PROTECTING ECOLOGICAL FUNCTION USING THE SOUTHEASTERN ECOLOGICAL FRAMEWORK

B. Richard Durbrow, MSPP, Program Analyst
Cory W. Berish, Ph.D., Chief PAB
John R. Richardson, Ph.D., Systems Ecologist
Neil B. Burns, Ph.D., Environmental Scientist
U.S. Environmental Protection Agency, Region 4
Planning and Analysis Branch
61 Forsyth Street, SW
Atlanta, Georgia 30303
Durbrow.rick@epa.gov
Berish.cory@epa.gov
Richardson.john@epa.gov
Burns.neil@epa.gov

Thomas S. Hoctor, Ph.D. Candidate
University of Florida
Department of Wildlife Ecology & Conservation
Gainesville, Florida
Tomh@geoplan.ufl.edu

ABSTRACT

Roads, agriculture, and 'sprawl', represent the most prevalent changes in out natural landscapes and cause natural systems to become divided into isolated parts. Research shows that landscapes lose their ecological integrity with increasing fragmentation, which can include the loss of biological diversity, the degradation of water quality and the loss of other important ecological services. Many natural ecosystem types in the southeastern United States have suffered significant losses and degradation. Longleaf pine forests, bottomland hardwoods and wetlands have lost 98%, 78% and 28% percent respectively of their pre-settlement extent in this region. These dwindling natural systems are falling under increased pressure to support a growing human population. By identifying a large scale, systematic regional framework, it is possible to provide a foundation in which protection of the large-scale ecological properties and processes can be optimized for multiple benefits at both the local and regional scale. Of the remaining natural areas in the region, not all are equal in their support of ecosystem services. Critical areas may include wetlands located up stream of drinking water intakes. Other critical areas may be identified as flood protection for a small farming town or riparian buffers to eliminate the need of a sediment filtration system. There are also many areas that have high ecological integrity or high biological diversity, have critical roles in watershed protection, or can provide the only possible linkages between other existing natural areas. After reviewing work produced at the University of Florida (UFL) identifying a green infrastructure for the state of Florida, EPA Region 4 entered into a cooperative agreement with UFL to apply their modeling processes to the Southeast. The Florida Ecological Network delineation process provided the foundation for the SEF by combining a systematic landscape analysis of ecological significance with the identification of critical landscape linkages in a way that can be replicated, enhanced with new data, and applied at different scales.

INTRODUCTION

The Environmental Protection Agency's mission 'to protect human health and to safeguard the natural environment – air, water, and land – upon which life depends' has not changed in the past 30 years, but the methods and approaches to solving environmental problems are changing and will continue to change. Resources, both natural and economic, are becoming more limited. For EPA to be effective in its mission, it is imperative to assign priorities that optimize both natural and economic resources. We feel that the landscape and systems approach presented in this paper will help achieve those goals.

With one of the greatest threats to ecosystem function being the fragmentation of landscapes (Harris, 1984), EPA must analyze landscape scale impacts on air, water and soil resources if we are to support communities, states and other federal agencies with innovative approaches to environmental protection. Roads, large-scale agriculture, and suburban growth or 'sprawl', represent changes in land use that directly impact the mission of our agency while continuing to cause natural systems to become divided into smaller and more isolated parts (Forman, 1995). By identifying a large scale, systematic regional framework, it is possible to provide a foundation in which protection of the large-scale ecological properties and processes can be optimized for multiple benefits at local and regional scales (Noss, 1991).

Many ecosystem types remaining in the southeast currently occupy less than 50% of their historic areas. Longleaf pine forests once occupied 90 million acres throughout the South; now there is currently less than 3 million acres (SENRLG, 2001). Seventy-eight percent of the pre-settlement bottomland hardwoods and twenty-eight percent of pre-settlement wetlands have been lost as of 1986 (Hefner, 1994). In addition, many acres of remaining forests have been modified and are in plantation forestry, leaving smaller, sometimes-isolated areas to preserve native habitat and ecosystem function. Natural ecosystem processes provide sustainable human needs, habitat for many species and desirable recreation activities (Salwasser et al., 1996). Furthermore, these processes provide valuable ecological services as long as they are not overloaded (Odum et al., 1998). The natural areas remaining in the southeast are under increasing pressure to provide ecological services for water quality, drinking water, storm water management, flood control, particulate matter removal and carbon sequestration, as well as food and shelter for native species (Noss, 1996).

Unfragmented natural areas provide many ecological services (Daily, 2000) and provide the corner stone of the SEF. These unfragmented ecosystems are supporting an ever-increasing human population and their fragmentation will make it difficult for EPA and other federal agencies to facilitate sustainable development. Of the remaining natural areas identified by the SEF, not all are equally in need of protection. Some natural areas have high ecological integrity or high biological diversity (Noss, 2000). Some areas play critical roles in watershed protection. And other areas provide the only functional link between existing natural areas. The fragmentation of functional links has potentially adverse impacts on the ability of the whole landscape to sustain ecological function (Harris, 1984; Forman & Godron, 1986). Fragmentation of natural land cover and corridors to accommodate urban sprawl, roads and agricultural products causes major problems with maintaining ecosystem integrity. Heightening conflicts in land use activities and undesirable impacts from pollution where the intensity of use is greater than the assimilative capacity of the natural areas (Mattikalli & Richards, 1996).

In addition to unfragmented natural areas, our work focused on other land use types. Lands in agricultural or silvicultural use can contribute to maintaining the regional landscape's overall ecological function and quality. These lands, if properly managed, have potential for maintaining connectivity between areas of higher ecological significance while providing direct economic benefits from production of food and fiber. So, lands in agriculture and silviculture can function as part of an ecological network or as buffer areas around native habitat (Daniels & Bowers, 1997). Unfortunately, agricultural lands as well as natural lands are being lost to urbanization in the southeast at a rapid pace.

In order to safeguard the natural environment and protect human health, threats to ecological function and conflicts in resource allocation need to be identified and prioritized. Effective and efficient protection measures must then be established to minimize environmental degradation and loss of economic well-being. The SEF is a way to focus resources and protection programs. When integrated with a watershed approach for resource protection and other stressor data sets available for the southeast, such as population growth, a framework can identify locations of natural areas and agricultural lands endangered from the impacts of urban sprawl, road development and other environmental stressors. The use of geographical information system tools provides an opportunity to visualize critical landscapes that may be at risk from various environmental stressors.

Trends in regional conservation during the past 5 years have moved toward spatial approaches to natural resource protection. Many organizations such as the World Wildlife Fund, The Nature Conservancy, and the Trust for Public Land are attempting to develop geographical information system tools for identifying hot spots, priority areas, or the last great remaining places to enable them to prioritize their respective conservation efforts. Significant problems with any geographical information system approach include identifying the appropriate scale for resource evaluation, the quantity and quality of data available and stakeholder involvement or local ownership of the final product (Peine, 1999). These issues became evident in 1995 after the Southern Appalachian Man and Biosphere (SAMAB) Cooperative completed the Southern Appalachian Assessment (SAA) through the collaborative efforts of federal agencies, state agencies, universities, special interest groups, and private citizens. That effort was the first regional attempt to evaluate the living systems of the Southern Appalachian Region, the animals, the plants, the land, air, and water that support them, and the enormous changes that have taken place during the 20th century

(SAMAB, 1996). The SAA received a Hammer Award for leveraging government resources to develop a consistent data set for the region. The project fell short, however, in providing useful information for local decision-makers. One problem was due in large part to the complexity of the GIS tools available at the time and a corresponding lack of training by municipal officials in the technology. A second significant problem with the SAA was that the majority of data was developed to identify trends at a county level, which provided little opportunity for understanding landscape changes within a county. Although point data and land use coverages were included in the final SAA, no further analysis of the relationship of multiple data sets was developed. This failed to give a firm indication of what land may be at risk from existing or potential growth in the future, what areas still provide ecosystem services in the region, or where the greatest threats to ecosystem functionality lay in regards to the wildland/urban interface (Berish et al., 1999).

The SEF provides a significant improvement over the SAA in that the SEF identifies areas that are linked or have the least amount of fragmentation and therefore, worth considering as high priorities for protection. Research has shown that landscapes lose their ecological integrity with fragmentation. These include such components as the loss of biological diversity, the degradation of water quality, and other important ecological services (Harris & Silva-Lopez, 1992; Forman, 1995; Harris et al., 1996a). It is important to realize that the SEF does not, however, identify all areas that need to be protected. In some cases, small areas that do not fall within the framework, due to the nature of modeling connectivity, can have significant contributions for the protection of biodiversity and should be protected. It is equally important to know that the SEF is a framework of ecologically significant lands and not a map of areas that must be protected.

SCIENCE

The Southeastern Ecological Framework (SEF) was developed by the University of Florida; based on their experience in creating the Florida Ecological Network (FEN) for the State of Florida. In Florida, conservation efforts have steadily progressed towards the identification and protection of an integrated system of protected areas that would sustain the state's rich native biodiversity while also protecting important ecological function and other natural resources. Following the work of Harris and Noss (Harris, 1984; Noss and Harris, 1986; Noss, 1987; Harris and Atkins, 1991), the state adopted the concept of an integrated habitat network as part of the Florida Greenways Program in 1992. Although greenways are often associated with linear recreational features such as rails-to-trails, the Florida concept was to include wildlife corridors, landscape linkages, and landscape-level conservation areas within an ecological network connecting public and private conservation lands across the state.

As part of the process to develop a statewide greenways plan, the University of Florida was funded to develop a spatial analysis model to help identify the best opportunities to protect ecological connectivity statewide. Geographical Information System (GIS) software was used to analyze all of the best available data on land use and significant ecological areas including important habitats for native species, important natural communities, wetlands, roadless areas, floodplains, and important aquatic ecosystems. This information was then integrated in a process that identified the FEN containing all of the largest areas of ecological and natural resource significance and the landscape linkages necessary to protect a functional statewide network. The process was collaborative and overseen by three separate state-appointed greenways councils. During the development of the model, technical input was obtained from the Florida Greenways Commission, the Florida Greenways Coordinating Council, other state, regional, and federal agencies, scientists, university personnel, conservation groups, planners and the general public in over 20 sessions. When the modeling was completed, the results were thoroughly reviewed in public meetings statewide as part of the development of the Greenways Implementation Plan completed in 1999 and the work was published in Conservation Biology, in August (Hoctor et al., 2000).

The FEN delineation process combined a systematic landscape analysis of ecological significance and the identification of critical landscape linkages in a way that could be replicated, enhanced with new data, and applied at different scales. The FEN connects and integrates existing conservation areas with unprotected areas of high ecological significance. This information can be used in concert with other information on conservation priorities to develop a more integrated landscape protection strategy. Such an integrated network will protect important ecological function, community and landscape juxtapositions, and the need for biotic movement more thoroughly than the present collection of isolated conservation areas (Noss and Cooperrider, 1994; Harris et al., 1996b).

The usefulness of GIS for analysis and planning at a local scale is not in question. Two factors, however, are enhancing the use of GIS for regional planning. The primary factor is the rapid development of effective GIS modeling tools. More sophisticated software and hardware capable of handling complex analyses of large spatial data sets are increasingly being developed to assist in analysis and synthesis of spatial information at a regional planning scale. There have been impediments to its wider application: thematic data accuracy and uncertainty, data handling and management, positional accuracy and the lack of regional data sets. These impediments are being eliminated. The consistency of data across political jurisdictions affords significant breakthroughs in data modeling. The development of national data sets for floodplains, hydrology, digital elevation, national land cover and the eventual release of some state data sets, such as Federal GAP Analysis and Natural Heritage data, provide a unique opportunity to integrate information to analyze ecological quality and degradation at large scales.

The second significant factor driving the increase and importance of regional conservation planning efforts is the growing awareness of the need for greenspace protection. Sentiment for greenspace protection and the valuation of ecosystem services has been growing steadily over the past few years. In 1998, 124 state and local open space protection referenda were passed on the November ballot (Land Trust Alliance, 1999). Local decision-makers are being charged with developing comprehensive plans that balance habitat protection, water and air quality, and economic growth for their communities. Clearly, regional conservation planning tools such as the SEF can play a key role in helping federal and state agencies, local governments, and non-profit organizations make coordinated natural resource conservation decisions that provide co-benefits for local and regional ecosystem services protection. We see the SEF as a critical step in regional planning because it crosses state boundaries and integrates activities of several Federal agencies.

The SEF provides a foundation for regional landscape and natural resource planning. Its value as an organizing theme to focus and coordinate environmental protection of large-scale ecological systems can be significant for state, federal and non-profit agencies involved in natural resource protection. Some examples of applicability include watershed protection, biodiversity and wildlife conservation, wetlands mitigation banking and restoration, land use planning, road right-of-way planning and wellhead protection program activities. The value of the SEF as an organizing theme for EPA, Region 4 is equally important for integrating landscape functionality into program decision making, prioritizing agency programs, allocating resources and evaluating GPRA goals.

STATE MODEL

The SEF modeling process is based on the methodology used to delineate the FEN (Hoctor et al., 2000). The FEN decision support model was created to facilitate the identification of key areas of ecological connectivity as part of Florida's land conservation programs. Since 1990, Florida has spent at least 300 million dollars per year to protect lands significant for conserving natural resources including biodiversity. The program criteria have evolved and pre-2000 assessments generally addressed issues of biodiversity, rarity or sensitivity on a case-by-case basis. Although over 500,000 hectares have been purchased through these programs, the Florida Greenways Commission (1994) felt that a more comprehensive approach to land acquisition was needed to ensure the viability of protected lands. Hence, in 1995, the University of Florida was asked to design a GIS-based model that could be used as a *decision support tool* for identifying all of the larger, potentially intact areas of ecological significance and opportunities for connectivity statewide. Once modeled, reviewed, and approved, a statewide ecological network could then be used to help integrate and coordinate land protection programs. The Florida Greenways Coordinating Council approved the FEN in 1999 after a detailed, statewide review process, and the Florida Legislature passed implementing legislation in 2000. The FEN is now being used as a primary planning tool to evaluate lands for the new state land acquisition program, Florida Forever.

The FEN modeling process is based on two parts of the primary reserve model advocated for effectively conserving biodiversity and other natural resources (Harris, 1984; Noss and Harris, 1986; Noss and Cooperrider, 1994). In this model, core areas, landscape linkages or connectivity zones, and buffer zones are identified in integrated networks designed to: 1. maximize protection for the most sensitive species, 2. provide enough space for viable populations of wide-ranging species, 3. maintain functional ecological processes and services, and 4. provide opportunities for biota to functionally respond to future environmental changes.

The FEN modeling process combines these parts into two primary components: the identification of ecological hubs and the identification of landscape linkages. Ecological hubs are larger areas of ecological significance that have the best potential for conserving biodiversity and functional ecological processes. Ecological hubs may be a combination of both core areas and buffer zones depending on existing and future management objectives of protected lands. Landscape linkages are the existing and potential zones of connectivity between ecological hubs that are expected to provide better opportunities for maintaining viable populations of species of conservation interest, functional ecological processes, and for protecting riparian resources.

The same modeling process was used by the University of Florida to delineate the SEF. The three primary steps, the identification of priority and significant ecological areas, the identification of ecological hubs, and the delineation of landscape linkages were conducted in both the FEN and the SEF. Though some assessment techniques used in the process, such as the land suitability analysis used to delineate landscape linkages, were slightly different (and, in our view, improved) in the SEF modeling process, the primary difference in the two models is the specificity and consistency of the data available in the assessments. Florida has good quality data on land use, land cover, and biodiversity, which were all used in the delineation of the FEN. Though significant progress is being made in other states and nationally to develop similar data, the SEF assessment had to be conducted with less comprehensive regional and state data sets.

In Florida, two data sets were available to assess land use and land cover as part of the FEN assessment. One data set was based on Landsat imagery and the other on high-resolution aerial photography. Both data sets allowed for a detailed assessment of land use and land cover. In particular, the level of natural community classification allowed for the identification of some of the coarser-scale natural communities of significance including longleaf pine, sand hills, scrub, tropical hammocks, and coastal strand. In the SEF, land use and land cover information was predominantly based (except in Florida) on the National Land Cover Data (NLCD, for regional land cover) formerly known as the Multi Resolution Land Cover (MRLC) dataset (Vogelmann et al., 1998). Although this data set is of an appropriate resolution for regional scale analysis (classified using 30-meter Landsat imagery), the classification is too coarse for standard representation analysis of natural communities. For instance, all forests communities (including plantations) are lumped into four classes: upland deciduous, evergreen, mixed, and woody wetlands.

The Florida Fish and Wildlife Conservation Commission completed a GIS analysis in 1994 that identified all of the areas needed to protect viable populations of over 30 species of conservation interest (Cox et al., 1994). These species are indicator species representing both important natural communities and umbrella species requiring large areas to support viable populations. The black bear (Ursus americanus) was used in the SEF model as a focal, umbrella species to identify larger blocks of intact habitat for this species that would provide habitat for other species of conservation interest. A wide-ranging focal species acts as a surrogate for large-scale ecological function in the model. Although similar assessments focused on biodiversity, such as the federal GAP Analysis Program and The Nature Conservancy's ecoregional planning initiative, these analyses are not yet completed at a scale (multi-state regions) that could have been used in a regional assessment of ecological function.

Florida's natural heritage program, Florida Natural Areas Inventory, developed a detailed GIS data layer identifying all potentially significant natural areas statewide (Cox et al., 1994). Although a similar data set was used for North Carolina, natural heritage programs in other states within Region 4 do not currently have this kind of data available. In addition, due primarily to data ownership concerns by various natural heritage programs, the SEF was developed without having species and natural community element occurrence data in all eight states. The delineation of the SEF included element occurrence data for Alabama, Georgia and Florida. However, this data has since been obtained for North Carolina and Mississippi, and more information on areas of biodiversity significance region-wide will likely be obtained from the Association of Biodiversity Information (ABI). This additional biodiversity data can be incorporated into the modeling process to prioritize specific areas for species protection.

Overall, the FEN contains more specific biodiversity information that is more consistent with efforts to identify reserve networks. This should not, however, be used to discount the modeling efforts used to delineate the SEF. As mentioned above, state-of-the-art biodiversity analyses and reserve design processes are developing rapidly. Though all of these efforts will provide more detailed biodiversity information in the near future, none of them are yet specific enough to answer all of the detailed questions about sites, area sizes and conditions needed to protect viable populations of all species of conservation interest. In general, there are currently no comprehensive regional biodiversity assessments available, and both the FEN and the SEF are based on the best information available at the time of the assessment. Ideally, future iterations of the SEF model will incorporate additional biodiversity information from these and potentially other initiatives.

Furthermore, the SEF is meant to be more than a biodiversity assessment and reserve design tool. It can also be termed a "green infrastructure rapid assessment technique" used to identify not only important areas for biodiversity but also areas significant for maintaining ecological services that support human communities. Though more specific information and analyses of hydrological processes would be useful, the focus of the SEF analysis on large wetland basins, intact riparian buffers, large forested areas, and intact coastal lands serves as a useful first step for identifying the areas potentially most important for maintaining water quality, air quality, flood control, and storm protection. The SEF can be considered to be a rapid assessment tool for quickly identifying larger intact landscapes and other important areas of ecological significance for both biodiversity and ecological services using the best available information. In addition, Region 4 EPA, with the help of the University of Florida, conducted an ecological framework assessment for the Mississippi Delta that incorporates information on ecological restoration priorities, which could be used in the modeling process in regions with higher levels of disturbed ecosystems.

REGIONAL MODEL

The identification of the Southeastern Ecological Framework involved four primary steps (see Figure 1). First, in what can be termed the inventory phase, all relevant available Geographical Information System data was collected, including regional, sub-regional, and state data layers. These GIS data were then assessed to determine areas of ecological conservation significance (Priority Ecological Areas and Significant Ecological Areas) as well as landuse and landscape features that could impact ecological integrity. Second, the largest intact areas of ecological significance (Hubs) are delineated. Third, a GIS model is developed to identify the best opportunities to maintain ecological connectedness (Corridors) between selected Hubs. Finally, all framework components are integrated and optimized to create the Southeastern Ecological Framework.

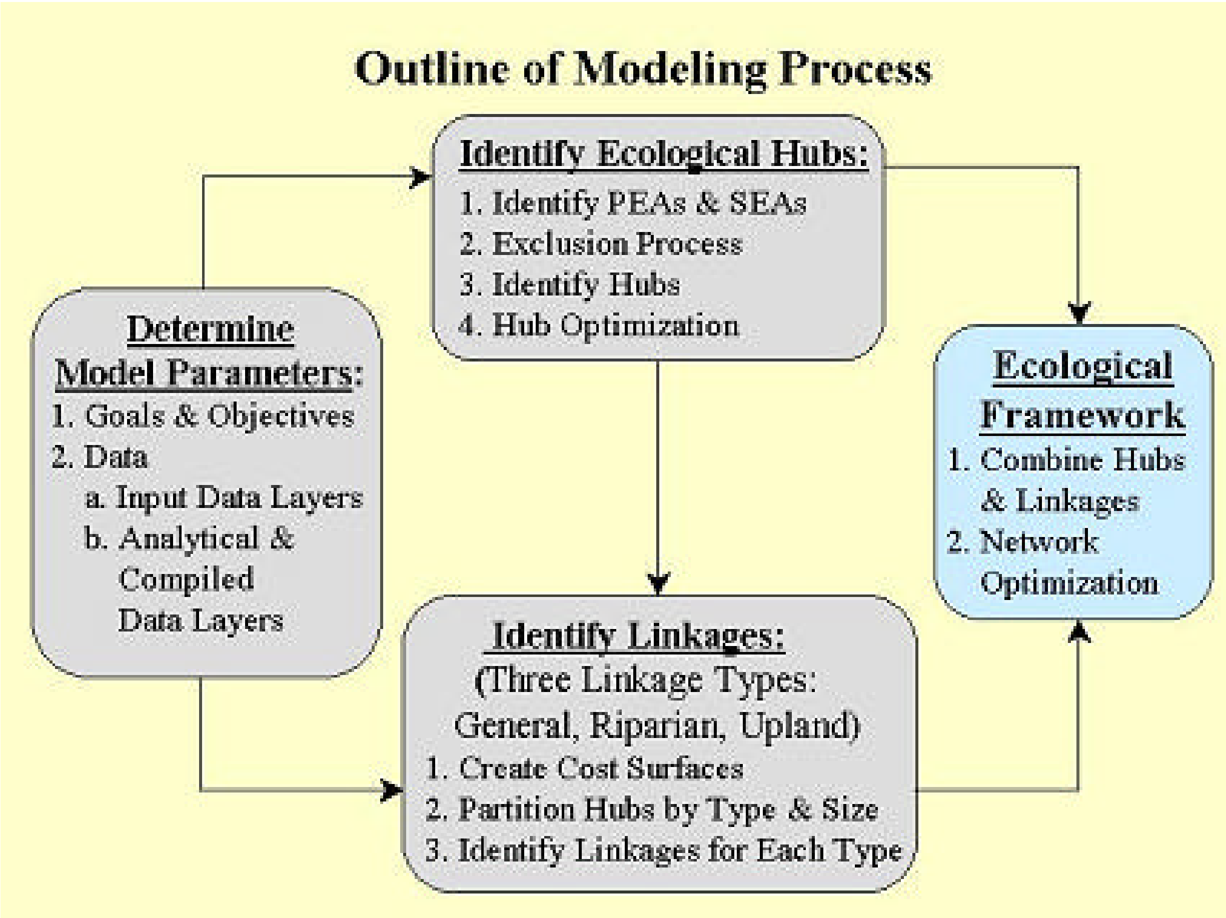

Figure 1. Outline of modeling process for the Southeastern Ecological Framework.

Identification of Priority Ecological Areas (PEAs) and Significant Ecological Areas (SEAs)

Using state and/or regionally available data sets and analyses. PEAs are the areas with the highest ecological significance identified using the best available GIS data and analyses. PEAs are the primary building blocks of the modeling process and are used to identify the larger ecologically significant areas in the region (Hubs) and the best opportunities to maintain ecological connectivity. All of the PEA criteria (See Table 1) are combined into one cumulative PEA grid where all PEAs are treated equally.

Data layer	Priority Area Criterion	State criterion used
Areas of high habitat diversity	Index of habitat diversity identifying areas with 5 or 6 different habitat types within a 90-meter pixel 27x27 neighborhood using NLCD land cover/land use data.	All states
Significant natural edge habitat	Identifies areas that border both significant natural open habitat and forest areas using NLCD.	All states
Wetlands	As defined by overlap of wetlands in both NLCD and wetlands in USGS 1:100,000 hydrology data or wetlands in LUDA data (USGS land use/land cover data).	All states
Areas with significant longleaf pine stands	Mature longleaf pine forests from the Eastwide Forest Areas Inventory Dataset. Longleaf pine stands are defined as stands that are at least 50 years old.	All applicable states
Old-growth forest stands	Old growth stands from the Eastwide Forest Areas Inventory Dataset. Old growth stands are defined as stands that are at least 100 years old.	All states
Potential black bear habitat	NLCD forest, not within ½ mile of Class 1 roads, road density of less than 2 miles per sq. mile AND greater than or equal to 10000 acres within 100 kilometers of occupied bear habitat.	All states
Existing public conservation lands and private preserves	All available existing conservation lands data within region 4, obtained from both state and regional sources	All states
Lands identified as part of the Coastal Barrier Resources Act	Undeveloped Coastal Barrier Areas (COBRA) as identified using Q3 Flood Data in FEMA's Flood Insurance Rate Maps (FIRMs) with open water excluded.	All states
Roadless areas	Areas 5000 acres or larger with no roads (excluding large water bodies) of any kind based on 1990 TIGER road	All states
Areas with high stream start reach densities	Defined as areas in the top 10% in stream start reach densities in the region with forested cover.	All states
National Estuarine Research Reserves, Shellfish Harvesting Waters, Wild and Scenic Rivers	All such designated aquatic ecosystems: All existing NERRs including a 1000 meter buffer, Wild and Scenic Rivers including a 1000 meter buffer, State Scenic Rivers (Florida only) including a 1000 meter buffer, approve & conditionally approved shellfish harvesting areas with 1000 meter buffer.	All states
Element Occurrence data on rare species and communities	Buffered element occurrences of rare species and communities, and areas with high densities of rare species occurrences. Buffer distances were based on precision (indicating the distance in which the occurrence was observed) or species or community type. Buffer distances ranged from 90 to 1800 meters. All buffered occurrences had a Global rarity of G1, G2 or G3 or a State rarity ranking of S1 or S2 observed after 1975.	Florida, Georgia, Alabama
Proposed public lands	All such land	Florida
Florida State Aquatic Preserves	All such designated aquatic features including a 1000 meter buffer	Florida
FNAI[b] Potential Natural Areas (PNAs)	Only PNAs within the top two priority levels (out of five).	Florida
FNAI[b] Areas of Conservation Interest	All ACIs	Florida
FWC[a] Strategic Habitat Conservation Areas (SHCA)	All SHCAs	Florida
FWC[a] Vertebrate Species Hotspots	Based on FWC recommendations, all areas with values 10 and greater were designated priority ecological areas.	Florida
North Carolina Significant Natural Heritage Areas	Significant natural areas ranked either A or B in a statewide inventory.	North Carolina

North Carolina land trust priority areas	All areas identified in a workshop by North Carolina land trusts as priority conservation areas.	North Carolina
Coastal Fish Nursery Areas	Coastal waters important for the initial post-larval and juvenile development of young finfish and crustaceans in North Carolina, including a 1000-meter buffer.	North Carolina
Anadromous Fish Spawning Areas	Important anadromous fish spawning areas identified by the Division of Marine Fisheries, including a 1000-meter buffer.	North Carolina
Coastal Reserve Research Areas	State-owned coastal research areas that are completely protected, including a 1000-meter buffer.	North Carolina
Bump up criterion	All SEAs that overlap with significant riparian areas (see SEA criteria below)	All States

Table 1. Criteria for selecting Priority Ecological Areas for the Southeastern Ecological Framework.
[a] The Florida Fish and Wildlife Conservation Commission was previously named the Florida Game and Fresh Water Fish Commission.
[b] Florida Natural Areas Inventory

SEAs are secondary areas that either may be "bumped up" to PEA status in some cases or are used in the landscape linkage identification process. They are other areas within the region that are of ecological significance but are not considered to be as important as PEAs. The SEA criteria (See Table 2) are combined into one cumulative grid where all SEA criteria are treated equally.

Data layer	Priority Area Criterion	State criterion used
Areas of high habitat diversity	Areas that have 4 habitat types within a 27x27 neighborhood using 90-meter pixels and NLCD data.	All states
Potential black bear habitat	NLCD forest, not within ½ mile of Class 1 roads, road density of less than 2 miles per sq. mile AND greater than or equal to 10000 acres within 100-140 kilometers of occupied bear habitat.	All states
Roadless areas	Areas 2500 to 5000 acres with no roads (excluding large water bodies) of any kind based on 1990 TIGER roads.	All states
Areas with high stream start reach densities	Defined as areas in the top 10% in stream start reach densities with forest cover within each ecoregion.	All states
Significant riparian areas	NLCD wetlands adjacent to streams (within 180 meters), intact riparian vegetation adjacent to streams (delineated as pixels with 75% density of natural/semi-natural landcover in a 5x5 neighborhood within a 180m stream buffer), and 100-year FEMA floodplains (where data was available).	All states
FNAI[b] Potential Natural Areas (PNAs)	Priority level 3 through 5 areas from the Florida statewide inventory of potentially significant natural areas.	Florida
FWC[a] Vertebrate Species Hotspots	Based on FWC recommendations, areas supporting potential habitat for 6-9 focal vertebrate species.	Florida
North Carolina Significant Natural Heritage Areas	Significant natural areas ranked C in a statewide inventory.	North Carolina

Table 2. Criteria for selecting Significant Ecological Areas for the Southeastern Ecological Framework.

Priority Ecological Area Exclusion

PEA exclusion involves deleting any areas of incompatible land use, high road density, or negative edge effect zones that overlap with the combined PEAs grid. The result, called the PEAX grid, contains the remaining Priority Ecological Areas that do not overlap with incompatible land uses or landscape features. The features deleted include: 1. All urban, residential, commercial and intensive agriculture land use, 2. Areas with road densities greater than or equal to 3 miles per square mile, using all roads except jeep trails within the 1990 TIGER roads data set, 3. All areas within "neighborhoods" with extensive urban land use in 90-meter 3X3, 9X9, and 27X27 windows. All areas with greater than or equal to 60% urban land use within all three window sizes are deleted, 4. All areas within 270 meters of a block of urban land use greater or equal to 100 acres.

Delineation of Hubs

All areas with the PEAX grid that are greater than or equal to 5000 acres are identified as Hubs for the region-wide Framework model. The 5000-acre threshold was based on the same criterion used in the Florida Ecological Network model, which was based on extensive discussion at review meetings. Such areas are large enough to support many species and ecological processes while still including relatively small areas of ecological significance. However, smaller size classes can also be easily identified to serve as additional areas of significance to facilitate the use of PEA criteria for conservation planning at local scales. Hubs are "optimized" by filling internal gaps that contain compatible land uses and smoothing outside edges. Internal gaps less than or equal to 25,000 acres are filled. Outside edges are smoothed using a combined expand and shrink algorithm to smooth minor indentations.

Identification of Landscape Linkages

The linkage process is then run to identify the best opportunities for physical ecological connections between appropriate Hubs. Linkage types include: 1. Riparian linkages including all major river systems and costal water bodies such as lagoons and connected estuaries, 2. Upland linkages (Used primarily in mountain and plateau ecoregions), 3. General Hub-to-Hub linkages (Considers wetlands and uplands as potentially suitable and was used primarily in the Coastal Plain and Piedmont ecoregions). Landscape Linkages are identified with an AML-based user interface in Arc-Info. The least cost path function, which can be used to identify the lowest cost, or conversely, the most suitable ecological path between destinations was the primary algorithm used in the interface. Cost surfaces were created for each linkage type, where most appropriate landscape features for supporting a landscape linkage are given the lowest number (1) and the least suitable landscape features are assigned the highest number. All three cost surfaces include the identification of large blocks of intact natural or semi-natural vegetation to help locate landscape linkages in wide, intact areas instead of narrow corridors whenever possible. These intact areas are separated into two classes: large and moderate. Large intact areas are defined as natural and semi-natural vegetation within both a 90 meter pixel 27X27 and 9X9 window containing 90% or more natural or semi-natural vegetation in blocks 5000 acres or larger and without primary roads. Moderate intact areas are defined as natural and semi-natural vegetation within both a 9X9 window containing 90% or more natural or semi-natural vegetation in blocks 1000 acres or larger and without primary roads.

Landscape linkages are then identified using a user-interactive process where hubs are selected for linkage, resulting least cost paths are examined, and accepted least cost paths are buffered based on the length of the linkage and the characteristics of the particular landscape. After buffering least cost paths, all linkages are "smoothed" using an algorithm that deletes outlier cells. The upland linkages are also optimized by adding agricultural land uses within 500 meters of the least cost path. The values in the cost surface represent the resistance to going through an individual cell. For example, the path would go through 99 cells valued as 1 instead of through a cell valued as 100.

All three cost surfaces include the identification of large blocks of intact natural or semi-natural vegetation to help locate landscape linkages in wide, intact areas instead of narrow corridors whenever possible. These intact areas are separated into two classes: large and moderate. Large intact areas are defined as natural and semi-natural vegetation within both a 27X27 and 9X9 window containing 90% or more natural or semi-natural vegetation in blocks 5000 acres or larger and without primary roads. Moderate intact areas are defined as natural and semi-natural vegetation within both a 9X9 window containing 90% or more natural or semi-natural vegetation in blocks 1000 acres or larger and without primary roads.

Integration and Optimization of Framework Components

All the optimized hubs and linkages are combined. Then additional optimization of the combined Ecological Framework is completed. This includes adding all PEAs after exclusion that are connected to the preliminary Ecological Framework; smoothing external edges; filling in areas containing suitable land use in narrow, linear gaps that are surrounded by the Ecological Framework; and filling in large internal gaps (less than or equal to 50,000 acres) inside the Ecological Framework that contain suitable land uses.

MODELING STREGTHS

The modeling process utilized in both the Florida Ecological Network and the SEF has important strengths that facilitate its ability to serve as a rapid assessment technique for different regions or scales. The process combines a systematic landscape analysis of ecological significance, large intact landscapes, and opportunities for ecological connectivity in a way that can be replicated, enhanced with new data, and applied at different scales. The identification of Priority Ecological Areas and corridors is query-based, which allows great flexibility in model inputs and decision-making processes. Without relying on complex weighting schemes, the modeling process can be adapted to various situations with different objectives and data sources. Criteria, thresholds, and the scale of the analysis can easily be changed, which can either be used to modify the existing model results or to re-run the model as resources allow. This affords the opportunity to develop the model process for other regions and allows for iterative identification processes as new data becomes available. The model can also be applied from local to regional scales, and local versions of the modeling process can be created using even more resolute and specific data sets to assist in connecting local conservation planning initiatives with larger scale ecological processes. In addition, ever-increasing sophistication of computer technology is allowing for large regional assessments to be done using more resolute data and analyses. For example, due to data processing and storage constraints the FEN model was conducted using 180 meter grid cells, while much of the SEF assessment was run with 30 meter cells with the final model results having a resolution of 90 meters (see Figure 2).

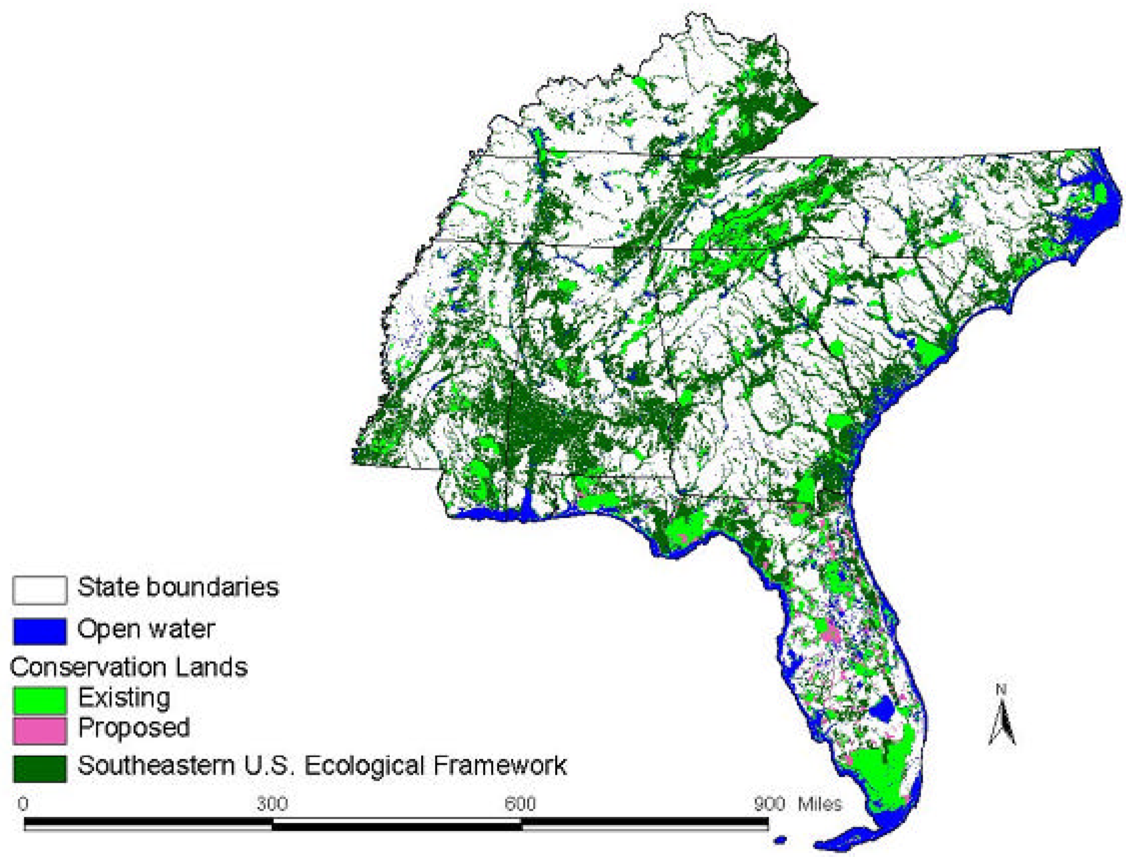

Figure 2. The Southeastern Ecological Framework for EPA Region 4 including existing conservation lands for all eight states and officially proposed conservation land projects in Florida.

The identification of areas of ecological significance and the design of reserve networks must be an iterative process to be successful. New information and technology will continue to become available and must be considered. In fact, one could argue that the work has only just begun once the first iteration of an ecological network or framework is identified. Furthermore, the SEF can serve as a catalyst that creates better opportunities for enhanced iterations or assessment techniques by fostering discussion and leading to partnerships. In our experience, the FEN and the SEF help people and organizations better visualize the concept of regional scale ecological and biodiversity planning. This important step then provides the opportunity for more discussion about available data and assessment methods that can strengthen future iterations. The SEF has already lead to discussions with organizations such as TNC and ABI about integrating additional biodiversity information sources and analyses into a much more comprehensive effort in the future.

CONCLUSION

The Southeastern Ecological Framework is an innovative approach to land use decision management across EPA program responsibilities. It provides the opportunity for program managers to visualize their responsibilities in the context of the ecosystem as a whole, rather than the typical stove pipe perspective. This narrow or single focus perspective has served EPA well in the past, when congress provided money for specific mandated activities. Standards were developed for pollutants, program staff went out into the field and sampled end-of-pipe discharges, permit writers wrote permits for the facilities and then enforcement reviewed compliance. However, the days of walking down a rivers edge and identifying the bad guys are gone for the most part. The new culprits are typically non-point sources or the cumulative impact of a dozen facilities that are all meeting best management practices. To address these issues, program managers are going to have to be aligned with other programs within their division, outside their division, across federal agencies and with various partners at the state, local and community level.
New approaches to creating synergy for environmental protection will have to be designed if we are to continue our progress. We believe that the SEF provides a new approach to coordinating and prioritizing EPA's work that allows for continued progress in protecting human health and safe guarding the environment. This is evident in the support that SEF provides for five of the agencies Strategic Planning golas. GIS modeling provides significant opportunity to overlay program specific data sets used in decision-making. Inclusion of the SEF in programmatic actions provides an opportunity to refine the decision structure in support of ecosystem function. Using the SEF as a *decision support tool* also provides a unique opportunity to work across agency programs and leverage scarce resources available for on the ground protection efforts.

The Southeastern Ecological Framework model has several advantages that make it adaptable to other regions. First, the identification of Priority Ecological Areas and Corridors is query-based, which allows great flexibility in model inputs and decision-making processes. The modeling process can be adapted to various situations with different objectives and data sources based on the question being asked. Criteria and thresholds of the analysis can easily be changed. The model is easily reproducible allowing for iterative identification processes as new data becomes available, which can then be used to modify the existing model results. The model can also be applied from local to regional scales, and local versions of the modeling process can be created using even more resolute and specific data sets to assist in local decision-making.

The input data, modeling products, and final Ecological Framework can all be used to promote and support conservation planning efforts by state and local entities. As stated above, the modeling process is adaptable to various scales and can be combined with additional data sets and reproduced at state and local scales. EPA and the University of Florida are developing a matrix of the data layers used in developing the Ecological Framework as well as new data that supports prioritization of critical habitat, longleaf pine forest or old growth forest stands, expansion of wildlife refuge areas to manage for a specific species, or any organizations primary concern. The use of the SEF as a base layer maintains focus on the larger ecological processes that are at work in a given watershed, but also support localized efforts by overlapping community data and issues for on-the-ground protection efforts. The characterization approach to identify areas that are more critical within the framework provides flexibility and coordination for natural resource protection efforts. The Southeastern Ecological Framework provides an opportunity to act rather than react, to coordinate rather than piecemeal fragmented options, and to leverage resources in a time when few resources are available.

REFERENCES

Berish, C.W., B.R. Durbrow, J.E. Harrison, W.A. Jackson and K.H. Ritters, 1999. Conducting regional environmental assessments: the southern appalachian experience. Pages 117-166 in J.D. Piene, editor, *Ecosystem management for sustainability: principles and practices illustrated by a regional biosphere reserve cooperative*. Lewis Publishers, Boca Raton.

Cox, J., R. Kautz, M. MacLaughlin, and T. Gilbert. 1994. Closing the gaps in Florida's wildlife habitat conservation system: recommendations to meet minimum conservation goals for declining wildlife species and rare plant and animal communities. Florida Game and Fresh Water Fish Commission, Tallahassee Florida.

Daily, G.C., 2000. Management objectives for the protection of ecosystem services. *Environmental Science and Policy* 3:6:333-339.

Daniels, T. and D. Bowers, 1997. *Holding our ground: protecting America's farms and farmlands*. Island Press,

Washington, D.C.
Florida Greenways Commission, 1994. Report to the Governor: creating a statewide greenways system: for people . . . for wildlife . . . for Florida. Florida Department of Environmental Protection, Tallahassee.
Forman, T.T. and M. Godron. 1986. *Landscape ecology*. John Wiley & Sons, New York
Forman, R.T.T., 1995. *Land mosaics: the ecology of landscapes and regions*. Cambridge University Press, Cambridge, United Kingdom.
Harris, L.D. 1984. *The fragmented forest: island biogeography theory and the preservation of biotic diversity*. University of Chicago Press, Chicago.
Harris, L. D., and K. Atkins. 1991. Faunal movement corridors in Florida. Pages 117-134 in W.E. Hudson, editor. Landscape linkages and biodiversity. Island Press. Defenders of Wildlife, Washington, D.C.
Harris, L.D., and G. Silva-Lopez, 1992. Forest fragmentation and the conservation of biological diversity. Pages 197-237 in P. Fielder and S. Jain, editors. *Conservation biology: the theory and practice of nature conservation*. Chapman and Hall, New York.
Harris, L.D., T.S. Hoctor, and S.E. Gergel, 1996a. Landscape processes and their significance to biodiversity conservation. Pages 319-347 in O.E. Rhodes Jr., K. Chesser, and M.H. Smith, editors, *Population dynamics in ecological space and time*. The University of Chicago Press. Chicago.
Harris, L. D., T. Hoctor, D. Maehr, and J. Sanderson. 1996b. The role of networks and corridors in enhancing the value and protection of parks and equivalent areas. Pages 173-198 in R. G. Wright, editor. *National parks and protected areas: their role in environmental areas*. Blackwell Science, Cambridge, Massachusetts.
Hefner, J.M., et. al., 1994. Southeast Wetlands: status and trends, mid-1970s to mid-1990s. U.S. Fish and Wildlife Service.
Hoctor, T.S., M.H. Carr, and P.D. Zwick, 2000. Identifying a linked reserve system using a regional landscape approach: the florida ecological network. *Conservation Biology* 14:4:984-1000.
Land Trust Alliance. 1999. Voters Invest in Parks and Open Space, 1998 Referenda Results.
Mattikalli, N.M. and K.S. Richards, 1996. Estimation of surface water quality changes in response to land use change: application of the export coefficient model using remote sensing and geographical information system. *Journal of Environmental Management*, 48:263-282.
Mysz, A.T., C.G. Maurice, R.F. Beltran, K.A. Cippollini, J.P. Perrecone, K.M. Rodriguez, and M.L. White, 2000. A Targeting approach for ecosystem protection. *Environmental Science and Policy* 3:6:347-356.
Noss, R.F., and L.D. Harris. 1986. Nodes, networks, and MUMs: preserving diversity at all scales. *Environmental Management* 10:299-309.
Noss, R.F., 1987. Protecting natural areas in fragmented landscapes. *Natural Areas Journal* 7:2-13.
Noss, R.F., 1991. Landscape connectivity: different functions at different scales. Pages 27-39 in W. E. Hudson, editor., *Landscape linkages and biodiversity*. Island Press and Defenders of Wildlife, Washington, D.C.
Noss, R.F., and C.A. Cooperrider, 1994. *Saving nature's legacy: protecting and restoring biodiversity*. Defenders of Wildlife and Island Press, Washington, D.C.
Noss, R.F., 1996. Protected areas: how much is enough? Pages 91-120 in R.G. Wright, editor, *National parks and protected areas: their role in environmental protection*. Blackwell Science, Cambridge, Massachusetts.
Noss, R.F., 2000. High-risk ecosystems as foci for considering biodiversity and ecological integrity in ecological risk assessment. *Environmental Science and Policy* 3:6:321-332.
Odum. H.T., E.C. Odum, M.T. Brown, 1998 Environment and Society in Florida, Lewis Publishers, Boca Raton.
Peine, J.D., 1999. *Ecosystem Management for Sustainability: Principles and Practices Illustrated by a Regional Biosphere Reserve Cooperative*. Lewis Publishers, Boca Raton.
Salwasser, H., J.A. Caplan, C.W. Cartwright, A.T. Doyle, W.B. Kessler, B.G. Marcot, and L. Stritch, 1996. Conserving biological diversity through ecosystem management. Pages 548-573 in Szaro, R.C. and D.W. Johnson, editors. *Biodiversity in managed landscapes: theory and practice*. Oxford University Press, Oxford, United Kingdom.
Southeast Natural Resources Leaders Group (SENRLG), 2001. Environmental status and trends in the southeast: 2000. http://www.gaatl.er.usgs.gov/srnrl.html.
Southern Appalachian Man and Biosphere (SAMAB) Cooperative, 1996. The southern appalachian assessment summary report. United States Department of Agriculture, Washington, D.C.
Vogelmann, J.E., T. Sohl, and S.M. Howard, 1998. Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering & Remote Sensing*.