Geospatial method for computing supplemental multi-decadal U.S. coastal land-use and land-cover classification products, using Landsat data and C-CAP products

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Abstract

This paper discusses the development and implementation of a geospatial data processing method and multi-decadal Landsat time series for computing general coastal U.S. land-use and land-cover (LULC) classifications and change products consisting of seven classes (water, barren, upland herbaceous, non-woody wetland, woody upland, woody wetland, and urban). Use of this approach extends the observational period of the NOAA-generated Coastal Change and Analysis Program (C-CAP) products by almost two decades, assuming the availability of one cloud free Landsat scene from any season for each targeted year. The Mobile Bay region in Alabama was used as a study area to develop, demonstrate, and validate the method that was applied to derive LULC products for nine dates at approximate five year intervals across a 34-year time span, using single dates of data for each classification in which forests were either leaf-on, leaf-off, or mixed senescent conditions. Classifications were computed and refined using decision rules in conjunction with unsupervised classification of Landsat data and C-CAP value-added products. Each classification's overall accuracy was assessed by comparing stratified random locations to available reference data, including higher spatial resolution satellite and aerial imagery, field survey data, and raw Landsat RGBs. Overall classification accuracies ranged from 83 to 91% with overall Kappa statistics ranging from 0.78 to 0.89. The accuracies are comparable to those from similar, generalized LULC products derived from C-CAP data. The Landsat MSS-based LULC product accuracies are similar to those from Landsat TM or ETM+ data. Accurate classifications were computed for all nine dates, yielding effective results regardless of season. This classification method yielded products that were used to compute LULC change products via additive GIS overlay techniques.

Keywords: Coastal monitoring, land use land cover mapping, decision rule image classification, Landsat, C-CAP, Alabama

1. Introduction

The goal of this paper is to report a set of techniques that can be used by the coastal zone mapping community to derive generalized United States (U.S.) coastal land-use land cover (LULC) maps that supplement those from NOAA's Coastal Change and Analysis Program (C-CAP). This method employs combined use of Landsat time series data and C-CAP products with the purpose of extending coastal LULC change maps across a multi-decadal era that begins approximately two decades before the first C-CAP products described by Dobson *et al.* (1995).

There is much uncertainty about the extent and impacts of LULC change for many coastal areas of the U.S., though much less from the early 1990s onwards. C-CAP products show coastal zone change in the U.S. since the mid-1990s with approximately a five-year interval between beginning and ending dates. The products from this service have supported coastal studies to determine the impacts of recent historical LULC change (Loveland *et al.* 1999, Wolter *et al.* 2006, C-CAP 2011). The first C-CAP products of the mid-1990s were produced independently from the USGS-based National Land Cover Database (NLCD) products that began in the early 1990s. Starting in the 2001, these two LULC mapping efforts were more closely coordinated. As of 2006, these products are fully integrated; they remain separate products but are produced in synch with each other at 5-year intervals (Xian *et al.* 2011).

Recent urban expansion along the coastal zone of the U.S. has been a concern to managers and planners responsible for habitat conservation and restoration (U.S. Commission on Ocean Policy 2004, Gulf Coast Ecosystem Restoration Task Force, 2011). Several recent studies identify the relationship between urban growth and declining water quality, bio-diversity, and/or native habitat quality and availability (White *et al.* 2006). For example, the USGS identified urbanization as the driver for the 4% reduction in forested cover from 1973-2000 across the eastern U.S. (Drummond and Loveland 2010). Deluca *et al.* (2008) found that development (e.g., urbanization and agriculture) near the estuarine coastlines of the Chesapeake Bay region is the main stressor affecting estuarine water bird community integrity, and that estuarine ecosystem integrity can be impaired even with extremely low levels of coastal urbanization. Urbanized watersheds in coastal southern California reduced native amphibian biodiversity and increased numbers of non-native crawfish (Riley *et al.* 2005).

Continued coastal wetland habitat loss due to urbanization in the southeastern U.S. is a recognized threat and concern. In particular, the northern Gulf of Mexico coastal region has experienced noteworthy human population growth in recent decades, associated with environmental degradation. Such coastal habitat degradation is further exacerbated by other factors such as coastal erosion, subsidence, sea level rise, and land loss (National Ocean Service 2008). Also, given that 52% of the U.S. population currently lives in coastal counties (NOAA 2012, U.S. Census Bureau 2012), additional current and historical geospatial information on coastal LULC trends are required by the coastal conservation and restoration communities to support development, implementation, and promotion of more effective coastal zone management and policies.

The C-CAP products only started in the mid-1990s. This is problematic for many LULC change studies that require longer time series to better identify when urbanization and other LULC change occurred. In many prominent urban centers across the U.S. coastal zone, much of the urbanization occurred prior to the 1990s. Such urbanization has caused impacts to the water quality of many estuaries. Given that C-CAP is refreshed on average every 5-years, another potential problem arises when fresher, more up-to-date coastal LULC change products are required. This can be the case with coastal regions that are being heavily developed or at risk for additional habitat loss due to urbanization. Needs for interim products also arise when natural and manmade disasters occur, such as hurricanes and oil spills. In such cases, these interim LULC change products support early impact assessments of the disaster in the affected region.

C-CAP products use 30 meter Landsat data with spectral bands in the visible, near infrared, and mid-infrared. C-CAP products have a relatively high classification scheme specificity of 24 standard coastal LULC classes (NOAA CSC 2012). This high specificity, however, is a potential impediment to the derivation of C-CAP products from Landsat MSS data, which has a nominal spatial resolution of 79 meters and bands only in the visible and near infrared portions of the spectrum. Not all members of the coastal zone management community require such high specificity to conduct basic, yet meaningful, coastal LULC change detection (e.g., Ellis *et al.* 2011). For example, some coastal zone managers are simply interested in determining basic LULC trends. Therefore, high classification schemes are not necessary to suit their needs and may add to the complexity of the task at hand, especially when it comes to interpreting all of the possible change categories. At full specificity, a two-date C-CAP change detection product could have as many as 576 potential change categories. In contrast, a more general classification scheme using seven classes only has 49 potential change categories.

Even if the high classification specificity of C-CAP products did not pose interpretation challenges to some product users, it seems unlikely that such classifications could be developed from Landsat MSS, due to the latter's lower spatial, spectral, and signal resolution compared to the Landsat TM and ETM+ data used for C-CAP product generation. In addition, the availability of Landsat MSS is more incomplete and therefore less likely to occur for multiple growing seasons over a 1-2 year span, compared to Landsat TM and ETM+. However, even with Landsat TM and ETM+ data, the availability of both leaf-on and leaf-off cloud free data existing it is not guaranteed for a targeted year and locale. In many coastal areas across the country, the cloud cover is prohibitively high to allow multiple seasons of cloud free data for a given Landsat path and row to be obtained. If a high specificity classification scheme is not required, a potential solution is to recode and generalize the classification scheme and consider only the classes most needed for general assessment of coastal LULC change.

There is an opportunity to conduct LULC change assessments spanning the Landsat era of 40 years plus, doing so at roughly 5-year and/or 10-year intervals. However, for such a method to be successful, it needs to be conducted using a simplified LULC classification scheme and with as few as one data set per 5-year interval. The simplified LULC scheme adopted in this study is based on end-user (resource manager) requirements as described by Ellis *et al.* (2011) and comprises: the following categories: 1) open water; 2) barren; 3) upland herbaceous; 4) non-woody wetland; 5) upland forest; 6) woody wetlands; and 7) urban. This scheme can also be readily applied to recoded (generalized) C-CAP and NLCD products. In doing so, this creates an opportunity to employ either C-CAP or NLCD products when developing of coastal LULC products over an extended time series, going back to the beginning of the Landsat era in 1972.

We used Mobile Bay, Alabama to test and demonstrate this approach. This method was applied to compute and analyze trends for general coastal LULC types across a 34-year era (1974-2008). Such products were developed to aid the Mobile Bay National Estuary Program (NEP), who required multi-decadal LULC change products and analyses to support coastal conservation and restoration decisions in this region (Ellis *et al.* 2011).

Mobile Bay is an ecologically rich and economically vital coastal region found along the northern Gulf of Mexico (Figure 1). This prominent coastal estuary has been subjected to gradually increasing urbanization over the past several decades (Ellis *et al.* 2011). Along with the expansion of urbanization comes a corresponding increase in impervious cover, which in turn increases runoff and water pollution (Schueler 1994, Arnold and Gibbons 1996, Brabec *et al.* 2002, Schueler *et al.* 2009). While data on impaired waterways, watersheds, shorelines, and estuaries are collected and reported by the U.S. Environmental Protection Agency (EPA) (e.g., EPA 2008) and NOAA (e.g., Kimbrough *et al.* 2008, NOAA 2012), there was a need by the Mobile Bay NEP to obtain LULC trend information at the regional and watershed scales to help assess the environmental quality of different watersheds draining into Mobile Bay.

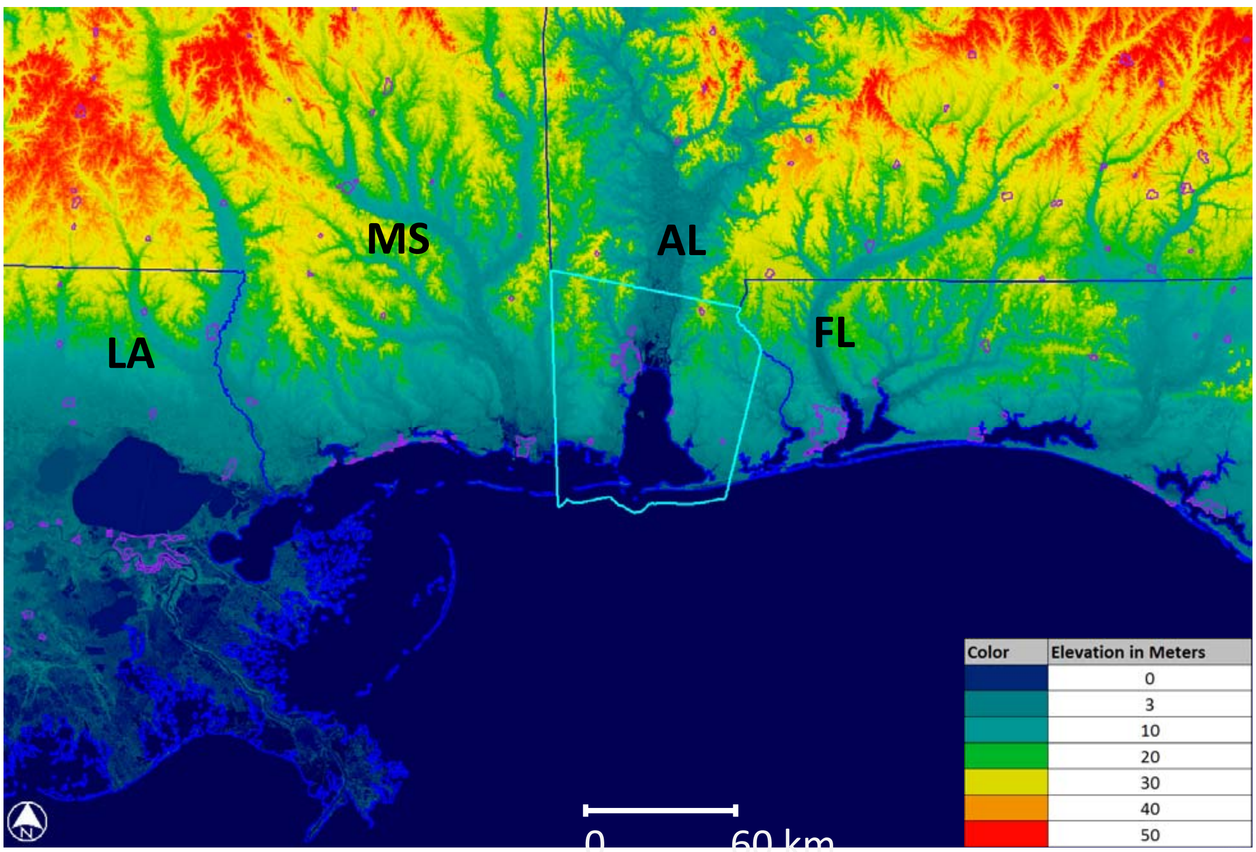

Figure 1. Study area location within Northern Gulf of Mexico. Study area, state, and city boundaries are shown as cyan, blue, and purple vectors, respectively. The image backdrop is from a 90-meter digital elevation model derived from NASA Shuttle Radar Topography Mission data. The large city polygon within the study area pertains to the City of Mobile, Alabama.

2. Previous Landsat-based LULC change assessments for U.S. coastal regions

Since the launch of Landsat 5 in 1984, several studies have employed multi-date Landsat imagery for assessing LULC change in the Gulf of Mexico coastal region (e.g., Ramsey and Laine 1997, Kelly 2001, Ramsey *et al.* 2001, Nelson *et al.* 2002, O'Hara *et al.* 2003, Yang and Liu 2005, Hilbert 2006, Martinez and Shealand 2009) and in other coastal regions of the United States, such as the Chesapeake Bay (Goetz *et al.* 2004, Jantz *et al.* 2005) of the Atlantic seaboard and the San Diego region of the Pacific coast (Rogan et al. 2003). Table 1 provides a summary of coastal LULC change studies that employed Landsat as the primary data source. Most, if not all, of these were conducted specifically for aiding resource assessment and management of specific coastal regions. Also, while most of these studies employed either Landsat TM data or a combination of Landsat TM and ETM+ data, one study by Nelson et al. (2002) used only Landsat MSS data (Table 1). In addition, only two studies employed data from Landsat MSS, TM, and ETM+ (Hilbert 2006, Ellis *et al.* 2011).

There are many image change detection methods that are used with Landsat data products, though not all are suitable for multi-temporal LULC change analysis. The main methods include image differencing, Principal Components Analysis (PCA), and post-classification change analysis (Lu et al. 2004). Image differencing is generally accomplished by subtracting one date of a given vegetation index from another (e.g., current versus historical date of NDVI). In some cases, analysts use a given spectral reflectance band instead of a vegetation index for image differencing based change detection. PCA change analysis is typically performed by classifying a two channel stack consisting of the same PC band computed for two dates. In doing so, the PC bands are derived from multispectral data collected for each of the two dates. The use of image differencing and PCA techniques tend to be used for change detection and do not necessarily provide information on the context of the change. Such context can be derived by comparison comparing change products to ancillary LULC data. In contrast, post classification change analysis usually involves the use of raster GIS techniques to derive a change product based on two dates of LULC classifications. In addition, a combination of change detection techniques is sometimes used to derive improved end products. For example, Klemas (2011) discusses use of image differencing and post-classification-based change analysis for deriving coastal LULC change products.

Based on available literature summarized in Table 1, most of the U.S. coastal LULC change studies have employed post-classification change techniques. For coastal LULC work, single date LULC products are generated using a variety of image classification procedures. For example, Ramsey *et al.* (2001) used a decision rule approach to improve a coastal LULC classification for Mermentau River Basin in coastal Louisiana, combining the original C-CAP coastal LULC classification method described by Dobson et al. (1995) along with GIS-masks of LULC "subregions". Sader *et al.* (1995) employed a similar expert-defined rule based classification method for classifying forest wetland classification areas of Maine that were either on or near the coast. O'Hara *et al.* (2003) later used this method to assess coastal LULC change in Mississippi for 1991-2000, using decision rules in conjunction with LULC specific spectral signatures for two (leaf-on and -off) dates of Landsat data acquired per year. In all three studies, the use of decision rule classification methods employed rules in conjunction with multiple input data layers to reduce classification confusion between similar LULC classes.

More recently, decision tree classifiers have been applied to produce regional coastal vegetation change products for the Chesapeake Bay area (Goetz *et al.* 2004) and San Diego, California region (Rogan *et al.* 2003). Decision tree classifiers have been used with Landsat and other geospatial data to compute national LULC data sets, beginning with the 2001 NLCD (Homer *et al.* 2004) and C-CAP (C-CAP 2011) products. The decision tree classification method differs from those employed by Ramsey *et al.* (2001) and Sader *et al.* (1995) in that the decision rules are defined by software, as opposed to the expert, in relation to the input data layers. In general, the decision tree classifier approach is used to compute higher specificity LULC products with reasonable overall accuracies. One potential disadvantage is for these techniques to be fully effective, a significant amount of training data accompanied by multiple Landsat scenes from multiple seasons are required.

Most of the coastal LULC classification studies described above included assessments of % overall classification accuracy and overall Kappa value. The Kappa statistic provides a means to quantify and assess classification agreement with reference data so that it is adjusted for agreement due to random chance (Congalton 1991). In a study of global vegetation maps, Monserud and Leemans (1992) rated observed Kappa values according to an eight class system describing quality of agreement: 1) no agreement is 0-0.05; 2) very poor is 0.05–0.20; 3) poor is 0.20–0.40; 4) fair is 0.40–0.55; 5) good is 0.55–0.70; 6) very good is 0.70–0.85; 7) excellent is 0.85–0.99; and 8) perfect is 0.99–1.00.

NLCD products were originally produced at 10-year intervals, starting in 1992 and at 5-year intervals starting in 2001. The 1992 NLCD products were produced using less advanced techniques that resulted in lower overall accuracies compared to the decision-rule based NLCD products of circa 2001 onwards. Circa 2001 NLCD LULC product resulted in average overall accuracies of 85% and 79% for Anderson Levels 1 and 2, respectively (Wickham *et al.* 2011). In contrast, the 1992 NLCD LULC products yielded average overall accuracies that ranged from 80% and 58% for Anderson Level 1 and 2 schemes, respectively (Wickham *et al.* 2011).

C-CAP products have been computed at 5-year intervals starting in 1996. The C-CAP products have higher classification scheme specificity for the wetland classes compared to NLCD, mapping the wetland classes according to the Cowardin wetland classification scheme (Cowardin *et al.* 1979). At full specificity, C-CAP products are produced with a targeted overall accuracy approaching 85% and targeted individual class accuracies of approximately 80% (NOAA-CSC 2011).

Unfortunately, the earliest available NLCD product is for 1992, which is 20 years after the launch of the initial Landsat system. Considering both NLCD and C-CAP, the lack of pre-1990s LULC products represent a data gap for coastal zone managers interested in assessing coastal change across the entire Landsat era of now more than 40 years. This is potentially problematic for studies of coastal areas subject to gradual conversion and degradation of native habitats to urban land uses and in need of more comprehensive coastal conservation and restoration planning. Such activities can benefit greatly from the consideration of coastal LULC data prior to when more modern era habitat conversion and degradation had occurred.

In many cases, coastal land management units occur within a single or few Landsat scenes. These areas do not typically require land cover mapping products with high classification scheme specificities associated with the NLCD or C-CAP products. However, these areas require spatio-temporal change analysis over a prolonged time frame that either precedes and/or proceeds the availability of either C-CAP or NLCD products. Given that the C-CAP and NLCD provide useful LULC data for their production years, there exists an opportunity for leveraging such products with other LULC products that can be derived with Landsat data for years either preceding or subsequent to available years of C-CAP and NLCD products. Furthermore, the C-CAP and NLCD products employ hierarchical classification schemes that can be generalized to a simpler scheme that is slightly more specific than Anderson Level 1 scheme but less specific than Level 2 (Anderson et al. 1976). Such a simplification increases the overall accuracy of the LULC classification (Wickham *et al.* 2011).

Table 1. Summary of published U.S. coastal LULC change studies based on multi-temporal Landsat data.

Publication	**Coastal Region**	**Duration of Time Series**	**Data Source(s)**
Ramsey and Laine (1997)	Southern Coastal LA	1990-1993	TM
Kelly (2001)	Coastal NC	1984-1992	TM
Ramsey et al. (2001)	Mermentau Basin, LA	1990-1996	TM
Nelson et al. (2002)	Barataria Basin, LA	1972-1992	MSS
O 'Hara et al. (2003)	Jackson County, MS	1991-2000	TM, ETM+
Rogan et al. (2003)	San Diego County, CA	1990-1996	TM
Goetz et al. (2004)	Chesapeake Bay, MD/VA	1990-2000	TM, ETM+
Jantz et al. (2005)	Chesapeake Bay, MD/VA	1990-2000	TM, ETM+
Yang and Liu (2005)	Pensacola Bay, FL	1989-2002	TM, ETM+
Hilbert (2006)	Grand Bay, MS	1974-2001	MSS, TM, ETM+
Martinez and Penland (2009)	Pontchartrain Basin, LA	1982-2005	TM
Ellis et al. (2011)	Mobile Bay, AL	1974-2008	MSS, TM, ETM+

3. Data acquisition

Given the need for LULC classification products, cloud free to nearly cloud free Landsat data sets were acquired for 9 dates at roughly 5-year intervals from 1974-2008 (Table 2). These included data sets from Landsat MSS, TM, and ETM+ systems. Data sets from all four seasons were selected in lieu of the project being started prior to the advent of universally free Landsat data and also the limited availability of cloud free data for the area during the targeted years. The majority of the selected data sets (7 dates) were either from the fall (3 dates) or the winter (4 dates) time frames. The selected data sets included those that contained hardwood forests that were either vast majority leaf-on (2 dates), vast majority leaf-off (4 dates), or partial leaf-off (3 dates). The acquired data included data at two spatial resolutions: 1) the Landsat MSS scenes provided visible and near infrared reflectance data at 60 meter resolution; and 2) the Landsat TM and ETM+ visible, near infrared and mid-infrared reflectance data sets were acquired at 30 meter resolution. For the leaf-off winter dates, there was variability noted in terms of observable flooding in the swamp forests. Overall, the selected Landsat data sets represent a diverse set of observation dates and growing conditions for assessing the multi-seasonal viability of the classification technique used in the study.

Table 2. Landsat data sets selected for LULC classification and change analyses.

Date #	**Acquisition Date**	**Acquisition Season**	**Phenological State of Deciduous Forest**	**Landsat Sensor**
1	11/12/1974	Fall	Mixed leaf-on/off	MSS
2	10/26/1979	Fall	Mixed leaf-on/off	MSS
3	9/6/1984	Summer	Majority leaf-on	MSS
4	2/22/1988	Winter	Majority leaf-off	TM
5	9/26/1991	Fall	Majority leaf-on	TM
6	1/27/1996	Winter	Majority leaf-off	TM
7	3/5/2001	Winter	Majority leaf-off	ETM+
8	3/24/2005	Spring	Mixed leaf-on/off	TM
9	3/16/2008	Winter	Majority leaf-off	TM

Several ancillary remote sensing data sets and derivative products were acquired to aid LULC product development and validation, including various vintages of high resolution aerial data from Digital Ortho Quarter Quad (DOQQ), National Aerial Imagery Program (NAIP), USGS National Wetland Research Center (NWRC), and Google Earth sources. Other acquired high resolution data included airborne hyperspectral data from the US Army Corp of Engineers (USACE), high resolution commercial satellite data (e.g., IKONOS and QuickBird) and declassified Corona satellite data. We also acquired Landsat-based LULC products from the NLCD for 1992 and 2001 and from C-CAP for 1996, 2001, 2005 (pre-Hurricane Katrina), and 2006 (the latter is a specialty assessment product in lieu of Hurricane Katrina). We also collected ground reference data for aiding assessment of the 2008 LULC classification results. During the field survey a subset of the randomly selected sample locations used in the 2008 LULC product accuracy assessment (see Section 4 for additional information on product validation method) were visited. At each visited location, GPS, digital photography, and notes were gathered to field check and further describe the predominant LULC type. Other historical National Wetland Inventory (NWI) maps and ground reference data for the 2002 NWI product were acquired from the USGS NWRC, along with documentation by Handley and Wells (2009).

4. Methods

LULC classification products were produced from all nine dates using Erdas IMAGINE® software (Leica Geosystems 2005) and the method described below. Initially, reflectance data for each acquired date were copied into a multichannel data stack, consisting of four reflectance bands for MSS data and six reflectance bands for TM and ETM+ data. We co-registered all nine dates of Landsat data to a common map projection, using the previously ortho-rectified 1991 data set as the reference. The latter was ortho-rectified as part of NASA's Scientific Data Purchase program (Goward *et al.* 2008).

Each date of Landsat data was classified using unsupervised clustering of Landsat reflectance stacks, in conjunction with a decision rule model, which compared clustering results to C-CAP data products to compute a seven class LULC map. We used an end-user defined classification scheme described in Section 1 that consisted of open water, barren, upland herbaceous, non-woody wetlands, woody uplands, woody wetlands, and urban. This scheme has classification specificity similar to Anderson Level I for all categories except for the two classes of wetlands, which are more comparable to the Anderson Level II specificity, as discussed by Anderson et al. (1976). Initially, an ISODATA unsupervised classification routine found in Erdas IMAGINE was used for clustering the Landsat data. In doing so, each data set was clustered into 20 classes to separate dominantly land from water cluster classes. Using the cluster busting technique described by Jensen (1996), the raw data for the land dominant clusters were reclassified into 30 cluster classes. Each resulting cluster class was interpreted and labeled to describe the predominant and secondary land cover types, using available reference data to attribute each apparent LULC type for a given cluster class. As available, such reference data included aerial photography, ground reference data, and raw Landsat RGBs. Given that more reference data was available for the most current date, we also used the Erdas IMAGINE Degrade routine to spatially average higher resolution aerial and commercial satellite data into Landsat TM or ETM+ or MSS resolutions RGBs and also for spatially averaging Landsat TM data into the Landsat MSS resolution. This process enabled a means to better understand the appearance of LULC types on the Landsat data, be it TM, ETM+, or MSS. Within the raster attribute table of each land classification, once the cluster class descriptions were completed, seven attribute columns were established so that there was one for each LULC category. For each LULC category, the image analyst determines whether the cluster class included each of the seven possible classes. In doing so, a positive association was coded 1 and a 0 was assigned for the converse. Afterwards, a spatial model was run to output seven different LULC maps, one for each targeted LULC class. At this point, the individual LULC classes are not necessarily mutual exclusive since certain clusters may be in fact relevant to multiple LULC classes. These binary LULC classifications can be thought of as a maximum potential of a given LULC class.

C-CAP LULC reference masks for non-woody wetlands, woody wetlands, and the urban categories were derived by considering all dates of available standard C-CAP products. In doing so, the original C-CAP LULC data products for 1996, 2001, and 2005 were recoded to match into the aforementioned seven class LULC scheme adopted for the study. Binary reference masks for the non-woody wetlands, woody wetlands, and urban classes were derived to refine the Landsat classifications. On a per class basis, the maximum extent of urban, woody wetlands, and non-woody wetland LULC mask were computed from the union of the 1996, 2001, and 2005 extent of each relevant LULC class.

To produce a predominant land cover classification, a series of spatial models were applied. First, each single LULC class classification was recoded according to a weighting scheme in conjunction with C-CAP reference data: water = 1; barren = 2, upland herbaceous = 3, non-woody wetland = 4, woody upland = 5, woody wetland = 6; and urban = 7. These recoded binary classifications were composited using a maximum value compositing routine so that the value of the weighting scheme could be realized. In doing so, the C-CAP-based reference masks of urban, woody wetlands, and non-woody wetlands were used in a decision rule capacity to reduce classification confusion of certain LULC classes. Application of the decision rules in conjunction with the weighting scheme was completed to improve separation of wetland and upland classes, in addition to improving the classification of urban areas.

In some cases, additional classification refinement was required to reduce obvious classification error compared to reference data. Such error reduction considered three techniques: 1) raw data masking and cluster busting techniques; 2) heads-up digitizing followed by zonal recodes; and 3) GIS editing based on C-CAP wetland versus upland designation. In particular, wetland clear cuts incorrectly tagged as upland herbaceous areas were edited using C-CAP wetland masks and omitted bridges were edited using heads-up digitizing and subsequent GIS editing. Afterwards, a standard color table was applied to each LULC classification. A common area mask was applied to each classification as a precursor to LULC change analysis, resulting in nine dates for finalized, refined LULC classifications (Figure 2).

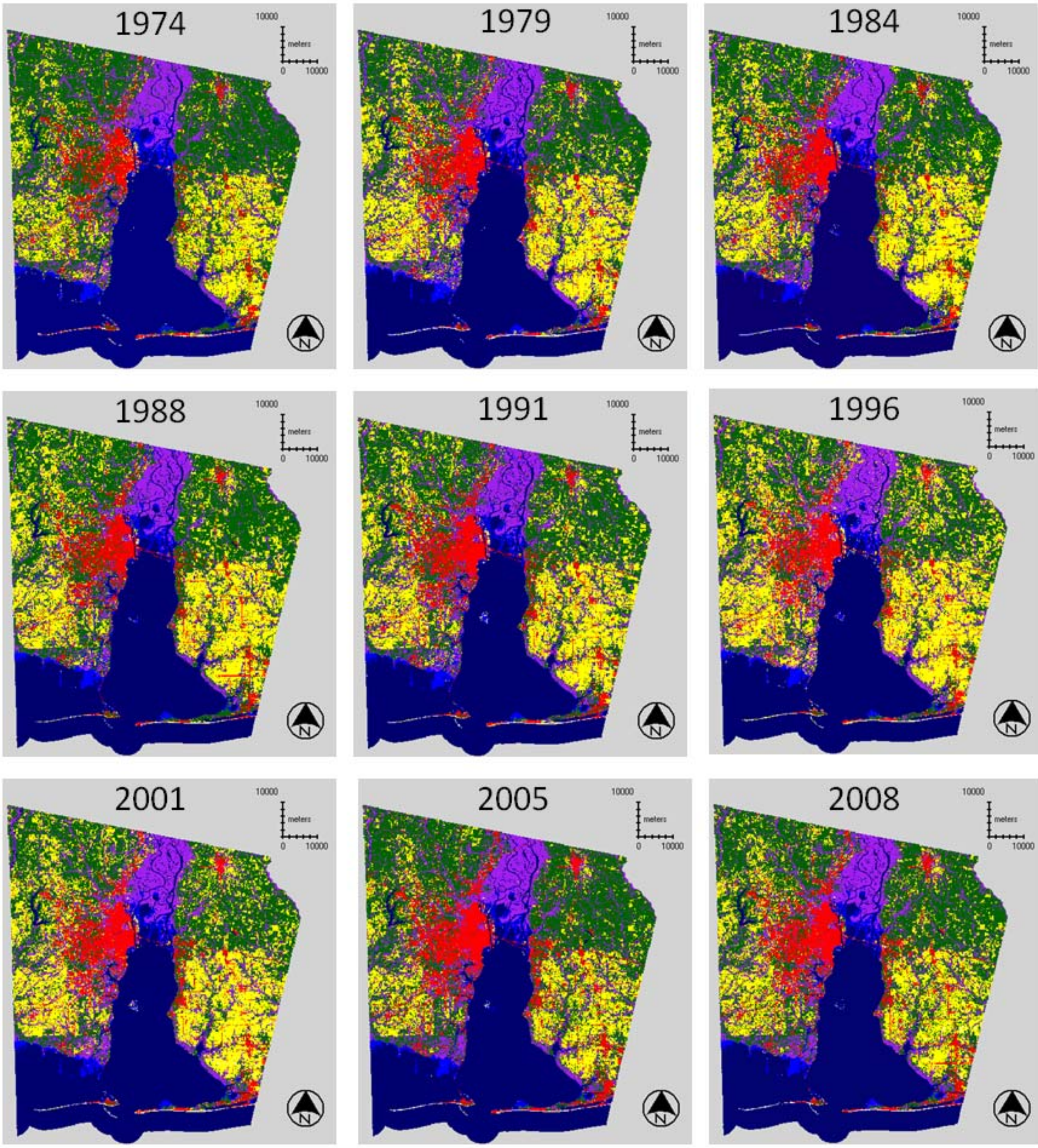

Figure 2. Results of Landsat LULC classifications for nine dates from 1974-2008.. Each classification is color-coded as follows: 1) water = dark blue; 2) barren = white; 3) upland herbaceous = yellow; 4) non-woody wetland = blue; 5) woody upland = dark green; 6) woody wetland = purple; and 7) urban = red.

Accuracy assessments were performed for all nine dates LULC classifications, using Congalton (1991) as a reference. In this case, accuracy refers to the measures of agreement between the randomly sampled test (Landsat results) and reference LULC (image interpreted results) classification compiled for each date. The intent of the LULC accuracy assessments was to derive estimators of overall accuracy for each classification. In particular, each classification's accuracy will be assessed in terms of percent overall agreement and overall Kappa value. Given the available resources, the goal was to quantify and assess overall classification accuracy for each date of LULC product and was not to derive estimates of individual class accuracies. Also, here we define success as results with an overall LULC classification accuracy exceeding 80%. For each date, at least 150 locations were randomly selected using a stratified random sampling approach in which the drawn total samples selected per class was, for the most part, proportionally allocated according to class frequency. The minimum number of drawn samples per class was five and the maximum was about 50 (usually in regard to upland forest). On a class by class basis, the samples were drawn in Erdas IMAGINE by randomly selecting 3 by 3 pixel samples in which the majority belonged to the targeted class.

Each of the randomly sampled locations was interpreted by trained, highly experienced image analysts to determine the predominant LULC class. The randomly sampled locations were viewed on available, temporally relevant digital geospatial reference data that included field survey data, high resolution orthorectified aerial photography, high resolution multispectral and panchromatic satellite or aerial data displays, digital elevation model data (for wetland class assessment), and NWI wetland cover type data (for wetland class assessment) in order to interpret the correct predominant LULC type. Landsat false color composites RGBs were also used as a reference in LULC map accuracy assessment when higher resolution imagery was not available. To aid in evaluation of LULC classifications from Landsat MSS data, analysts also viewed spatially averaged simulated Landsat MSS, TM, and ETM+ RGB displays derived from high spatial resolution aerial and satellite imagery. Doing so helped the image interpreters to further assess the appearance of the targeted LULC classes on the Landsat data versus the higher resolution remotely sensed data. A classification error matrix was computed for each date of LULC classification and summarized to compute estimates of classification accuracy.

5. Results and discussion

The results of the accuracy assessments are summarized in Table 3 and 4. Table 3 reports accuracy assessment results for individual dates of classifications. Table 4 reports the average percent overall agreement and Kappa values for all nine LULC classification dates, all three dates of MSS-based classifications, all 6 dates of TM and ETM+ classifications, and according to the data acquisition season used in classification. Considering all dates, the overall agreement between the Landsat and reference LULC classifications ranged from 83.1% to 91.3%, yielding an average overall agreement of 88.4%. The overall Kappa values ranged from 0.78 to 0.89 with an average overall Kappa of 0.85. These observed overall Kappa values range from very good to excellent, according to the rating scheme put forth by Monserud and Leemans (1992).

In reference to both Tables 2 and 3, the early spring mixed leaf-on/leaf-off date of 3/24/2005 yielded the lowest classification agreement with reference data. One factor associated with this date is that it is from a time of year in which deciduous forests are quite variable in terms of leaf status. Given Hurricane Katrina occurred later that year, it was decided to avoid using immediate post hurricane Landsat data for 2005. We therefore selected a 3/24/2005 data set prior to the hurricane as the best of what was available for 2005. This data set was the only date of classification that was derived using Landsat data from the spring. It is conceivable that a higher accuracy from spring time data could be obtained if the data was acquired later in the spring after full leaf out. Nonetheless, the results for 2005 were still acceptable given the objective of obtaining % overall agreements of 80% or higher. The Kappa value for this year is 0.78, which is very good, but lower than the rest of the classification dates.

Table 3. Results of all dates of LULC classifications in terms of % overall agreement and Kappa

Year	Date	Landsat Sensor	Total Samples	Overall Agreement (%)	Overall Kappa
1974	11/12/1979	MSS	150	87.3	0.84
1979	10/26/1979	MSS	150	89.3	0.87
1984	9/6/1984	MSS	150	90.0	0.87
1988	2/22/1988	TM	150	91.3	0.89
1991	9/26/1991	TM	155	89.7	0.87
1996	1/27/1996	TM	160	86.7	0.84
2001	3/5/2001	ETM+	150	89.3	0.87
2005	3/24/2005	TM	160	83.1	0.78
2008	3/16/2008	TM	192	89.1	0.86

Based on data acquired in the winter, the 1988 classification showed the highest overall agreement and Kappa values of 91.3% and 0.89 respectively (Table 4). The 1984 classification from fall Landsat MSS data almost performed as well, yielding a 90% overall agreement and a Kappa value of 0.87.

The six dates of Landsat TM/ETM+ classifications produced an overall agreement of 88.2% and an overall Kappa value of 0.85 (Table 5). The three dates of Landsat MSS classifications yielded a higher mean overall agreement of 88.9% and overall Kappa of 0.86. The classification results in terms of mean percent overall agreement appear to be quite similar for summer, fall, and winter LULC classifications with 90.0, 88.8, and 89.1%, respectively. The mean overall Kappa value is also similar for these three seasons with 0.87, 0.86, and 0.87, respectively. These results are based on one, three, and four dates of classifications for the respective summer, fall, and winter Landsat data sets. The single date of LULC classification from the spring, as discussed above, did not perform as well. While the results are encouraging, the study only included one single date LULC classification that was derived from spring data and one that was derived from summer data. Assessments of additional dates of spring and summer LULC classifications would be useful for further understanding the viability of the classification approach for use with Landsat data from all four seasons.

The classification approach provided a means to compute LULC classification products for several dates prior to the earliest C-CAP product of 1996. It also enabled a current LULC classification that was subsequent to most recent C-CAP product.

Table 4. Results of LULC classifications summarized according to all dates, all MSS dates, all TM/ETM+ dates, and according to season of data acquisition.

Classification(s)	Date(s)	Landsat Sensor	Mean Total Samples	Mean Overall Accuracy (%)	Mean Overall Kappa
All - Mean	9 dates	MSS, TM, ETM+	157	88.4	0.85
All MSS - Mean	3 dates	MSS	150	88.9	0.86
All TM/ETM+ - Mean	6 dates	TM/ETM+	161	88.2	0.85
Winter - Mean	4 dates	TM/ETM+	163	89.1	0.87
Spring - 1 Date	3/24/2012	TM	160	83.1	0.78
Summer - 1 Date	9/6/2012	MSS	150	90.0	0.87
Fall - Mean	3 dates	MSS, TM	152	88.8	0.86

6. Conclusions

The LULC classification approach developed and used in this study produced acceptable, useful LULC classifications for all nine dates across the 34-year period of 1974-2008, both in terms of percent overall agreement and overall Kappa value. Viable LULC classifications were derived from Landsat data collected across all four seasons. Acceptable LULC classifications were produced only using a single date of Landsat MSS, TM, or ETM+ data.

The classification approach employed in this study provides a tested method for the U.S. coastal zone management community to utilize in assessing general coastal LULC change over multi-decadal periods spanning the Landsat era. The technique requires both Landsat data for targeted dates not covered by C-CAP products in addition to C-CAP LULC products. The success of the approach depends on the quality of employed Landsat data and also in part on the thematic map and positional accuracy of C-CAP LULC products that are used in a reference capacity. In particular, the C-CAP product delineation of urban zones as well as wetland and upland areas is a key to success in addition to the selection of quality Landsat data sets that are essentially cloud free.

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