceeded 80 in 1997 (Figure 5-16), yet at the same time population levels were estimated to remain relatively constant (approximately 250 – 300; Calvo and Silvy 1996). The greatest threat to population levels of the Florida Key deer is habitat loss and fragmentation from human development activities (Lopez et al. 2003, and USFWS 1985; Figure 5-17). Road density on the island is 41.2 km/km^2. To protect the remaining area, an ecosystem management approach was adopted that included development moratoriums and land-use plans, construction of underpasses and highway improvements, high profile signage, public education, and targeted land acquisitions (USFWS 1985).

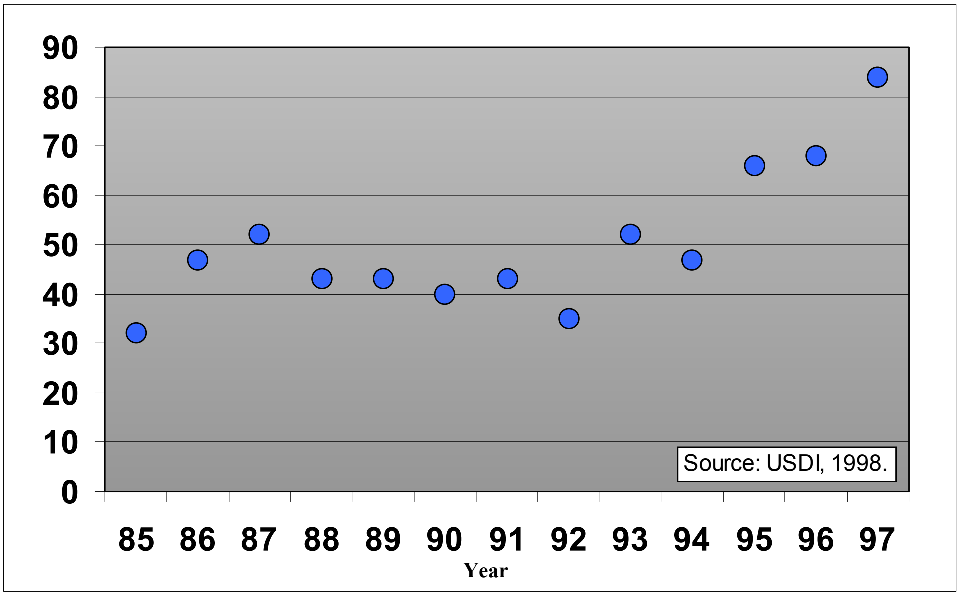


Figure 5-16. Highway mortality of key deer in Florida.

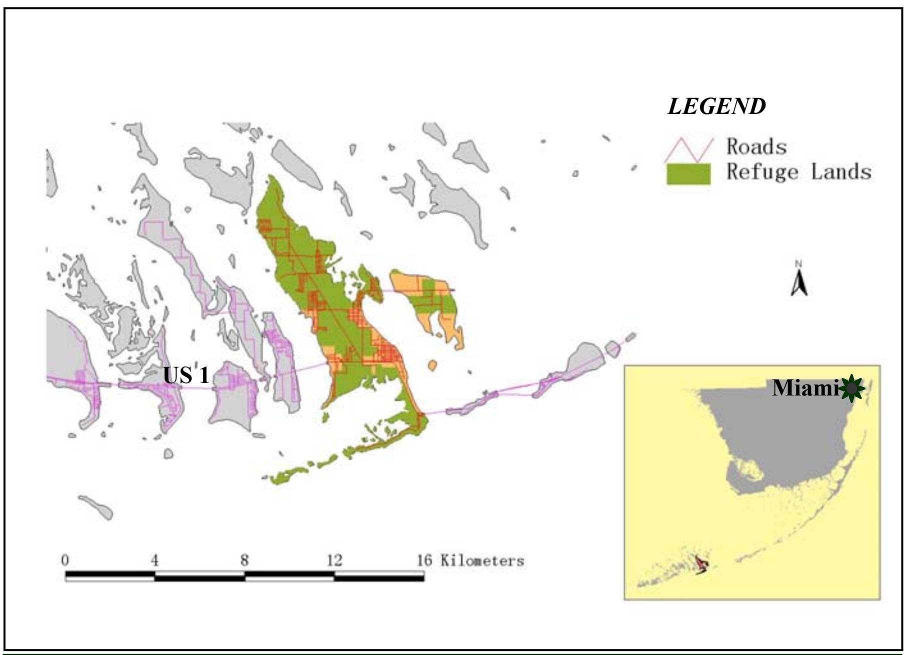


Figure 5-17. Road density on Big Pine Key and Florida Key Deer National Wildlife Refuge. Road density on the island was 41.2 km/km^2 in 1997.

Road Impacts and Planning in Florida

Human population growth and the level of road impacts are best explained in terms of their statistical levels:

- Human population growth—28 new residents/hr (USCB 2000)
- Road construction—8.8 km of new road constructed/day (FDOT 1998)
- Highway traffic—approx. 372.1 million vehicle km/yr (FDOT 1998)
- Fuel consumption—29.1 billion liters of gasoline/yr (FDOT 1998)
- Conveyances—12 million registered private vehicles (FHWA 1996)

These levels rank among the highest nationwide (Chapter 1). Transportation planning is the principle means of addressing the impacts of roads, and the need for additional roads to accommodate the burgeoning population and associated increase in traffic.

In Florida, road projects are programmed on three time horizons, annually, 5 years and 25 years (discussed in a later section). These time horizons correspond to: 1) project implementation, 2) project engineering and contract bidding, and 3) plan review and impact assessment, respectively. Environmental review most appropriately occurs under 3 (above); and must occur by the 2nd time horizon (above) to affect change in engineering plans. At the annual level, it is normally too late to provide input concerning environmental impacts, unless unique circumstances exist. Given these process guidelines, transportation and conservation planners, working together, appears the most effective way to appropriately address ecological issues associated with proposed road projects.

Biodiversity Conservation and Transportation Planning and Policy

Coordination between transportation agencies and resource conservation agencies is essential to the development of effective policies that protect ecological systems, while simultaneously providing safe and efficient transportation systems. Significant efforts in this direction began in Florida in the early 1990s.

Planning for Habitat Connectivity

Along with the encroachment of roads and development, isolation and fragmentation of ecosystems and associated wildlife populations has occurred with varying detrimental effects, as previously discussed (see also Chapter 6). Harris (1985) presented one solution to this phenomenon—establishing "conservation corridors" or landscape linkages to connect large conservation areas. Numerous conservation biologists have since discussed the potential positive and negative aspects of corridors to landscape reintegration (Bennett 1999, Beier and Noss 1998, Dobson et.al. 1998, Csuti 1991, Soulé 1991, Noss 1987, Simberloff and Cox 1987, and Noss and Harris 1986).

Land bridges connecting continents, according to paleontologist records, provide evidence of use of corridors by entire faunas (Harris 1985). Physical connectors of sufficient size to promote genetic flow in two directions of full and balanced plant and animal communities are necessary to maintain intended ecosystem functions and processes (Noss and Cooperider 1994, Noss 1991, and Harris 1985). Standards below this objective may serve only to increase the spread of "weedy species", and maintain the isolation of interior specialists and those requiring large territorial boundaries (Harris 1985; also see Beier and Noss 1998, Dobson et.al. 1998, and Simberloff and Cox 1987). Eisenberg (1986) explains that these linkages may not increase population size, but would increase the likelihood that recolonization of locally extinct species could occur. In addition, such connections would protect against the weakening effects of inbreeding (Eisenberg 1986).

These corridors must have sufficient width to maintain interior habitat qualities that would enhance use by threatened area-sensitive species (Noss 1983; see also Noss and Cooperider 1994, and Soulé 1991). Design of these landscape connections; however, are thwarted by the presence of roads within and surrounding habitat islands. These roads act as barriers to dispersal and function as "wildlife killing machines" (a term coined by Walt Thomson of the Florida Department of Environmental Protection; in Harris and Gallagher 1989). Studies of reserve network design recognize road density as a critical indicator for evaluating system integrity (Noss 1995). Roads, as a barrier to animal movement, are considered one of the six major determinants of functional connectivity (Noss and Cooperider 1994). Recommended designs now illustrate use of wildlife crossings to permeate transport facilities (Noss 1995).

The Statewide, Greenways Network Plan was designed to provide guidance for conserving valuable natural resources of Florida; and to restore connectivity between core conservation reserves and other isolated conservation areas. As defined by the University of Florida Greenways Planning Team (FGPT), "a greenway is a corridor of protected open space that is managed for conservation and/or recreation" (FGP 1999, page 1). They function as linkages between parks and nature reserves to create an interconnected system. The FGPT followed a regional, landscape approach designed to establish a plan for an ecologically functional, statewide habitat system (Hoctor et.al. 2000). The recommended greenways plan includes 9.31 million ha (57% of the state). Of this area, 63% is public land, CARL or SOR proposals, or open water (FGP 1999). These lands include many large natural hubs (core conservation areas) and connecting linkages (Figure 5-18). Within the core conservation areas and associated linkages identified in the greenways plan are many intersections with roads. The Marjorie Harris Carr, Cross-Florida Greenway, a State Recreation and Conservation Area, provides a fitting example of the possible extent for conflicts with approximately 24 major road intersections (Figure 5-19). As part of the design of a functionally integrated, ecological network, many of these road intersections will require some type of mitigation measures, such as wildlife underpasses.

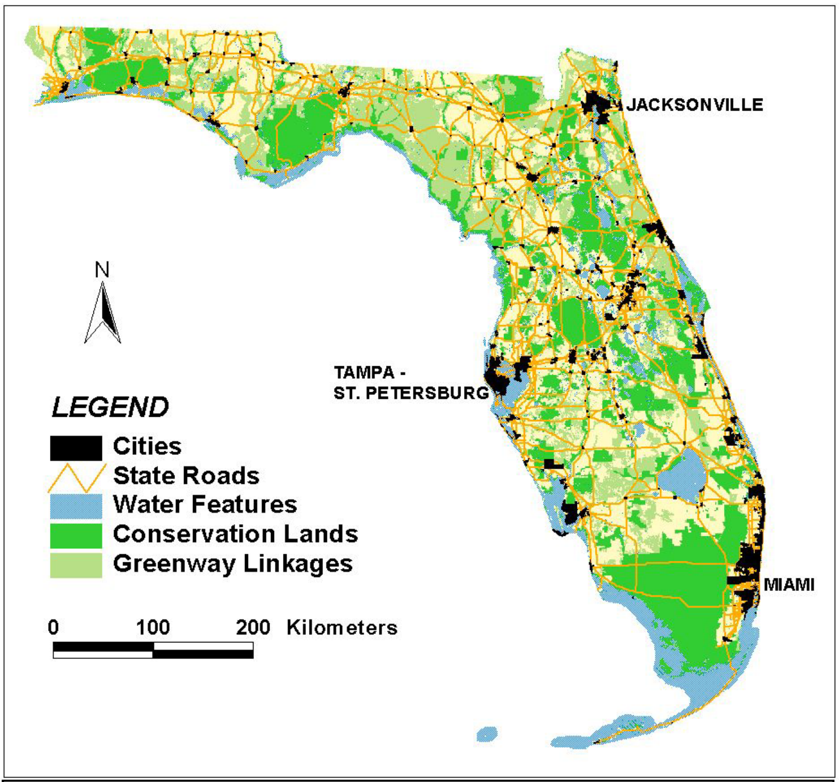


Figure 5-18. Greenway-highway interfaces. The map displays important linkages necessary to maintain connections between remaining primary conservation areas for wildlife populations, including the Florida panther and black bear. Major roads that intersect greenway linkages are shown in orange. Many of these act as semi-permeable barriers to wildlife movement and alter various landscape-level ecological processes.

The use of highway crossing structures at intersections with greenway linkages (habitat corridors) offers a method to reduce transportation-related, wildlife mortality and restore connectivity to the landscape. It has provided a realistic opportunity for ecologists and engineers to reduce the negative effects of roads, by restoring natural processes (e.g., wildlife movement and migration, flood, and fire) to a semblance of conditions prior to fragmentation of the landscape.

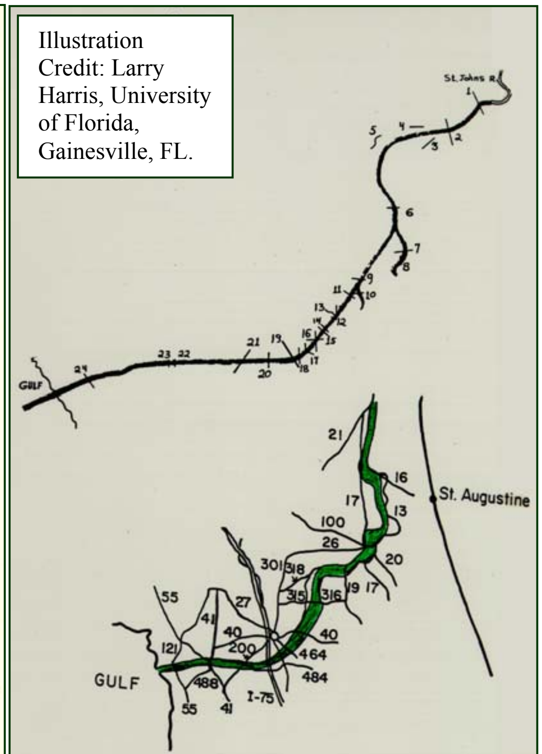


Figure 5-19. The Marjorie Harris Carr, Cross-Florida Greenway. Spanning over 140 km in length, there are 24 major road intersections to plan for in maintaining connectivity throughout the linear park.

The objective of the Florida Greenways Program is to establish an ecological network of green infrastructure whereby the aforementioned processes can occur across landscapes throughout the state. This program is closely linked with other programs with similar goals—Preservation 2000/Florida Forever 2010 and FFWCC Gap Analysis.

Transportation-related Environmental Policies

As a result of public opinion about major transportation projects in the 1980s and early 1990s, including those discussed in Chapter 1, Florida politicians and administrators began adjusting policies to address wildlife protection. On September 22, 1993, FDOT Secretary Ben Watts established the following policy: *"FDOT will coordinate with the State Comprehensive Greenways Program to properly locate new transportation facilities such that the least possible impact upon corridors of native habitat occur. In addition, wildlife crossing structures will be installed on existing facilities where impacts on wildlife are determined to be necessary. These issues will be evaluated in coordination with other agencies and the public"* (Watts 1993, Page 1). Subsequent to this policy, FDOT's mission statement in the 2020 Florida Transportation Plan (FTP) included the language *"…sustaining the quality of our environment"* (FDOT 1995).

From Goal 5 of the 2020 Florida Transportation Plan, *"…travel choices to insure mobility, sustain the quality of the environment, preserve community values, and reduce energy consumption"*, the FDOT seeks strategies to reduce urban sprawl and encourage transit use. Conservation strategies include support for ecosystem management through mitigation banking and greenway planning, and increased use of native plantings on right-of-ways (FDOT 1994).

The 2020 FTP (long-range transportation plan) is reviewed and revised periodically (approximately every 5 yrs) to keep current with changes in public policy and transportation needs. The ongoing planning process and public involvement stages for the 2020 FTP provides critical opportunities for environmental planning and inclusion of ecological designs to reduce impacts of highways on Florida's shrinking natural ecosystems.

Figure 5-20 displays the proposed road projects in the Florida Transportation Plan through the year 2020. Five particular projects potentially impact important greenway linkages identified in the Statewide Greenways Network Plan (discussed in more detail in the last section). These include: the 4-laning of SR 40 through Ocala National Forest, the outer Jacksonville beltway, the Florida Turnpike extension, the northwest section of the Orlando beltway, and the Suncoast parkway. The latter four, most importantly, possess the potential to dramatically increase development in currently rural areas. State Road 40 has the potential to increase fragmentation in the Ocala National Forest by magnifying the size of the current barrier.

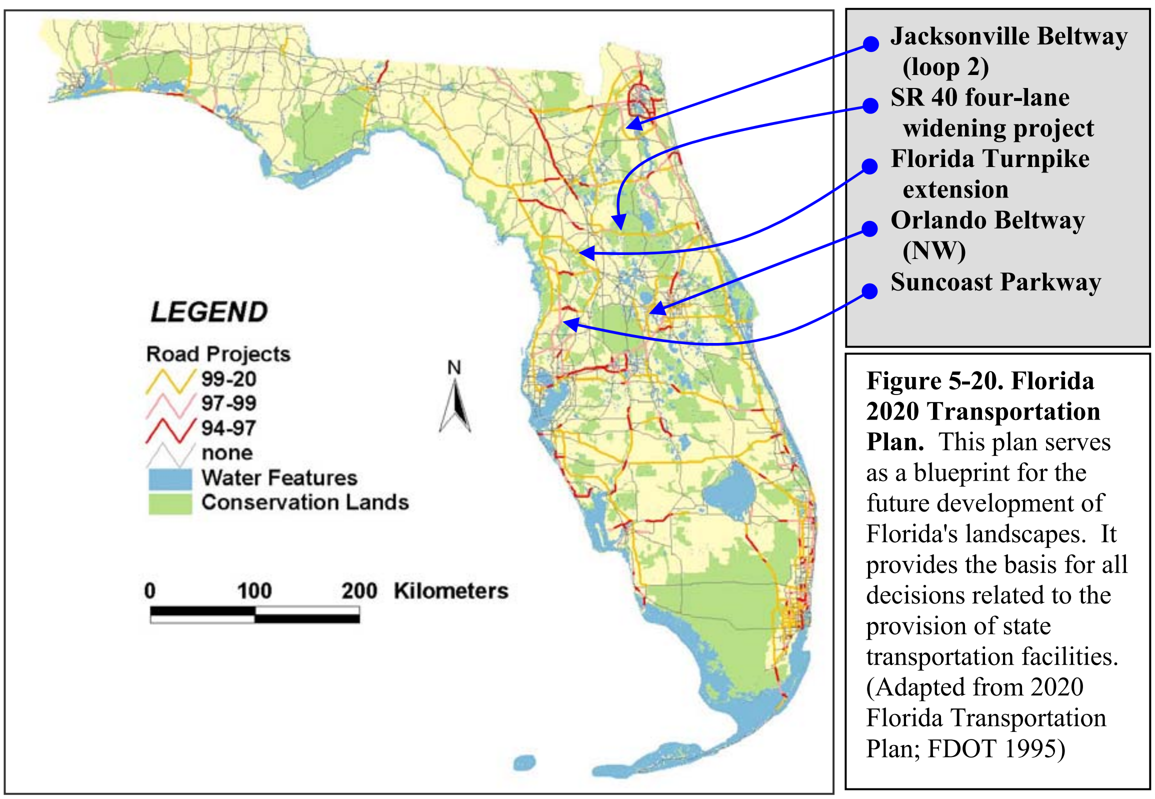


Figure 5-20. Florida 2020 Transportation Plan. This plan serves as a blueprint for the future development of Florida's landscapes. It provides the basis for all decisions related to the provision of state transportation facilities. (Adapted from 2020 Florida Transportation Plan; FDOT 1995)

The Orlando-Orange County, Expressway Authority (OOCEA), an autonomous political authority created by state legislative act (initiated by the City of Orlando and Orange County), proposes to build new expressways to link the City of Orlando with major population centers and statewide transportation corridors in an eight county region of central Florida (Figure 5-21). Though the project locations have been proposed; no environmental assessments have been performed to evaluate the location of the planned corridors, before being published in government-sponsored newsletters (OOCEA 2000). Ecological assessments should be conducted, at least generally, before maps are published proposing new routes that may cause tremendous environmental impacts. The model presented in Chapter 2 and Appendix B was designed specifically for this purpose, to provide quick identification of good and poor locations for alternative road corridors. Preliminary results can be discussed among officials and followed up by rapid site assessments prior to proposal to the public.

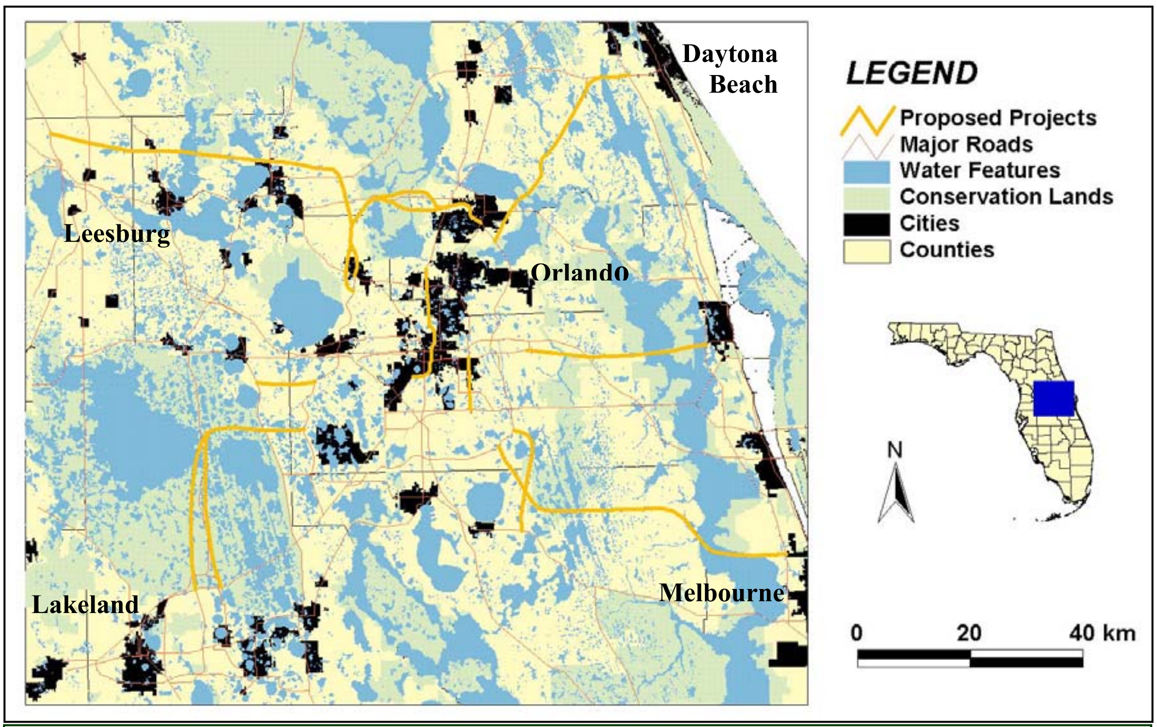


Figure 5-21. The Orlando – Orange County, Expressway Authority (OOCEA) 2025 Transportation Plan for the greater Orlando area. The proposed plan would link an eight county region of central Florida with high-speed expressways and toll roads. (Adapted from Expressway 2025 Master Plan; OOCEA 2003)

Considerations for Site Design that Enhance Use By Wildlife

Landscape ecology principles can be used to integrate transportation and conservation planning. An ideal meeting of road and greenway networks would look something like the engineering marvels constructed as part of the original Cross Florida Barge Canal Project (Figure 5-22). This type of structure probably allows movement of complete faunal and floral assemblages. More economically viable and innovative solutions are required however.

Figure 5-22. Cross-Florida Barge Canal overpass. Marion County Road 316 passes high above the Oklawaha River floodplain in Ocala National Forest. (Photo Credit: Larry Harris, University of Florida, Gainesville, FL)

Due to the large amount of carnage occurring on our highways, many methods and devices have been tested and used to help prevent wildlife-vehicle collisions. Examples include wildlife underpasses, tunnels or ecoducts, barrier fencing, creation of new habitat areas, warning signs, human intervention and assistance, temporary road closures, headlight reflectors, and sound devices and infrared sensors for vehicles.

Underpasses are used in south Florida by the Florida panther and other wildlife that cross Interstate-75 (Foster and Humphrey 1995). Other species that underpasses were constructed for include mountain goats *Oreamnos americanus* (Singer and Doherty 1985), black bears (Roof and Wooding 1996), deer (Kuennen 1989, Ford 1980, and Reed et al. 1975), mountain pygmy possums *Burramys parvus* (Mansergh and Scotts 1989), and badgers *Taxidea taxus* (Ratcliffe 1974). Smaller animals (such as toads and salamanders) were shown to use tunnels or culverts (Norden 1990, Langton 1989b, Tyning 1989, and Ryser and Grossenbacher 1989). Barrier fences can prevent deer from entering the roadway (Day 1990, Stadler 1987, and Feldhamer et al. 1986), but likely intensify the fragmenting effects of roads. Headlight reflectors, warning whistles, and motorist signage have provided inconsistent performance at best in reducing vehicle collisions with wildlife (Pafko and Kovach 1996, Reeve and Anderson 1993, Romin and Dalton 1992, Schafer and Penland 1985, and Pojar et al. 1975).

Most research indicates that ecopassage-barrier fence systems are the most effective method for increasing road permeability while simultaneously reducing wildlife-vehicle collisions. Effective vs. ineffective design, correct vs. incorrect placement at heavily used crossing sites, or good maintenance (that provides containment) vs. poor maintenance (that allows circumvention) on fencing or barriers can be keys to success or failure of ecopassages.

The following list of parameters can be used in practice to improve permeability of highways and increase connectivity of adjacent conservation areas:

- Context Sensitivity—vegetation consistent with surrounding habitat
- Environmental variability—provide for terrestrial passage at semi-aquatic sites during periods of high water levels
- Vegetative screening—block headlights, diminish traffic noise and provide cover

- Directional fencing—funnel wildlife through passages and away from road surface
- Berming—reduce effects of traffic noise and lights
- Topography—road should be designed to "fit into" the landscape (e.g., minimize alteration in slope of underpass/ overpass approaches)
- Substrate—consistent with adjacent area
- Lighting—reduce tunnel effects by increasing openness value (height*width/length) and providing light penetration in medians of divided highways
- Human presence—reduce human access associated with crossing sites

Economic road construction practices commonly include cut and fill techniques to overcome problems associated with uneven ground. While in areas of minimal topographic relief, this technique may be suitable for constructing level roadbeds; when relief is more significant, more ecologically sound practices should be used (Figure 5-23) to increase landscape connectivity. If we must build roads, instead of simply "placing them on" the landscape, they should be designed to "fit into" the landscape to minimize barrier effects and maximize landscape connectivity.

Effects of local topography and scouring (e.g., formation of depressions at culvert entrances), and seasonal and interannual variation in precipitation were shown in Chapter 4 to prevent functionality of certain culverts. Under dry conditions use by wildlife was recorded, yet under wet conditions flooding of depressions prevented access by terrestrial organisms. Road maintenance should include routine filling of depressions or employ methods to prevent persistent pooling of water at culvert entrances. One means of addressing this issue is the construction of multi-cell units. Multi-cell culverts could be designed at multiple elevations to provide dry passage at various water stages (Figure 5-24); alternatively in Europe some culvert designs include an elevated sill alongside creek drainages to provide adjacent passage for terrestrial species (Veenbaas and Brandjes 1999).

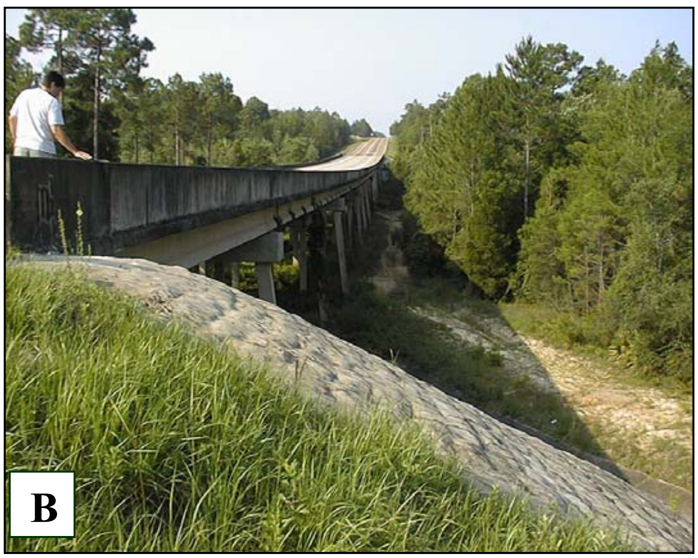


Figure 5-23. Existing highway structures and potential sites for wildlife crossings. A. An example (Florida Turnpike) where topographic relief could be used to construct functional overpasses and underpasses for connecting proposed greenways instead of following standard fill practices for road-building. **B.** An underpass that was constructed over a stream reach and ravine on SR 123 in Eglin Air Force Base, Florida provides an example of ecologically sound road-building practices.

The efficacy of underpasses is largely determined by site characteristics outlined above. Vegetation and substrate are two such characteristics that can be controlled through management practices. Wildlife movement monitoring efforts (discussed in Chapter 4) identified the lack of use of structures with substrate consisting of coarse rip-rap (large rocks or concrete designed to prevent scouring and erosion) and avoidance of open non-vegetated structures by black bears. Figure 5-25 provides examples of good and poor design features. Where scouring effects are severe, a soil base is insufficient to maintain structural integrity of bridge pilings; however, substitute materials could be applied such as tiles, asphalt or concrete paving around pilings and below the bridge.

Figure 5-24. An example of a multi-cell culvert in northwest Gainesville, Florida. In two separate years of monitoring, this culvert experienced dry and wet periods. Wet periods significantly reduced use by wildlife.

The primary objective of efforts to retrofit existing roads or plan for new roads should be to identify appropriate measures at the proper locations (Figure 5-26). An integrated transportation/conservation planning approach that incorporates landscape ecology principles and uses tools such as GIS can achieve this objective. The research presented here has endeavored to follow this approach.

Figure 5-25. Effects of vegetation and substrate at wildlife underpasses. Through wildlife movement monitoring efforts, these examples showed that well landscaped sites with soft ground were used much more frequently.

A. US 17 bridge over Deep Creek in Volusia County.
•Dimensions: 51 m wide (includes 25 m terrestrial connection, no recorded large animal movement), 14 m long, 2 m high
•Grass-regularly mowed, coarse rubble substrate (inset)
Wildlife bridge extension on SR 46 over the Wekiva River in central Florida. •Dimensions: 162 m wide (includes 74 m terrestrial connection regularly used by black bears, deer, etc.), 14 m long, 3 m high
•Native trees/shrubs, clay-loam

Social and Economic Priorities and Future Research Needs

As an annual comparison of investment, Florida spends $5.8 billion (FHWA 2002c) for highways versus $1.3 billion (BEBR 2001) for conservation and natural resource management (4.5:1 differential in expenditures). Only $300 million is dedicated to conservation land acquisition. This reflects a significant preference by society to devote public resources toward transportation rather than conservation.

Figure 5-26. Identifying sites for retrofits (increasing permeability of roadways).

- Can we identify what type structures should be where?
- Example of wrong structure at the wrong spot. In this case road-killed deer were recorded (A) where a frequently used deer trail (B) crossed a highway fitted with a small double pipe culvert (C).

Each year in the U.S., over one million deer-vehicle collisions occur that cost $1.1 billion in property damage, and cause an estimated 29,000 human injuries and 211 human fatalities (Conover et al. 1995). Although estimates of vehicle collisions with elk, moose, black bear, etc. were not available, they likely are similar in extent of damage but fewer in number. These values demonstrate the need, from a human perspective (economic and social), to increase priorities for conservation strategies designed to reduce these impacts.

What is the Economic Equation for Success?

Short of a needed shift in social and economic priorities, only frugal and creative mechanisms are available to reduce impacts of roads on conservation areas. In 1992, the

FDOT had an inventory of 5,771 bridges (FDOT 1992). Due to limited resources, the FDOT annually carries a backlog of more than 1,000 of these bridges in need of repair and 350 in need of replacement. With appropriation of funds for these projects, significant opportunities would exist for enhancement to designs to increase habitat connectivity.

A summary of FHWA transportation funding could shed light on mechanisms for partial funding of road mitigation at greenway intersections. A total of $1.68 billion in Federal funds will be allocated annually for the next five years for transportation improvements in the State of Florida (FDOT 1999). Over this 5-yr period, $45 million annually is dedicated to the TEA-21 program for transportation system enhancements in 12 eligible categories (Gary Evink-FDOT, Personal Communication). A new category now eligible for these funds is mitigation for environmental impacts on wildlife. A major stipulation; however, is that TEA-21 funds can only be used when the project is linked to highway mortality of wildlife. Administratively, TEA-21 funds are distributed to individual FDOT operational districts; and local government Metropolitan Planning Organizations (MPOs) determine their application. The primary use, to date, has been for alternative transportation enhancement (e.g., bicycle trails, pedestrian or recreational trails and walks, landscaping and aesthetics). The first project funded by TEA-21 monies for wildlife impacts was a Florida panther underpass on SR 29 in south Florida.

Legal mandates for wetland protection have existed in Florida and the United States since the 1970s. Required under Section 404 of the U.S. Clean Water Act and additional state regulations regarding wetland protection, the FDOT must provide compensation or replace wetlands destroyed as a result of road construction. The standard practice followed by the FDOT is provision of funds to regional water management districts that are primarily used in wetland mitigation banking programs (P. Southall-FDOT, Personal Communication). Similar measures are needed for rapidly disappearing native upland communities that act as critical linkages in an integrated ecological network. To mitigate fragmentation of intact native upland communities by new highway corridors, transportation agencies should be required to provide underpasses that maintain connectivity between severed habitat areas.

An economic program designed to improve functional connectivity of ecological networks must take advantage of available funding sources through all programs associated with negative impacts of highways such as wetland mitigation, river protection and restoration (e.g., Save Our Rivers, FDOT bridge replacements), TEA-21 enhancements, and conservation land acquisition (e.g., CARL, Florida Communities Trust).

Land Ownership, Conservation Easements and Highway-Greenway Interface Zones

State agencies have been reluctant to spend public funds for underpass structures on roads adjacent to private lands, when long-term use of the property for conservation is not guaranteed (Gary Evink-FDOT, Personal Communication). Although uncertain future use of land is a legitimate concern; private lands that currently function as commercial forest land, livestock grazing, or other low-intensity agricultural uses serve as valuable assets as landscape linkages between public conservation areas. It is important to identify highway-greenway interfaces within private lands as potential sites for mitigation. Perhaps, if these areas were designated as part of a statewide, habitat conservation network, land development could be directed into other less critical areas; and prevent urban sprawl and strip development along roads in rural areas.

A mitigation strategy should not only include construction of underpasses or other means designed to reduce fragmentation of habitat linkages, but land-use controls or conservation designations as well. As property values along roads soar it has become increasingly difficult to justify outright purchase of land (fee simple acquisition) to further conservation goals. Opposite from outright purchase are zoning and land-use restrictions; however, these are unpopular with landowners and subject to change under political transitions. And, therefore, are less effective than perpetual land conservation devices (Wright 1994).

Alternative strategies that are becoming more attractive include control of partial interests of land (i.e., conservation easements) through—donated development rights (DDRs), purchased development rights (PDRs), and transference of development rights (Wiebe 1997). The use of PDRs, the most widely used option, began in earnest in the 1930s when the U.S. National Park Service established the Blue Ridge and Natchez Trace parkways; purchasing adjacent development rights to preserve views of scenic open space (Haapoja 1994). The State of Wisconsin also exercised this method to preserve vistas along the Great River Road in the 1950s (Wright 1993). As of 1993, only nine states have conservation easement programs protecting approximately 83,000 ha (Wright 1993). In Florida, PDRs have been used to establish conservation easements on commercial forest lands in critical floodplain management and aquifer recharge areas.

The use of DDRs by conservation trust organizations has been more successful resulting in the protection of over 1.1 million ha of private lands from development

(Wright 1993). Over 57% of the State of Florida has been identified as part of the Florida statewide ecological network. Of those lands identified, 22% are in private ownership with little to no development restrictions. The use of DDRs and PDRs can play a critical role in protecting these private lands from development; aside from costly fee-simple acquisition purchases that remove land from the property tax rolls.

These techniques establish conservation easements, yet provide multiple benefits to the property owner by preserving the land's current economic use, reducing property tax assessments through devaluation of the land, and include either a cash payment (for sale of development rights) or income tax deductions (qualified as charitable contributions) for relinquishing development rights in perpetuity (Haapoja 1994). Considering that conservation easements were deemed appropriate for protecting scenic vistas in the 1930s, they are just as essential now for maintaining critical linkages at greenway-highway interfaces for an ecological network.

Future Planning and Research to Integrate Transportation and Conservation Objectives in Florida

More intensive wildlife movement studies of key indicator species should be conducted to analyze behavior associated with encounters with roadways. Planners and policymakers could use this information to make better decisions regarding road corridor locations, road construction methods and designs, and integration of road and ecological networks.

Specifically, linking the results of the ecological hotspots on highways model (Chapter 2) and the Florida statewide greenways model would support the goal to conserve Florida's remaining biodiversity. This goal can be facilitated by using the model results to program mitigation with future road projects, and by using the inventory of existing infrastructure (Chapter 3) at prioritized greenway-highway interfaces to evaluate the present permeability of existing roads. The information generated from the study on wildlife use of existing bridges and culverts (Chapter 4) should be used toward the development of design standards for new wildlife crossing structures.

Capability to coordinate greenway priorities with road crossing priorities could be further strengthened by modifying the prioritization model (Chapter 2, Appendix B) to include the ability to assess development pressure. A matrix that plots the intensity of development pressure against a gradient of strategic importance could further fine-tune the prioritization process; both with regard to road projects and acquisition of critical habitat-corridors (Figure 5-27).

Evaluation Criteria

- regional greenway systems
- strategic habitat conservation areas
- ecologically-based design vs. engineering band-aids
- existing highway structures
- sheet flow, floodplains, riparian zones
- chronic road-kill sites
- threatened and endangered species
- charismatic species
- public relations value
- developmental pressure

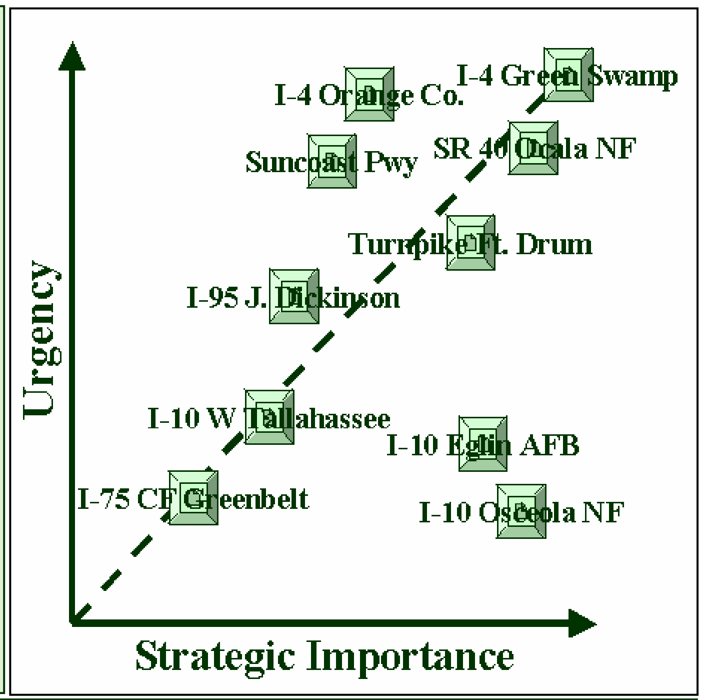


Figure 5-27. A conceptual matrix to further fine-tune ability to establish priorities for restoring connectivity/constructing wildlife underpasses.

CHAPTER 6
LITERATURE REVIEW

Ecological Effects of Roads

Highways and motor vehicles increase mobility of humans, but often at a high cost to wildlife. Construction of roads results in fragmentation of wildlife habitat (Hall et al. 1994, Salisbury 1993, Harris and Silva-Lopez 1992, Andrews 1990, Mech et al. 1988, and Dickman 1987), creation of barriers to wildlife movement and dispersal (Clarke et al, 1998, Madsen 1996, Brody and Pelton 1989, Harris and Gallagher 1989, and Wilkins 1982), negative edge effects (Lindenmayer et al. 1999, Gibbs 1998, and Mader 1984), and increased mortality of species attempting to cross these roads (Gilbert and Wooding 1994, Cristoffer 1991, Stadler 1987, Wooding and Brady 1987, Oxley et al. 1974, and Sargeant and Forbes 1973). General reviews and case studies of these effects can be found in Evink et al. (1999), Evink et al. (1998), Forman and Alexander (1998), Spellerberg (1998), Evink et al. (1996), and Bennett (1991).

These and other pronounced ecological effects not only occur at the interface between highways and habitats, but also may extend thousands of meters beyond (Forman 1995). Direct and indirect impacts of roads to landscape-level ecological processes and species composition can be separated into four categories: traffic, isolation and barrier effects, edge effects, and human access. Each road effect can be further characterized by the specific relationships between ecological patterns and processes (Table 6-1).

Table 6-1. Ecological Effects of Roads

Effects	Direct Impacts	Indirect Impacts
Traffic	**(Pattern)** Cause direct mortality through wildlife-vehicle collisions **(Process)** that can reduce population levels, alter age structure and reduce long-term viability (Fahrig et al. 1995)	**(Pattern)** Attract carrion feeding species to road-kills that can, in turn, lead to additional vehicle-related mortality (Bedford and Griffiths 1995, and Harding 1986) **(Process)** that could impact predator-prey relationships and population dynamics of predator species
Isolation/ Barrier	**(Pattern)** Create effective barriers/ filters to movement for many species, **(Process)** thus altering normal migratory, foraging and mating behavior (Harris and Scheck 1991)	**(Pattern)** Create fragmented habitat mosaics consisting of isolated habitat islands among dense road networks and urban development **(Process)** that can lead to genetic isolation and decay (Mader 1984), and loss of populations and species (Harris 1984)
Edge	**(Pattern)** Facilitate the rapid spread of invasive 'weedy' species **(Process)** that often out-compete native species, and are not as subject to predation (Stiles and Jones 1998, Wilcox 1989, and Verkaar 1988) and thus displace native species	**(Pattern)** Alter adjacent habitat through drainage modifications, erosion and siltation **(Process)** that may affect vegetation structure, wildlife composition, reproduction and movement success (Gunn and Sein 2000, and Southall 1991)
	(Pattern) Act as passive repositories for human-generated pollutants **(Process)** that degrade habitat quality and increase the threat of toxic poisoning (Muskett and Jones 1980, and Leedy 1975)	**(Pattern)** Create habitat ecotones (subject to altered environmental gradients of light, moisture, noise, temperature, etc.) **(Process)** that negatively effect breeding of area sensitive and forest interior species; generally characterized by increased predation and parasitism by opportunistic species
Human Access	**(Pattern)** Create greater human access to remote areas, **(Process)** thus facilitating commercial resource extraction and habitat loss through land conversion and development	**(Pattern)** Increase access to remote resource areas for hunting, poaching and recreation **(Process)** that may alter wildlife population dynamics (Noss and Harris 1986, and Holbrook and Vaughn 1985)

Vehicle-Wildlife Collisions

Numerous authors have documented wildlife fatalities on roads due to vehicle collisions (McRae 1997, Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Smith 1996, Belant 1995, Cristoffer 1991, Harris and Scheck 1991, Day 1990, Dodd et al. 1989, Harris and Gallagher 1989, Lalo 1987, Stadler 1987, and Wooding and Brady 1987). Noteworthy examples of road-kills would include impacts on endangered species and on biological phenomena in general (e.g., amphibian migrations). Several instances of massive amphibian road-kills are reported in Europe, New England, and Florida where large overnight migrations occur (Barichovich and Dodd 2002, Smith and Dodd 1999, Jackson 1996, Smith 1996, and Langton 1989a).

The Florida panther, Florida black bear, Florida key deer *Odocoileus virginianus clavium*, and American crocodile *Crocodylus acutus* serve as critical examples of highway mortality on populations of large threatened and endangered species. Automobile-related deaths of the Florida panther gained international attention in the 1970s with the planned extension/expansion of I-75 (Alligator Alley). Several studies discuss issues associated with the highway project and Florida panthers in south Florida, including installation and effectiveness of wildlife underpasses (Logan and Evink 1985, Foster and Humphrey 1995, and LoBuono 1988).

From 1976 to 1999, 729 black bears died from vehicle collisions on Florida highways (FFWCC 2000). Annual mortality levels from vehicle collisions continue to grow every year. In 1998, 88 black-bear deaths were recorded on Florida highways (FFWCC 2000). There is a direct positive relation between black-bear road-kills and traffic volume on 2-lane highways (Figure 6-1).

The population of Florida key deer (limited mainly to Big Pine Key in South Florida) averaged more than 50 deaths/yr from vehicle collisions between 1985 and 1997 (USDI 1998). The only population of American crocodiles in the United States also has been impacted by road fatalities. Gaby (1987) has shown that 46% of human-related mortality of crocodiles in Florida is from vehicle collisions.

The threat is further exacerbated when the exceedingly low population levels are considered. There are an estimated 46 to 74 Florida panthers (Maehr 1997); only seven core populations of Florida black bears, with some 2,000 to 2,500 individuals (Eason and O'Meara 2000, and Walt McCown, personal communication); 250 to 300 Florida key deer (Calvo and Silvy 1996); and approximately 800 American crocodiles (Sharp 1999).

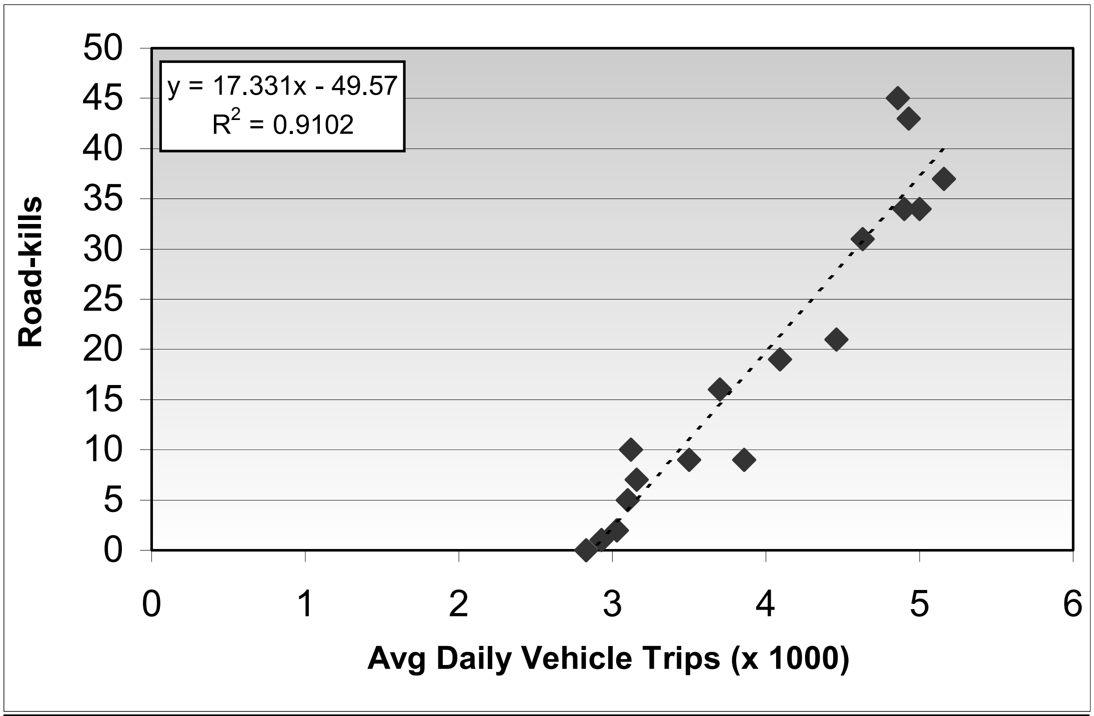


Figure 6-1. Comparison of Florida black bear road-kills and average daily vehicle trips (ADVTs). As traffic volume increases black bear-vehicle collisions increase. (Data source: Florida Fish and Wildlife Conservation Commission 1994)

Habitat Loss, Fragmentation, and Isolation

Habitat isolation and fragmentation by linear structures such as roads may have drastic effects on biological diversity. Human influence threatens native biological diversity through loss of species from genetic inbreeding, elimination of large uninterrupted habitat, and invasion of alien species (Forman and Alexander 1998, Andrews 1990, and Harris and Gallagher 1989). The rapid fragmentation of landscapes by roads and urbanization results in the loss of normal dispersion patterns (Harris and Scheck 1991, and Andrews 1990). Landscape character has switched from one of humans in a natural landscape matrix to one of natural areas in a human-dominated landscape. Dickman (1988) investigated mammalian species richness as affected by proximity to habitat-fragmenting forces, such as roads and urban development. He found that small patches were unsuitable for long-term maintenance of species diversity, as mammalian species richness declined rapidly with decreasing distance to roads, buildings, and so on. Areas of insufficient size cause local extinctions and inbreeding depression for species with large area requirements, due to isolation of gene pools (Dickman 1988). It was also found that specialists were usually excluded and generalists retained when patches were less than 0.65 ha (Dickman 1988).

Maehr and Cox (1995) demonstrated the importance of habitat contiguity for the Florida panther in South Florida. By correlating landscape features with radio-telemetry point locations, they were able to show that panthers preferred large forested habitat areas and avoided open cover types. Size of occupied suitable habitat patches averaged 20,816 ha (Maehr and Cox 1995). Additional analysis showed that only six adequate roadless areas of this size remain in Florida. Four of these areas, all located in south Florida, are contiguous, but separated by major highways and canals. Furthermore, collisions with automobiles represent the principal means of human-related mortality for the Florida panther (Maehr et al. 1991). Successful dispersal and expansion of the current range of the Florida panther will depend on provision of large contiguous forested habitat areas.

Likelihood of patch occupancy by black bears in Florida also appears to increase as patch size increases (Hellgren and Maehr 1992). In fact, bears used public preserves of less than 100,000 ha only when adjacent to larger occupied tracts of land (Hellgren and Maehr 1992). Key management issues for Florida panther and black bear include increasing permeability of roads and reducing habitat loss and fragmentation through cooperative land management schemes with private landowners.

Density of Roads

One of the primary effects of fragmentation on the presence of certain wildlife populations is road density. Several studies have examined the effect of road density, with conclusions varying depending on the species involved. The consensus among studies of wolves *Canis lupus* in the Great Lakes region, was that wolves require areas with road densities less than 0.54 to 0.69 km/km^2 to sustain viable populations (Mech 1989, Mech et al. 1988, Jensen et al. 1986, and Theil 1985). Lyon (1983) presented evidence that elk *Cervus canadensis* use of habitat areas in Montana, Idaho and Washington reduced to 25% when road densities were greater than 3.11 to 3.73 km/km^2. Road density was also determined to be a critical factor in habitat suitability for the moor frog *Rana arvalis* in Europe (Vos and Chardon 1998).

Roads appear to have an effect on habitat use by the Florida panther, especially with regard to den locations. Maehr (1997) found that resident females without kittens use habitat areas near roads, while those with kittens prefer den locations greater than one km from roads. This suggests that habitat areas with roads may be suitable Florida panther habitat provided significant road permeability is afforded between marginal road-inclusive areas and larger roadless denning-habitat areas.

Extent of habitat fragmentation and isolation caused by increasing road densities in developing areas is critical for determining the persistence of disturbance-sensitive species. Based on numerous studies that have documented these impacts for various species (Bowers and Matter 1997, Rodgers and Smith 1996, Van Dyke et al. 1986, and

Opdam et al. 1985), the best prescription for retaining disturbance-sensitive species would include conservation reserve designs that maintain contiguous large reserves. Ideally these reserves would contain wetland-upland gradients of suitable habitat (high landscape structural complexity preferred) and network connections that contain similar characteristics and that minimize negative edge effects.

Negative Edge Effects

The high diversity of wildlife associated with edges and ecotones has been widely accepted as a fundamental principle in ecology (Harris 1988). Historically, this was considered a positive effect and resulted in prescribed strategies for increasing edge habitat to increase game populations (Paton 1994). However, it is now recognized that the management strategy of increasing edge habitat can be detrimental to many edge-sensitive species.

The attractiveness of road verges has been noted for numerous birds, rodents, and deer; all species that prefer open fields or maintained grassy areas for foraging or nesting (Canaday 1996, Paton 1994, Rich 1994, and Harris and Gallagher 1989). Marini et al. (1995) and Harris (1988) used the term “ecological trap” to refer to the attractive yet destructive effects of edge habitat on traditionally forest-interior nesting birds. Although forest-interior nesting birds occupy edges, the greater presence of nest predators and parasites (e.g., brown-headed cowbird, *Molothrus ater*) there renders the habitat less suitable (Harris and Gallagher 1989, and Harris 1988). Increased edge can impact interior species by increasing predation from edge predators as far as 300 to 600 m into a forested patch (Norse et al. 1986). Disruption of normal behavior, communication skills, and mating success can also result, as was shown for nocturnal frogs by artificial lighting

(Buchanan 1993) and for anurans and birds by traffic and other technogenous noise pollution (Il'ichev et al. 1995, and Barrass 1985).

Reijnen et al. (1997, 1995) attributed forest breeding bird's aversion to road verges to reduced habitat quality (primarily caused by traffic noise; and to a much lesser extent, visual disturbance or pollutants). These studies examined the effect of proximity to roads on breeding-bird density and found a 60% reduction in species diversity in plots adjacent to roads. The threshold where bird densities decline was defined as the distance from the highway where traffic noise is 42 decibels (dB) or higher (Reijnen et al. 1995). Yet other studies have found a notable variation in negative edge effects on breeding-bird nesting success, depending on the species (Marini et al. 1995); nest location preferences (e.g., clearcut, forest, and grassland) (Rudnicki et al. 1993); or type of edge (e.g., landscape structural differences, abrupt v. gradual edges) (Suarez et al. 1997). Fahrig et al. (1995) demonstrated the reduction in anuran densities as traffic intensity increases. These studies suggest significant complexity and variability in edge effects according to landscape structure, species composition, and physical attributes associated with traffic density and roadway type.

Widening of highways increases the potential magnification of negative edge effects, including the absence or reduction of species sensitive to noise or visual disturbance and increased presence of predators and weedy species (e.g., birds, rodents, and omnivores) (Forman and Alexander 1998; Gibbs 1998; Reijnen et al. 1997, 1995; Bennett 1991; Andrews 1990; Garland 1984; Adams and Geis 1983; Wilkins 1982; Ferris 1979; Kozel and Fleharty 1979; and Oxley et al. 1974). In summary, roads seem to increase the richness of species that are competitively advantaged in disturbed environments, while decreasing the abundance and richness of area-sensitive or forest-interior species.

Alteration of Ecological Processes and Changes in Community Composition

The creation of edge, caused by roads, agriculture, silviculture, and urbanization results in severe reductions of native biological value by artificially introducing abiotic and biotic forces (Harris and Scheck 1991). Roads act as barriers; and also alter the intensity of light, wind speed, temperature, humidity, evaporation rates, and noise levels that cause certain species to avoid road verges (Forman and Alexander 1998, Harris and Scheck 1991). Light penetration and structural macrohabitat variables (such as canopy cover, litter cover, and presence of stumps and snags) were critical in determining distance effects of roads on presence of amphibians (Demaynadier and Hunter 1998). These results present valuable implications for intensive forest-management schemes that typically remove much of this structure and their integral function in the persistence of amphibian populations.

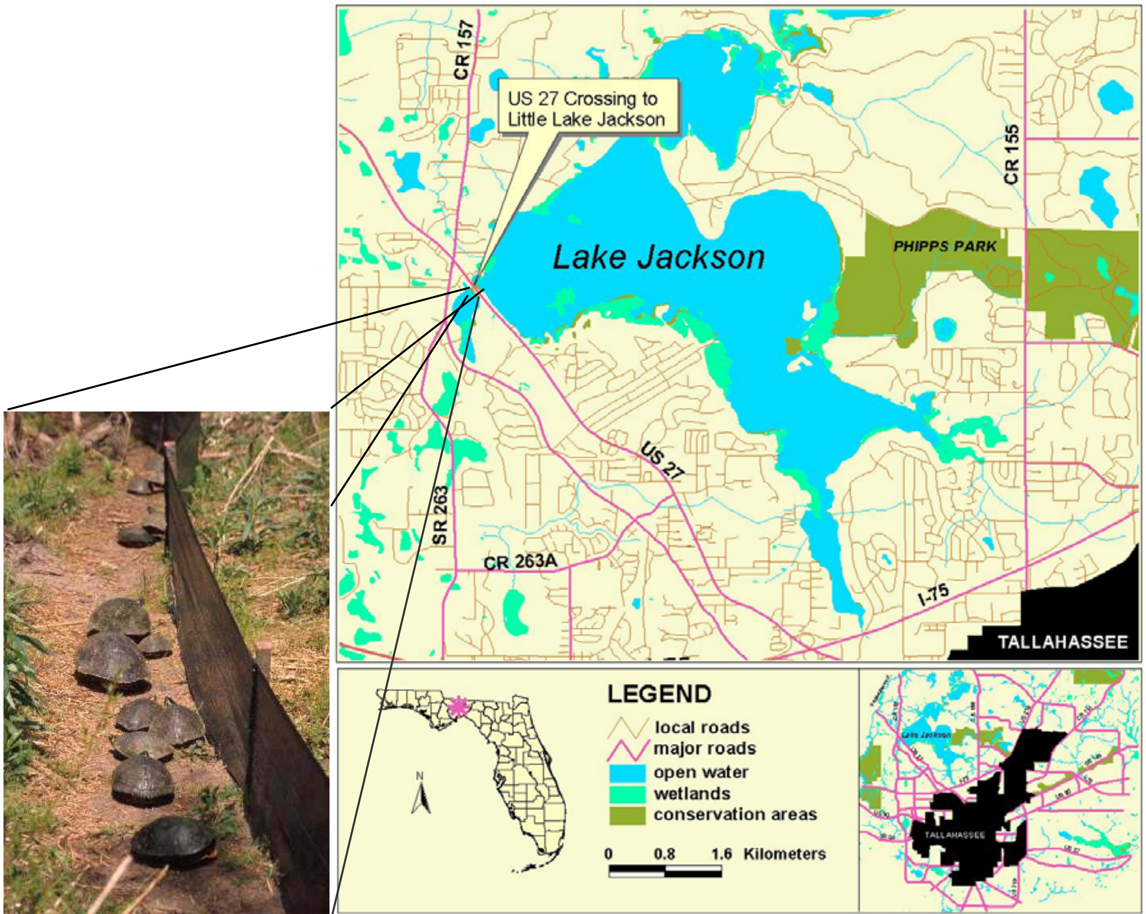
Roads also may act as significant barriers to important ecological processes such as animal and plant dispersal and migration. For instance, Langton (1989b) and Tyning (1989) documented the obstruction of normal migratory patterns of amphibian populations by roads. In Denmark, Hels and Buchwald (2001) calculated mortality rates of amphibians on minor (0.34 to 0.61 at 3,200 vehicles/day) and major (0.89 to 0.98 at 15,000 vehicles/day) highways. Mortality rates increased as mobility of various species decreased. For populations of slower amphibian species, high-traffic roads become an interminable barrier, effectively disrupting metamorphosis.

U.S. Highway 27, a four-lane highway constructed in the 1960s on a raised roadbed, bisects Lake Jackson, in Leon County, Florida. A single culvert provides the only connection between the two sections of the lake (Figure 6-2). To prove the inadequacy of this culvert, Aresco (2001) recorded 7,195 turtles attempting to cross the road over 18 months. Although he rescued most of these with a temporary fence (Figure 6-2), previous road-kill surveys estimated as much as 90% mortality. In fact, roads are suspected to be a major cause of population declines for turtles throughout the eastern United States (Gibbs and Shriver 2002). Aresco (2001) suggests that severe reductions in turtle diversity and abundance could result in changes to ecosystem processes including alterations to primary and secondary productivity, plant biomass levels, species composition and food web structure.

Harris and Silva-Lopez (1992) argue that faunal collapse can occur when disturbance levels are sufficient to cause fundamentally different intensities of ecological processes to prevail. An example of such collapse may result from removal or extirpation of gopher tortoises *Gopherus polyphemus* that provide habitat within their burrows for many other species. Such loss would reduce populations of all commensals. Divisive fragmentation on forest conservation areas caused by roads would facilitate this effect, thus altering the existing ecological processes (Harris and Silva-Lopez, 1992).

Roads act as barriers or inhibitors to movement of small mammals and arthropods (Mader 1984, Wilkins 1982, Kozel and Fleharty 1979, and Oxley et al. 1974) and thus may affect species distributions and community interactions. When high-intensity roads prevent crossings by wolves and black bears (Pacquet and Callahan 1996, and Brody and

Pelton 1989) the reduction in predation rates in isolated areas could result in higher prey densities and greater herbivory pressure on plant communities (Peterson 1977).



(Photo credit: Matt Aresco, Florida State University, Tallahassee, FL)

Figure 6-2. Lake Jackson and Little Lake Jackson wildlife crossing. US Highway 27 bisects Lake Jackson into two fragments connected by a single box culvert. This site exhibits exceptional numbers of migrating aquatic turtles. The barrier effect caused by the road is estimated to cause as much as 90% mortality (Aresco 2001). A temporary fence was set up to prevent turtles from being killed on the road (inset).

Roads also act as conduits for invasive plants and disease. Many predators, scavengers, and large mammals are known to use lightly traveled roads as movement corridors (Forman and Alexander 1998, and Brody and Pelton 1989). Opportunistic predators (such as black bears, coyotes *Canis latrans*, and raccoons *Procyon lotor*) serve as dispersal vectors along roadsides for pathogens (e.g., Rabies *Lyssavirus spp*.), and exotic or invasive species (e.g., Brazilian pepper *Schinus terebinthifolius*). Gelbard and Belnap (2003) reported that cover and richness of invasive plants was 50% greater and richness of native plants was 30% lower adjacent to paved roads than on 4-wheel-drive trails in southern Utah. Imported red fire ants *Solenopsis invicta* are known to use road right-of-ways as dispersal corridors and entry points for invasion of adjacent habitat areas (Stiles and Jones 1998). In south Florida, probability of occurrence of imported red fire ants was greatest when distance to roads or urban development was less than 150 m (Forys et al. 2002).

Roads can impose dramatic restrictions (related to human health and safety) on wildfires, another ecological process considered an important land-management tool (in the form of prescribed burning) for maintaining certain community types. This is especially relevant where high-volume, high-speed highways and urban sprawl are within or adjacent to conservation areas. For example, the Florida Division of Recreation and Parks must use alternative methods to control the growth of invasive woody species near two major highways that cross Payne's Prairie State Preserve (a large, wet prairie) because fire and smoke are believed to pose risks to driver safety (Southall 1990). Herbicide sprays and artificially controlled, water levels have proven marginally successful in reducing invasive woody species.

Dispersal of Toxic Substances and Environmental Pollution

The dispersal of motor-vehicle-produced chemicals and trace metals from roads upon road verges and adjacent habitat is well documented, probably because of the need to monitor human health risks and degradation to air and water resources (25, 19, 16 and 22 articles on this subject were found in the literature from the 1970s, 1980s, 1990s and

2000s, respectively). Road-related substances also contribute to contamination of adjacent habitats (e.g., petroleum, asphalt debris and other particulates, r-o-w maintenance chemicals, and deicing agents).

Elevated levels of nitrogen oxides near roads can promote increased dominance by a few plant species, resulting in reductions of diversity; and in some cases altering adjacent plant communities (Angold 1997, Weighell 1997). Documentation exists on roadside accumulation in soil and plants of lead, cadmium, nickel (Muskett and Jones 1980), copper, manganese, zinc (Yousufzai et al. 2001), platinum group metals (Rauch et al. 2000), polycyclic aromatic hydrocarbons (Krein and Schorer 2000), carbonyl compounds (Viskari et al. 2000), and deicing agents (Banasova 1986) disseminated by motor vehicles. Sutherland and Tolosa (2001) and Muskett and Jones (1980) examined dispersal distance of potentially toxic contaminants from roads. Both studies indicate that levels of lead, cadmium, and zinc in soil decrease with distance from the road surface. Concentration of other trace metals (e.g., nickel and copper) did not show a distinct pattern with distance from road, although anthropogenically elevated levels were apparent at certain test locations 50 to 100 m from the road, suggesting more complex factors affecting dispersion (e.g., wind, water flow, vegetation type, and seasonality).

Few studies address the direct impact of these substances on specific wildlife. Those that exist indicate potential for serious health risks to wildlife. In Idaho's Coeur d'Alene River Basin, Hoffman (2000) documented that ingested lead-contaminated sediment caused abnormal post-hatching development, disease, and 22% mortality of wild geese and mallards *Anas platyrynchos* (but see Beyer et al. 2000, regarding adult mute swans *Cygnus olor* exposed to toxic sediments). High concentrations of lead have also been reported for frogs sampled from highway drainages (Birdsall et al. 1986). A study (Harrison and Dyer 1984) on mule deer *Odocoileus hemionus* forage near roadways in Rocky Mountain National Park found that concentrations of lead were inversely correlated to distance from roads. It was also estimated that only 1.4% of daily intake of roadside vegetation was necessary to introduce excessive amounts of lead to mule deer diet.

Floodplain and Hydrologic Alterations, Effects of Erosion and Chemical Runoff

Hard-surfaced roads affect aquatic and semi-aquatic systems by altering runoff patterns, storage capacity, hydroperiods, stream velocity and depth, and sediment and chemical transport. Runoff associated with roads can increase velocity and quantity of water within riparian systems, resulting in modifications to stream morphology and stream migration within the floodplain (Winter 2001). Roads can also have negative effects on groundwater flow, reductions in percolation, and aquifer recharge. In topographically significant terrain, cutbanks in roads are known to interrupt slow moving groundwater seeps converting them to fast moving surface water (Forman and Alexander 1998). This leads to accelerated peak discharges and downstream flooding. Accelerated water flows lead to increased erosion and sediment transport; deposition of increased sediment loads downstream can adversely impact spawning areas by filling pools and gravel beds (Ruediger and Ruediger 1999).

Roads also contribute to degradation of adjacent aquatic and wetland habitats through the distribution of deicing salts, agriculture-related chemicals, and heavy metals (that may cause serious health problems and reduce reproductive success rates) (Harris and Scheck 1991). Research by Findlay and Bourdages (2000) indicates that changes to wetland communities due to road construction may not become apparent soon after, as the effects on certain taxa may not take place for many decades. This suggests that time horizons of most highway impact studies (less than 5 yrs) are inadequate to insure protection of overall wetland biodiversity. Improved understanding of these effects and more thorough project planning are needed.

Unpaved and aggregate-surface forest-roads pose significant negative ecological effects to otherwise undeveloped resource conservation areas. Of the approximate 644,000 km of national forest roads, impacts to aquatic systems include: slope and bank destabilization and erosion, suspended sediments in surface waters, alterations to natural watercourse or channelization, and changes to water levels and flow rates (Sheehy 2001, Ruediger and Ruediger 1999). Best Management Practices (BMPs) describe measures to reduce these impacts (FDOF 1987a, FDOF 1987b, Hynson et al. 1982). Management actions of particular interest are roadbed maintenance, slope and bank stabilization, and proper design and placement of culverts. Sheehy (2001) and Hynson et al. (1982) discuss methods to reduce erosion of the roadbed, banks, and slopes including: improved roadbed design and maintenance; use of buffers; and bank stabilization by vegetation, terracing, and "rock-filled" gabions.

The dynamics of natural fluctuation in water levels and flow rates must be considered when constructing stream crossings. Crossings can be designed to provide functional passage for local fish populations during high and low water levels by using multiple culverts, sills or weirs, resting pool excavations, etc. (Ruediger and Ruediger 1999, and Hynson et al. 1982). In summary, road impacts on aquatic ecosystems may include increased flow rates, aquatic habitat alteration, sediment and chemical transport and redistribution, and erosion of biodiversity.

Effects of Increased Human Access

Four human activities derive from increased access to natural areas: commercial resource extraction (e.g., logging and mining), non-commercial resource extraction (e.g., hunting, fishing, plant and animal collecting), recreation (e.g., camping, hiking, birdwatching, canoeing), and settlement (e.g., development and agricultural activities).

Roads provide primary access for resource extraction activities that often negatively impact wildlife through human disturbance and habitat destruction. For example, clearcut harvesting requires extensive road systems that increase vulnerability of carnivores, such as black bears to hunters (Brody and Stone 1987). Logging truck traffic was shown to reduce presence of female adult grizzly bears *Ursus horribilis* as far as 200 m from roads (Archibald et al. 1987). Clearcut logging activity can also eliminate potential nesting sites for cavity-nesting birds by removing or knocking down snags. Dead snags of various age or basal area are required to satisfy specific nest requirements for flickers *Colaptes auratus*, pileated *Dryocopus pileatus*, downy *Dendrocopos plibescens*, and hairy woodpeckers *D. villosus* (Conner et al. 1975). Nellemann and Cameron (1998) studied aversion of Caribou *Rangifer tarandus* to an oil-field complex near Prudoe Bay, Alaska. Their results showed that females and calves are highly sensitive to surface development (particularly initial construction of roads and related facilities). Avoidance greatly exceeded the physical footprint of the development.

Over-exploitation of wildlife resources is another consequence of increased human access within habitat areas. Extensive road systems were the most important factor for successful hunting of lynx *Lynx lynx* in rural areas of Norway and turkeys *Mealeagris gallopavo* in the Piedmont of Virginia (Sunde 1998, Holbrook and Vaughan 1985). Both dispersing and resident black-bears in the Pisgah Bear Sanctuary of North Carolina were subjected to legal and illegal killing near roads adjacent to the Sanctuary suggesting controlled access is needed along protected areas (Powell et al. 1996). Berish and Diemer (1998) interviewed 98 snake collectors in north Florida and found that 94% searched opportunistically along roads and other human-disturbed sites. Alarmingly, many collectors suggested they would kill rattlesnakes *Crotalus spp.* regardless of financial gain. Construction of a 12-km forest road was cited as the reason for increased exploitation of lake trout in Michaud Lake (Gunn and Sein 2000).

To maintain healthy wildlife populations, the State of Oregon instituted a cooperative road closure program to control human access within conservation areas (Hyder 1982). Successful agreements gained acceptance by users because of sufficient public education, well-maintained signage, and law enforcement presence (Hyder 1982). Elk and deer hunters (75 to 95 % favored road closures) discovered after the first few years that reduced hunting pressure resulted in greater hunting success (0.31–road closures, 0.04–roads open). Other benefits included reduced maintenance costs, less damage from traffic, and healthier wildlife populations. In 1982, Oregon operated 52 road closures covering 764,414 ha (Stein 1982).

Access provides opportunities for recreational activities within wildlands, yet negative ecological consequences often result. Campgrounds located in or near carnivore habitat areas are intrusions into otherwise native habitat that attract bears, coyotes, foxes, etc. in search of food, often resulting in human-wildlife conflicts (Creachbaum et al.

1998). Mace and Waller (1996) described several factors designed to reduce human-bear conflicts (visitor reductions, strategic trail placement, public education, and negative conditioning of grizzly bears). Road closings and mass transit provision have been used to reduce wildlife disturbance and habitat destruction from overcrowding problems in Yosemite (Ritter 1998) and Denali national parks (Brown 1978). Trail systems used for ecotourism, recreation, and research can also change ecological systems (e.g., increased erosion, light penetration, and disturbance from humans and domestic predators). Human traffic caused activity shifts or avoidance by sensitive species near trails, and increased numbers of unaffected or habituated species (Griffiths and van Schaik 1993).

Two factors are important to understand how access for human settlement practices can degrade habitat: landscape fragmentation (discussed previously), and habitat alteration near buildings and roads. In Summit County, Colorado, Theobald et al. (1997) found that pattern of development was a stronger indicator of habitat disturbance than building density; demonstrating that traditional village planning (e.g., cluster development characterized by condensed, development areas and large, uninterrupted, open spaces) is superior to contemporary suburban development (e.g., scattered, low-density developments on individually owned, large lots) in reducing the negative impacts on wildlife habitat (Arendt 1994).

Rossell and Litvaitis (1994) used harvest data for black bears and human demographic variables from 1961 to 1984 to explain the effect of urbanization on black-bear presence in townships of New Hampshire. Black-bear presence was negatively correlated to the increase in human population density and development intensity; black-bear harvest rates were positively correlated to the amount of agricultural land and the increase in forest road density (an indication of increased observability and human access). In Yellowstone National Park, grizzly bears exhibited reduced occupancy and inefficient foraging habits near human facilities, and displacement of subordinates by dominant individuals into inferior habitat nearer development (Mattson 1987).

Roads and development within and surrounding the Ocala National Forest (ONF) threaten area-sensitive interior-species and those species requiring large uninterrupted territories (Figure 6-3). There are approximately 39,160 ha of privately owned inholdings in the ONF (this represents 19% of the total area). These inholdings create access points for the spread of common weedy species. Harris and Silva-Lopez (1992) estimated that as many as 200 species of exotic plants now inhabit the ONF, effectively changing the composition and diversity of species within the forest. Property development within forest boundaries limits the use of prescribed burning that could control the proliferation of these intrusive plants. Reduced frequency of fire in the ecosystem increases the spread of oaks that favor species such as gray squirrel *Sciurus carolinensis*, but reduce habitat suitability for endemic and endangered red-cockaded woodpeckers *Picoides borealis* (Harris and Silva-Lopez 1992).

Hannah (1992) examined the effects that presence of roads and edge habitat had on habitat core areas in Ocala National Forest. Estimated penetration of edge effects into forest-interior ranged as high as 600 m. Edge habitat represented 35% of roadless forest patches, of which 30% was attributed to the presence of roads. Road-kills and human depredation of gopher tortoise has been facilitated by presence of roads and increased access (Hannah, 1992). Comparatively, in California, desert tortoises *Gopherus agassizii* were reduced by 60% as far as 1.6 km from the highway (Fusari 1982). Increased access to interior areas from adjacent forest roads is also suspected as the cause for increased presence of edge-dominant predators (e.g., raccoon, opossum *Didelphis virginiana*, gray fox *Urocyon cinereoargenteus*, bobcat *Lynx rufus*, and skunks) (Hannah, 1992). Lastly, high road density (1.84 km/km^2) increases forest-wide human presence for hunting and recreation activities and shrinks core refuge areas for large wildlife (Figure 6-3).

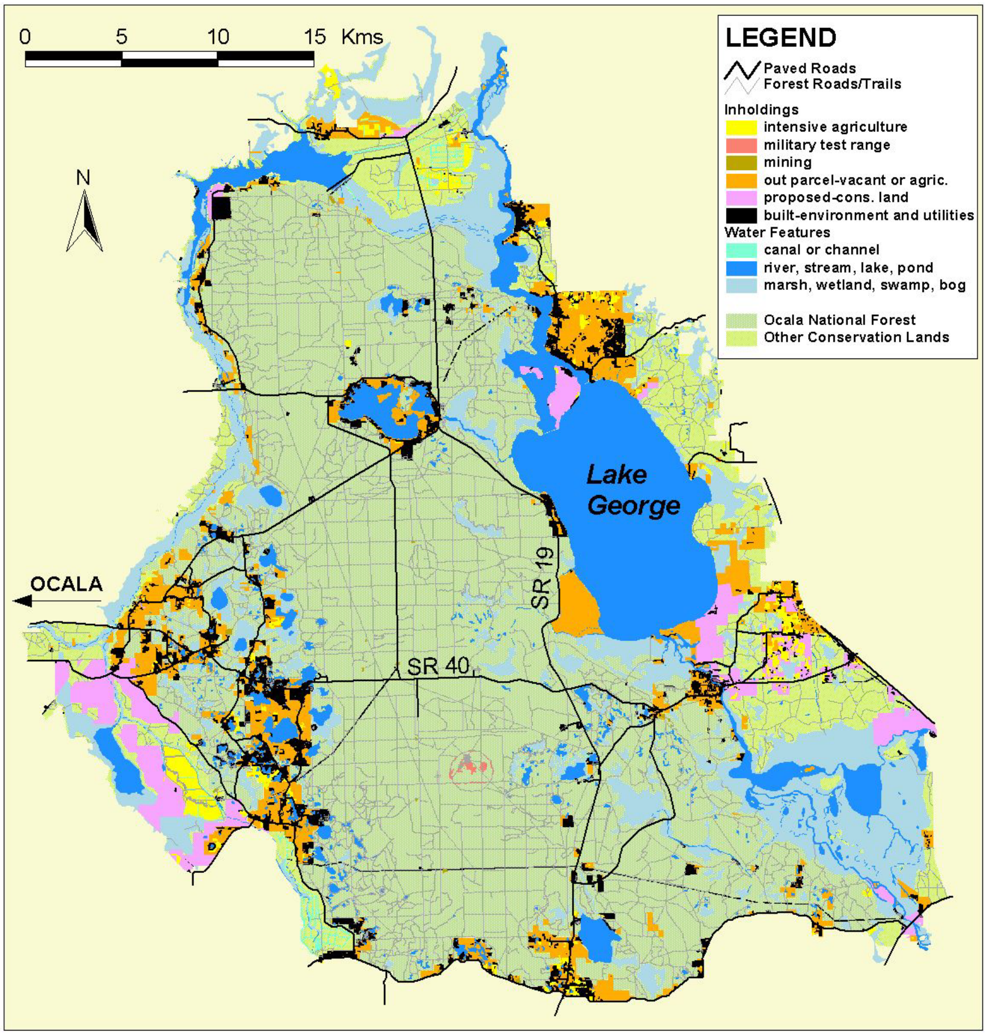


Figure 6-3. Greater Ocala National Forest ecosystem. Human impacts on this conservation area are pervasive. Because of the intensity of use, it did not qualify in the recent deliberations to establish designated roadless areas in National Forests by the U.S. Forest Service. There are 640 km of state and county highways and 3,295 km of forest roads and trails. Over 39,350 ha of private inholdings exist either as developed areas, agriculture, military installations or vacant areas. Of these, 25% (9,663 ha) are designated for purchase as additions to public conservation areas.

APPENDIX A
QUESTIONNAIRE REGARDING WILDLIFE MORTALITY ON ROADS

A survey was conducted at the FDOT-sponsored Transportation-Related Wildlife Mortality Seminar, May 1, 1996, in Orlando, Florida. The questionnaire consisted of two parts: 12 general questions concerning wildlife and roads, and 15 specific questions concerning selection criteria for prioritizing sites for wildlife underpasses. A 5-point Likert response format (strongly agree to strongly disagree) was used for the questionnaire. Significance of responses was evaluated according to demographic and subject groupings. Frequency distribution and statistical analysis of responses was performed using 2-way contingency tables, Chi-square, and Fisher's Exact Test (ET) in SAS Analyst (SAS Institute, Cary, N.C.). Fisher's ET was most applicable because of small sample size. The demographic makeup of the 65 respondents at the seminar is listed in Table A-1.

Table A-1. Respondent demographics

Organization/ agency type	**%**	**Geographic location**	**%**	**Job responsibility**	**%**	**Area of expertise**	**%**
Transportation	32	Florida	62	Research/ extension/ education	49	Biological/ ecological sciences	82
Private consultant	29	Other*	38	Regulatory enforcement/ impact assessment/ policy/compliance	26	Engineering/ transportation/ planning	18
Natural resource/ academic	39			Planning/design/engineering/ management	25		

*A combined group from U.S., Canadian, and International origin.

Wildlife and Transportation Issues

General questions were grouped according to four factors (road density, road right-of-way characteristics, traffic, and adjacent habitat/land-use characteristics) that affect permeability of roads for wildlife movement and wildlife persistence in areas where roads are present.

General Trends

Seventy-five percent of respondents (n = 65) agreed or strongly agreed that road density was useful as a predictor of probable number of adverse road-wildlife interactions. It was generally agreed that aversion to roads (74%, n = 48 of 65) and roadside habitat value (63%, n = 41 of 65) were a function of road size (road right-of-way width). Based on evidence from previous studies, respondents agreed that wildlife-vehicle collisions were a function of traffic speed (67%, n = 44 of 65) and that aversion to roads was a function of traffic volume (74%, n = 48 of 65). For certain species (e.g., herpetofauna) that mobility is characteristically slow and seem unaffected by traffic intensity or road size, survey takers agreed that road width and traffic volume would be useful indicators of road-kill rates (72%, n = 47 of 65).

Other general questions addressed the importance of wildlife preserves, urban woodlands, and linear habitat connectors (such as topographic ridges, riparian corridors, roadside strips, hedgerows, and fence-lines). Within urban-suburban and open-agricultural landscapes, the audience agreed that linear-habitat features (such as those listed above) were important concentration points for wildlife movement (74%, n = 48 of 65) and associated road-kills (79%, n = 51 of 65). It was overwhelmingly decided that roads bisecting preserve areas would manifest greater negative impacts on wildlife than roads bisecting human-dominated landscapes (90%, n = 59 of 65); and that open space areas within human-dominated landscapes, whether woodland or pasture, would exhibit more frequent road-kills (81.5%, n = 53 of 65).

Response by Demographic Variables

Statistical tests were performed on responses to general questions by demographic variables (Table A-1). Response by job responsibility was significant (Likelihood Ratio $\chi^2 = 7.84$, $p < .10$; Fishers ET, $p < .08$) concerning certain species aversion to roads as a function of traffic volume. More negative responses came from those in regulatory (agree–70%, no opinion–12%, disagree–18%) and management (agree–56%, no opinion–13%, disagree–31%) professions than academic professions (agree–84%, no opinion–13%, disagree–3%). Job responsibility also was a factor regarding whether more structured habitats would be points of concentration for negative road-wildlife interactions in range- or grass- land species ($\chi^2 = 9.45$, $p = .05$; Fishers ET, $p = .08$). In this case, the data reveals the absence of negative responses from those in regulatory (agree–88%, no opinion–12%) and academic professions (agree–69%, no opinion–31%).

Field of expertise was important pertaining to answers to questions no.3 and no. 9 (Exhibit A), respectively, that roadside habitat value was considered a function of road width ($\chi^2 = 5.26$, $p = .07$; Fishers ET, $p = .08$); and that urban wildlife would experience higher road-kill rates in urban open spaces than in adjacent developed areas ($\chi^2 = 10.46$, $p = .01$; Fishers ET, $p = .01$). Differences in responses to the former question revealed that those with planning or engineering backgrounds, 92% agreed; whereas those with science backgrounds, 56% agreed. Regarding the latter question, difference among respondents was reversed; 50% of planners and engineers agreed and 89% of scientists agreed.

Wildlife Mitigation Priorities on Roads

Questions concerning selection criteria, for prioritizing ecological hotspots on roads, focused on 5 specific issues: land ownership, road right-of-way and pavement width, site identification methods (e.g., field studies vs. GIS modeling), importance of preserve size, and road project programming.

General Trends

Four questions addressed importance of land ownership as a priority for mitigation. Respondents were asked to give priority to: 1) existing, public, wildlife reserves over private-lands or potential linkages between public, wildlife reserves; 2) critical road-kill sites, regardless of adjacent land-ownership, than to roads only in public, wildlife reserves; 3) retrofitting existing substandard structures through habitat corridors (e.g., riparian systems), regardless of adjacent land-ownership, over constructing new bridge-like structures only in existing, public, wildlife reserves (that are not associated with landscape function other than wildlife movement); and 4) retrofitting existing substandard structures through habitat corridors (e.g., riparian systems), regardless of adjacent land-ownership, over constructing new bridge-like structures in privately owned areas of high conservation value (that are not associated with landscape function other than wildlife movement).

Responses to these questions were mostly contradictory. Only no. 2 above received predominantly positive responses (71% strongly agree or agree, 14% no opinion, 15% disagree). The other three questions received fairly equal positive and negative responses, the average reaction being “no opinion”. The language and length of the questions likely were too confusing, and resulted in poor performance (Exhibit A, Questions 13 – 16, and next section, Question 16).

Two questions dealt with road size (number of lanes), asking survey takers to select from two opposing ideas: two-lane roads that produce greater numbers of road-kills; or four-lane roads that act as habitat boundaries, creating aversion zones for certain wildlife. Again responses were mixed, the average answer being “no opinion”. Responses favoring priority for two-lane roads averaged 44.5%, whereas responses favoring priority for four-lane roads averaged 25.5%. In this case, the simplistic nature of the questions (Exhibit A, Questions 17 and 18) may not have been appropriate to accurately gage opinion on the issue. A case-by-case approach is probably required to implement mitigation for these conditions.

Choosing appropriate methods of analysis for setting mitigation priorities was the subject of three criteria-related questions. Respondents were asked questions regarding GIS modeling and remote-sensing analyses that assemble indirect evidence, and field studies that gather direct evidence of wildlife phenomena. The first question stated that data for spatial modeling must only be used in conjunction with case-by-case on-site ground-truthing for siting underpass locations. Most respondents (82%) strongly agreed or agreed with this statement. The second question asked whether GIS analysis models were inadequate and diversionary from more direct methodologies for determining sites for underpasses. Responses were generally negative (12.5% agreed or strongly agreed, 26% no opinion, 61.5% disagreed or strongly disagreed). The third question stated that radio-telemetry data or other direct evidence of species movement were the only effective methods for determining locations for wildlife underpasses. Answers were slanted against this statement (20% agreed or strongly agreed, 11% no opinion, 69% disagreed or strongly disagreed).

Respondents generally had no opinion (11%), or disagreed or strongly disagreed (54%) regarding the irrelevance of reserve size as a criterion for determining locations for underpasses.

Three questions addressed the importance of FDOT work-plans in prioritizing mitigation sites for underpass construction. Attendees were asked to respond to the following: 1) should a road be excluded from consideration, if it is not included in an area already scheduled for road improvements; 2) should the priority of a road be lower, if it is not included in an area already scheduled for road improvements; and 3) should mitigation priorities (determined by ecological criteria) be ranked without regard to their inclusion/exclusion in FDOT work-plans? Responses favored determining mitigation priorities based on ecological criteria rather than dependence upon inclusion in FDOT work-plans (Exhibit A, Questions 23 to 25).

Response by Demographic Variables

Statistical tests were performed on responses to questions regarding mitigation priorities by demographic variables (Table A-1). One demographic factor was significant regarding emphasis on priority to retrofit existing, substandard structures through habitat corridors (e.g., riparian systems), regardless of adjacent land-ownership, over construction of new bridge-like structures in privately owned areas of high conservation value (that are not associated with landscape function other than wildlife movement). According to geographic location (Likelihood Ratio $\chi^2 = 13.03$, $p < .002$; Fishers ET, $p <$

.002) 55% of Floridians agreed whereas the majority of those from outside Florida (48%) disagreed.

Three demographic factors were significant concerning whether mitigation priorities determined by ecological criteria should be ranked without regard to their inclusion/exclusion in FDOT work-plans. With reference to organization type (Likelihood Ratio $\chi^2 = 11.24$, $p < .03$; Fishers ET, $p < .05$), more negative responses came from transportation agency personnel (52% agree, 19% no opinion, 29% disagree) than from consultants (84% agree, 16% no opinion) or resource organization personnel (68% agree, 16% no opinion, 16% disagree). Responses by geographic location (Likelihood Ratio $\chi^2 = 14.06$, $p < .001$; Fishers ET, $p < .003$) revealed that 22.5% of Floridians disagreed, but non-Floridians either agreed (68%) or had no opinion (32%). Regarding field of expertise, more positive responses came from individuals with scientific backgrounds (74% agree, 17% no opinion, 9% disagree) than from those with planning or engineering backgrounds (50% agree, 17% no opinion, 33% disagree).

Response by job responsibility was significant (Likelihood Ratio $\chi^2 = 15.71$, $p < .004$; Fishers ET, $p < .006$) for setting higher priority to two-lane roads (that produce greater numbers of road-kills) than four-lane roads (that act as habitat boundaries, creating aversion zones for certain wildlife). More negative responses came from academic professions (31% agree, 25% no opinion, 44% disagree) than from regulatory (59% agree, 35% no opinion, 6% disagree) or management (75% agree, 6% no opinion, 19% disagree) professions. Job responsibility also was a factor regarding whether the priority of a road should be lower, if it is not included in an area already scheduled for road improvements (Likelihood Ratio $\chi^2 = 11.03$, $p < .03$; Fishers ET, $p < .04$). In this case, the data reveals that while regulatory professions (24% agree, 12% no opinion, 65% disagree) gave predominantly negative responses, management/engineering (44% agree, 6% no opinion, 50% disagree) and academic (34% agree, 38% no opinion 28% disagree) professions did not lean either way.

Habitat-Corridor Planning and Criteria for Setting Mitigation Priorities

Two questions sought opinions on real-situation habitat-corridor planning, and identification and prioritization of selection criteria for GIS modeling of ecological hotspots on roads.

Applied Habitat-Corridor Planning

One specific question asked the conference attendees to respond to a real-life scenario designing a functional habitat-corridor between two existing, public, conservation areas (Exhibit A, Question 27). Answers to the question did not produce statistically significant results, although 60% of all respondents agreed that the third alternative was the most logical choice. As mentioned previously for other questions, the issue was more complex than the way it was portrayed in the question. As such, the responses simply provide expert opinion on logical use of existing information for generating methods to determine priorities for mitigation.

Selection Criteria for Modeling Ecological Hotspots on Highways

Respondents were asked to list and rank specific criteria for use in a GIS model that identifies and prioritizes sites for underpass construction (Exhibit A, Question 27). Answers to this question were analyzed to determine if any trends for or against any particular criteria were present according to demographic groups. Frequency procedure was performed in SAS, however sample size was too small for a chi-square test; therefore Fisher's Exact Test (ET) was used.

Analysis by organization type provided significant findings regarding rankings of four criteria. The criterion, road-kill, was ranked first and the criterion, road projects, was ranked last for all organization types. Significant differences were found among choices between organizational groups regarding SHCAs (Fisher's ET, $p < .08$) and greenways (Fisher's ET, $p < .09$). Whereas the resource management group selected SHCAs 4th most frequently (24%), transportation and consultant groups chose SHCAs 8th (24%) and 7th (32%) most often, respectively. Transportation and consultant groups ranked greenways most frequently 4th (24%) and 5th/6th (41%), respectively; and resource management organizations chose 2nd (28%) most often. No other trends were found for the other seven criteria that shifted rankings frequently, according to organizational type.

An analysis of response, by geographic area of work, revealed no significant variation between groups. However, most criteria ranked the same or within one ranking of each other for both groups, with the exception of listed species, greenways, and separate resources. These results are shown in Table A-2.

Table A-2. Average response by geographic area

Rank	Florida	Other
1	Roadkill	Roadkill
2	Migration route	Greenway
3	Hotspots	Migration route
4	Listed species	Hotspots
5	Greenway	SHCA
6	SHCA	Separate resources
7	Riparian system	Riparian system
8	Core area	Core area
9	Separate resources	Listed species
10	Public land	Public land
11	Road projects	Road projects

An analysis of response by area of expertise also revealed similar responses among groups. All criteria were ranked the same or within one ranking of each other for these two groups, with the exception of two criteria, greenways and SHCAs. These results are shown in Table A-3. Significant differences between these groups were found regarding ranking of criteria, road projects (Fisher's ET, $p < .09$) and separate resources (Fisher's ET, $p < .07$). For road projects, those with biology/ecology backgrounds chose 3rd to 9th in 20 out of 53 opportunities, while those with engineering/transportation/planning backgrounds chose 3rd to 9th in 2 out of 12 opportunities. Concerning separate resources, many different choices between groups were evident. Of particular note were lack of choices for 1st, and 4th to 7th (total of 8%) for the engineering/transportation/planning group, whereas the biology/ecology group selected these ranks 29 out of 53 times (54%). Opposite selections were also the case for rankings 2nd and 8th, as biologists/ecologists selected these 6 out of 53 times (11%); but engineers/planners chose these ranks 7 out of 12 times (58%).

Table A-3. Average response by area of expertise

Rank	Biology/ecology	Engineering/transportation/planning
1	Roadkill	Migration route
2	Migration route	Roadkill
3	Greenway	Hotspots
4	Hotspots	SHCA
5	Listed species	Listed species
6	SHCA	Greenway
7	Riparian system	Separate resources
8	Separate resources	Riparian system
9	Core area	Core area
10	Public land	Public land
11	Road projects	Road projects

Analysis according to job responsibility revealed significant differences for three criteria, road-kill (Fisher's ET, $p = .005$), hotspots (Fisher's ET, $p = .09$), and core areas

(Fisher's ET, *p* = .07). Road-kill was selected predominantly 1st or 2nd by regulatory (59%) and academic (70%) professions, yet management/engineering professions selected it 1st or 2nd only 6 out of 16 times (37%). Academic and management/engineering professions chose hotspots 1st to 3rd most often (69% and 50%, respectively) while those in regulatory professions picked it 7th to 11th (59%) most often. Median ranks for core areas by professional groups were 4th (academic), 10th (regulatory), and 9th (management/engineering). Public lands and road projects were ranked 10th and 11th, respectively by all but one group, planning/engineering/design/management. The other nine criteria shifted rankings frequently, according to job types.

Demographic analysis revealed little significant bias between groups; in fact results showed remarkable consistency in rankings for road-kill (1), migration (2), public lands (10), and road projects (11). This shows strong preference for the first two criteria as primary indicators of wildlife movement travel routes (locations where construction of wildlife underpasses should receive top priority). In reference to the latter two criteria, the survey indicates that their significance in determining location of underpasses should be minimized. The other criteria exhibited more variability among demographic groups, and their significance is less clear.

Summary of Results from the Questionnaire

First, for general questions on wildlife-road issues, respondents acknowledged that: road density was a predictor of probable number of adverse road-wildlife interactions; aversion to roads and roadside habitat value were a function of road size; wildlife-vehicle collisions were a function of traffic speed; and aversion to roads was a function of traffic volume. It was also agreed that linear habitat features (e.g., riparian corridors) in agricultural areas, urban woodlands, and ecological preserves were important concentration points for wildlife movement, and therefore would exhibit more frequent road-kills. Statistical differences were evident for job responsibility and field of expertise response groups.

Second, regarding specific questions focused on determining mitigation priorities, respondents favored giving priority to critical road-kill sites, regardless of adjacent land ownership. They also strongly favored the use of GIS technology and data for spatial models (to identify sites for underpasses) in conjunction with on-site ground-truthing. Lastly, the audience agreed that mitigation priorities should be based on ecological criteria, rather than dependence upon inclusion in FDOT work-plans.

Third, an expert's list of criteria was generated that could be used to develop a modeling protocol for prioritizing ecological hotspots on highways (Table A-5).

Table A-5. Rankings of road prioritization criteria by expert opinion

Rank	Criterion
1	Chronic road-kill sites
2	Known migration/movement routes
3	Identified hotspots of focal species
4	Landscape linkages (designated greenways)
5	Presence of listed species
6	Identified strategic habitat conservation areas
7	Riparian corridors (with potential for retrofitting existing structures)
8	Core conservation areas
9	Presence of separate-required ecological resources (e.g., a forest patch and ephemeral wetland breeding area for amphibians that is separated by a highway) for a species or set of species
10	Public ownership (or in public land acquisition program) as opposed to private lands
11	Potential to be included in proposed road improvement project

Exhibit A

Questionnaire Regarding Wildlife Mortality on Roads

Presented at the Florida Department of Transportation Sponsored
Transportation-Related Wildlife Mortality Seminar, Orlando, FL., May 1, 1996

Goal 1: To assemble and rank criteria for utilizing available information to describe and analyze landscape patterns, processes, and ecologically based greenways, animal movements and location of likely points of conflicts with existing and future highway locations and linear construction projects.

Goal 2: To use these criteria for developing a GIS-compatible algorithm that will process existing spatial data layers and assist with prioritization of highway-greenway interfaces to be addressed by FDOT in district workplans for installation of wildlife underpasses or appropriate corrective measures.

INSTRUCTIONS

Circle the most appropriate response or give a brief statement as requested.
Response percentages are shown in magenta.

RESPONDENT DEMOGRAPHICS (n = 65)

What type of organization do you work for?

1. transportation agency 0.32
2. resource management/research 0.39
3. private consulting firm 0.29

In what geographic area do you work? (e.g., country, and state or province)

1. Florida 0.62
2. other 0.38

What is your primary responsibility within your organization? (e.g., university professor, transportation engineer, research scientist, etc.)

1. research/extension/education 0.49
2. regulatory enforcement/impact assessment/policy/compliance 0.26
3. planning/engineering/design/management 0.11

What is your field of expertise? (e.g., game management, transportation corridor planning, etc.)

1. biological/ecological sciences 0.82
2. engineering/transportation/planning 0.18

GENERAL QUESTIONS

1. Given that road density is a known factor of consequence to wide ranging species (e.g., wolf, elk), it follows that a simple measure of road density could be used to predict the probable number of negative road-wildlife interactions.

a. strongly agree	0.09	d. disagree	0.15
b. agree	0.66	e. strongly disagree	0.02
c. no opinion	0.08		

2. Given that road right-of-way width is commonly a function or derivation of road size and given that some animals (e.g., adult female elk) apparently manifest aversion to roads of any size, it follows that aversion to roads should be some function of road size.

a. strongly agree	0.14	d. disagree	0.09
b. agree	0.60	e. strongly disagree	0.02
c. no opinion	0.15		

3. Given that road right-of-way width is commonly a function or derivation of road size and given that some animals (e.g., white-tailed deer, love bugs) commonly manifest an attraction to managed rights-of-way, it follows that roadside habitat values should be some function of road size.

a. strongly agree	0.09	d. disagree	0.26
b. agree	0.54	e. strongly disagree	0.02
c. no opinion	0.09		

4. Roads in-and-of-themselves do not kill wildlife, it is usually a function of traffic. It was shown in Nebraska that wildlife road-kills are a direct function of average traffic speed (Case, 1978). Can we therefore conclude that road-kill is a function of traffic speed?

a. strongly agree	0.15	d. disagree	0.25
b. agree	0.52	e. strongly disagree	0.05
c. no opinion	0.03		

5. Clearly some species seem to manifest an aversion to roads, even small unpaved roads (e.g., female elk, wolves). Given that some species manifest an aversion to traffic, the logical inference is that aversion could also be a function of traffic load.

a. strongly agree	0.17	d. disagree	0.12
b. agree	0.57	e. strongly disagree	0.02
c. no opinion	0.12		

6. Given that some wildlife species develop more of an aversion as roads become larger and/or carry heavier traffic loads (e.g., black bear—M. Pelton), it follows logically that road size and/or traffic load is not a predictor of negative road mortality for some species.

a. strongly agree	0.09	d. disagree	0.17
b. agree	0.34	e. strongly disagree	0.02
c. no opinion	0.38		

7. Many species seem oblivious to size and/or traffic load (e.g., snakes—Paynes Prairie, FL), therefore it follows that large roads (which have the effect of increasing the time necessary to cross the road) and/or roads with heavy traffic loads would be useful predictors of kill rate for this type of species.

a. strongly agree	0.20	d. disagree	0.14
b. agree	0.52	e. strongly disagree	0.00
c. no opinion	0.14		

8. Given that wildlife preserves or sanctuaries maintain larger populations of many species as compared to human-dominated landscapes, it follows that a road bisecting a preserve would manifest greater negative road-wildlife interactions than a road passing through a human-developed landscape.

a. strongly agree	0.43	d. disagree	0.08
b. agree	0.47	e. strongly disagree	0.00
c. no opinion	0.02		

9. Given that human-developed landscapes commonly contain open spaces such as pastures or woodlands and that wildlife commonly use these open spaces in preference to more highly developed urban and suburban areas, it follows that road-kills would be more frequent in these lesser-developed areas than in the nearby highly developed areas.

a. strongly agree	0.245	d. disagree	0.14
b. agree	0.57	e. strongly disagree	0.00
c. no opinion	0.045		

10. Given that human-dominated landscapes commonly contain open spaces such as ridgetops and riparian systems, and that wildlife commonly travel along these open spaces in preference to more highly developed urban and suburban areas, it follows that road-kills would be more frequent in these areas than in the nearby highly developed areas.

a. strongly agree	0.28	d. disagree	0.12
b. agree	0.51	e. strongly disagree	0.00
c. no opinion	0.09		

11. In areas where little topographic relief exists, long distance wildlife movement occurs primarily along continuous linear structures such as riparian corridors, roadside strips, hedgerows or fencelines rather than across discontinuous open spaces (patches) that contain no cover and/or significant barriers or boundaries to movement.

a. strongly agree	0.20	d. disagree	0.08
b. agree	0.54	e. strongly disagree	0.00
c. no opinion	0.18		

12. Given that even open-land species commonly disperse and/or move the longest distances along the more densely structured available habitat, it follows that more structured habitats such as hedgerows and fencelines when intersected with highways would probably be points of negative road-wildlife interactions.

a. strongly agree	0.15	d. disagree	0.03
b. agree	0.60	e. strongly disagree	0.00
c. no opinion	0.22		

<u>SELECTION CRITERIA</u>

13. When considering factors that determine where wildlife underpasses should be constructed, it would be more important to address roads that bisect existing public wildlife reserves or sanctuaries than privately owned areas or potential linkage areas between existing public wildlife preserves or sanctuaries.

a. strongly agree	0.17	d. disagree	0.36
b. agree	0.32	e. strongly disagree	0.05
c. no opinion	0.10		

14. When considering factors that determine where wildlife underpasses should be constructed, it would be more important to address roads identified as critical road-kill sites for listed species (regardless of adjacent land-ownership) than roads that bisect or are adjacent to existing public wildlife reserves or sanctuaries.

a. strongly agree	0.14	d. disagree	0.15
b. agree	0.57	e. strongly disagree	0.00
c. no opinion	0.14		

15. When considering factors that determine where wildlife underpasses on roads are constructed, it would be more important to retro-fit existing structures (e.g., bridges over riparian systems) with a functional terrestrial connection (regardless of adjacent land-ownership), than to construct new bridge-like structures that are unassociated with any functions other than provision of safe wildlife movement in <u>public wildlife reserves or sanctuaries</u>.

a. strongly agree	0.08	d. disagree	0.34
b. agree	0.36	e. strongly disagree	0.02
c. no opinion	0.20		

16. When considering factors that determine where wildlife underpasses on roads should be constructed, it would be more important to retro-fit existing structures (e.g., bridges over riparian systems) with a functional terrestrial connection (regardless of adjacent land-ownership), than to construct new bridge-like structures that are unassociated with any functions other than provision of safe wildlife movement in <u>privately owned areas</u> (known to contain significant wildlife populations).

a. strongly agree	0.06	d. disagree	0.22
b. agree	0.43	e. strongly disagree	0.03
c. no opinion	0.26		

17. It has been discovered that in many situations two-lane roads with high traffic loading produce the greatest number of road-kills. It follows, therefore, that these roads should be addressed first when prioritizing sites for underpass construction rather than modifying a four-lane highway that may be creating it's own aversion zone (e.g., black bear, M. Pelton).

a. strongly agree	0.09	d. disagree	0.28
b. agree	0.40	e. strongly disagree	0.00
c. no opinion	0.23		

18. Even though it has been shown, in many situations, that two-lane roads (with high traffic volume) produce greater numbers of road-kills than certain four-lane highways, such four-lane highways (which act as severe barriers to dispersal) should be addressed first with concern to installing underpasses.

a. strongly agree	0.06	d. disagree	0.40
b. agree	0.17	e. strongly disagree	0.015
c. no opinion	0.355		

19. Data layers used for spatial modeling (i.e., habitat conservation areas, hydrology, topography, land ownership, wildlife hotspots or listed-species locations) must only be used in conjunction with case by case on-site ground truthing for siting locations of underpasses.

a. strongly agree	0.30	d. disagree	0.08
b. agree	0.52	e. strongly disagree	0.02
c. no opinion	0.08		

20. GIS analysis models that use data layers such as habitat conservation areas, hydrology, topography, land ownership, wildlife hotspots or listed-species locations are not only inadequate but diversionary from more expedient methodologies for determining where wildlife underpasses should be located.

a. strongly agree	0.02	d. disagree	0.51
b. agree	0.105	e. strongly disagree	0.105
c. no opinion	0.26		

21. Radio-telemetry or other direct evidence of species movement are the only effective and realistic methods for determining where underpasses should be located to facilitate safe wildlife movement.

a. strongly agree	0.03	d. disagree	0.66
b. agree	0.17	e. strongly disagree	0.03
c. no opinion	0.11		

22. Size of a wildlife conservation area (e.g., 4,000 acres vs. 400,000 acres) is irrelevant for determining whether underpasses to facilitate safe wildlife movement should be constructed on roads that bisect or surround them.

a. strongly agree	0.06	d. disagree	0.46
b. agree	0.29	e. strongly disagree	0.08
c. no opinion	0.11		

23. Roads in areas that qualify for installation of a wildlife underpass (i.e., have high priority rating based on ecological criteria) should be excluded from consideration if the road is not included in the FDOT workplan for other road work such as new construction or existing road improvements.

a. strongly agree	0.015	d. disagree	0.615
b. agree	0.03	e. strongly disagree	0.28
c. no opinion	0.06		

24. As opposed to the above question, rather than over-ruling the need for a wildlife underpass on a road that is not in the FDOT workplan, it should simply be given a lower priority, so that those underpass locations that are included in other FDOT road construction projects will receive a higher priority.

a. strongly agree	0.03	d. disagree	0.31
b. agree	0.31	e. strongly disagree	0.12
c. no opinion	0.23		

25. Roads in areas that qualify for installation of a wildlife underpass based on ecological criteria should be ranked without regard to whether they would be included in the FDOT workplan for other road work such as new construction, or existing road improvements.

a. strongly agree	0.28	d. disagree	0.14
b. agree	0.41	e. strongly disagree	0.00
c. no opinion	0.17		

26. A list of criteria for prioritizing the location of underpasses on Florida roads in order to alleviate road-kills and to provide ecological linkages might include the following (Please rank by number—1,2,3,etc. and add any additional criteria not included that you think is important):

Rank	**Avg. Score**	**Criteria**
8	4.65	core conservation areas (_________ acres minimum)
1	2.58	existing site of chronic road-kills of listed species
6	4.48	existence of listed species in area
10	5.94	public ownership (or in public land acquisition program) as opposed to private lands
4	3.80	landscape linkages (designated greenways)
7	4.60	existing riparian corridors (with potential for retrofitting existing structure)
5	4.42	identified strategic habitat conservation area
3	3.60	identified hotspots of listed species
11	6.26	potential to be included in proposed road improvement project
2	3.49	existence of known migration route
9	4.69	existence of separate required ecological resources (e.g., ephemeral pond for breeding amphibians) for a species or set of species

27. This question concerns a real-life scenario from north Florida (a segment of a linkage that would connect Ocala National Forest to Osceola National Forest):

- say 5 publicly owned conservation areas exist in close proximity (100 km)
- one is a very large wildlife refuge, (300,000 ha) (by eastern standards)

  a). one linkage scenario based on investment in existing public lands would suggest a linkage trajectory to the northeast.

  b). a second linkage scenario based on large land parcels (private ownership) including a privately owned wildlife management area, would project a northwesterly trajectory.

  c). a third linkage scenario was found by looking at topographic relief and hydrologic features, and it was noted that a very small gap (approx. 2 km) existed between a north flowing and a south flowing pair of streams, and this scenario would lead due north.

It follows from wildlife landscape ecology that the third scenario would be more beneficial for biodiversity conservation in a rapidly changing Florida environment than the other two which only reflect human land-use and /or real estate considerations.

a. strongly agree	0.09	d. disagree	0.06
b. agree	0.51	e. strongly disagree	0.02
c. no opinion	0.32		

** Note: If you have any literature that strongly supports or **
detracts from any of these statements, please list citation.

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APPENDIX B
INTERACTIVE MODEL FOR IDENTIFYING AND PRIORITIZING ECOLOGICAL HOTSPOTS ON HIGHWAYS

Introduction

This research included the use of Geographic Information Systems (GIS) analysis to create a model/algorithm that employs existing datasets to identify ecological hotspots on highways and evaluate need for wildlife crossing structures or underpasses (Smith et al. 1998). These hotspots could then be prioritized and ranked for use in FDOT district work-plans, in coordination with new construction and improvement projects. The process would utilize existing biological and physical parameters such as species locations, habitat, hydrology, topography, and road coverages (Smith et al. 1996).

Knowledge-based and Rule-based Modeling Applications and GIS

The GIS application is based on concepts used in knowledge-based and rule-based models. Knowledge-based or decision-support models apply expert opinion, scientific literature and empirical data to geographic datasets to make informed, accurate decisions, to achieve specific goals or objectives (Clevenger and Wierzchowski 2001, Maurer 1999, Carr et al. 1999, and Aspinall 1994). Rule-based models utilize data overlays to develop suitability surfaces and apply user-defined weights or scores to set priorities (Aspinall 1994, and Mcharg 1969). Variations of these models have been used for several applications: habitat suitability and population viability analysis (Akcakaya 2000, and Clark and Van Manen 1992), determining locations and priorities for wildlife underpasses on highways (Clevenger and Wierzchowski 2001, and Smith et al. 1998), creating ecological networks (Carr et al. 1999, 1996), and environmental sensitivity assessment in transportation planning (Maurer 1999, and Herzer et al. 1991).

Geographic Information Systems analysis has increased the ability and ease of performing spatial analyses at previously prohibitive large scales, such as landscape and regional levels. Use of raster or cell-based models in GIS allows application of mathematical algorithms to multiple layers of geographic data, whereby individual cell locations are evaluated based on attribute information of multiple data layers (to perform environmental suitability and sensitivity analyses).

This appendix discusses development and capabilities of an independent GIS application utilizing a sample dataset, whereas, Chapter 2 discusses the actual state-level analysis presented to FDOT in 1998 (including suggested data improvements and application upgrades).

Model Parameters

To provide FDOT the capability to identify and prioritize important ecological hotspots on highways, a GIS application was developed using Arcview© Avenue scripts (Environmental Systems Research Institute, Inc., Redlands, California) to perform the following functions: 1) utilize an assembled and formatted set of existing raster data layers (scale independent), 2) establish a utility for setting appropriate analysis extent, 3) design a utility for inputting user-defined criteria weights, 4) perform prioritization analysis based on user-provided data and weightings, 5) provide for online cursory evaluation of results, and 6) establish a platform to view spatial relationships of associated field verification data.

This application functions as an Arcview© project that is located in a common directory with associated data files and Avenue scripts. A detailed set of instructions automatically pops up when the project file is opened. The instructions text-file provides details on hardware and software requirements, and information to guide users through the prioritization process and use of the image and data viewer. The "instructions.txt" file can be viewed as the opening window in the project or viewed with any text viewer, prior to opening the project file in Arcview.

The project includes three separate views: the first displays background data, the second displays raster data used for the prioritization process, and the third contains field data for use with the image and data viewer utility.

Data Format and Assembly

The first step was selection of appropriate data, second it was necessary to assign base values to attribute information in the data layer, third similar data were assembled into groups, and fourth the data were formatted so an Avenue script could recognize it. Six types of existing data were found for Florida that could be used to identify ecological hotspots along roads. These included biological features, landscape features, infrastructure improvement programs, land ownership, conservation plans, and road-kill. These data (Table 2-1) correspond to the selected criteria that were identified and ranked in the expert questionnaire discussed previously (Appendix A). Other sources and types of data could be used based on availability, user preferences, and objectives sought.

All vector data must be converted to raster format for use in the model and an appropriate cell resolution must be selected. In most cases, it would be desirable to select a cell size based on the highest cell resolution of the existing datasets and the desired scale of analysis (e.g., a regional or large-scale study would be coarser than a site-specific or small-scale study). Each data layer must be formatted according to the relative value of the inherent attribute information contained in the dataset. A description of necessary data format can be explained by the following example:

> Suppose a data layer provides documented locations of federally listed species (Figure B-1). A simple means of assigning base values for this type of data would be to use a sliding scale of importance (e.g., endangered = 3, threatened = 2, and species of special concern = 1; the highest value representing the most important).

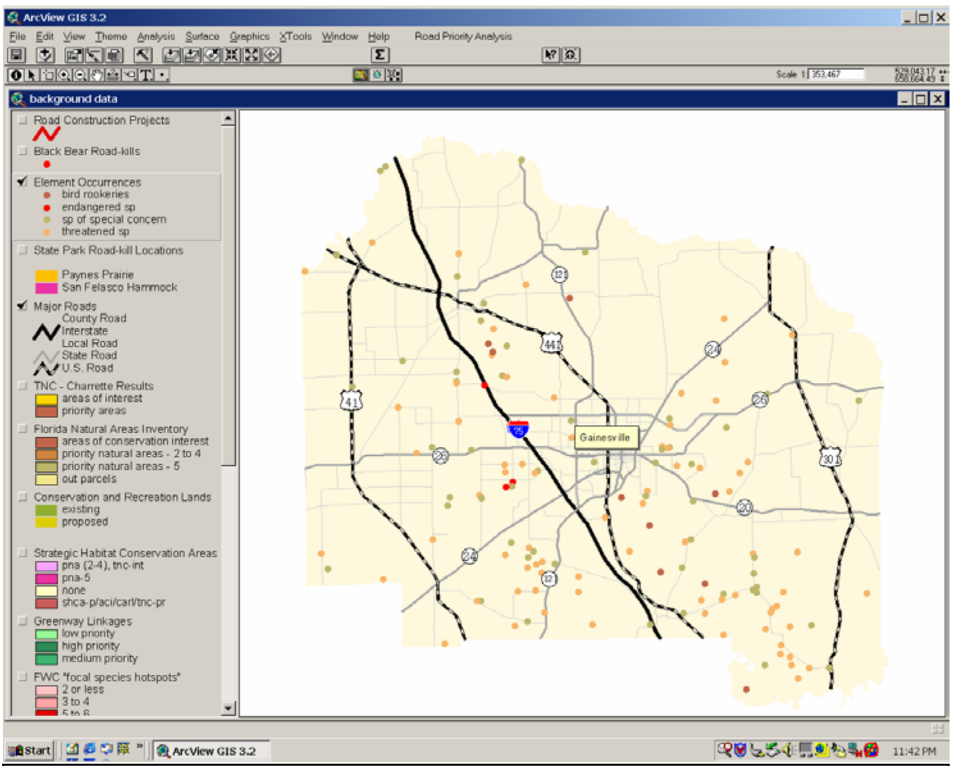

Figure B-1. Documented locations of listed species. Florida Natural Areas Inventory element occurrences is a database that includes documented locations of listed species, bird rookeries, and migratory bird congregation areas (FNAI 1999).

Once each dataset was assigned base values, they were grouped into specific categories (Table 2-1). Note that categories are determined by the user and can therefore represent any variation of data and objectives; those shown in Table 2-1 simply represent those applicable to the Florida highway analysis completed in 1998 for FDOT. Datasets for each category were pooled using the combine function in Arcview. This local procedure creates a new dataset that tabulates all possible combinations for each cell location, for all datasets in the group. An excerpt from a combined dataset table illustrates this process (Table B-1).

Table B-1. An example of a combined dataset table

Value	Count	Hotspots	Fleo_hr	Sum
1	191066	2	0	2
2	413763	1	0	1
3	945034	0	0	0
4	5830	2	1	3
5	47894	0	1	1
6	6693	1	1	2
7	104551	3	0	3
8	195220	2	2	4
9	133868	1	2	3
10	502973	0	2	2
11	168052	3	2	5
12	4219	1	3	4
13	33659	0	3	3
14	16918	3	3	6
15	6160	2	3	5
16	5413	3	1	4

The new raster layer table contains fields of new values and counts for each combination, and the original values from each of the input layers; in this case, listed species locations, FLEO_HR (Figure B-1), and focal species hotspots, HOTSPOTS (Figure B-2). For the dataset to correctly reflect the hierarchy of base values, a numeric "sum" column must be added to the raster table. The value in this column is derived by adding the values of each of the original data values (e.g., focal species hotspots, HOTSPOTS, and listed species locations, FLEO_HR), shown in Table B-1. This is the field that is used in calculations by the Avenue program. For the program to recognize each combined dataset, the dataset name in the view must end with "comb", an abbreviation of the word–combination (Figure B-3). The program will only recognize data layers with this suffix. Note that the actual dataset name does not have to be changed, only the name reflected in the active view.

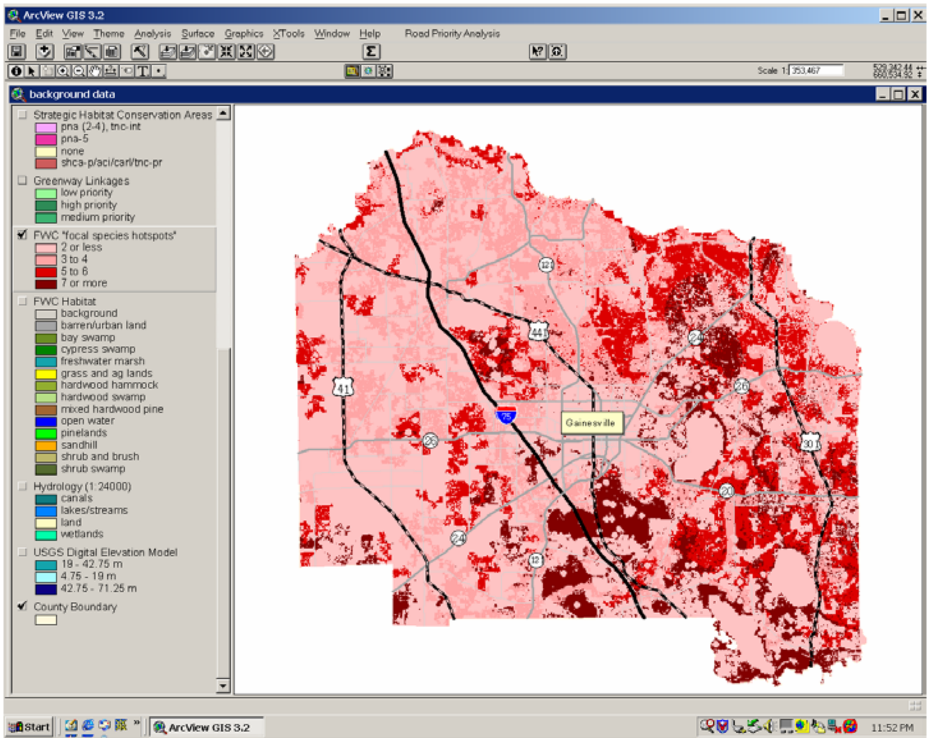

Figure B-2. Focal species hotspots dataset for Alachua County, FL. Based on an analysis of 44 species of conservation interest, this dataset displays areas where various numbers of species of conservation interest co-occur (e.g., 2 or less, 3-4, 5-6, or 7 or more) (FFWCC 1994).

Analysis Extent Utility

To provide an interactive platform for various users and locations, it was necessary to design an environment that allowed multiple methods for selecting an analysis extent. The analysis extent utility allows the user to select from three methods: using a pre-existing roads dataset, creating a custom rectangular-analysis-area, or creating new alternative road alignments. The utility uses the selected dataset as a mask, and excludes everything outside the selected area from the analysis. Since this process was designed to identify and prioritize ecologically sensitive areas adjacent to roads within major greenways, an additional masking parameter was added that allows the user to select for or against urban land-uses. This option provides the opportunity to narrow the focus by excluding intensively developed areas from the analysis. This utility is illustrated in examples in the application functions summary.

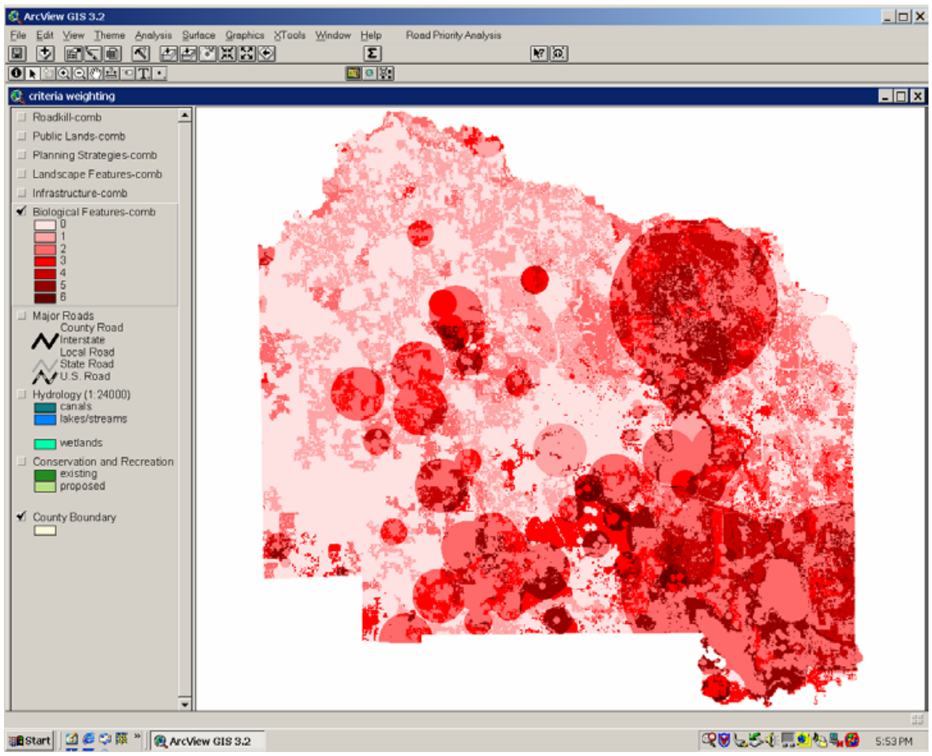

Figure B-3. Biological features combined dataset for Alachua County, FL. This dataset represents the combined data from Figures B-4 and B-5. Note that the dataset name in the legend contains the suffix “comb”, the call word used by the Avenue script to recognize data-layers (used in the prioritization analysis).

Prioritization Algorithm

After choosing an analysis extent, the prioritization process begins by selecting the criteria to set priorities, those selected are then assigned weights (multipliers) from 1 to 50. An algorithm within an Avenue script then processes the combined datasets for each category. It sorts the combinations, assigns the selected weightings, multiplies the base values for the cells in each raster layer by the appropriate weighting, and sums the weighted combinations from each raster layer (to develop a single priority layer based on the assigned weightings of the criteria categories). This process is illustrated in examples in the application functions summary.

Cursory Evaluation of Results

A simple tool was added to allow examination of values and criteria for prioritized raster cells. Once the priority data layer has been generated, simply clicking on the "view criteria values and ranking for cells" button, or selecting this option from the "Road Priority Analysis" menu, allows the user to select any individual cell (Figure B-4). Once selected, a table is automatically generated that displays prioritized value, count, and each criterion evaluated (including the associated value for that cell) (Figure B-5).

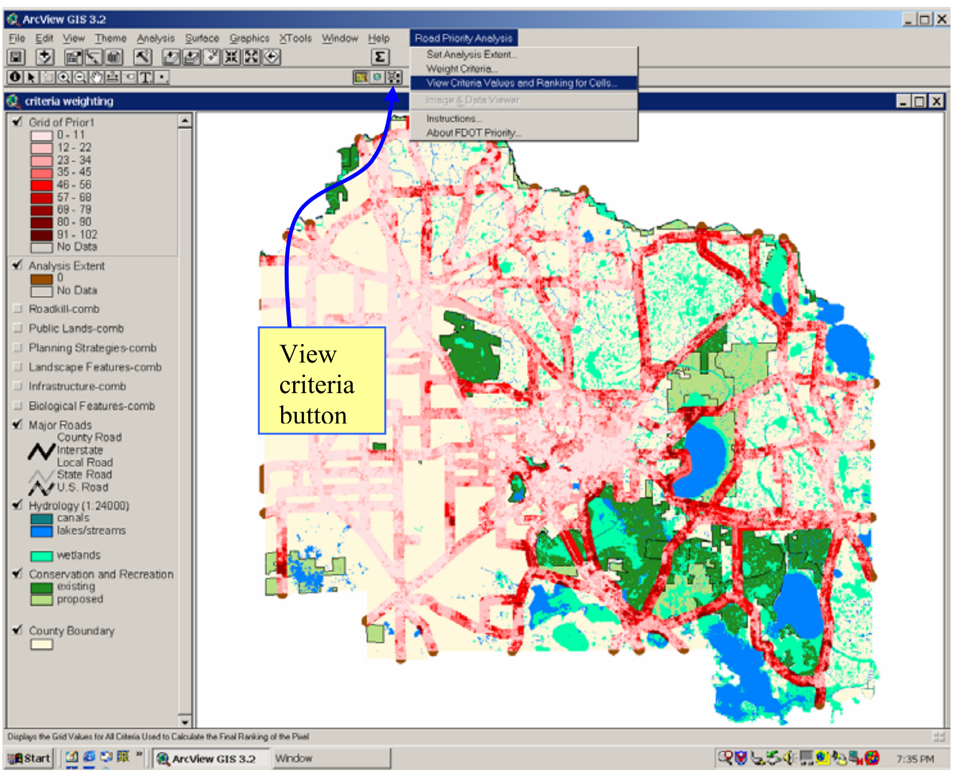

Figure B-4. Viewing criteria and ranking of individual cells. Values and rankings for prioritized cells can be viewed either, by clicking the option from the menu or the tool-bar, and then selecting individual cells.

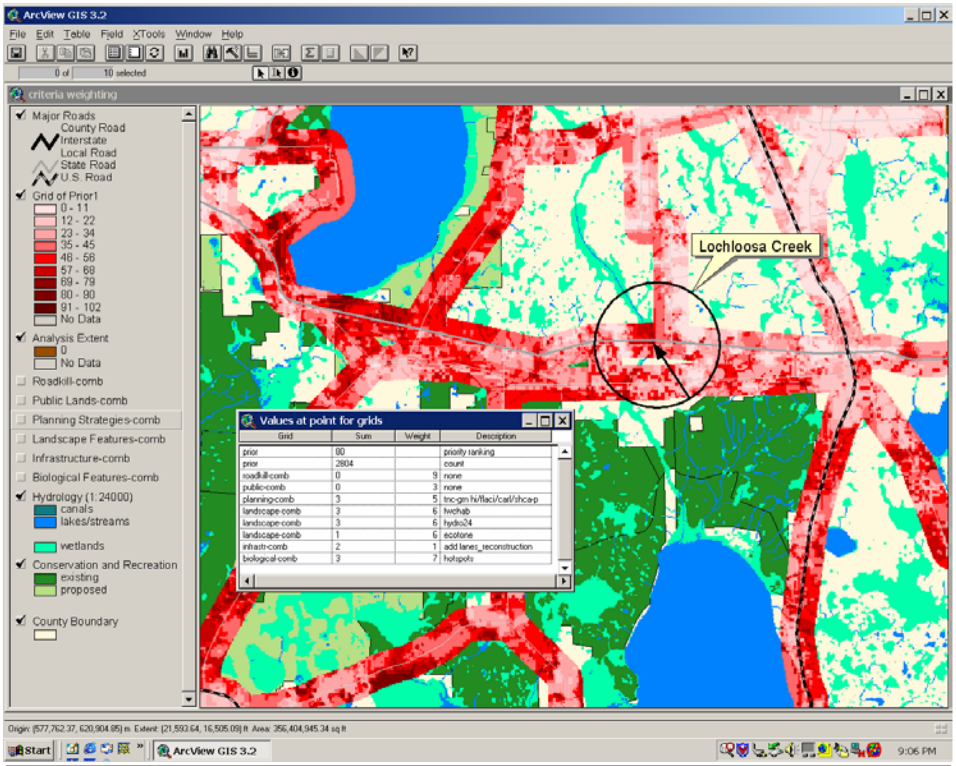

Figure B-5. Table displaying values at selected points. Once a cell is selected, a pop-up table is displayed that includes information on priority value, and individual values and rankings for each data-layer used to rank the cell.

Viewing Associated Field Verification Data

Lastly, the application provides the means to view field data associated with the model results. An image and data viewer was created using the dialog-designer function in Arcview. Clicking on the "image and data viewer" button, or selecting this item from the "Road Priority Analysis" menu (Figure B-6), opens a button box that provides options to view aerials, photographs and data for field sites, and obtain help (Figure B-7). Clicking on the help button provides instruction on use of the utility. To activate the other buttons, a point must be selected (Figure B-8). Once activated, clicking on any button in the image and data viewer button box will display the selection (i.e., an image or data table) (Figures B-9 to B-11). The utility allows for up to four field photographs per field site.

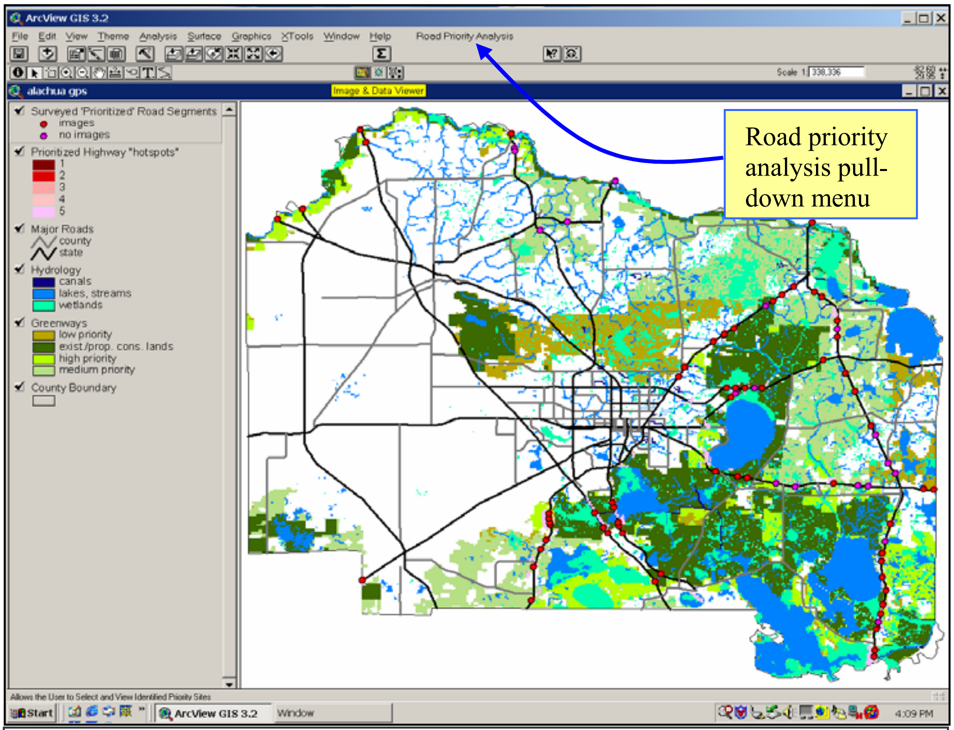

Figure B-6. Image and data viewer. Images and data from field sites are selected and displayed by clicking the button-bar item or selecting from the pull-down menu.

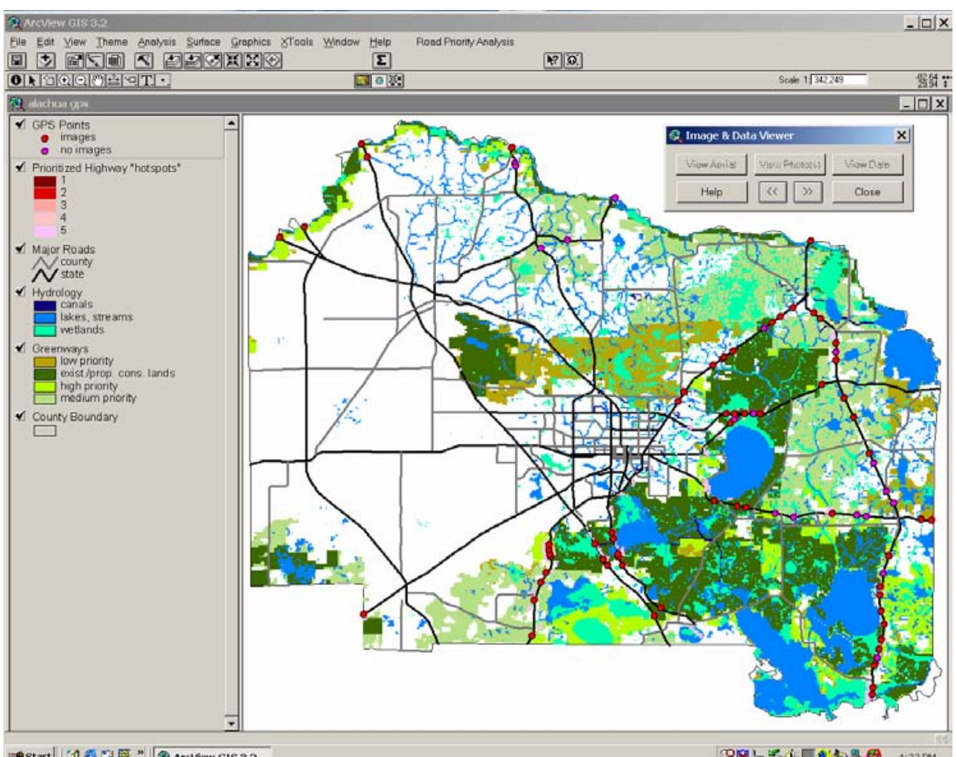

Figure B-7. Image and data viewer—button-box. The button-box appears when the image and data viewer is selected.

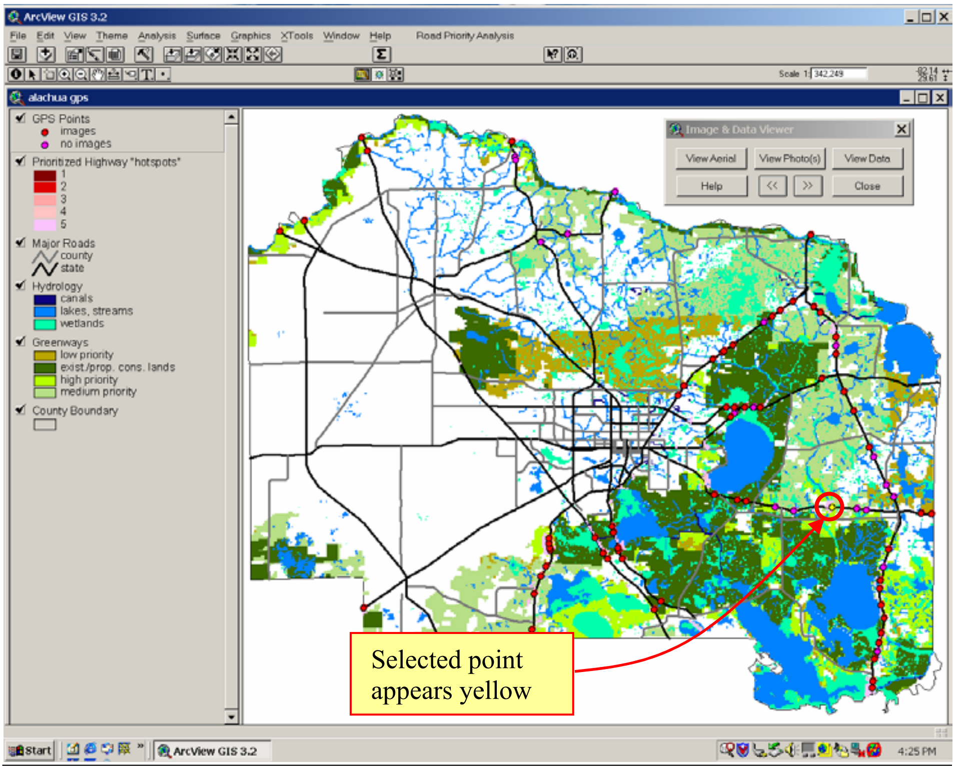

Figure B-8. Site selection for image and data viewer. Sites are selected by clicking the cursor on a chosen point; once selected the button box becomes active.

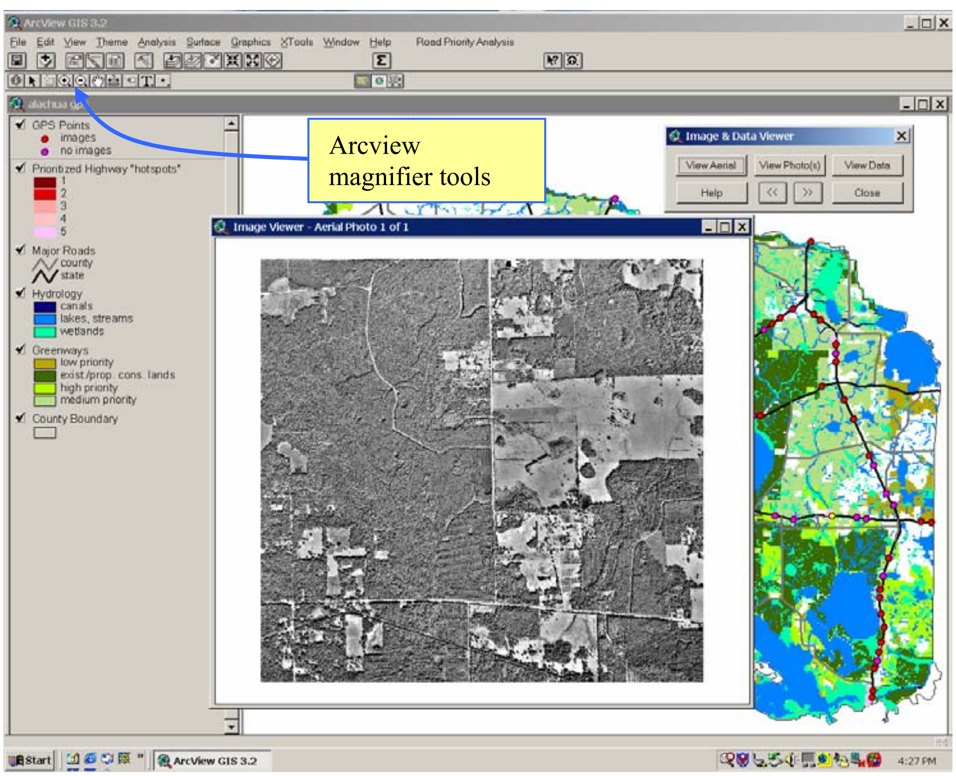

Figure B-9. Image and data viewer—aerial. Clicking the "view aerial" button displays an aerial photo that can be magnified by using the Arcview magnifier tool.

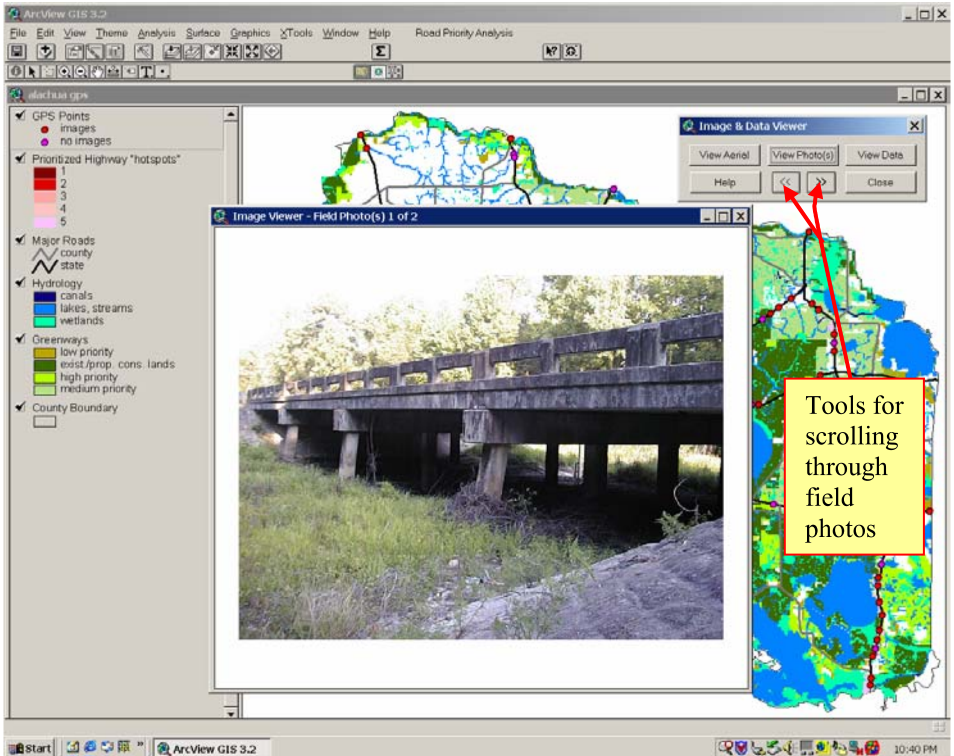

Figure B-10. Image and data viewer—photographs. Clicking the “view photos” button displays a field image (maximum of 4 available) for the selected point.

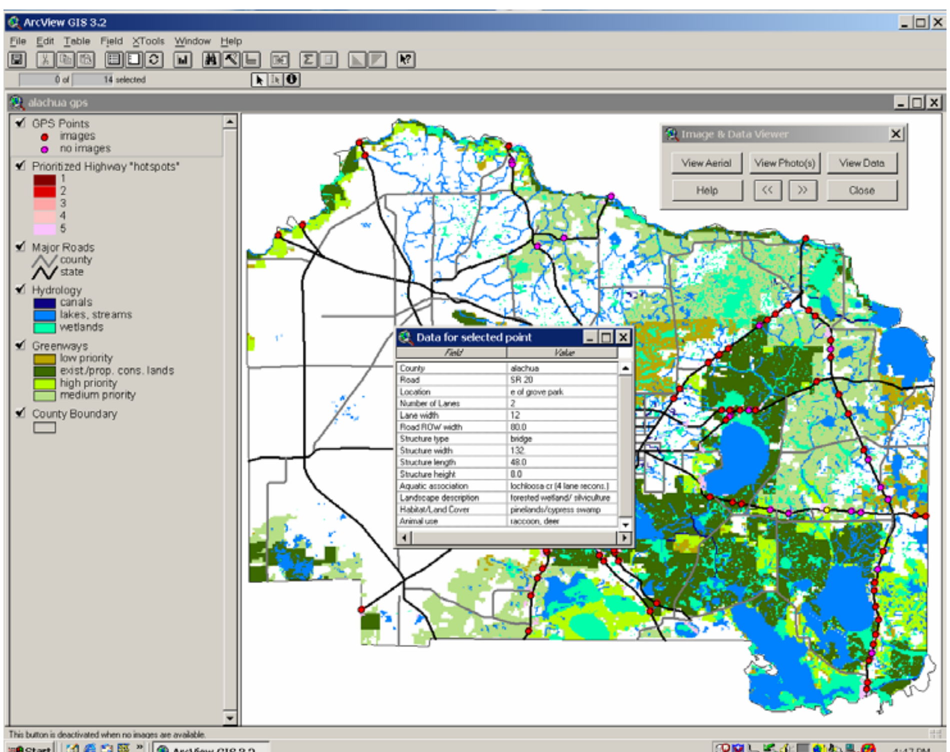

Figure B-11. Image and data viewer—data file. Clicking the “view data” button displays the data table for the selected point.

The user can scroll through these by using the forward and back arrows below the "view photo" button in the image and data viewer button box (Figure B-10). The magnifier function on the Arcview tool-bar is used to enlarge selected images.

Application Functions Summary

The process described above was assembled into an interactive platform so that users could run the same prioritization process on any independent dataset, at any scale. Several Avenue scripts were developed to perform four primary functions: setting the analysis extent, assigning weights and generating a priority layer, viewing criteria values and rankings for individual cells, and image and data viewing of field-verified sites. The following section provides an example for each of the three different approaches to using the prioritization model.

Using an Existing Roads Buffer as an Analysis Mask

An existing road coverage can be used as an analysis mask, by buffering the coverage, and converting the buffer to a raster-file (this process is described in general GIS texts). This is the process that was used in Chapter 2 to produce a statewide priority-analysis for Florida roads. This raster-file then can be used as the analysis extent.

The first step in the priority process is selection of the analysis extent. The analysis extent is set either, by selecting the option from the pull-down menu, or clicking on the "set analysis extent" button on the tool-bar (Figure B-12). The analysis extent option-box will open and the "existing grid" option is selected (Figure B-13). Next, an existing file must be selected from the "open theme" dialog-box (Figure B-14). The selected analysis extent mask automatically displays in the view (Figure B-15).

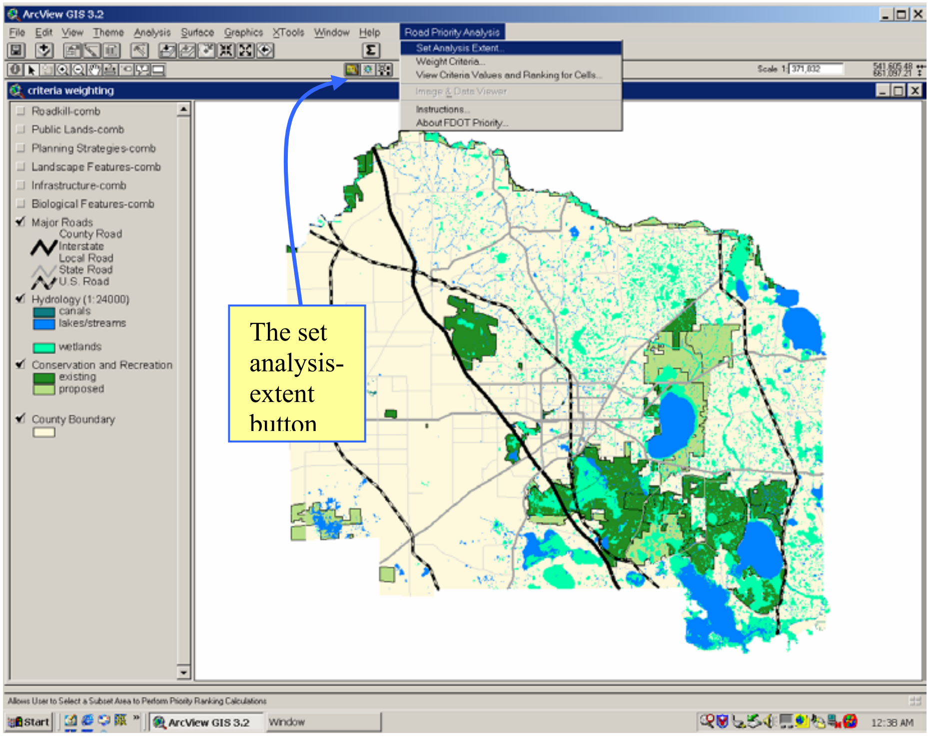

Figure B-12. Setting the analysis-extent. An analysis-extent is set by **c**licking the "set analysis-extent" button on the tool bar or by choosing the option from the pull-down menu.

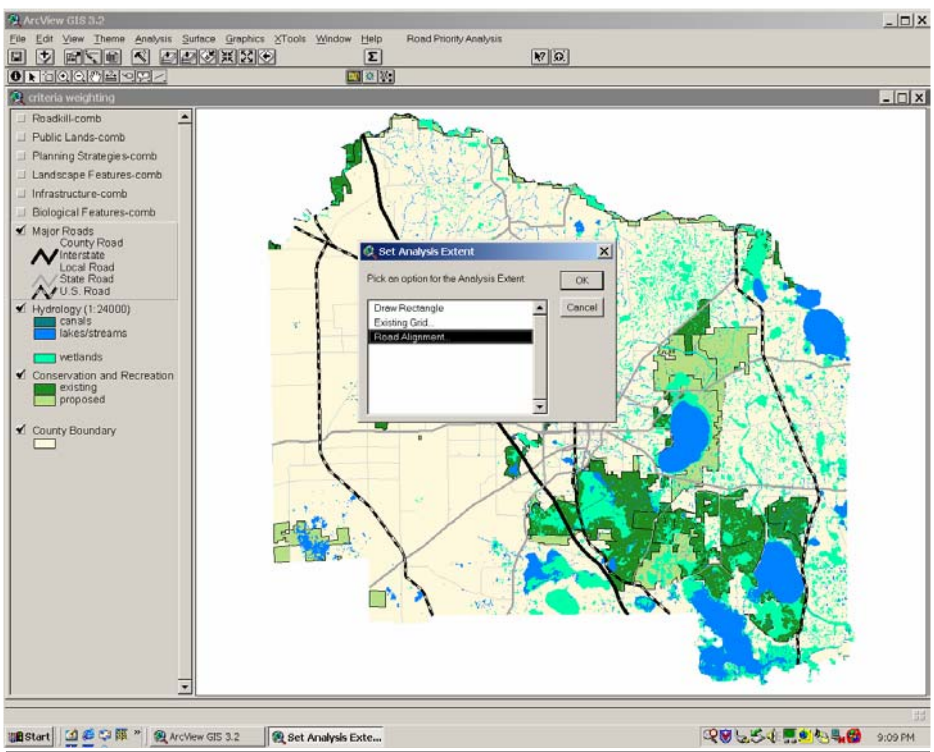

Figure B-13. Setting the analysis-extent—options box. The user can select from three possible extents: existing grid, drawing a rectangle, or new road alignment.

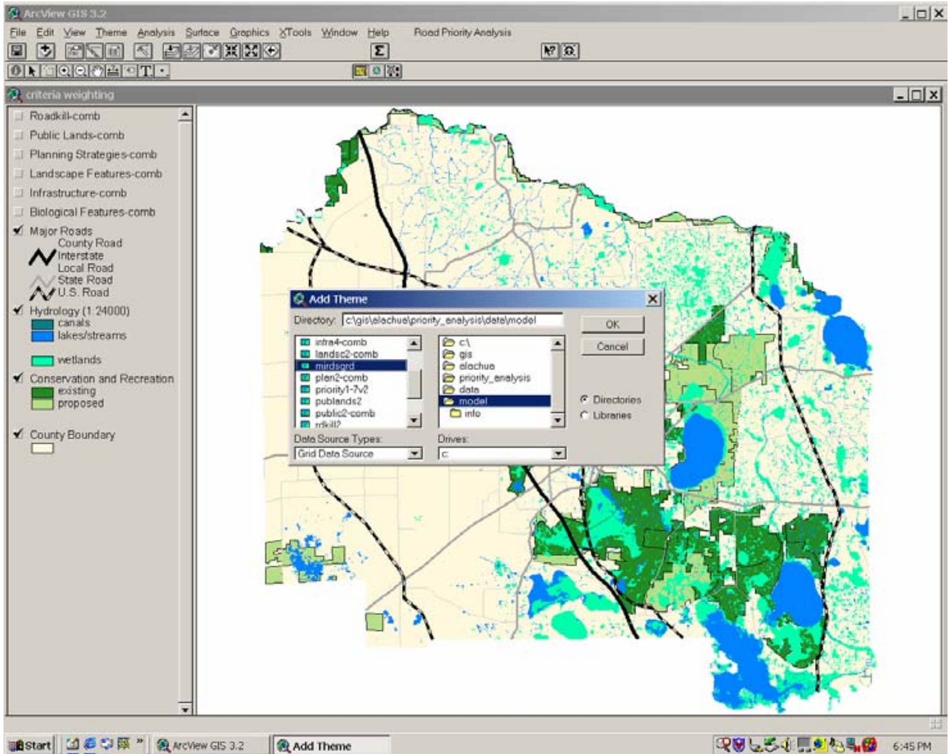

Figure B-14. Setting the analysis-extent—selecting an existing file. The "add theme" box allows the user to select an existing raster (grid) file.

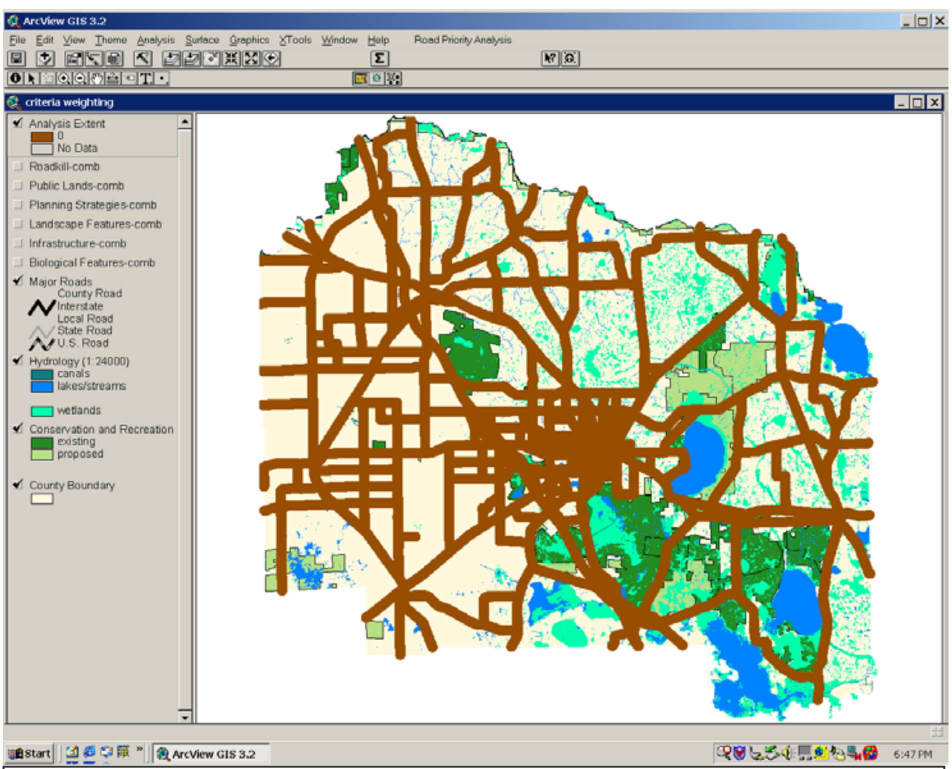

Figure B-15. Setting the analysis-extent—using an existing file. The existing file serves as an analysis-extent and a mask, excluding outside areas from the analysis.

The second step is criteria weighting, found in the "Road Priority Analysis" pull-down menu. The user is given the choice to include or exclude intensively developed urban-lands (Figure B-16). If no is selected, an urban-area grid that defines these areas as "no data" is automatically added, excluding them from the analysis. If yes is selected, then the next step in the procedure follows.

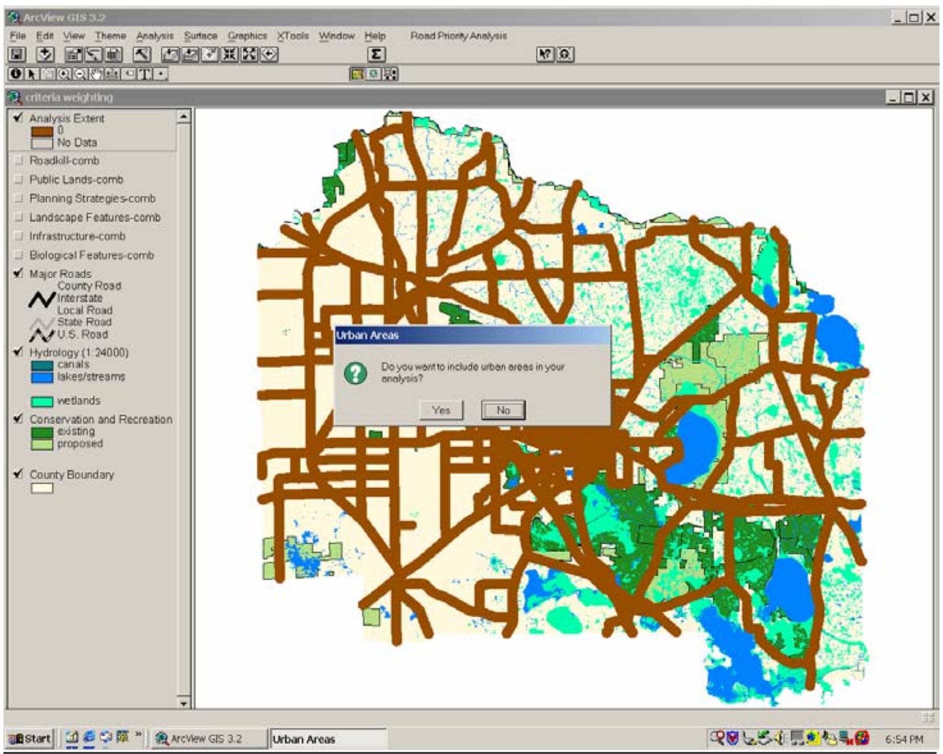

Figure B-16. Criteria weighting—urban areas option. First option in the priority process is to decide whether or not to include intensive urban lands in the analysis. If no, an urban area grid that defines these areas as "no data" is automatically added, and they are then excluded from analysis.

The third step is selection of criteria to be weighted. Criteria layers are automatically displayed in a dialog-box, after the urban-area option request is processed. The user selects criteria layers from those displayed in the dialog-box (Figure B-17). Once selected, a new dialog-box asks the user to input criteria weights, numeric values from 1 to 50 (Figure B-18). Lastly, a file name must be provided, after which the prioritization algorithm calculates and displays the priority layer (Figure B-19).

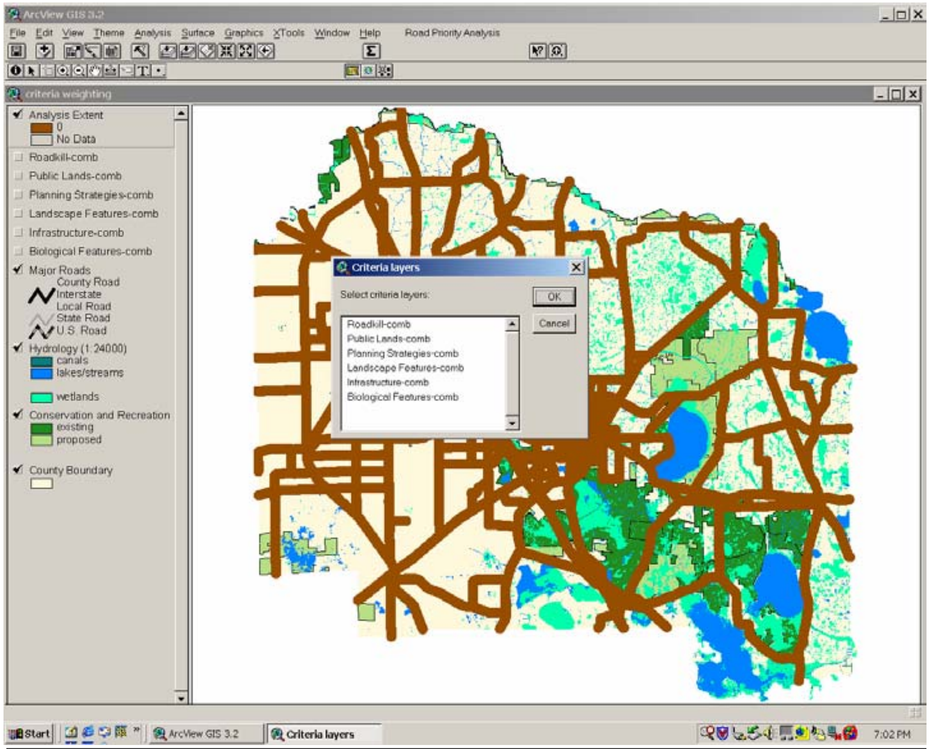

Figure B-17. Criteria weighting—selecting criteria. One or more criteria are selected for the priority analysis by using the mouse and shift key simultaneously.

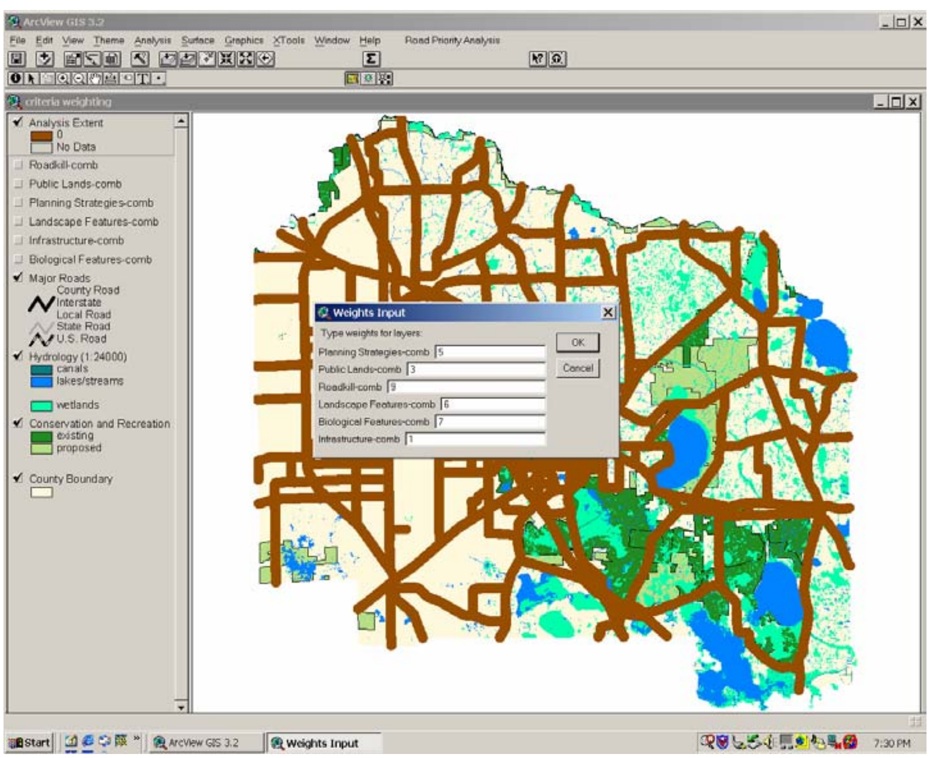

Figure B-18. Criteria weighting—assigning weights. The user may enter a multiplier from 1 to 50 in the blank next to each criterion to reflect its importance.

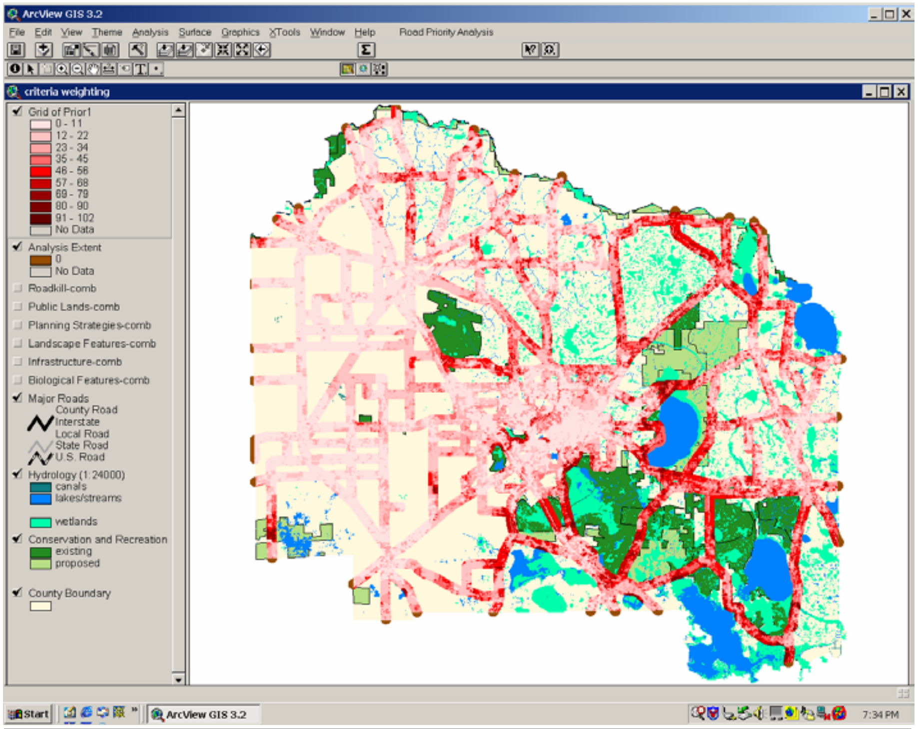

Figure B-19. Priority analysis—final priority layer. Once the algorithm calculates the values for each cell, the priority layer automatically displays. The highest values in the legend and darkest shades represent the highest priorities.

Creating a Custom Analysis Extent (changing scales)

The priority analysis on roads can be performed at different scales. Suppose that following the countywide analysis conducted on Alachua County (Figure B-19) that a specific site needed evaluation (due to an upcoming road construction project). In this case, State Road 24 (adjacent to Austin Cary Forest) will be used as an example. To narrow the analysis extent, the “create rectangle” option will be used (Figure B-13). Once this option is selected, the user draws a rectangle (with the mouse) over the area of interest (Figure B-20). A new analysis extent is automatically created and added to the view (Figure B-21). The process also automatically zooms to the new analysis extent. The same process described in the previous example can be used to generate a priority layer (Figure B-22).

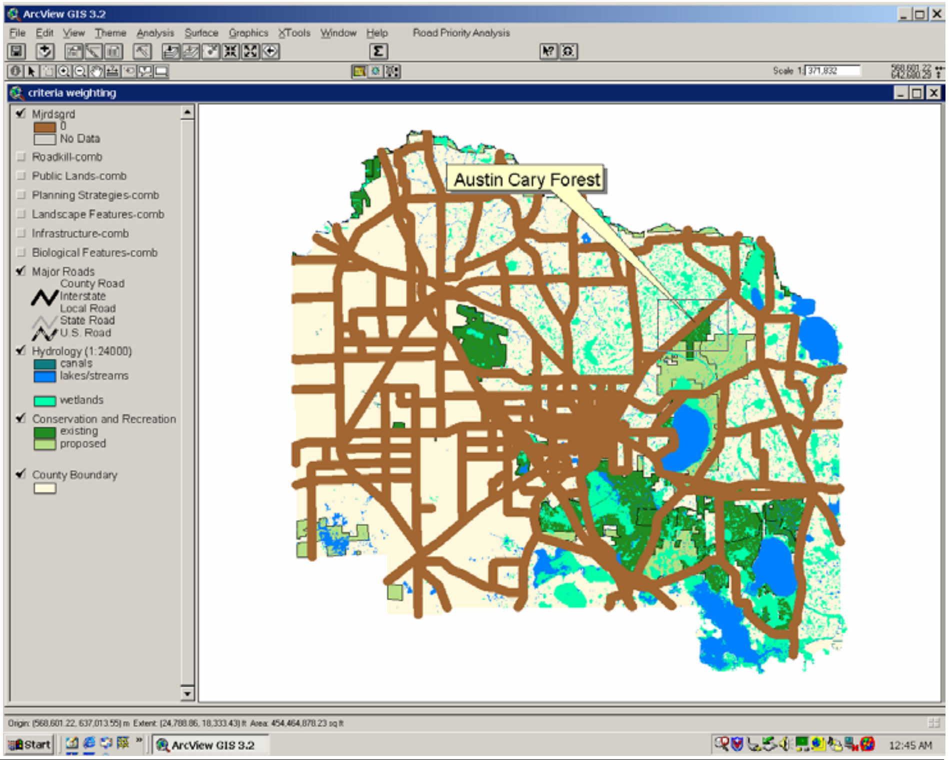

Figure B-20. Setting the analysis-extent—custom rectangle. Users can draw a custom-sized rectangle that serves as the analysis-extent and mask.

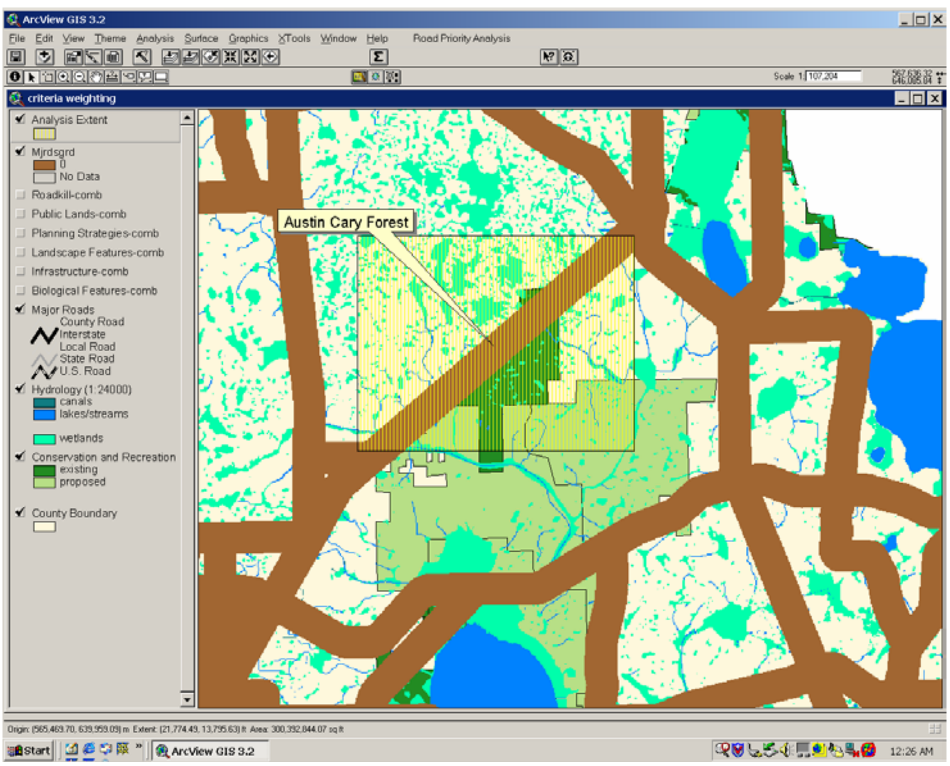

Figure B-21. Setting the analysis-extent—custom rectangle zoom-in. Once drawn the rectangle will automatically be shaded and magnified.

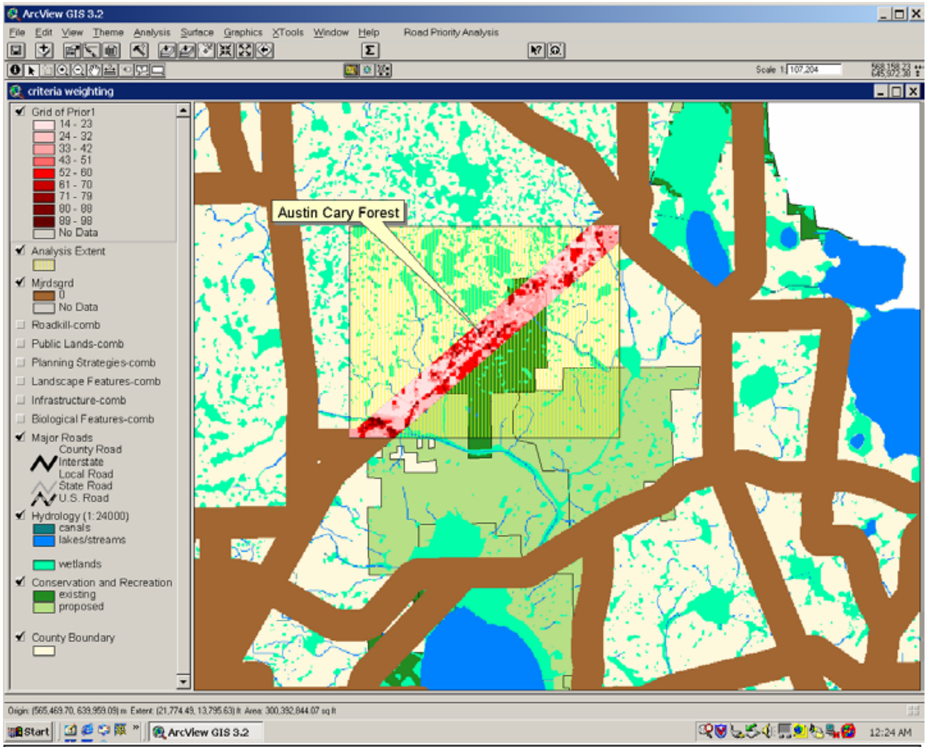

Figure B-22. Priority analysis—site specific priorities. The priority layer is limited to the customized analysis rectangle and the roads layer mask.

Selecting and Assessing New or Proposed Road Alignments

The priority-analysis application provides a method for quick evaluation of alternative road alignments. The once-proposed Tampa to Jacksonville toll-road provides an example of this option (Figure B-23). In the late 1980s, the Tampa to Jacksonville toll-road was proposed as an alternative expressway to the I-95/I-4 corridor. It became a highly controversial project due to potential environmental impacts and routing through existing conservation lands; and was eventually dropped from the Florida Transportation Plan (FTP). Nevertheless, this example shows the value of the application to identify environmentally sensitive areas, within proposed road corridors. Evaluating alternative road alignments requires the user to input analysis masks that represent the proposed routes.

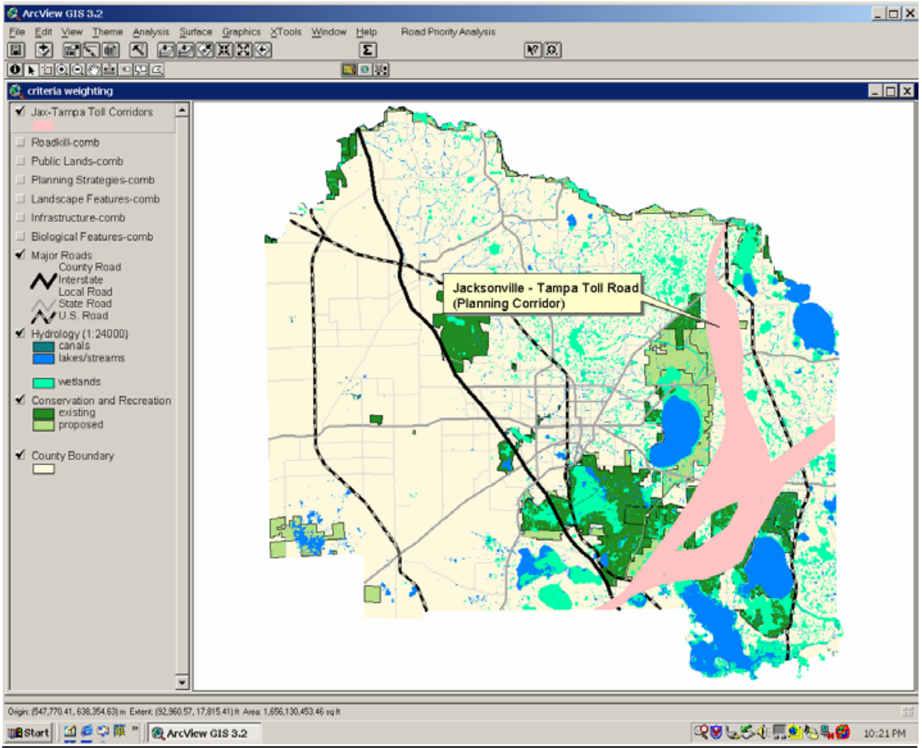

Figure B-23. New or proposed road alignments. The alternative alignments in Alachua County for the previously proposed Jacksonville to Tampa toll road (that runs through the congested Daytona Beach and Orlando areas).

The first step is to set the analysis extent (Figure B-12) and select the road alignment option (Figure B-13). A pop-up box will appear that directs the user to draw a line that represents the proposed route (Figure B-24). Once drawn, the user clicks on the "next" button in the pop-up box; and a new pop-up box will open that requires the user to input a buffer distance value (Figure B-25). The Avenue script generates an analysis mask of the line at the specified buffer distance (Figure B-26). Following the priority process outlined previously generates a priority layer (Figure B-27) that can be compared to other alternative alignments for the proposed road. Alternative road alignments can be evaluated simultaneously by following the same steps, drawing the potential route (Figure B-28), buffering it, and running the prioritization analysis (Figure B-29).

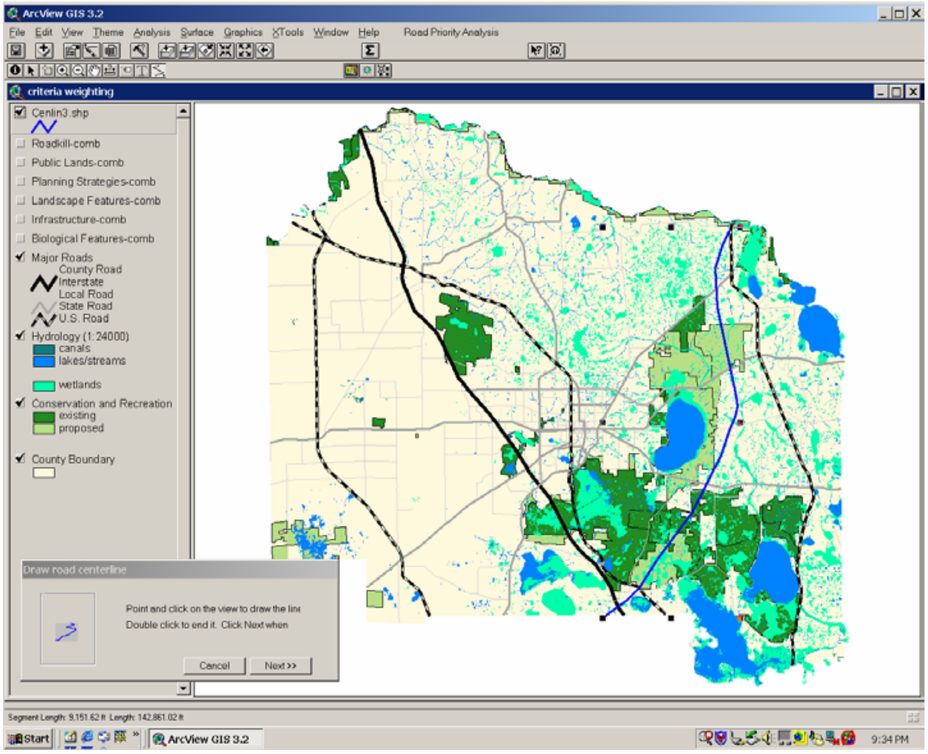

Figure B-24. Drawing the proposed road alignment. The utility allows the user to draw a line anywhere on the map to represent a potential road alignment.

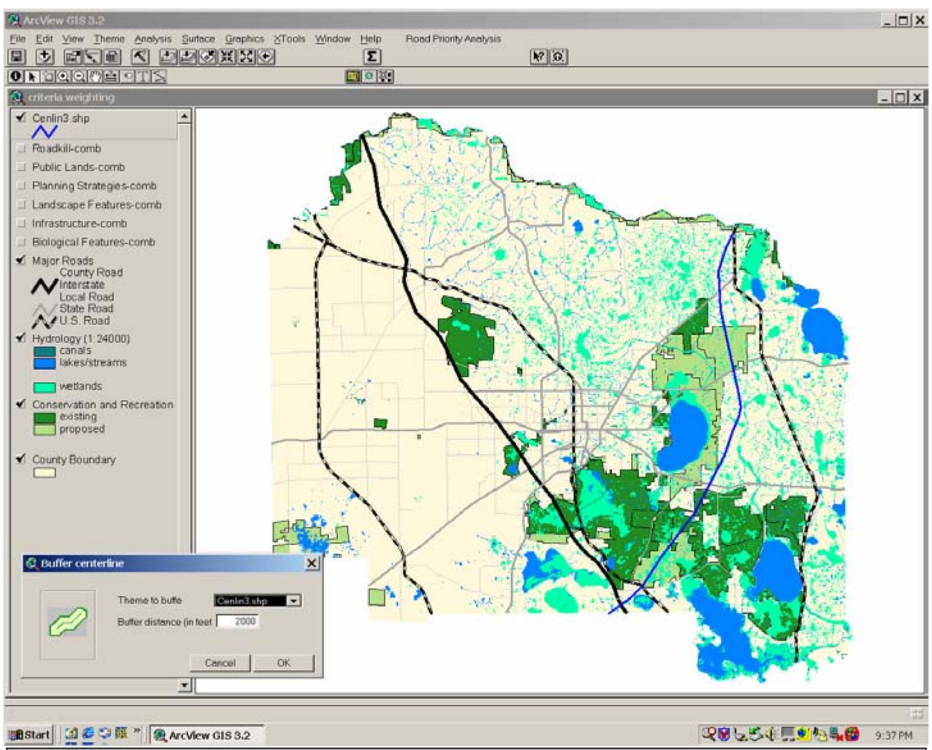

Figure B-25. Buffering the proposed road alignment. After drawing the potential road alignment, the user is asked to enter a buffering distance value.

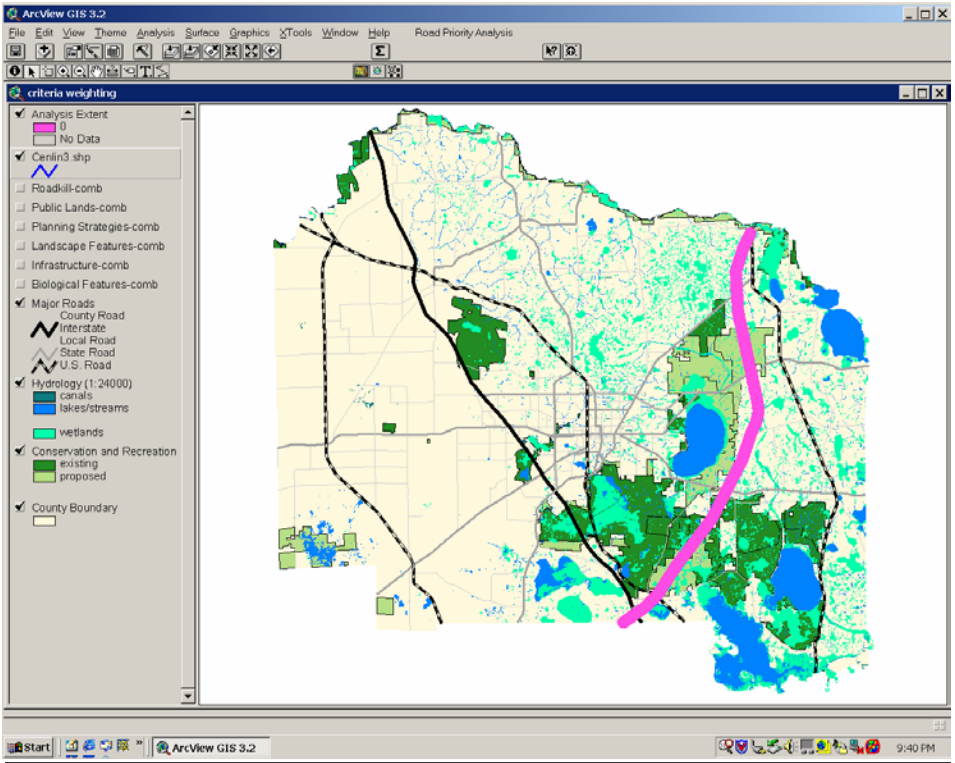

Figure B-26. Buffered analysis mask. The Avenue script automatically generates an analysis mask at the buffer width submitted for the proposed alignment.

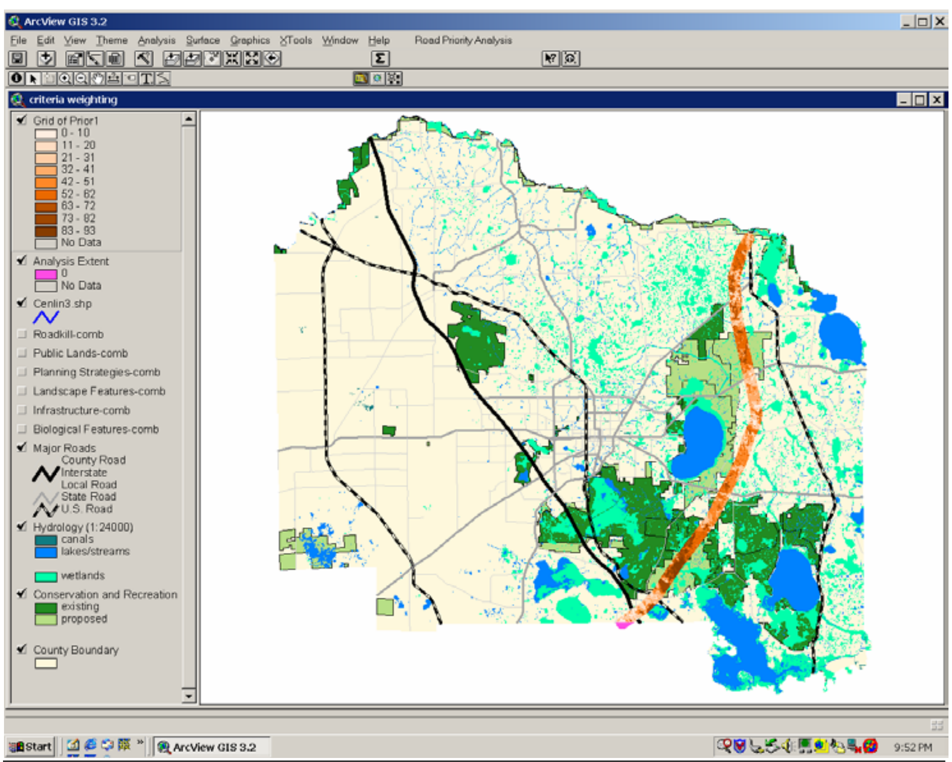

Figure B-27. Priority areas in proposed road alignment. The priority layer is limited to the potential road alignment. Darker shades indicate sensitive areas.

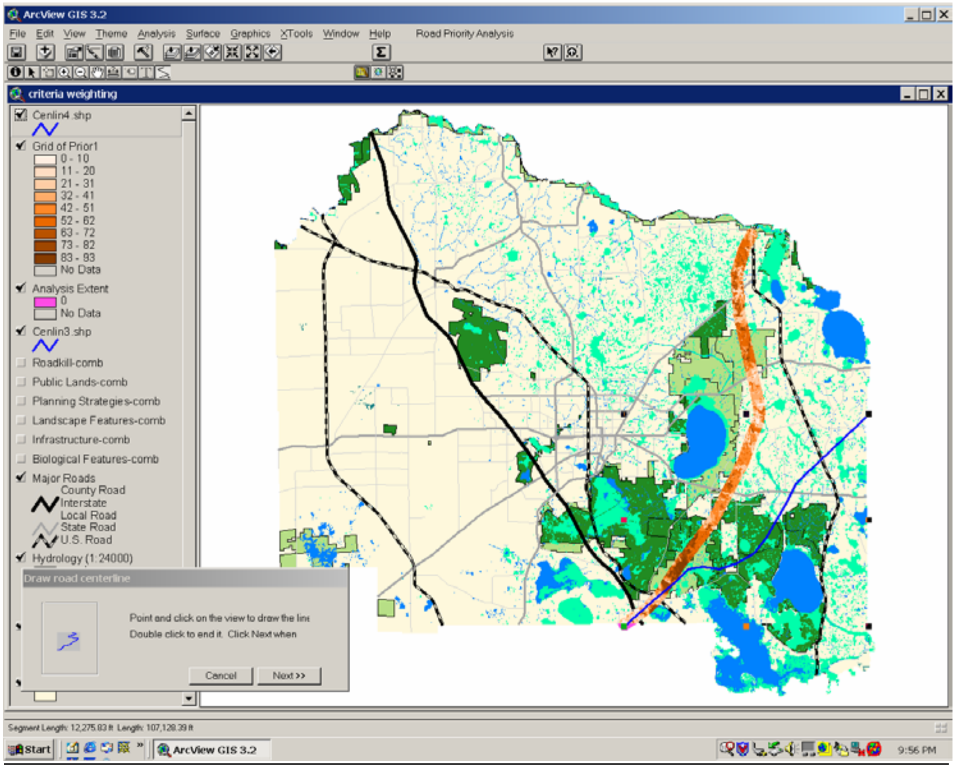

Figure B-28. Adding an alternative road alignment. Alternative alignments are added by repeating the same process. Here another potential road corridor is drawn.

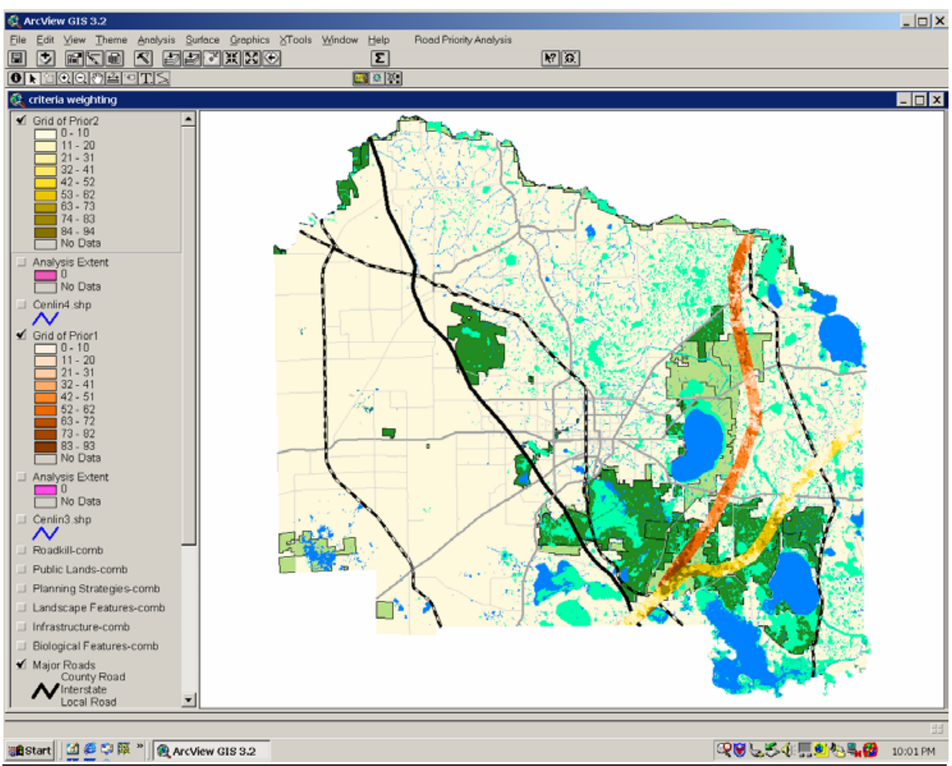

Figure B-29. Alternative proposed road alignment evaluation. Simultaneous evaluation of alternative potential alignments can be performed as shown here.

Assessment of Results

This application is designed as a planning tool that transportation planners and engineers can use to identify and prioritize ecological hotpsots on roads, based on relative environmental sensitivity. It can also provide preliminary assessments, regarding severity of potential impacts from new or proposed road projects.

Besides the cursory evaluation shown in Figures B-7 and B-8, a more extensive evaluation can be performed on each prioritized layer by two different methods; one quantitative and one qualitative. Quantitative assessment could be performed on the input data layers that generated the sensitivity levels of each cell in the priority layer. Since raster-files (grids) are made up of individual cells with the same dimensions, area can be computed from the data table of each input data layer in the analysis. This is calculated by multiplying the count for a particular value (class) by the cell size.

For example, suppose it was critical to minimize the impact of the proposed Jacksonville to Tampa toll-road on rare xeric habitats and hardwood hammocks in Alachua County. This can be determined by comparing the number of hectares of rare habitats within the two proposed alignments (Figure B-29). The "landscape features-comb" grid (Table B-2) contains the data from the input criteria for landscape features, including rare habitats. The values for each field in Table B-2 represent a specific class (e.g., 4 = hardwood hammocks and xeric communities, 3 = wetlands, 2 = pinelands and mixed hardwood-pine forests, 1 = open water, and 0 = agriculture, urban, and shrub and brush lands). The analysis extents for the two alignments are used as analysis masks, then the rare habitats field is selected within the Arcview "map calculator"; and a new rare habitat grid is calculated for the analysis mask area only.

Each proposed corridor must be calculated separately to obtain the correct data for each area. In this case, the count (number of cells) for xeric habitats and hardwood hammocks for corridor one and two are 4,105 and 1,459 cells, respectively. Each cell is 900 m^2, therefore using the following formula,

$$\text{hectares (ha)} = \#\ \text{cells} \times \text{cell size (m)} / 10{,}000\ m^2,$$

reveals that 369.45 ha exist for alignment one and 131.31 ha exist for alignment two. Quantitative indicators of other impacted resources of interest might include area of other rare habitat types, public conservation lands and greenways, number of creek crossings, number of housing units, etc.

Table B-2. Attributes of landscape features-comb

Value	Count	Ecotones	Rare Habitats	Ridges	Hydrology	Sum
1	162067	0	4	0	0	4
2	64695	1	4	0	0	5
3	6502	0	2	0	3	5
4	341085	0	2	0	0	2
5	1957	1	4	0	3	8
6	4421	0	4	0	3	7
7	848865	0	0	0	0	0
8	63510	0	3	0	0	3
9	100062	1	2	0	0	3
10	171469	1	0	0	0	1
11	13735	0	0	0	2	2
12	21422	1	3	0	0	4

Qualitative assessment in this type of analysis includes setting and identifying relative rankings from the priority results (Chapter 2 presents a statewide application). To compare the relative impact of the two alternatives in Figure B-29, they must have the same scale of values. The data range of values for alignment one was 0–94 and alignment two was 0–93. Each dataset was reclassified into 5 equal interval classes between 0 and 100 (Figure B-30); darkest shades of red (value = 5) indicate the most sensitive areas. A comparison of the number of cells for each class (Table B-3) shows that alignment one has significantly greater environmental impact than alignment two, with greater counts for classes 2 to 5. Other qualitative indicators that could be used to evaluate each proposed alignment include assessing habitat quality (SHCAs) and identifying listed species, FFWCC focal species hotspots, and FFWCC priority wetlands within each corridor.

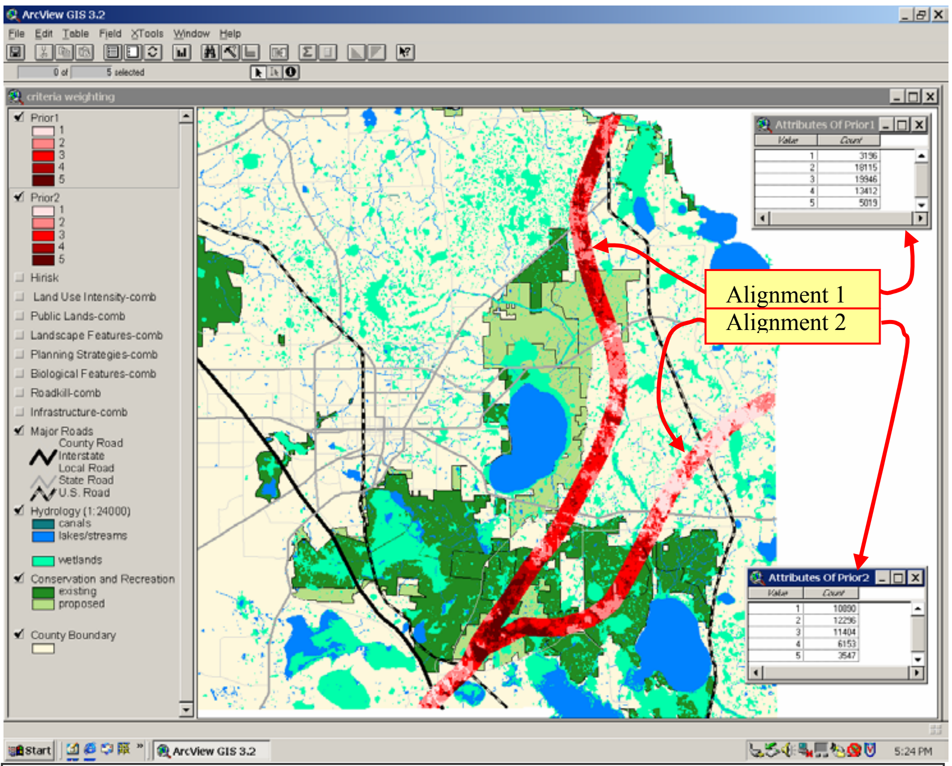

Figure B-30. Reclassified priority layers for alternative road alignments. Priority layers were reclassified to an equivalent scale; tables reflect quantity of prioritized sites for each alignment on a scale of 1 to 5, 5 being most important (reflected by darkest shades of red).

Table B-3. Alternative road alignment environmental sensitivity comparison

Sensitivity value	Alignment 1 count	Alignment 2 count	Difference
5	5,019	3,547	+1,472
4	13,412	6,153	+7,259
3	19,946	11,404	+8,542
2	18,115	12,296	+5,819
1	3,196	10,890	-7,694

APPENDIX C
RECOMMENDED CORRECTIVE ACTIONS AT SPECIFIC SITES
IN FLORIDA TO IMPROVE PERMEABILITY OF ROADS FOR WILDLIFE

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
1	Big Cypress National Preserve, Fakahatchee Strand State Preserve and Florida Panther National Wildlife Refuge Region	US 41	79-84	Located from the entrance to Collier-Seminole State Park, extending 0.8 km east and west
				Includes a cluster of five black-bear road-kills
				Replace low level aquatic bridges with medium-level height and longer span bridges and add barrier fencing
			85-88	Located from 3.5 to 5.3 km west of CR 92
				Includes a cluster of three black-bear road-kills
				Replace low level aquatic bridges with medium-level height and longer span bridges and add barrier fencing
			91-94	Located at Port of the Islands entrance to 0.8 km east
				Includes two black-bear road-kills, post 1996
				Road-kills located on a curve prior to the canal bridge and one east of the canal bridge
				Recommendations include removal/reduction of curve to increase visibility
			106-107	Located 1.4 km west of CR 841 at curve
				Two black-bear road-kill incidents 0.6 miles apart
				Upgrade bridge on curve, add fencing
		SR 29	119-121	Located 3.7 km north of northernmost underpass from US 41 intersection
				Two black-bear road-kills in area
				Add additional underpass, complete fence enclosure
			114	Located 0.6 km north of US 41
				Two black-bear road-kills within 0.3 km
				Add additional underpass/fencing
			124-127	Located 4.7 km south of I-75
				One Florida panther and two black-bear road-kills within 1.6 km
				Add additional underpass and complete fence enclosure
			139-141	Located 5.2 km north of second underpass north of I-75
				Includes a black bear and Florida panther road-kill
				Add wildlife bridge at GPS point location #140, extend fencing
			142-143	Located 8.4 km north of second underpass north of I-75
				Add additional wildlife crossing bridge and extend fencing
				Extend/purchase lands north of Florida Panther NWR (identified in the Florida Greenways Analysis)

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
1	Big Cypress National Preserve… continued	I – 75	132-133	Located 6 km east of intersection with SR 951
				Includes 4 black-bear road-kills
				Upgrade box culvert to bridge/add high-level fencing
				Purchase Western Big Cypress CARL land to north and south of site
			134-135	Located 1.3 km west of Everglades Blvd. Overpass
				Includes 3 black-bear road-kills
				Wildlife fence ends at point 135
				Two bridges present and capable of accommodating use by black bears, etc.
				Extend high-level wildlife fence past Everglades Blvd.
				Purchase Golden Gate Estates CARL
	Fisheating Creek CARL / SOR (Conservation and Recreation Lands / Save Our Rivers) lands, Archbold Biological Station and Lake Wales Ridge Conservation Areas	US 27	158	Located just north of intersection with CR 731
				Includes 5 black-bear road-kills
				Add underpass and fencing
				Project must include acquisition of adjacent lands that functionally connect Johnson ranch lands with greenways to the east and north of Fisheating Creek
			160	Located 4.2 km north of CR 731
				Includes 4 black-bear road-kills
				Replace existing box culvert associated with unknown creek with larger combination creek/wildlife bridge, add wildlife fencing
				Purchase lands south of Archbold BS, adjacent to roadway, and to the east along unknown creek that connects south to Fisheating Creek
			184-186	Located from intersection with SR 17 going south 2 km
				Includes 2 black-bear road-kills
				Increase size of existing box culverts to accommodate larger fauna, e.g. black bear; add fencing
				Critical to purchase Saddle Blanket Scrub CARL and greenway corridor to the east to provide linkage between Arbuckle State Forest and the Charlie Creek SOR corridor
		US 98	171	Located 1 km east of CR 17
				Includes 3 black-bear road-kills
				Upgrade concrete pipe creek drainage with bear crossing culvert and add fencing
				Recommendations also include purchase of adjacent Lake Wales Ridge CARL land that is currently posted for sale
		SR 66	173-178	Located along a 4.8 km section of road west of CR 635
				Two black-bear road-kills located just to the east, potential use by bears likely
				Recommendations include replacement of pipe and box culverts with larger structures capable of facilitating movement by black bear, deer, etc.; add wildlife fencing.

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
1	Fisheating Creek…continued	SR 66	173-178	Purchase greenway lands on the south side of roadway adjacent to Highlands Hammock State Park
	Myakka River State Park, Myakka Prairie State Preserve, Lower Myakka system CARL and SOR projects	I–75	1-8	Located within the Myakka River system beginning at the Englewood exit and extending 8 km south
				Increase permeability of roadway through area by enlarging existing box culverts associated with multiple creeks that cross the highway
				Purchase Lower Myakka SOR properties
		US 41	42-47	Located within the Myakka River system beginning at intersection of CR 777 extending 1.9 km west
				Increase permeability of roadway through area by replacing existing culverts with larger structures associated with creek drainages that cross the highway
				Purchase Taylor Ranch SOR properties
		SR 72	11-20	Located at 0.8 km west of Myakka SP entrance extending east for 13.7 km
				Upgrade existing "old" bridges with wider span structure and replace assorted pipe culverts with large wildlife culverts or bridges to increase connectivity among existing state conservation-lands in the area
	Other Road Projects	US 17	33	Peace River bridge replacement, near Zolfo Springs
				Maintain open character and height of existing bridge across floodplain valley
		US 41	108	Turner River bridge replacement #030083
				Recommend increasing bridge span and fill removal or perforation with box culverts to add terrestrial linkage under bridges and increase roadway permeability
2	Ocala National Forest, Cross-Florida Greenway and Etonia Creek CARL	SR 19	285	Located 0.6 km north of CR 310
				Extend Dunn's Creek bridge when replacement scheduled and add second bridge to north
				These measures will increase permeability of roads for herpetofauna in bisected hardwood swamp that functions as greenway linkage for Ocala NF and Cross-Florida Greenway/Etonia Creek CARL
			287	Located approximately 1 km north of Ocklawaha River
				Replace existing 'aquatic' box culvert with expanded medium-level bridge
				Important crossing point along the Ocklawaha River riparian corridor
		SR 20	198	Located at Rice Creek within the Etonia Creek CARL
				Scheduled bridge replacement should include longer span medium-level bridge capable of facilitating use by the Florida black bear

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
2	Ocala National Forest…continued	SR 20	198	In addition, raised road bed within the Rice Creek basin should be fitted with additional wildlife passages constructed up to 2.1 km east and west of the main channel bridge
				Erect wildlife fence the length of the Rice Creek basin (approx. 4.8 km)
				Florida black-bear road-kill 2.1 km east of Rice Creek
				Complete purchase or conservation easement of Etonia Creek CARL
			144	Located 2.1 km west of SR 21, Fowler's Prairie
				Replace existing box culvert with longer medium-level bridge
				In addition, raised road bed within the basin should be fitted with additional wildlife passages
		SR 100	193-197	Located 4.5 km east of Coral Farms Rd and extending east another 10.9 km
				Series of 7 black-bear road-kills in area
				Replace Rice Creek bridge (GPS pt. #197) with medium-level span when scheduled in FDOT bridge replacement program
				Replace concrete pipes (GPS pts. #193, 194, 196) with wildlife passages appropriate for Florida black bears and add large wildlife fencing
				Topography at these sites provides sufficient relief to install large (3 m tall) culverts without need for additional fill
				Complete purchase or conservation easement of Etonia Creek CARL
	Fish Swamp WMD (water management district) project and Twelve-Mile Swamp CARL	SR 206	200	Located 1.6 km east of CR 305, Fish Swamp greenway
				Black-bear road-kill at site
				Replace existing small box culvert associated with unknown creek with medium-level bridge
				Add additional wildlife passages to the east to increase roadway permeability and add large wildlife fencing
	St. Mary's River corridor and Cary and Jennings State Forests	US 90	115-116	Located 4.7 and 5.1 km west of US 301, respectively
				Deep creek bridge scheduled replacement, install medium-level height and longer span
				Railroad bridge # 770002 scheduled replacement, needs to be at least medium height to accommodate Florida black-bear movement
				Black-bear movement corridor adjacent to corresponding bridges on I – 10

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
2	St. Mary's River…continued	US 90	115-116	Central greenway linkage connecting Osceola NF/St. Marries River corridor and Cary SF/Jennings SF/Camp Blanding MTS needs to be targeted for CARL or SOR program
			92	Located 5.3 km east of US 301
				Brandy branch bridge scheduled replacement, install medium-level height and longer span
				Important connection between Cary and Jennings SF
		I–10	100	Located 6.4 km west of US 301
				One black-bear road-kill near existing railroad bridge
				Abandoned railroad bridge needs to be supplemented by wildlife fencing along roadway to ensure passage through structure by black bears
	Camp Blanding Military Training Site	SR 16	217-219	Located at South Fork Black creek and extending 2.7 km west.
				Black-bear road-kills at creek bridge and 0.8 miles west (GPS pt. #218)
				Supplement South Fork Black Creek bridge with high-level wildlife fence extending west to SR 21
				Add two wildlife tunnels (bear culverts) at one mile intervals west from South Fork Black Creek bridge
		SR 21	220-221	Located 1 and 4 km south of SR 16, respectively
				Replace small concrete box culvert and wooden-based bridge with medium-level long span bridges
				Topographically sharp valleys present
				Implementation of these measures will increase permeability of SR 21 that functionally divides Camp Blanding from Etonia Creek CARL
			222-223	Located just south of intersection CR 315
				Replace two box culverts with medium-level longer span bridges
				Implementation of these measures will increase permeability of SR 21 that functionally divides Camp Blanding from Etonia Creek CARL
			224-225	Located east and west of Goldhead Branch State Park entrance
				Install a series of Gopher tortoise tunnels/drift fences to remedy road-kill problem documented by park officials
	Lochloosa Forest Conservation Easement, Newnan's Lake CARL and Cross Florida Greenway	SR 20	72	Lochloosa Creek bridge scheduled replacement; install longer span, medium-level structure
				Important linkage for Florida black-bear movement between Lochloosa and Austin Cary forests
		SR 26	155	Located 1.6 km west of US 301
				Site includes one black-bear road-kill

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
2	Lochloosa Forest…continued	SR 26	155	Eliminate sharp curve and reconfigure intersection with dirt road
				Area represents a travel corridor for black bears between Austin Cary, Newnan's Lake Carl, Lochloosa and lands to the east of US 301
		US 301	132-133	Located at Alachua/Marion county line
				Replace low-level existing bridge with longer span medium-level bridge that incorporates part of the upland ecotone (e.g. SR 46 Wekiva River bridge)
				Replacement will enhance use by Florida black bear and other wetland-dependent species moving along the Orange Creek corridor
			136, 142	Located 4.2 km north of CR 325 (Lochloosa swamp) and 1.8 km south of CR 200 (Lochloosa conservation easement), respectively
				Black-bear road-kill at GPS pt. # 142
				Replace existing box culverts with large black-bear culverts or medium-level bridges
				Purchase designated greenways to the east that functionally connect Lochloosa conservation easement with the Cross Florida Greenway
	Cedar Key Scrub State Preserve	SR 24	331-335	Includes a 7 km section of highway beginning at the Channel #4 bridge going east
				Increase permeability for scrub/sandhill associated herpetofauna by installing small box culverts
				Take measures to reduce harmful erosion along right-of-way caused by human trampling and off road vehicles
	Aucilla River Wildlife Management Area and Econfina River Corridor	US 98	345-346	Located 2.3 km east of CR 14 and Econfina River
				Three black-bear road-kills
				Replace concrete pipe with large wildlife tunnel, include fencing for 1 mile each direction
				Econfina River bridge should be lengthened and raised according to scheduled replacement date
			347	Aucilla river bridge at the Taylor/Jefferson county line
				Florida black-bear road-kill
				Replace bridge with longer span medium-level bridge and add wildlife fencing that extends beyond floodplain
		US 27	386	Located at the Econfina River
				Existing bridge should be lengthened and raised according to scheduled replacement date
				Add wildlife fencing that extends beyond floodplain
			383, 385	Located 2.7 km south of Aucilla River and 2.6 km south of CR 14, respectively
				Two black-bear road-kills each at or near both sites
				Add black-bear underpass at GPS pt. #385

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
2	Aucilla River…continued	US 27	383, 385	Replace existing culvert (associated with Aucilla River tributary) at point #383 with medium-level bridge that includes upland passage beyond the creek floodway or high water mark
				Secure purchase of conservation easement along Aucilla River and tributaries (wmd project)
	Pinhook Swamp, Osceola NF and Suwannee River	US 441	253, 255-257	Points #253 and #255, located 1.6 and 4.2 km south of Georgia line, respectively, are sites of Florida black-bear deaths
				Point #257 and #256 are located at the intersection with CR 6 and 2 km north of CR 6, respectively
				Point #257 is also the site of a road-kill Florida black-bear
				All sites are associated with proposed SOR project that connects the Suwannee River with Pinhook Swamp, purchase should be accelerated
				Add black-bear passages at all sites except the intersection with CR 6
				CR 6 intersection should be cleared to increase driver visibility
		SR 2	245-250	Located along an 13 km section of road beginning 2.3 km west of the St. Mary's River
				Four road-kill black-bears
				Replace railroad crossing 1.4 mi west of St. Mary's River with high-level bridge
				Replace two low-level bridges at points #247 – 249 with longer span medium-level bridges
				Add black-bear passage between two small concrete pipes located at points #245 and 246.
				Add high-level wildlife fencing
				SR 2 bisects Pinhook Swamp-Okefenokee Swamp NWR; these measures will increase the permeability of the road and reduce road-kill incidents.
		I–75	269	Abandoned railroad bridge 1.4 km north of US 129
				Black-bear road-kill
				Extend high-level wildlife fencing from existing bridge
	Other Road Projects	SR 51	301-302	Road widening through Mallory Swamp
				Potential opportunity to upgrade several low quality wood-based bridges with longer span floodplain bridges
				Replace two small box culverts associated with Owl Creek, 2.1 and 3.1 km south of CR 357 at Cooks Hammock
		US 301	96-97	US 301 add lanes and reconstruction
				Adjacent to Cary State Forest and Brandy Branch Creek corridor to St. Mary's River

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
2	Other Road Projects…continued	US 301	96-97	Replace existing bridges at Brandy Branch and those 2.4 km north of CR 119 with longer span medium-level bridges capable of accommodating black-bear movement
3	Aucilla Wildlife and Water Management Area	US 27	301	Located at the Aucilla River, Madison county line
				Includes one black-bear road-kill
				Extend high-level wildlife fence from existing bridge in both directions to help prevent black bears from entering traffic lanes
			299-300	Located 3.5 to 4.2 km west of Madison County line
				Three black-bear road-kills
				Replace small culvert with black-bear underpass, add fencing
				Movement corridor through Aucilla R. WMA/WMD lands and proposed greenways
			296-298	Located 4.5 to 5.8 km east of US 19
				Includes two black-bear road-kills
				Replace concrete pipe with black-bear wildlife passage at GPS pt. # 297
				Movement corridor through Aucilla R. WMA/WMD lands and proposed greenways
			295	Located 3.1 km east of US 19
				Includes two black-bear road-kills
				Add wildlife passage and associated high-level fencing
				Movement corridor through Aucilla R. WMA/WMD lands and proposed greenways
			294	Located 1.4 km east of US 19
				Includes five black-bear road-kills
				Replace concrete pipe with medium-level bridge and associated wildlife fencing
				Movement corridor through Aucilla R. WMA/WMD lands and Red Hills conservation area
		US 98	2-3	Located 0.8 to 2.1 km west of the Aucilla River
				Three black-bear road-kills
				Install two black-bear culverts/wildlife bridges
				Include wildlife fencing extending east to Aucilla River and west around curve in road
			4	Located 3.5 km east of SR 59 on curve
				Site of three black-bear road-kills
				Add black-bear wildlife underpass and associated fencing
				Aucilla WMA
			6	Located 1.6 km east of SR 59
				Includes one black-bear road-kill
				Replace existing box culvert with wildlife underpass, add wildlife fencing

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
3	Aucilla Wildlife…continued	US 98	6	Proposed greenway expansion of Aucilla WMA, recommend adding to SOR or CARL
			7, 291	Located at intersection of SR 59 and 1.6 km west of SR 59, respectively
				Includes two black-bear road-kills
				Replace existing pipe culvert with wildlife underpass
				Purchase land surrounding intersection to eliminate potential for development
				Proposed greenway expansion of Aucilla WMA, recommend adding to SOR or CARL
	Wakulla Springs State Park and CARL Projects and St. Marks NWR	US 98	284-285	Located at the Wakulla River and 1.1 km east, respectively
				Includes one black-bear road-kill
				Add lower river corridor to Wakulla CARL proposal as linkage to St. Marks NWR
				Secure land adjacent to Wakulla River bridge to limit development
				Install wildlife underpass at location of bear road-kill 0.7 miles east of river
		SR 267	279-283	Located 0.8 to 4 km west of intersection with CR 61
				Extend McBride Creek bridge span when replacement scheduled
				Install two additional wildlife underpasses west of McBride Creek
				Purchase Wakulla Springs CARL to secure linkage to Apalachicola NF
	Apalachicola National Forest, Tates Hell SF-CARL and Apalachicola River WMD Project Areas	US 98	252-259	Apalachicola Bay shoreline from intersection with SR 65 to east of US 319
				Eleven black-bear road-kills
				Land cover ranges from urban and transitional development to native xeric oak/longleaf pine forest and coastal salt marsh
				Secure purchase of remaining linkages from coast to interior forest habitat and consider construction of underpasses at these sites
				Alternatively improve visibility along curves and at intersections with vegetation management and road realignments
			207-211	Located from Franklin county line traveling west 2.1 km
				Includes three black-bear road-kills
				Linkage from St. Joe's Bay Buffers to Apalachicola River WMD lands
				Replace two small box culverts with black-bear wildlife underpasses

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
3	Apalachicola NF…continued	US 98	207-211	Add wildlife fencing 1.6 km going each direction from structures (approx. 4.8 km)
		SR 71	217-218	Located 3.6 to 4.3 km north of US 98
				Three black-bear road-kills within 0.5 km
				Construct black-bear underpass 3.9 km north of US 98, add high-level fencing
				Private forest land that represents landscape linkage from Apalachicola NF to Tyndall AFB
			221-224	Located from 1 km south of CR 387 to 6.4 km north of CR 387
				Six black-bear road-kills evenly spaced at 5 points approx. 1.6 km apart
				Construct/replace existing culverts with black-bear underpasses at above mentioned intervals/ add high-level fencing
				Replace wood-base bridge at Cypress Creek with medium-level longer span bridge
				Private forest land that represents landscape linkage from Apalachicola NF to Tyndall AFB
		SR 65	247	Located 0.6 km north of Dunn's Creek
				Black-bear road-kill near curve and dirt access road
				Reduce severity of curve on approach to bridge/improve visibility
				Ecotone where Tates Hell SF reaches coastal salt marsh
			246	Located 3.1 km north of Dunn's Creek
				Black-bear road-kill near curve
				Reduce severity of curve/ improve visibility with vegetation management
				Ecotone where Tates Hell SF reaches coastal salt marsh
			240	Located 10.4 km south of Liberty county line in Apalachicola NF
				Black-bear road-kill near bridge
				Supplement bridge with high-level wildlife fencing
				Replace bridge with longer span if high water line is above sides of bridge
			236	Located 8.5 km south of CR 12 in Apalachicola NF
				Black-bear road-kill
				Investigate effects of access road use by black bears
				Replace pipe culverts with wildlife underpass for black bears/add fencing if unable to eliminate access road
	Tyndall Air Force Base	US 98	198	Located 2.9 km west of AFB boundary
				Two black-bear road-kills
				Investigate impact of access road, consider removal of side road, or improve visibility at intersection

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
3	Eglin Air Force Base	SR 87	174-176	Located from the Yellow River bridge traveling south 1.6 km
				Three black-bear road-kills
				Area characterized by steep banks along road bed, access roads and curves
				Recommend removing what access roads possible, reducing severity of curve/improve visibility and adding high-level wildlife fence from the bridge extending 3.2 km south
				An alternative is to perforate the high road bed with large wildlife crossing culverts
			179	Located 8.9 km south of intersection with CR 184
				One black-bear road-kill
				Steep banks within valley provides opportunity to perforate road bed with large wildlife crossing culvert
		SR 123	122	Located 1.9 km south of intersection SR 85
				One black-bear road-kill
				Steep ravine has inadequate existing culvert associated with unknown creek, replace with one or two large wildlife crossing culverts that maintains terrestrial and aquatic zones
		SR 85	127-128	Located from 0.8 to 1.8 km north of intersection SR 123
				Two black-bear road-kills
				Replace existing small culvert with medium-level wildlife bridge
				Supplement bridge with high-level wildlife fencing
		I–10	134-145	Located from 5.8 km west of CR 4 overpass going west to 5.8 km east of SR 87
				Topography characterized by high ridges and deep ravines conducive to retrofitting highway without disturbing existing road surface
				Includes 12 sites with small pipe or box culverts (less than 1.7 m high), replace these with large wildlife tunnels and associated fencing along right-of –way and through wooded medians (a.k.a. Trans-Canada Highway)
				Sites of most importance are GPS point nos. 136 – 145.
				Critical linkage (Yellow River Ravines CARL) connecting Blackwater State Forest to Eglin AFB
	Proposed Greenway Linkages and Private Forest Lands	SR 22	225	Located 12.9 km west of SR 71, Wewahitchka
				Two black-bear road-kills near curve
				Remove curve in road/improve visibility
				Private forest lands that form linkages from Apalachicola NF to Eglin AFB and other conservation lands west of the Apalachicola River

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
3	Proposed Greenway Linkages…continued	SR 20	49-50	Located from 5.8 to 8.4 km east of US 231
				Three black-bear road-kills, one near curve
				Replace existing small culvert at site of two bear deaths with black-bear underpass/ add fencing
				Reduce severity of curve/improve visibility with vegetation removal
				Private forest lands that form linkages from Apalachicola NF to Eglin AFB and other conservation lands west of the Apalachicola River
	Other Road Projects	US 98	180-184	From 2.6 km west of CR 30a to 0.6 km west of US 331
				Road project involves additional lanes and reconstruction
				Road bisects Topsail Hill State Park and Point Washington State Forest
				Project should include installation of multiple wildlife crossing structures that vary in size from deer passages to tunnels for gopher tortoises, etc. to maintain a level of connectivity between inland and shoreline habitats for native fauna
		US 331	89	Located 4.2 km north of SR 20
				Project involves new construction to convert to four lane highway
				This area represents one of two important greenway linkages connecting Eglin AFB to conservation lands to the east.
				In conjunction with road reconstruction, wildlife underpasses should be constructed
4	Blue Cypress SOR, Kissimmee River SOR and Ft. Drum Marsh WMD lands	SR 60	6-7	Located from just west of intersection of CR 512 extending west 3.5 km
				Road project programmed- add lanes and reconstruction- coordinate with wildlife considerations
				Considerable evidence of herpetofauna mortality on the road, e.g. several species of aquatic turtles
				Perforate high road bed crossing through marsh by adding multiple medium-sized cross drainage culverts from CR 512 west to 1.6 km past the c-52 canal
				Road bisects the Blue Cypress Creek-Ft. Drum conservation areas
			8-9	Road project programmed- add lanes and reconstruction- coordinate with wildlife considerations
				Located 7.4 and 8.4 km west of intersection of CR 512, respectively
				Lengthen existing bridge span to provide terrestrial linkage under bridge on western side along high ground

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
4	Blue Cypress SOR…continued	SR 60	8-9	Perforate high road bed crossing through marsh by adding multiple medium-sized cross drainage culverts 1 mile east and west of existing bridges
				Road bisects the Blue Cypress-Kissimmee River SOR, and Ft. Drum conservation areas
			10	Located 7.6 km east of Osceola county line
				Road project programmed- add lanes and reconstruction- coordinate with wildlife considerations
				Padgett marsh bridge adequate during dry periods to allow movement by non-aquatics under bridge, high water periods may eliminate movement under bridge by non-aquatics
				Extend bridge span in conjunction with road project
			11-12	Located 6 and 4.4 km east of Osceola county line, respectively
				Add wildlife passage culverts as part of programmed road project to increase connectivity between Blue Cypress conservation area and Indian River county preserve-Kissimmee River wmd lands
				Four laning will increase barrier effects of roads, wildlife passages can maintain some measure of permeability of the roadway for wildlife
	Cypress Creek CARL	SR 70	51-54	Located from 2.3 to 4.3 km east of Okeechobee county line
				In conjunction with programmed road project (add lanes and reconstruction)
				Bridge replacements scheduled for bridge numbers 940010 – 940012
				Replace low level bridges and box culverts with medium-level wildlife underpasses and add wildlife fencing
				Road bisects Cypress Creek CARL lands
5	Ocala National Forest	SR 19	70-76	Located from 2.4 to 9.3 km south of CR 314
				Area is associated with 12 black-bear road-kills
				Sites of road-killed bears occur on slopes of hills or curves in the highway
				Possible remedies for sites at GPS points 70 – 74 include construction of black-bear underpasses or road reconstruction that increases driver visibility by eliminating slopes and straightening curves
				Recommend construction of underpass at GPS point #76, a straight section of road NW of Lake George where multiple bear road-kills have occurred
				Where underpasses are recommended 3 m fencing should be erected

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Ocala National Forest…continued	SR 19	77-78	Located near the access roads to Pat's Island and Silver Glen Springs, respectively
				GPS point locations are associated with six black-bear road-kills
				Sites of road-killed bears occur on slopes of hills, curves in the highway, and near dirt access roads
				Possible remedies include construction of black-bear underpasses/barrier fencing or road reconstruction that increases driver visibility by eliminating slopes and straightening curves
			80-81	Located at and north of Juniper Creek
				GPS point locations are associated with six black-bear road-kills
				Recommend Juniper Creek bridge replacement that includes a 120 – 150 m medium-level span capable of facilitating safe travel for black bears beneath the bridge
				Bridge should be equipped with barrier fencing that extends north 1.2 km (beyond curve in highway)
			82	Located 4 km north of SR 40
				Includes two black-bear road-kills
				Bear fatalities occurred on the upslope of a hill
				Possible remedies include construction of black-bear underpass/barrier fencing system or road reconstruction that increases driver visibility by eliminating slope
			96-98	Located from 0.6 to 3.5 km south of SR 40
				Associated with four black-bear road-kills
				Possible remedies include construction of black-bear underpass/barrier fencing system or road reconstruction that increases driver visibility by eliminating slopes
			99, 105	Located at Beakman Lake and south of CR 445a
				Associated with three black-bear road-kills
				Replace existing stream culvert with combination drainage/wildlife underpass
				Realign road away from northeast side of lake to eliminate curve and reduce road associated runoff to the lake
				Purchase forest inholdings
			102-104	Located from 0.2 to 1.1 km north of Forest Service rd 595
				Associated with two black-bear road-kills
				Replace existing stream culvert with combination drainage/wildlife underpass
			100-101	Located from 0.8 to 3.2 km north of CR 445
				Associated with 11 black-bear road-kills

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Ocala National Forest…continued	SR 19	100-101	Recommend construction of two underpasses, one at each point
				Fencing should be erected that runs from 0.8 km south to 4 km north of CR 445
				Purchase forest inholdings
		SR 40	93	Located 1 km east of CR 314a
				Associated with 7 black-bear road-kills
				Include remedies (below) as part of road project that includes adding lanes and reconstruction
				Recommend construction of wildlife underpass/fencing system, fence should extend from CR 314a west 1.6 km
				Purchase remaining inholdings that are not within development clusters
			64, 92	Located at intersections of Forest Service roads 97 and 88
				Associated with two black-bear road-kills
				Improve visibility near intersections through vegetation management, reduce speed near intersections
			89-91	Located from intersection with Forest Service road 65 going east 2.7 km, Juniper Spgs entrance
				Associated with 12 black-bear road-kills
				Road corridor characterized by rolling hills and curves
				Proposed remedy includes a combination of two underpasses and road reconstruction that increases driver visibility by eliminating slopes and curves
				Erect fence that extends from SR 19 to Forest Service road 65
			88	Located 0.4 km east of Juniper Springs entrance
				Associated with six black-bear road-kills
				Area adjacent to Juniper Prairie ecosystem
				Road corridor characterized by rolling hills and curves
				Proposed remedy includes a combination of two underpass and road reconstruction that increases driver visibility by eliminating slopes and curves
				Erect fence that extends from SR 19 to Forest Service road 65
			84-86	Located from intersection with SR 19 and west 2.4 km
				Associated with six black-bear road-kills
				Road corridor characterized by rolling hills and curves
				Construct two underpasses
				Erect fence that extends from SR 19 to Forest Service road 65
			106-108	Located from 0.4 to 1.9 km east of SR 19
				Associated with four black-bear road-kills

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Ocala National Forest…continued	SR 40	106-108	Road separates Wildcat Lake ecosystem from wetlands to the north
				Construct underpass approx. 1 km east of SR 19
				Erect fencing from SR 19 intersection and extend east 2.4 km (beyond double curve)
			110-111	Located just west of Blue Creek Lodge road
				Includes seven black-bear road-kills
				Reduce severity of curve and install wildlife underpass/fencing
			112-113	Located from intersection of CR 445a to 1.8 km east
				Includes 17 black-bear road-kills
				Include remedies (below) as part of road project that includes adding lanes and reconstruction
				Replace box culvert at unknown creek with long span medium-level bridge that includes terrestrial connection above high water line beneath bridge
				Add additional underpass to west (approx. 0.6 to 1.1 km from unknown creek)
				Include fencing from CR 445a to 1.8 km west (Ocala NF boundary)
		CR 42	n/a	Area parameters not included in GIS analysis.
				Although the analysis was restricted to state roads, it should be recognized that CR 42 accounted for 19 documented black-bear road-kills as of 1999
				As such it should receive serious consideration for improvements to reduce impacts on black-bear movement
	Lake Woodruff NWR, Hontoon Island State Park and Wekiva River Basin – Ocala greenway	SR 44	132	Located 0.2 km west of CR 42
				Includes one black-bear road-kill
				Purchase remaining private lands up to 1.6 km west to secure connection between Ocala NF/Lake Woodruff NWR and the Wekiva River Basin
	SOR lands		134-135	Located from entrance of Royal Trails development west 4.8 km to Cassia
				Includes six black-bear road-kills
				Area includes scattered rural-development, as top priority for this site - recommend purchase of land in area (undeveloped inholdings and key developed parcels) to secure quality of corridor
				Construct two underpasses in area (contingent on ability to tie-up future development potential of area)
			136-137	Located east and west of CR 44a intersection (past Blackwater Creek)
				Includes 11 black-bear road-kills

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Lake Woodruff… ...continued	SR 44	136-137	Add wildlife underpasses east and west of Blackwater Creek bridge, enclose section in wildlife fencing, and lengthen bridge span when replacement scheduled
	Wekiva River State Park and Seminole State Forest	SR 46	145-146	Located from 3.5 to 4.2 km west of CR 46a
				Site includes seven black-bear road-kills
				Site occurs on double curve
				Straighten road and add wildlife underpass/fencing system
				Purchase remaining BMK ranch lands
			141-144, 66	Located from intersection with CR 46a going east 2.7 km
				Includes eight black-bear road-kills from 1996 -99, after installation of underpass/fence
				Recommend additional underpass be constructed to the east of existing one and fencing be extended
				Purchase remaining private inholdings in area including key developed parcels
			139-140, 65	Located from Wekiva River west 1.3 km
				Area includes eight black-bear road-kills
				Add wildlife underpass west of Wekiva River bridge and extend fencing from bridge west 1.6 km
				Top priority for the entire Wekiva River Basin area should be purchase of parceled lots for sale adjacent to the river and south of SR 46; this is a critical link from Wekiva River State Park to Seminole State Forest
				Other remaining private inholdings should also be purchased
	Lake George State Forest and Haw Creek WMD Project Lands	US 17	114-116	Located from 1.9 to 3.9 km south of SR 40
				Includes five black-bear road-kills
				Important linkage from Ocala National Forest to conservation lands east of the St. Johns River
				Construct one underpass 1.6 km north of Deep Creek bridge
				Erect fencing from Deep Creek bridge 2.4 km north
				Replace crushed rock substrate under Deep Creek bridge
		SR 40	119	Located 3.2 km west of intersection CR 4023
				Creek drainage with black-bear road-kills to the east and west
				Replace existing culvert with longer span medium-level bridge capable of accommodating black bears
				Purchase private inholdings or development rights to restrict future development of area
			120	Located at the Little Haw Creek bridge
				Black-bear road-kill
				Replace bridge with medium-level (3 m or greater) long span bridge and add wildlife fencing

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Lake George…continued	SR 40	120	Purchase Container Corp tract (WMD project) or development rights
	Tiger Bay State Forest, Deep Creek and Other Proposed State Greenway Lands	I–4	126-129	Located from 0.8 km west of US 92 to 3.7 km east of SR 44
				Includes 10 black-bear road-kills in three clusters
				Recommend replacement of existing small box culverts with wildlife bridges and installation of associated high-level wildlife fencing
		US 92	161-166	Located from 4.8 to 13.2 km east of CR 4101
				Includes two black-bear road-kills
				Deep Creek and Tiger Bay systems
				Replace existing small box culverts with wildlife bridges when replacements scheduled
		SR 44	175-180	Located from 2.3 km west of CR 4118 to 2.6 km east of Interstate 4
				Includes one black-bear road-kill and numerous small mammals and reptiles at or near wetland sites
				Replace existing small culverts with large wildlife bridges, add additional passages at other wetland sites and straighten alignment of road
				These recommendations should be incorporated into planned road project to add lanes and reconstruct highway
				Purchase Deep Creek property and Tiger Bay proposed additions
		SR 415	181-182	Located from 3.5 km south of SR 44 to 2.1 km north of CR 4152
				Rapidly developing area that requires serious attention to save greenway connections from the St. Johns River to Tiger Bay State Forest
				Purchase remaining corridors along road right-of-ways
				Replace existing creek culverts with long span medium-level bridge
	Other Road Projects	SR 520	272-288	SR 520 project- add lanes and reconstruction
				Existing culverts should be upgraded to large wildlife culverts/bridges
				Existing bridges over Jim and Second creeks should be lengthened to include terrestrial connections beneath the bridge that are above high water lines
				Secondary culvert as part of the St. John’s floodplain needs to be upgraded to a bridge with terrestrial linkages
		US 192	291-293	US 192 project- add lanes and reconstruction
				Bridges over the St. John’s river should be lengthened to include wider terrestrial links during high water periods

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
5	Other Road Projects…continued	US 192	291-293	Additional culverts/wildlife bridges should be constructed east and west of the St. John's River bridges to increase permeability of the highway throughout the St. John's River prairie system
		SR 60	District 1: 196	Bridge replacement at the Kissimmee River
				New bridge should be longer to incorporate terrestrial linkages under the bridge as part of restoration of the river and establishment of unbroken riparian corridor
		I–4	214	Interstate 4 lane additions
				Project should include replacement of Reedy Creek bridge that includes a lengthened and higher span creating a functional terrestrial linkage for habitat areas north and south
				Other box culverts west of Reedy Creek should be upgraded to wildlife bridges
		SR 100	148-153	SR 100 project- add lanes and reconstruction
				Replacement bridge at Crescent lake 'creek' should be a longer and higher span that incorporates a terrestrial habitat linkage
				Box culverts should be replaced with combination terrestrial wildlife/creek drainage bridges
6	Everglades National Park, Model Lands Basin, Southern Glades SOR and Crocodile Lake NWR	US 1	1-12	Located from intersection with CR 905 extending north to the C-111 canal
				Multiple road-kills of the endangered American crocodile within this section of highway
				Perforate existing roadbed with the installation of aquatic wildlife crossings, recommended minimum width of openings approx. 6 m
				Wider openings are preferred to minimize predator-ambush activity and to help restore natural flow patterns between Biscayne and Florida Bays
				Placement guidelines in this study coincide with FDOT crocodile crossing location plan (9/94 project nos. 90060-3501, 90060-3585, 87010-3509)
			13-16	Located from C-111 canal north to intersection with CR 997
				Multiple road-kills of American alligator and numerous signs of trails used by crocodilians
				Generally agree with FDOT proposed wildlife crossing plan (9/94 project nos. 90060-3501, 90060-3585, 87010-3509) regarding C-111 bridge and crossing structure dimensions
				Recommend four additional crossing structures within this 13.7 km section of highway

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
6	Everglades National Park…continued	US 41	n/a	Located from the Dade county line extending east through Shark River Slough to SR 997
				Although this area was not surveyed, it did receive a low priority from the GIS analysis, and as such should be considered regarding water/wildlife management issues
				This corridor (it is assumed) will be addressed in the Everglades restoration effort
	Big Pine Key, Key Deer National Wildlife Refuge, Cupon Bight CARL Project and Bahia Honda, Long Key and John Pennekamp State Parks	US 1	18	Located on Big Pine Key from the Spanish Harbor channel bridge extending south approx. 3.2 km
				Includes multiple/annual road-kills of endangered Florida Key deer
				Recommend installation of wildlife underpasses at 0.4 km intervals (optimum width of 4.5 - 6 m) and include barrier fencing of appropriate height to prevent deer from entering lanes of traffic
				Top priority acquisition of remaining habitat, including purchase and restoration of key developed areas to secure corridor connections from either side of the island
			n/a	Crossing through Bahia Honda, Long Key and Pennekamp State Parks
				These sites received lower priorities, however US 1 effectively divides the two prior state parks
				Small mammal/herpetofauna tunnels installed through these areas would increase connectivity for local fauna and reduce road-kill problems in these parks
7	Chassahowitzka NWR/WMA and Annuteliga Hammock CARL Project	US 19	4-10	Location begins 4.8 km south of US 98 and extends 9.7 km south
				Six of the seven sites are associated with Florida black-bear road-kills
				All black-bear road-kills occurred at sites where dirt trails/access roads intersect the highway or on curves in the highway
				Recommend three possible measures- increased vegetation management at access points, removal of access roads and reduction in curves, or installation of wildlife passages designed for black bears
				This section of highway splits the Chassahowitzka lands from Annuteliga hammock/Withlacoochee SF to the east- an important connection for persistence of this isolated population of black bears
		US 98	2-3	Located 4.4 and 7.9 km east of US 19, near the Suncoast parkway corridor
				Sites are within a scheduled road project- 4 lane reconstruction

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
7	Chassahowitzka NWR…continued	US 98	2-3	Wildlife underpasses/bridges need to be constructed at approx. 4.4, 7.2 & 10.5 km from US 19 intersection to maintain connections between Chassahowitzka NWR and Annuteliga Hammock/Withlacoochee SF
				This area also should be a high priority CARL purchase, given potential development pressures in the surrounding area
		Sun-coast Park-way	n/a	Critical area is from CR 480 south to CR 476
				New toll-expressway construction project
				Strategically placed wildlife underpass bridges (five recommended) are necessary along this corridor to maintain connections between Chassahowitzka NWR and Annuteliga Hammock/Withlacoochee SF
	Withlacoochee State Forest	US 41	31-33	Located from 2.4 km north to 0.6 miles south of CR 476
				Narrow strip corridor of Withlacoochee State Forest
				Highest priority to purchase greenway linkages to the east and west that would establish a contiguous forest from Chassahowitka to the Green Swamp
				Replace existing small culverts with large wildlife underpasses
		SR 50	37-38	Located at the little Withlacoochee river and 1 km west
				Existing bridge and culvert need to be replaced with medium-level long span bridges
				This section of highway winds through the Withlacoochee State Forest at an important connection to conservation lands to the northwest
		US 301	36	Located at the little Withlacoochee river
				Bridge is sufficient, however spreading rural-development surrounding the area threatens this important linkage between tracts of the Withlacoochee State Forest, purchase of the remaining undeveloped area is critical
	Cypress Creek Corridor and Pasco SOR/WMD lands, Lower Hillsborough WMD lands	SR 52	11-12	Located from 0.5 to 1.6 km west of CR 583
				Install series of large box culverts at sites of cypress strand, pond/marsh/wet & dry prairie ecosystems to increase permeability of roadway and to facilitate safe movement of small mammals/herpetofauna through the PASCO SOR corridor that connects to Cypress Creek/Hillsborough River
		SR 54	13-14	Located at 4.5 and 7.7 km from I-75, respectively
				Multi-lane construction is occurring at the latter point as part of a new road (SR 56) that cuts through the Cypress Creek tract

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
7	Cypress Creek…continued	SR 54	13-14	Wildlife underpasses and an expanded bridge should be included in the plan as mitigation for wetland impacts; these stipulations should also apply to SR 56
				In addition the multi-cell culvert at the first GPS point should be replaced with a combination creek/wildlife bridge
		I–75	15-16	Located 4.4 and 2.1 km north of Interstate 275
				When construction (lane additions, etc.) is planned, the two structures at these points need to be upgraded to long span medium-level bridges
				These sites are part of the Cypress Creek-Hillsborough River linkage
	Hillsborough State Park, Hillsborough River corridor (SOR) and Blackwater Creek	US 301	23-25	Located at the entrance to Hillsborough SP and north 1.9 km
				Install large wildlife underpasses at each site north and south of the Hillsborough River to increase the permeability of the roadway for wetland-dependent species
		SR 39	27-28	Located at Blackwater Creek
				Scheduled bridge replacement
				Install a single length span to replace both structures at medium-level height (3+ m)
	Other Road Projects	US 19	1	Located at the cross-Florida barge canal
				Scheduled construction of additional new span
				New bridge should be similar to existing one in length and of at least medium height to maintain openness of cross-Florida greenway corridor
		SR 200	29	Located at the Withlacoochee River
				Road project involves additional lanes and bridge construction
				New bridge should be expanded past existing span, remove existing fill and lengthen span- especially on east side of bridge where a continuous linkage of public conservation lands are proposed
		SR 44	30	Located at the Withlacoochee River
				Road project involves additional lanes and possible bridge construction
				If bridge construction planned; remove additional approach fill and establish cut terrestrial underpass via culvert installation/ or extend bridge
				Adjacent to Flying Eagle ranch

Appendix C. continued

Dt*	Conservation Area	Road	Site Nos.	Location, Highlights, and Recommendations
7	Other Road Projects…continued	Sun-coast Park-way, SR 52, US 41	n/a	Starkey Wilderness Area
				The US 41 lane addition project crosses the last remaining linkage for the area to the Pasco SOR land; construction of an underpass at this location should be investigated
				The new Suncoast Parkway also should include on-site mitigation for fragmentation impacts, e.g., construction of multiple underpasses
				State Road 52 lane addition project would sever a small area identified in the Florida greenways project

Notes: 1) the site numbers correspond to the GPS locations shown in the respective FDOT district maps (Chapter 3, Figures 3-11 to 3-17).
2) * - "Dt" refers to FDOT maintenance district number

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BIOGRAPHICAL SKETCH

Daniel J. Smith was born September 20, 1957. He graduated from Maynard Evans High School in Orlando, Florida in 1975, and attended the University of Florida receiving a Bachelor of Science degree in horticulture from the College of Agriculture in 1983. Continuing his education at the graduate level at the University of Florida, Daniel obtained a Master of Urban and Regional Planning degree in 1989 from the College of Architecture. After 6 years practicing environmental planning at the local government level and successfully receiving certification from the American Institute of Certified Planners, Daniel returned to graduate school to pursue a career in ecological science. After receiving a second master's degree in 1995 (Master of Forest and Resource Conservation from the College of Agriculture and Life Sciences at the University of Florida), he continued in the Department of Wildlife Ecology and Conservation at the University of Florida to pursue the Doctor of Philosophy degree; which was awarded December 2003.