Land Cover Trends in the Southern Florida Coastal Plain

Scientific Investigations Report 2009–5054

U.S. Department of the Interior
U.S. Geological Survey

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By Steven Kambly and Thomas R. Moreland

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On the cover: Photograph showing a view of Arthur R. Marshall Loxahatchee National Wildlife Refuge, one of several publically owned lands that contain wetland habitat in the Southern Florida Coastal Plain. The refuge includes approximately 570 square kilometers (221 square miles) of the Everglades.

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Introduction

In this report, we present an assessment of land use and land cover change in the Southern Florida Coastal Plain (SFCP) ecoregion for the period from 1973 to 2000. The ecoregion is one of 84 level III ecoregions defined by the Environmental Protection Agency (Omernik, 1987). Ecoregions have been designed to serve as a spatial framework for environmental resource management and denote areas that contain a geographically distinct assemblage of biotic and abiotic phenomena, including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. We used the Land Cover Trends methodology established by the U.S. Geological Survey (USGS) to generate estimates of land use and land cover change using a probability sampling approach and change-detection analysis of thematic land cover images derived from Landsat satellite imagery. Parts of this report are derived from Kambly (2008).

Ecoregion Description

The SFCP ecoregion covers an area of approximately 22,407 square kilometers (km^2) [8,651 square miles (mi^2)] across the lower portion of the Florida peninsula, from Lake Okeechobee southward through the Florida Keys (fig. 1). It comprises “flat plains with wet soils, marshland and swamp land cover with Everglades and palmetto prairie vegetation types” (U.S. Environmental Protection Agency, 2002, p. 12).

The climate of the SFCP is generally frost-free and subtropical, consisting of a dry and a wet season. About 140 centimeters (cm) [55 inches (in.)] of rain fall annually in the ecoregion, with approximately 106 cm (42 in.) of rainfall occurring in the wet season from June through September. The warm dry season, from October through May, allows for year-round crop production and has been instrumental in the cultivation of winter vegetables. Tomatoes, beans, squash, peppers, and other crops are grown during the winter for shipment to northern markets. Sugarcane is also widely grown and has formed the basis of the domestic sugar industry since the early 1960s. In addition, the region has a large nursery industry and grows a variety of exotic fruits. All these forms of agriculture rely to varying degrees on irrigation.

Steady population increases and concomitant expansion of developed lands have occurred in coastal areas of the SFCP—especially along the Atlantic coast where urbanization extends from southern Miami-Dade County to Palm Beach County. Population in the ecoregion grew from approximately 2.3 million to 5.3 million between 1970 and 2000 with 92 percent of the growth concentrated in the coastal counties of Miami-Dade, Broward, and Palm Beach. By contrast, the ecoregion’s interior, which is dominated by the State and Federal parks and refuges and by agricultural lands, is sparsely populated.

Within the SFCP lie four distinct subregions—the Everglades, Big Cypress, the Miami Ridge and Atlantic Coastal Strip, and the Southern Coast and Islands—each with its own physical and biological characteristics that influence the type and spatial distribution of land cover (Griffith and others, 1997).

The Everglades

The central portion and by far the largest part of the SFCP consists of the Everglades, which has been described as a river of grass (Douglas, 1947) and whose extent before human intervention ranged from the southern shore of Lake Okeechobee to the Gulf of Mexico. The Everglades is a subtropical wetland ecosystem that hosts an extremely rich variety of plant and animal habitats. Its nutrient-poor environment has been subject to surface water runoff from urban and agricultural sources, which has led to changes in habitat health and diversity. Moreover, surface water levels and sheet flow in the Everglades are very sensitive to any differences in topography because of the ecoregion’s exceedingly expansive and flat terrain (Desmond, 2003). As a result, water level changes of only a few centimeters in elevation may have significant impact on the distribution of plant and animal communities.

The historical flow through the Everglades originated from the Kissimmee River in central Florida and drained into shallow Lake Okeechobee about 5 meters (m) [16 feet (ft)] above sea level. An expansive sheet flow of water, more then 64 kilometers (km) [40 miles (mi)] wide, would then pass through the Everglades—providing sustenance to plant and animal life and feeding freshwater aquifers—and eventually exit into the Florida Bay and the Gulf of Mexico. The water would move slowly across Lake Okeechobee and overflow its

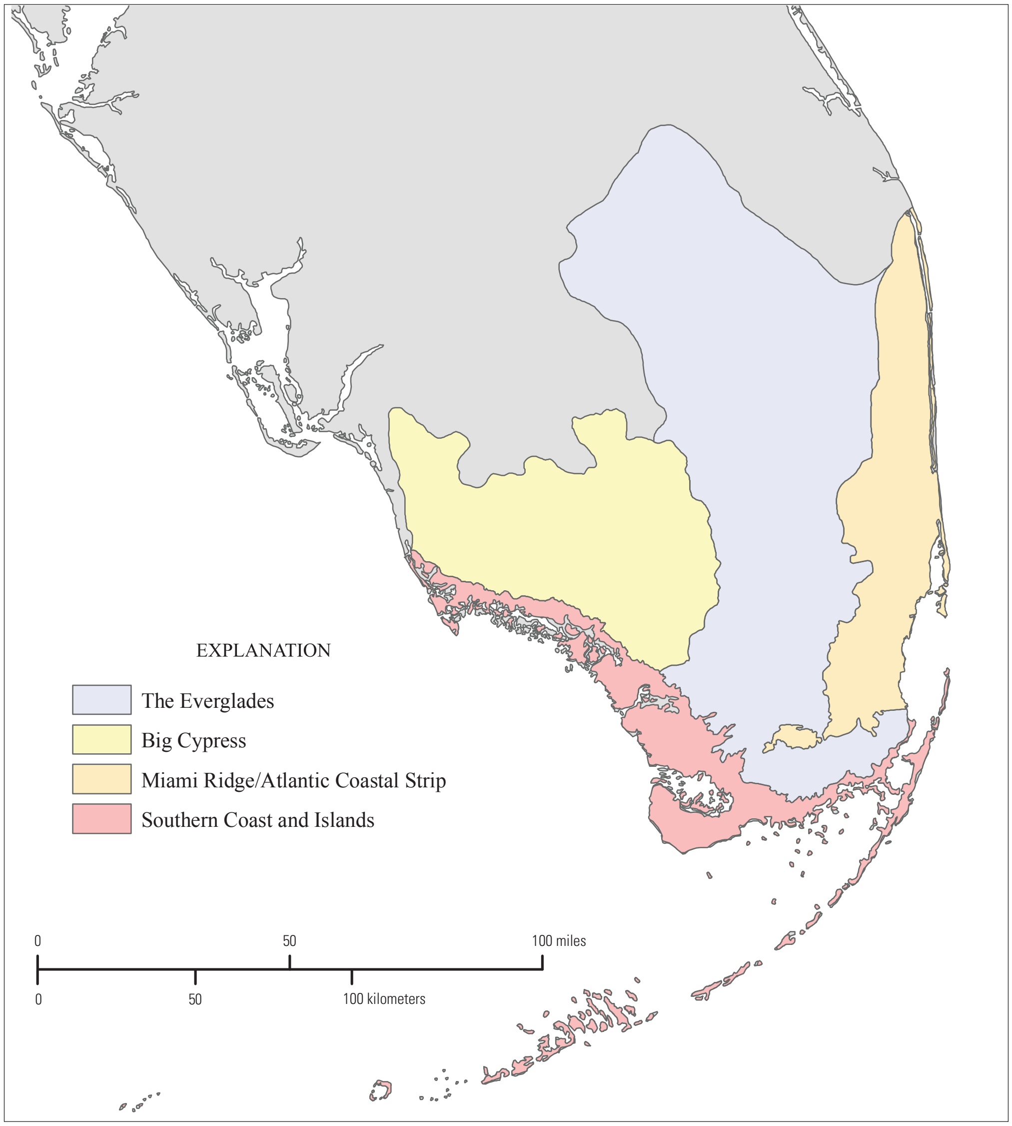

Figure 1. Map showing the U.S. Environmental Protection Agency level 4 subregions of the Southern Florida Coastal Plain. Source: Western Ecology Division, U.S. Environmental Protection Agency.

southern lip into the marshes of the northern Everglades. The flow was much less or nonexistent in the dry season when the water would concentrate in the sloughs, the deepest part of the Everglades. Tree islands developed in elevated areas.

In the decades after World War II, the interruption of the natural hydrology by newly constructed levees, canals, and other water control measures led to a disconnected hydrological regime. This has resulted in a spatial redistribution of water that has severely reduced the size and biotic diversity of the Everglades (McCally, 1999, p. 175). Approximately 50 percent of the original extent of the Everglades has been lost since the beginning of the 20th century.

With the establishment of Everglades National Park in 1947, Loxahatchee National Wildlife Refuge in 1951 (which serves as a water conservation area), and additional water conservation areas, most of the remaining Everglades ecosystem was protected from further development, though it continues to be vulnerable to impacts from urban and agricultural uses that lie beyond park and refuge boundaries.

Big Cypress

Like the Everglades, Big Cypress is a wetland ecosystem that supports a diversity of plant and animal species. It is mainly forested with varieties of cypress trees, pine flatwoods, hardwood hammocks, and mangrove trees. It also comprises extensive areas of wet and dry prairies and freshwater marshes. Several of its native plants and animals are endangered species, most notably the Florida panther. In 1928, the Tamiami Trail (U.S. Route 41), which traverses Big Cypress, made the area accessible to development. During the 1930s and 1940s, lumbering in Big Cypress all but eliminated the bald cypress, and the dwarf pond variety of cypress is now predominant. Other forms of resource exploitation have included oil and gas drilling, real estate speculation, and agricultural use by the Seminole and Miccosukee Native American tribes. A commercial airport was proposed for the southern edge of Big Cypress in 1967. Concerns about its environmental impact kept it from being completed but not before a 3,200 m (10,500 ft) runway had been built. In 1974, 2327 km^2 (898 mi^2) of the Big Cypress were designated as a National Preserve—and another 595 km^2 (230 mi^2) have since been added— but resource and land use issues remain, among which are oil and gas drilling and the use of off-road vehicles.

Miami Ridge and Atlantic Coastal Strip

On the eastern side of the ecoregion lies the Miami Ridge and Atlantic Coastal Strip, a highly urbanized area that extends 161 km (100 mi) from central Miami-Dade County through Broward and into Palm Beach County. Its western extent consists of flat terrain with urban and agricultural lands that have replaced the original wet and dry prairie marshes and rockland and saw-grass marshes (Griffith and others, 1997). The Miami Ridge lies to the east and ranges in height from 2 to 7 m (8 to 24 ft) and is from 6 to 16 km (4 to 10 mi) wide. It is about 64 km (40 mi) in length, extending along the Atlantic coast from southern Miami-Dade County to Broward County. Due to its relatively high elevation, the ridge acted as an eastern barrier to water flow through the Everglades and was the site of early commercial and residential development in southeastern Florida. It now forms the backbone for much of the heavily urbanized Atlantic coast. Agriculture also gained a foothold but moved westward as it was displaced by encroaching development. Early developers cleared the forested ridge and, as a result, eliminated most of the rockland pines, which formed the dominant habitat of the southern part of the ridge and one of the most diverse plant habitats in the ecoregion. About 7,689 hectares (ha) (19,000 acres) of the remaining rockland pines are found in Everglades National Park (U.S. Department of the Interior, 2005). Outside the park's boundaries, only about 1.5 percent of the original 65,424 ha (161,660 acres) still exists.

Southern Coast and Islands

The southern coast and islands extend over the extreme southern portion of the Florida Peninsula, Florida Bay, and the Florida Keys. Reserved Federal lands, including Everglades National Park, and several national wildlife refuges cover much of its area. Mangrove swamps, upland forests, coastal marshes, and coral reefs characterize the region. Native animals include alligators, crocodiles, the Key deer, manatees, and a variety of birds, fish, and turtles. Many of these species are endangered or threatened, including the crocodile, Key deer, and manatee. Some of the Keys have experienced increasing urbanization largely driven by tourism. In 1974, the State of Florida designated the Keys as an "Area of Critical Concern" to protect environmental assets and provide oversight on local land use decisions.

Land Cover History

Though climate and access to water were enough to attract wealthy tourists in the early days of settlement, the transformation of the ecoregion could not have taken place without large-scale changes to the landscape. Many participants in the ecoregion—including government at all levels, and private interests such a real estate developers, industrialists, and railroad owners—played a key role in fostering continued development and population growth throughout the late-19th and 20th centuries. From the late 1960s onward, however, nongovernmental organizations such as environmental and conservation groups took on an increasingly significant role as advocates for preserving environmental assets and, in particular, for restoration of the Everglades.

Land cover change in the SFCP is an integral part of the region's history because the alteration of the landscape has been essential to the area's development as a major producer of agricultural goods, a retirement haven, and an international tourist destination. Soon after Florida achieved statehood, the Federal Government transferred approximately 8.1 million ha (20 million acres) of wetlands to the State under the Swamp and Overflowed Lands Act of 1850. The central figure in early drainage efforts was northern industrialist Hamilton Disston who purchased 1.6 million ha (4 million acres) of swamp and overflowed lands from the State in 1880 and promised to drain a total of 4.9 million ha (12 million acres). Though his drainage projects were largely ineffective, Disston's purchase helped the State retire its debt, which in turn spurred increased population growth, tourism, and railroad construction (Grunwald, 1990, p. 87).

Along the Atlantic coast, the extension of the East Coast Florida Railway from West Palm Beach to Miami in 1896 provided access for new settlers and tourists. Coupled with aggressive real estate promotion, the railway ushered in the beginning of large-scale settlement of southern Florida's east coast. Increasing development generated renewed interest in wetland drainage (Grunwald, 1990, p. 110) and in the early 1900s, the State of Florida embarked on its own program financed mainly by drainage taxes and land sales to development companies. But this attempt again proved difficult and was plagued by an incomplete understanding of the task, real estate profiteering, and a lack of financial resources (Light and Dineen, p. 55) and technical expertise to manage many new problems created by drainage such as the burning and subsidence of muck soils, and salt water intrusion into water freshwater wells (McCally,1999, p. 140–141). Despite these obstacles, by 1931 about 708 km of canals had been constructed (Light and Dineen,1994, p. 55).

These changes and many that followed—including the various land development, infrastructure, and water management projects during the 20th century—set the stage for the kinds of change documented in the USGS Land Cover Trends project for the period between 1973 and 2000. Indeed, to a great extent, these later changes reflected a continuation of land cover patterns that had been in place before the study period.

The most dramatic human intervention on the southern Florida landscape in the 20th century was the large-scale re-engineering of the Everglades natural hydrology by the U.S. Army Corps of Engineers beginning in the late 1940s. The impetus for the project was a quick succession of hurricanes in 1947 that resulted in massive flooding along the urbanized Atlantic coast and in the northern Everglades (Snyder and Davidson, 1994, p. 98). The Corps began construction of a complex and extensive regime of water control infrastructure, the Central and South Florida Project for Flood Control and Other Purposes, to help ensure flood mitigation and water supply for urban areas on the Atlantic coast and agricultural interests near Lake Okeechobee (fig. 2). The project consisted of dikes, levees, canals, water pumping stations, spillways, three water conservation areas, and other structures to control the supply of water to urban and agricultural interests, in particular the Everglades Agricultural Area (EAA) south of Lake Okeechobee, as well as the Everglades National Park (fig. 3). The EAA was an important feature of the project and was created by draining the northern Everglades. It was initially cultivated primarily with fruits and vegetables for winter markets in the Northeast and Midwest. After the Cuban Revolution in the late 1950s, however, trade restrictions on sugar and other goods were imposed against the newly installed communist regime, resulting in a dramatic increase of sugarcane production in the EAA.

Figure 2. This flow regulator, located in Miami-Dade County, is part of the U.S. Army Corps of Engineers South and Central Florida Project for Flood Control and Other Purposes. The project transformed the ecoregion through extensive flood control and water supply measures and drained approximately 323,760 hectares (800,000 acres) south of Lake Okeechobee to create the Everglades Agricultural Area. Photograph by the U.S. Geological Survey Land Cover Trends project.

Figure 3. Sugarcane production increased dramatically, becoming the dominant crop in the Everglades Agricultural Area after the Cuban Revolution led to an embargo on goods from that country. Photograph by the U.S. Geological Survey Land Cover Trends Project.

Another critical component of the project was the eastern perimeter levee—a 3- to 6-m-high (10- to 20-ft-high) levee located 30 km (19 mi) from the Atlantic coast and extending 160 km (99 mi) from Miami-Dade to Palm Beach Counties and designed to prevent flooding to agricultural and urban areas. The levee, which runs along the eastern edge of the three water conservation areas, made it possible for development to advance further inland; in some cases development spread to areas immediately adjacent to the levee (fig. 4). The flood control project was largely complete by the early 1970s and remains in place as the means by which water is allocated and controlled throughout the eastern half of the ecoregion.

In addition to Federal water management activities, several other factors contributed to the explosive population growth in the ecoregion between 1950 and 1970. These included improved transportation infrastructure, widespread use of air conditioning, mosquito control measures, and growth promotion efforts on the part of land developers and local and State officials (Solecki, 2001, p. 349). As a result of these and other factors, the period between 1950 and 1970 witnessed not only tremendous population increases but also the development of contemporary patterns of land cover change, such as increasing urbanization along the Atlantic and Gulf coasts, expansion of agriculture, and encroachment by agriculture and urbanization on wetland areas. Approximately 5,800 km^2 (2,239 mi^2) was converted from natural land cover to either agriculture or urban land cover between 1953 and 1973 (Solecki and Walker, 2001, p. 264). It should be noted that the existence of reserved public lands and water conservation areas curtailed development of wetlands within the central portion of the ecoregion and perhaps resulted in an intensification of development along the Atlantic coast (fig. 5).

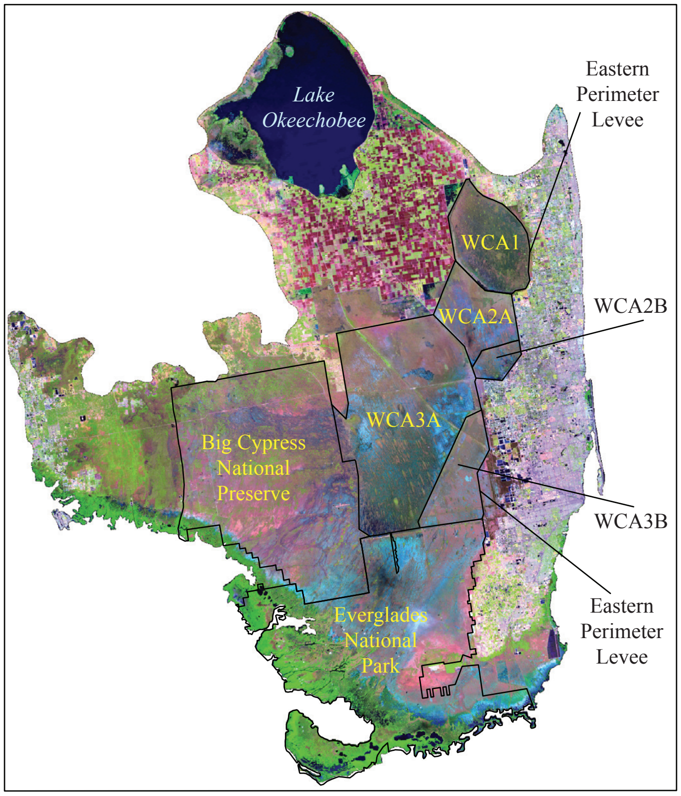

Figure 4. Satellite image showing of the Everglades Agricultural Area, Water Conservation Areas (WCA), and major park lands; Lake Okeechobee lies to the north. The eastern perimeter levee is visible as a line that separates the urbanizing Atlantic coast from the smoother textured wetland areas.

Decades of landscape alteration in the ecoregion contributed to widespread environmental consequences that have taken many forms, including the desiccation and subsidence of muck soils, the near-total disappearance of the rockland pine ecosystem, and the dramatic decline in wading bird populations in the Everglades. Agricultural runoff into Everglades National Park, the increase of exotic, invasive plant species, and saltwater intrusion into freshwater aquifers have also become major concerns. In addition, recent studies suggest that wetland drainage and the concomitant loss of the moderating effect on nighttime air temperature by surface water have led to increased crop freezes (Marshall, Pielke, and Steyaert, 2003).

The environmental threat to the region due to anthropogenic change was perhaps best symbolized by the proposed construction in 1967 of an international airport 10 km (6 mi) from the northern boundary of Everglades National Park within the marshlands of Big Cypress and strategically located between major population centers on the Atlantic and Gulf coasts of Florida. The rationale for the airport was to relieve the burden of increased traffic at Miami International Airport. The new airport would be completed in three phases. First, a training facility would be built for commercial airline pilots. Then, the airport would be expanded to accommodate cargo traffic. The final phase of the project would transform the facility into the largest commercial passenger airport in the world, covering 101 km^2 (39 mi^2) of marshland. A national debate ensued in which the plight of the southern Florida ecosystem was brought into public awareness. In 1970, the Nixon administration rejected the Big Cypress site for the airport, but only after the construction of a 3,200 m (10,500 ft) runway that is now used as a training facility.

The airport controversy signaled the beginning of an era in southern Florida in which concern for its unique subtropical ecosystems became a significant factor in future development plans and both the U.S. Congress and the Florida State legislature moved towards protecting Big Cypress. In 1974, the Federal Government purchased 2,327 km^2 (898 mi^2) of wetlands and established Big Cypress as a national preserve. With the addition of the Big Cypress National Preserve, the largest remaining unprotected expanse of wetlands in the SFCP was brought under public management (fig. 6).

Environmental Crises

From the 1970s onward, the ecological decline of the Everglades stimulated debate among environmentalists, government officials, developers, and farmers about possible remedies. A series of environmental crises in the 1970s and 1980s, including severe droughts and floods, a massive algal bloom in Lake Okeechobee, and changes in vegetation patterns due to excessive nutrient runoff into the water conservation areas, gave rise to a variety of governmental responses. At the State level, these responses included a proposal for a regional land and water management agency, changes in water deliveries to Everglades National Park, the Save Our Everglades Program, which proposed hydrological and environmental measures to restore the Everglades, and the Surface Water Improvement and Management Act (Gunderson and others, 1995, p. S68-S69).

In 1988, a Federal lawsuit filed against the State of Florida on behalf of Loxahatchee National Wildlife Refuge and Everglades National Park led to the 1994 passage of the Everglades Forever Act by the Florida State legislative. The original suit claimed that the State violated its own water quality standards by allowing phosphorous-laden agricultural runoff into lands owned by the park and the refuge. In order to decrease phosphorous levels, flow-through filtration marshes, also known as stormwater treatment areas, were constructed to sequester the phosphorous before it entered the protected lands owned by Everglades National Park and Loxahatchee National Wildlife Refuge. The act also required farmers in the EAA to implement new techniques to filter and reduce runoff from their lands.

Currently, the State of Florida and the Federal Government are cooperating in the Comprehensive Everglades Restoration Plan (CERP). The CERP was developed from a comprehensive review—authorized by Congress in 1992—of the Central and South Florida Project, which was constructed by the U.S. Army

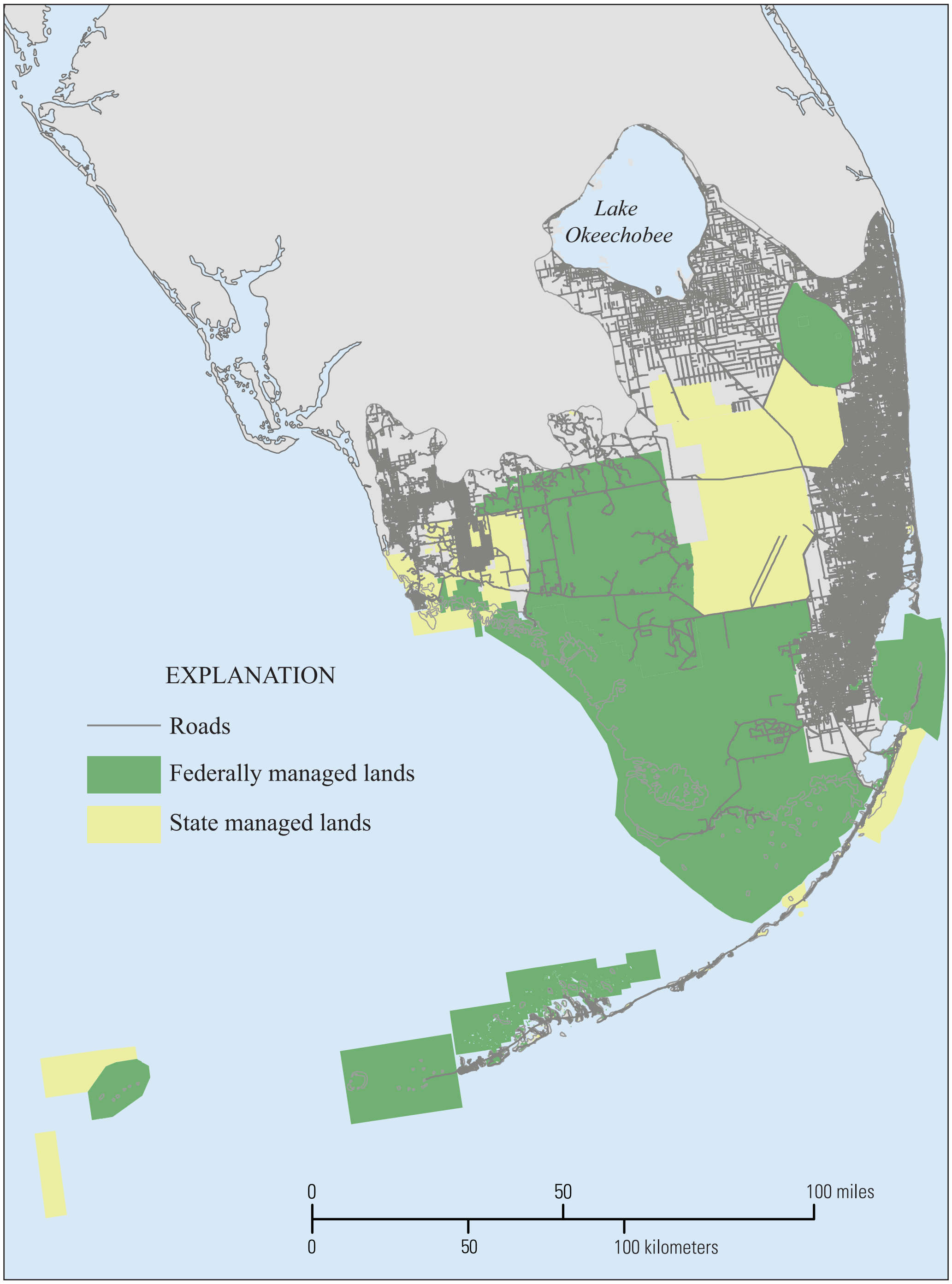

Figure 5. The ecoregion's road network shows that development is confined mainly to coastal areas and away from public lands, with the greatest intensity of urbanization in Miami-Dade, Broward, and Palm Beach Counties along the Atlantic coast. Roads immediately south of Lake Okeechobee are within the Everglades Agricultural Area. Source: Florida Natural Areas Inventory and U.S. Geological Survey *The National Map*.

Corps of Engineers between 1950 and 1972. The CERP would remove many of the structures put in place by the project and seek to restore a more natural movement of water through the Everglades reminiscent of its original hydrology. Though meeting the water needs for agricultural production and increasing population growth is an integral part of the plan, its primary goal is ecosystem restoration. Major objectives of the plan include increased and better timed water flow to Everglades National Park and the estuaries, removal of levees and canals that divide marshes, restoration of sheetflow, and recapture of freshwater that currently flows into the Atlantic Ocean.

Methods

The USGS Land Cover Trends project used thirty 10- by 10-km sample sites in the SFCP ecoregion (depicted in fig. 7) to generate estimates of contemporary land cover change for the study period 1973 to 2000. For each sample site, land cover maps were prepared for five distinct dates within the following intervals: 1973 to 1980, 1980 to 1986, 1986 to 1992, and 1992 to 2000. Landsat imagery was used as the base source for these land cover maps and was supplemented

Figure 6. Reserved lands, such as Everglades National Park, have played an integral part in restricting development. Photograph by the U.S. Geological Survey Land Cover Trends Project.

by aerial photography and other sources. Land covers were mapped using 11 distinct thematic classes (see appendix). Estimates of land cover change were computed by comparing the temporal series of land cover maps for each sample block in the ecoregion. Additional information on project methodology may be found in Loveland and others (2002).

Land Cover Change: 1973–2000

The Southern Florida Coastal Plain ecoregion experienced an estimated 5.8 percent change in land cover during the study period, a moderate amount of land cover change compared with that of other ecoregions and, in particular, its neighbor, the Southern Coastal Plain, which had an estimated land cover change of 24.9 percent (fig. 8).

An estimated 4.4 percent of the area (986 km^2 or 381 mi^2) was converted to other land covers just once, and 1.4 percent of the ecoregion (314 km^2 or 121 mi^2) was converted more than once (table 1). Approximately 94.2 percent of the ecoregion's land cover remained unchanged. The spatial distribution of change was very uneven, with high amounts in urbanizing coastal areas and relatively little change inland, where the presence of reserved lands inhibits change.

Table 1. Overall spatial change in the Southern Florida Coastal Plain ecoregion and number of changes in the ecoregion during one or multiple time periods.

[—, zero]

	Change (%)
Overall spatial change	5.8
Number of changes in ecoregion:	
One change	4.4
Two changes	1.2
Three changes	0.2
Four changes	—

The dominant pattern in the first and second intervals—1973 to 1980 and 1980 to 1986—is the conversion of natural covers, primarily wetland to agriculture. From the mid-1980s onward, conversions to developed lands from agriculture, wetland, grassland and shrubland, and other land cover types outpaced all other conversions combined.

Estimated Change per Interval

Estimated change per interval varied from a high of 2.5 percent between 1973 and 1980 to a low of 1.4 percent between 1992 and 2000 (table 2). The two intervening intervals—1980 to 1986 and 1986 to 1992—had a 1.7 and 1.9 percent change, respectively.

Estimated Average Annual Rate of Change

When the change per interval was annualized for the entire study period, the estimated overall rate of change was 0.3 percent. The 1973 to 1980 interval showed the highest rate of change at 0.4 percent (table 2). During this interval, the leading conversions were from wetland to agricultural land and a fire-related conversion from nonmechanically disturbed land to wetland. The interval with the least change, 0.2 percent, was the 1992 to 2000 interval. The leading conversions during this interval were from agricultural land to developed

Table 2. Estimated rate of land cover change.

[Estimated change per interval, associated confidence intervals, and annual average rates of change]

	Period				
	1973–1980	1980–1986	1986–1992	1992–2000	1973-2000
Total change (percentage of ecoregion)	2.5	1.7	1.9	1.4	1.9
Margin of error (85 percent at confidence level)	±1.3	±0.9	±1.1	±0.7	±0.8
Average annual rate of change (percent per year)	0.4	0.3	0.3	0.2	0.3

land and from wetland to nonmechanically disturbed land, again due to fire.

Estimated Percentage Change by Land Cover Type

Percentage change of area by land cover type indicates which land covers changed significantly between intervals and which were relatively stable (table 3). Developed land increased in each interval, from 2.3 percent of the ecoregion in 1973 to 4.1 percent in 2000. Agricultural land increased from 17.2 percent in 1973 to 18.4 percent in 1980, but then declined in each subsequent interval, back to 17.3 percent of the ecoregion in 2000. Nonmechanically disturbed land fluctuated between 0 and 0.6 percent between 1973 and 1992, reflecting the incidence of fire and regrowth in the Everglades. In 2000, nonmechanically disturbed land represented 0.3 percent of the ecoregion. Wetlands declined in each interval, except between 1986 and 1992, and overall from 73.7 percent in 1973 to 72.1 percent in 2000, primarily as a result of expanding agricultural land and developed land covers.

Agricultural conversions occurred on both the Atlantic and Gulf coasts during the study period, and agricultural land moved inland, overtaking wetlands and other natural covers. As demand for development increased, agriculture lands were displaced further inland—consuming more wetlands in the process—and in many cases were eventually converted to urban lands. This was especially true on the Atlantic coast where urbanized lands had expanded off the coastal ridge and had begun to advance westward towards the Everglades. During the 1990s, westward expansion of urbanization in many areas had reached the eastern perimeter levee put into place by the U.S. Army Corps of Engineers decades earlier (fig. 9). The levee has, in effect become a growth boundary for the urbanized portions of the Atlantic coast (Light and Dineen, 1994, p. 60).

Leading Conversions

Wetland to agricultural land was the leading conversion, with an estimated 348 km^2 (134 mi^2) converted between 1973 and 2000 (table 4). The highest rate of change occurred in the first interval (1973 to 1980), as 284 km^2 (110 mi^2) of wetland covers were converted to farmland. When conversions to developed land from agricultural land, forest and woodland, mechanically disturbed land, wetland, and grassland and shrubland are combined, more land—an estimated 413 km^2 (159 mi^2)—was converted to developed land than any other cover type during the study period. Conversions from agricultural lands to developed lands along accounted for 197 km^2 (76 mi^2) of that total and were the third most common conversion.

Fire-related conversions of nonmechanically disturbed land to wetland and of wetland back to nonmechanically disturbed land were the second and fourth most common conversions, respectively. Wetland, despite a continual decrease from 1973 to 2000, remained the dominant land cover.

Driving Forces: 1973–2000

Several factors contributed to contemporary land cover change in the SFCP. Driving forces behind land cover change during the study period included significant population growth of the ecoregion, continued demand for domestically produced sugar, and changes in local climate, perhaps as a consequence of wetland drainage that have resulted in damaging freezes to citrus crops. Other factors that played a role in change were

Table 3. Estimated land area by ecoregion land cover classes.

[km^2, square kilomenter: —, zero]

Land use and land cover class	1973		1980		1986		1992		2000		Net change, 1973-2000	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Water	616	2.7	620	2.8	636	2.8	667	3	705	3.1	89	0.4
Developed	516	2.3	586	2.6	671	3	814	3.6	922	4.1	406	1.8
Mechanically disturbed	31	0.1	19	0.1	52	0.2	36	0.2	46	0.2	15	0.1
Mining	1	—	3	—	—	—	3	—	2	—	—	—
Barren	6	—	6	—	6	—	6	—	6	—	—	—
Forest	648	2.9	619	2.8	602	2.7	583	2.6	575	2.6	-73	-0.3
Grassland and shrubland	82	0.4	77	0.3	64	0.3	79	0.4	56	0.3	-26	-0.1
Agriculture	3,859	17.2	4,124	18.4	4,085	18.2	3,943	17.6	3,871	17.3	11	0.1
Wetland	16,517	73.7	1,6350	73	16,160	72.1	1,6275	72.6	16,166	72.1	-351	-1.6
Nonmechanically disturbed	131	0.6	—	—	131	0.6	—	—	58	0.3	-73	-0.3

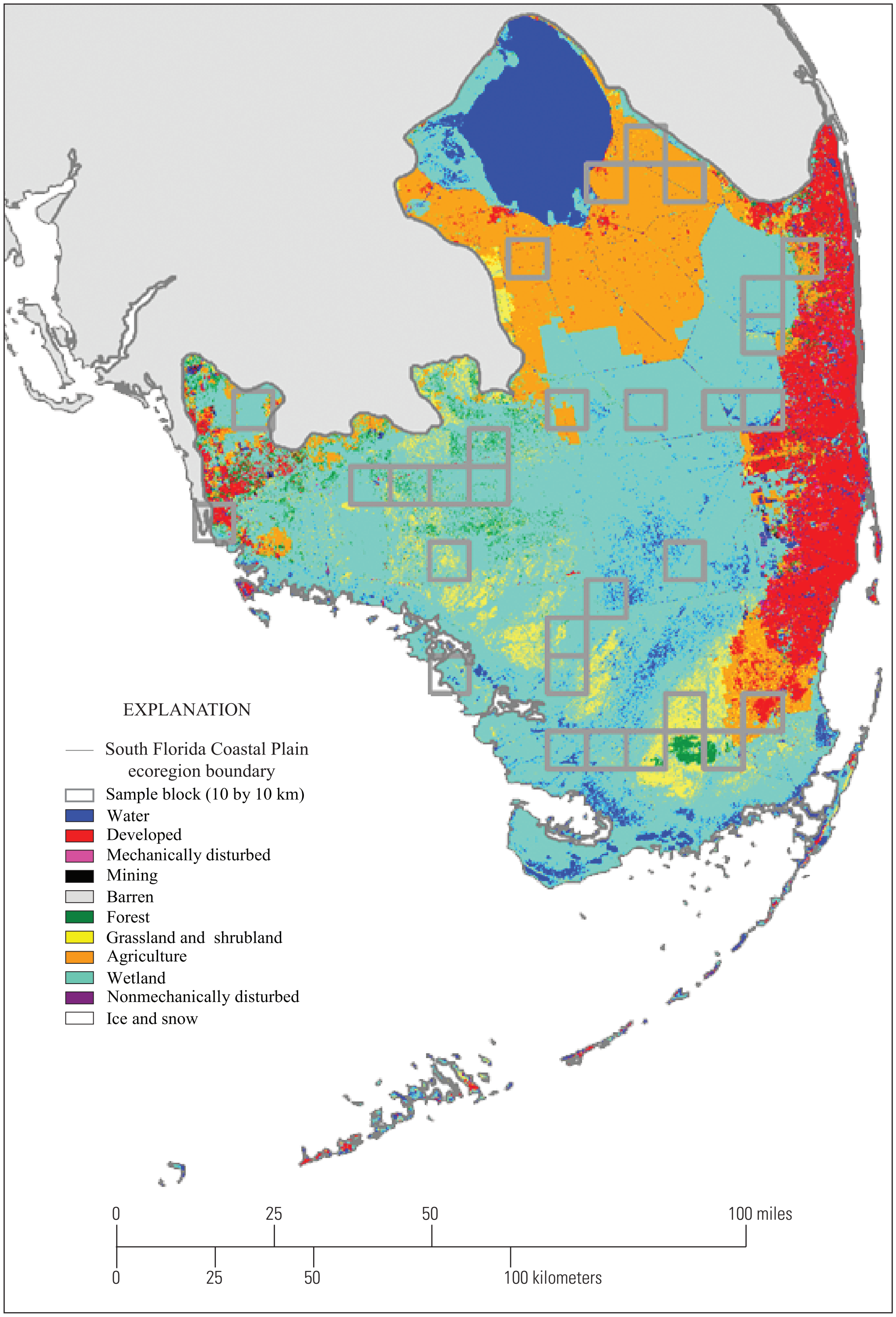

Figure 7. Map showing land use and cover of the Southern Florida Coastal Plain. The randomly selected 10 by 10 kilometer sample blocks are shown along with land use and land cover data from the 1992 National Land Cover Dataset which have been reclassified to the Land Cover Trends scheme (see appendix). Source: National Land Characteristics Database.

the increase in tourism, which created demand for additional development in urbanized coastal areas, and the incidence of land cover disturbances by fires and storms. The primary force that has inhibited the advance of developed lands towards the ecoregion's interior has been the creation and maintenance of large areas of State and Federal park lands.

The influence of government programs and initiatives on land cover change in southern Florida is significant and has had a direct bearing on the region's population growth and its sugarcane industry. Social Security—combined with private pensions and other nonemployment income—for example, has increased the financial independence of retirees (Graff and Wiseman, 1978, p., 379) and fueled their migration into the ecoregion. In addition, Federal import quotas on foreign sugar, price supports, and the trade embargo on Cuban goods have been critical in maintaining the economic viability of domestic

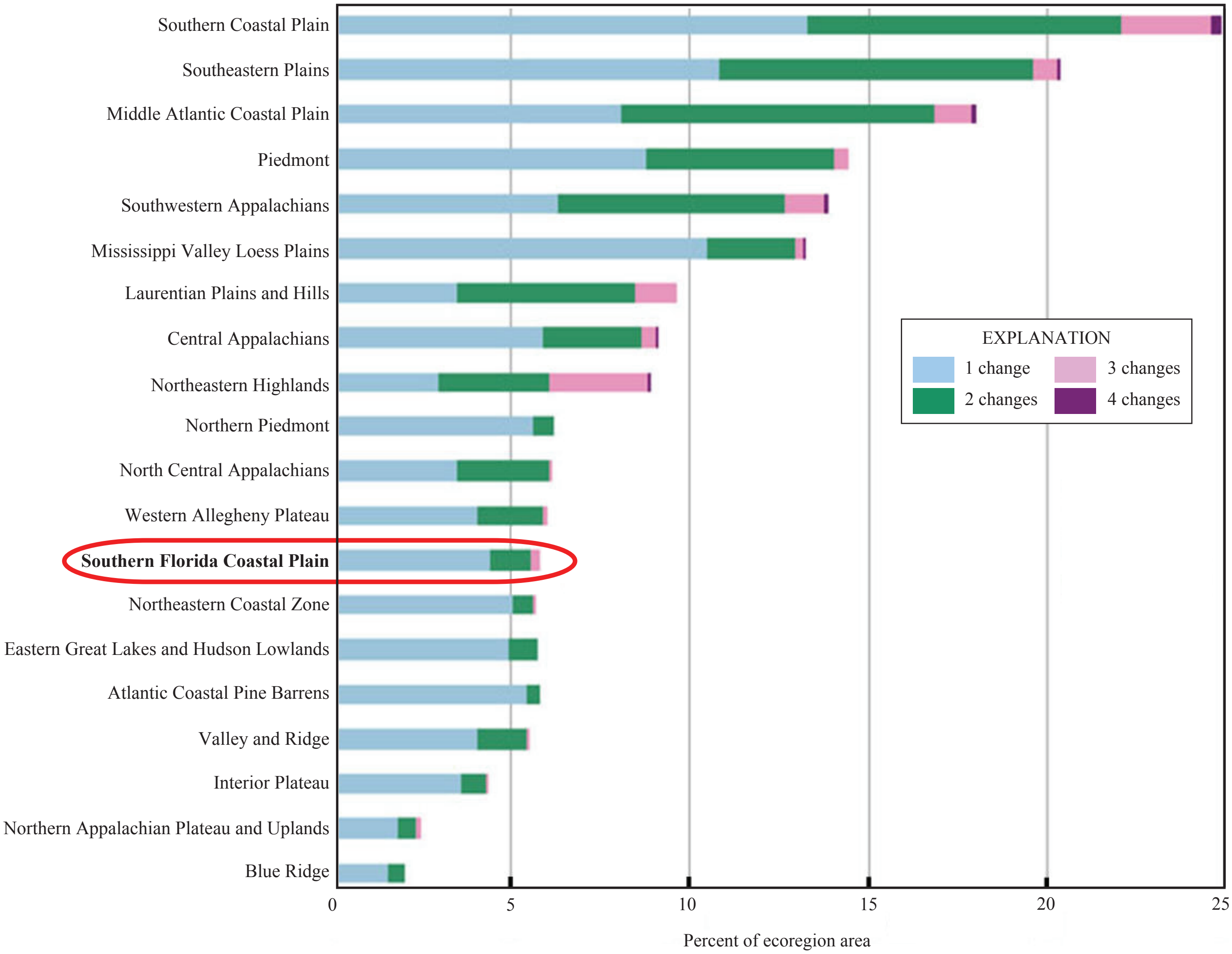

Figure 8. Bar graph illustrating change in the Southern Florida Coastal Plain (circled) compared with that in other ecoregions in the Eastern United States.

sugarcane production (McCally, 1999, p. 171; Solecki and Walker, 2001, p. 259). Government support and operation of water management infrastructure throughout the eastern half of the southern Florida peninsula have enabled continued growth of both agricultural and urban uses (Gunderson and others, 1995, S69; McCally, 1999, p. 171).

Land cover change in the ecoregion from 1973 to 2000 was characterized, in large part, by the expansion of agricultural and developed lands. Agricultural lands expanded through the conversion of natural land cover, such as forest, grassland, and wetland. Many of these conversions occurred in areas several kilometers inland from existing developed lands, in particular those along the western edge of the urbanized Atlantic coast. In addition, agriculture increased south of Lake Okeechobee in the EAA as sugarcane cultivation continued to expand at the expense of grazing lands for beef cattle and fallow lands (McCally, 1999, p. 172). Finally, movement of citrus operations southward into the ecoregion in response to the increasing frequency of overnight freezes has resulted in habitat fragmentation due to the conversion of natural land covers to citrus groves (Pearlstine and others, 1997, p. 160–161).

Rural-Urban Fringe

As the population of the ecoregion increased, development pressure along the rural-urban fringe in Miami-Dade, Broward, and Palm Beach Counties increased as well. These counties show significant growth in population between 1970 and 2000, especially in the newly urbanizing inland suburbs. Sunrise, situated near the eastern perimeter levee in Broward County, had a population of 7,403 in 1970 and was characterized by agricultural and low-intensity urban uses. By 2000, its agricultural land had disappeared, having been replaced by residential and commercial development; its population had grown by more than tenfold to 85,779. Other localities

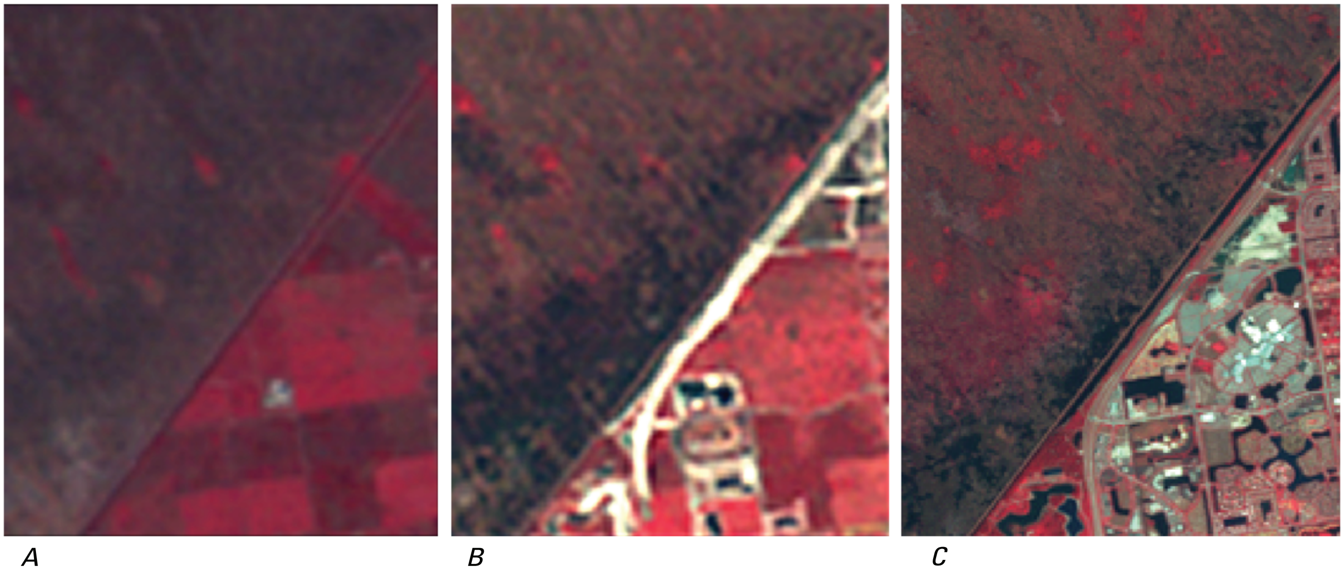

Figure 9. These Landsat satellite images show the process of land cover conversion along the rural and urban fringe near the inland community of Sunrise in Broward County. *A*. In 1973, agricultural lands and wetlands appear near the eastern perimeter levee. *B*. By 1978, some wetland areas were converted to farming, while lands that were previously in farming were developed. *C*. By 1991, the conversion of wetlands and agricultural lands continues throughout the 1980s and 1990s until developed lands extend to areas adjacent to the levee.

show similar gains between 1970 and 2000—Coral Springs increased from 1,489 to 117,549, and Tamarac increased from 5,078 to 55,588.

Much of southern Florida's population growth can be attributed to migration from Latin America and the Caribbean and from the Midwestern and Northeastern United States (Solecki and Walker, 2001, p. 258). While foreign immigrants tended to settle in Miami-Dade County, middle-class Americans, many of whom were retirees supported by public or private pensions and health care plans, began to settle in greater numbers in Broward and Palm Beach Counties where new retirement communities were developed to accommodate them. Moreover, a shift occurred from coastal high rises to inland areas as new complexes were established west of the coast, some on lands that had been farmed for winter vegetables (Winsberg, 1983). The westward shift was significant as the proportion of Broward and Palm Beach residents age 65 and older living four or more miles from the coast increased from about one-third to one-half between 1970 and 1980 (Winsberg, 1983). The region's tourism industry was an important driver of this shift as demand for hotel and resort development and associated amenities resulted in high land values along the Atlantic coast (Walker and others, 1997, p. 41). This, in turn, contributed to the movement of residential development inland (Walker and others, 1997, p. 41). Lower density urbanization away from the coast was instrumental in losses of agricultural land and natural areas.

The process of rural-urban fringe land conversion in the ecoregion is similar to that described by Hart (1991) in which the most intensive agricultural uses are converted to the least intensive urban uses. As the fringe extends further into rural aeas, lands adjacent to the ecoregion's leading edge tend to be converted to the agricultural use that was consumed by urbanization. As development advances inland, however, movement of agricultural uses inland is limited, especially as they approach the eastern perimeter levee and public land boundaries. Some of these transitions have been captured in several sample blocks, which are situated near the interface between human and natural land covers (fig. 7). By 2000, agricultural lands had been largely replaced by developed lands in Broward County, while Palm Beach County maintained row crops and other high-intensity agricultural uses, including tree crops, and nurseries on its urban fringe. Other growth constraints, such as the urban development boundary in Miami-Dade County, have restricted conversions of agriculture to developed land.

Sugarcane Production

In the northern portion of the ecoregion, agricultural land devoted to sugarcane production in the EAA has expanded since the U.S. embargo on Cuban goods in the early 1960s. The amount of land in sugarcane was about 19,021 ha (47,000 acres) in 1959 prior to the embargo (Snyder and Davidson, 1994, p. 101). Sugarcane cropland increased from approximately 92,272 ha (228,000 acres) in the 1964–65 season (Salley, 1986) to 176,835 ha (436,954 acres) in 1997 (U.S. Department of Agriculture, 1999). As sugarcane became established as the dominant crop in the EAA, lands were diverted from other crops and extensive areas of pasture and fallow lands were brought into production.

Table 4. Leading land conversions by time period.

Period	From class	To class	Area changed (km^2)	Percentage of all changes
1973–1980	Wetland	Agriculture	284	51
	Nonmechanically disturbed	Wetland	130	23
	Forest	Developed	25	4
	Mechanically disturbed	Developed	19	3
	Agriculture	Developed	17	3
	Other	Other	84	15
	Total		559	100
1980–1986	Wetland	Nonmechanically disturbed	131	34
	Agriculture	Mechanically disturbed	37	10
	Wetland	Agriculture	37	10
	Agriculture	Developed	34	9
	Forest	Developed	18	5
	Other	Other	123	32
	Total		380	100
1986–1992	Nonmechanically disturbed	Wetland	131	31
	Agriculture	Developed	86	20
	Agriculture	Grassland and shrubland	31	7
	Mechanically disturbed	Developed	27	6
	Forest	Developed	22	5
	Other	Other	129	30
	Total		426	100
1992–2000	Agriculture	Developed	60	20
	Wetland	Nonmechanically disturbed	57	19
	Wetland	Agriculture	22	7
	Wetland	Water	19	6
	Agriculture	Mechanically disturbed	18	6
	Other	Other	129	42
	Total		305	100
Overall				
	Wetland	Agriculture	348	21
	Nonmechanically disturbed	Wetland	261	16
	Agriculture	Developed	197	12
	Wetland	Nonmechanically disturbed	187	11
	Agriculture	Mechanically disturbed	80	5
	Other	Other	598	36
	Total		1,671	100

The development of a domestic sugarcane crop was a result of the Cuban Revolution and the subsequent decline in relations between the United States and Cuba. Over the years, sugar growers have received considerable support from the Federal Government to ensure the its continued cultivation. Publically funded water management, immigration policies that enabled access to low-cost foreign labor, and import quotas and subsidies helped maintain the presence of sugarcane. A change in the Cuban regime, however, could lead to a relaxation of import restrictions and reduce future domestic production.

Southward Migration of Citrus Operations

During the early 1980s, a number of severe freezes occurred in the citrus belt of central Florida. In the following years, growers appear to have adjusted to the perceived climatic risk by relocating their operations to southwestern Florida. The migration southward is evidenced by large increases in citrus production in counties such as Lee, Hendry, and Collier. These counties had increases in total (bearing and nonbearing) acreage of 33, 43, and 47 percent, respectively, between 1980 and 1986. Counties in central Florida suffered losses in total citrus acreage ranging from 3 to 95 percent during the same period, with higher percentage losses occurring in the northernmost counties, as reported by the Florida Livestock and Crop Reporting Service (Miller and Glantz, 1988, p.145–147). The amount of citrus acreage in southwestern Florida increased by more than twofold and, by the late 1990s, extended over approximately 75,000 ha (835,323 acres) (Main and others, 1999, p. 1,264).

Much of the increase in citrus has occurred on previously cleared forest land; however, conversion of existing forest lands to citrus crops has contributed to a decades-long decline of pinelands in southwestern Florida. The loss of forest, along with other natural covers, has resulted in increased fragmentation of habitat, especially for wide-ranging species such as the black bear and Florida panther (Pearlstine and others, 1997).

Fire

Before human settlement, most fires were caused by lightning strikes between April and June—the transitional months between the dry and wet seasons. Generally, fires act to preserve the ecological integrity of plant communities by eliminating decaying organic matter and reducing the incidence of invading species. Southern Florida's pinelands, for example, depend on fire to limit the growth of hardwood species (Lodge, 1994, p. 60).

Sources of fire now include prescribed burns by park managers and accidental or arson-related fires in adjacent urban areas that spread across park boundaries (fig. 10) (Lockwood and others, 2003, p. 465). Prescribed burns may be employed to eliminate fuel in the dry season to preempt larger fires that may spread to urban or agricultural areas, to manage wildlife resources, or to recreate fire frequencies that resemble natural regimes (Lockwood and others, 2003, p. 465). The Everglades are especially susceptible to widespread fire during periods of drought. During an extended drought in the early 1970s, fire engulfed more than 300,000 ha (741,290 acres) (Gunderson and others, 1995, p. S68).

Weather Events

The ecoregion's proximity to the Atlantic and the Caribbean has made it vulnerable to tropical storms and hurricanes, and loss of life and destruction of property from major storms in the late 1920s and again in the late 1940s led to the construction of flood control and other water management infrastructure. The most severe weather event during the study period was Hurricane Andrew, which made landfall in southern Florida on August 24, 1992. Property damage to Miami-Dade County housing stock was extensive and resulted in the permanent relocation from the county of an estimated 40,000 people, of which approximately 12,000 settled in Broward County (Smith and McCarty, 1996, p. 272). The increase in population may have accelerated demand for housing and contributed to the expansion of developed lands in southwestern Broward County.

Figure 10. Photograph of a fire started by a passing airboat. Photograph courtesy of Chuck Hinkle.

The hurricane also caused significant damage to natural areas. Losses of pinelands and hammocks on Long Pine Key in Everglades National Park were reported, as well as loss of pinelands in southern Big Cypress (Loope and others, 1994, p. 239). Extensive damage to mangrove forests in southern Florida was also reported (Doyle and others, 1995 p. 166).

Reserved Public Lands

Much of the ecoregion's distribution of population and development patterns can be attributed to the presence of State and Federal parks and refuges. A major addition to public land ownership during the study period was the creation of Big Cypress National Preserve in 1974. While Everglades National Park and Arthur R. Marshall Loxahatchee National Wildlife Refuge were established in 1947 and 1951, respectively, the wetland ecosystem that comprises Big Cypress remained outside of public management. The proposed airport and ensuing controversy, however, made clear that protection of southern Florida's wetlands was incomplete (Carter, 1974, p. 228), and environmentalists and government officials sought to secure Big Cypress from future development.

Validation

In an effort to validate our findings, change statistics were measured within a margin of error of ±1 percent at an 85 percent confidence interval. Change estimates with a margin of error greater than ±1 percent may result from inadequate sampling density and (or) unevenly distributed change. In the SFCP ecoregion, two intervals (1980 to 1986, and 1992 to 2000) were within the precision goal of the Land Cover Trends

Project (table 2). The margin of error for the 1973 to 1980 and the 1986 to 1992 intervals slightly exceeded the preferred margin of error. The margin of error for the entire 1973 to 2000 study period did meet the statistical goal.

In addition, we have tried to verify overall changes in land cover through comparison with other relevant data, including agricultural, population, and housing census statistics. We are particularly interested in the changes in developed and agricultural land covers, since these categories are the most dynamic of the 11 land cover categories for which change statistics have been collected. This is consistent with historical patterns of change in the ecoregion, which show enormous amounts of land converting from wetland and other natural covers to agricultural lands since the early 1900s. Between 1973 and 1988, however, the historical dominance of agricultural conversion appeared to be overtaken by conversions of agricultural and natural covers to developed lands, especially on the Gulf and Atlantic coasts (Walker and Solecki, 2004, p. 316). Land Cover Trends data are consistent with these observations. During the first half of the study period, the conversion of wetland, forest, and grassland and shrubland to agriculture was the dominant land cover change. Subsequently, conversions from agriculture to developed lands emerged as a pattern of land cover change.

In the five counties that lie entirely or mostly in the SFCP—Miami-Dade, Broward, Palm Beach, Collier, and Monroe—census data are used to examine the trends in agriculture, population, and housing. The U.S. Department of Agriculture statistics (table 5) generally reflect the Land Cover Trends Project results that show agricultural lands increasing from 1973 to approximately the midpoint of the study period, and then decreasing thereafter. The most common conversion from 1973 to 1980 is from wetlands to agricultural lands. In subsequent intervals, conversions to agricultural lands taper off, while those to developed lands—especially from agriculture—increase.

Data for each county show increasing population in all the decades from 1970 through 2000 and a corresponding increase in housing units during that time as well. Each of the counties has an extremely high rate of growth, both in percentage and in absolute numbers, during the study period. When examining these data, one would expect that there would be more of an increase in the developed area of the ecoregion. The slower growth in developed areas and subsequent increased density of housing may be partly due to development constraints imposed by reserved lands.

Summary

The SFCP underwent enormous landscape change during the 20th century. Estimates of change developed between 1973

Table 5. Agricultural statistics for the Southern Florida Coastal Plain.

[compiled from U.S. Department of Agriculture. Data between 1974 and 1986 are not available. —, zero]

County	Total acres of agricultural land[1]				
	1974	1987	1992	1997	2002
Broward	39,814	28,291	16,191	27,533	16,481
Collier	203,395	231,389	202,164	191,133	91,398
Miami-Dade	70,262	74,591	78,415	73,839	73,954
Monroe	—	—	—	—	—
Palm Beach	483,541	619,678	595,072	544,641	492,592
Total	797,012	953,949	891,842	837,146	674,425

[1]Sum of the total crop land and true pasture.

Table 6. Population and housing statistics for the Southern Florida Coastal Plain.

[Data are from the U.S. Census Bureau]

County	Population				Housing units			
	1970	1980	1990	2000	1970	1980	1990	2000
Broward	620,100	1,018,257	1,255,488	1,623,018	253,320	486,161	628,660	741,043
Collier	38,040	85,971	152,099	251,377	17,580	50,743	94,165	144,536
Hendry	11,859	18,599	25,773	36,210	3,985	7,032	9,945	12,294
Lee	105,216	205,266	335,113	440,888	43,511	111,013	189,051	245,405
Miami-Dade	1,267,792	1,625,509	1,937,094	2,253,362	453,908	665,282	771,288	852,278
Monroe	52,586	63,188	78,024	79,589	20,731	38,088	46,215	51,617
Palm Beach	348,993	576,758	863,518	1,131,184	141,363	295,536	461,665	556,428

and 2000 were made using Landsat imagery and ancillary data, including historical aerial photography. Thirty randomly selected 10-km^2 blocks were interpreted using a modified Anderson level 1 classification scheme. Five sets of land cover data were generated for each sample block. The dates of each interpreted land cover dataset are approximately 1973, 1980, 1986, 1992, and 2000.

The results of our study show that the most common land cover conversions were from wetland to agriculture and from agriculture to developed lands. Conversions to agriculture predominate in the first half of the study period, while conversions to developed lands occur primarily between 1986 and 2000. Fire, occurring both naturally and as a result of human activity, also accounted for change in the Everglades as wetland vegetation burned and regenerated.

It is important to note that the essential patterns of land cover in the SFCP had been established prior to the study period. These patterns—in which developed lands occur in coastal areas, especially along the Atlantic coast, and agriculture exists primarily in the EAA south of Lake Okeechobee—became firmly established after World War II.

Several factors contributed to these patterns. Perhaps the most important was the comprehensive effort by the Federal Government to control and manage water supply in the region, beginning in the late 1940s. Flood mitigation and drainage made the establishment of the EAA possible and ensured water supply for urban areas along the Atlantic coast.

Population increases arising from relocation of retirees from the Midwest and Northeast and of immigrants from the Caribbean and Latin America created new demand for housing and related development. Tourism, fueled by improved roads and increased air travel to the region, resulted in millions of visits per year by tourists and spurred hotel and resort development.

On the other hand, the presence of State and Federal lands has inhibited change in the interior of the ecoregion. Concern about the health of southern Florida's ecosystems has contributed to numerous government polices and practices intended to address their decline. Efforts to understand the impacts of urban, industrial, and agricultural uses in the ecoregion continue.

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Appendix—Land Cover Classes and Definitions Used in the Land Cover Trends Project

Definitions used in this project are the land use and land cover definitions used in the U.S. Geological Survey Land Cover Trends project, which was based on the original level I definitions by Anderson and others (1976). With the use of the following modified Anderson classification, the land cover data developed are consistent with those produced through other projects. The spatial resolution of the trends database is 60 square meters (m^2). Features with ground footprints smaller than the minimum mapping unit are not mapped. Our ability to identify and map these land cover classes is limited by the technical specifications of Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus sensors and by the local and regional landscape characteristics that affect the form and contrast of land cover characteristics.

water Areas persistently covered with water, such as bays, canals, lakes, oceans, reservoirs, or streams.

developed Areas of intensive use where much of the land is covered with structures (for example, high-density residential, commercial, industrial, or transportation), or less intensive uses where the land cover matrix includes both vegetation and structures (for example, low-density residential areas, recreational facilities, cemeteries, or transportation and utility corridors), including any land functionally related to the developed or built-up activity.

mechanically disturbed or transitional Land in an altered unvegetated state that, because of disturbances by mechanical means, is in transition from one cover type to another. Mechanical disturbances include chaining, earth moving, forest clearcutting, reservoir drawdown, scraping, and other related human-induced changes.

mining Areas with extractive mining activities that have a significant surface expression. This includes (to the extent that these features can be detected) mining buildings, quarry pits, overburden, leach, evaporative, tailings, or other related components.

barren Land comprising natural occurrences of rocks, sand, or soils where less than 10 percent of the area is vegetated.

forest Tree-covered land where the tree-cover density is greater than 10 percent. Note that cleared forest land (that is, clearcuts) will be mapped according to current cover (for example, mechanically disturbed or grassland and shrubland).

grassland and shrubland Land predominately covered with grasses, forbs, or shrubs. The vegetated cover must comprise at least 10 percent of the area.

agriculture Land in either a vegetated or nonvegetated state used for the production of food or fiber. This includes cultivated and uncultivated crop lands, hay lands, pasture, orchards, vineyards, and confined livestock operations. Note that forest plantations are considered as forests or woodlands, regardless of the use of the wood products.

wetland Lands where water saturation is the determining factor in animal communities, soil characteristics, and vegetation types. Wetlands comprise water and vegetated cover.

nonmechanically disturbed or transitional Land in an altered nonvegetated state that, because of disturbances by nonmechanical means, is in transition from one cover type to another. Nonmechanical disturbances include animals, fire, floods, wind, and other related sources.

snow and ice Land where the accumulation of snow and ice does not completely melt during the summer period.

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