

A Landsat-based Assessment of Mobile Bay Land Use and Land Cover Change from 1974 to 2008

Joseph Spruce,¹ Jean Ellis,² James Smoot,¹ Roberta Swann,³ William Graham⁴

¹Science Systems & Applications, Inc., Stennis Space Center, MS 39525

²University of South Carolina, Columbia, SC 29208

³Mobile Bay National Estuary Program, Mobile, AL 36615

⁴NASA Code PA30, Stennis Space Center, MS 39529

Abstract- This paper discusses results of a Gulf of Mexico Application Pilot project conducted in 2008 to quantify and assess land use land cover (LULC) change from 1974 to 2008. Led by NASA Stennis Space Center, this project involved multiple Gulf of Mexico Alliance (GOMA) partners, including the Mobile Bay National Estuary Program (NEP), the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration's (NOAA's) National Coastal Data Development Center (NCDDC), and the NOAA Coastal Services Center. The Mobile Bay region provides great economic and ecologic benefits to the Nation, including important coastal habitat for a broad diversity of fisheries and wildlife. The Mobile Bay region has experienced considerable LULC change since the latter half of the 20th century. Accompanying this change has been urban expansion and a reduction of rural land uses. Much of this LULC change (largely urbanization) has reportedly occurred since the landfall of Hurricane Frederic in 1979. Regional urbanization threatens the estuary's water quality and aquatic-habitat dependent biota, including commercial fisheries and avian wildlife. Coastal conservation and urban land use planners require additional information on historical LULC change to support coastal habitat restoration and resiliency management efforts. This project quantified and assessed LULC change across the 34-year time frame and at decadal and mid-decadal scales. Nine Landsat images were employed to compute LULC products because of their availability and suitability for the application. The project also used Landsat-based national LULC products, including coastal LULC products from NOAA's Coastal Change & Analysis Program (C-CAP), available at 5-year intervals since 1995. Our study was initiated in part because C-CAP LULC products were not available to assess the region's urbanization prior to 1995 and subsequent to post-Hurricane Katrina in 2006.

The study area included the majority of Mobile and Baldwin counties that encompass Mobile Bay. Each date of Landsat data was classified using an end-user defined modified Anderson level 1 classification scheme. LULC classifications were refined using a decision rule approach in conjunction with available C-CAP products. Individual dates of LULC classifications were validated by image interpretation of stratified random locations on raw Landsat color composite imagery in combination with higher resolution remote sensing and in situ reference data. Overall classification accuracies for five separate single-date products ranged from 83% to 89%. The results of the LULC change analysis indicate that during the 34-year study period, urban areas increased from 96,688 to 150,227 acres, representing a 55.37% increase, or 1.63% per annum. Most of the identified urban expansion regarded the conversion of rural forest and agriculture to urban cover types. Final LULC mapping and metadata products were produced for the entire study area as well as for multiple watersheds of concern within the study area. The final project products, including LULC trend information, were incorporated into the Mobile Bay NEP State of the Bay report. Products and metadata were also transferred to NOAA NCDDC to allow free online accessibility and use by GOMA partners and by the public.

I. INTRODUCTION

This paper discusses an effort to employ Landsat time series data to quantify and assess land use land cover (LULC) change in the Mobile Bay region over the past 35 years. Such products are needed to aid planning efforts for sustainable land use, coastal conservation, and coastal restoration planning in the region.

A. Project Rationale and Objectives

The Mobile Bay region provides great economic and ecologic benefits to the Nation, including important coastal habitat for a broad diversity of fisheries and wildlife. It has also experienced considerable LULC change since the latter half of the 20th century. Accompanying this change has been urban expansion and a reduction of rural land uses. Much of this LULC change (largely urbanization) has reportedly occurred since the landfall of Hurricane Frederic in 1979. Mobile Bay was designated as an estuary of national significance in 1996 [1]. Regional urbanization threatens the estuary's water quality and aquatic-habitat dependent biota, as well as commercial fisheries and avian wildlife. Approximately 50% of Alabama's wetlands were lost by the mid-1980s [2]. Coastal conservation and urban land use planners in this region require additional geospatial information on historical LULC change to support coastal habitat restoration and resiliency management efforts [3, 4].

In response, a Gulf of Mexico Application (GOMA) Pilot project was conducted in 2008 to quantify and assess LULC change from 1974 to 2008. Led by NASA Stennis Space Center, this project involved multiple GOMA partners, including the Mobile

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Bay National Estuary Program (MBNEP), the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration's (NOAA's) National Coastal Data Development Center (NCDDC), and the NOAA Coastal Services Center. The study area includes the majority of Mobile and Baldwin counties that encompass Mobile Bay (Fig. 1). The primary research objective was for NASA SSC to compute Landsat-based historic and current LULC change detection products for aiding MBNEP coastal resource planning, outreach, and education decision support needs. This research objective included four main technical objectives that applied Landsat time series data to quantify and assess 1) regional LULC change from 1974 to 2008; 2) regional change due to urban expansion at decadal scales; 3) LULC change for specific watersheds of concern from 1974 to 2008; and 4) watershed-scale change due to urban expansion at decadal scales. This paper focuses on technical objectives one and two. Information on watershed scale analyses (technical objectives three and four) are discussed in the project's final report [5].

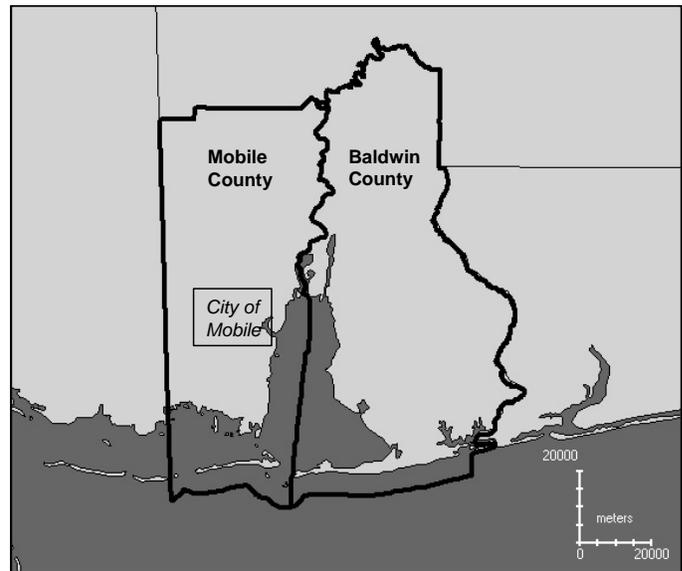


Fig. 1 Location map for study area.

B. Previous Relevant Coastal LULC Efforts Based on Landsat Data

Much of the previous coastal LULC work with Landsat data pertains to products from the Coastal Change and Analysis Program (C-CAP) administered by NOAA's Coastal Services Center [6]. The C-CAP has been producing LULC products at 5-year intervals since the mid-1990s. In addition, C-CAP produced products in 2006 for the region impacted by Hurricane Katrina, which includes Mobile Bay. Most of these products have been produced using Landsat TM or ETM data in conjunction with the Cowardin wetland [7] and the Anderson LULC [8] classification schemes. The available C-CAP products have much higher classification specificity than can be needed for basic LULC change detection analyses. Coastal zone managers without GIS skills and computer equipment are not necessarily able to recode C-CAP products into more generalized, end-user customized LULC schemes. C-CAP products have a high overall accuracy specification of 85% or better [9].

Landsat data have been used on multiple occasions to quantify and assess LULC change in Gulf of Mexico coastal areas, including (going west to east) coastal south-central Louisiana [10], Mermentau River Basin of Louisiana [11], Barataria Basin of Louisiana [12], Coastal Mississippi [13], Grand Bay of Mississippi [14], Pensacola Bay of Florida [15], and Tampa Bay of Florida [16]. Similar applications have been done in other coastal regions of the country, such as for Chesapeake Bay [17]. In contrast, a literature review revealed a few previous studies of Mobile Bay LULC change, although none were identified as using multiple dates of Landsat data throughout the Landsat era. To the best of the authors' knowledge, none of these efforts have been published in peer-reviewed journals.

Change detection products from C-CAP are produced through image classification of LULC for a given year followed by post-classification change detection of two different years. The LULC classification for each surveyed year is computed through use of multiple seasons of Landsat data in conjunction with elevation, impervious cover, and tree canopy cover products. This process is similar to that used in the National Land Cover Database (NLCD) of 2001, although at a higher level of classification specificity for the wetland categories. Given the cloud cover frequency of the region, it is difficult to acquire multiple seasons of cloud-free Landsat data for a given year. Fortunately, there are image processing and GIS techniques that can enable useful coastal LULC products from single-date Landsat data, although doing so usually requires adoption of a more general classification scheme compared to C-CAP products. C-CAP products are not available for dates prior to the mid-1990s.

Other relevant LULC classification products are also available for the study area, including NLCD and National Wetland Inventory (NWI) products. The latter has been enhanced for the Mobile Bay region to include more upland and urban categories than is common to standard NWI products. However, in going from the 1950s to 2002, these products were produced from multiple types (e.g., panchromatic and color infrared) and multiple scales of aerial photography. Consequently, even with C-CAP, NLCD, and NWI products available, additional Landsat change detection analysis spanning the Landsat era was desirable and therefore pursued for this project.

II. METHODS

The necessary LULC change detection products were computed from Landsat time series data from 1974 to 2008. Single dates of largely cloud-free Landsat data were acquired for 9 different years including 11/12/1974, 10/26/1979, 09/06/1984, 02/22/1988, 09/26/1991, 01/27/1996, 03/05/2001, 03/24/2005, and 03/16/2008. Each date of Landsat data was georeferenced to a common database: the orthorectified Landsat Thematic Mapper scene from 09/26/1991. The latter was an orthorectified product acquired

through NASA's Scientific Data Purchase program. Each Landsat dataset was imported into ERDAS IMAGINE® software. All acquired Landsat data was 30 meter resolution, except for three dates of Landsat MSS data (1974, 1979, and 1984) sampled at 60 meter resolution. The 30 meter Landsat data were processed so that each dataset contained a 6-channel data stack of the visible, near infrared, and shortwave infrared reflectance bands. The Landsat MSS data were processed into a 4-channel data stack consisting of visible and near infrared bands.

Each date of Landsat data was classified using a decision rule model in conjunction with unsupervised classification techniques. In doing so, an end-user defined LULC classification scheme was utilized, containing upland herbaceous, upland forest, non-woody wetland, woody wetland, open water, and urban categories, which is equivalent to a modified Anderson Level I classification system [7]. An ISODATA unsupervised classification routine resident to ERDAS IMAGINE software was used to cluster each Landsat scene into spectral cluster classes. Each cluster class was interpreted using reference data (e.g., aerial photography of comparable vintage to the Landsat date) to identify each represented LULC type.

A decision rule classifier deployed as a series of spatial models in ERDAS was then used to compute a refined classification based on a weighting scheme that involved the use of C-CAP products. On a per-cluster class basis, a value of one was assigned to the attribute column for each LULC class when the cluster included that LULC category. A value of zero was assigned to the attribute column for each LULC class when the cluster class did not pertain to a given LULC class. Spatial models were constructed to produce binary masks of each targeted LULC class. C-CAP products were used to reduce classification confusion of certain targeted classes; in particular, urban, woody wetlands, and non-woody wetlands. C-CAP LULC data products for 1996, 2001, and 2005 (pre-Hurricane Katrina) were recoded using our 7-class Landsat classification system. Maximum extent images of urban, woody wetlands, and non-woody wetland LULC categories were computed from the union of the 1996, 2001, and 2005 extent of each applicable category. These masks were not mutually exclusive and additional editing was performed using a maximum value compositing approach to compute a discrete, thematic, wall-to-wall refined classification.

For each sampled Landsat date, a spatial model was implemented to merge the individual classifications of LULC classes into a wall-to-wall product to complete the primary LULC classification process. This model used a maximum value compositing technique in which certain LULC categories were weighted higher to reduce classification confusion. If needed, additional classification refinement was completed to reduce visible classification error. Such editing usually was done by reclassification of an identified problematic class, generally using raw data masking and cluster busting techniques described by [18].

Accuracy assessments were performed for several dates of LULC classifications. In doing so, locations on each date of classification were randomly sampled using a stratified random sampling approach in which the drawn sample per class was proportionally allocated according to class frequency. The randomly sampled locations were viewed on available digital reference data that included ground reference 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). Landsat false color composites RGBs were also used as a reference in LULC map accuracy assessment when higher resolution imagery were not available.

Change detection analysis consisted over post-classification GIS-based overlay analysis for each 2-date comparison of interest to the end-user, including comparisons of LULC change across the entire time series and at decadal time frames. These comparisons were then simplified to further assess phenomenon of urbanization. Landsat scenes were cropped to include only Mobile and Baldwin counties for regional scale analysis.

III. RESULTS

Below are examples of results obtained in the project, including sample results for assessments of regional LULC change and regional urbanization change.

A. Regional LULC Change

Comparisons of LULC classification products provided visual indication of where LULC change occurred within the study area. As suspected, for the Landsat time series, much of the LULC change appeared to occur prior to the C-CAP era. This change is primarily due to urbanization. The rural areas that fringe the City of Mobile metro area also showed change attributed to plantation forestry practices. The change between 1974 and 2008 is depicted in Fig. 2. The most prominent visual indication of the urban expansion is around the City of Mobile and along the eastern shore of Mobile Bay. The northeast portion of the study area shows that some upland forest has changed to the upland herbaceous land cover type. This change is probably transitional in nature, due to forest harvesting cycles. The results of the LULC change analysis indicate that during the 34-year study period, urban areas increased from 96,688 acres to 150,227 acres, representing a 55.37% increase, or 1.63% per annum.

A graphical comparison of percent coverage of each LULC category for each date of classification is given in Fig. 3. Urban cover increases throughout the time series with an approximate 30% increase in this type between 1974 and 1979. The urban cover frequency increases to about 60% when considering the entire time series. There is noteworthy fluctuation among the upland herbaceous and upland forest landscapes. These data suggest a cyclical land swapping between upland herbaceous and

upland forest landscape, however, this research was unable to make this conclusion definitely. The non-woody wetlands decreased over time (-6.4%, or ~2400 acres), while the woody wetlands slightly increased (+3.4%, or ~6500 acres).

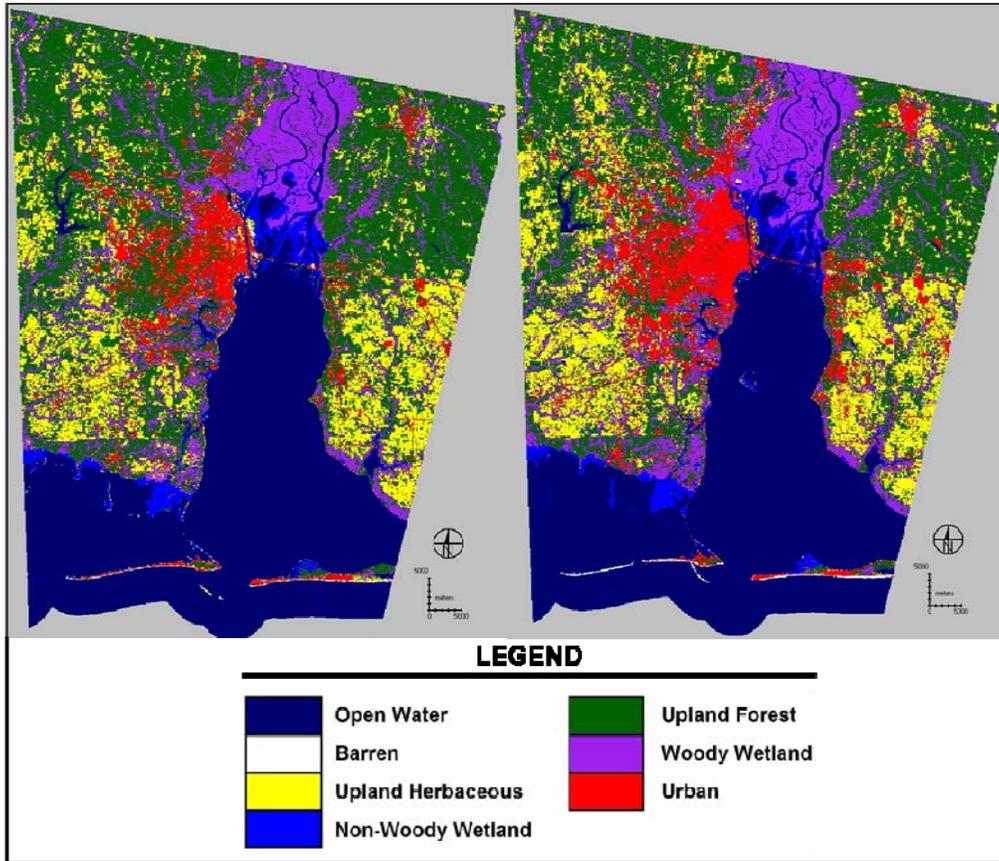


Fig. 2 Landsat-derived land-use and land-cover data product for 1974 (left) and 2008 (right) showing surveyed area within Mobile and Baldwin counties (graphic previously published in [20]).

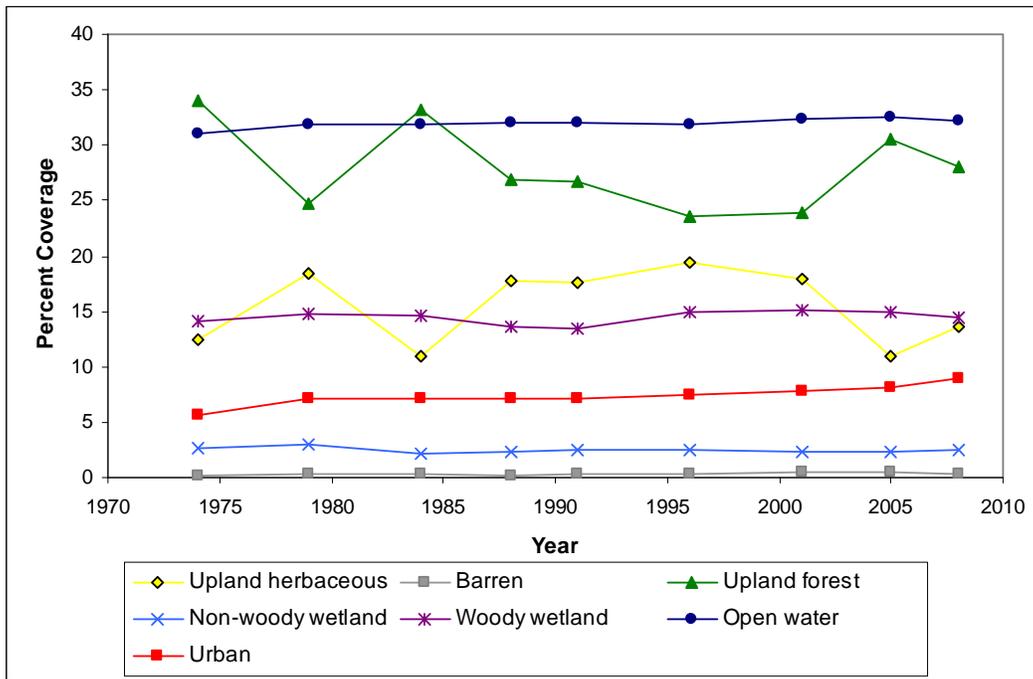


Fig. 3 Percent coverage change relative to 1974 for each land-use and land-cover class (except barren) for Mobile and Baldwin counties. Tabular data show the Landsat-derived geospatial statistics for each land-use and land-cover class in acres. Barren was excluded from the figure because this land cover type comprises a small percent of the total coverage (<0.5%, is often transitional in nature, and its small acreage changes are not readily observed in relation to the other LULC categories).

The results of the LULC classification accuracy assessment are given in Table 1. The overall accuracy (i.e., agreement with reference data) ranged from 83.13% (2005) to 89.33% (1979), and the Kappa values for these classifications ranged from 0.78 (2005) to 0.87 (1979). The sampling intensity for these assessments ranged from 150 (1979) to 190 (2008) total random samples per classification. In all cases, the overall accuracy exceeded 80% and the Kappa either approached or exceeded 0.8 (on a scale of 0 to 1). The use of Landsat MSS data (1979, at 60 m, rather than post 1984 at 30 m) did not seem to lower the accuracy. However, only one MSS product was assessed for accuracy, and additional accuracy assessment is needed.

B. Regional Urbanization Change

Urbanization visualization products illustrate urban expansion at the decadal scale throughout the Landsat time series (Fig. 4). Much of the apparent expansion occurs on the western flank of the City of Mobile, although some is also evident on the eastern settled portion of Mobile Bay in Baldwin County. Most of the urbanization occurs in the 1974-1984 time frame, which precedes the time during which C-CAP products are available. The urban growth compared to the underlying elevation model in Fig. 4 show the relationship of urbanization to the low lying land and to the waterways in these areas. In some cases, development occurs in close proximity to waterways, representing a potential increased risk for water pollution issues.

Table 1 Overall accuracy of 1979, 1996, 2001, 2005, and 2005 land-use land-cover classifications compared to available reference data.

Year	Overall Accuracy (%)	Overall Kappa	Total Samples
1979	89.33	0.87	150
1996	86.88	0.84	160
2001	88.00	0.85	150
2005	83.13	0.78	160
2008	89.06	0.86	192

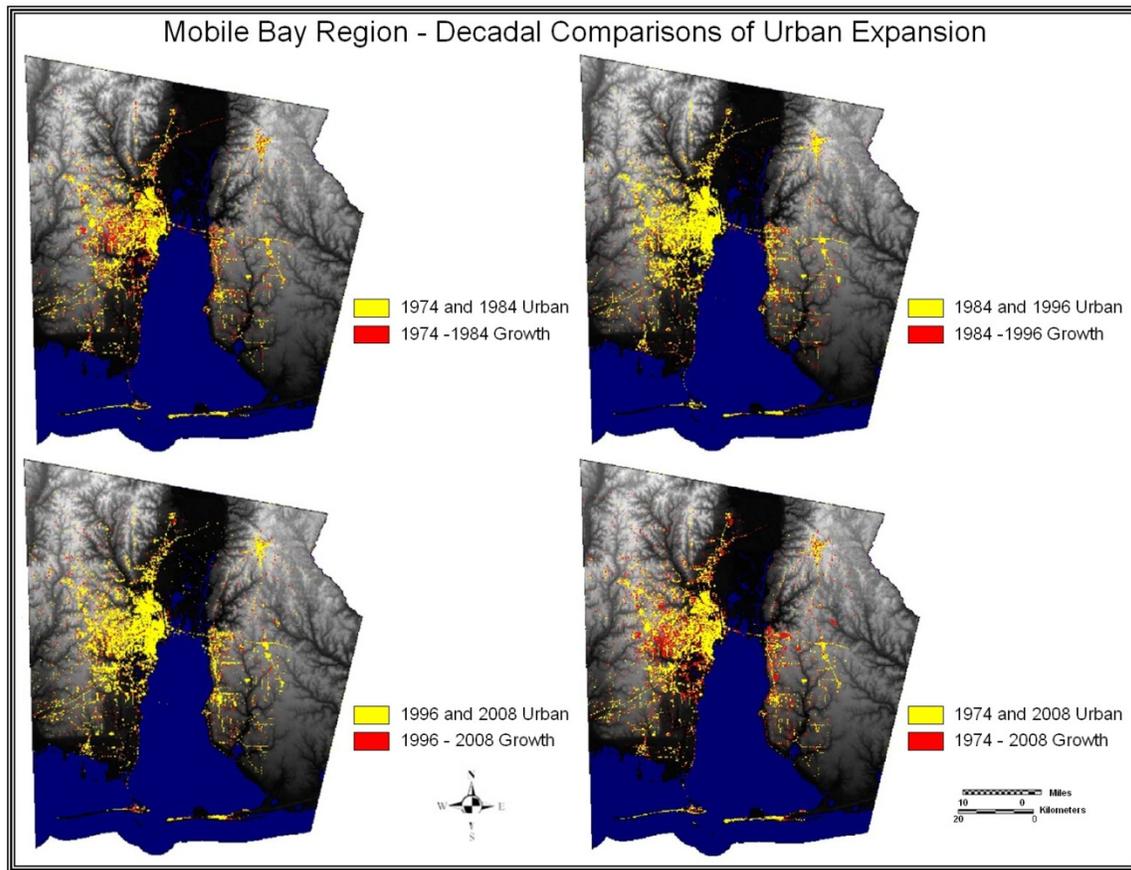


Fig. 4 Decadal-scale of urban expansion for Mobile and Baldwin counties. The area shown is common to all four dates used in the analysis, done in an effort to standardize change comparisons across all dates.

IV. CONCLUSIONS

Multitemporal Landsat data were useful for quantification and assessment of LULC change in the Mobile Bay region over the surveyed 34-year time frame. This was the case for regional- as well as watershed-scale analysis. The LULC classification technique employed in this study enabled products with high apparent classification accuracy (i.e., agreement) compared to available reference data for all 5 dates of classifications examined for relative accuracy. The LULC products here have recently been utilized to aid the Mobile Bay NEP in efforts to promote and aid coastal conservation and habitat restoration. In particular, the final project products, including LULC trend information, were incorporated into the Mobile Bay NEP State of the Bay report and Comprehensive Conservation and Management Plan (CCMP) work plan [3, 4]. To benefit GOMA partners, the public, and academic institutions, products and metadata are available for free download from a NOAA NCDDC FTP site [19]. Additional information on this work is given in the final report for the project [5].

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