FLORIDA VEGETATION 2003 AND LAND USE CHANGE BETWEEN 1985–89 AND 2003

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Abstract: *The purposes of this study were to create an updated vegetation map for Florida and to measure land use change over a 14–18 year period. We used Landsat Enhanced Thematic Mapper+ satellite imagery from 2003 to map Florida vegetation and land cover. We then compared the 2003 data with an earlier digital data set derived from 1985–89 Landsat imagery. About 611,845 ha of natural and semi-natural cover types were converted to urban or other developed uses, and 703,292 ha were converted to agricultural uses. About 355,437 ha of agricultural and pasture lands were converted to urban or developed uses over this 14–18 year period. Pinelands experienced the greatest decline in total area with about 243,508 ha having been converted to other uses. Dry prairie experienced the greatest decline in percent area with about 25% of the area existing in 1985–89 converted to urban, developed, or agricultural uses by 2003. Upland cover types experienced greater declines than wetland types over the study period. Natural and semi-natural cover types were lost at a rate of 73,063–93,938 ha per year, and agricultural lands declined at a rate of 19,746–25,388 ha per year over this period.*

Key Words: Vegetation, land use change, habitat loss

In 1990, the Florida Fish and Wildlife Conservation Commission (FWC) completed a project to map Florida vegetation and land cover using 1985–89 Landsat Thematic Mapper satellite imagery (Kautz et al., 1993). The resulting digital database contained 17 natural and semi-natural land cover types, 4 land cover types indicative of human disturbance, and 1 water class. Since its inception, this digital database has been applied in a variety of ways to land use and conservation planning, land management, public land acquisition, and research in Florida. The data also were used as the basic vegetation data layer for wildlife habitat and landscape linkage modeling (Cox et al., 1994; Cox and Kautz, 2000; Hoctor et al., 2000; Kautz and Cox, 2001).

However, over time, the 1985–89 vegetation and land cover data set has become increasingly out of date. Since this data set was created, Florida's population has grown from 12.9 million to an estimated 17.4 million residents in 2004, and recent data indicates that almost 80 million tourists visited Florida in 2004. The large numbers of new residents and tourists have resulted in conversion of both natural and disturbed areas of the Florida landscape to more intensive human uses. These changes have led to the need for newer

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vegetation and land cover data for application to landscape-scale conservation planning. Specifically, this information is needed to refocus past conservation planning efforts (Kautz and Cox, 2001) in response to changes in land use over time.

Our objectives for this project were twofold. Our first objective was to create updated digital vegetation and land cover data for Florida using Landsat satellite imagery from 2003. Our second objective was to assess land use change in Florida by comparing the 1985–89 and 2003 land cover data sets.

METHODS—*Vegetation mapping*—We purchased 14 scenes of raw Landsat Enhanced Thematic Mapper+ (ETM) satellite imagery for Florida from the U. S. Geological Survey EROS Data Center in Sioux Falls, SD. Scenes as purchased had a resolution of 28.5 m pixels, but we resampled each scene to 30 m pixels. Image collection dates ranged between January 8 and March 24, 2003 (Fig. 1). We mapped one Landsat scene at a time using a series of iterative classification steps and comparison ancillary data sets. Ancillary data sets included 1995 land use/land cover data created by Florida's water management districts and the Florida Department of Environmental Protection,

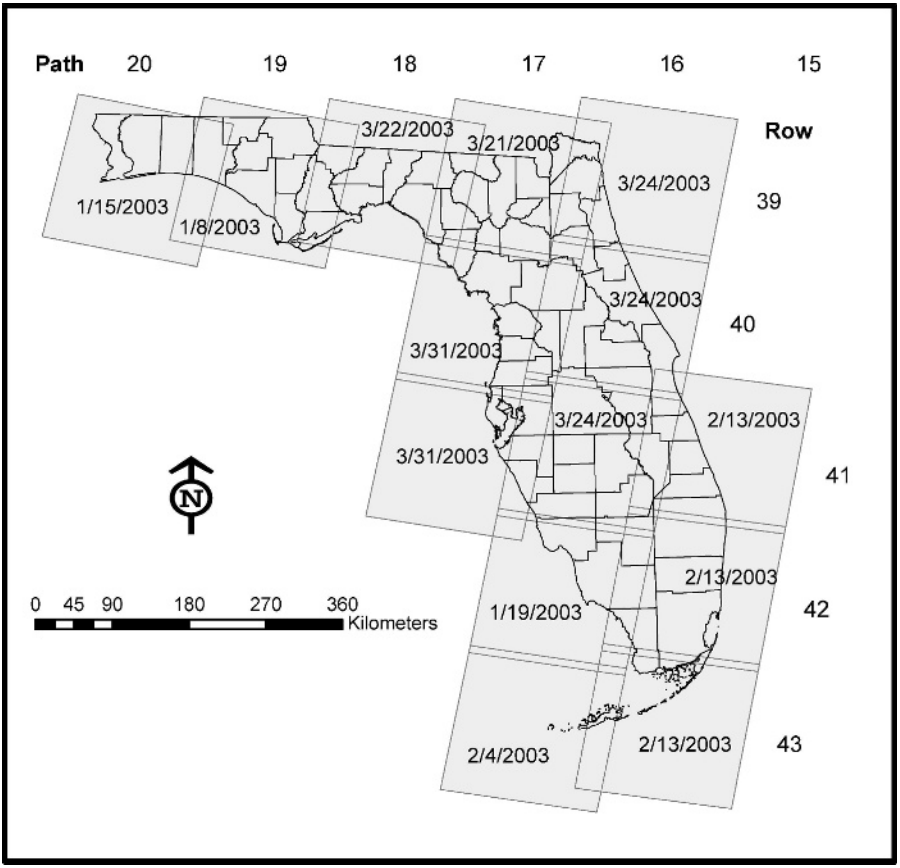

FIG. 1. Dates of Landsat ETM^{+} satellite imagery used to map Florida vegetation and land cover.

U. S. Fish and Wildlife Service National Wetlands Inventory (NWI) digital boundaries of Florida wetlands, detailed digital soils (SSURGO) data sets, a 1985–89 land cover map (Kautz et al., 1993), and 1999 digital orthographic quarter quadrangle (DOQQ) aerial photography.

We projected raw Landsat ETM+ imagery to Albers HPGN (North American Datum 1983) using ERDAS Imagine 8.6 image processing software. The projected imagery was geo-referenced to U. S. Bureau of Census TIGER road files using the Image Analysis 1.1 extension of ArcView GIS 3.3 (ESRI, Redlands, CA). All scenes were geo-referenced with at least 20 control points to a root-mean-square (RMS) positional accuracy of $<$15 m. The imagery was clipped along the coastlines, if necessary, to reduce file size and increase effectiveness of classifications.

Image classification was conducted in ArcView GIS 3.3 using the Image Analysis 1.1 extension. Normalized Difference Vegetation Index (NDVI) ratio bands were created for each scene to provide a measure of vegetation density useful for class discrimination. Image classification proceeded according to the following general steps:

(1.) Unsupervised classifications were performed on each Landsat scene in its entirety. Initial classifications were performed on all six 30 m pixel spectral bands. The number of resultant spectral classes was typically set to 75–100.

(2.) The 75–100 spectral classes resulting from Step 1 were reviewed individually. Each spectral class was visually checked against the Landsat imagery as well as the ancillary data. If any of the spectral classes consistently identified a specific target land cover type (e.g., mangrove swamp, pine forest, coastal strand), those spectral classes were labeled according to the vegetation or land cover type they represented, and those classes were considered final and were excluded from further analyses.

(3.) All unlabeled pixels remaining after Step 2 were then subjected to additional unsupervised classifications. Varying band combinations were used to group similar areas into distinct cover types. Resultant spectral classes ranged from a few to over 50. These steps were repeated until all pixels fell into a specific land cover type or into a larger, temporary grouping (e.g., disturbed). Additionally, areas with unique features or areas resulting in classification confusion were clipped from the scene, and unsupervised classifications were then performed only on the clipped areas.

(4.) The data sets resulting from Step 3 that consistently represented specific natural land cover types were assigned the appropriate label, were added to the final data set, and were excluded from further analyses.

(5.) Using agricultural and urban land use classes from the 1995 digital data set of statewide land use/land cover as an overlay, spectral classes that had been identified as disturbed and that fell within the agricultural or urban land use class overlay were isolated. Unsupervised classification was performed on these areas to spectrally isolate agricultural areas from urban areas.

(6.) By comparing spectral classes resulting from Step 5 with the ancillary data sets, particularly 1995 land use/land cover and 1999 DOQQ, disturbed spectral classes were categorized into six agricultural land use classes (i.e., improved pasture, unimproved pasture, sugar cane, citrus, row and field crops, other agriculture), two urban classes (i.e., high density urban, low density urban), and extractive (i.e., mining). All pixels in these classes were added to the final data set and were excluded from further analyses. Visual interpretation of spectral classes and the Landsat imagery was required in areas where there was new urban growth and where agricultural lands were in a bare soil state, creating a false urban signature. Very often it was necessary to isolate these areas individually and assign the appropriate label. Areas that classified as disturbed but were not within the agricultural and urban lands overlay were checked visually against the Landsat imagery and other ancillary data layers. Often these disturbed areas were new areas of agriculture or urban lands, or they represented recent land clearings due to silvicultural practices or unknown causes.

(7.) Once an entire scene had been analyzed, specific geographic areas of similar physiographic features (e.g., coastal wetlands, xeric ridges) were examined, and, if necessary, additional unsupervised classifications were performed on any remaining classes of pixels that could not be separated based on spectral information developed at the level of the entire Landsat scene. Any classes that consistently represented a specific land cover type were assigned the appropriate land cover label, added to the final data set, and excluded from further analyses.

(8.) Any remaining areas that did not have a specific land cover label were visually reviewed in relationship to the Landsat imagery, land use/land cover data, and DOQQ. If possible, unlabeled groups of pixels were assigned to appropriate land cover types by hand, and were added to the final data set and excluded from further analyses.

(9.) Once all pixels within a Landsat scene had been classified, labeled, and added to the final data set comprising the updated vegetation and land cover map, specific areas of the map were visited in the field for ground-truthing. Any mistakes discovered in the ground-truthing process were then corrected to create a final draft vegetation map covering an entire Landsat scene.

(10.) Once a scene was complete, it was edge-matched and merged with adjacent scenes to create a seamless statewide vegetation and land cover data set based on 2003 imagery.

Land use change—We co-registered the 1985–89 land cover data (Kautz et al., 1993) to the 2003 land cover data using 30 ground control points. The co-registered data sets had a root mean square error of 36 m. The 22 land cover types from 1985–89 and the 43 land cover classes from the 2003 data were reclassified to 17 standard vegetation and land cover types (Table 1) to overcome classification differences. The 17 class values from the 1985–89 data were multiplied by 100 to create a new grid with class values of 0100, 0200, 0300,…1700. Then the data sets for the two dates were added together to produce a new four-digit integer grid, the class values of which contained all possible combinations of change between the two dates. The first 2 digits indicated the land cover class in 1985–89 and the last 2 digits indicated land cover in 2003.

Due to limitations inherent in the 1985–89 data, we performed an additional manipulation of the data to improve our ability to detect conversions of natural or agricultural lands to urban or other developed uses between the two dates. In the 1985–89 data, Kautz and co-workers (1993) grouped all types of barren and urban lands into the same category with no differentiation of urban lands from other types of barren lands, such as beaches, spoil mounds, clearcuts, and fallow fields. Thus, we grouped all barren and urban land cover types (i.e., bare soil/clearcut, sand/beach, extractive, high and low intensity urban) together in the 2003 data set to facilitate direct comparison of land cover types between the two dates. However, this grouping of types in the 2003 data made it impossible to specifically differentiate lands converted to urban or developed uses from lands simply cleared as part of routine agricultural or silvicultural practices.

To overcome this problem, all pixels coded as bare soil/clearcut in the 2003 land cover data were extracted and used as a mask, and pixels under the mask were extracted from the new four-digit change detection grid. The extracted pixels were then reclassified to a new four-digit code, the first two digits of which indicated the 1985–89 cover type and the last two digits of which were coded to 18, a value we assigned to indicate conversion from a previous land cover type to bare soil/clearcut. For example, if an area had been mapped as pinelands in 1985–89 but was mapped as bare soil/clearcut in 2003, pixels representing the area in the change detection grid would have been recoded from 0316 to 0318. The reclassified pixels were then merged back into the master four-digit change grid.

Similarly, pixels mapped as sand/beach in 2003 were extracted and used as a mask, and pixels under the mask were isolated from the change detection grid. Then, the last two digits of the extracted pixels were recoded to 19 to indicate a change to sand/beach, and the recoded pixels were merged back into the master change grid. With this step, the first two digits represented the land cover type of a pixel in 1985–89 and the last two digits (i.e., 19) indicated a change to sand/beach.

The two steps just described allowed for conversions of natural, semi-natural, or agricultural lands to urban/developed, bare soil/clearcut, or sand/beach to be detected independent of one another. These steps produced a final change detection grid in which any pixels that had a value of

TABLE 1. Reclassification scheme applied to 1985–89 and 2003 land cover data for assessing land use change.

2003 Vegetation and Land Cover Types	1985–89 Class Number	2003 Class Number	Land Use Change Vegetation And Land Cover Types	Change Class Number
Coastal strand	1	1	Coastal strand	1
Sand/beach	22	2	Barren/urban	16
Xeric oak scrub	6	3	Scrub	4
Sand pine scrub	4	4	Scrub	4
Sandhill	5	5	Sandhill	5
Dry prairie	2	6	Dry prairie	2
Mixed hardwood-pine forest	7	7	Upland forest	6
Hardwood hammock and forest	8	8	Upland forest	6
Pineland	3	9	Pineland	3
Cabbage palm-live oak hammock	8	10	Upland forest	6
Tropical hardwood hammock	9	11	Tropical hardwood hammock	8
Freshwater marsh and wet prairie	11	12	Freshwater marsh	11
Sawgrass marsh	11	13	Freshwater marsh	11
Cattail marsh	11	14	Freshwater marsh	11
Shrub swamp	15	15	Shrub swamp	12
Bay swamp	14	16	Forested wetland	7
Cypress swamp	12	17	Forested wetland	7
Cypress/pine/cabbage palm	12	18	Forested wetland	7
Mixed wetland forest	13	19	Forested wetland	7
Hardwood swamp	13	20	Forested wetland	7
Hyrdric hammock	8	21	Upland forest	6
Bottomland hardwood forest	17	22	Forested wetland	7
Salt marsh	10	23	Salt marsh	10
Mangrove swamp	16	24	Mangrove swamp	9
Scrub mangrove	16	25	Mangrove swamp	9
Tidal flat	10	26	Salt marsh	10
Water	18	27	Water	17
Shrub and brushland	20	28	Shrub and brushland	13
Grassland	19	29	Grassland/agriculture	14
Bare soil/clearcut	22	30	Urban/barren	16
Improved pasture	19	31	Grassland/agriculture	14
Unimproved pasture	19	32	Grassland/agriculture	14
Sugarcane	19	33	Grassland/agriculture	14
Citrus	19	34	Grassland/agriculture	14
Row/field crops	19	35	Grassland/agriculture	14
Other agriculture	19	36	Grassland/agriculture	14
Exotic plants	21	37	Exotic plants	15
Australian pine	21	38	Exotic plants	15
Melaleuca	21	39	Exotic plants	15
Brazillian pepper	21	40	Exotic plants	15
High impact urban	22	41	Urban/barren	16
Low impact urban	22	42	Urban/barren	16
Extractive	22	43	Urban/barren	16

16 for the last two digits represented lands that in 2003 were either urban or some other intensive developed human use (e.g., mining, military bombing range), and the first two digits indicated the land cover type converted to urban/developed between the two dates.

All data manipulation and analysis was accomplished using ArcView 3.3 with either the Spatial Analyst 2.0 extension or the Image Analysis 1.1 extension (ESRI, Redlands, CA).

RESULTS—*Vegetation mapping*—The final 2003 digital data set covering all of Florida contained 43 vegetation and land cover types compared to the 22 types appearing in the earlier data set (Kautz et al., 1993). The new map contained 26 natural and semi-natural vegetation types, 16 types of disturbed lands (e.g., agriculture, urban, mining), and 1 water class (Table 2). Area estimates for each vegetation and land cover type in 2003 also appear in Table 2.

Land use change—Of 9.86 million ha of natural and semi-natural land cover types present in Florida in 1985–89, 1.32 million ha (13.3%) were converted to urban, developed, or agricultural land uses between 1985–89 and 2003 (Table 3) (Fig. 2). Conversions of natural and semi-natural cover types to urban and developed lands accounted for 0.61 million ha (6.2% of natural cover types present in 1985–89), and conversions to agricultural uses accounted for 0.70 million ha (7.1% of natural cover types present in 1985–89). Shrub and brush was the most heavily impacted semi-natural type, having lost around 0.60 million ha (36.3% of that present in 1985–89) to intensive human uses. However, this may be misleading as the shrub and brush class in the older vegetation map included both citrus groves and old-field successional stages (i.e., lands often undergoing conversion to intensive human uses, or lands where several-year-old disturbances due to routine agricultural or silvicultural practices are the norm).

Pinelands, a land cover type that includes large tracts in silvicultural use, experienced the greatest impact in terms of total area of conversion with 0.24 million ha (9.2% of the area present in 1985–89) having been lost, most (64%) of which was to urban and developed uses. Dry prairie experienced the greatest degree of loss with respect to percent of conversion, with 0.14 million ha (25.4% of the area present in 1985–89) having been converted, 73% of which was lost to agriculture. Sandhill, a formerly abundant but rapidly diminishing natural xeric community (Kautz, 1998), also experienced a relatively high degree of loss with 53,356 ha (15.5% of that present in 1985–89) converted to other uses between 1985–89 and 2003, and 72% of the conversion was to urban or other developed uses. Scrub, a natural community type often associated with a high degree of endemism and rare species (Myers, 1990), likewise experienced a relatively high degree of loss, with 21,208 ha (12.4% of the area present in 1985–89) having been converted, 79% of which was lost to urban or other developed uses. Coastal strand, a rare natural community distributed along high-energy coastlines, and tropical hardwood hammock, a rare south Florida community, both declined about 10.8% relative to the area present in 1985–89, with virtually all of the loss to urban or other developed uses.

TABLE 2. Area of Florida land cover types mapped from 2003 Landsat ETM imagery.

Class Value	Land Cover Class	Hectares
1	Coastal strand	6,081
2	Sand/beach	13,263
3	Xeric oak scrub	59,450
4	Sand pine scrub	78,608
5	Sandhill	308,405
6	Dry prairie	497,085
7	Mixed pine-hardwood forest	361,605
8	Hardwood hammocks and forests	385,257
9	Pinelands	2,648,441
10	Cabbage palm-live oak hammock	3,982
11	Tropical hardwood hammock	6,231
12	Freshwater marsh and wet prairie	894,318
13	Sawgrass marsh	282,745
14	Cattail marsh	26,332
15	Shrub swamp	437,670
16	Bay swamp	82,548
17	Cypress swamp	630,830
18	Cypress/pine/cabbage palm	18,725
19	Mixed wetland forest	591,081
20	Hardwood swamp	740,237
21	Coastal hammock	14,205
22	Bottomland hardwood forest	34,451
23	Salt marsh	181,057
24	Mangrove swamp	238,337
25	Scrub mangrove	2,638
26	Tidal flat	6,181
27	Open water	3,089,017
28	Shrub and brushland	670,390
29	Grassland	32,527
30	Bare soil/clearcut	445,280
31	Improved pasture	1,199,464
32	Unimproved pasture	57,458
33	Sugar cane	211,571
34	Citrus	385,312
35	Row/field crops	567,907
36	Other agriculture	90,707
37	Exotic plant communities	21,734
38	Australian pine	53
39	Melaleuca	27
40	Brazilian pepper	286
41	High impact urban	1,258,331
42	Low impact urban	399,391
43	Extractive	51,476
	Total land area (excluding water)	13,941,680
	Total area (including water)	17,030,697

TABLE 3. Land use conversions between 1985–89 and 2003.

Land Cover Type	Area in 1985–89 (ha)	Conversion to Urban or Developed (ha)	%	Conversion to Agriculture (ha)	%	Total Conversion (ha)	Total Conversion (%)
Pinelands	2,645,854	156,146	5.90	87,361	3.30	243,508	9.20
Shrub and brush	1,654,021	223,953	13.54	376,030	22.73	599,983	36.27
Forested wetlands	1,535,713	26,628	1.73	18,836	1.23	45,464	2.96
Upland forests	1,152,370	73,379	6.37	57,112	4.96	130,491	11.32
Freshwater marsh	1,095,282	26,897	2.46	37,812	3.45	64,709	5.91
Dry prairie	554,929	38,450	6.93	102,726	18.51	141,176	25.44
Sandhill	344,515	38,528	11.18	14,829	4.30	53,356	15.49
Shrub swamp	272,424	3,393	1.25	4,027	1.48	7,420	2.72
Mangrove swamp	221,263	1,389	0.63	59	0.03	1,448	0.65
Coastal salt marsh	196,489	5,065	2.58	68	0.03	5,133	2.61
Scrub	170,817	16,796	9.83	4,412	2.58	21,208	12.42
Tropical hammock	6,178	648	10.48	19	0.31	667	10.79
Coastal strand	5,324	573	10.77	0	0.00	573	10.77
Total (natural and semi-natural)	9,855,179	611,845	6.21	703,292	7.14	1,315,138	13.34
Agriculture and pasture	2,535,856	355,437	14.02	-	-	355,437	14.02
Total (natural and agricultural)	12,391,035	967,283	7.81	-	-	1,670,575	13.48

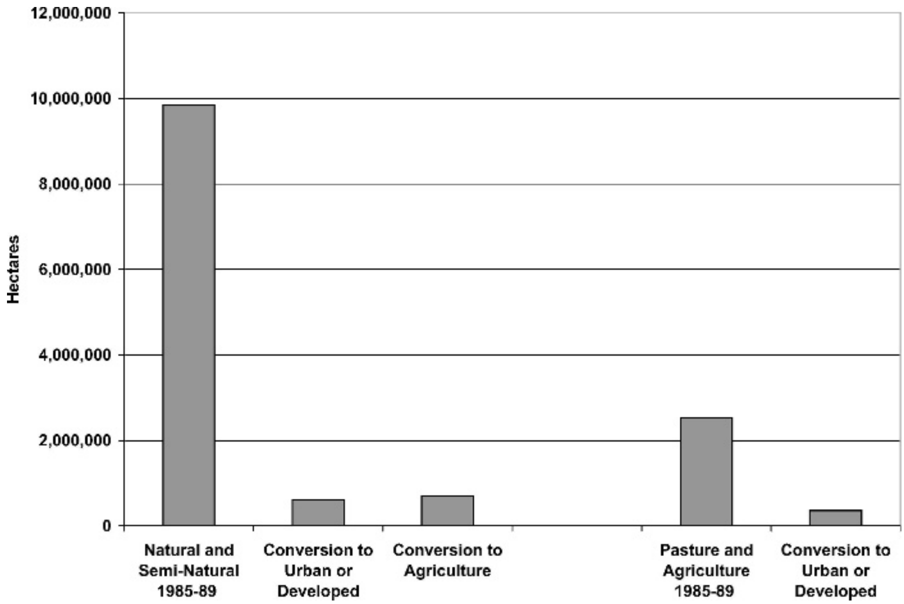

FIG. 2. Area of natural and semi-natural lands, and pasture and agricultural lands, present in Florida in 1985–89, and the amount of each converted to urban, developed, or agricultural uses between 1985–89 and 2003.

In general, wetland types experienced the lowest rates of decline among natural and semi-natural vegetation types. The saltwater community types, salt marsh and mangrove swamp, declined only 5133 ha (2.6% of that present in 1985–89) and 1448 ha (0.65% of that present in 1985–89), respectively, with virtually all of the loss due to conversion to urban or other developed uses. Freshwater wetland types, on the other hand, experienced much larger total area losses. Forested wetlands declined 45,464 ha (3% of that present in 1985–89) over the study period, with conversion to urban and developed uses accounting for 59% of the loss. Herbaceous freshwater wetlands declined 64,709 ha (5.9% of that present in 1985–89), with 58% of the loss due to conversion to agricultural uses. Shrub swamps declined only 7420 ha (2.7% of that present in 1985–89), approximately half of which was due to agricultural conversion and half was due to conversion to urban or developed uses.

Agricultural and pasture lands also experienced conversions to urban or other developed uses over the study period. There were 2.54 million ha of agricultural and pasture lands in Florida during the 1985–89 period. By 2003, 0.36 million ha (14% of that present in 1985–89) of agricultural and pasture lands had been converted to urban and developed uses (Fig. 2).

DISCUSSION—Florida's base of natural and semi-natural vegetation types declined at a rate of between 73,063 and 93,938 ha per year between 1985–89 and 2003, depending on whether 1985 or 1989 is the date selected for the comparison. Similarly, agricultural and pasture lands declined at a rate of between 19,746 ha and 25,388 ha per year over this period. It is difficult to obtain a more precise estimate because the older land cover data set derived from Landsat scenes with varying dates. Of the 16 Landsat scenes used by Kautz co-workers (1993), 2 scenes (Florida Keys) were from 1985, 4 were from 1986, 5 were from 1987, 3 were from 1988, and 2 were from 1989. Thus, the data from 1985–89 represent more of a smudge in time than a single-year snapshot.

Estimates of the rate of land use conversions are further confounded by the inclusion of citrus groves and agricultural old fields in the shrub and brush class in the 1985–89 data. Perhaps a more realistic picture of natural cover type conversion would be accomplished by subtracting the shrub and brush figures from the estimate of total conversion because shrub and brush usually indicates lands that have experienced recent disturbance of some sort. When shrub and brush conversions are left out of the calculation, the estimate is that natural and semi-natural vegetation types declined at a rate of between 39,731 ha and 51,083 ha per year over the 14–18 year study period.

A review of land use change maps produced during this project yields the following impressions of the geographic locations of the various types of land use conversions between 1985–89 and 2003. Conversions of natural and semi-natural lands to urban and developed uses most often occurred proximal to lands that were in urban or other developed uses in 1985–89. Areas of particular note include the Florida west coast from Citrus County south through Collier County; the Florida east coast from Duval County south through Brevard County; the vicinity of Orlando in Orange, Seminole, and southwest Volusia counties; the vicinity of Jacksonville in northeast Florida; the corridor from Tallahassee to the Gulf coast in the Big Bend region; and the vicinity of Panama City in the panhandle.

Conversion of agricultural lands to urban uses was more prominent in the southeast Florida counties of Palm Beach, Broward, and Miami-Dade; along the I-4 corridor between Tampa and Lakeland; along the I-75 corridor in southern Marion County and northern Sumter County; and, to a lesser extent, in the vicinity of Orlando.

Conversions of natural and semi-natural cover types to agricultural uses were most noticeable in the interior reaches of the Florida peninsula, particularly from the vicinity of Lake County in the center of the peninsula to Hendry County south of Lake Okeechobee. As indicated previously, this result may be a little misleading because the shrub and brush class in the 1985–89 data included both citrus groves and untended croplands that had succeeded to a shrub and brush seral stage. Thus, many of the areas of apparent conversion of shrub and brush to agricultural uses in the central peninsula already were in agricultural use in 1985–89, and the apparent change may not be real. However, not all areas of the central peninsula converted to agricultural use were in shrub and brush in 1985–89. A closer review of the data reveals that many lands converted to agriculture supported dry prairie and freshwater marsh, and to a lesser extent, pinelands and scrub in 1985–89. These results suggest a true intensification of agricultural use in the landscape of the central Florida peninsula over the study period.

Other regions of the state where conversions of natural and semi-natural land cover types to agricultural uses were visually apparent include the ridge country of Suwannee, Columbia, Gilchrist, and Alachua counties in the north central portion of the peninsula, and, to a lesser extent, the rolling hills of the panhandle south of the Alabama and Georgia state lines. Most of these areas were in the shrub and brush class in 1985–89, and the conversions probably were from old fields or timber clearcuts to more intensive agricultural uses.

A more thorough interpretation of the land cover conversions at the local scale is possible by reviewing the actual GIS data layers produced in the land use change analysis. However, to some extent, interpretation of results is hampered by the relative coarseness of the original data layers and by the need to reduce the number of cover types from 22 to 17 in the 1985–89 data and from 43 to 17 in the 2003 data. This lumping of the original data resulted in a loss of information from both data layers, but it was necessary to allow for a comparative analysis of land cover type change over the 14–18 year period separating the dates of imagery. Hopefully, the 2003 vegetation and land cover data will prove to be of greater utility in future efforts to discern land use change than did the 1985–89 data.

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