Identifying a Linked Reserve System Using a Regional Landscape Approach: the Florida Ecological Network

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Abstract: *We completed an analysis of potential ecological connectivity to identify areas with priority conservation significance and landscape linkages as part of a state of Florida program called Greenways. This is the latest step in the state's design and protection of a reserve system based on an aggressive land acquisition program. We used geographic information systems software (Arc-Info) to develop a decision support model that uses land-use data and information on significant ecological areas—including important habitats for target species, priority ecological communities, wetlands, roadless areas, floodplains, and important aquatic systems—to identify larger areas of ecological priority and potential ecological linkages. The result of this process, the Florida Ecological Network, includes approximately half the state's area, with over half of this network already in conservation lands or public-domain water. This network could provide a linked state-wide reserve system containing most of each major ecological community and most known occurrences of rare species. Although the ecological network represents significant progress toward a more integrated approach to biodiversity conservation in Florida, further analysis is needed to (1) ensure that the needs of wide-ranging species, such as the Florida panther (*Puma concolor coryi*) and Florida black bear (*Ursus americanus floridanus*), are addressed; (2) identify other biodiversity elements not well represented; and (3) designate a system of cores and buffers that will address management issues. Reserve design is an iterative process, and future plans need to address new information, including the results of the Florida GAP analysis project and ongoing habitat loss.*

Identificación de un Sistema de Reservas Conectado Usando una Estrategia de Paisaje: la Red Ecológica de Florida

Resumen: *Completamos un análisis de conectividad potencial ecológica para identificar áreas con trascendencia prioritaria de conservación y conectividad de paisaje como parte de un programa del estado de Florida llamado "Greenways." Este es uno de los últimos pasos en el diseño y la protección de un sistema de reservas del estado basado en un programa agresivo de adquisición de tierra. Usamos un programa de sistemas de información geográfica (Arc-Info) para desarrollar un modelo de apoyo de decisiones que usa datos de uso del suelo e información sobre áreas ecológicamente importantes—incluyendo hábitats importantes para especies clave, comunidades ecológicas prioritarias, humedales, áreas sin carreteras, planicies de inundación, e importantes sistemas acuáticos—para identificar áreas grandes de prioridad ecológica y potenciales conexiones ecológicas. Los resultados de este proceso, la Red Ecológica de Florida, incluye aproximadamente la mitad del área del estado, con más de la mitad de su red de conexiones en tierras de conservación o en aguas de dominio público. Este sistema de redes puede proveer un sistema de reservas a nivel estatal que contenga la mayoría de las comunidades ecológicas más importantes y de los casos más conocidos de presencia de especies raras. A pesar de que la Red Ecológica representa un avance significativo hacia una estrategia más integrada para la conservación de la biodiversidad de Florida, aún se necesita más análisis para (1) asegurar que las necesidades de especies de amplio rango, tales como la pantera de Florida (*Puma concolor coryi*) y el*

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*oso negro de Florida (*Ursus americanus floridanus*) sean atendidas; (2) identificar otros elementos de la biodiversidad que no estén bien representados; y (3) designar un sistema de núcleos y amortiguamientos que atiendan temas relacionados al manejo. El diseño de una reserva es un proceso iterativo, y los planes futuros necesitan atender información nueva que incluya los resultados del proyecto de análisis GAP de Florida y la actual pérdida del hábitat.*

Introduction

Since the reports of Wright et al. (1933) and Wright and Thompson (1934), there has been a growing awareness that typical protected areas such as national parks are often not sufficient to protect viable populations of sensitive species and biological diversity as a whole (Noss & Harris 1986; Harris et al. 1996*a*, 1996*b*). With the coalescence of the field of conservation biology over the last two decades, reserve design concepts and principles have continued to evolve. In the state of Florida the application of integrated reserve design principles has been forwarded since the 1980s as a means to effectively conserve biological diversity in the face of rapid human population growth and habitat fragmentation (Harris 1984; Harris 1985; Noss & Harris 1986; Noss 1987*b*; Harris & Gallagher 1989; Harris & Atkins 1991; Harris & Scheck 1991). Included in this process was the Florida reserve design proposal by Noss (1987*b*; Noss & Cooperrider 1994) (Fig. 1) and the results of a mapping

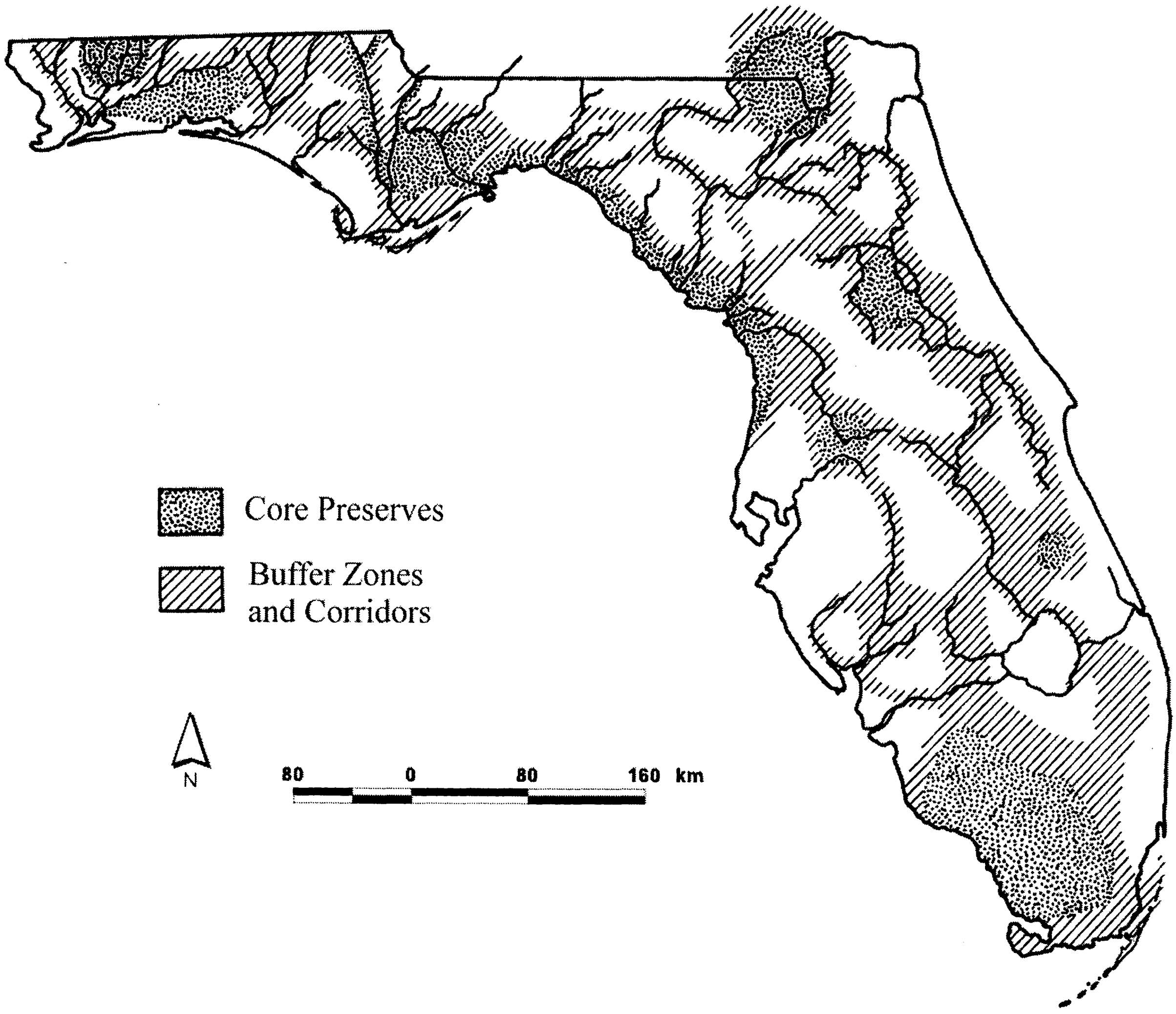

*Figure 1. Reserve network for Florida proposed by Noss (1987*b*; Noss & Cooperrider 1994 [reprinted with permission from Island Press, Washington, D.C.])*

workshop coordinated by The Nature Conservancy that used a variety of experts to identify conservation priorities and areas of conservation interest (Fig. 2).

In this atmosphere, the Conservation Fund of Washington, D.C. and 1000 Friends of Florida began the Florida Greenways Program in 1991 with the goal of public endorsement and adoption of a greenways initiative. A gubernatorial commission was created, which completed a report in 1994, and greenways legislation was adopted the following year. The departments of Environmental Protection (DEP) and Transportation funded the greenways plan through the federal transportation program known as the Intermodal Surface Transportation Efficiency Act (ISTEA), and DEP was the lead state agency. Although often misconstrued as simply a recreation program, the state interprets greenways to include an ecological conservation component. In fact, considerable emphasis was placed on the definition, delineation, and implementation of the ecological component.

We applied geographic information system (GIS) technologies to assist in the physical design of the Florida greenways system. This included the identification of

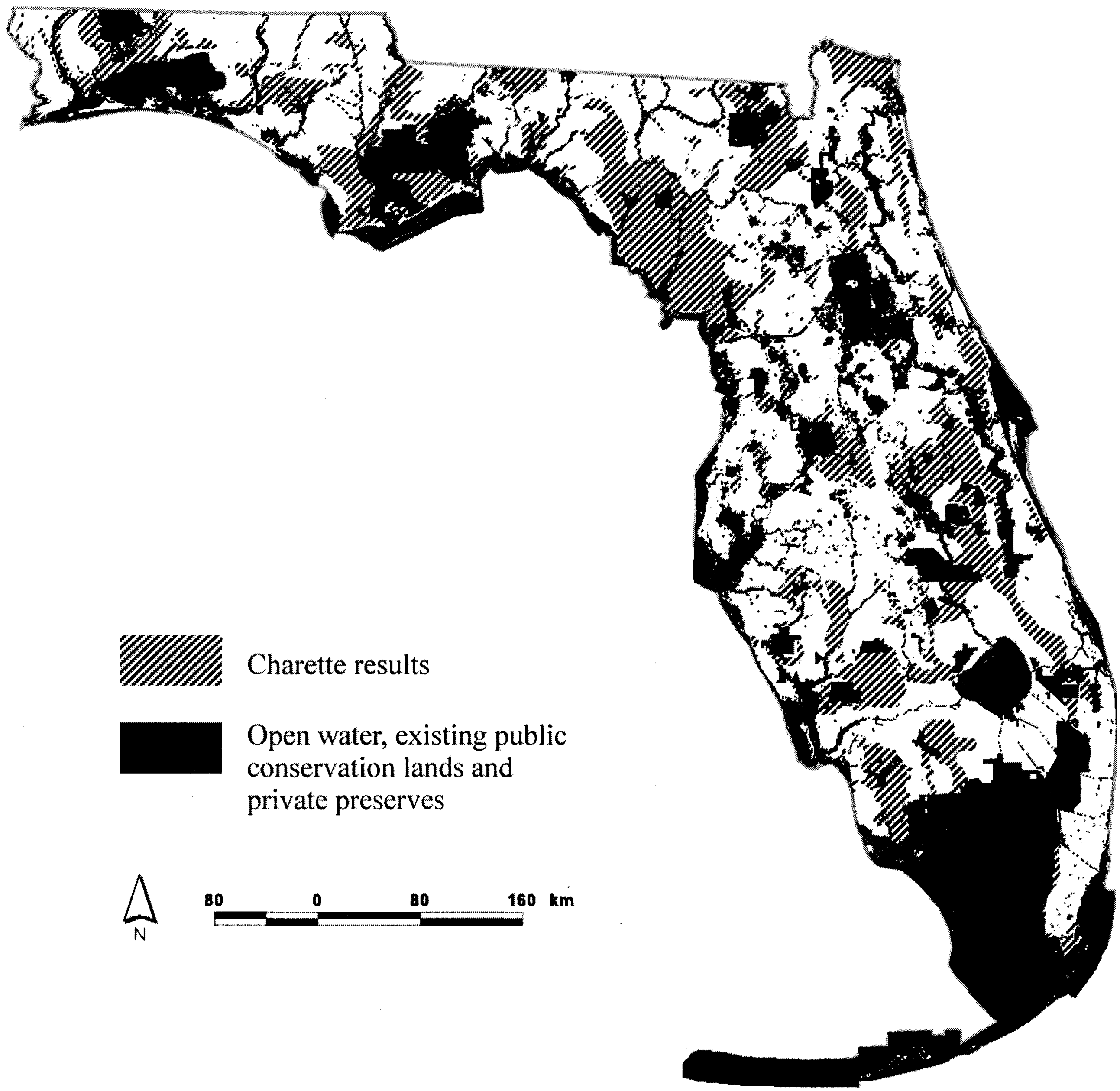

Figure 2. Results of 1991 mapping workshop (charette) coordinated by The Nature Conservancy identifying conservation priority areas and areas of conservation interest.

large areas of ecological significance and landscape linkages integrated as a connected statewide reserve network. Because rapid human population growth and habitat destruction (Harris & Atkins 1991; Kautz 1993) continues in Florida, the identification and protection of a large-scale, connected reserve network is an essential, primary element in the effort to conserve the state's biological diversity. The Florida greenways program provides the opportunity to further advance the identification and protection of such a network. The goal of our analysis was to use a regional landscape approach to design an ecologically functional statewide greenways system that (1) conserves critical elements of Florida's native ecosystems and landscapes, (2) restores and maintains essential connectivity among diverse native ecological systems and processes, (3) facilitates the ability of these ecosystems and landscapes to function as dynamic systems, and (4) maintains the evolutionary potential of the biota of these ecosystems and landscapes to adapt to future environmental changes (Florida Greenways Commission 1994).

The rationale is that a functional reserve network integral to effectively conserving Florida's biological diversity and other natural resources can be identified by using a landscape approach guided by regional conservation planning principles combined with information on areas needed to protect viable populations of target species and natural communities. We accomplished this by incorporating assays of ecological significance, such as locations of rare and listed species, intact ecological communities, habitat areas needed to maintain viable populations of sensitive species, and land-use data, into a reserve design process integrating these components. The result is the first iteration of an interconnected Florida reserve system called the Florida Ecological Network (based on the definition by Forman 1995). This effort is similar to other projects in North America and Europe to identify, plan, and protect regional reserve networks (Jongman 1995; Soulé & Terborgh 1999).

Methods

Review Process

Because of the complexity of the modelling process and its broad goals and objectives, we had to make numerous modelling assumptions and decisions about specific modelling parameters and sequence. To ensure the appropriateness of our modelling decisions and to gain input on the use and application of available statewide data, we gathered information in over 20 sessions from 1995 through 1997. We received input from the Florida Greenways Commission, the Florida Greenways Coordinating Council, scientists, university personnel, conservation groups, planners, and other personnel in federal, state, and regional environmental agencies, and the general public.

GIS Analysis

Geographic information systems are increasingly being used to assist in the analysis and synthesis of information in environmental planning and design. The Florida Game and Fresh Water Fish Commission (whose name has recently been changed to the Florida Fish and Wildlife Conservation Commission, FWC) used a GIS to identify strategic habitat conservation areas for selected species and communities of conservation interest (Cox et al. 1994). The GAP analysis protocol is dependent on GIS to analyze vegetative communities and to identify potential habitat for all selected species (Scott et al. 1993). Although the usefulness of GIS for analysis and planning has never been questioned, there have been impediments to its wider application: thematic data accuracy and uncertainty, data handling and management, positional accuracy, lack of data, and unwieldy software. These are gradually being eliminated, making the increased future application of GIS to conservation a certainty.

The GIS decision-support model we used was composed of four steps. The majority of the work was done in a raster format using Environmental Systems Research Institute's Grid module of the ArcInfo software package. Grid utilizes a map-algebra spatial language, which is a computational language valuable for spatial modelling. The cell, or pixel, size for the analysis was 180×180 m (approximately 3 ha). We used a 180×180 m cell size to reduce data storage requirements and model simulation speed and to maintain analysis and mapping scales within the U.S. Geological Survey national mapping accuracy standards. Presently, our team is updating the results using a cell size of 30×30 m because disk storage, machine memory, and speed have increased significantly, resulting in the ability to work with data sets of enormous size.

The identification of areas of ecological significance (step 1), was performed through queries and re-classification of various GIS data layers. These data layers included strategic habitat conservation areas, priority natural communities, existing conservation lands, roadless areas, and information on significant aquatic ecosystems. We developed rankings for each of the layers and combined all areas with primary ecological significance into a single layer called priority ecological areas (Table 1). An area was included if it fell in one of the areas of ecological significance (data layers), and no significance was given to areas that met multiple criteria. These areas represented the primary building blocks of the linked reserve network.

Selection of hubs (step 2), involved identification of potential core areas for the protection of biological diversity and ecological processes. We began with the priority ecological areas layer (step 1) and then selected the areas with the highest ecological integrity potential. We accomplished this through the application of a five-part process.

(1) We eliminated more intensive land uses ranging from improved pastures and croplands to residential, commercial, and industrial lands. This helped rectify potential inconsistencies or errors in data used to determine areas of ecological priority. We identified these areas with land-use data from Florida's five water-management districts (WMD). Their data were derived from satellite imagery and aerial photo-

Table 1. Criteria for selecting priority ecological areas for the Florida Ecological Network.

Data layer	*Priority area criterion*	*Explanation/rationale*
FWC[a] strategic habitat conservation areas (SHCA)	all SHCAs	Includes lands outside existing protected areas needed to maintain or restore minimally viable populations of 30 focal vertebrate species, rare natural community types, important wetlands for wading birds and globally rare plant species. Many focal species used in this analysis are umbrella species whose conservation requirements will meet the needs of other species, and the natural communities identified represent a coarse-filter approach to protecting suites of species.
FWC hotspots	areas containing potential habitat for seven or more focal species	Areas containing potential habitat for seven or more of the focal species analyzed in the identification of SHCAs. FWC staff recommended the threshold of seven.
FWC wetland hotspots	areas containing potential habitat for seven or more wetland-dependent species or four or more species requiring both wetland and upland habitat	Areas represent wetlands within Florida with habitat to potentially support additional wetland-dependent and partially wetland-dependent vertebrate species. FWC staff recommended the thresholds.
FNAI[b] areas of conservation interest (ACIs)	all ACIs	ACIs were identified outside existing public lands by means of aerial photos, natural heritage data, and expert knowledge. ACIs are high-quality, relatively pristine sites in which rare species occur.
FNAI potential natural areas (PNAs)	all PNAs except those receiving the lowest rank due to significant disturbance	Includes most of the remaining sites available to conserve native ecosystems in Florida, although some disturbance may be present and the status of tracked species may not be completely known.
Rare and priority natural community types based on FWC habitat data and rankings by FNAI	all community types ranked S2 or higher that could be identified by means of the 22-class FWC landcover map that included coastal strand, dry prairie, sand pine and oak scrub, sandhill, tropical hardwood hammocks, freshwater marsh, and wet prairie	FNAI "S" ranks are state ranks based on The Nature Conservancy's global rankings (G1-G5, 1 being most imperiled). FWC landcover data are classified LANDSAT imagery from 1985-1989, but because of the coarse scale of the classification, some S1 communities were not identified in this data set; however, these communities were represented in the SHCA, ACI, and PNA analyses.
Existing public conservation lands and private preserves (e.g., Audubon, The Nature Conservancy)	all such lands	Approximately 20% of the state is now contained in conservation lands. Although management practices vary widely, all sites are potentially significant building blocks for a statewide reserve system.
Proposed public conservation lands and easements	all such lands	Approximately 6% of the state has been identified for purchase through Florida's aggressive conservation land-acquistion program. These parcels were selected based on the presence of high-quality natural communities, habitat for rare species, opportunities to protect connectivity, or other conditions supportive of conservation objectives.
Lands identified as part of the Coastal Barrier Resources Act	all such lands	Typically coastal barrier islands identified by the federal government as undeveloped. Such sites are significant for conserving coastal ecosystems.
Roadless areas	2,000 ha or larger containing no roads of any kind	Roadless areas are important to species sensitive to humans, are typically buffered from disturbance, and provide connectivity for species isolated by roads. A 2000-ha area was used based on federal roadless standards, average home-range size for the Florida black bear, and recommendations by reviewers.

continued

Table 1. (continued)

Data layer	*Priority area criterion*	*Explanation/rationale*
"Roadless" areas without major roads	40,000 ha or larger containing no major roadways such as interstate, federal or state highways, or large-capacity county roads	Large areas containing no high-volume roads may be critical for maintaining many sensitive species, especially wide-ranging animals such as the Florida black bear and the Florida panther. The threshold is consistent with the FWC's objective to prevent major road construction in areas of >40,000 ha currently without major roads.
State aquatic preserves, national estuarine research reserves, outstanding Florida waters, shellfish harvesting waters, wild and scenic rivers	all such designated aquatic ecosystems	The greatest dearth in information about Florida's natural communities and species is for aquatic ecosystems. In the absence of such data, these designated aquatic areas, all indicating a level of quality that could support functional aquatic ecosystems, were used as a surrogate for a more comprehensive identification of significant aquatic features.
Overlap criteria	moderately ranked FWC focal species, FWC wetland species hotspots, and lower-ranked FNAI PNAs, smaller roadless areas (1,000 ha or greater and 20,000 ha or greater, respectively) that overlap with 100-year floodplains or areas of significant aquifer recharge	Moderately ranked habitat areas and roadless areas that overlap with areas significant for maintaining aquatic ecosystems and processes are also significant conservation features.

[a] *The Florida Fish and Wildlife Conservaton Commision was previously named the Florida Game and Fresh Water Fish Commision.*
[b] *Florida Natural Areas Inventory.*

graphy taken from 1988–1994. To ensure removal of areas that were no longer suitable, we updated the information on the most intensive land uses (urban) with SPOT imagery taken from 1995–1996.

(2) We removed areas of extremely high road density that greatly exceeded general road density standards for protecting sensitive species ($\geq$3km/km^2) (Noss 1992).

(3) We removed areas with the greatest potential for negative edge effects, which were modeled coarsely as areas within 180 m of urban land uses. This was the minimum edge-effect distance that could be modeled given our cell size, and it was selected as a minimal estimate for the most intensive potential negative edge effects (Meffe et al. 1997).

(4) We identified the remaining priority ecological areas that were $\geq$2000 contiguous ha in size, based on recommendations from reviewers during model development. Such areas are large enough to support many species and ecological processes while still including relatively small areas of ecological significance (Forman 1995).

(5) The resulting hubs were "optimized" by smoothing edges and filling in internal gaps by adding lower-priority native habitat and potentially compatible land uses such as pine plantations and rangelands, which were identified by means of a combination of the FWC land-cover and WMD land-use data.

Identification of linkages (step 3) was the most complex portion of the GIS modelling. We used the National Wetlands Inventory classification system (Cowardin et al. 1979) as the starting point for the derivation of three native landscape units: (1) upland dominated, (2) riverine and large wetland basins, and (3) coastal (Table 2). These landscape units served as a logical, broad basis for identifying various potential landscape linkage types. The landscape units were used to partition hubs into the three general landscape classes and to develop linkage types.

Next we identified the five linkage types from the three landscape units. Linkage types included (1) coastal to coastal, (2) riverine to riverine, (3) upland to upland, (4) riverine to coastal, and (5) cross-basin hub to hub. Linkages between hubs of like types were modeled before linkages between hubs of different types. The last linkage type, cross-basin hub to hub, is a broad category that allowed for exploration of linkage feasibility between, for example, an upland ridge system and a neighbouring river corridor or through agricultural landscapes where some restoration may be needed to restore connectivity.

An algorithmic function called "least-cost path" was used to identify landscape linkages. To apply the function, a suitability surface ("cost surface" in ArcInfo parlance) was created. Its purpose was to represent the relative suitability of every cell for potential inclusion in a linkage. Five different suitability surfaces were created, with one for each linkage type. In each suitability surface, the value assigned to each cell was inversely proportional to its relative suitability for that linkage type, (e.g., a cell with the value of 1 is most suitable, 2 is next most suitable, and so forth; example provided in Tables 3 & 4; Fig. 3). The function also allows for the identifica-

Table 2. Landscape unit classification employed in landscape linkage identification for the Florida Ecological Network.

Landscape unit	*Ecosystems*
Coastal	open coastal waters, coastal strand, coastal salt marsh, mangrove, inshore marine habitats, all other native habitats within contiguous 100-year coastal flood zone
Riverine and large wetland basins	open waters of major Florida rivers* plus the following when contiguous to major rivers or ≥400 ha: bottomland hardwood forest, cypress swamp, freshwater marsh and wet prairie, bay swamp, mixed hardwood swamp, shrub swamp, freshwater aquatic habitats, open lake waters
Upland-dominated landscape	dry prairie, flatwoods, xeric scrub, sandhill, mixed hardwood-pine forest, hardwood forest, tree plantations, wetland/isolated aquatic habitats <400 hectares

**Florida Resources and Environmental Analysis Center 1990.*

tion of unsuitable cells in which a potential linkage could not be located. The relative suitability of each cell was determined by querying original data layers and data layers derived in steps 1 and 2. The suitability surfaces ranged from simple for the like-type linkages such as riverine to riverine (Table 4) to complex for the general hub linkages that required a much broader range of suitability values to discriminate between highly suitable and much less suitable areas (Table 5). The least-cost path function was then run to find the optimal path for selected hub pairs for each linkage type. Accepted paths were widened to include all contiguous cells of native habitat or lower-intensity land uses up to a width of 25% of the linkage length to incorporate corridor widths that would provide wide landscape linkages, maintain habitat gradients from aquatic to upland ecosystems, and buffer aquatic ecosystems in riverine and coastal landscapes.

Creation of the Florida Ecological Network, step 4, was achieved by combining the identified hubs and linkages.

Results

Florida still supports large areas of intact native ecological communities and potentially compatible land uses that could serve as a connected statewide reserve system. The Florida Ecological Network links the larger public conservation lands and incorporates other important landscape features of each region (Fig. 4). In the Florida Panhandle, the numerous rivers that flow north to south (e.g., the Apalachicola) form a network from the Blackwater River State Forest and Eglin Air Force Base to the Apalachicola National Forest. Northcentral Florida is dominated by the Suwannee River corridor, which links the lowlands of the Big Bend on the Gulf Coast to the Osceola National Forest–Pinhook Swamp–Okefenokee National Wildlife Refuge complex, and a large landscape linkage parallel to the western shore of the St. Johns River that connects the Ocala and Osceola National Forests. In central Florida, river and swamp basins, including the Kissimmee, Peace, St. Johns, Myakka, and Withlacoochee rivers, join the sandhills and scrub of the Lake Wales Ridge and Brooksville Ridge to provide the primary elements of a network that includes the Ocala National Forest, Green Swamp, Three Lakes Wildlife Management Area, and Avon Park Bombing Range. Southern Florida is dominated by the Everglades National Park–Big Cypress National Preserve complex, with linkages to ecological features in central Florida via Okaloacoochee Slough and Fisheating Creek west of

Table 3. Riverine suitability surface values for the Florida Ecological Network.*

Category	*Value*
Criteria for highly suitable areas	
open water associated with major Florida rivers classified as PNAs	1
freshwater wetland ecosystems classified as PNAs	1
open water associated with major Florida rivers classified as SEAs	2
freshwater wetland ecosystems classified as SEAs	2
Criteria for moderately suitable areas	
open water associated with major Florida rivers not classified as PNA or SEAs	3
freshwater wetland ecosystems not classified as PNAs or SEAs	3
open water and areas with high road density or negative edge effect	4
areas with high road density or negative edge effect that meet the riverine open water or freshwater wetland criteria for this linkage type	4
Criteria for unsuitable areas	
intensive agriculture and urban lands	no value
all other cells	no value

**The lower the value the higher the suitability. PNA, potential natural area. An SEA, or significant ecological area, is an area meeting criteria for moderate significance such as moderately ranked hotspots of the Florida Fish and Wildlife Conservation Commission and potential natural areas of the Florida Natural Areas Inventory.*

Table 4. Hub-to-hub suitability surface values for the Florida Ecological Network.[a]

Category	*Value*
Potential natural areas (PNAs) that meet all but the 2000-hectare size criteria for hubs and that are contiguous to significant coastal and/or inland aquatic features	1
Other PNAs that meet the 2000-acre size filter	2
SEAs[b] contiguous to significant coastal and/or inland aquatic features	2
Native habitat contiguous to significant coastal and/or inland aquatic features	3
All remaining SEAs[b]	3
All other native habitat	4
Low-intensity land use or land cover that is contiguous to significant coastal and/or inland aquatic features	4
All other low-intensity land use or land cover	5
Native habitat lands with areas of negative edge effects or areas of high road density	600
Lands with low-intensity use and areas of negative edge effects or high road density	700
Improved pasture contiguous to significant coastal and/or inland aquatic features	7000
Cropland contiguous to significant coastal and/or inland aquatic features	8000
All other lands in moderate-intensity use that are contiguous to significant coastal and/or inland aquatic features	9000
Improved pasture	70,000
Cropland	80,000
All other lands with moderate-intensity use	90,000
Open water	100,000
Urban lands	no value
All other cells	no value

[a] *The lower the value the higher the suitability.*
[b] *An SEA, or significant ecological area, is an area meeting criteria for moderate significance such as moderately ranked hotspots of the Florida Fish and Wildlife Conservation Commission and potential natural areas of the Florida Natural Areas Inventory.*

Lake Okeechobee and via the Corbett Wildlife Management Area and the flatwoods, prairies, and sloughs east and northeast of Lake Okeechobee.

Of the approximately 9.3 million ha (57.5% of the state) incorporated into the ecological network, 4.8 million ha (52.2% of the network) are within existing public conservation lands of various federal, state, regional, and local designations; private preserves such as those owned by The Nature Conservancy; or open water, considered public domain by Florida law. Thus, less than half of the identified ecological network is on private land that may need protection (Table 5). Of the private land included in the ecological network, more than 50% is either within an existing conservation project, wetlands, or 100-year floodplains. Although these areas may be more easily protected than the 2 million ha of uplands in private ownership, the model results still identify a total of approximately 4.5 million ha of unprotected land.

Comparisons with Other Ecological Inventories

There are good analyses and data for Florida that indicate potential priority areas for conserving biological diversity. Two key analyses used in the ecological model were the strategic habitat conservation areas identified by the FWC (Cox et al. 1994) and areas of conservation interest and potential natural areas of the Florida Natural Areas Inventory (Table 1). Although we used other data, as described above (such as for the identification of roadless areas), the FWC and FNAI data were integral to identifying a connected statewide reserve system. Because of the details and sequence of the modelling process, not all areas represented by the FWC and FNAI data were included in the ecological network. For example, (1) the lowest-ranking FNAI potential natural areas were not automatically included because of the level of disturbance found on lower-priority sites; (2) areas of intensive land use identified from data sources more current than the FNAI and FWC data were excluded from consideration; and (3) even if an area was included in FNAI and/or FWC results, if it was not within a hub of at least 2000 ha it was not automatically included in the ecological network.

Though not comprehensive, comparisons between the FWC and FNAI data and the ecological network are useful measures of the potential significance of the model results for conservation of focal species and natural communities. Over 80% of the strategic habitat conservation areas and over 68% of the areas of conservation interest and potential natural areas were contained in the network (Table 6). Most of the strategic habitat conservation areas that did not overlap with the ecological network were primarily isolated wetlands and scrub or areas in southcentral Florida recommended for conservation of the Crested Caracara (*Polyborus plancus*) which overlapped with lands classified as improved pasture, so these were excluded from consideration in the

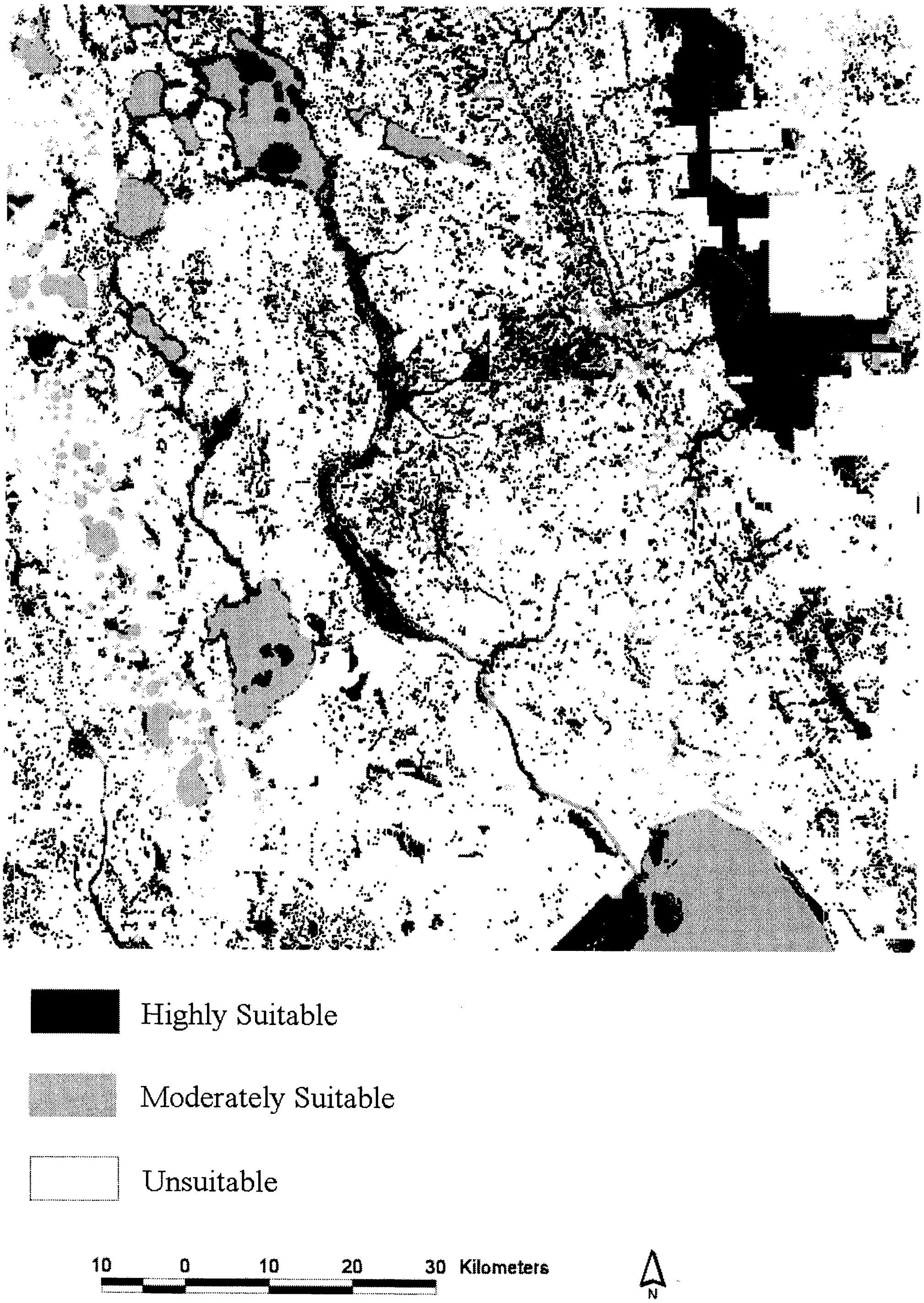

Figure 3. Example from southcentral Florida and the Kissimmee River basin (headwaters of the Everglades) of a suitability surface used for identifying potential riverine and large wetland-basin landscape linkages and corridors. Original suitability values are categorized as highly suitable, moderately suitable, and unsuitable.

hub identification process. In addition, over 80% of the network is represented by either (1) existing or proposed conservation lands; (2) inland or coastal waters; (3) strategic habitat conservation areas; or 4) areas of conservation interest and potential natural areas. This suggests that the rest of the network contains other potentially suitable areas that are needed to spatially integrate these primary ecological features (Fig. 5).

Table 5. Area of land in various land-ownership categories within Florida's Ecological Network.

Land Use	*Hectares*	*Percentage of state area*	*Percentage of model results*
Public ownership	3,239,476	20.0	34.8
Open water (outside existing conservation areas)	1,613,418	10.0	17.4
Proposed public conservation lands	985,936	6.1	10.6
Private ownership in wetlands[a]	701,650	4.3	7.5
Private ownership in 100-yr. floodplain[a,b]	656,691	4.1	7.1
Private ownership in uplands[a]	2,101,559	13.0	22.6
Totals	9,298,742	57.5	100.0

[a] *Hectares of private ownership in wetlands, 100-year floodplain, and uplands is calculated as if all proposed public acquisitions are or will be completed.*
[b] *Floodplain data were not available for Bradford, Columbia, Dixie, Gilchrist, Hamilton, Jefferson, Lafayette, Madison, Okeechobee, Taylor, and Union Counties, so the statistics shown above underestimate total floodplain.*

Representation

In reserve design, representation analysis involves the comparison of features of ecological significance, usually natural communities or species, with existing protected areas to determine which features require greater protection (Scott et al. 1993; Noss 1996). A coarse habitat representation analysis can be done by comparing total existing hectares of major ecological communities (Cox et al. 1994) with the amount found within existing conservation areas and the ecological network. Although some important elements are not included in the ecological network, it is clear that the identified ecological network significantly enhances the protection of each community type (Table 7). The increases for sand pine scrub, xeric oak scrub, and longleaf pine sandhill are of particular significance. These community types are endangered globally and provide habitat for many endangered, threatened, and endemic species and a host of species that are candidates for listing (Myers 1990; Noss et al. 1995; Platt 1998).

Protecting the majority of intact natural and seminatural landscapes in Florida may prove to be an effective coarse-filter strategy (Noss 1996) for protecting most of Florida's biological diversity, although this strategy must be complemented by other analyses and protection efforts for specific rare natural communities and species that may not be well represented by focal-species analyses (Caro & O'Doherty 1999) or coarse-habitat classifications (Noss 1996). To begin to address this question, we also compared the ecological network results to information for natural communities and rare species from the FNAI. Of 69 natural communities contained in the FNAI data, all occurred at least once in the ecological network, and only four had <50% of their occurrences within the ecological network. The analysis of rare-species occurrences indicates that there are 32 species (mostly plants) not known to be found on existing conservation lands or within the ecological network, which represents only 6% of the species analyzed. Therefore, most rare natural communities and species are represented in existing conservation areas and the ecological network, but more work needs to be done to assess whether this representation is sufficient and to identify other areas needed to increase protection for those not protected adequately.

Discussion

The Ecological Network identified as part of the Florida Statewide Greenways planning process is another significant step toward protection of an integrated state reserve system. Harris (1985), Noss (1987*b*), and The Nature Conservancy recommended linked reserve systems through intuitive representations of networks and mapping charettes. Next, the strategic habitat conservation area analysis by the FWC and the natural areas identification by the FNAI provided systematic assays identifying priority areas for conservation (Mann 1995). But the progress represented by the design and execution of the ecological network delineation process was the combination of a systematic landscape analysis of ecological significance and the identification of critical landscape linkages in a way that can be replicated, enhanced with new data, and applied at different scales. The ecological network connects and integrates existing conservation areas and 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 reserve network will more thoroughly protect important ecological functions, community and landscape juxtapositions, and the need for biotic movement than the present collection of isolated conservation areas (Noss & Harris 1986; Harris et al. 1996*a*, 1996*b*). The ecological network also includes most of the intact natural communities and most known occurrences of species tracked by the FNAI. These factors suggest that the ecological network will be integral to efforts to conserve Florida's biological diversity.

Although we believe that the ecological greenways network model is a significant step in Florida's conserva-

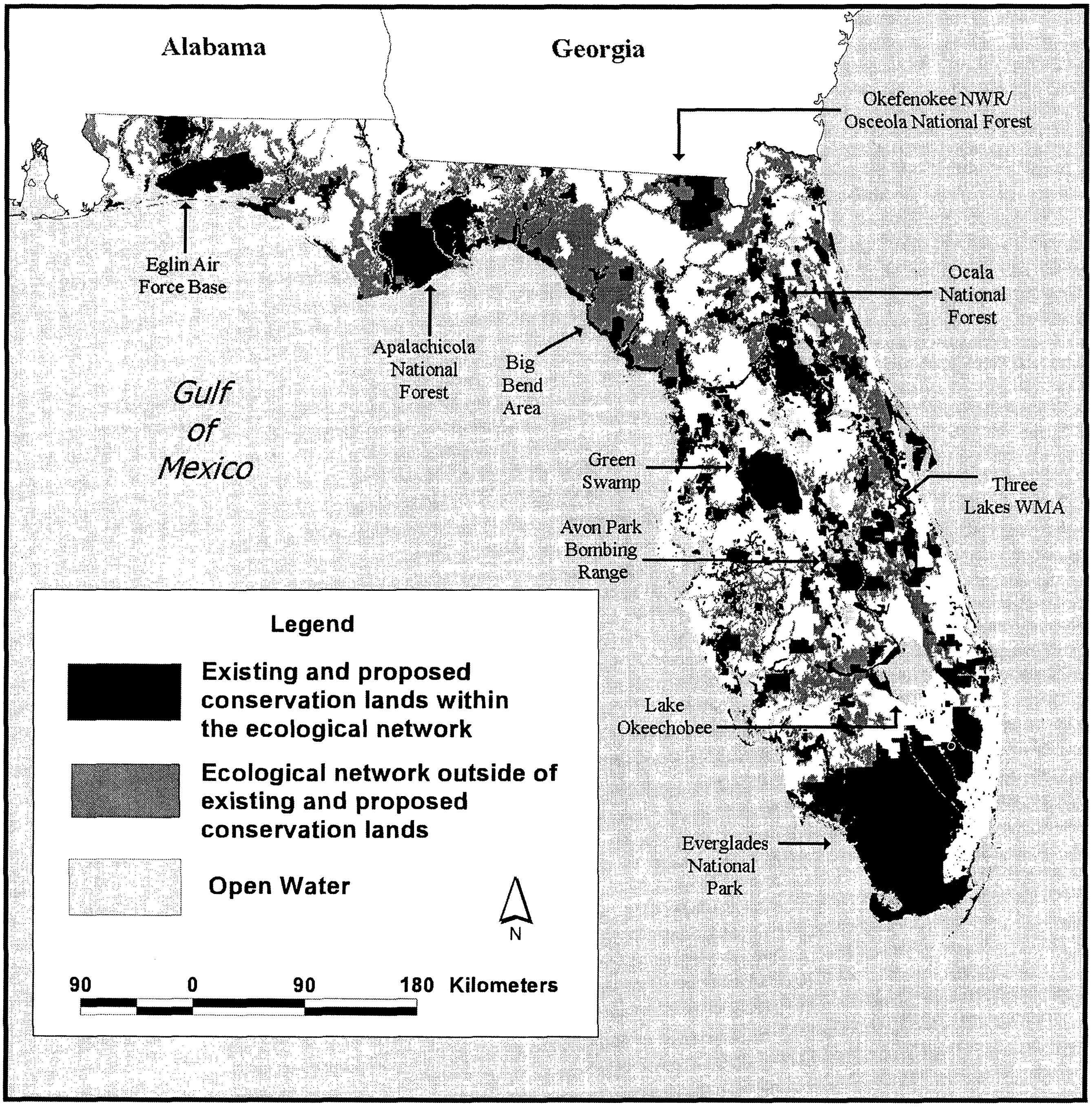

Figure 4. Florida Ecological Network model results, including existing and proposed conservation lands within the ecological network. Existing conservation includes all public lands with at least some conservation management and private preserves such as lands managed by The Nature Conservancy. Proposed conservation lands include all projects within official federal, state, regional, and local land acquisition or protection programs. Although the ecological network includes water within all of the major rivers and most intact estuarine systems, these features have not been differentiated from other areas of open water in this figure.

tion strategy, many issues and questions remain to be addressed. Among these is the need for a more thorough analysis of the relationship between the model results and specific conservation needs for sensitive species and all communities. In the process of identifying potentially viable reserve networks, Noss (1996) recommended three primary steps: special element mapping, representation analysis, and area-dependent species analysis. Although we incorporated these steps at least to some degree in the ecological network delineation process, there are

Table 6. Comparison of the Florida Ecological Network and other ecological resource inventories and existing and proposed conservation lands.[a]

Comparison categories	Area of category within model results (ha)	Percentage of model results	Percentage of category within the model results	Area of category in study area (ha)	Percentage of state
State	na	na	na	16,175,928	100.0
Ecological network model results	9,298,742	100.0	na	9,298,742	57.5
FWC[b] strategic habitat conservation areas (SHCAs)	1,586,567	17.1	80.6	1,968,587	12.2
FNAI[c] areas of conservation interest (ACIs) and potential natural areas (PNAs)	1,521,085	16.4	68.7	2,214,813	13.7
Existing or proposed conservation lands, open water, SHCAs, or ACIs	7,539,052	81.1	81.4	9,259,270	57.2

[a] *na, not applicable.*
[b] *Florida Game and Fresh Water Fish Commission (renamed Florida Fish and Wildlife Conservation Commission in 1999).*
[c] *Florida Natural Areas Inventory.*

still gaps in the analysis. The model benefited from previous analyses of habitat needed to protect potentially viable populations of 30 focal species. But Cox et al. (1994) recommended limiting the strategic habitat conservation area for the Florida panther (*Puma concolor coryi*) to within or near the area currently occupied by the known breeding population in southwest Florida, and their recommendations for the Florida black bear (*Ursus americanus floridanus*) were limited to expanding the habitat base for the five largest populations left in the state.

These recommendations are essential, but a large connected reserve network in Florida will go significantly further to enhance the survival of these umbrella species and the ecological integrity of the landscapes they would occupy in the future (Harris et al. 1996*b*; Maehr 1997). Although the ecological network model may identify landscape linkages that will provide functional connectivity and promote the re-establishment of statewide populations, species-specific analyses should be conducted for both the Florida panther and black bear to better establish this possibility. Broad landscape analyses of connectedness are useful, but species-specific analyses are essential for determining the potential for connectivity of particular populations and for identifying viable areas for metapopulations (Beier 1995; Maehr & Cox 1995; Beier 1996; Beier & Noss 1998). One of us is currently working on a statewide GIS model to assess the potential for connectivity between Florida black bear populations and the landscape-based ecological network identified in the model.

One of the most discussed issues in the model development process was the determination of minimum hub size. Several reviewers thought that areas at least as small as 400 ha should also be considered because areas smaller than 2000 ha may be ecologically significant and because the completed ecological network could draw attention away from the conservation significance of smaller, isolated tracts. Isolated sites can contain critical elements of biodiversity that should be protected as part of a statewide reserve system (Shafer 1995). One of the most important steps within a reserve design process is a thorough representation of all native ecological communities and species (Noss & Cooperrider 1994). Not all important sites and species are contained within the model results; for example, some of the remaining globally imperiled pine rocklands in southeast Florida (Snyder et al. 1990) and oak-scrub tracts along the Lake Wales Ridge support many rare species. More work is required to assess the needs of specific rare species and natural communities, especially in aquatic systems. The FWC continues to analyze additional species (Hoehn 1998; R.S. Kautz, personal communication), and the federal GAP analysis project for Florida is ongoing. Also, we are currently assisting The Nature Conservancy in an ecoregional planning process for Florida to identify all sites necessary to protect all natural communities and focal species, including vertebrates, plants, and insects.

Another important consideration in a reserve design process is the identification of potential core areas, corridors, and buffers (Harris 1984; Noss & Harris 1986; Noss & Cooperrider 1994; Soulé & Terborgh 1999). In the ecological network delineation process, hubs were used as destinations, but they typically cannot be considered equivalent to core areas, where core areas are defined as reserves managed exclusively or primarily for conserving biological diversity (Scott et al. 1993; Noss & Cooperrider 1994). The few managed areas in Florida that might meet this definition include private preserves managed by The Nature Conservancy and others, some designated wilderness areas, national parks, and state preserves. Yet managers of many of these areas allow uses contradictory to the ideal of a core area, and many face external threats or disruption of natural ecological processes including fire suppression and changes in hydrologic regimes (as in Everglades National Park). If all these areas, including Everglades National Park, are considered cores, Florida currently has 17% of its public conservation lands and private preserves in strictly managed areas, it has only 5% if Everglades National Park is excluded.

Clearly there is a need to identify other areas within the Florida reserve system that might also be managed

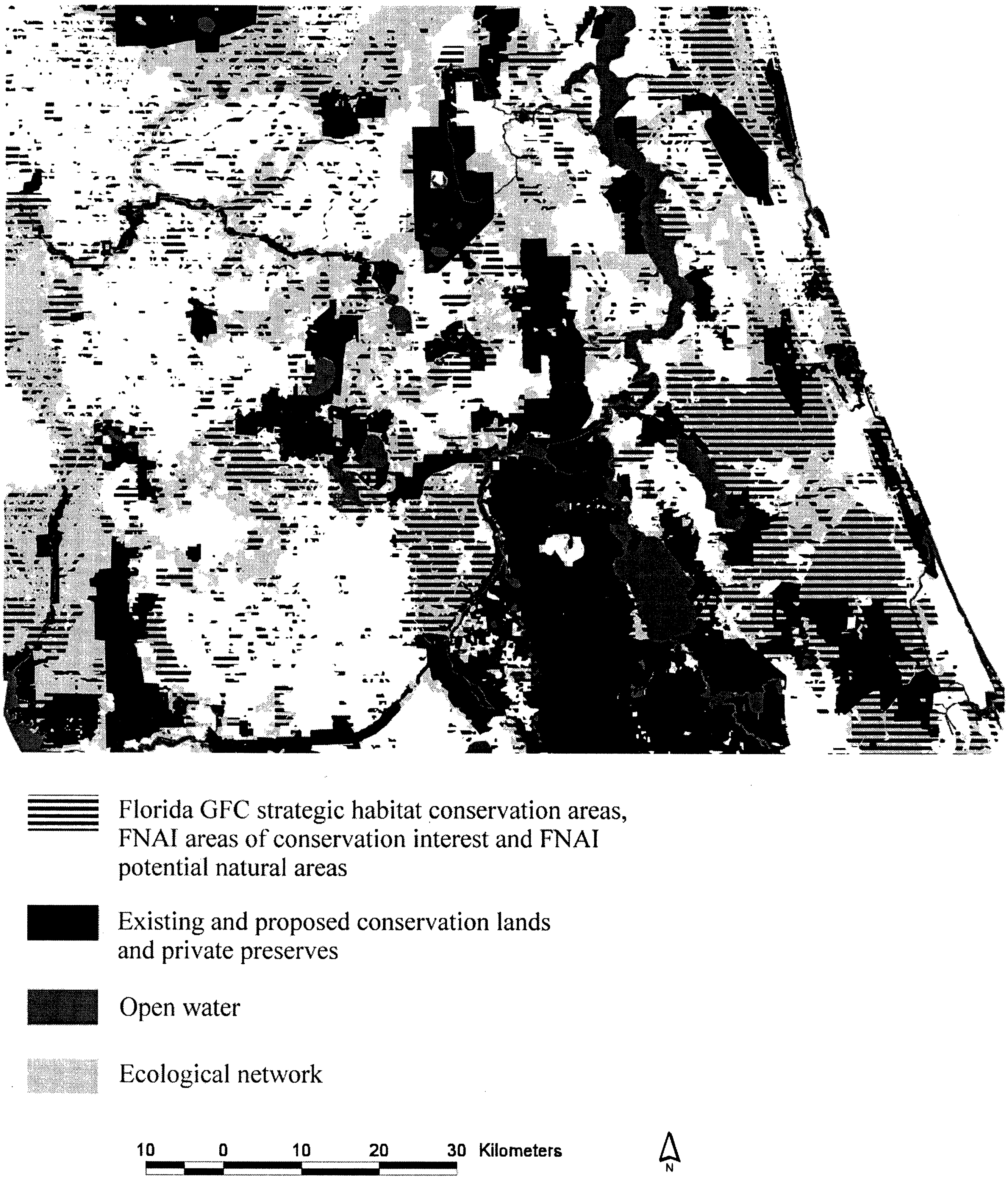

Figure 5. Comparison of the Florida Ecological Network with the strategic habitat conservation areas from the Florida Fish and Wildlife Conservation Commission (previously the Florida Game and Fresh Water Fish Commission) and areas of conservation interest and potential natural areas from the Florida Natural Areas Inventory in northcentral Florida.

Table 7. Comparison of the total land area of existing ecological community types (habitats) in the state of Florida, with area of habitat types found in existing conservation lands and the amount included in the Florida Ecological Network.

Ecological community type	*Total area (ha)*	*Area in existing conservation lands (ha)*	*Total habitat in existing conservation lands (ha)*	*Area in ecological network (ha)*	*Habitat in ecological network (ha)*	*Increase in protected area (ha)*	*Percent increase in protected area*
Coastal strand	4,281	3,145	73.4	3,475	81.2	330	7.7
Dry prairie	519,895	133,334	25.6	422,050	81.2	288,716	55.5
Pinelands	1,651,235	413,066	25.0	1,076,578	65.2	663,512	40.2
Sand pine scrub	131,708	105,501	80.1	117,500	89.2	11,999	9.1
Sandhill	390,056	146,250	37.5	248,888	63.8	102,638	26.3
Xeric oak scrub	52,628	22,272	42.3	38,967	74.0	16,695	31.7
Mixed hardwood-pine forests	387,889	46,532	12.0	197,300	50.9	150,767	38.9
Hardwood forest	818,030	185,651	22.7	530,194	64.8	344,544	42.1
Tropical hardwood forest	5,872	3,313	56.4	4,210	71.7	897	15.3
Saltmarsh	195,710	121,584	62.1	182,616	93.3	61,032	31.2
Freshwater marsh-wet prairie	1,153,285	778,923	67.5	1,023,724	88.8	244,801	21.2
Cypress	621,504	253,454	40.8	546,964	88.0	293,509	47.2
Mixed hardwood swamp	1,076,484	276,915	25.7	864,698	80.3	587,783	54.6
Bay swamp	57,968	16,763	28.9	47,102	81.3	30,339	52.3
Shrub swamp	252,327	152,976	60.6	222,950	88.4	69,974	27.7
Mangrove swamp	229,012	198,100	86.5	221,703	96.8	23,603	10.3
Bottomland hardwoods	40,033	23,532	58.8	39,926	99.7	16,394	41.0

with a greater emphasis on biodiversity. Much of the land identified in the ecological network is generally managed for multiple uses on both public and private lands. Outside Everglades National Park, the remaining public land is dominated by national forests and military reservations. Such management often conflicts with biodiversity conservation (Noss & Cooperrider 1994), although progress has been made on military reservations under the rubric of "ecosystem management" (Gordon et al. 1997) and to some extent within the national forest system (Salwasser et al. 1996). Further progress in protecting sensitive species on public lands could be made by closing nonessential roads wherever possible to decrease road kills, isolation, and negative edge effects, disturbance by humans, and poaching (Noss & Cooperrider 1994).

Even though important and high-quality natural communities can be found on private lands, much has been converted to conifer plantations and rangelands (Kautz 1993). These areas may be the "buffer areas" of a future Florida conservation reserve system, but the model did not include the specific identification of buffer areas. In some cases it may be necessary to identify buffers for narrower corridors and potential bottlenecks, especially around network components identified in central and south central Florida (Fig. 4). Although these network elements are currently surrounded primarily by low-intensity agriculture, their function could be endangered if land use intensifies.

The identification of core areas and buffers will be an important part of the reserve design process in Florida. The focus for now, however, should be on protecting lands from conversion to more intensive uses because of rapid human population growth and resulting habitat loss and fragmentation. Florida's population is currently almost 15 million people and is increasing by approximately 250,000 residents each year. Estimates of habitat loss run as high as 60,000 ha per year (Harris & Scheck 1991; Harris & Silva-Lopez 1992). This raises questions about how much land must be protected to meet biodiversity conservation objectives (Noss 1996; Soulé & Sanjayan 1998). Furthermore, guidelines need to be developed to identify priorities so that the most critical lands are protected first. Although Florida has committed at least $300 million per year since 1990 for land acquisition and related conservation efforts, the approximately 4.4 million ha within the ecological network plus other sites will require at least three or four decades to protect at current funding levels. Our initial efforts to identify areas of highest priority in the ecological network suggest that the most critical lands amount to approximately 2.4 million ha, and more work is currently being done to refine priorities.

The need for setting priorities also involves debate about the importance of protecting corridors versus protecting core areas of high-quality habitat (Noss 1987*a*; Simberloff & Cox 1987; Simberloff et al. 1992; Hobbs 1992; Beier & Noss 1998). How are state conservation decisionmakers to choose between these alternative strategies? The Florida Greenways Project provides some insight. First, these approaches are not mutually exclusive: prioritization of land protection can include both considerations. Landscape linkages that also contain high-quality habitat needed to maintain viable populations of sensitive species can be identified. The high degree of overlap between the model-generated ecological greenways network, strategic habitat conservation areas, and priority sites identified by the FNAI suggests this will occur frequently (Fig. 5). Then, landscape linkages most significant for facilitating connectivity for wide-ranging species and isolated sites containing critical elements of biodiversity should also be identified as priorities. Although there is likely to be additional debate about landscape linkage and corridor projects, connectivity has been accepted as a critical reserve design principle (Harris et al. 1996*b*; Beier & Noss 1998). Because natural landscapes are generally connected, the burden of proof should be on those who remain skeptical about the need to protect landscape linkages and corridors (Noss 1987*a*, 1991; Beier 1996; Beier & Noss 1998). There will always be the option to sever linkages in the future if necessary, but the opportunity to protect existing landscape linkages or to restore them will diminish rapidly as Florida's human population continues to grow.

Another challenge is to retrofit the existing highway system in Florida and plan future road projects to be as compatible as possible with the protection of a statewide reserve system. The Florida Department of Transportation has made significant progress, including construction of a comprehensive system of underpasses where Interstate 75 crosses the Big Cypress National Preserve which allows Florida panthers and many other species to safely cross under the highway (Foster & Humphrey 1992). One underpass has been constructed at a black bear roadkill hotspot in central Florida, and more are planned (Roof & Wooding 1996). A comprehensive assessment of all potential interfaces between major roads and priority ecological conservation areas for future mitigation (e.g., lengthening existing bridges and culverts, constructing new wildlife underpasses) coordinated with the ecological network modelling process has recently been completed (Smith 1999). Nevertheless, there is still a need to avoid major new road projects, several of which now threaten important elements of the ecological network.

Land protection programs in Florida continue to shift toward greater emphasis on the use of conservation easements and agreements. The Florida Department of Environmental Protection (1998) has adopted an ecosystem management approach that includes conservation agreements as a critical component, and the state legislature has adopted a 10-year extension of the Preservation 2000 land acquisition program (now called Florida Forever) at current funding levels with a much greater emphasis on easements. There are disadvantages to this approach, such as monitoring compliance, but the benefits include significantly lowering land-protection and management costs (Daniels & Bowers 1997). Although there will still be a need to acquire and protect high-quality habitat for the most sensitive species, lands supporting lower-intensity land uses can provide habitat, potential linkages, and buffers for wide-ranging species and other species of conservation interest (Harris 1984; Noss & Cooperrider 1994). Conservation easements can maintain such lands in current uses while also establishing management practices that are more compatible with conserving biological diversity.

Reserve design is an iterative process that must continually account for new information. Work on refining and enhancing a Florida reserve network is progressing in several projects and scales. We are continuing efforts to prioritize elements within the ecological network, including coordination with additional species-specific habitat analyses. Florida's federal GAP analysis project has yet to be completed, the Florida Fish and Wildlife Conservation Commission continues to analyze additional species, and The Nature Conservancy is engaged in ecoregional planning that includes many focal species and all natural communities. These projects likely will identify priorities to be addressed in future iterations of a state reserve system plan, and, as always, field assessments of priority sites need to be done as part of the protection process. As land development continues, loss of habitat will have to be monitored and conservation plans adjusted as necessary. Finally, considering Forman's (1987) comments on the "ethics of isolation," we are working with the U.S. Environmental Protection Agency to identify a regional ecological conservation network for the southeastern United States, which could lead to coordination with other efforts to identify and protect reserve networks in North America (Soulé & Terborgh 1999).

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