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Corridors and Vegetated Buffer Zones: A Preliminary Assessment and Study Design

by Richard A. Fischer, Chester O. Martin, WES

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WES

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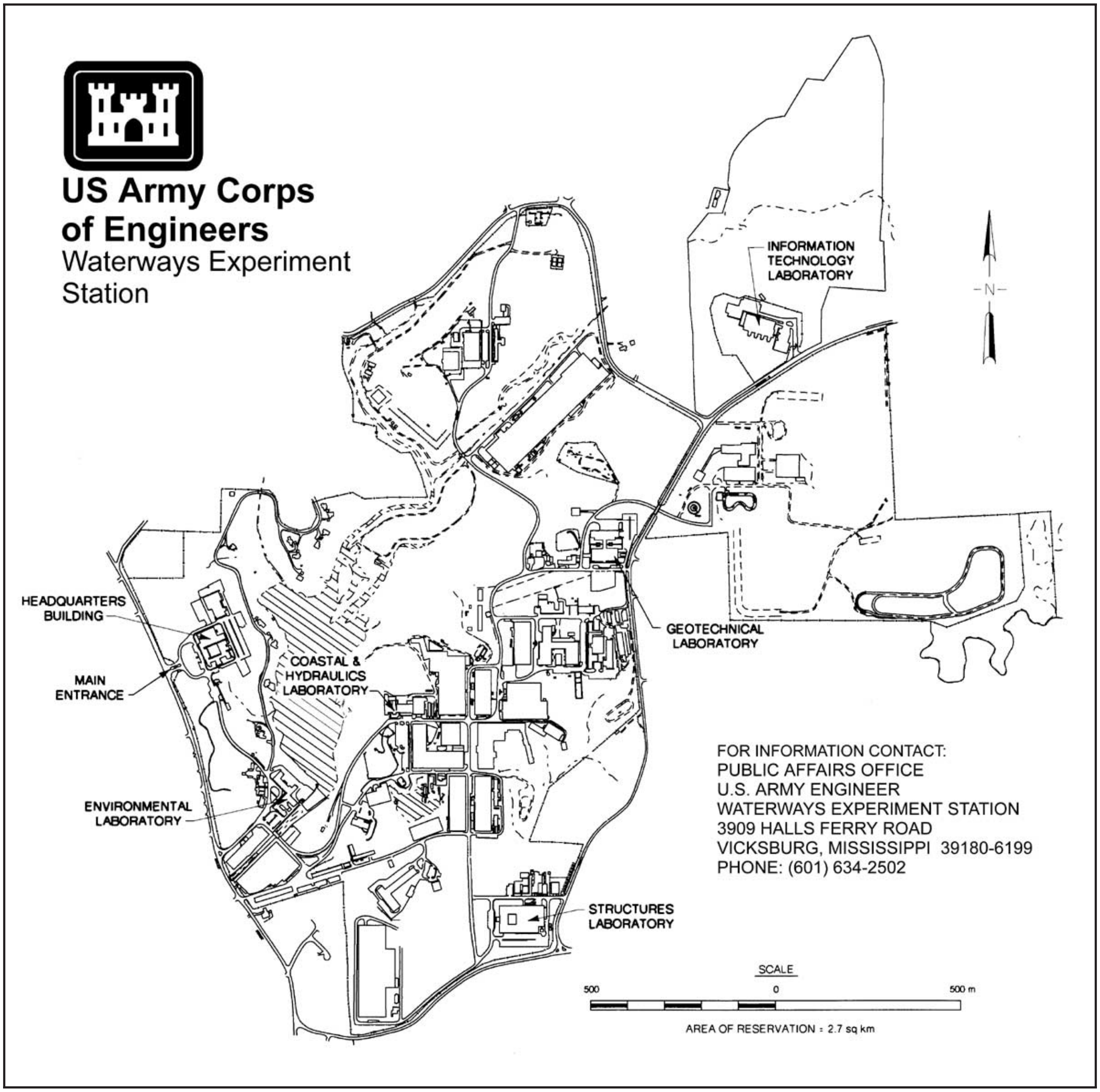

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Preface

The work described herein was authorized by the Ecosystem Management and Restoration Research Program (EMRRP), Washington, DC. The work was performed under the EMRRP study entitled "Corridors and Vegetated Buffer Zones on Corps of Engineers Projects."

This report was prepared by Dr. Richard A. Fischer and Mr. Chester O. Martin, Natural Resources Division (NRD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, a complex of five laboratories of the Engineer Research and Development Center (ERDC), and Messrs. Dwight Barry and Karl Hoffman, and Drs. Kenneth L. Dickson, Earl G. Zimmerman, and Douglas A. Elrod, Institute of Applied Sciences, University of North Texas, Denton, TX.

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1 Introduction

Background

Healthy rivers and their adjacent vegetation (i.e., riparian zones) are a vital part of many landscapes because they provide numerous functions and values. Flood storage, improved water quality through reduction of sediment and nutrients, pollution and noise-abatement, wildlife habitat and travel corridors, aquifer recharge, recreation, and aesthetics are all well-known values of riparian zones and together provide considerable rationale for their conservation (Figure 1) (Mitsch and Gosselink 1993; Naiman, DeCamps, and Pollock 1993; Bayley 1995). Maintaining vegetated riparian buffer strips between human activity and aquatic resources is an effective management practice that can provide many of these benefits (Karr and Schlosser 1978; Thomas, Maser, and Rodiek 1979; Brinson et al. 1981; Budd et al. 1987, Knopf et al. 1988).

The potential value of riparian zones for provision and enhancement of wildlife habitat is often overlooked. Although riparian zones typically are a small component of the landscape, they provide essential habitat for many species of birds (Johnson, Haight, and Simpson 1977; Stevens et al. 1977; Stauffer and Best 1980; Knopf 1985), mammals (Zwank et al. 1979; Wharton et al. 1982; Taylor, Cardamone, and Mitsch 1990), and herpetofauna (Lowe 1989, Wake 1991). For example, riparian areas in the western United States comprise less than 1 percent of the total land area, yet these areas are used by more species of breeding birds than any other habitat in North America (Knopf et al. 1988). However, many riparian zones in North America are degraded to the point that they do not provide the resources needed to make them suitable as habitat or as movement corridors for wildlife. This degradation also negatively affects many of the other important functions and values these landscape features provide.

The majority of inland Corps of Engineers (CE) civil works projects are constructed along streams and rivers. There is increasing interest in the value of riparian zones adjacent to these aquatic resources as corridors and vegetated buffer strips, especially as potential wildlife habitat (Fischer and Martin 1994, 1995). A variety of activities affect riparian habitats on CE lands, including project construction and operation, agriculture, and recreation. The operation of projects for flood control, water supply, navigation, and hydropower exert

Figure 1. Corps projects not only provide numerous recreational opportunities, they also have riparian buffer zones that supply numerous benefits, including improvement of water quality, wildlife habitat and movement corridors, and aesthetic values (photo courtesy of U.S. Army Corps of Engineers)

considerable stress on the riparian habitats at many CE projects. These projects often modify natural flows and flooding regimes and divert ground and surface waters, thus producing substantial alterations to the riparian zone.

Corps projects are also influenced by surrounding land uses, including agriculture, livestock grazing, timber harvest, industry, and urbanization. Activities within the upland portions of the watershed can also be detrimental to riparian and aquatic habitats. Following disturbance in a watershed (e.g., logging), sediment enters downslope aquatic ecosystems for many years (Harr and Nichols 1993). This is especially true where adequately designed buffer strips are not retained or established and subsequently managed as part of the project plan. This can lead to long-term degradation of water quality, wildlife and fish habitat, and recreation resources, thus eliminating many economic benefits that could have been achieved through better guidelines.

Habitat fragmentation[1] resulting from land-use practices adjacent to CE projects often highlights the importance of these projects on a landscape scale. Many CE projects provide some of the best contiguous habitat for many wildlife species within a landscape dominated by agriculture, small forest fragments, and urbanization. This is an important consideration, as the effect of habitat

[1] Habitat fragmentation is the transformation of a landscape into smaller patches and islands of ecosystem types that are isolated from each other and from the larger remaining tracts of intact habitat (Harris 1984; Wilcove, McLennan, and Dobson 1986).

fragmentation on wildlife populations has been called “the most serious threat to biological diversity and the primary cause of the present extinction crisis” (Wilcox and Murphy 1985). Primarily at risk of extinction from habitat fragmentation are birds and mammals because of their relatively low population densities when compared with other taxa (Wilcox 1980). The loss of the genetic diversity of isolated species adds to the already accelerating erosion of global biodiversity (Schonewald-Cox et al. 1983; Soulé 1987). Furthermore, the loss of “keystone” species, or those that play extensive roles in their local food webs, can lead to the decline of many other local species (Soulé et al. 1988; Terborgh 1988; Bond 1993). The preservation and/or creation of habitat corridors and landscape linkages is becoming an important aspect of wildlife conservation strategy and has been proposed as the main tool to reconnect fragmented habitat “islands.”

Vegetated buffer zones are often examined in terms of vegetation type and minimum width needed to protect water quality (Budd et al. 1987; O’Laughlin and Belt 1995). Studies have especially addressed the influence of buffer zone width on their capacity to filter and buffer nonpoint source pollution (NPSP) (e.g., nutrients and sediments) in runoff before it enters aquatic systems (e.g., Lowrance et al. 1984; Lowrance, Sharpe, and Sheridan 1986; Peterjohn and Correll 1984; Pinay and Decamps 1988). Unfortunately, recommended design criteria are highly variable and there have been few systematic attempts to define criteria that mesh water quality width requirements with conservation and wildlife values, specifically, the use of these buffer zones as either habitat or as corridors for wildlife dispersal between habitats in highly fragmented landscapes. Many riparian buffer zones on CE lands are in need of guidelines for design criteria when planning for restoration and management, but only limited information is presently available to make sound management decisions (Fischer and Martin 1998).

Importance to Wildlife Communities

Riparian buffer zones can provide habitat for plants and animals if enough area and resources are available to meet life-history needs. These same landscape features also can function as corridors for migration and dispersal of animals if they provide connections between disjunct habitats. If the buffer zone functions as a corridor, it also has the potential to mix successional types in a landscape, which could provide more ecological complexity and/or diversity to a region (Forman and Godron 1981, 1986; Weins et al. 1992; Turner, Gardner, and O’Neill 1995). Corridors also can expand the distribution of wide-ranging animals or may provide avenues of escape from predators (Harris and Scheck 1991, Harrison 1992). Noss (1987a, 1987b) viewed corridors as the connections that may return the levels of genetic interchange that existed prior to extensive fragmentation.

Avian communities

Riparian zones are an important component of the landscape for avian communities. Brinson et al. (1981) reported that avian density in riparian areas is often double that of adjacent uplands, although there is regional variation throughout the Unites States. Approximately 50 and 82 percent of bird species of the southwestern United States (Johnson, Haight, and Simpson 1977) and northern Colorado (Knopf 1985), respectively, nest in riparian habitats. Many breeding-bird species in the Southwest are riparian obligates[1] (Hunter, Ohmart, and Anderson 1987; Rich 1998), such as the southwestern willow flycatcher (*Empidonax traillii extimus*) and least Bell's vireo (*Vireo bellii pusillus)*.

Throughout riparian areas of the United States, riparian width often is related positively to avian species richness, both within and adjacent to riparian zones (Stauffer and Best 1980; Triquet, McPeek, and McComb 1990; Keller, Robbins, and Hatfield 1993; Kilgo et al. 1998). Several recent studies in North America, mostly in the eastern United States, have attempted to identify minimum vegetated buffer widths to sustain bird populations. For example, many neotropical migrants in Virginia (e.g., Acadian flycatcher [*Empidonax virescens*], American redstart [*Setophaga ruticilla*], hooded warbler [*Wilsonia citrina*], Louisiana waterthrush [*Seiurus motacilla*]) have strong affinities for riparian buffer strips, but many will not inhabit strips narrower than 50 m (164 ft) (Tassone 1981). In Kentucky, neotropical migrants were more abundant in corridors wider than 100 m (328 ft); riparian areas less than 100 m (328 ft) wide were inhabited mainly by resident or short-distance migrants (Triquet, McPeek, and McComb 1990). Similarly, Spackman and Hughes (1995) investigated stream corridor widths along midorder streams in Vermont. Corridor widths of 150 and 175 m (492 and 574 ft) were necessary to include 90 and 95 percent of the bird species, respectively, at most sites. In the boreal forests of Canada, Darveau et al. (1995) compared bird abundance and species composition in riparian forest strips of varying widths and found that riparian strips at least 60 m (196 ft) wide were needed to sustain forest-dwelling birds. Kilgo et al. (1998) investigated breeding-bird communities in bottomland hardwood (BLH) stands of varying widths in South Carolina and concluded that although narrow strips can support an abundant and diverse avifauna, vegetated buffer zones at least 500 m (1,641 ft) wide are necessary to maintain the complete avian community of BLH.

Narrow buffers and corridors often favor forest-edge species and may not provide adequate habitat for forest-interior species (Robbins, Dawson, and Dowell 1989; Keller, Robbins, and Hatfield 1993). For example, Vander Haegen and DeGraaf (1996) investigated the relationship between buffer zone width and the effects of predation on songbirds in Maine. They suggested that managers leave vegetated buffer strips at least 150 m (492 ft) wide to reduce edge-related predation. Although recent research has shown the importance of

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[1] "Riparian obligate species" are defined as those species that place >90 percent of their nests in riparian vegetation or for which 90 percent of their abundance occurs in riparian vegetation during the breeding season (Rich 1998).

considering habitat needs of birds in riparian areas, avian habitat requirements are rarely included in the designation of riparian area width in riparian restoration and management plans.

Mammalian communities

Mammals are an important component of riparian areas throughout the United States (Wharton et al. 1982; Taylor, Cardamone, and Mitsch 1990), but unlike birds, few species are restricted to these ecosystems. In the southeastern United States, many mammalian species are known to reach peak densities in BLH habitats (Wigley and Roberts 1994). Zwank et al. (1979) reported that BLH supported twice as many white-tailed deer (*Odocoileus virginianus*) per hectare as did upland forest types. Numerous small- and medium-size mammals occur in riparian areas, but there have been few long-term studies of these species to determine their specific habitat requirements in BLH. Medium-size mammals closely tied to streams and BLH in the southeast and south-central regions include the raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), mink (*Mustela vison*), river otter (*Lutra canadensis*), beaver (*Castor canadensis*), nutria (*Myocaster coypus*), and swamp rabbit (*Sylvilagus aquaticus*) (Wigley and Lancia 1998). Both the gray squirrel (*Sciurus carolinensis*) and fox squirrel (*S. niger*) occur in lowland hardwoods, but the gray squirrel is more closely tied to bottomland habitats. Small mammal communities in alluvial floodplains are often dominated by a few species that may vary among hydrologic zones (Wigley and Lancia 1998).

Few studies have attempted to determine corridor width and other metric requirements for mammals, and little information is available to show the influences of riparian area width on mammalian populations. Dickson and Huntley (1985) found that uncut hardwood stringers through young pine stands in east Texas contained resident gray squirrels only if stringers were more than 50 m (164 ft) wide. Dickson and Williamson (1988) reported that small mammals in pine plantations were more abundant in narrow streamside zones ($\leq$ 25 m (82 ft)) characterized by intact overstory and midstory, sparse shrub and herbaceous vegetation, and abundant leaf litter than in wider zones (30 to 40 m (98 to 131 ft), 50 to 90 m (164 to 295 ft)) without this vegetation structure. This was apparently related to the abundance of low, dense vegetation with ample forage, fruits, and seeds, and the presence of downed logs and slash in the narrower zones. However, medium and wide streamside management zones with closed tree canopies were likely beneficial for a variety of other wildlife. Sufficient quantitative data are not presently available to make informed decisions concerning the adequacy of riparian buffer zones to support most mammalian species. There is a need for comprehensive studies to determine management requirements for entire mammal communities associated with riparian ecosystems.

Reptile and amphibian communities

The majority of North American herpetofauna inhabit wetland habitats, including riparian areas. Approximately 190 species of North American amphibians depend on wetlands, especially for breeding purposes (Clark 1979), and many reptiles are functionally tied to wetlands (Harris and Gosselink 1990). The distribution and abundance of herpetofaunal species in wetland ecosystems are controlled by several macrohabitat factors including wetland size and location, relationship to adjacent terrestrial and aquatic systems, flooding regime, water quality, substrate, and vegetation structure (Clark 1979, Jones 1986). Amphibian species are declining steadily in many regions of the United States, with greatest losses attributed to habitat loss and destruction and water pollution (Livermore 1992, Blaustein 1993). Because of their narrow habitat requirements, amphibians and reptiles may serve as the best indicator species for riparian ecosystems (Lowe 1989, Wake 1991).

Little information is available on the relationship between riparian width and herpetofaunal communities. In general, wide riparian areas support more amphibians and reptiles than narrow areas. In the southeastern United States, Dickson (1989) determined that streamside zones >30 m (98 ft) wide supported more amphibians and reptiles than narrower (i.e., <25 m (82 ft)) zones in southern forests. The wider streamside zones had a distinct overstory, a shaded understory, and an accumulation of ground litter, whereas the narrow zones had minimal overstory and a dense understory. Rudolph and Dickson (1990) also showed that streamside zone width significantly affected the abundance of herpetofauna within these zones in southeastern pine plantations. In this study, fewer amphibians and reptiles were found in narrow (0- to 25-m (82 ft)) streamside zones than in wider (30- to 95-m (98-312-ft)) zones. Understory shading and ground litter increased with the width of riparian areas, providing more suitable habitat for herpetofauna (Rudolph and Dickson 1990). Burbrink, Phillips, and Heske (1998) investigated reptile and amphibian species richness in corridors of varying widths in Illinois and found little relationship to corridor width. Instead, they suggested addressing the specific life-history requirements of individual species desired in the corridor rather than focussing solely on corridor width. Besides these studies, there is little information available on the relationship between riparian width and herpetofaunal communities.

Potential Negative Effects of Corridors

Although corridors are often viewed as providing only positive benefits to a landscape, both critics and proponents of corridor theory have noted several potential drawbacks of corridors. They may facilitate the spread of introduced exotic species (Forman 1991, Harris and Scheck 1991, Hobbs and Hopkins 1991, Panetta and Hopkins 1991), promote disease transmission (Hess 1996) and spread of parasites, promote faunal mixing (Knopf 1986), increase populations of habitat generalists (e.g., avian nest parasites such as brown-headed cowbirds [*Molothrus ater*] and nest predators), facilitate fires, or contribute to other catastrophes (Simberloff and Cox 1987). Also, predators may have easier access to prey species in corridors (Ambuel and Temple 1983; Catterall, Green, and Jones 1991; Hobbs 1992). Corridors with low habitat suitability could act as population "sinks," which could drain off healthy animals from "source" populations, potentially leading to a higher risk of extinction for local species (Pulliam 1988, Henein and Merriam 1990, Soulé 1991, Soulé and Gilpin 1991).

Land managers need to understand the benefits and potential drawbacks of corridors and buffer strips so that the potential benefits can be weighed against the costs of creating, maintaining, or managing these landscape features (Dawson 1994). This must also be compared with the costs and benefits of other potential management options such as improvement of existing habitat, reintroducing species, or enlarging biological reserves (Simberloff and Cox 1987, Nicholls and Margules 1991, Dawson 1994).

Design Considerations of Wildlife Corridors

Corridor protection efforts and designs for wildlife often rely on natural history and vagility information for particular species to define areas of biological importance, usually by comparing corridor width and/or length with indicator species' home range sizes and dispersal abilities (Fahrig and Merriam 1985, Knopf and Samson 1994, Tiebout and Anderson 1997). For example, Harrison (1992) calculated minimum wildlife corridor widths for some terrestrial mammals based on estimates of home range size. The parameter of corridor width or length would intuitively seem to be of great importance, and previous research has indicated such to be the case given certain contexts and situations (Wegner and Merriam 1979; Henderson, Merriam, and Wegner 1985; Lindenmayer and Nix 1993). While there has been general acceptance of corridors as an effective conservation tool (Dendy 1987, Harris and Gallagher 1989), there is a lack of studies that test the effectiveness of conservation corridors (Harrison 1992, Inglis and Underwood 1992, Lindenmayer and Nix 1993), and few of these tests have yielded more than ambiguous results (Simberloff et al. 1992; Spackman and Hughes 1995). Many CE Districts are dealing with corridor/buffer zone issues with little or no information on proper design criteria. Research is needed to examine buffer zones and corridors with respect to the needs of CE planners, managers, and project personnel.

2 Approach

A 3-year research project on corridors and vegetated buffer zones was initiated in FY97 at the U.S. Army Waterways Experiment Station (WES) as part of the Ecosystem Management Restoration and Research Program (EMRRP). The goals of this research project are to develop technical guidelines from current literature and field studies to improve design, evaluation, restoration, and management of riparian corridors and use these guidelines to assist CE personnel in making decisions for riparian buffer zone and corridor designs based on the most accepted scientific criteria. The objectives to reach these goals include: (a) determining the suitability of these landscape features to provide various project needs (e.g., fish and wildlife habitat improvement/creation, river and stream conservation, erosion control, noise abatement/visual screening, reduction of nonpoint source pollution); (b) identifying measurable physical, biological, and ecological variables and integrating them with current design criteria; and (c) applying these designs to improve planning for and management of vegetated buffer strips on Corps lands. Current or future planned activities to meet these objectives are discussed below.

Objective 1

Determine suitability of corridors and vegetated buffer zones to provide various CE project needs.

a. Task A. Conduct CE planning workshop. The study was initiated with a 2-day workshop at WES during May 1997 to discuss the application of corridors and vegetated buffer strips on CE projects and identify those issues that should be addressed by research activities. Workshop attendees represented five U.S. Army Engineer Districts, Fort Worth, Vicksburg, Mobile, Louisville, and Rock Island, and one U.S. Army Engineer Division, Lower Mississippi Valley. District representatives discussed ongoing or potential projects that would benefit from this work unit, and a large number of research needs and issues associated with corridors and buffers were identified; these issues were defined, discussed in detail, and prioritized (Table 1).

Table 1
Issues Associated with Corridors and Vegetated Buffer Zones Identified by District Representatives, WES Workshop, May 1997

Issue/Concern	Research Priority
Spatial aspects (dimensions & configurations)	High
Habitat diversity/biodiversity management	
Preserving/restoring riparian values	
Neotropical migrant birds	
Fee-title vs. easement lands	
Landscape linkages	
Quantifying functions and values	
Buffer adjacent land uses	Medium
Channel maintenance	
Human dimensions (e.g., aesthetics, noise, visual, education benefits)	
Streambank/shoreline erosion (natural vs. artificial)	
Aquatic habitat protection/provision	
Effects of recreational use	
Public safety (e.g., hunting)	
Floodwater retention/attenuation	
Threatened and endangered species	
Plant species selection (e.g., cordgrass, smartweed, shrubs)	Low
Economic benefits	
Exotic plant species	

Corridor and vegetated buffer zone issues common to most of the Districts included: (1) a need for better CE guidelines, especially to determine appropriate corridor locations, designs and dimensions, and management requirements; (2) protection of CE lands from adjacent land uses, especially urbanization, recreation activities (e.g., golf courses, campgrounds), and certain timber harvest practices (e.g., clearcuts); (3) wildlife habitat development and improvements along riparian corridors; (4) provision of habitat for neotropical migrant birds; (5) maintenance of aesthetic qualities; (6) improved guidelines for biodiversity management in riparian areas; and (7) bank protection. Issues specific to buffer zones included protection of scenic views, screening of commercial or other off-project development, screening of developed recreation areas, protection of wetlands, maintaining the integrity of natural systems, and protection of threatened and endangered species habitat.

Districts were particularly concerned about encroachments and abuse of project lands along boundaries and adjacent to stream and lakeside riparian habitats. Several districts reported that adjacent land owners have a tendency to cut trees on property belonging to the Government to enhance their view of aquatic areas, especially along lake edges. Private landowners frequently build houses or other structures immediately adjacent to CE property and clearcut large areas up to the project boundary. In some cases, timber companies have made extensive clearcuts adjacent to project lands, and in some agricultural areas adjacent landowners have requested permission to cut large trees within environmental easements to improve farm field conditions. Trespass and illegal dumping is also a problem along corridors, especially in remote areas where surveillance and enforcement is limited. In reservoir areas, one of the most critical concerns is an influx of requests for increased recreational development from local governments and private concessionaires who manage resorts, marinas, and other structures on CE projects.

All CE Districts were interested in improved designs and wildlife habitat management strategies for corridors and buffers. Specific concerns included fragmentation, provision of migration corridors, invasion of nuisance species, neotropical migrant bird habitat management, protection of natural areas, appropriate timber and forest management practices, wetland creation, restoring native plant species, reestablishment of bottomland hardwoods, monitoring of fauna and flora, and endangered species management. Several CE Districts were interested in habitat management for black bears (*Ursus americanus*) and establishing buffers for such species as bald eagles (*Haliaeetus leucocephalus*). A need for wildlife viewing areas in some locations was also noted.

b. Task B. Use available research and technology transfer from other CE projects. Several recent CE studies have addressed various aspects of corridor management at Civil Works projects. Research needs for riparian systems were initially discussed at a CE Riparian Zone Restoration and Management Workshop held in San Antonio, TX, during February 1986. A proceedings was published that summarized the presentations by CE biologists and resource managers (Martin and Allen 1988); results of this workshop provided the background information on riparian zones for development of this work unit. A riparian zone ecology and management training program was developed for DOD installation personnel as part of the DOD Legacy program, and a workshop entitled “Riparian Zone Ecology, Restoration, and Management for DoD Land Managers: Northwestern United States” was conducted in Billings, Montana, June 1994 (Fischer, Martin, and Allen 1995). A CE prospect course entitled “Riparian Zone Ecology, Restoration, and Management” recently was developed; the initial course was conducted in Vicksburg, MS, July 1998. Future sessions will be offered in Augusta, GA, April 1999, and in Fresno, CA, June 1999; Harlingen, TX, in FY2000; and in yet-to-be determined locations in subsequent years. An investigation of the environmental value of riparian vegetation was recently conducted as part of the Environmental Impact Research Program (Davis et al. 1996). Additionally, several riparian ecology studies were performed as part of the CE Wetlands Research Program.

Objective 2

Identify measurable physical, biological, and ecological variables and integrate them with current design criteria.

a. Task A. Identify and describe other Federal and state programs that provide recommendations for riparian corridor and buffer zone management. Other state and Federal agencies have either begun or are currently initiating programs to provide recommendations for vegetated riparian buffers and corridors. For example, in April 1997, the USDA officially launched the new National Conservation Buffer Initiative to assist private landowners in installing approximately 2,000,000 miles of conservation buffers by the year 2002. The initiative is led by the Natural Resources Conservation Service (NRCS) in cooperation with numerous other Federal and state agencies and public and private partners. The Buffer Initiative provides economic incentives to farmers and ranchers through such programs as the continuous Conservation Reserve Program (CRP) sign-up, Environmental Quality Incentives Program (EQIP), Wildlife Habitat Incentives Program (WHIP), Wetlands Reserve Program (WRP), Stewardship Incentives Program (SIP), and Emergency Watershed Protection Program (EWP) (USDA-NRCS 1998). The Environmental Protection Agency is interested in initiating research in the mid-Atlantic states to address the ecological role of buffers and corridors adjacent to streams and rivers that drain into the Chesapeake Bay. Other Federal and state programs have also been initiated. Information from these programs will be gathered and we will seek opportunities to collaborate on research where possible.

b. Task B. Investigate state Best Management Practices (BMPs) and their potential effectiveness in conservation of riparian corridors. BMPs are techniques or land-use practices that give Federal, state, and private landowners guidelines to follow in practicing good land stewardship. BMPs are a combination of management, cultural, and structural practices that scientists, the Government, or some other planning agency decides upon to be the most effective and economical way of controlling problems without disturbing the quality of the environment (Florida Stewardship Foundation 1998). The concept of BMPs was first introduced in response to the Clean Water Act as a practical and effective means to reduce nonpoint source pollution. Most BMPs are designed to minimize the impact of silvicultural practices and related activities on water quality and other functions and values, including wildlife populations (South Carolina Forestry Commission 1998). Many CE projects may be using state BMPs as guidelines for corridor and buffer management. While these practices likely provide good protection to aquatic resources, recommendations addressing vegetated buffer zones may not be adequate for providing suitable habitat or movement corridors for wildlife populations. The adequacy of recommended BMPs to provide these critical habitat requirements will be examined.

c. Task C. Conduct field research by measuring variables important in determining corridor design and address issues of scale (e.g., variation in results obtained from various scales). There was consensus among workshop participants that the study design should be regionally based and include standard guidelines for determining width and dimensions of corridors and buffers that will not only protect water quality but also provide numerous ecological benefits. District representatives suggested several CE projects in the southeastern United States as potential field study sites. After careful consideration of available resources, the Ray Roberts Reservoir Greenbelt in Texas was selected as a focal site for intensive field studies that address selected research priorities identified by the CE Districts. WES and U.S. Army Engineer District, Ft. Worth, personnel selected the University of North Texas (UNT), Institute of Applied Sciences, to conduct field research germaine to the central premise of the work unit. Subsequently, the UNT developed a proposal entitled, "Issues of Scale in Wildlife Corridor Assessment: Exploring Landscape, Community, and Species-Level Thresholds of Riparian Forest Use by Wildlife" (Chapter 3).

To address the problem of the diversity of data requirements needed for forest corridor evaluation, design, management, and restoration, this project will explore, analyze, compare, and contrast as many of these variables as possible at various scales of resolution to determine their relative importance in assessing a riparian forest for corridor values. Landscape characterization metrics and GIS-based spatial analysis will be employed to obtain an ecological land-cover characterization of the Lake Ray Roberts Greenbelt. This characterization will be used to delineate study points and zones within the greenbelt, which subsequently will be sampled using vegetation and habitat analysis, and nonintrusive avian and mammalian survey methods. Field data will be used to provide a thorough characterization of the ecology (i.e., flora and fauna) of the greenbelt and to determine the important ecological thresholds, based upon scale and resolution of the analysis, that affect species occurrence and native biodiversity within the greenbelt. These data also will be used to explore the relationships between habitat quality, corridor width, and species utilization of the various habitat patches within the greenbelt. In addition, the data obtained from the landscape and field analyses will be evaluated for the ecological relationships between remotely sensed data and field observations.

Results of the study will be used to develop a set of ecologically based guidelines and criteria for designing, managing, and evaluating riparian corridors for native wildlife utilization and other environmental benefits.

A final report will detail the specific criteria and methods of this study, as well as an in-depth evaluation of its results and conclusions.

Objective 3

Apply information from literature and field studies to improve planning for and management of vegetated buffer strips on Corps lands.

Field studies will primarily address spatial aspects, habitat, and biodiversity issues in buffer zones and corridors. However, a number of other high and medium priority issues have been identified by CE representatives (Table 1).

Pertinent literature on vegetated buffer zones and corridors other than those addressed in field studies (e.g., studies addressing water quality, channel maintenance, protection of aesthetic values, fragmentation, recreation) will be synthesized and summarized. This information will be combined with results from field research to provide more thorough guidelines for management and design of current and future corridors and buffer strips. Specific products include developing a guidance document for designing habitat corridors and buffer strips on CE lands and submitting relevant journal articles resulting from field research and other related activities.

3 Field Study Design

Objectives and Field Research Protocol

Research at the Ray Roberts Greenbelt will explore how biodiversity assessment (a workshop high priority), habitat analysis, and landscape evaluations at various scales can provide conceptual guidelines for the design, evaluation, restoration, and management of riparian wildlife corridors. Specific objectives are to:

a. Characterize potential wildlife source habitats of the Lake Ray Roberts Greenbelt and adjacent landscape and corridors between such habitats.

b. Describe the vegetation community composition of the riparian forest.

c. Evaluate species richness, distribution, and abundance of birds and mammals in the riparian forest.

d. Evaluate habitat suitability for selected indicator/umbrella species in the riparian forest using standard habitat evaluation methods (i.e., Habitat Evaluation Procedures (HEP)).

e. Evaluate relationships between floral and faunal presence/absence and habitat quality (e.g., width, habitat complexity, vegetation metrics).

f. Determine gradients and thresholds of habitat qualities and metrics that affect the presence or absence of native faunal biodiversity within the corridor.

g. Analyze remotely sensed data at various scales of resolution (i.e., 20-m (66-ft) SPOT data and 1-m (3-ft) Digital Orthophoto quadrangle) using standard landscape analysis metrics to explore the relationships between spatial scales of available data and quality of the information each provides for corridor assessment and management.

h. Explore possible correlations between landscape analysis and field biodiversity data to evaluate potential corridor assessment techniques.

i. Develop a set of guidelines and criteria important in designing, analyzing, and managing riparian corridors for native wildlife populations.

The Ray Roberts Greenbelt will be ecologically characterized and analyzed during 1998-1999. Various sampling methodologies will be used to investigate the birds, mammals, and forest community to obtain a thorough characterization of the ecology of the greenbelt. This study will assume that the spatial patterns of species presence/absence and α (within a habitat) and β (between habitat) diversity are an expression of some underlying ecological and environmental structures and processes (e.g., size, shape, and orientation of habitat patches, gradients of variables influencing life histories) that influence species' distributions. The analytical phase of this project will address the nature, effect, and relative importance of these processes on the distributions of native species within the greenbelt.

This field project will use the following research hypotheses as organizing themes of analysis and discussion:

a. Conservation biology theory suggests that forest corridors serve as important habitat to link remnant stands of forest in fragmented landscapes. If this is the case, then forest patches with high connectivity should have higher forest-obligate α diversity as compared with forest patches of lower connectivity. We will test the null hypothesis that there will be no difference in the occurrence of forest-obligate mammal and bird species between forest patches. Moreover, we will test the null hypothesis that there is no difference in the occurrence of forest-obligate mammal and bird species between corridors and patches.

b. The distributions of a large proportion of the extant species of the greenbelt are probably affected by common environmental thresholds (at all relevant spatial scales). If this is the case, the spatial distribution of a large proportion of the species sampled will coincide or correlate with a set of environmental variables and gradients. We will test the null hypothesis that there is no correlation between environmental gradients and the spatial distributions of the flora and fauna of the greenbelt.

c. Recent studies have suggested that the scale of measurement or spatial resolution will have a strong influence on the results and analysis of the sampling data. If this is the case, there will be little correspondence between similar sampling data taken at different spatial scales. We will test the null hypothesis that spatial scale has no effect on the results and analysis of sampling data.

d. Many management strategies are predicated on the assumption that the HEP and Habitat Suitability Index (HSI) indicator models for bottomland avian and mammal species can be used effectively as indicators to represent a larger community of faunal assemblages. If this is the case, there should be a strong correlation between the results of the HEP analysis and the presence of a large proportion of the native species, guilds, and communities. We will test the null hypothesis that HSI models do not indicate the presence of a larger forest-obligate community of birds or mammals.

Study Site Description

Denton County, Texas

Denton County occupies approximately 2,450 km^2 (946 square miles) in north-central Texas (Figure 2). Throughout the county, soil type is the key factor explaining native vegetation distribution (Bailey 1995). The U.S. Department of Agriculture (USDA) describes the climate as humid subtropical, with hot summers and mild winters (mean temperatures of 21 to 27 °C (70 to 81 °F) in summer and 10 to 16 °C (50 to 61 °F) in winter), with moderate rainfall of 890 mm (35 in.) per year and periodic drought (USDA 1980, Bailey 1995).

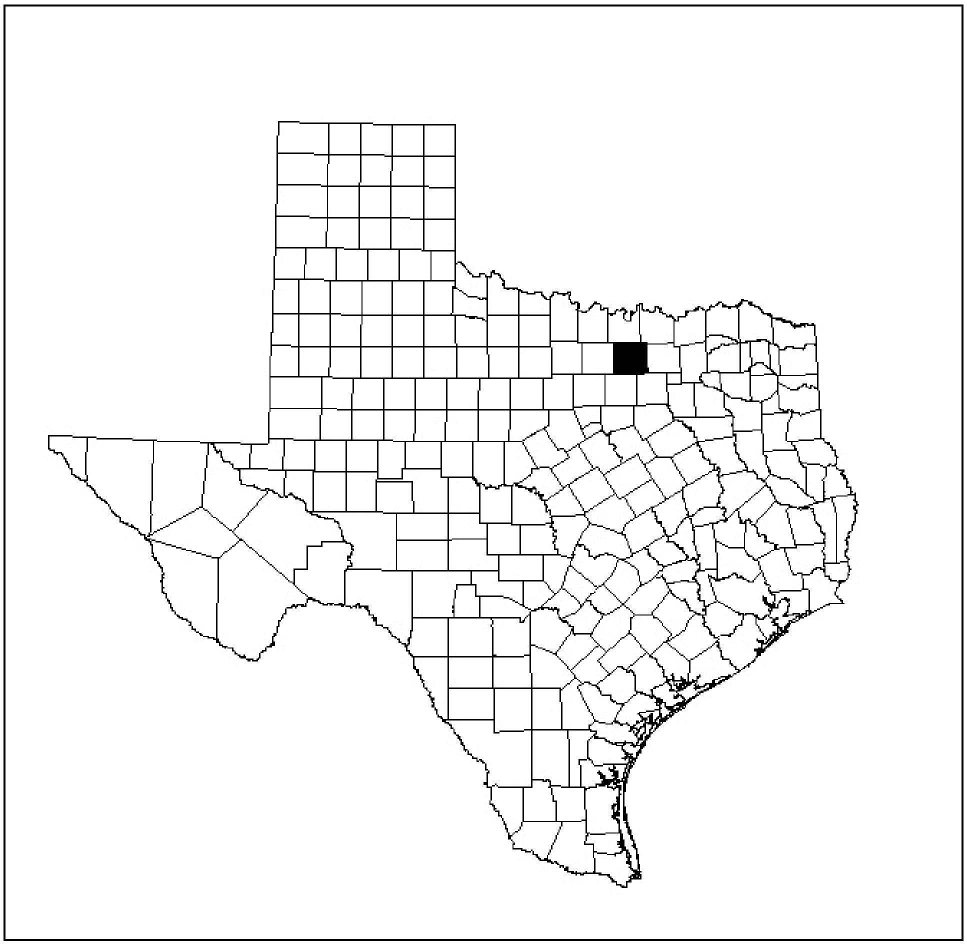

Figure 2. Denton County, Texas

The three primary bioregions found in Denton County include the Blackland and Grand Prairies, the Cross Timbers, and the Bottomland Hardwoods. The prairies comprise the majority of the county and represent the southernmost extent of the tallgrass prairie of North America. Although most of the original prairie is gone, the soils are still characterized by dark, calcareous clays (USDA 1980). These prairies were once dominated by big bluestem (*Andropogen gerardii*), little bluestem (*Schizachyrium scoparium*), and dropseed (*Sporobolus* spp.) grasses, with switchgrass (*Panicum virgatum*) common along the watercourses. With the increase in agriculture and the control of fire, these prairies were gradually subsumed into shrubland or agroecosystems. Less than 1 percent of the original extent of tallgrass prairie still remains in Texas (Sharpless and Yelderman 1993).

The Cross Timbers is a savannah ecosystem located on a sandy, acidic stretch of soils running north-south though Denton County. The soils are variable but are often acidic loamy sands and sandy loams, or neutral to calcareous sandy loams and silt loams (USDA 1980). The characteristic tree species of the Cross Timbers include post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), and hickory (*Carya* spp.). The understory vegetation is similar to the Blackland Prairies (Vines 1982).

The bottomland hardwood forests occur in the floodplains of the river and creek bottoms of the county. The term “bottomland hardwoods” is most often used to describe mixed hardwood forests that grow on floodplain soils that are saturated or inundated during certain parts of the year. These forests grow on alluvial floodplain sites, although nonalluvial wet sites may share similar hardwood species (Hodges 1997). The bottomland hardwood ecosystem extended over 6.5 million ha in Texas prior to European settlement; it is estimated that only 20 to 40 percent of this original extent still remains (Frye 1986, King 1996), with only a few small and isolated patches of old growth scattered among the floodplains of the eastern one-third of the state.

The primary human land uses in the region are urban development and agriculture, although agriculture is gradually being replaced by urbanization from the expanding Dallas/Ft. Worth metroplex. Other recent changes in human land uses (particularly over the past 50 years) include the creation of several thousand surface acres of reservoirs for water supplies and recreation.

The Ray Roberts Greenbelt

The Ray Roberts Greenbelt is located to the northeast of Denton, situated between the upper end of Lewisville Lake at U.S. Highway 380 and the Lake Ray Roberts Dam at Farm Road 428 (Figure 3). The greenbelt comprises nearly 2,000 ha (4,942 ac), approximately 500 ha (1,236 ac) of which are remnant stands and corridors of bottomland forest. The Elm Fork of the Trinity River flows through the greenbelt, traversing approximately 22 river kilometers (13.7 mi) over the space of 16 linear kilometers (10 mi). The drop in elevation is approximately 6 m (20 ft), from an elevation of approximately 168 m (551 ft)

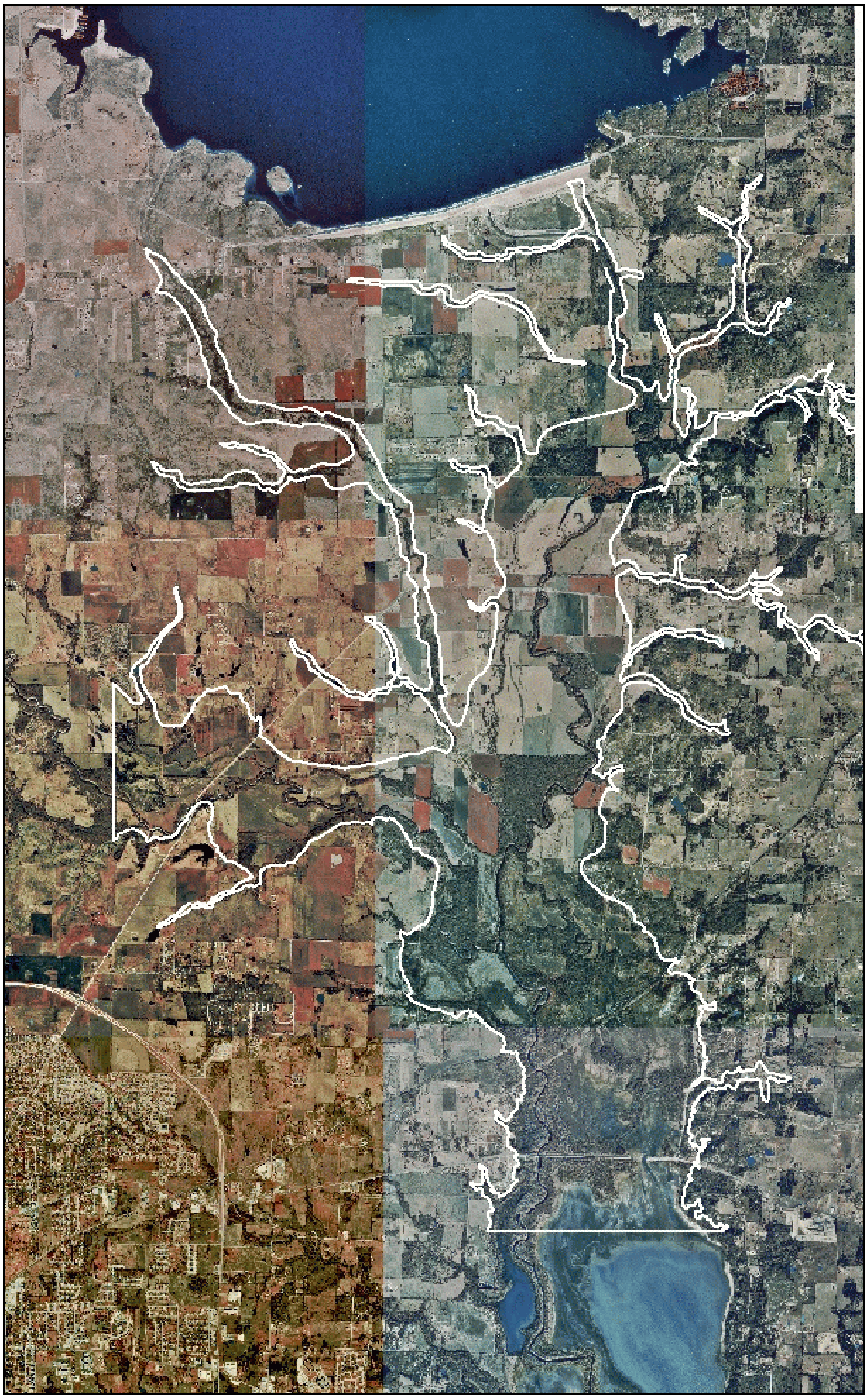

Figure 3. The Ray Roberts Greenbelt is located along the East Fork of the Trinity River in Denton County, Texas, between Lake Ray Roberts and Lewisville Lake

above mean sea level at the outflow structure below the Ray Roberts Dam to approximately 162 m (532 ft) at the point where the Elm Fork flows beneath U.S. Highway 380 to enter Lewisville Lake. All three major ecosystem types within Denton County can be found within the greenbelt study area. While the extent of the bottomland forest in the area has decreased significantly over the past 200 years, analysis of aerial photos taken in 1970 and 1998 shows that the areal extent and patch shape/position within the greenbelt has remained almost static for the past 30 years.

The variety of vegetation (Figure 4) of the greenbelt is dominated by cedar elm (*Ulmus crassifolia*), hackberry (*Celtis occidentalis* and *C. laevigata*), and green ash (*Fraxinus pennsylvanica*), with occasional occurrence of bur oak (*Quercus macrocarpa*), pecan (*Carya illinoensis*), and eastern cottonwood (*Populus deltoides*) (Barry and Kroll 1997). This elm-ash-hackberry type is recognized as a late successional stage in many bottomland hardwood forests, although in the absence of repeated disturbances, it may occupy the site for 200 to 300 years (Hodges 1997). Black walnut (*Juglans nigra*), chittamwood (*Bumelia lanuginosa*), bois d'arc (*Maclura pomifera*), box elder (*Acer negundo*), and hawthorn (*Crataegus* spp.) are also present. The dominant tree species occur throughout all age and size classes, while the pecan, black walnut, and chittamwood are represented by a few rare mature trees and numerous seedlings. The forb layer is a mixture of common greenbrier (*Smilax rotundifolia*), poison ivy (*Rhus toxicodendron*), coralberry (*Symphoricarpos orbiculatus*), and Virginia wild rye (*Elymus virginicus*). Livestock still graze on occasion within the forest; it is unknown what effect their browsing and trampling is having on the composition of the forest community.

Methods

Objective 1

Conduct a preliminary landscape-level analysis to define the forest corridor and patch study zones and sampling locations throughout the greenbelt.

The initial phase of landscape analysis will entail acquiring digital orthophoto quads to develop a land cover map of the Ray Roberts Greenbelt. Using this map, the greenbelt will be divided into landcover classes of forest, cropland, pasture, water, and trails and roads. Once the initial map is completed, it will be field verified for accuracy, then used to help determine transect and plot placement for field work. It will also be used to delineate the greenbelt into two major forest zones: corridor patches (herein referred to as "corridors"), which are long linear forest features adjacent to the Elm Fork of the Trinity River; and larger forest patches (herein referred to as "patches"), which serve as major blocks of habitat for resident flora and fauna, and which are connected by the corridors. Area for each patch and corridor will be recorded and summed to obtain areal coverage of the entire greenbelt as well as for the two distinct forest classes of the greenbelt. The area and maximum/minimum widths of each corridor and larger forest patch will be calculated. Corridor length between each

Figure 4. The Ray Roberts riparian greenbelt is comprised of a variety of different habitats, including wetlands (photo by D. Barry, Institute of Applied Sciences, University of North Texas)

patch (connectivity distance) will be calculated, as will connectivity indices for each corridor subdivision. Distance from the river channel to the edge of the forest will be computed along with the width of the canopy opening above the river. An abstracted nodes/networks diagram (Pickett and Cadenasso 1995) will be plotted from the land cover map for qualitative evaluation of the landscape connections within the study area.

A soil association map of Denton county (USDA 1980) will be overlain on the land cover map to differentiate vegetative cover from ecosystem groups (soil/vegetation associations). Digital elevation models, elevation contour data, and 100-year floodplain maps will be used in conjunction with the soil maps to delineate the probable recent-historical physical boundaries of the bottomlands. The resulting delineations will be used to classify the greenbelt into ecosystem groups to assist in the ecological stratification of the greenbelt for field analysis purposes.

The combination of all of these factors will help illuminate potential transition zones in the ecology of the greenbelt, so that their presence (if any) can be taken into account during subsequent analysis of the other research themes. Furthermore, such analysis can assist with restoration and management of the site and provide methods by which other sites may be evaluated.

Objective 2

Characterize the vegetative communities of the greenbelt using community analysis methods.

We will examine intensively and extensively the forest community to obtain a thorough characterization of the within-patch and between-patch vegetation heterogeneity of the greenbelt. If there are statistical differences between the forest classes (i.e., between corridors and patches), the environmental thresholds and/or gradients that may contribute to such differences will be explored.

A standard vegetative community analysis will be conducted using appropriate methodology (Lapin and Barnes 1995; Brower, Zar, and Von Ende 1998). Forest metrics will be sampled using a systematic plot layout. Trees and large shrubs will be recorded in each plot and data will be analyzed for their relative importance values with respect to species, basal area (dominance), density, and frequency.

A set of approximately three hundred 100-m^2 (1,076 ft^2) circular plots (radius = 5.64 m (19 ft)) will be sampled during the summer and fall of 1998 and the spring of 1999. These plots will be spaced 50 m (164 ft) apart along transects extending the length and width of the entire greenbelt within the study area. A Global Positioning System (GPS) unit will be used to mark the location of each plot. These transects will be stratified by forest class (corridor or patch) and major soil associations. Within each plot, all standing live or dead trees greater than or equal to a 10-cm (4-in.) diameter at breast height (dbh) will be counted, and reference will be made to plot number, species, and size. Trees will be defined as woody stems that stand alone or branch below breast height and are greater than or equal to a 10-cm (4-in.) dbh. If the tree stem splits above breast height, it will be counted as one tree; if it splits below breast height (i.e., multiple stems), it will be counted as two (or more) trees. In each plot, all trees and large shrubs whose boles are at or inside the plot perimeter are counted as inside the plot. If a tree is at an angle, the dbh tape will be placed at an angle as well. If the tree is on a slight slope, breast height will be measured from the side of the tree which has the lowest point. In general, the greenbelt terrain is level, and there will be little need to make adjustments in plot size to account for slope.

Importance values for each species will be calculated for the forest as a whole, as well as for each forest patch through an averaging of relative dominance, density, and frequency of occurrence values. Besides providing a means by which the various species in a forest may be weighed against one another, the importance values allow comparisons among spatially distant plots, sites, and patches. Snag (standing dead tree) density and importance will be calculated and evaluated as a component of the forest as well as on its own. Species importance curves, species-area curves, and lognormal abundance curves will be plotted for each species by patch type and for the forest as a whole.

The spatial distribution of tree species and snags within the greenbelt will be analyzed with pattern analysis. Morisita's Index of Dispersion will be calculated for each tree species to determine the type of spatial distribution pattern (random, contagious, or regular), and whether there are differences in spatial distribution in these species between corridors and patches. Correlations between species occurrence patterns will be explored with respect to co-presence and pattern emergence between patch and corridor sections of the forest. Pattern analysis should also illuminate whether or not some environmental gradients exist within the greenbelt forest that are not visually obvious (Nixon et al. 1990). Shannon Diversity, Simpson Diversity, and Morisita's Index of Community Similarity will be calculated to determine if there is a difference in tree diversity and forest community composition between corridors and larger patches of the greenbelt. Complexity index (CI) values (adapted from Holdridge et al. 1971; Shear, Lent, and Fraver 1996) will be calculated for each plot using the formula:

$$\text{CI} \quad \text{density} \times \text{sum of basal area} \times \text{canopy layers} \times \text{species richness} \times 10^{5}$$

For estimation of tree age, tree species representing various size classes will be randomly selected for tree boring. A 40.5-cm (16-in.) increment borer with a 0.5-cm (0.2-in.) diameter will be used to drill into each sampling tree at breast height to obtain a core sample. The rings will be double counted in the field, and each tree will be recorded by species and dbh. The cores will be replaced in the hole and covered with a small quantity of mud to help prevent decay and/or insect or disease intrusion into the tree bole (Lorenz 1944; Hepting, Roth, and Sleeth 1949). Linear regression will be performed on age (independent variable) and dbh (dependent variable) data for each species chosen for age class analysis.

Objective 3

Sample avian communities within "corridors" and "patches."

Avian surveys will be conducted during fall 1998 and 1999 (to detect fall migrants), winter 1998 and 1999 and 1999 and 2000 (winter residents), spring 1999 and 2000 (spring migration), and summer 1999 and 2000 (breeding). The objectives of these surveys are to sample the avian community to characterize seasonal abundance and distribution of birds in the greenbelt and to detect potential differences in bird use of corridors and patches. If there are statistical differences between use of corridors and patches, we will attempt to illuminate some of the environmental thresholds and/or gradients that may contribute to such differences.

Sixty-two permanent point count stations will be established along a transect placed through the length of the greenbelt, and locations of each will be documented with a GPS unit. Stations will be placed 250 m (820 ft) apart along this transect to reduce the probability of double counting individual birds. Transects will be delineated so that point count stations will be placed an equal distance from the forest edge perpendicular to the transect. Each point will be sampled at least once during each of the four seasons.

Surveys will be conducted as extensive unlimited distance point counts as described by Ralph et al. (1993). Surveys will be conducted beginning 0.25 hr before sunrise and up to 4.5 hr after sunrise when wind speed is less than 20 kmph (12 mph), air temperature is above 0 °C (32 °F) (except in winter), and no more than a light drizzle is falling. Sampling will commence when observers reach each point-count station. Sampling duration per point count station will equal exactly 10 min. Samplers will record every bird species seen or heard while sampling at each station. Any new birds seen or heard outside of the sampling period will be recorded separately but will not be entered on the data sheet. Samplers will wear drab clothing and remain relatively quiet to avoid bias. A GPS unit will be used to record and map point count locations, and location data will be rectified with base station data upon return to the lab.

In each of the two forest subdivisions (corridors and patches), avian species richness and Percent Community Similarity will be calculated. Species-area curves and relative frequency curves will be plotted for each species by patch type and for the entire greenbelt. All calculations will be subject to seasonal as well as aggregated analysis. These calculations will be used to determine whether avian community composition differs between corridors and patches and to characterize the within- and between-patch variabilities in species occurrence. Discriminant function analysis and cluster analysis will be used to explore potential patterns in the spatial aggregation of guilds (e.g., insectivores vs. granivores), competitors (e.g., cowbirds vs. songbirds), life histories (e.g., generalists vs. forest-obligate), and co-presence (in general, but with additional attention to exotics vs. native species).

Objective 4

Sample mammal communities using scent stations and sand-strip transects at stratified locations throughout the greenbelt; use radiotelemetry to document movement patterns of mammals through the greenbelt.

The objective of the mammalian survey field work is to sample the mammalian community to obtain a characterization of mammal use of the greenbelt. This characterization will explore whether there is a difference in mammal utilization of corridors and patches. If there are statistical differences between corridors and patches, we will explore some of the environmental thresholds and/or gradients that may contribute to such differences.

Several methods will be utilized to assess the presence of mammal species in a given forest patch (Gabor et al. 1994; Bookhout 1996). These techniques will include scent stations, spotlight censusing, radio-collar tracking, and mark-recapture trapping. Scent station visitation and radio tracking will provide data on species occupation of a particular forest patch. Spotlight censusing and mark-recapture trapping of small mammals will assess relative numbers of organisms utilizing a patch. Each of these techniques is described in detail below.

Scent stations will be established (following the methodology described by Conner, Labisky, and Proguluske (1983) and Gabor et al. (1994) in each of the major patches and corridors. These stations will be placed approximately every 750 m (2,460 ft) (avian point count sites will be used when feasible) for a total of 21 stations within the greenbelt. There will be four sampling periods (fall, winter, spring, and summer), with three sampling days each, coinciding with avian sampling days. At each station, a scent post will be established at the center of a 1-m (3-ft)-diam circular sand plot. Deer urine will be utilized as the attractant. On sampling days, each scent station will be sampled (data = presence/absence of a species) to evaluate the past 24 hr of use by mammals within the area in which each transect is located. On days prior to and immediately after sampling, scent-post sand plots will be raked smooth for better track identification.

Spotlight censuses will be conducted 3 nights per month for 3 hr each night. The spotlight census will target primarily medium- to large-size mammals (opossums, skunks, raccoons, bobcat, coyote and white-tailed deer). However, sightings and locations of all vertebrate organisms will be recorded. Spotlight censusing will provide relative numbers of organisms utilizing a particular patch. This censusing technique provides direct evidence of organism utilization of a patch. Routinely, specific individuals of a given species can be identified and movements and utilization of patches charted.

For each of the major patches, a uniform live trapping scheme employing mark-recapture techniques will be used to determine small mammal availability as a food source for carnivores (mammals and raptors). A series of three trapping transects will be used, extending perpendicular from the Elm Fork, traversing the forest, and projecting into adjacent public land. Transects will consist of three lines, 10 m (32 ft) apart, with Sherman live traps placed at 10-m intervals along each line. Traps will be baited with rolled oats and set the afternoon prior to sampling, then checked for three consecutive days. All small mammals will be identified to species and released after marking with permanent, nontoxic ink. This temporary marking will permit identification of recaptures and prevent biased estimates of small mammal densities. If species more apt to be captured by trapping (e.g., eastern cottonrat *Sigmodon hispidus*) occur in relatively high numbers during the first 2 days of the sampling period, these individuals will be retained until the sampling period is completed. They will be returned near point-of-capture at the end of the sampling period. This will increase the probability of sampling species that are less susceptible to trapping. Comparisons of small mammal populations, and hence availability of food for mammalian and avian carnivores, will be made between zones of the sampling localities and between localities using the number of mammals present per 100 trap-nights. This technique has been used extensively in the local area and will provide important comparison data for this study (Institute of Applied Sciences 1995).

Species richness, species density, and Percent Community Similarity of the mammal communities will be calculated in corridors and forest patches. Species-area curves and relative frequency curves will be plotted for each species by patch type and for the greenbelt. These calculations will be used to determine potential differences in mammal communities between the corridors and patches, and will also be used to characterize the within- and between-patch variability in species occurrence. Discriminant function analysis and cluster analysis will be used to explore the coincidence of mammal species, as well as potential patterns in the spatial aggregation of certain guilds, competitors, life histories, and co-presence of mammals. Finally, the locations of game trails that cross the Elm Fork will be recorded and mapped with a GPS unit in the early spring to explore the possible effect of the river (width, depth, canopy opening, etc.) on the spatial distribution of mammals within the greenbelt.

In their literature analysis, Hobbs and Wilson (1999) report only a few papers (five to six) that lay some claim to yielding knowledge to the movement function of corridors. Also, they report very few of these studies have utilized radiotelemetry technologies to identify presence of organisms within the corridor. However, the use of radiotelemetry to study space and habitat use patterns of animals is standard practice in wildlife research. Radiotelemetry information should provide information on the utilization of the corridor by two different high profile mammal species.

White-tailed Deer (*Odocoileus virginanus*) and raccoon (*Procyon lotor*) were identified based on the criteria established by Lambeck (1997). These two mammals represent key species identified as likely to be limited or threatened by particular characteristics of the landscape. Lambeck (1997) considered three groups of species whose movements can provide insight into characterizing habitat utilization of corridors by the way they view their habitat (i.e., coarse-grained or fine-grained, or their interactions with specific parameters of their biology). White-tailed deer and raccoons view their environment in two ways, relatively speaking, as coarse-grained and fine-grained, respectively. White-tailed deer represent a species that is limited by availability of large patches of suitable habitat, while raccoons represent a mammal species whose habitat utilization is limited by connectivity of patches. Both species occur within the greenbelt in sufficient numbers and are of a size that is conducive to fitting with radio collars for tracking.

Radiotelemetry data will assist in the development of a set of guidelines and criteria important in designing, analyzing, and managing riparian corridors for native wildlife utilization potential. From this, we will develop a set of guidelines and criteria important in designing, analyzing, and managing riparian corridors for native wildlife utilization potential. We will also evaluate relationships between floral and faunal presence/absence with respect to habitat qualities (e.g., width, habitat complexity, vegetation metrics).

To affix animals with radio collars, organisms will be captured either by live trapping (tomahawk live traps) or tranquilizing with a dart gun. All organisms will be tranquilized/sedated prior to a radio collar being affixed to the neck. All collared organisms will be released at the site of capture within 4 hr. Drugs used for sedation and tranquilization will be identified and provided by a licensed veterinarian.

Two mobile receiving units will track organisms 7 nights per week each month for 1 year. Triangulation bearings will be obtained every 2 hr with an estimated 250 to 350 fixes/organism. The mobile recievers will be used to provide up to four simultaneous fixes per organism per night. Schmutz and White (1990) demonstrated that locational errors caused by animal movement can be eliminated by taking simultaneous bearings using two receivers. Therefore, simultaneous fixes will reduce error associated with animal movement. Bearings will only be utilized if the intersection of the two compass azimuths are >45E and <135E in order to reduce the amount of error in locations.

Analytical methods that provide improved estimates of habitat use and correct for radio-telemetry triangulation errors are provided by Samuel and Kenow (1992). Measurement error, the difference between “true” and a estimated location values, can have substantial effect on the variability of statistical estimators. Serious underestimation of total variability can result from ignoring measurement error. These are referred to as “response errors.” Two types of errors occur when habitat use is misclassified as a result of such errors. False negative errors occur when the true location of an animal is in a specific habitat, but the estimated location falls in another habitat. False positive errors occur when the estimated location may be in one habitat, while the true location of the animal is in an alternate habitat. The former can result in underestimates of habitat use, while the latter can result in overestimates of habitat use.

To correct for such errors, Samuel and Kenow (1992) proposed a method for estimating measurement of error and habitat use in the proportion of animal use. Samuel and Kenow (1992) demonstrated that the subsampling method was the most effective in reducing error in locating an animal by triangulation. Opertationally, each telemetry location for an animal is estimated by trangulation using directional bearings from at least two locations. A confidence interval for estimated location is calculated by maximum likelihood procedures using the standard deviation of the directional bearings. A subsample of random points for each telemetry location is generated from its confidence interval. The resulting bearings are used to estimate the position of each random point by repeating the maximum likelihood procedure. This procedure produces a distribution of points that approximate the error distribution for each estimated animal location.

Defining landscape perceptions provides information on whether species share similar perceptions of a landscape structure within a range of scales and also serves to identify transitions between spatial domains. This provides a focus for more specific explorations of the mechanistic bases of responses to heterogeneity. The primary assumption is that the structure of movement patterns reflects encounters with the patch structure of the landscape. The primary limitation of such an analysis does not, by itself, provide a mechanistic explanation of why an organism exhibits a particular response to heterogeneity. With (1994) determined that fractal analysis of movement patterns of grasshoppers helped identify that different species were perceiving different scalar levels of habitat heterogeneity. Fractal analysis offered a methodology for assessing pattern structure across a range of scales and afforded a scale-independent measure of movement (as it removes the effect of differences in net displacement such as distance).

We will explore the procedures outlined by With (1994) using fractal dimension as it can be calculated and used to identify the perceptive resolution of a species (the spatial grain and extent at which they are able to perceive and respond to heterogeneity) and make comparisons of fractal dimensions of different species within the same environment to examine how species perceive landscape structure. Analysis of movement patterns across a range of spatial scales may reveal shifts in fractal dimension that reflect transitions in how species such as white-tailed deer and raccoons respond to the patch structure of the landscape at different scales. If the fractal dimension exhibits abrupt shifts between ranges of scale, it could indicate that there is a concomitant shift in the underlying processes responsible for the pattern.

Objective 5

Analyze each study zone within the greenbelt with the U.S. Fish and Wildlife's Habitat Evaluation Procedure (HEP).

The HEP was developed by the U.S. Fish and Wildlife Service (USFWS) to quantify habitat variables important to a target species or set of target species chosen to represent the faunal communities of which they are a part (USFWS 1980a, 1980b). Life history requirements of the target species are quantified into a Habitat Suitability Index (HSI) model that is specific to each animal and its primary habitat(s) and sometimes specific to a particular region. The HEP calculates Habitat Units based on the multiplication of HSI model results with cover-type area within the study site.

The HSI models use various habitat metrics to evaluate particular sites for habitat suitability for a given species. Each species with an HSI model is matched to a particular cover type or a set of cover types, depending upon the life-history requirements of the target species. The HSI model is then used to predict the habitat suitability for the site for that particular animal. This figure is then multiplied by the areal extent of that particular habitat for the site to obtain Habitat Units, which allow for comparisons of habitat suitability between sites of different areas of similar cover types. The HSI models chosen for this study include those of the Bobcat (*Lynx rufus*), Raccoon, Hairy Woodpecker (*Picoides villosus*), Pileated Woodpecker (*Drycopus pileatus*), and Barred Owl (*Strix varia*).

HSI evaluation of the life-history requirements of the chosen species will be conducted at the avian/mammal survey points. Results of HSI models and information on habitat units will be calculated in corridors and forest patches and analyzed to determine if there is a difference in HSI values and habitat units between these two classes. Cluster analysis will be used to explore any possible pattern in the spatial distribution of suitable habitat.

In addition, a set of habitat characteristics (i.e., number of canopy layers, mean height of each canopy layer, canopy coverage, soil type, edge type (if forest edge is <50 m (164 ft) from plot), and any other distinguishing ecological features) will be recorded at each plot.

Objective 6

Apply standard landscape and GIS-based spatial analysis techniques and metrics (e.g., cohesion, contagion, edges, width, distance between patches) to remote sensing data of the greenbelt (Turner 1989).

A GIS database and maps of the greenbelt will be generated. These maps will include such information as vegetation sampling points, avian point count locations, scent station locations, adjacent land-use practices, habitat types, and features of ecological importance. Concurrent with field work, a soil series map will be developed from USDA (1980) soil series data and used in conjunction with field soil analysis to develop a finer-scale soil data layer. The soil association, texture, and series maps will be used to explore variations in the distributions of the extant biota of the greenbelt. The surface soil texture will be noted for each HSI plot and compared with USDA soil survey data for possible differences between mapped soils and plot results.

Landscape heterogeneity, fragmentation, and connectivity metrics will be obtained from current literature and evaluated for their usefulness in application and relevance to the project objectives. Landscape metrics (e.g., patch density, patch size, patch variability, edge length and width, fractal dimension, shape, core area, nearest-neighbor, diversity, contagion, interspersion) will be applied to remote sensing data at two scales of resolution: 20-m (66-ft) (SPOT data) and

1-m (3-ft) Digital Orthophoto quadrangle[1] (DOQ data). These results will subsequently be compared with each other to determine the merits of each method relative to amount of explained variation in the data with the least amount of error. Principal Components Analysis will be used to determine if a large set of metrics can be reduced into a small set while allowing for an explanation of a great deal of the variation in the landscape (Riitters et al. 1995).

We will explore the effect of resolution and scale in remote sensing data in landscape to determine if a change in resolution leads to a change in landscape metrics for the same patches within the study area, as was the case in a review by Cale and Hobbes (1994). Land cover type and soil class data will be evaluated separately and together to determine if there is a scalar threshold at which point landscape metrics become more or less useful. This analysis will explore which scale is most ecologically appropriate for minimum mapping units in the context of the study objectives. Fractal dimensions will be calculated for each scale of resolution and to compare and contrast forest patch geometry to determine approximately how many processes are influencing the shape of these patches (Krummel et al. 1987).

Objective 7

Use integrative analysis to explore possible predictive and/or correlational relationships between metrics obtained through forest and habitat analysis, faunal sampling results, and fragmentation/landscape metric analysis.

To ecologically characterize a corridor and the surrounding landscape sufficiently, three major factors must be evaluated: (a) the physical constraints on the ecology, such as soils, climate, landscape structure, and landform; (b) the biota of the area; and (c) the interactions between the biota and between the biota and the physical environment (Hunter, Jacobson, and Webb 1988; Gosz 1992). Once each individual theme (forest, avian, mammalian, HSI, landscape) of the research has been analyzed and thoroughly characterized by itself, the faunal data will be compared with the forest and landscape data to explore single-taxon responses to the environmental and ecological variables that characterize the greenbelt. In addition to ecological factors, considerations of socioeconomic factors (such as adjacent land use and road and housing density) will be added to the list of variables that might influence the ecology of a corridor and will be compared with floral, faunal, and environmental data. Each taxon will be compared with forest data and landscape data individually and then will be compared with an aggregation of forest and landscape data. For example, soil texture and forest width data for each class will be compared with tree diversity, forest importance values, and habitat characteristic values to determine

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[1] A digital orthophoto is a digital image of an aerial photograph in which displacements caused by the camera and the terrain have been removed. It combines the image characteristics of a photograph with the geometric qualities of a map. The standard digital orhtho photo produced by the USGS is a black-and-white, or color infrared, 1-m (3-ft) ground resolution quarter quadrangle image (USGS 1998).

whether these physical attributes of the system have a significant influence (such as in the possible case of gradients of soil moisture (USDA 1980; Nixon et al. 1990)) on the ecology of the greenbelt. These types of comparisons will be made with all ecologically relevant variables (e.g., forest patch area or fractal dimension and native avian species richness).

Because different patterns in the ecology of a landscape emerge at different spatial scales of sampling and analysis (Allen and Hoekstra 1992), each section of this analysis will be evaluated at six different scales of resolution: plot-by-plot, nearest-neighbor/most similar aggregation of adjacent plots, individual patch or corridor segment (aggregation of plots within the patch), forest class (corridor or patch), forest type (vegetation/soil relationships), and the forest as a whole (Table 2). By comparing and contrasting the various results at these different scales, key environmental constraints within these contexts may be illuminated (Allen and Hoekstra 1992), which should improve the predictive ability of ecological assessments and studies of riparian forests.

Table 2
Scalar Hierarchy for Data Analysis

Level	Scale	Description
1st	Plot analysis	Individual plots
2nd	Forest stand-species relationships	Plots aggregated/averaged by common vegetative characteristics
3rd	Forest patch-species relationships	Plots aggregated/averaged into common individual patch or corridor segment
4th	Forest class analysis	Plots aggregated/averaged by forest class (patch or corridor)
5th	Forest type analysis	Plots aggregated/averaged by forest type (based on vegetation/soil relationships)
6th	Landscape analysis	Plots aggregated/averaged for entire forest within the greenbelt

The calculations of diversity, similarity, complexity, HSI values, and other metrics described above will allow qualitative and quantitative comparisons between habitat variables by plot, by individual patches, and by patch class to determine which metrics are useful in distinguishing important differences in habitat that importance value analysis may miss. All forest and habitat characteristic values will also be analyzed with cluster analysis for plot-by-plot comparisons. Cluster analyses will use K-Means clustering for specified cluster designation, the complete linkage joining algorithm in order to maximize differences between plot distance values, percent disagreement distance algorithm for categorical (presence/absence) data, and City-block distance algorithm for continuous (habitat characteristics) data to minimize the effects of extreme values. Graphical ordination through Principal Components Analysis will be used to determine which factors and/or metrics contribute most to the various ordinations and/or clusters of plots.

The objective of the multiple cross-comparisons at different scales is to look for and define gradients in the ecological communities of the greenbelt. Such patterns should allow for the identification of major driving factors in the ecological processes influencing the greenbelt. An exploration of the thresholds that influence the presence and distributions of the fauna of the greenbelt will be an explicit component of this analysis. These factors and gradients can then be explored in greater detail to arrive at some conceptual guidelines for the evaluation of similar systems. The many metrics used to quantify pattern and process in the ecology of this riparian forest might be reduced to simpler sets of a few univariate metrics that can still explain the majority of variation in spatial distribution.

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Appendix A
Formulas

1. Connectivity indices:

$$cn_1 \quad \frac{\text{minimum width of corridor}}{\text{distance between connected patches}}$$

$$cn_2 \quad \frac{\text{average width of corridor}}{\text{distance between connected patches}}$$

2. Dominance = basal area per species per unit area (m^2/ha)

3. Density = number of trees per species per unit area (#/ha)

4. Frequency = number of plots in which a species occurs / total number of plots

5. Relative Dominance (%) = $\frac{\text{Dominance of a species}}{\text{total dominance}} \quad 100$

6. Relative Density (%) = $\frac{\text{Density of a species}}{\text{total density}} \quad 100$

7. Relative Frequency (%) = $\frac{\text{Frequency of a species}}{\text{total dominance}} \quad 100$

8. Importance Value (%) =

$$\frac{\text{Relative Dominance} \quad \text{Relative Density} \quad \text{Relative Frequency}}{3}$$

9. Morisita’s Index of Dispersion: $I_d \quad n \, \frac{\Sigma X^2 \quad N}{N \, (N \quad 1)}$

where

n = number of plots

N = total number of individuals counted on all n plots

ΣX^2 = squares of the numbers of individuals per plot, summed over all plots

9. Simpsons’ Index of Dominance: $I \quad \dfrac{\Sigma n_i \; (n_i \quad 1)}{N \; (N \quad 1)}$

where

n_i = abundance of each species

N = total abundance

10. Simpson’s Index of Diversity: D = 1 - I

11. Morisita’s Index of Community Similarity: $I_M \quad \dfrac{2\Sigma X_i \; Y_i}{(I_1 \quad I_2) \; N_1 \; N_2}$

where

x_i = number of individuals in species *i* in community 1

y = number of individuals in species *i* in community 2

I_1 = Simpson’s Index of Dominance for community 1_2

I = Simpson’s Index of Dominance for community 2

N_1 = total abundance of individuals in community 1

N_2 = total abundance of individuals in community 2

12. Foliage height diversity (FHD): $H' = -\Sigma\, p_i \log p_i$

where

H' = Shannon diversity index

p_i = the proportion of foliage density in each canopy layer

13. Complexity Index:

CI = density * Σ(basal area) * canopy layers * species richness * 10^{-5}

14. Graphical presentation of seral stage analysis: $RIV_j \quad \frac{IV_j}{\Sigma IV}$

where

RIV_j = relative importance value of a species in seral stage j

IV = importance value of that species in seral stage j

ΣIV = sum of importance values of all species in all stages

15. Species Richness: s = number of species in habitat type

16. Species Density = $\frac{\text{number of species}}{\text{unit area}}$

17. Pielou's Rarity Index: $\text{R} \quad \frac{\text{number of species found only one}}{\text{species richness}}$

18. Relative Frequency: $Rf \quad \frac{f}{\Sigma f}$

19. Percent Community Similarity: $PS = \Sigma$ minimum ($p1i$, $p2i$)

where

$p1i$ = the proportion of species i in class 1

$p2i$ = the proportion of species i in class 2

20. Ecological Species Density = $\frac{\text{number of species}}{\text{unit area of suitable habitat}}$

Appendix B
Study Hypotheses

Table B1
Vegetation Community Analysis Study Questions and Testable Hypotheses

Null Hypothesis or Descriptive Statement	Test(s)
The spatial distribution of each tree species does not approximate a random distribution.	Morisita's Index of Dispersion, Chi-square
There is no significant difference in spatial distribution of tree species between corridors and patches.	Morisita's Index of Dispersion, ANOVA [1]
There is no significant difference in tree diversity between corridors and patches.	Simpson's Index of Diversity, ANOVA
There is no significant difference in similarity of the forest communities between corridors and patches.	Morisita's Index of Community Similarity, ANOVA
There is no significant difference in similiarity of forest communities between corridors and patch edges (patch plots within 50 m of edge).	Morisita's Index of Community Similarity, ANOVA
There is no significant difference between FHD values between corridors and patches.	ANOVA
There is no significant difference between CI values between corridors and patches.	ANOVA
There is no significant correlation between percent canopy coverage and tree diversity.	Spearman's Rank-Order correlation
There is no significant correlation between soil texture class and tree diversity.	Spearman's Rank-Order correlation
There is no significant correlation between mean width of a forest patch, average patch slope, average patch elevation above baseline, tree diversity, FHD values, and CI values.	Correlation
There is no significant predictable relationship between dbh and age for each tree species.	Regression
There is no significant difference in forest community by seral stage between corridor patches and larger patches of the forest.	Morisita's Index of Community Similarity, ANOVA
Correlations between species occurrence patterns will be explored with respect to co-presence as well as with respect to whether patterns emerge between patch and corridor sections for the forest.	Covariation, correlation, cluster analysis, spectral analysis
Which analysis factors (e.g., importance values, diversity values, similarity values, habitat characteristic values) contribute the most to the quantitative and qualitative differences between all forest patches? Between corridors and larger forest patches?	Cluster analysis, Mantel analysis, principal components analysis (PCA)
There is no difference in analysis results when forest data are compared and/or aggregated and averaged with forest data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation
There is no nestedness of tree species within the extent of the forest, and thus no discernible gradient in extinction vulnerability.	Cluster analysis, Monte Carlo simulation

1 Note: All questions in this study that use ANOVA to test the null hypothesis will also employ the use of multiple pair-wise comparisons to determine the nature of any differences detected by ANOVA.

Table B2
Avian Analysis Study Questions and Testable Hypotheses

Null Hypothesis	Test(s)
There is no discernible pattern in the spatial aggregation of avian guilds, competitors, life histories, and co-presence, particularly with respect to whether patterns emerge between patch and corridor sections of the forest.	Covariation, correlation, spectral analysis, discriminant function analysis, cluster analysis
There is no significant difference in avian species richness between corridor sections and forest patches.	ANOVA
There is no significant difference in avian species density between corridor sections and forest patches.	ANOVA
There is no statistically significant difference in avian rarity between corridor sections and forest patches.	ANOVA
There is no significant difference in avian percent community similarity between corridor sections and forest patches.	Percent Community Similarity, ANOVA
There are no significant differences between percent community similarity, species richness, and relative frequency in corridor sections contrasted with patches during the four seasons.	2-way ANOVA
There is no significant relationship between forested corridor width and avian species richness.	Regression
There is no significant relationship between forested corridor width and avian species density.	Regression
There is no significant relationship between forested patch area and avian species richness.	Regression
There is no significant relationship between forested patch area and avian species density.	Regression
There is no difference in analysis results when avian data are compared and/or aggregated and averaged with avian data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation
There is no nestedness of bird species within the extent of the forest, and thus no discernible gradient in extinction vulnerability.	Cluster analysis, Monte Carlo simulation

Table B3
Mammal Analysis Study Questions and Testable Hypotheses

Null Hypothesis	Test(s)
There is no discernible pattern in the spatial aggregation of mammal guilds, competitors, life histories, and co-presence, particularly with respect to whether patterns emerge between patch and corridor sections of the forest.	Covariation, correlation, spectral analysis, discriminant function analysis, cluster analysis.
There is no significant difference in species richness between corridor sections and forest patches.	ANOVA
There is no significant difference in species density between corridor sections and forest patches.	ANOVA
There is no statistically significant difference in rarity between corridor sections and forest patches.	ANOVA
There is no significant difference in percent community similarity between mammal communities in corridor sections and forest patches.	Percent Community Similarity, ANOVA
There are no significant differences between percent community similarity, species richness, and relative frequency in corridor sections contrasted with pataches during the four seasons.	2-way ANOVA
The spatial distribution of game trails that cross the Elm Fork have no relationship to the forest class (corridor/patch) nearest to the trail.	Discriminant function analysis, cluster analysis
The spatial distribution of game trails that cross the Elm Fork have no relationship to the land cover types adjacent to the riparian forest.	Discriminant function analysis, cluster analysis
There is no significant relationship between forested corridor width and mammal species richness.	Regression
There is no significant relationship between forested corridor width and mall species density.	Regression
There is no significant relationship between forested patch area and mammal species richness.	Regression
There is no significant relationship between forested patch area and mammal species density.	Regression
There is no significant difference in analysis results when mammal data are compared and/or aggregated and averaged with mammal data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation
There is no nestedness of mammal species within the extent of the forest, and thus no discernible gradient in extinction vulnerability.	Cluster analysis, Monte Carlo simulation

Table 4 **HEP Analysis Study Questions and Testable Hypotheses**	
Null Hypothesis	**Test(s)**
There is no discernible pattern in the spatial aggregation of suitable habitat (as defined by Habitat Suitability Index (HSI) variables), particularly with respect to whether patterns emerge between patch and corridor sections of the forest.	Covariation, correlation, spectral analysis, discriminant function analysis, cluster analysis
There is no significant difference in habitat units for each HSI model between and within corridor sections and forest patches.	Friedman's ANOVA
There is no significant relationship between forested corridor width and HSI results.	Regression
There is no significant relationship between forested patch area and HSI results.	Regression
There is no significant relationship between forested corridor width and Habitat Units (HU) results.	Regression
There is no significant relationship between forested patch area and HU results.	Regression
There is no difference in analysis results when HSI data are compared and/or aggregated and averaged with HSI data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation

B5 **Landscape Phase II Analysis Study Questions and Testable Hypotheses**	
Null Hypothesis	**Test(s)**
Which landscape metrics and fragmentation indices explain the most variation in the landscape at different scales of resolution? Can a reduced set of univariate metrics represent the data with little additional error?	PCA
There is no relationship between landscape diversity and spatial grain.	Regression
There is no relationship between landscape dominance and spatial grain.	Regression
There is no relationship between landscape contagion and spatial grain.	Regression
There in no significant correlation between corridor width, soil-erosion potential, and stormwater alleviation potential.	Correlation
There in no difference in analysis results when landscape data are compared and/or aggregated and averaged with landscape data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation

Table B6 **Chart of the Integrative Analysis Comparisons**	
Compare	**With**
Phytosociology, avian, mammal, HSI results (separately) Avian, mammal, HSI, landscape results (separately) Avian, mammal, HSI results (separately)	Landscape results Phytosociology results Phytosociology results and landscape results (together)
Phytosociology, avian, mammal, HSI results (together) Avian, mammal, HSI, landscape results (together) Avian,May 4, 1999 mammal, HSI results (together)	Landscape results Phytosociology results Phytosociology results and landscape results (together)

Table B7 **Scalar Hierarchy for Data Analysis**	
Scale	**Data Analyzed with Results**
1st Level plot analysis	Individual plots
2nd Level site-species relationships	Plots aggregated/averaged into their common individual patch or corridor segment
3rd Level community relationships	Plots aggregated/averaged by forest class (corridor or patch)
4th Level landscape analysis	Plots aggregated/averaged for the whole forest within the greenbelt

Table B8 **Integrative and Comparative Analysis Study Questions and Testable Hypotheses**	
Null Hypothesis or Descriptive Statement	**Test(s)**
There is no significant correlation between any of the variables sampled in this study.	Multivariate correlation
There is no difference in analysis results when individual theme or integrated data are compared and/or aggregated and averaged with integrated or individual theme data at different spatial scales.	Cluster analysis, Mantel analysis, ANOVA, correlation
The spatial distribution of a large proportion of the species sampled will not coincide or correlate with a set of environmental variables and gradients.	Cluster analysis, correlation, Mantel analysis
There is no significant correlation between similar sampling data taken (or aggregated and averaged) at different spatial scales.	Correlation
A subset of the variables sampled will not explain as much variation as does the aggregated and averaged results for each division of the study as well as with the overall results.	Correlation, PCA
Species diversity in the riparian forest is a function of: (a) habitat diversity; (b) disturbance (including adjacent land use); (c) area and shape of forest patches and corridors; (d) age of forest patches and corridors; (e) landscape heterogeneity; (f) isolation; and (g) boundary discreteness (edge effects).	Cluster analysis, PCA
Avian and mammal species' distributional responses to landscape heterogeneity vary depending on the following factors: (a) vegetative community type; (b) edge effects; (c) seral stage of vegetative community; (d) distance from road(s); and (f) ecosystem type (soil/vegetation/topographic relationship)	Cluster analysis, PCA
Vegetative species' distributional responses to landscape heterogeneity vary depending on the following factors: (a) ecosystem type; (b) vegetative community type; (c) seral stage of vegetative community; (d) edge effects; and (e) distance from road(s).	Cluster analysis, PCA
The highest levels of α and β biodiversity will not be found in areas of the forest with favorable physical characteristics (such as with soil-moisture status, slope, soil type, edge length, and so on).	Cluster analysis, correlation, ANOVA
Forest patches with high connectivity will not have higher α and β diversity as compared with forest patches of lower connectivity.	Connectivity indices, cluster analysis, ANOVA
There is no significant correlation between the results of the HEP analysis and the presence of a large proportion of the native species, guilds, and communities.	Correlation
Environmentally stressed patches and corridors within the greenbelt will not have significantly different numbers of r-strategists, different numbers of α biodiversity, or different levels of dominance by extant species.	ANOVA
Which variables sampled in this study explain the most variation in the landscape at each scale of analysis? Do patterns emerge that transcend the various scales?	PCA

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13. ABSTRACT ***(Maximum 200 words)***

The majority of inland Corps of Engineers civil works projects are constructed along streams and rivers. There is increasing interest in the value of riparian zones adjacent to these aquatic resources as corridors and vegetated buffer strips, especially as potential wildlife habitat. Flood storage, improved water quality through reduction of sediment and nutrients, pollution and noise-abatement, wildlife habitat and travel corridors, aquifer recharge, recreation, and aesthetics are all well-known values of riparian zones and together provide considerable rationale for their conservation.

This report concentrates on a 3-year research project on corridors and vegetated buffer zones that was initiated in FY97 with goals to develop technical guidelines from current literature and field studies to improve design, evaluation, restoration, and management of riparian corridors. These guidelines will be used to assist CE personnel in making decisions for riparian buffer zone and corridor designs based on the most accepted scientific criteria. Current and future planned activities to meet these goals are discussed in this report.

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