A Threatened Ecosystem:

Quantifying Urban Expansion around Everglades National Park and

Big Cyprus National Preserve from 2000 to 2020

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Abstract

Southern Florida has been experiencing sustained population growth and urban expansion for decades. This region of the state is also home to a valuable, yet fragile, ecosystem: the Everglades. The Everglades is a large freshwater wetland that provides critical habitat for a number of threatened and endangered species. The urban growth in this area is at least partly responsible for a variety of environmental issues, including loss of biodiversity and poor water quality in the Greater Everglades region. Remote sensing and geospatial technology provide an important tool that can be used in the analysis of land cover change, and particularly urban growth, in this area. This paper assesses changes in urban areas within a 30-mile radius of Everglades National Park and Big Cypress National Preserve from 2000 to 2020 using Landsat satellite images. Change detection analysis shows that 164,040 acres of land within this radius were developed and converted to urban areas during this time frame. Information on the past two decades of urban growth can be used to inform projections of future growth and assist natural resource planners in their work to restore the water quality and health of the Greater Everglades region.

Keywords: remote sensing; urban expansion; change detection; Everglades; Florida

Introduction

Everglades National Park is the largest subtropical wilderness in the United States, a World Heritage Site, and a designated Wetland of International Importance. The Greater Everglades region, which the park protects a portion of, is the largest freshwater marsh in the country. Numerous rare and endangered species of plants, invertebrates, fish, reptiles, birds, and mammals call Everglades National Park home (National Park Service 2022a). The park is bordered to the north by Big Cypress National Preserve, a freshwater swamp that also provides habitat for many threatened and endangered species. Together, Everglades National Park and Big Cypress National Preserve make up over 2 million acres of protected lands in southern Florida (National Park Service 2021). The Greater Everglades ecosystem covers even more ground outside of these protected areas.

Everglades National Park and Big Cypress National Preserve are bordered to the east by cities like Miami and Fort Lauderdale, and to the west by the resorts of Marco Island and Naples. Florida's population has been rapidly growing for decades and much of that growth has been concentrated in the southeast and southwest parts of the state (Smith 2005). This rapid population growth, along with a growing tourism industry in the area, has put immense strain on the Florida Everglades ecosystem. Much of the Everglades outside of the national park have been drained and converted to farmland, severely damaging the hydrologic function of the wetland area. Additional portions of the Everglades and the surrounding area have been converted to urban areas to meet the needs of the growing population (Walker 2001). Perry (2004) describes the remaining Everglades region as an ecosystem in "a continuing state of decline ... as evidenced by vegetation change, declining wildlife populations, and organic soil loss." The extent of the effects of agriculture and urban development on this region prompted the development of the Comprehensive Everglades Restoration Plan (CERP), which seeks to improve water management and hydrologic connectivity in this area (Perry 2004). However, sustained urban expansion in southern Florida poses a continual challenge to the goals of the CERP.

Remote sensing images preserve a record of conditions at a given location at different points in time, enabling characterization of changes over time. Change detection, the process of identifying differences in the condition of a location at different points in time, can be applied to remotely sensed images to identify both long-term and short-term changes in a landscape. (Hawash et al. 2021). Lu et al. (2004) categorized change detection into seven types: algebra, transformation, classification, advanced models, remote sensing and GIS integration, visual analysis, and other change detection techniques. Change detection is often combined with classification techniques to provide more detailed "from-to" change information. The random forest algorithm is an ensemble classifier that produces multiple decision trees using a subset of the training data. This classifier is popular within the remote sensing community due to its high level of accuracy (Belgui et al. 2016).

The use of remote sensing to identify and quantify areas of urban development is well-documented (Al-Dail 1998; Hawash et al. 2021; Hegazy, et al. 2015; Ji et al. 2001); thus far, however, these techniques have not been applied to the Greater Everglades region of Florida. The present work utilizes remotely sensed imagery and change detection techniques to demonstrate evidence of urban expansion between 2000 and 2020 within 30 miles of Everglades National Park and Big Cypress National Preserve.

Study Area

Everglades National Park and Big Cypress National Preserve are located at the southern tip of the Florida peninsula in the United States, between longitudes 80° and 81° W and latitudes 25° and 26°50’ N.

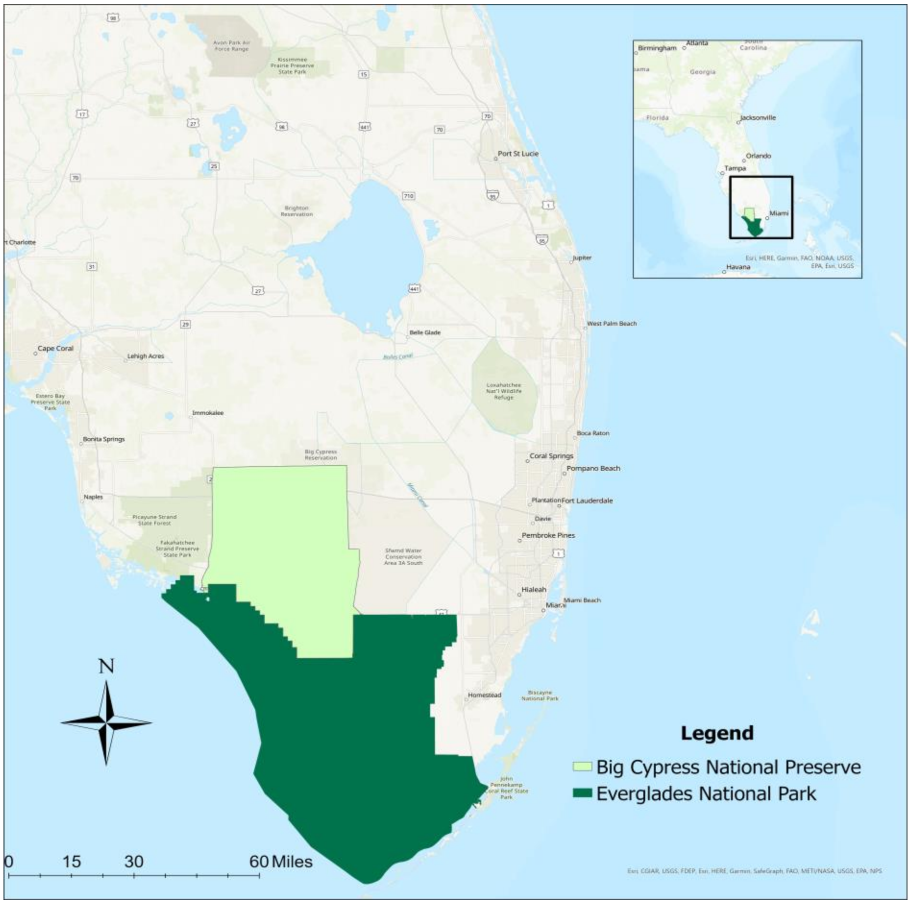

Figure 1. Location of Everglades National Park and Big Cypress National Preserve.

The present study analyzed the region within a 30-mile radius of the park and preserve.

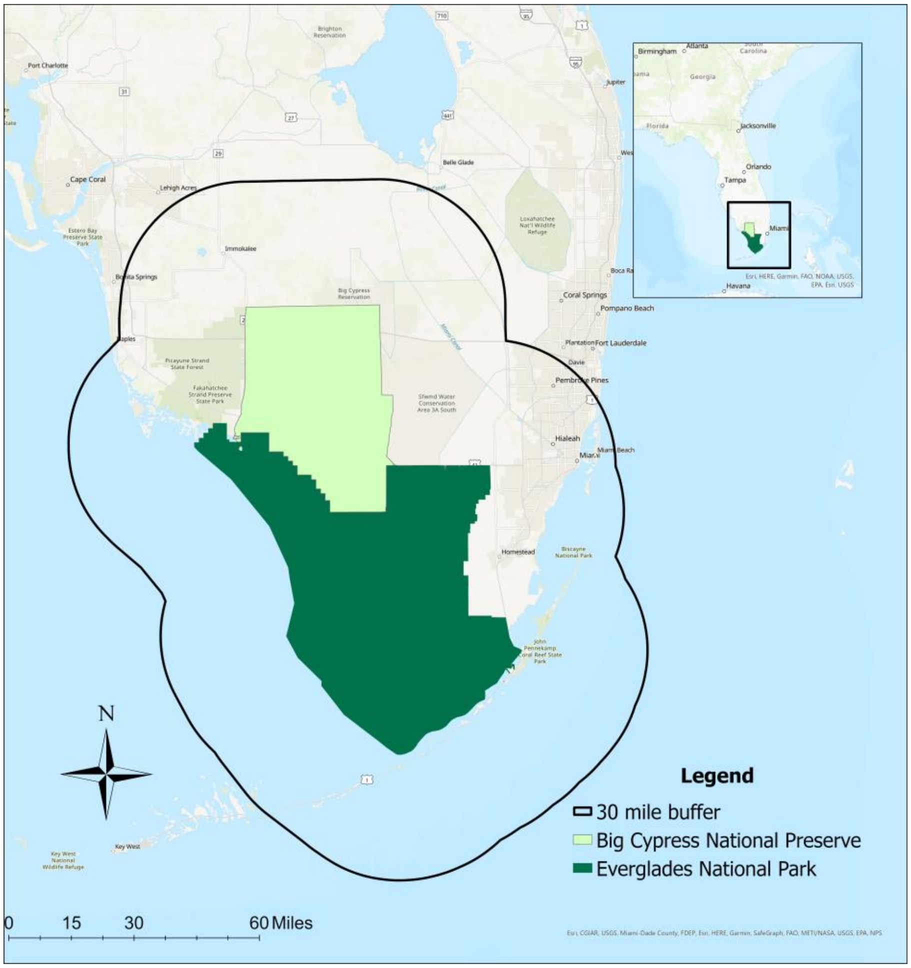

Figure 2. Depiction of the study area as a 30-mile buffer around the park and preserve.

Methods

Data

The remotely sensed images used in this analysis were collected by several Landsat satellites: Landsat 5 (Thematic Mapper), Landsat 7 (Enhanced Thematic Mapper Plus), and Landsat 8 (Operational Land Imager). All images collected by these satellites between January 1, 2000 and December 31, 2020 were obtained from the Google Earth Engine Data Catalog (Gorelick et al. 2017). The shapefile containing the boundary lines for Everglades National Park and Big Cypress National Preserve was obtained from the National Park Service's open data hub (National Park Service 2022b).

Software

This analysis was primarily conducted using Google Earth Engine's JavaScript code editor (Gorelick et al. 2017). All code used in the analysis can be accessed using the following link: https://code.earthengine.google.com/4fc016c42500c5f8fec55ab78ca4daea. Additional processing of the boundary area shapefiles and obtaining ground-truth values for all accuracy assessments was completed using ArcGIS Pro 3.0.0.

Image pre-processing

After the Landsat images were retrieved for the date ranges of interest, a cloud mask was applied to remove pixels identified as containing clouds and cloud shadows by the QA_PIXEL band of the image. A scaling factor was then applied to extract the actual surface reflectance values from the image. After this processing, a cloud-free composite for the summer months (June-August) in each year of interest (2000 and 2020) was created for the study area using a median reducer.

Classification

The pre-processed composite images were then classified using supervised classification methods to identify the land cover classes present in the study area. Training data was obtained from the National Land Cover Database's 2019 release. The original NLCD dataset was cropped to the study area and reclassified to simplify the land cover types. The final land cover types included: developed, open water, forest, shrubland/herbaceous cover/agriculture, wetlands, and barren land. A stratified random sample of the reclassified data was used as the input to a random forest classifier with 150 trees. The trained model was then used to classify the land cover types present in the 2000 and 2020 summer composite images. The resulting classified maps were transformed into binary maps of urban vs non-urban areas in order to identify areas of urban-specific change after performing the change detection analysis.

Change detection

Image differencing was used to detect changes between the two composite images. In the image differencing technique, one band of one image is subtracted from the same band of the second image. The result is an image with positive and negative pixel values in areas of change and zero values in areas of no change. The current analysis uses the second shortwave infrared band (SWIR 2), which is band 7 on all Landsat sensors used in the analysis, for the subtraction. The SWIR 2 band is good at discriminating water from its surroundings, which is helpful when analyzing an area such as the Greater Everglades region which is particularly wet. There is also precedent for using the SWIR 2 band in change detection studies of urban expansion, including in work done by Al-Dail (1998). A threshold for pixel values indicating positive change was determined through visual inspection of the image.

The resulting thresholded difference image contained indications of all types of changes, regardless of whether they occurred in urban areas or elsewhere in the study area. Because the present study is concerned with finding areas of urban *expansion*, i.e., places that were not urban in 2000 but became urban by 2020, the 2020 binary map of urban vs non-urban areas was applied as a mask to the difference image to limit the scope of changed areas to places that were known to be urban at the conclusion of the study period. All changed pixels within that area are assumed to indicate change from a non-urban class to the urban class.

Results

Classification

The land cover maps obtained from the random forest classification for the years 2000 and 2020 are shown in Figures 3 and 4, respectively. Notably, the classified map for 2000 misclassified the sections of the center portion of the study area as developed. These areas are not classified as developed in the 2020 image, giving the appearance that a substantial portion of the area has been converted from developed areas back to wetland. A large portion of these misclassified areas are within the boundaries of the national park or preserve which are protected from development, and these areas were in fact not developed in 2000. Because the current analysis is primarily concerned with areas of urban expansion, not conversion away from the developed category, this misclassification does not significantly impact the conclusions of this study.

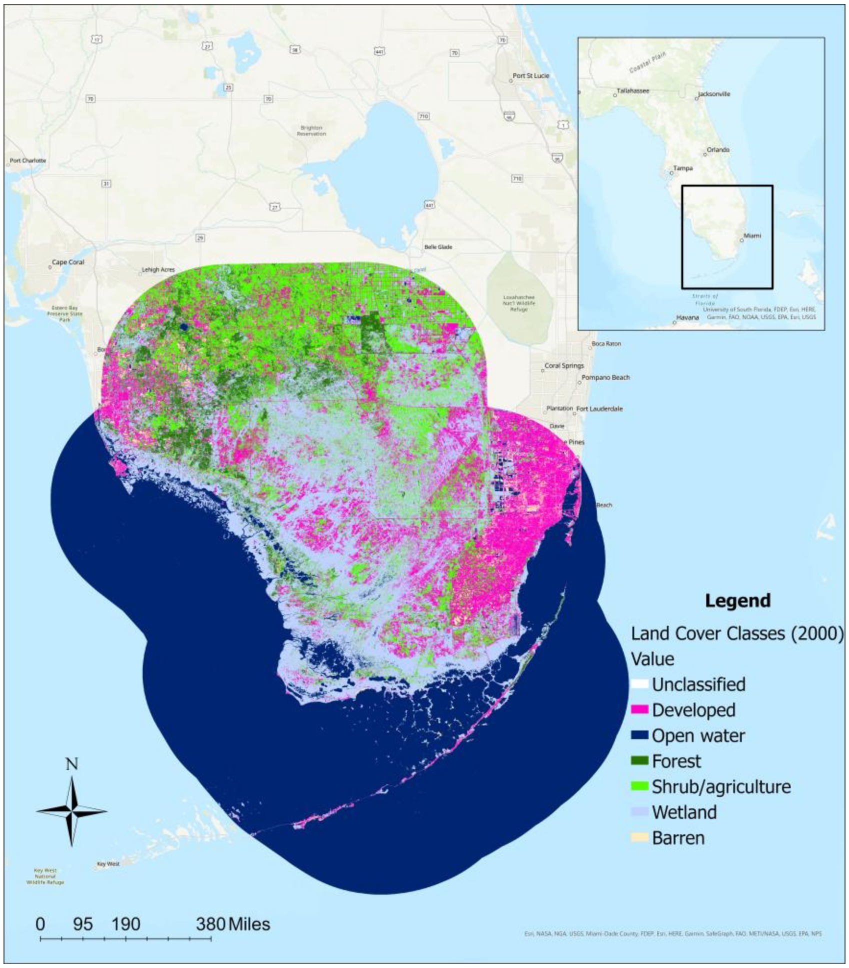

Figure 3. Land cover classification of the study area for the 2000 composite image.

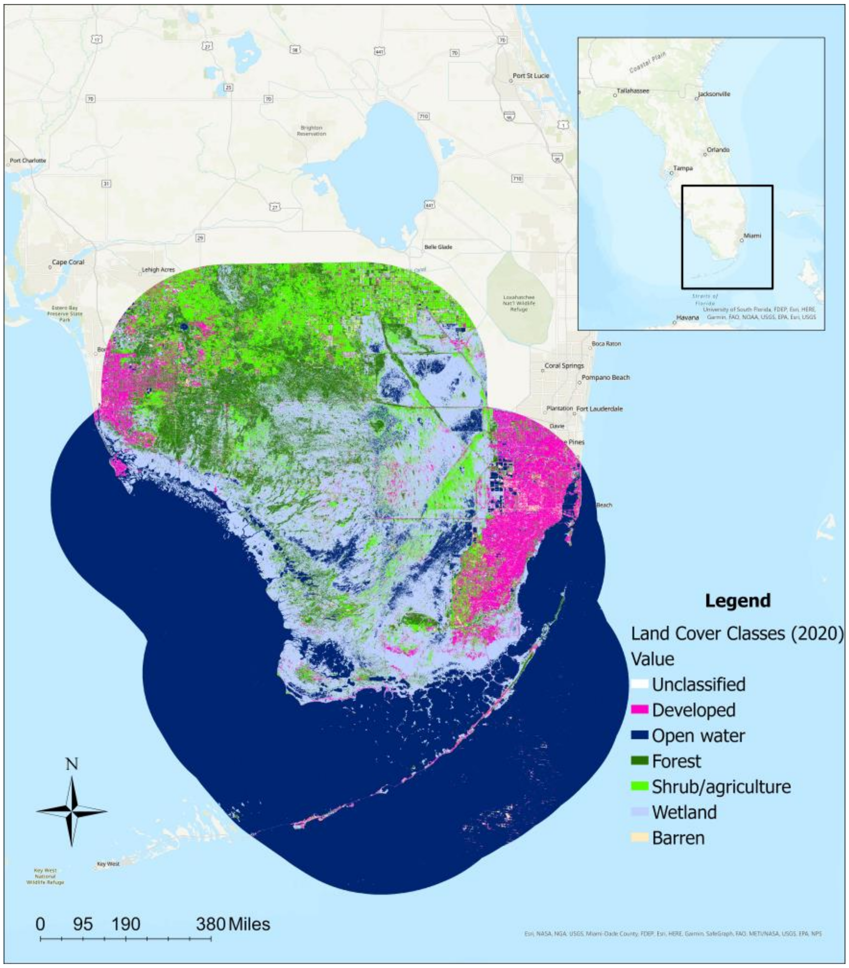

Figure 4. Land cover classification of the study area for the 2020 composite image.

The classified map for the 2000 image composite had an overall accuracy of 72.67%. The most confusion occurred between the barren and developed classes, with some developed pixels being inaccurately classified as barren land.

		Ground Truth					
		Developed	Water	Forest	Shrub/ag	Wetlands	Barren
Classified Results	Developed	28	0	0	4	14	4
	Water	0	50	0	0	0	0
	Forest	0	0	39	9	0	2
	Shrub/ag	1	0	2	39	7	1
	Wetlands	0	2	3	5	40	0
	Barren	25	1	0	2	0	22

Table 1. Error matrix for the 2000 image composite classification.

The classified map for the 2020 image composite had an overall accuracy of 77.337%. Again, the most confusion occurred between the developed and barren classes. Because this classified map was transformed to the binary map (urban vs non-urban) shown in Figure 5, any confusion that did not involve the developed class did not affect the final result of this analysis. However, the confusion between the barren and developed classes does affect the rest of the analysis, as mentioned in the Discussion section.

		Ground Truth					
		Developed	Water	Forest	Shrub/ag	Wetlands	Barren
Classified Results	Developed	36	0	1	0	1	12
	Water	0	50	0	0	0	0
	Forest	0	0	45	5	0	0
	Shrub/ag	0	0	4	43	3	0
	Wetlands	0	0	2	5	43	0
	Barren	18	3	0	7	7	15

Table 2. Error matrix for the 2020 image composite classification.

Change detection

The difference image that resulted from the image subtraction change detection technique is shown in Figure 5. Bright white areas represent areas with new urban development between 2000 and 2020, while gray areas represent areas of no change during that time period.

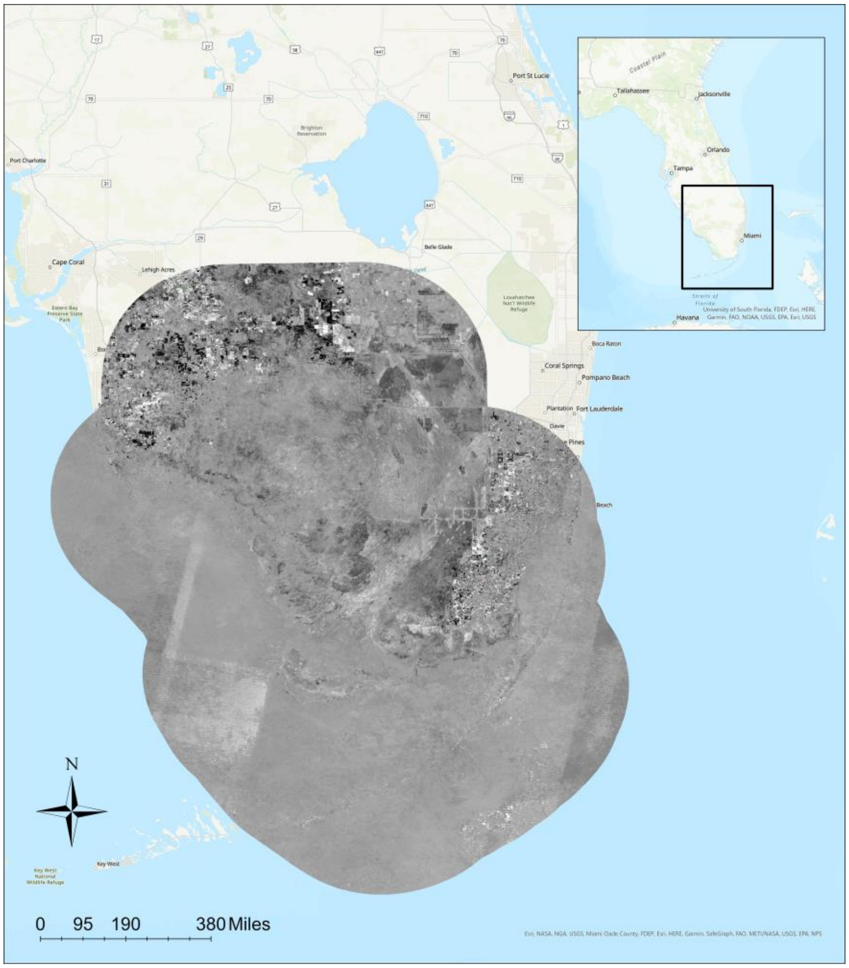

Figure 5. Image representation of pixel value differences between 2000 and 2020.

Figure 6 shows the final three-class map identifying areas of urban expansion between 2000 and 2020, stable urban areas, and stable non-urban areas. By summing the areas of all pixels classified as the expanded developed class, we determined that 164,040 acres of land had been converted to developed land between the years 2000 and 2020.

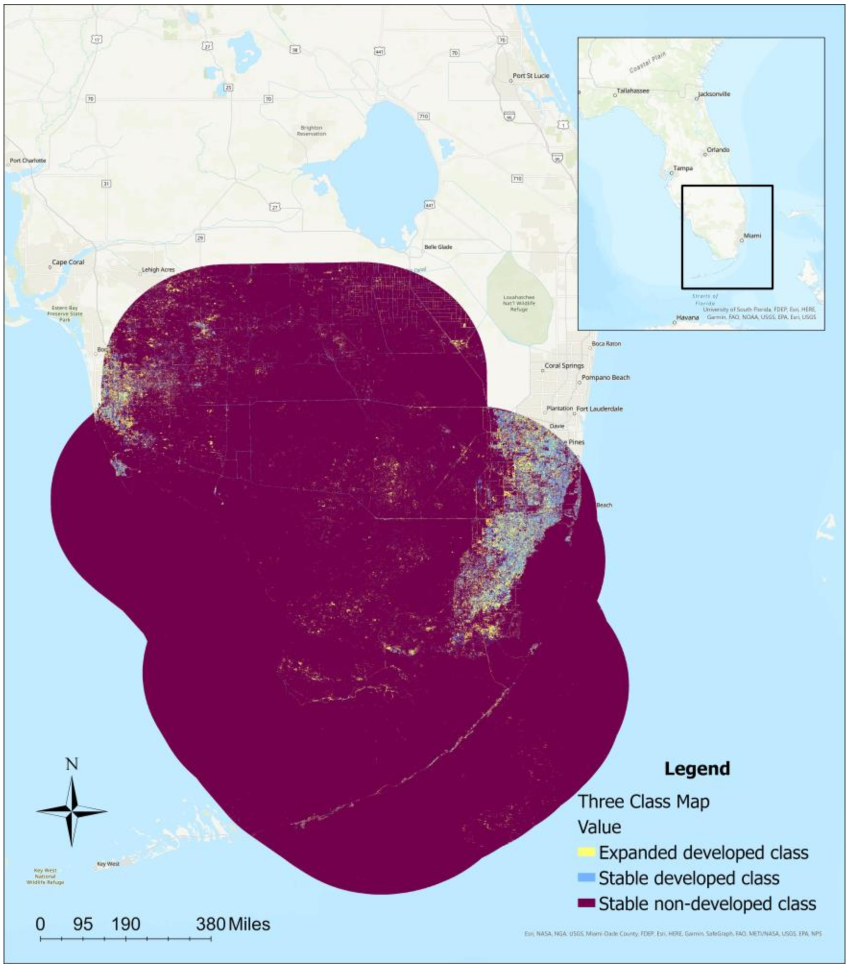

Figure 6. Map showing areas of urban expansion in yellow, stable urban areas in blue, and stable non-urban areas in dark pink.

Figure 7 shows the same map, zoomed to show the Miami area, which had a large amount of land converted to urban areas during the study time period.

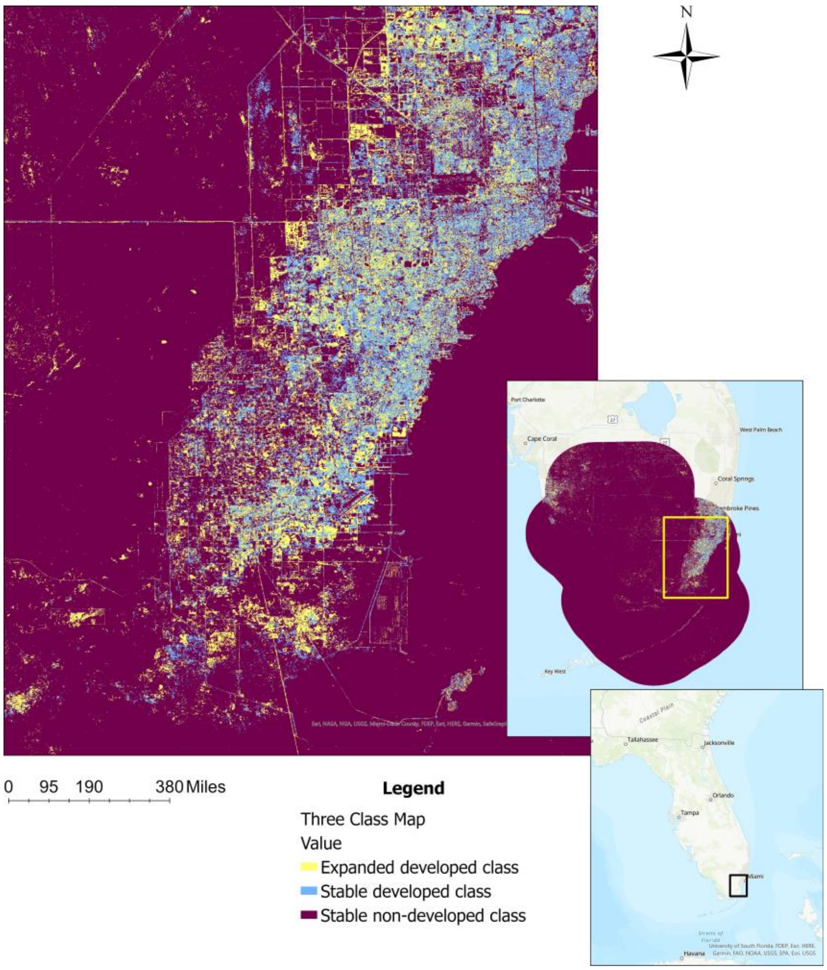

Figure 7. Map showing areas of urban expansion around the Miami area in yellow, stable urban areas in blue, and stable non-urban areas in dark pink.

The three-class map had an overall accuracy of 80.0%. The confusion between developed areas and barren ground noted above contributed to the errors between the developed expansion class and the stable non-developed class here.

Ground Truth				
Classified Results		Developed Expansion	Stable Developed	Stable Non-Developed
	Developed Expansion	32	3	15
	Stable Developed	1	39	10

	Stable Non-Developed	0	1	49

Table 3. Error matrix for the difference image.

Discussion

This study identified that 164,040 acres of land had been developed and urbanized in the years between 2000 and 2020. Much of this development occurred around the urban centers of Miami and Naples, two rapidly growing regions that are located on either side of the Everglades region.

Continued development and human impact in this region poses a serious threat to the health of the Everglades ecosystem, and careful urban planning is necessary to limit human impacts on this environment. Miami-Dade county has had an urban development boundary in place for decades that restricts westward urban expansion. That boundary, which was implemented to protect the Everglades region, has faced numerous challenges over the past several years. Just recently, in November 2022, the county commissioners voted to move the line and allow development to spread farther west, towards the Everglades (Morejon 2022). Given that much of the urbanization identified by the current study occurred in the Miami region, this decision by the Miami-Dade county commissioners could cause serious harm to the Everglades region.

There are several limitations to this analysis. First, all Landsat data is acquired at a spatial resolution of 30 m. This means that each pixel in the image is 30 m x 30 m, and it is not possible to detect changes that occurred at a finer spatial resolution. Future analyses could expand on this work by utilizing the high spatial resolution sensors being developed by companies like Planet and others. Second, the accuracy of the initial land cover classifications was only moderately accurate at between 72 and 77%. Further exploration of viable machine learning algorithms for supervised classification would be advised for future work in this area – it is possible that the use of another algorithm such as a support vector machine would yield higher accuracy results. The relatively high degree of confusion between developed land and barren ground in the land cover classifications complicates the result of this analysis.

Conclusion

Urbanization is one of the main threats facing the Greater Everglades region. This study utilizes remote sensing imagery and change detection techniques such as land cover classification and image differencing to provide one view of the extent of urbanization in this region over 2 decades. The work of the Comprehensive Everglades Restoration Plan (CERP) alone will not be enough to restore the health and security of this fragile ecosystem. Strong regulations, careful management, and thoughtful urban planning are necessary to reduce pollution of all types in this area and limit the impact of humans on the Everglades environment.

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