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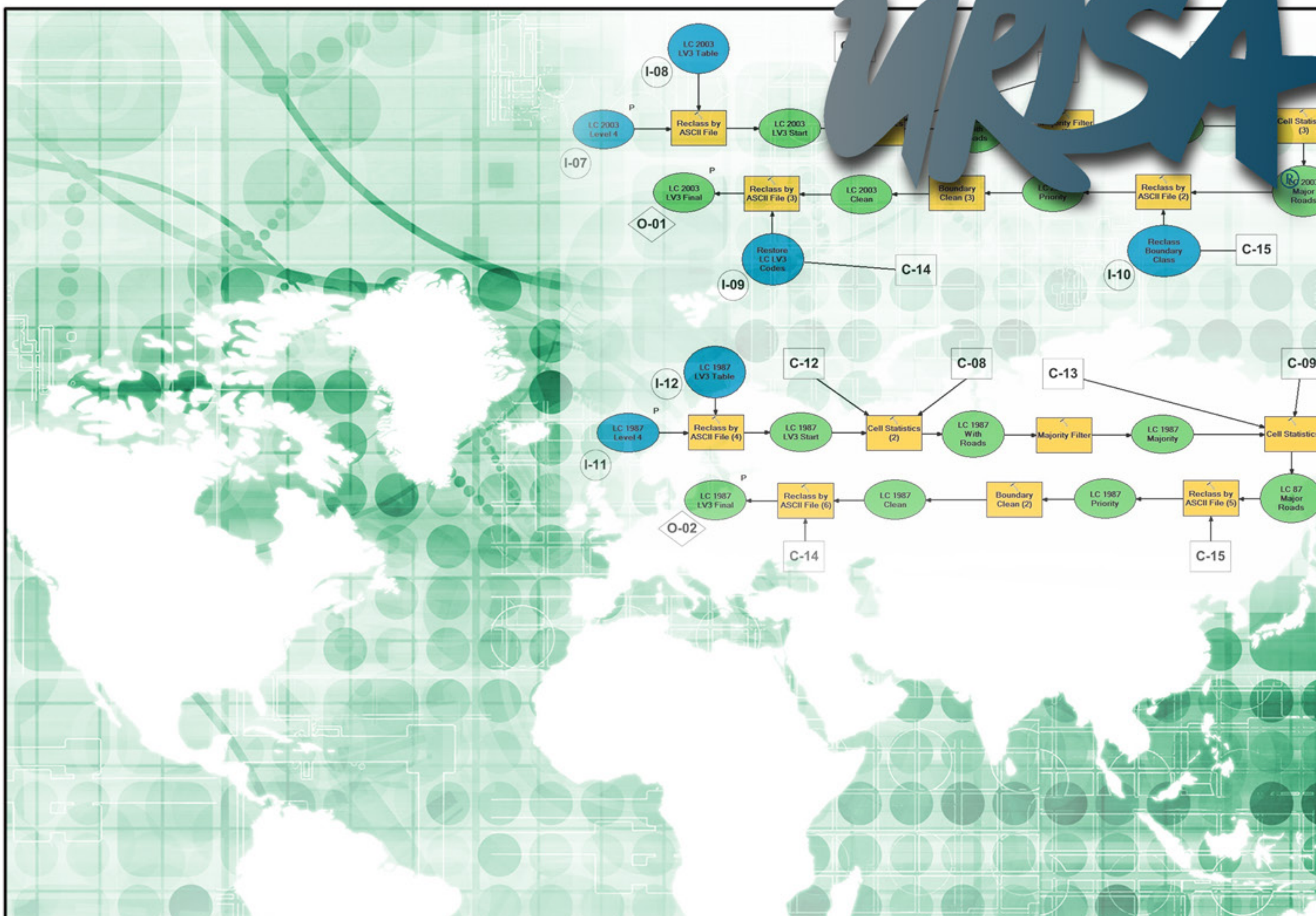

A Method for Normalizing Classified Land-cover Imagery for Use in Change-detection Analysis

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A Method for Normalizing Classified Land-cover Imagery for Use in Change-detection Analysis

Michael J. Gilbrook and John F. Weishampel

Abstract: *The availability of a long historical record of Landsat satellite imagery made possible the development of multitemporal land-cover mapping for large regions. Use of these data sets for change detection and other landscape analyses sometimes is hampered by differences in the image-classification methods employed at different times. To resolve these problems for 1987 and 2003 land-cover data for Florida from the Florida Fish and Wildlife Conservation Commission, the authors developed an automated GIS-based technique that relied on comparisons between the two land-cover data sets as well as ancillary land-use data from Florida's five Water Management Districts. This Land Cover Correction Process demonstrably improved the accuracy of the 1987 and 2003 land-cover data and permitted more reliable measures of anthropogenic land-use changes. The improved habitat loss rates estimated for ecologically important vegetative communities such as pinelands, sandhills, and scrub using the corrected data provide valuable guidance for conservation efforts in Florida.*

INTRODUCTION

The science of landscape ecology owes its existence in part to the revelations made possible by the advent of aerial photography. Only with access to aerial imagery could ecologists begin to accurately map and study the patterns of natural vegetative communities and the effects of human disturbances (Turner et al. 2001). Collection of aerial imagery for the same areas over time provided the means for studying landscape changes, both natural and artificial, but drafting land-cover maps from aerial photography was a slow and labor-intensive process (Ruelland et al. 2011). The Landsat series of remote-sensing satellites that have been collecting medium-resolution imagery since 1972 dramatically improved the ability to develop land-cover maps at the regional or continental scale (Irons and Rocchio 2012a, 2012b). Landsat imagery could be rendered into the form of a digital land-cover map using either supervised or unsupervised image-classification techniques more cost-effectively than was possible for such large areas using traditional aerial photo-interpretation techniques (Mosbech and Hansen 1994). As the Landsat digital archive grew, opportunities arose to perform land-cover change detection between months, seasons, years, or even decades for any place on the planet, making Landsat a valuable tool for conservation biology (Leimgruber et al. 2005).

Numerous studies have employed Landsat imagery to evaluate anthropogenic changes in land cover between time periods spanning a year or more (Fuller 2001, Wang and Moskovits 2001, Yang and Lo 2002, Rogan et al. 2003, Boyd and Danson 2005, Ruelland et al. 2011, Pflugmacher et al. 2012). Although it is possible to directly compare changes in the raw Landsat imagery spectral reflectance values to perform change detection, the preferred approach involves classification of the imagery for each time period first, then performing change detection as a map-to-map comparison (Yang and Lo 2002). Researchers who performed their own classification of Landsat imagery for map-to-map change-detection studies could ensure that the different date epochs were classified consistently. The advent of statewide land-cover mapping programs in the United States, including those associated with the U.S. Geological Survey Gap Analysis Program (USGS 2013), provided a source of already classified Landsat imagery that could be used in change-detection analysis (Cox et al. 1994, Caicco et al. 1995, Laba et al. 2002, Pearlstine et al. 2002, Reese et al. 2002). However, inconsistencies in the Landsat imagery-classification approach used in creating successive land-cover maps make direct comparison of these data difficult (Wardlow and Egbert 2003, Wilkinson et al. 2008).

The case in Florida is a good example. The Florida Fish and Wildlife Conservation Commission (FWC) developed a statewide land-cover map from Landsat data collected during the mid-1980s to the late 1980s, then created a new map using a different land-cover classification scheme with Landsat data from 2003. The period 1987 to 2003 is of interest to conservation biologists and urban planners because it represents the first 16 years during which Florida's land regulation was governed by the requirements of the landmark Local Government Comprehensive Planning and Land Development Regulation Act of 1985 (Florida Statutes §163.3164). Changes in land cover between 1987 and 2003 could be used to evaluate the effectiveness of local government land-use planning and regulation in curtailing urban sprawl or minimizing impacts to natural ecosystems. However, the disparate land-cover classification systems used for the two statewide inventories, as well as certain systematic errors present in the data, did not allow for direct comparison between them. This paper describes a process for normalizing the two land-cover data sets to make a valid change-detection analysis possible.

METHODS

Land-cover Data

Two sources of statewide land-cover data for Florida were obtained from public sources. The oldest was developed by the FWC from Landsat imagery collected between 1985 and 1989 (Cox et al. 1994). For convenience, this data set will be referred to as the 1987 land cover (LC87). The more recent land-cover data were prepared by the FWC from Landsat imagery collected in 2003 (Kautz et al. 2007) and will be referred to as the LC03 data set. Both land-cover data sets were stored in Esri ArcInfo™ raster format at 30-m resolution and included all 67 Florida counties. USGS Digital Line Graph (DLG) 1:24,000 county boundaries were used to clip both the LC87 and LC03 statewide land-cover data sets into county raster files. All land-cover data were projected to the Florida statewide Albers Equal Area Projection established by the Florida Geographic Data Library (FGDL 2012).

The FWC classified the LC87 data into 22 land-cover classes (Cox et al. 1994), while the LC03 data were classified into 43 more narrowly defined land-cover classes (Kautz et al. 2007). In an effort to perform change detection between the two dates, the FWC developed a crosswalk between the LC87 and LC03 classification schemes to a new 18-class system (see Table 1). Although these schemes do not follow the hierarchical structure of an Anderson land-cover classification system (Anderson et al. 1976), it is useful to think of the original 1987 and 2003 classification schemes as Level 4 and the 18-class system into which they collapse as Level 3 codes. We established even more generalized Level-2 and Level-1 categories for working with these data (Table 1); the Level-1 scheme was not used in this study.

Land-cover Issues

Several systematic issues inherent in the FWC 1987 and 2003 land-cover data impeded their use in change-detection analysis:

Confusion between urban and barren lands. The LC87 scheme classified all disturbed lands into a single class (Class 22—Urban/barren). Consequently, recently cleared agricultural fields or natural vegetative communities containing significant amounts of highly reflective sandy soil were assigned the same land-cover classification as urbanized areas (shown in Figure 1). These same areas typically were assigned a more correct land-cover designation in the LC03 data, resulting in an apparent change from urban to nonurban land cover. The FWC sought to correct this problem in its change-detection analysis by using a series of raster masks employed during data processing (Kautz et al. 2007). This technique, however, only corrected the problem during the change-detection analysis itself. A better approach would permanently correct the data sets so that they could be used for any ad hoc analysis.

Confusion between urban and forested lands. Land-cover classification using Landsat imagery is limited by the fact that heavy tree cover may obscure urban lands beneath the tree canopies. One consequence of this limitation is that older traditional town centers built on a gridded street network planted with

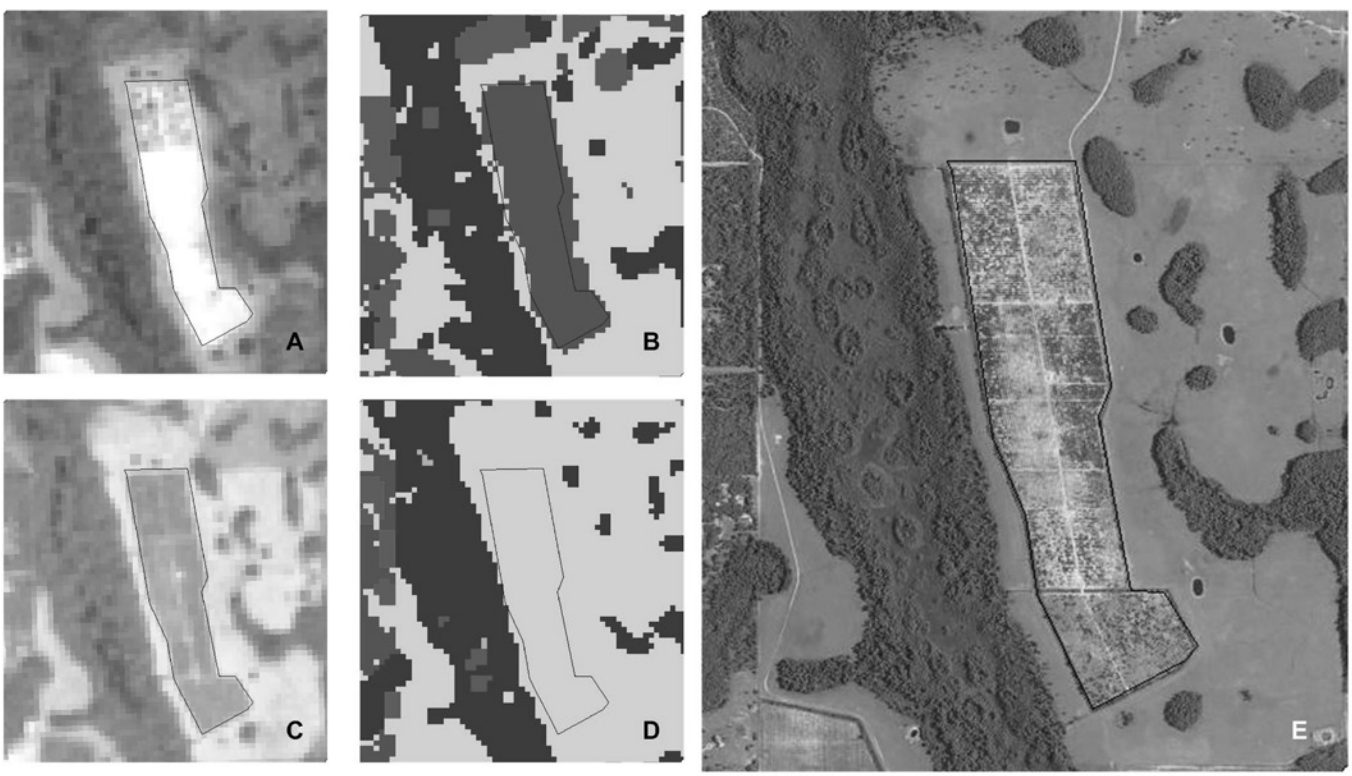

Figure 1. Misclassification of agricultural areas: (A) 1986 Landsat of a recently established orange grove (black outlined area). (B) classification of sandy, highly reflective cleared land as Urban/barren in FWC 1987 land-cover data. (C) 2003 Landsat image of orange grove with leafy trees growing. (D) Level-2 classification of the orange grove at as Upland, nonforested in FWC 2003 land-cover data. (E) The 1.0 meter resolution natural color USDA NAIP imagery of the location for December 2010 clearly showed the orange groves.

Table 1. Land-cover classifications. The LC03 and LC87 codes were taken from Kautz et al. (2007) and represent the most granular (Level-4) classifications for their respective years. The LC87 codes for Urban/barren (17) and Water (16) were reversed from their original order to simplify some of the land-cover generalization processing steps.

Land Cover 2003 Description	LC03 Code	Land Cover 1987 Description	LC87 Code	Land Cover Level 3 Description	Level 3 Code	Land Cover Level 2 Description	Level 2 Code
Sand/beach	2	Urban/barren	22	Urban/barren	17	Urban/barren	1
Bare soil/clear cut	30	Urban/barren	22	Urban/barren	17	Urban/barren	1
High-impact urban	41	Urban/barren	22	Urban/barren	17	Urban/barren	1
Low-impact urban	42	Urban/barren	22	Urban/barren	17	Urban/barren	1
Extractive	43	Urban/barren	22	Urban/barren	17	Urban/barren	1
Exotic plants	37	Exotic plants	21	Exotic plants	15	Exotic plants	2
Australian pine	38	Exotic plants	21	Exotic plants	15	Exotic plants	2
Melaleuca	39	Exotic plants	21	Exotic plants	15	Exotic plants	2
Brazilian pepper	40	Exotic plants	21	Exotic plants	15	Exotic plants	2
Coastal strand	1	Coastal strand	1	Coastal strand	1	Upland, nonforested	3
Dry prairie	6	Dry prairie	2	Dry prairie	2	Upland, nonforested	3
Shrub and brushland	28	Shrub and brushland	20	Shrub and brushland	13	Upland, nonforested	3
Grassland	29	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Improved pasture	31	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Unimproved pasture	32	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Sugarcane	33	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Citrus	34	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Row/field crops	35	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Other agriculture	36	Grassland	19	Grassland/agriculture	14	Upland, nonforested	3
Pineland	9	Pinelands	3	Pineland	3	Upland, forested	4
Sand pine scrub	4	Sand pine scrub	4	Scrub	4	Upland, forested	4
Xeric oak scrub	3	Xeric oak scrub	6	Scrub	4	Upland, forested	4
Sandhill	5	Sandhill	5	Sandhill	5	Upland, forested	4
Mixed hardwood forest	7	Mixed hardwood-pine forest	7	Upland forest	6	Upland, forested	4
Hardwood hammock and forest	8	Hardwood hammocks and forests	8	Upland forest	6	Upland, forested	4
Cabbage palm–live oak hammock	10	Hardwood hammocks and forests	8	Upland forest	6	Upland, forested	4
Hydric hammock	21	Hardwood hammocks and forests	8	Upland forest	6	Upland, forested	4
Tropical hardwood hammock	11	Tropical hardwood hammock	9	Tropical hardwood hammock	8	Upland, forested	4
Water	27	Open water	18	Water	16	Water	5
Salt marsh	23	Salt marsh	10	Salt marsh	10	Wetland, nonforested	6
Tidal flat	26	Salt marsh	10	Salt marsh	10	Wetland, nonforested	6
Freshwater marsh and wet prairie	12	Freshwater marsh and wet prairie	11	Freshwater marsh	11	Wetland, nonforested	6
Sawgrass marsh	13	Freshwater marsh and wet prairie	11	Freshwater marsh	11	Wetland, nonforested	6
Cattail marsh	14	Freshwater marsh and wet prairie	11	Freshwater marsh	11	Wetland, nonforested	6
Shrub swamp	15	Shrub swamp	15	Shrub swamp	12	Wetland, nonforested	6
Cypress swamp	17	Cypress swamp	12	Forested wetland	7	Wetland, forested	7
Cypress/pine/cabbage palm	18	Cypress swamp	12	Forested wetland	7	Wetland, forested	7
Mixed wetland forest	19	Mixed hardwood swamp	13	Forested wetland	7	Wetland, forested	7
Hardwood swamp	20	Mixed hardwood swamp	13	Forested wetland	7	Wetland, forested	7
Bay swamp	16	Bay swamp	14	Forested wetland	7	Wetland, forested	7
Bottomland hardwood forest	22	Bottomland hardwood forest	17	Forested wetland	7	Wetland, forested	7
Mangrove swamp	24	Mangrove swamp	16	Mangrove swamp	9	Wetland, forested	7
Scrub mangrove	25	Mangrove swamp	16	Mangrove swamp	9	Wetland, forested	7

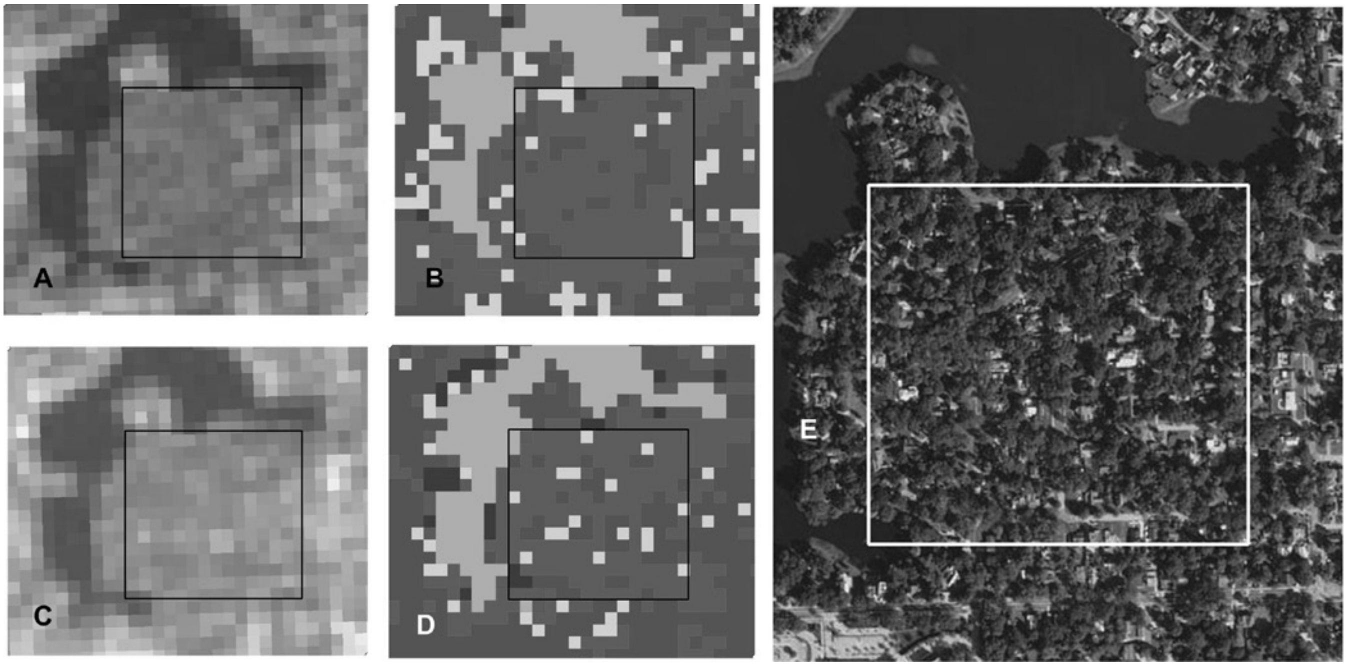

Figure 2. Misclassification of urban areas: (A) 1986 Landsat image with 4,3,2 band combination showed heavy tree canopy (red) in an established residential area (black rectangle). (B) FWC 1987 land cover largely classified the residential area as Upland, forested (green) interspersed with Urban (red) at Level 2. (C) 2003 Landsat image appeared essentially unchanged from 1986. (D) FWC 2003 land cover still showed the residential area as mostly Upland, forested. (E) The rooftops and tree-lined street grid network of a medium density residential area were clearly visible in 1.0 meter natural color USDA NAIP imagery for December 2010.

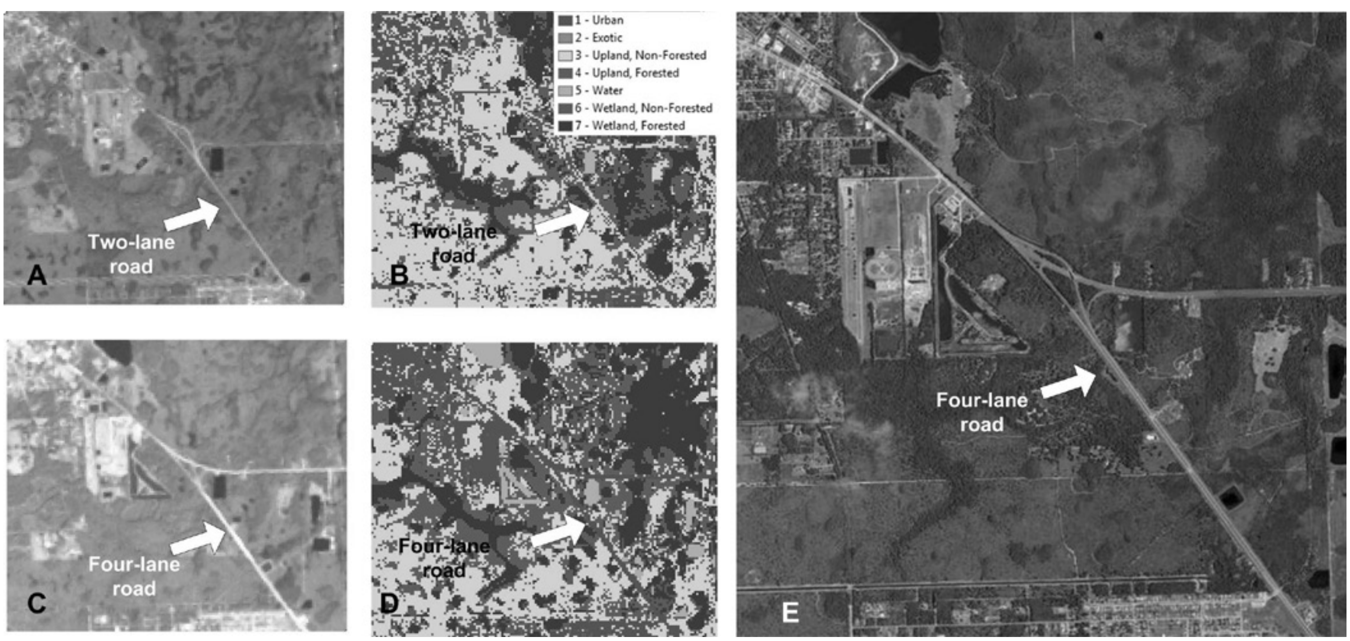

Figure 3. Misclassification of linear transportation features: (A) Narrow two-lane roadways in 1986 Landsat image were represented by pixels that mixed the bright signature of the roadway surface with that of the vegetation bordering the roadway. (B) FWC 1987 land cover classified parts of the roadway as Upland, forested, or Upland, nonforested vegetation, leaving apparent gaps in the continuity of the roadway. (C) Wider four-lane roadway in 2003 Landsat image presented a clear urban signature that was two or more pixels across. (D) FWC 2003 land cover correctly classified the wider roadway in this location. (E) The roadways that dissected the natural land cover were clearly visible in 1.0 meter resolution USDA NAIP natural color imagery for December 2010.

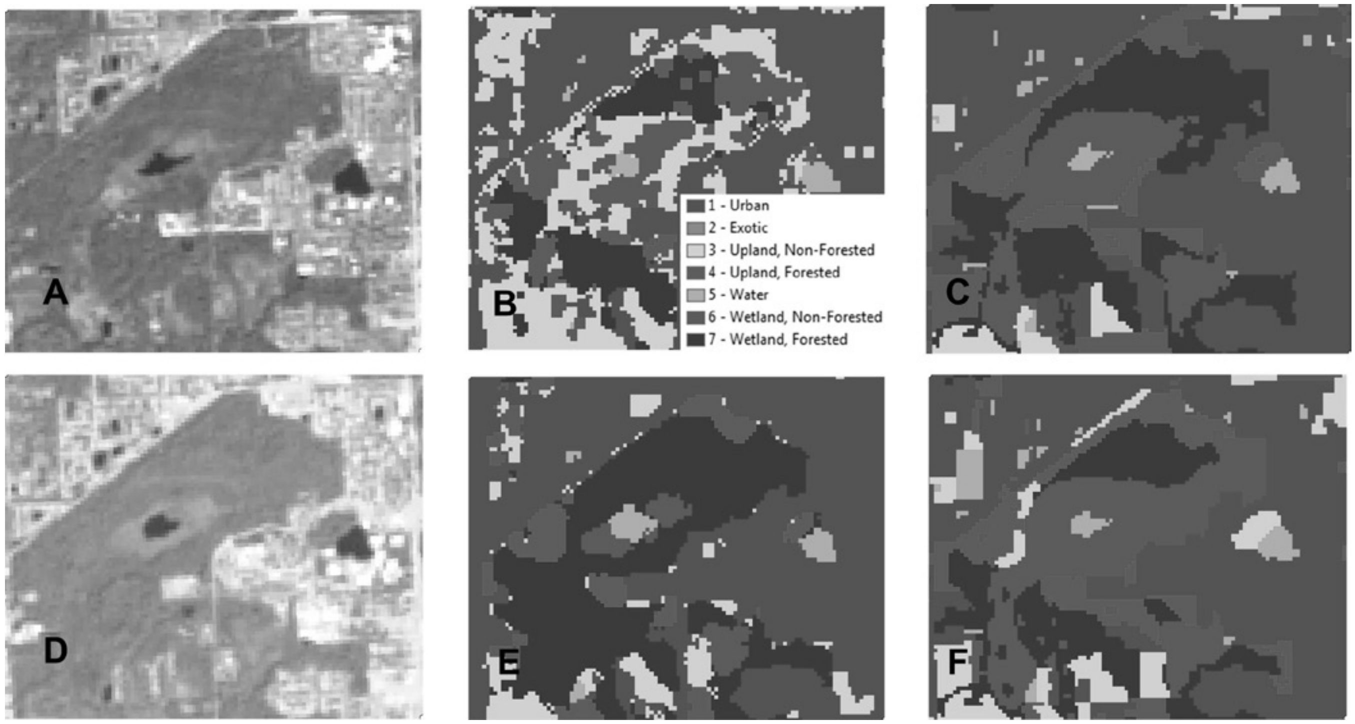

Figure 4. Misclassification of wetland areas: (A) 1986 Landsat image with 4,3,2 band combination of small lake surrounded by natural vegetative cover; (B) FWC 1987 land cover classified a mix of upland and wetland forested and nonforested vegetation around the lake. (C) Land-use data from aerial photo interpretation by the St. Johns River Water Management District (SJRWMD) in 1990 identified a large area of nonforested wetlands around the lake. (D) 2003 Landsat image shows the area around the lake was essentially unchanged; (E) FWC 2003 classified zones of wetland, nonforested, wetland forested, and upland forested vegetation very different from the pattern identified in FWC 1987. (F) SJRWMD 2004 land-use data showed a wetland pattern that differed from the FWC 2003 in the distribution of nonforested wetlands but generally agreed in the overall spatial extent of wetland vegetation.

canopy trees often were classified as forested lands in the FWC data (see Figure 2). Similarly, narrow roadway or rail corridors with overhanging tree canopies, or even vegetated land cover that occupied a greater proportion of a 30-m pixel than an adjacent linear transportation feature, obscured that urban feature (shown in Figure 3).

Confusion between uplands and wetlands. Some naturally vegetated areas identified as wetlands in 1987 sometimes were classified as uplands in 2003 or vice versa. These classification errors can be attributed to differences in the hydroperiod at the times during which imagery was collected. The presence of water contributes a very strong absorption signature in the near-infrared (Band 4) and midinfrared (Band 5) bands of Landsat TM imagery and, therefore, are useful in discriminating between wetland and upland vegetative communities (Frazier and Page 2000, Harvey and Hill 2001, Ozesmi and Bauer 2002). During times of drought, however, a wetland might have such a low water signature as to be spectrally confused with an upland vegetative community (see Figure 4). Conversely, standing water following a rain or flooding event could make an upland vegetation type appear spectrally similar to a wetland type. Pixel-level heterogeneity confused as land-cover change: Classification of Landsat imagery at the pixel level often results in spurious assignment of single pixels within a larger area of homogenous land cover to one or more differing land-cover types (as seen in Figure 5). These artifacts, referred to as "speckling" or "salt-and-pepper" effects, result in erroneous change-detection results when the spurious land-cover types in the image of one epoch align with the correct land cover in another (Masek et al. 2000). Similarly, even a small registration difference in the pixel locations of two images may result in a band of apparent land-cover change on the boundaries between land-cover types (Frazier and Page 2000). Using majority filter and boundary-cleaning techniques in GIS can reduce these errors (Yang and Lo 2002).

The presence of these errors did not deter using the FWC 1987 and 2003 land-cover data in a number of conservation biology, regional planning, and wildlife management studies (Gilbrook 1989ba, 1989ab; Hoctor et al. 2000; Gilbert et al. 2001; Kautz and Cox 2001; Dixon et al. 2006; Oetting et al. 2006; Maehr and Cox 2009). These land-cover classification errors, however, would be detrimental to accurate assessment of land-cover change over time. The following section describes the suite of GIS-based remedies that were devised to address each of these sources of land-cover error.

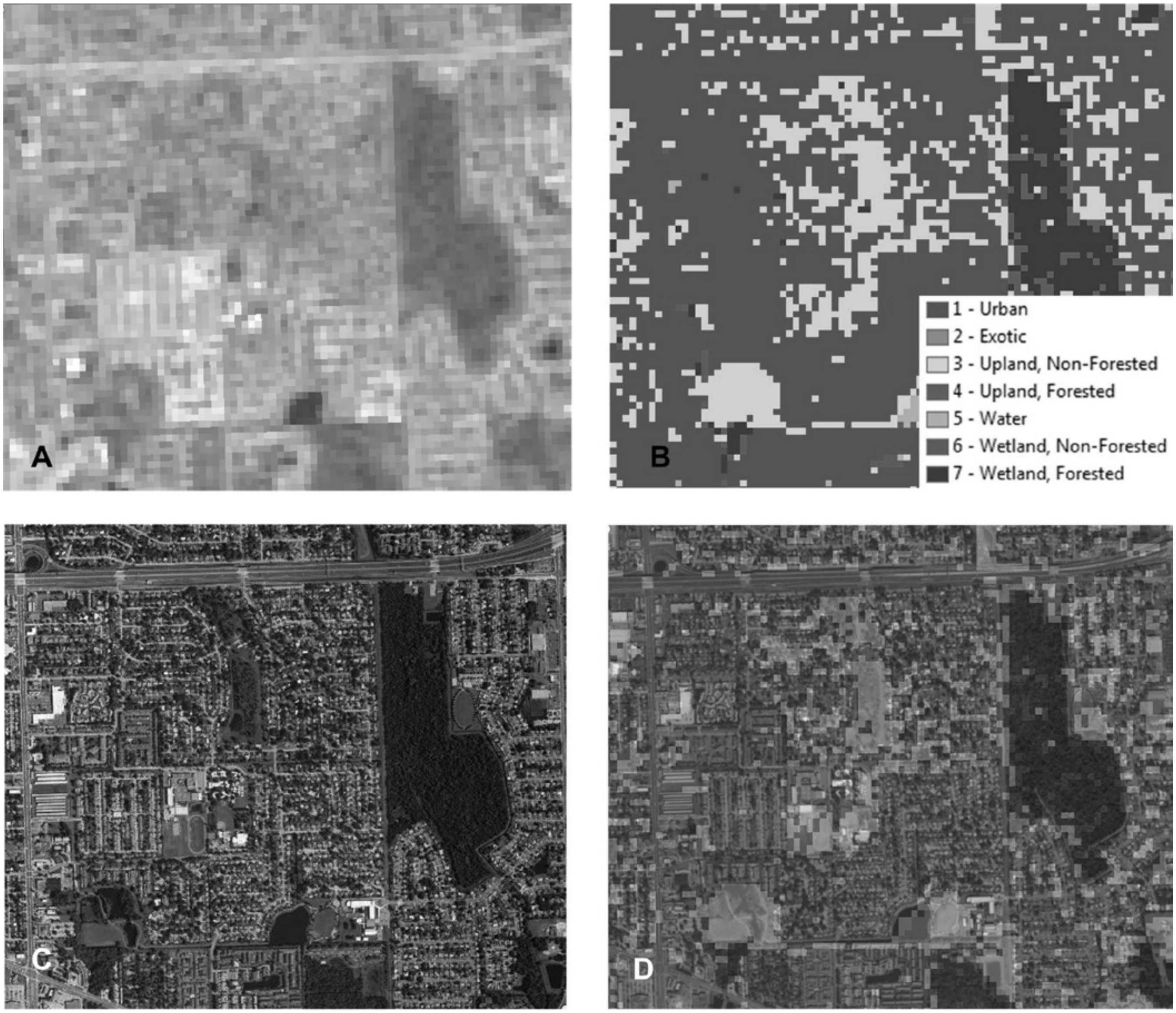

Figure 5. Speckling in classified Landsat imagery: (A) A 4,3,2 band combination of Landsat imagery in a built-out urban area. (B) Level 2 classified imagery of the land cover for the same area. (Note the small inclusions of Upland, nonforested land cover within the "homogenous" Urban areas, and the Upland, forested and Upland, nonforested areas within the large Wetland, forested area to the east). (C) A high-resolution (1.0 meter) USDA NAIP natural color image of the area for December 2010. (D) The land-cover mapping from panel B shown superimposed over the overhead imagery from panel C to better illustrate the speckling of heterogeneous land-cover classifications within areas of homogeneous land cover.

LAND-COVER CORRECTION PROCESS

The Land Cover Correction Process (LCCP) was developed entirely within the Esri ArcGIS™ 10.0 software environment. Esri Spatial Modelbuilder™ was used to create the algorithm for the LCCP. Many of the geoprocessing tools used in the LCCP required the ArcInfo (ArcGIS Desktop Advanced) license level of ArcGIS. Raster functions in the LCCP relied on geoprocessing tools within the Spatial Analyst™ extension to ArcGIS. The components of the LCCP algorithm were exported from Spatial Modelbuilder to Python 2.6 scripts which were modified to facilitate batch processing of the raster land cover data for all 67 Florida counties.

The LCCP employed three techniques that, working together, sought to address the systematic flaws identified in the FWC land cover data:

Generalization – Land cover accuracy can be significantly improved by using a majority filter technique to eliminate the spurious heterogeneity caused by single pixel misclassifications (speckling) and boundary effects (Yang & Lo 2002, Guerschman et al. 2003). The LCCP used the ArcGIS Majority Filter and Boundary Clean functions to reduce speckling and smooth bor-

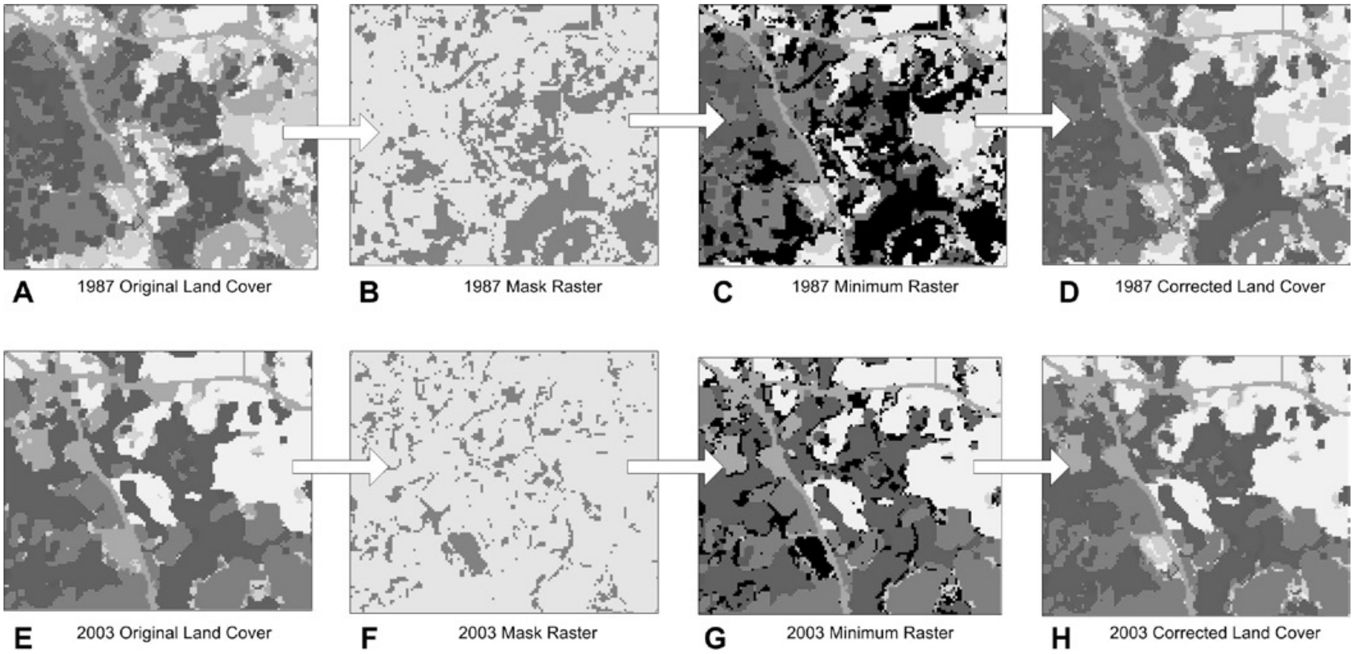

Figure 6. Illustration of the land-cover correction process for a 4 km x 3 km area in Madison County: (A) the original 1987 land-cover data at Level 3; (B) the Mask Raster placed a value of 0 (gray) at every pixel for which the land-cover change matrix indicated that the 2003 land-cover data had the more correct land-cover value and a value of 100 (tan) at every pixel that was properly classified in the 1987 data; (C) the Minimum Raster generated by performing a minimum raster analysis between the Mask Raster and the original 1987 land cover placed a 0 value (black) at every pixel that was 0 in the Mask Raster and the original land-cover classification at every pixel for which the Mask Raster had a value of 100; (D) the final 1987 corrected land-cover raster was generated by replacing every pixel with a 0 value in the Minimum Raster with the land-cover classification for that pixel from the original 2003 land-cover raster. Steps (E) through (H) illustrate the same process performed for the 2003 land-cover data.

ders between land cover types.

Superposition of Transportation Networks – The spectral signatures of many roads and railroads in the FWC land cover data were obscured at times by adjacent or overhead vegetation, even in some densely urbanized areas. The LCCP converted contemporaneous vector roadway networks and railroads to raster and superimposed them over the original FWC land cover data to restore the integrity of linear transportation networks. In areas with dense urban street grids under heavy tree canopies this also had the effect of replacing an inappropriate forested land cover type with a more accurate urban land cover designation.

Land Cover Logical Comparison – This was the most powerful of the three techniques employed to correct land cover errors. From a matrix of all possible combinations of LC87 to LC03 land cover change there were many pairings that were improbable, such as LC87 Urban changing to LC03 Upland, forested. In many such cases, resolving the conflict was easy. In this example, since urban areas typically do not transition to upland forests in less than two decades, most likely the correct land cover type in the LC87 data should have been Upland, forested. Land cover pairings for which there was no a priori reason to favor one type over another (e.g., LC87 Wetland, forested to LC03 Upland, forested) could be resolved through reference to ancillary near-contemporaneous land use data from a third party. For example, if 2004 vector land use data from the local Water Management District indicated that Wetland, forested was the correct land cover type, then the LC03 value of Upland, forested was most likely in error. The LCCP used lookup tables and a series of raster algebra techniques to make these comparisons and perform the appropriate corrections.

The LCCP was developed as two interlocking models. A detailed description of the LCCP including lists of all input and output files, a step-by-step discussion of the GIS processing techniques it employed, and a listing of its Python 2.6 code appears in Gilbrook (In Press). The first component of the LCCP was the Land Cover Generalization Model (LCGM), which performed the generalization and transportation network superposition steps described above. The outputs of the LCGM served as inputs to the Land Cover Correction Model (LCCM), which performed the geoprocessing steps that repaired misclassifications identified in either the LC87 or LC03 land cover layers. The fundamental idea behind the LCCM was that some land cover changes were unreasonable, and therefore represented likely misclassifications. For example, although it was not unexpected that pasture in 1987 would become urbanized by 2003, it was very unlikely that urbanized land in 1987 would become pasture in 2003. The LCCM was designed to detect this and other similarly unlikely land cover changes, and compare the land cover data at those locations to ancillary land use data which would decide which of the two land cover inputs (1987 or 2003) was correct.

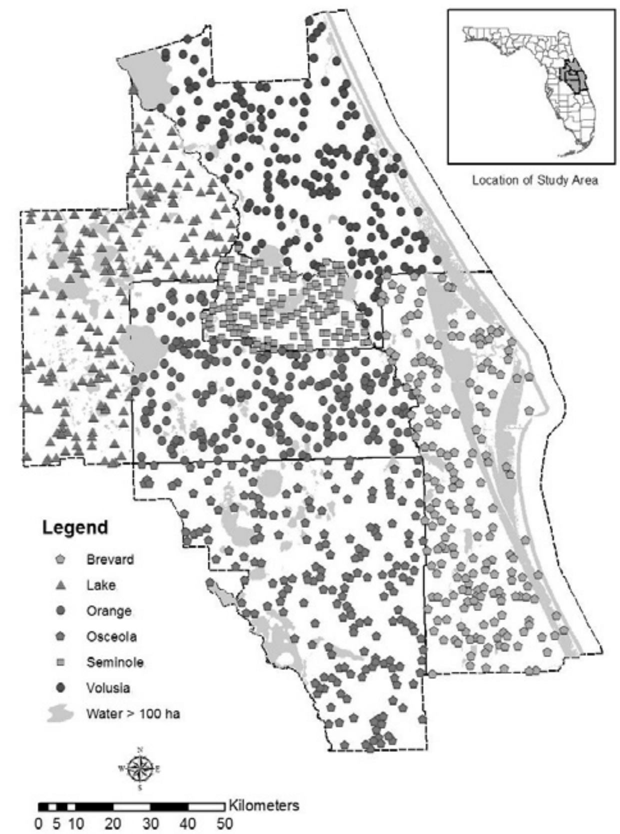

Figure 7. Randomly selected ground-reference points for evaluating land-cover accuracy in six central Florida counties

The evaluation to determine whether an original FWC land cover classification required correction relied on a confusion matrix which contained all possible combinations of the two input land cover rasters from 1987 and 2003, plus a third "tie breaker" layer developed from near-contemporaneous land use data prepared by Florida's five Water Management Districts (WMDs) and made available on Florida's statewide GIS data depository (FGDL 2012). Since the confusion matrix for the 18 Level 3 land cover classes from three sources was unreasonably large (18^3 = 5,832 combinations), the land cover data were evaluated using the simpler Level 2 classification system which entailed only seven classifications, and a much smaller number of combinatorial outcomes (7^3 = 343). Vector land cover data for 1990 and 2004 were rasterized and reclassified to the Level 2 classification scheme for each of the 67 Florida counties to provide a check on the 1987 and 2003 FWC raster data, respectively.

The most likely correct LC87 or LC03 land cover type for many of the 343 combinations in the confusion matrix were assigned *a priori* based on a logical evaluation. For example, a matrix value indicating an LC87 class of Urban, an LC03 type of Upland, non-forested and a WMD 1990 land cover type of Upland, non-forested was almost certainly a misclassification of the land cover in 1987; the corrected LC87 land cover value for this combination was set to Upland, non-forested. These initial logical assignments of corrected land cover were evaluated and revised as needed following visual assessment of the original Landsat imagery from 1987 and 2003 as well as DigitalGlobe high-resolution (0.3 meter) natural color imagery from December 2010. The final results were lookup tables that identified when the land cover data from one year should be replaced with the more correct value from the other year. Note that in this process new land cover values from the WMD data were never substituted for either of the original FWC land cover values. This approach ensured that the LCCM algorithm only made choices between the original data collected by the FWC, and did not introduce new information that wasn't present in either the FWC data from 1987 or 2003.

The final steps in preparing the binary logic that would assign corrected land cover values in the LCCM algorithm involved creating the reclassification instructions that would be used to generate "mask layers" in the LCCM model. For each county analyzed by the LCCM, these mask layers would contain only two values, 100 or 0. A cell value of 100 indicated that the current value of an input land cover raster (e.g., that from 1987) should persist to the corrected output raster, while a pixel value of 0 meant that the land cover code from the other year (e.g., 2003) should be output to the final raster. This process is illustrated for a small area of Madison County (Figure 6).

Land-cover Accuracy Assessment

Congalton and Green (2009) established the importance of assessing the accuracy of land-cover classifications by using the confusion matrix, and they provided guidelines for the collection of valid ground-reference data for such assessments. To assess the accuracy of the land-cover data output from the Land Cover Correction Process, the corrected 1987 and 2003 land-cover data for six counties in east central Florida (Brevard, Lake, Orange, Osceola, Seminole, and Volusia) were generated by the LCCP for evaluation. Although these counties were conterminous, they represented a wide variety of the land-cover types common throughout Florida, from coastal estuaries to xeric highlands. A set of ground-reference sample points were generated within each county (see Figure 7), using the ArcGIS Create Random Points function in keeping with findings that simple or stratified random sampling were the most accurate ways to collect ground-reference locations for evaluating land-cover data derived from remote sensing (Congalton 1991). The Create Random Points process was applied with an option to maintain a minimum distance of 1 km between sample points to reduce the effects of spatial autocorrelation (Congalton 1988). The process also excluded placement of sample points within water bodies ≥ 100 ha in size. Larger water bodies were easily classified, and excluding them ensured that sample points would be distributed primarily in upland areas that would provide a better test of the Land Cover Correction Process. Two hundred sample points were generated for five of the six counties. Only 150 points were selected for Seminole County because of its small size; one point fell at an edge location for which land-cover data were missing, leaving 149 valid points for that county. The sample size of 1,149 ground reference points exceeded the worst-case multinomial solution (885 points) necessary to evaluate the accuracy of 17 land-cover classes at 95 percent confidence (Congalton and Green 2009).

Three undergraduate students with no prior exposure to the FWC land-cover data were recruited to collect ground-reference data. Each reviewer was provided 1987 and 2003 Landsat TM imagery for two counties in several different band combinations: natural color (bands 3,2,1), false-color infrared (4,3,2), wetland enhanced (4,5,3), and vegetation enhanced (7,4,2). Ancillary GIS data provided to assist the reviewers in land-cover interpretation included the Soil Survey Geographic (SSURGO) soils data of the National Conservation Resources Service (FGDL 2012); 1990 and 2004 land-use data from the WMDs (ibid.); and recent high-resolution (0.30-m resolution) natural color imagery from DigitalGlobe. For each of the randomly selected points, each reviewer chose the Level-2 and Level-3 land-cover types (see Table 1) present at that location for 1987 and 2003. After the ground-reference reviewers had completed their assessments, GIS techniques were used to extract the land-cover data value from the FWC and corrected land-cover rasters for both 1987 and 2003 at each of the sample points. The tabular data from those county point feature classes were concatenated into a single table that was used to generate confusion matrices (Foody 2002, Congalton and Green 2009) and kappa statistics (Gwet 2001) for evaluating the accuracy of the FWC and corrected land-cover data sets.

As a further check of the efficacy of the LCCP, the land-cover assignments of the original FWC and corrected land-cover data for each of the six central Florida counties were compared to the near-contemporaneous WMD land-use data on a pixel-by-pixel basis. The Level-2 FWC and corrected land-cover data for 1987 were combined by raster overlay techniques with the WMD 1990 land-use data at Level 2 to calculate a confusion matrix. The process was repeated for the 2003 FWC and corrected land-cover data and the 2004 WMD land-use data. More than 18.8 million pixels were compared across six counties using this method.

Land-cover Change Analyses

Land-cover change between the final corrected 1987 and 2003 land-cover rasters was performed by county for both the Level-3 and Level-2 classification schemes. For the Level-2 data, the 1987 land–cover raster values for each pixel were multiplied by a constant value of ten then added to the 2003 land-cover value, resulting in a raster that contained the 1987 and 2003 land-use codes for every pixel. The same approach was used for the Level-3 data, except that a constant value of 100 was used because of the two-digit Level-3 land-cover codes. Using this method, not only the magnitude of land-cover change (summarized as the count of pixels) but the identity of the land-cover types that had undergone conversion were preserved. The tabular land-cover change data from each county were imported into spreadsheets for disaggregation into their 1987 and 2003 land-cover classifications for analysis. The Level-3 data also were reorganized for direct comparison with the land-cover coverage and percent change results reported by Kautz et al. (2007).

RESULTS AND DISCUSSION

Land-cover Accuracy Assessment

Using confusion matrices has become a staple in the assessment of land-cover accuracy (Congalton 1991, Congalton and Green 2009, Foody 2010). A detailed discussion of the confusion matrices comparing the original FWC land-cover data and the corrected land-cover data to the ground reference data at 1,149 randomly selected sample locations appears in Gilbrook (in press). The percent overall accuracy and the kappa statistic are the two metrics that are most useful for evaluating the agreement between classified land-cover data and the ground-reference data in confusion matrices (Congalton and Green 2009). The overall accuracy represents the fraction of all observations of land-cover data that were in perfect agreement with the ground-reference data, as indicated by those observations that fell into the diagonal cells of the confusion matrix. Although overall accuracy is easy to compute and readily understood, the kappa statistic is a better measure of the strength of agreement in land-cover data because it is also sensitive to the extent and distribution of the errors of omission or commission represented by the counts in the off-diagonal cells of the confusion matrix (Congalton 1991).

The percent accuracy and kappa scores from the confusion matrices used to assess the accuracy of the original and corrected land-cover data against the ground-reference data are summarized in Figure 8. In each pairwise comparison of the original FWC land cover versus corrected land cover for a given year (1987,

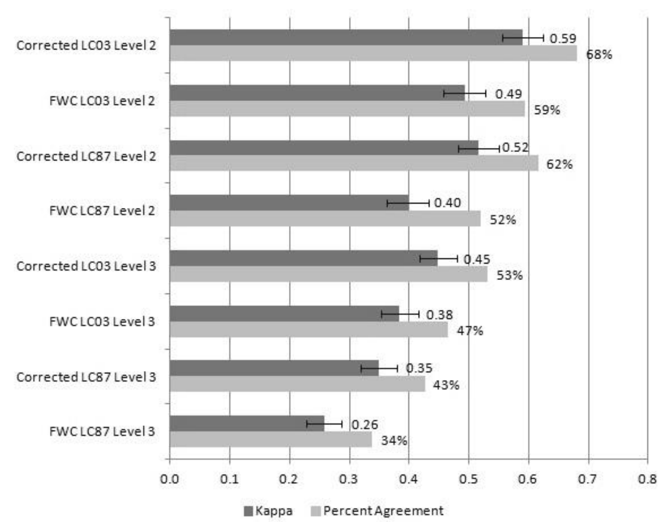

Figure 8. Comparison of percent agreement and kappa statistic for confusion-matrix accuracy assessments of original FWC and corrected land-cover data for two different epochs (1987, 2003) and two different levels of land-cover classification (Level 3 = 18 classes, Level 2 = 7 classes). Kappa statistics are shown with 95 percent confidence limits.

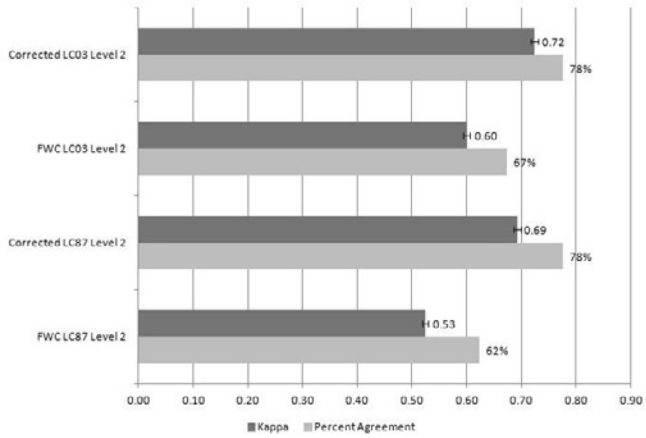

Figure 9. Comparison of percent agreement and kappa statistic for confusion-matrix accuracy assessments of original FWC and corrected land-cover data for two different epochs (1987, 2003) at Level 2 against Water Management District land-use data (1990, 2004) aggregated to Level 2. Kappa statistics are shown with 95 percent confidence limits.

2003) and land-classification scheme (Level 2, Level 3), both the percent accuracy and the kappa score was higher for the corrected data. The improvement in overall accuracy for the corrected 1987 Level-3 land-cover data was substantial, increasing from 33.8 percent to 42.6 percent, an increase of 26.3 percent. Improvements for the other pairwise comparisons ranged from a difference of 6.6 percent (a 14.2 percent improvement) for the 2003 Level-3 data to 9.7 percent (an 18.6 percent improvement) for the 1987 Level-2 land cover. Landis and Koch (1977) established a scale for the strength of interrater agreement based on the kappa statistic, where kappa values from 0.21 to 0.40 represented Fair agreement, and those ranging from 0.41 to 0.60 indicated Moderate agreement. Based on that scale, the strength of accuracy assessments for both original FWC and corrected Level-3 land-cover data were mostly only Fair, while most of the Level-2 land-cover comparisons were rated Moderate. Nonetheless, the improvements in accuracy for the corrected land-cover data over their uncorrected counterparts as measured by the kappa statistic were statistically significant ($\alpha = 0.05$) for all comparisons, as indicated by the 95 percent confidence intervals (see Figure 8).

The data in Figure 8 exhibit two other trends besides the consistent improvement in accuracy for corrected land cover over the original FWC land cover. The 2003 data sets were consistently more accurate than their 1987 counterparts. This can be attributed to the more sophisticated land-cover classification process used to develop the original FWC 2003 data, including the use of spatial masks to identify disturbed areas, which better differentiated between urban and agricultural lands (Stys et al. 2004, Kautz et al. 2007). Additionally, Level-2 classifications were consistently more accurate than the comparable Level-3 data in keeping with the observation of Congalton (1991) that two or more detailed land-cover categories that can be collapsed into a single more general category will produce higher accuracies than are reported for the individual categories.

Confusion matrices between all pixels in the original FWC and the corrected land cover for 1987 and 2003 for six counties (Brevard, Lake, Orange, Osceola, Seminole, and Volusia) versus the Water Management District land-use data for 1990 and 2004 corroborate the findings of the comparison using randomly selected ground-reference locations (see Figure 9). The overall accuracy of the corrected 1987 land-cover data increased to 77.6 percent from 66.2 percent for the original FWC data, an improvement of 17.2 percent. Overall accuracy for corrected 2003 land cover increased from 67.3 percent to 77.6 percent, a gain of 15.3 percent. The kappa statistic for the corrected land-cover data increased by 31.8 percent over the uncorrected FWC data for 1987, and by 20.5 percent for the 2003 data. The kappa statistic improvements were statistically significant ($p < 0.01$) for both time periods. Furthermore, the strength of the agreement as measured by the kappa improved from a rating of Moderate (between 0.41 to 0.60) for the original FWC land-cover data to Substantial (0.61 to 0.80) per the rating scale of Landis and Koch (1977).

The accuracy assessments demonstrated that the Land Cover Correction Model clearly improved the quality of the land-cover data for both the 1987 and 2003 epochs, and the comparison of original to corrected land-cover data show that those improvements were significant. Consequently, those corrected land-cover data provided better source material for analysis of land-cover change over time than the original land-cover data from which they were derived.

Land-cover Change Analysis

A change-detection analysis for all 67 Florida counties was performed for both the original FWC and the corrected land-cover data and the percent change in each Level-3 land-use category was calculated (shown in Table 2). Marked differences were evident between the areal extent of many of the FWC and corrected land-cover classes. A Chi-Square test (GraphPad Software 2014) applied to the normalized areal proportions of the land-cover data showed that these differences were significant ($p < 0.0001$). A confusion matrix between the corrected 1987 and 2003 land-cover data provided details on the land-cover changes (see Table 3).

In the original FWC data, class 17–Urban/barren had the largest coverage in both 1987 (2,761,256 ha) and 2003 (3,082,965 ha), while in the corrected land cover, the most extensive coverage was in class 14–Grassland/agriculture (2,835,419 ha and 2,826,754 ha for 1987 and 2003, respectively). In fact, in the corrected land-cover data, 17–Urban/barren had only the fourth largest coverage in 1987 following 14–Grassland/agriculture, 3–Pineland, and 7–Forested wetland (see Table 2). By 2003, the corrected 17–Urban/barren had become the second largest land-cover type (2,732,638 ha) at a little more than 100,000 ha behind 14–Grassland/agriculture in size. The overestimation of 17–Urban/barren land cover in the original 1987 FWC data was important because it masked the true magnitude of urban growth in Florida between 1987 and 2003. The areal extent of 17–Urban/barren increased by 11.65 percent in the original FWC land-cover

Table 2. Statewide land-cover change at Level 3 between 1987 and 2003 for original FWC and corrected land-cover data.

	FWC Land Cover				Corrected Land Cover			
Level 3 Land Cover Type	1987 (ha)	2003 (ha)	Change (ha)	Change (%)	1987 (ha)	2003 (ha)	Change (ha)	Change (%)
1-Coastal strand	4,368	4,595	227	5.19%	5,917	5,653	-264	-4.46%
2-Dry prairie	679,998	554,128	-125,869	-18.51%	634,252	599,371	-34,880	-5.50%
3-Pineland	2,236,938	2,238,703	1,764	0.08%	2,692,444	2,447,959	-244,484	-9.08%
4-Scrub	155,083	127,413	-27,670	-17.84%	164,834	131,569	-33,265	-20.18%
5-Sandhill	315,694	287,819	-27,875	-8.83%	345,500	287,800	-57,700	-16.70%
6-Upland forest	623,432	391,961	-231,472	-37.13%	525,010	429,556	-95,453	-18.18%
7-Forested wetland	1,676,349	2,241,244	564,895	33.70%	2,176,268	2,268,321	92,053	4.23%
8-Tropical hardwood hammock	5,085	5,985	900	17.70%	5,523	5,621	98	1.77%
9-Mangrove swamp	228,477	243,012	14,536	6.36%	248,265	255,016	6,751	2.72%
10-Salt marsh	170,796	166,613	-4,183	-2.45%	178,846	168,736	-10,110	-5.65%
11-Freshwater marsh	934,957	1,029,836	94,879	10.15%	974,634	1,031,248	56,614	5.81%
12-Shrub swamp	251,796	304,162	52,366	20.80%	275,120	242,872	-32,248	-11.72%
13-Shrub and brushland	1,435,546	550,548	-884,998	-61.65%	1,005,642	548,204	-457,438	-45.49%
14-Grassland/agriculture	2,521,370	2,624,980	103,609	4.11%	2,834,419	2,826,754	-7,665	-0.27%
15-Exotic plants	18,488	18,494	6	0.03%	17,427	15,635	-1,792	-10.28%
16-Water	1,797,904	1,915,638	117,735	6.55%	1,798,125	1,837,369	39,243	2.18%
17-Urban/barren	2,761,256	3,082,965	321,710	11.65%	1,952,098	2,732,638	780,540	39.98%
Total	15,817,536	15,788,095	-29,441	-0.19%	15,834,323	15,834,323	0	0.00%

Table 3. Confusion matrix of changes in corrected land cover from 1987 to 2003 for land-cover classes 1 through 9. Row totals are for LC87 land cover summed across all LC03 land-cover types.

	Corrected LC03 Level 3										
Corrected LC87 Level 3	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Row Total**	**Row Change %**
1-Coastal strand	4,818.2	19.6	33.9	4.3	1.3	12.9	16.7	9.4	102.8	**5,916.7**	**18.6%**
2-Dry prairie	4.5	398,345.9	22,130.4	1,243.4	164.2	2,253.2	8,582.8	1.7	34.9	**634,251.9**	**37.2%**
3-Pineland	162.1	25,355.6	2,055,121.9	5,563.0	20,996.0	75,255.6	115,252.3	124.4	231.1	**2,692,443.6**	**23.7%**
4-Scrub	31.2	2,508.8	10,734.8	115,538.0	4,636.4	2,111.9	852.6	1.0	5.3	**164,834.2**	**29.9%**
5-Sandhill	0.1	209.0	28,508.4	4,254.1	251,649.9	3,768.5	1,419.2	0.0	0.0	**345,499.7**	**27.2%**
6-Upland forest	13.4	5,873.2	93,428.6	1,982.4	2,275.7	291,634.3	47,968.7	833.6	1,202.6	**525,009.5**	**44.5%**
7-Forested wetland	2.3	6,983.6	51,260.8	484.4	496.2	19,509.2	2,013,110.8	7.9	747.7	**2,176,267.8**	**7.5%**
8-Tropical hardwood hammock	43.4	5.3	255.7	0.0	0.0	107.6	126.5	4,028.7	397.7	**5,522.7**	**27.1%**
9-Mangrove swamp	32.2	37.1	100.7	7.6	0.0	148.6	197.2	211.2	232,953.1	**248,265.1**	**6.2%**
10-Salt marsh	17.7	104.5	276.5	5.9	0.5	283.0	919.9	21.8	12,020.0	**178,846.3**	**16.2%**
11-Freshwater marsh	9.5	16,235.1	4,302.0	195.0	160.2	1,029.0	28,108.5	126.5	619.9	**974,634.2**	**14.6%**
12-Shrub swamp	3.7	1,505.9	5,917.3	51.3	29.4	743.3	14,357.2	35.6	119.3	**275,119.6**	**44.5%**
13-Shrub and brushland	297.8	41,132.7	110,398.6	1,375.7	3,592.4	16,323.3	21,226.6	3.7	88.6	**1,005,641.9**	**62.2%**
14-Grassland/agriculture	10.8	97,684.5	58,955.0	490.7	3,282.9	14,077.1	11,520.2	14.9	29.7	**2,834,419.4**	**18.4%**
15-Exotic plants	17.2	153.6	660.5	0.5	0.0	263.8	407.8	70.6	250.7	**17,426.9**	**49.2%**
16-Water	147.3	342.5	251.6	10.9	15.2	108.9	1,622.7	46.8	5,991.7	**1,798,125.5**	**3.7%**
17-Urban/barren	41.6	2,874.5	5,622.8	361.7	500.0	1,926.5	2,631.4	83.0	221.3	**1,952,098.1**	**2.2%**
Column Total	**5,653.0**	**599,371.5**	**2,447,959.4**	**131,568.9**	**287,800.2**	**429,556.3**	**2,268,320.9**	**5,620.7**	**255,016.4**	**12,843,601.1**	**81.1%**
Column Change %	**14.8%**	**33.5%**	**16.0%**	**12.2%**	**12.6%**	**32.1%**	**11.3%**	**28.3%**	**8.7%**		

Table 3 (continued). Confusion matrix of changes in corrected land cover from 1987 to 2003 for land-cover classes 10 through 17. Row totals are for LC87 land cover summed across all LC03 land-cover types.

	Corrected LC03 Level 3									
Corrected LC87 Level 3	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Row Total**	**Row Change %**
1-Coastal strand	68.8	0.2	0.1	58.1	21.2	0.0	208.3	541.3	**5,916.7**	**18.6%**
2-Dry prairie	250.7	18,870.9	2,404.4	6,514.1	129,587.1	1,573.7	9,854.1	32,435.8	**634,251.9**	**37.2%**
3-Pineland	729.5	6,521.3	11,099.6	73,185.0	25,630.4	238.1	5,463.2	271,514.6	**2,692,443.6**	**23.7%**
4-Scrub	41.9	355.3	109.0	1,338.5	655.0	1.2	331.7	25,581.6	**164,834.2**	**29.9%**
5-Sandhill	0.3	207.9	105.1	3,795.7	3,282.5	0.0	257.9	48,041.2	**345,499.7**	**27.2%**
6-Upland forest	734.4	1,912.6	1,624.4	11,949.8	9,801.1	1,337.1	2,777.5	49,660.2	**525,009.5**	**44.5%**
7-Forested wetland	210.1	19,843.0	12,006.4	11,757.4	7,984.4	85.4	7,157.8	24,620.5	**2,176,267.8**	**7.5%**
8-Tropical hardwood hammock	50.9	22.2	6.2	0.3	1.7	0.5	49.2	426.9	**5,522.7**	**27.1%**
9-Mangrove swamp	6,501.0	279.4	11.3	41.7	49.1	23.2	7,096.3	575.6	**248,265.1**	**6.2%**
10-Salt marsh	149,928.8	7,507.7	370.2	188.3	30.3	3.8	6,005.7	1,161.8	**178,846.3**	**16.2%**
11-Freshwater marsh	2,161.1	831,987.5	44,694.3	3,969.4	18,039.3	143.8	13,696.9	9,156.2	**974,634.2**	**14.6%**
12-Shrub swamp	582.8	88,183.0	152,742.3	3,321.0	2,928.1	308.9	1,747.6	2,542.8	**275,119.6**	**44.5%**
13-Shrub and brushland	504.4	5,104.8	4,119.8	380,025.9	308,508.6	958.4	13,686.8	98,294.0	**1,005,641.9**	**62.2%**
14-Grassland/agriculture	64.3	16,345.3	6,679.2	50,225.5	2,311,571.8	1,685.5	24,921.8	236,860.5	**2,834,419.4**	**18.4%**
15-Exotic plants	72.4	239.8	388.8	20.6	873.6	8,856.5	368.3	4,782.3	**17,426.9**	**49.2%**
16-Water	6,057.7	29,410.0	4,414.7	292.6	976.5	21.3	1,731,629.9	16,785.2	**1,798,125.5**	**3.7%**
17-Urban/barren	777.3	4,457.6	2,096.1	1,520.5	6,813.4	397.4	12,115.5	1,909,657.6	**1,952,098.1**	**2.2%**
Column Total	**168,736.1**	**1,031,248.4**	**242,871.8**	**548,204.1**	**2,826,753.9**	**15,635.0**	**1,837,368.5**	**2,732,638.0**	**12,843,601.1**	**81.1%**
Column Change %	**11.1%**	**19.3%**	**37.1%**	**30.7%**	**18.2%**	**43.4%**	**5.8%**	**30.1%**		

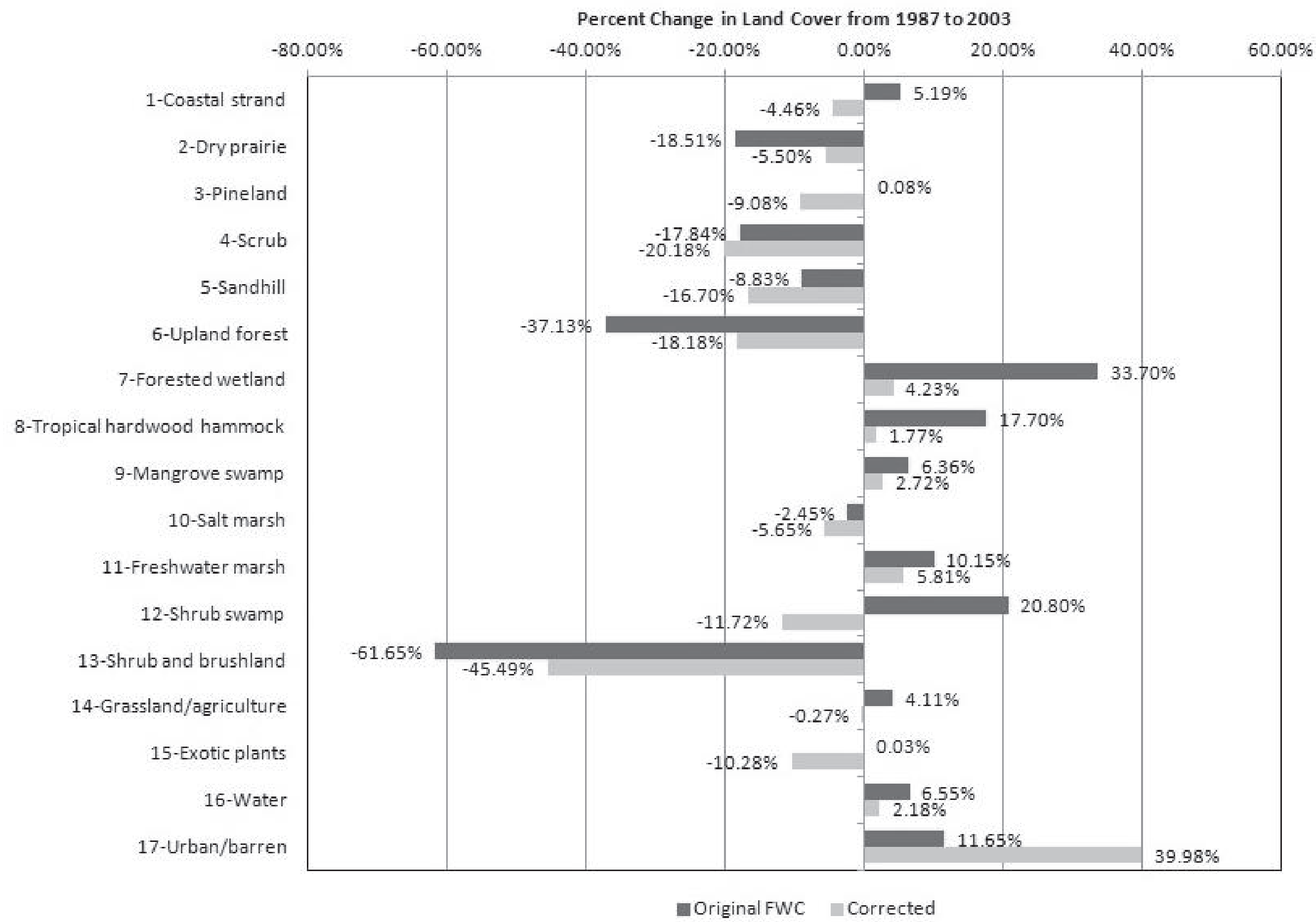

Figure 10. Percent change in Level-3 land cover between 1987 and 2003 for original FWC and corrected land-cover data.

data, while the corrected land-cover data showed an increase of 39.98 percent over the same time period (see Table 2, Figure 10). The latter growth rate in urban area is more consistent with the 42 percent increase in Florida's population between 1987 and 2003 (FOEDR 2014).

The areal extent of several other key land-cover classes in the corrected data also differed substantially from those in the original FWC data. Coastal strand is a critically endangered vegetative community that is home to several endemic threatened or endangered species (Johnson et al. 1992, Mann 1995). The 1–Coastal strand class in the corrected data for 1987 (shown in Table 2) measured 35.4 percent greater in area (5,917 ha) than in the uncorrected FWC data (4,368 ha). More important, the trend from 1987 to 2003 in the original FWC data showed a 5.19 percent increase in coastal strand, while the corrected data showed a -4.46 percent decrease in this community (see Figure 10), a finding consistent with the assessment that coastal strand was among the most rapidly disappearing vegetative communities in Florida (FNAI 1990). Most of the decline in coastal strand (541 ha, 9.1 percent of the original coastal strand coverage) was attributable to conversion to 17–Urban/barren land cover, while 208 ha (3.5 percent) of the coastal strand decline involved conversion to open water (see Table 3).

The longleaf pine–wiregrass ecosystem is a fire-climax community that is home to a number of rare plant and animal species (Noss et al. 1995). Longleaf-pine forest coverage in North America has been reduced by more than 98 percent from its historical extent (Noss 1989) and includes extensive losses to urbanization and silviculture in Florida (Diemer 1986, FNAI 1990, Means et al. 1996, Van Lear et al. 2005, Carr et al. 2010). Consistent with the historic trend in longleaf-pine habitat loss, the corrected land-cover data showed a -9.08 percent decline in the 3–Pineland class between 1987 (2,692,444 ha) and 2003 (2,447,959 ha), with most of the decline (271,515 ha) occurring as conversion to 17–Urban/barren (see Tables 2 and 3). In contrast, the uncorrected FWC data remained nearly unchanged from 1987 (2,236,938 ha) to 2003 (2,238,703 ha), an increase of +0.08 percent (see Table 2, Figure 10). The corrected land-cover data for pinelands appeared to more accurately capture the decline of this critical habitat during the study period than the original uncorrected data, and would be a more suitable basis for guiding pineland habitat conservation and management decisions.

The turkey oak–longleaf pine association captured by the 5–Sandhill class is another rapidly disappearing fire-dependent

Florida community that is home to a number of endemic species (Diemer 1986, FNAI 1990, Menges and Hawkes 1998, Kautz and Cox 2001, Carr et al. 2010, Breininger et al. 2011). The uncorrected FWC data recorded a -8.83 percent (-27,875 ha) decline in 5–Sandhill between 1987 and 2003 (see Table 2, Figure 10), while the corrected data showed a habitat loss nearly twice as large (-16.70 percent, 57,700 ha). The more extensive loss of the sandhill habitat shown by the corrected land-cover data would be of interest to policy makers concerned with conservation of this vegetative community and its associated endemic species.

Wetland area also changed substantially in the corrected land-cover data. The areal coverage of the 7–Forested wetland class for 1987 was more than half a million hectares larger in the corrected land-cover data (2,176,268 ha) than in the original FWC uncorrected data (1,676,349 ha), while the 2003 values were nearly identical for the FWC (2,241,244 ha) and corrected (2,268,321 ha) data sets (see Table 2). As a consequence of its lower coverage estimate for 1987, the areal extent of 7–Forested wetland increased by 33.7 percent between 1987 and 2003 in the FWC land-cover data (shown in Figure 10). Given the demonstrated difficulty of restoring or creating forested wetlands (Stanturf et al. 2001), it is unlikely that any agency in Florida was responsible for the restoration or establishment of more than 500,000 ha of forested wetlands during this time period. In contrast, the corrected land-cover data indicated that the area of 7–Forested wetland remained essentially unchanged. A static or slightly increasing coverage by forested wetlands could be attributed to the modest successes of wetland protection and mitigation measures, particularly restoration of wetlands in "mitigation banks," pursuant to the "no net loss" of wetlands policy instituted at the federal level in 1989 (Brown and Lant 1999, Reiss et al. 2009).

Conversion of coastal salt marsh to mangrove forest has been observed throughout south Florida and has been attributed to multiple factors, including sea-level rise, a warming climate, and anthropogenic changes in estuarine salinity (Ball 1980, Krauss et al. 2011, Raabe et al. 2012). The trend of increasing mangrove forestation and loss of salt marsh was evident in both the original FWC and corrected land-cover data, but the magnitude of the changes differed. The uncorrected FWC data showed a 6.36 percent increase in the 9–Mangrove swamp class from 228,477 ha in 1987 to 243,012 ha in 2003, while 10–Salt marsh declined by 2.45 percent from 170,796 ha in 1987 to 166,613 in 2003 (see Table 2, Figure 10). Conversely, in the corrected land-cover data, the 9–Mangrove swamp cover increased by only 2.72 percent (6,271 ha), from 248,265 ha in 1987 to 255,016 ha in 2003, while 10–Salt marsh declined by 5.65 percent from 178,846 ha to 168,736 ha. The confusion matrix for examining land-cover change in the corrected data showed that 4.7 percent (12,020 ha) of the total 9–Mangrove swamp class in 2003 was formerly 10–Salt marsh (see Table 3). Given the relatively small differences in the areal extent of both mangrove swamp and coastal salt marsh between the original FWC and the corrected land-cover data sets, it isn't clear which data provided the better results for these classes. Detailed examination of the changes in specific stands of vegetation with reference to high-resolution overhead imagery could settle the question.

The coverage of the 11–Freshwater marsh class increased in both the original FWC and the corrected land-cover data (shown in Table 2). The baseline area for freshwater marsh in 1987 was nearly 50,000 ha larger in the corrected data (974,634 ha) than in the uncorrected data (934,957 ha), while the 2003 area for the two data sets differed by only 1,412 ha. Consequently, the absolute and percentage increase in freshwater marsh was nearly twice as large in the uncorrected data than in the corrected data (see Table 2, Figure 10). Although the overall trend for freshwater marsh coverage in Florida has been negative, as it has been for the nation as a whole, some artificial ponds and wetlands have increased in area (Hefner and Brown 1984, Zedler and Kercher 2005). Spot inspection of the corrected land cover and the original Landsat imagery suggested that emergent wetlands associated with newly constructed stormwater treatment facilities probably account for most increases in the freshwater marsh coverage in Florida.

Comparison to Previous Change-detection Analysis

Kautz et al. (2007) relied on a number of remedial measures applied during the change-detection process to correct for known deficiencies in the original FWC land-cover data, after which the data were used to estimate the amount of anthropogenic land conversion to urban and agricultural uses between circa 1987 and 2003. They reported that 9,855,179 ha of Florida's natural and seminatural land cover was converted either to urban uses (611,845 ha, 6.21 percent) or agricultural uses (703,292 ha, 7.14 percent) for a total loss of 1,315,138 ha (13.34 percent). Estimates computed using the corrected land-cover data (see Table 4) show 9,232,253 ha of natural land reduced by 564,552 ha (6.12 percent) for urban uses and 506,519 ha (5.49 percent) for agricultural uses, for a total habitat loss of 1,071,071 ha (11.6 percent).

Computing the differences between the values in Table 4 and the comparable Table 3 in Kautz et al. (2007) highlights how the evaluation of land conversion was altered by the improvements made to the land-cover data by the Land Cover Correction Process. The total of all natural or seminatural land cover in Florida circa 1987 was 622,926 ha less for the corrected land-cover data (see Table 5). Conversion to urban uses in the corrected data was 47,293 ha lower, and conversion to agricultural uses was reduced by 196,773 ha, resulting in 244,067 ha less anthropogenic land conversion than had been previously estimated by Kautz et al. (2007). Although the corrected land-cover data showed that overall land conversion of natural areas was lower compared to the earlier estimate, the corrected data showed proportionally greater habitat losses for four important habitat types. Pinelands cover was reduced by 10.08 percent in the corrected land cover as compared to 5.90 percent, a difference of 4.18 percent (see Tables 4 and 5). Likewise, upland forest in the corrected land-cover data declined by 9.46 percent versus 6.37 percent, sandhill

Table 4. Land cover conversion to urban and agricultural land uses between 1987 to 2003 data using the corrected land cover data following the format of Table 3 in Kautz et al. (2007).

Land Cover Type	Area in 1985–89 (ha)	Conversion to Urban or Developed (ha)	%	Conversion to Agriculture (ha)	%	Total Conversion (ha)	Total Conversion (%)
Pineland	2,692,444	271,515	10.08	25,630	0.95	297,145	11.04
Shrub and brushland	1,005,642	98,294	9.77	308,509	30.68	406,803	40.45
Forested wetland	2,176,268	24,620	1.13	7,984	0.37	32,605	1.50
Upland forest	525,010	49,660	9.46	9,801	1.87	59,461	11.33
Freshwater marsh	974,634	9,156	0.94	18,039	1.85	27,196	2.79
Dry prairie	634,252	32,436	5.11	129,587	20.43	162,023	25.55
Sandhill	345,500	48,041	13.90	3,282	0.95	51,324	14.85
Shrub swamp	275,120	2,543	0.92	2,928	1.06	5,471	1.99
Mangrove swamp	248,265	576	0.23	49	0.02	625	0.25
Salt marsh	178,846	1,162	0.65	30	0.02	1,192	0.67
Scrub	164,834	25,582	15.52	655	0.40	26,237	15.92
Tropical hardwood hammock	5,523	427	7.73	2	0.03	429	7.76
Coastal strand	5,917	541	9.15	21	0.36	562	9.51
Total (natural and semi-natural)	9,232,253	564,552	6.12	506,519	5.49	1,071,071	11.60
Grassland/agriculture	2,834,419	236,860	8.36			236,860	8.36
Total (natural and agricultural)	12,066,673	801,413	6.64	506,519	4.20	1,307,931	10.84

Table 5. Difference between the land-cover conversion data of Kautz et al. (2007) and the corrected land-cover data. Positive differences indicate larger values for the corrected land-cover data. Values in the percent columns represent the arithmetic difference in the percent values reported for the two data sets.

Land Cover Type	Area in 1985–89 (ha)	Conversion to Urban or Developed (ha)	%	Conversion to Agriculture (ha)	%	Total Conversion (ha)	Total Conversion (%)
Pineland	46,590	115,369	4.18	-61,731	-2.35	53,637	1.84
Shrub and brushland	-648,379	-125,659	-3.77	-67,521	7.95	-193,180	4.18
Forested wetland	640,555	-2,008	-0.60	-10,852	-0.86	-12,859	-1.46
Upland forest	-627,360	-23,719	3.09	-47,311	-3.09	-71,030	0.01
Freshwater marsh	-120,648	-17,741	-1.52	-19,773	-1.60	-37,513	-3.12
Dry prairie	79,323	-6,014	-1.82	26,861	1.92	20,847	0.11
Sandhill	985	9,513	2.72	-11,547	-3.35	-2,032	-0.64
Shrub swamp	2,696	-850	-0.33	-1,099	-0.42	-1,949	-0.73
Mangrove swamp	27,002	-813	-0.40	-10	-0.01	-823	-0.40
Salt marsh	-17,643	-3,903	-1.93	-38	-0.01	-3,941	-1.94
Scrub	-5,983	8,786	5.69	-3,757	-2.18	5,029	3.50
Tropical hardwood hammock	-655	-221	-2.75	-17	-0.28	-238	-3.03
Coastal strand	593	-32	-1.62	21	0.36	-11	-1.26
Total (natural and semi-natural)	-622,926	-47,293	-0.09	-196,773	-1.65	-244,067	-1.74
Grassland/agriculture	298,563	-118,577	-5.66	0	0.00	-118,577	-5.66
Total (natural and agricultural)	-324,362	-165,870	-1.17	506,519	4.20	-362,644	-2.64

losses amounted to 13.90 percent versus 11.18 percent, and scrub declined by 15.52 percent compared to 9.83 percent (see Tables 4 and 5). Given the relatively small areal extent of some of these habitats, the larger percent loss estimates over the study period revealed by the corrected land-cover data are cause for even greater concern by conservation planners and policy makers.

CONCLUSIONS

The Land Cover Correction Process outlined here significantly improved the accuracy of two statewide mapping products generated from Landsat imagery more than 15 years apart and made it possible to perform change-detection analyses with a greater degree of confidence. Now that the 1987 and 2003 land-cover datasets are more directly comparable, they can be used to further explore the patterns of urban development, habitat loss, and forest fragmentation throughout Florida during a time when growth was rampant, but also when important new growth management controls were in place. The value of the LCCP model, however, is not limited to these two land-cover data sets in Florida. This same technique can be applied to any pair of roughly similar land-cover mapping data sets provided that their original classification systems can be composed by a crosswalk into a single scheme, and that one or more ancillary data sets are available to serve in the tie-breaker role performed here by the near-contemporaneous land-use data from Florida's WMDs. The Soil Survey Geographic (SSURGO) and State Soil Geographic (STATSGO) soils data of the National Resource Conservation Service have been used in GIS analyses to reconstruct historical presettlement vegetative cover (Stetler et al. 2003) and could easily be adapted to provide the ancillary tie-breaker data required by the LCCP.

Similarly, the National Land Cover Dataset (NLCD) or the statewide habitat mapping of the USGS GAP Analysis Program provide readily available sources of ancillary land-cover data (Wardlow and Egbert 2003). Applying the Land Cover Correction Process using these ancillary data may provide opportunities to conduct change detection between disparate land-cover data sources that heretofore were considered too incompatible for that purpose.

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