MAPPING FOREST HEIGHT IN LOWER MISSISSIPPI ALLUVIAL VALLEY

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ABSTRACT

Remote sensing techniques have been widely used in forest resource assessment and biodiversity studies. Remotely sensed data are being used to efficiently monitor forest restoration around the world. Forest restoration has been applied over the Lower Mississippi Alluvial Valley (LMAV), USA over the past decades, but their impacts haven't been fully evaluated at regional scales. This research is intended to provide a versatile tool to map forests on a multi-spatial and temporal scale to facilitate the evaluation process. This study maps forest height over LMAV using remotely sensed observations from satellite imagery and spaceborne LiDAR data. The generated tree height observations were compared among various vegetation types and areas experiencing different disturbances over different time and location. The ultimate goal is to generate a wall-to-wall vegetation height and biomass maps at fine spatial resolution. These maps will provide useful information to evaluate the impacts of forest disturbance of ecosystem values in terms of wildlife habitat and climate change mitigation, and prioritize effort for forest restoration.

INTRODUCTION

Monitoring forest structure is important for preserving biodiversity and ecosystem values. To accurately map the forest resources, precise methods are needed. Remote sensing is one of the most important techniques commonly used in forest resource assessment and biodiversity studies. Remotely sensed data are used to efficiently monitor forest restoration around the world. Forest restoration has also been implemented in the Lower Mississippi Alluvial Valley (LMAV), USA over the past decades for the benefits of carbon stock, purifying soil and air pollution from agriculture activities, and to diversify wildfire habitats and improve overall ecosystem values. Around 65% of Mississippi State is covered by forests (Morgan et al., 2012). These forests face major disturbances like floods, hurricane damage, wildland fire, and timber harvest. Although forest restoration has been applied over the LMAV over the past decades, the impacts of restoration projects haven't been fully evaluated at regional scales. These assessments are needed to understand how management practices and natural disturbances like fires, tornadoes, and hurricanes are affecting forest characteristics, and to provide a basis for making management and policy decisions (M. Li et al., 2009).

Satellite remote sensing offers a cost-effective solution for large-scale applications for monitoring large areas such as LMAV. Spatially contiguous Advanced Topographic Laser Altimeter System

(ATLAS) instrument onboard the Ice, Cloud and land Elevation Satellite-2 (ICESat-2), and optical remote sensing data sets are more readily available for large scale mappings like that of LMAV. Remote sensing techniques like these facilitate the evaluation of forest restoration. Many restorations projects have been evaluated using the traditional optical data which shows the structural parameters of the forests, but suffer from the saturation effects because they cannot penetrate the vegetation canopy. However, LiDAR (Light Detection and Ranging) data have the capability to penetrate through the vegetation canopy and map the lower vegetation including the ground data.

Several studies have integrated the optical data with other datasets like Synthetic Aperture Radar (SAR) for forest disturbance mapping (Fagua et al., 2019; Hirschmugl et al., 2020). Combining different data sets significantly increases the accuracy, as well as allows for a more rapid detection needed for near real-time alerting (Reiche et al., 2018). Integrating two different datasets can detect small scale forest disturbances more accurately (Hirschmugl et al., 2020). Earlier studies mostly focused on using airborne LiDAR as a reference sample for identifying the forest parameters by integrating multispectral and SAR data. Studies have also used a combination of airborne LiDAR along with optical and SAR data to map canopy heights (Fagua et al., 2019). However, a newly available dataset ICESat-2's use is yet to be addressed in evaluating the forest restoration process. This provides an opportunity for us to integrate the ICESat-2 data with optical imagery to assess the LMAV restoration process.

In order to reconstruct forest disturbance history and age structure, Huang et al., (2010) developed a Vegetation Change Tracker (VCT) algorithm (Huang et al., 2010; Huang, Goward, Masek, et al., 2009; Huang, Goward, Schleeweis, et al., 2009). The VCT is a highly automated forest change mapping algorithm designed for recreating forest disturbance history using Landsat Time Series Stacks (LTSS) (A. Li et al., 2011). Huang et al., (2010) used LTSS-VCT for reconstructing forest disturbance history to examine disturbance patterns with a biennial temporal interval using three disturbance magnitudes i.e. Integrated Forest Z-score (IFZ), Normalized Difference Vegetation Index (NDVI), and Normalized Burn Ratio Index (NBRI). This VCT-LTSS algorithm targets to derive forest distribution map products for discrete events with a limited range of disturbance magnitudes (Cohen et al., 2017).

Data from ICESat-2 along with other data sources like Landsat haven't been applied to assess restoration in LMAV. Therefore, this study will make use of these data sources and evaluate their effectiveness. This study will focus on the use of the VCT data to quantify the disturbance and evaluate the restoration process on the LMAV using the newly available dataset ICESat-2 along with optical data like Landsat. It will provide a versatile tool to map forests on a multi-spatial and temporal scale to facilitate the evaluation process using the observations from new data sources. This study aims to:

1. Map tree height on the LMAV restoration region using spaceborne LiDAR data
2. Use the VCT approach to quantify the disturbance and evaluate the restoration process

MATERIALS AND METHODS

1. Study Area

The study will be conducted in the Lower Mississippi Alluvial Valley (LMAV), southern part of the USA (Figure 1). This alluvial plain is created by the Mississippi River which lies on parts of seven U.S. states, from southern Louisiana to southern Illinois (Illinois, Missouri, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana). The LMAV, as defined in our study, encompasses about 119540 km^2 with an elevation of 100 to 300 feet above sea level. The temperature ranges from 14° to 21°C and precipitation averages from 1150 to 1650 mm annually with a humid subtropical climate. 70% of the LMAV forest area is covered by bottomland hardwood forests (elm-ash-cottonwood and oak-gum-cypress forest-type groups). Other forest type groups found in the LMAV include sugarberry hackberry-elm-green ash and sweetgum-Nuttall oak-willow oak, bald cypress-tupelo forests, oak-hickory, loblolly-shortleaf, and various mixed forest-type groups (Oswalt, 2013).

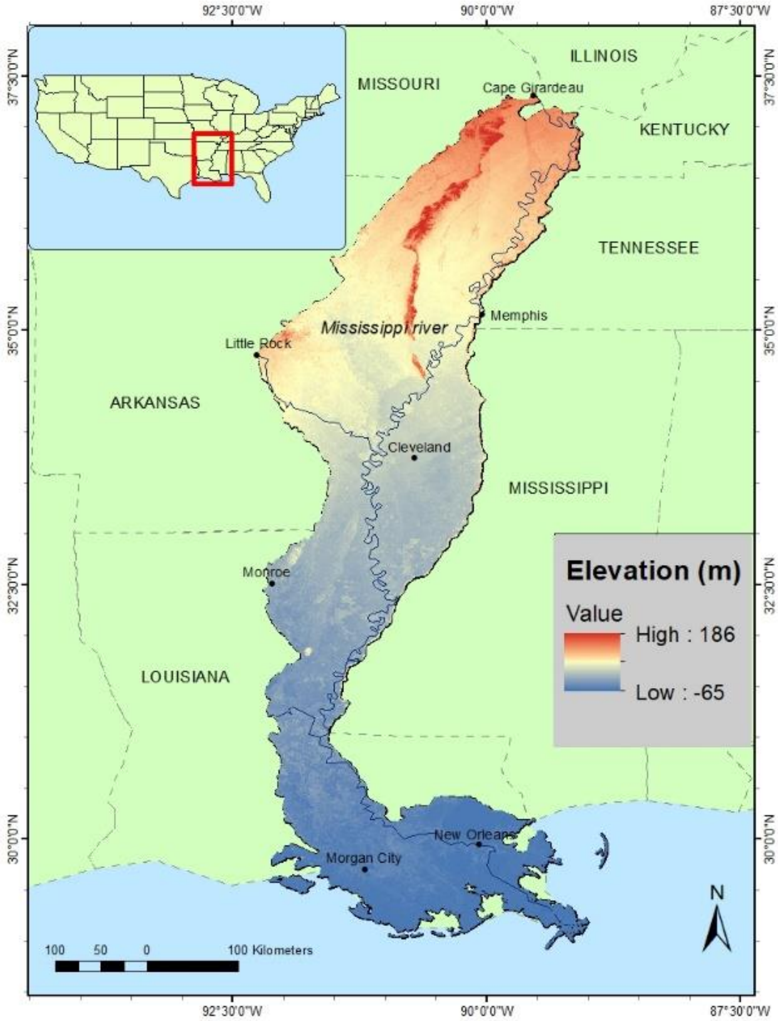


Figure 1. Study Area

2. Approach Overview

We used the LTSS–VCT (Landsat Time Series Stack-Vegetation Change Tracker) algorithm data product to assess the disturbance and recovery trajectory of the forests in the LMAV region. We used the National Land Cover Database (NLCD) data to visualize the land cover over LMAV and ICESat-2 data to retrieve the forest height. We used the VCT algorithm data product by Huang et al., (2010) to identify the forest disturbances in LMAV.

For the VCT algorithm, the Landsat time series forest disturbance history images were downloaded from the ORNL DAAC website from 1986-2010 (https://daac.ornl.gov) (Goward S.N. et al., 2015). Similarly, the NLCD 1992, 2006, 2013, and 2016, land cover data was downloaded using the Google Earth Engine (GEE), a cloud computing platform. The ICESat-2, ATL08, Land and Vegetation Height data from 2018-2020 was downloaded from https://nsidc.org/data/icesat-2 website. These data were analyzed using GEE, and ArcGIS software. The procedure proceeds as shown in Figure 2.

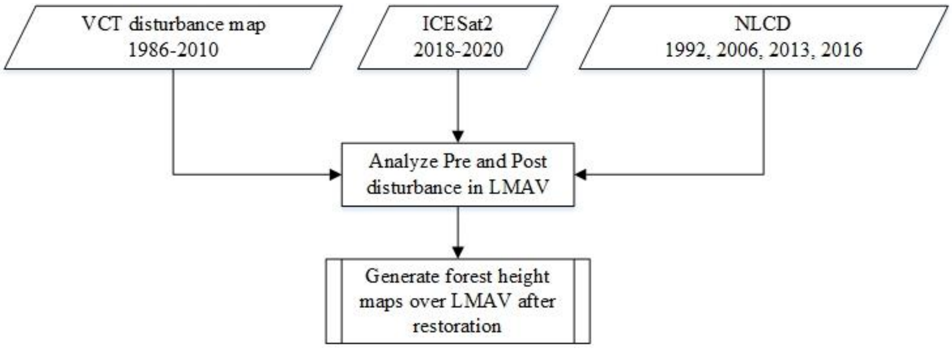


Figure 2. Overall Data Flow and Processes

3. Data

The instrument onboard ICESat-2 is the Advanced Topographic Laser Altimeter System (ATLAS which uses a 532 nm (green) laser to actively map surface elevations. The laser is split into six beams arranged in three pairs of strong and weak energy beam (ratio 4:1) (Neumann et al., 2019). The ATL08 data used in this study were screened for power beams. We used the 'h_canopy' attribute of the ATL08 product which refers to the 95% height of all the individual relative canopy heights for the segment (Neuenschwander et al., 2018). In our study, we subset the ICESat-2 data and analyzed using python programming. We used only the strong beam's data products for our study. Ten tracks of ICESat-2 footprints have been used to cover the entire study area. We used data from the openaltimetry website (https://openaltimetry.org/) for generating the canopy height maps. The canopy height data was also plotted over the map using the ArcGIS software.
The VCT algorithm was applied to the LTSS to produce time-series VCT annual disturbance maps. The data products obtained from the VCT annual disturbance maps (1986-2010) showed attributes like water, absence of forest cover, and forest cover in the present year, and disturbances that occurred in that year as discussed by Huang et al., (2010). We assembled the VCT data of each year from 1986 to 2010 over the LMAV.
NLCD data from 1992, 2006, 2013, and 2016 was downloaded and each land cover type were analyzed using ArcGIS. The NLCD maps were subset for the LMAV region and each map was analyzed separately to determine the area of each land cover for every year. Land cover change charts were generated from different NLCD year maps. Also, the ICESat-2 footprints were overlaid on the NLCD maps to determine the relationship between the canopy height and the land cover.

RESULTS

1. Tree Height Estimations at GLAS Footprints

10 tracks of ICESat-2 footprints were used for determining the canopy heights over LMAV from 2018 to 2020. We selected the tracks in such a way that unless there were data gaps, we chose the tracks at an equal interval. The data obtained were filtered only for strong beams in flat areas with a slope smaller than 5 degrees as suggested by other studies (Wang et al., 2014). As a result, we derived the forest canopy heights from 20,953 qualified ICESat-2 footprints out of 97,180 total

ones as shown in Figure 3 and Table 1. The mean vegetation height over LMAV was 20.1m with a standard deviation of 6.6m. Incorporating the ICESat-2 data and the NLCD 2016 land cover map, we found that most of the trees were found in the woody wetlands (63%), whereas the mixed forest, evergreen forest, and deciduous forest only contributed less than 5% in total. The mean tree height ranged from 21.2m in the deciduous forest to 22.2m in woody wetlands without significant difference, but all taller than herbaceous types, which averaged at 15.5m (Figure 4).

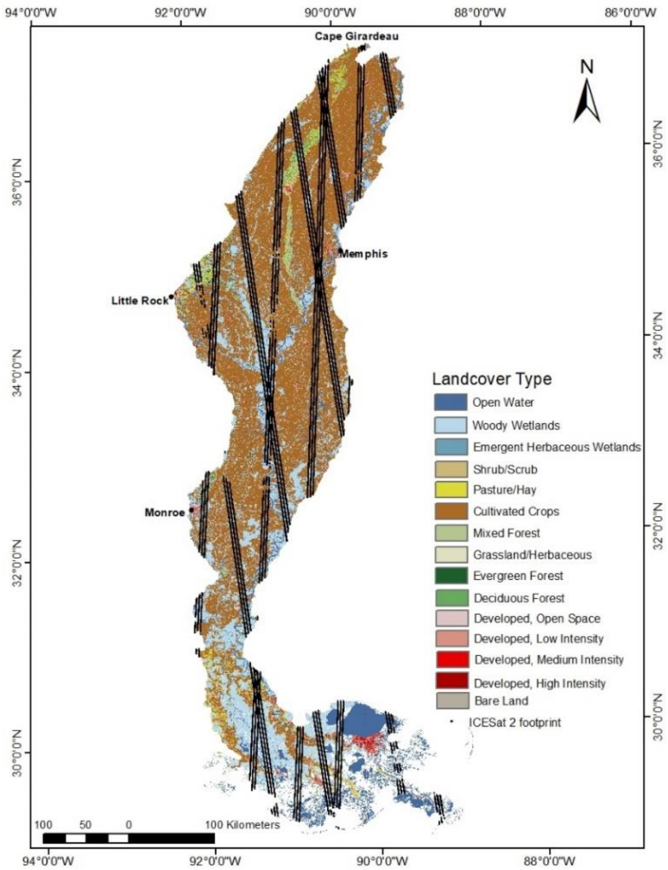
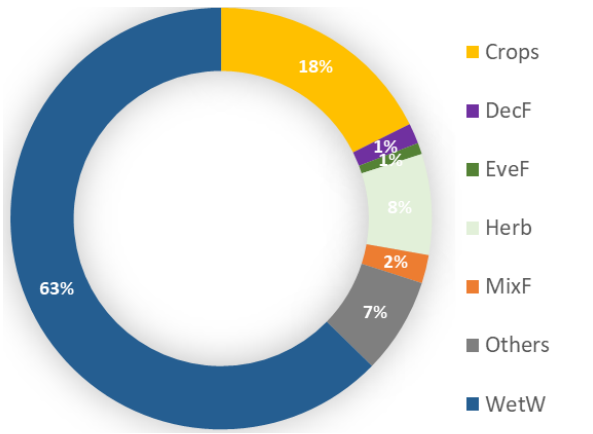
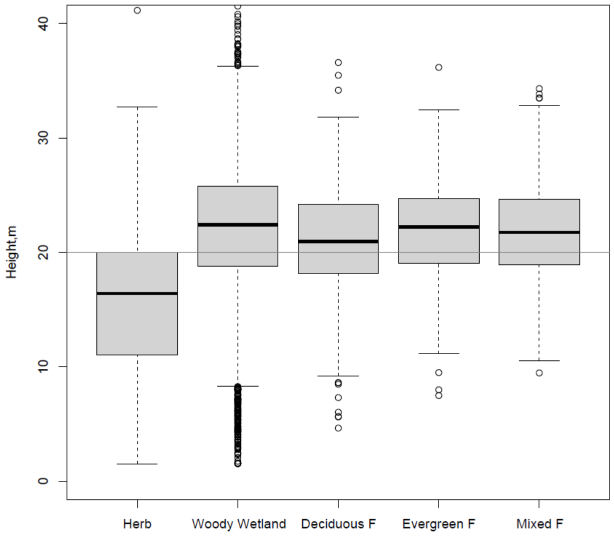


Figure 3. Distributions of ICESat-2 Footprints Collected over 2018-2020 Overlaid on the NLCD 2016 Land Cover Types over the LMAV Region.

Table 1. The Number of ICESat-2 Footprints Represented by the NLCD Types, and their Percentage over the Total Number of Qualified Footprints in LMAV.

NLCD	Number	Type
Crops	3390	Crops
Deciduous forest	302	DecF
Evergreen forest	167	EveF
Herbaceous	1488	Herb
Mixed forest	419	MixF
Others	1417	Others
Woody Wetlands	12067	WetW





Pairs	Mean Dif.	Lwr 99%	Upr 99%	Sig.
DecF-Herb	5.7	4.6	6.9	***
MixF-Herb	6.5	5.5	7.5	***
EveF-Herb	6.6	5.1	8.0	***
WetW-Herb	6.7	6.2	7.2	***
MixF-DecF	0.8	-0.6	2.2	Ns
EveF-DecF	0.8	-0.9	2.6	Ns
WetW-DecF	1.0	-0.1	2.1	*
EveF-MixF	0.0	-1.6	1.7	Ns
WetW-MixF	0.2	-0.7	1.1	Ns
WetW-EveF	0.2	-1.3	1.6	Ns

Figure 4. Boxplot of Vegetation Height Obtained from ICESat-2 Footprints among Five Main Vegetation Types Obtained from the NLCD 2016 Map. The Difference in Vegetation Heights among the Five Types is Evaluated using Tukeyhsd Test.

2. VCT Disturbance History

The annual VCT disturbance maps from 1986 to 2010 were analyzed to demonstrate the trends in forest disturbance (Figure 5). The VCT disturbance map shows a peak disturbance during 1999 followed by 2010, and the lowest disturbance during 1994 over the period of study.

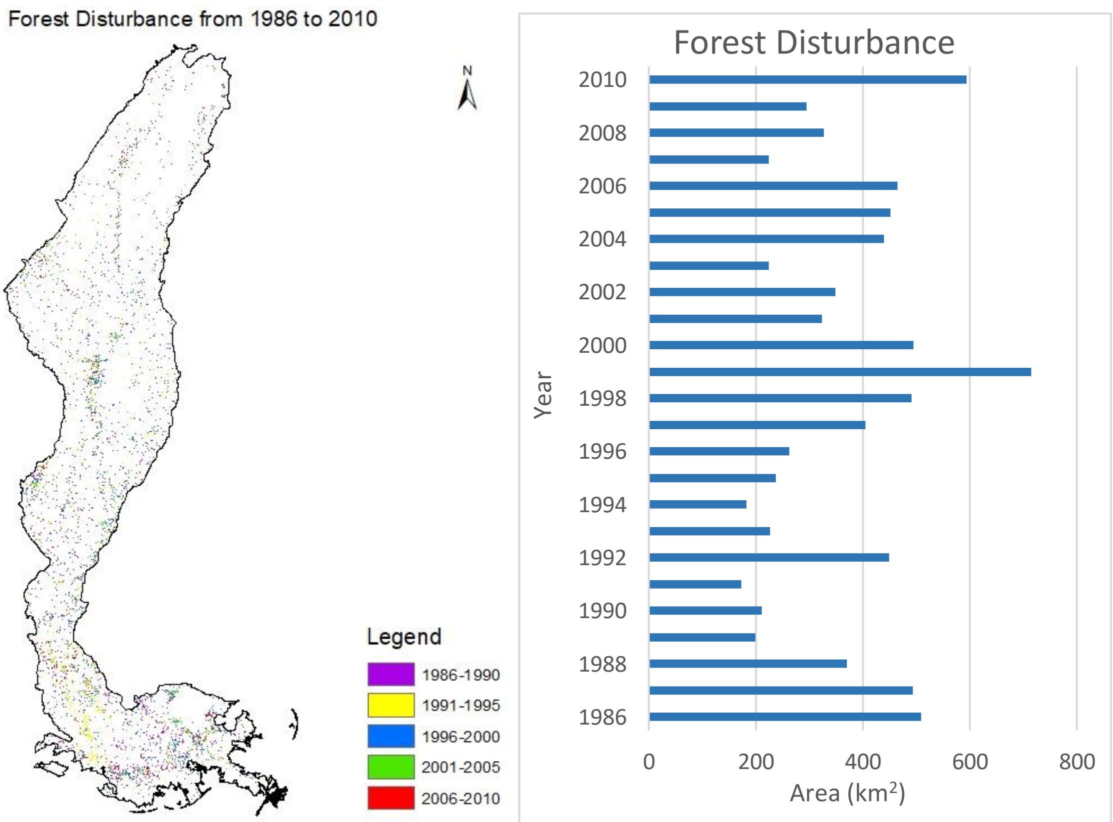


Figure 5. Distributions of Forest Disturbance in Each Five-Year Period from 1986-2010 were

Obtained from Annual VTC Products over the LMAV Region. On the Right Sub-Figure, the Total Area Being Disturbed over Each Year is Summarized.

ICESat-2 (2018-2020) footprints over VCT 2010 disturbance map estimated the mean canopy height of 18.59m on the previously disturbed forest area, 3.02m lower than the mean height in forest covered area without disturbance in 2010. Moreover, mean canopy height of 14.09m can also be seen in an area previously considered to be without forest cover (Figure 6).

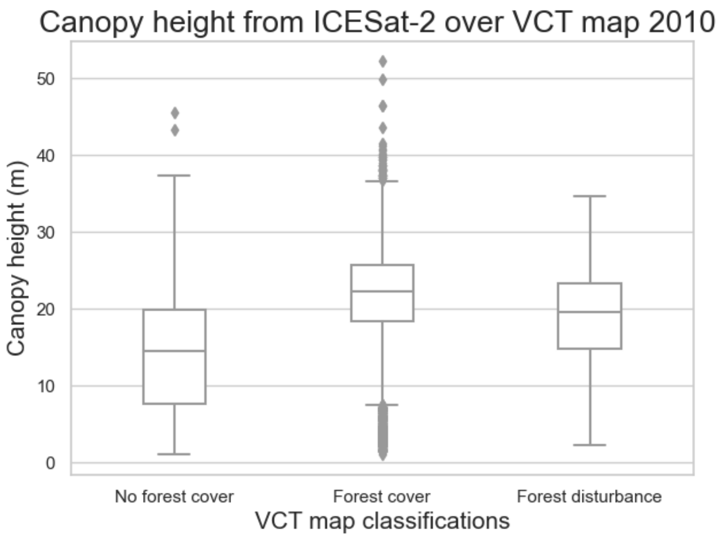
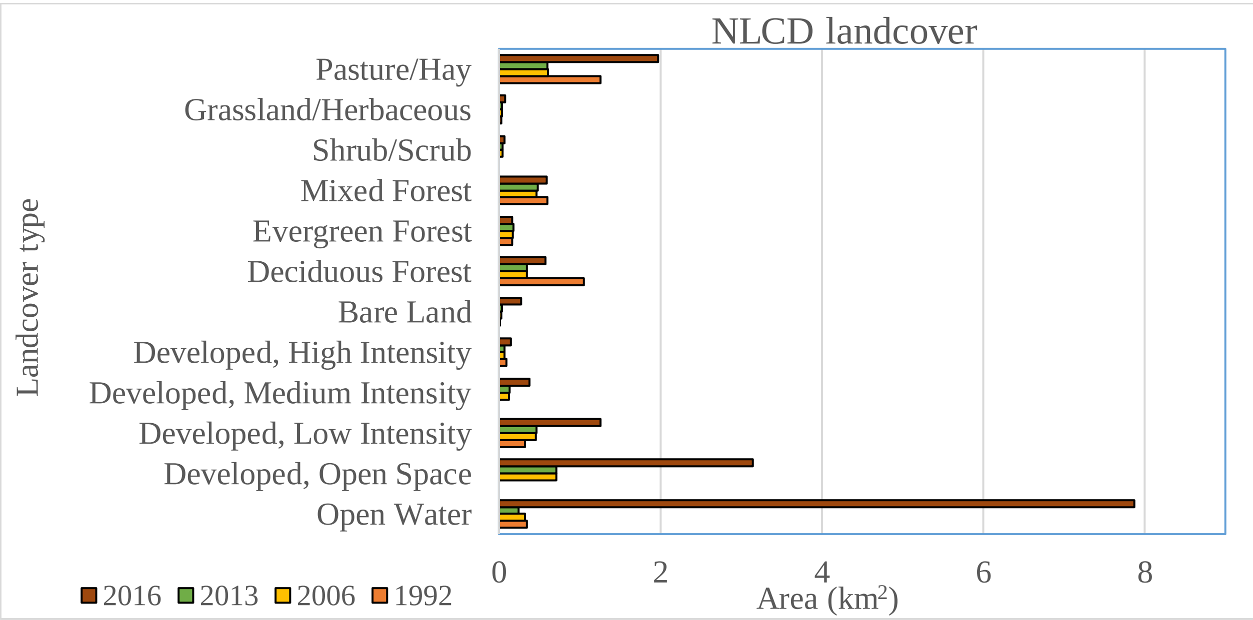


Figure 6. Boxplot of Canopy Height Derived from the ICESat-2 Data over the VCT Map in 2010 in Non-Forest, Forest, and Disturbed Classes.

3. Land Cover Change Trend

NLCD data from 1992 to 2016 indicate a substantial rise in both open water and wetland vegetation. There is a slight increase in forest area compared to earlier land cover data. Similarly, developed areas are also growing along with pastures.



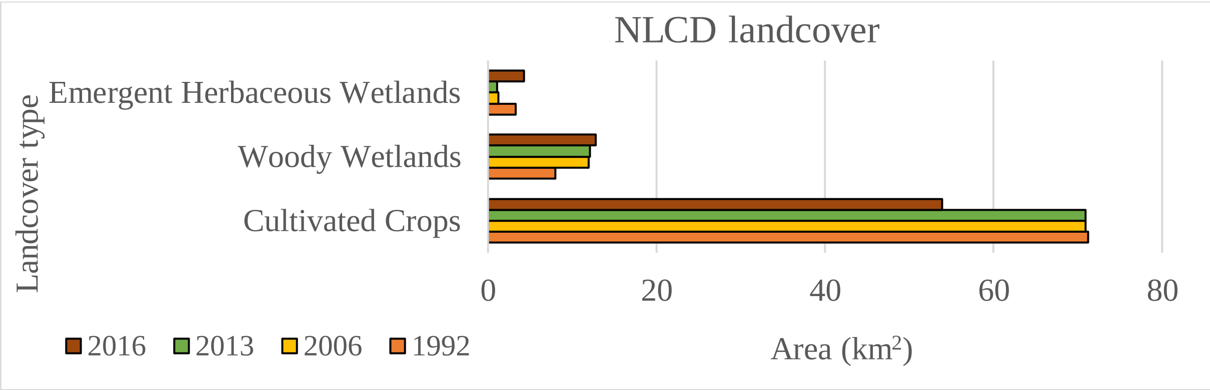


Figure 7. Bar Chart of Different NLCD Land Cover Types and its Area from 1992 to 2016

DISCUSSION

The goal of this paper is to present the vegetation height (ATL08) data products from the ICESat-2 mission to evaluate disturbance and restoration in the LMAV region. We analyzed the vegetation height over the study area and found its mean value to be 20.1m. We found slightly taller trees in the wetland, the dominant land cover type in this region. This may be due to the wetland restoration conservation practices like reforestation and plantation activities over the LMAV region between 2000 and 2006 (Faulkner et al., 2011).

The VCT disturbance maps revealed the extent of forest disturbance from 1986-2010 over LMAV. The findings indicate that forest disturbance reached a peak disturbance rate in 1999 followed by a decline until 2003 and an abrupt increase in 2010. Overall, over the study period, it shows a good recovery of the disturbed forest over the LMAV region.

NLCD maps from 1992 to 2016 reveal that water bodies have increased over the past decades in the LMAV region which complies with research by Karstensen & Sayler, (2009) who demonstrated the leading land-cover conversion over 1973-2000 to be wetlands to water. Similarly, developed areas are seen rising sharply. With land conversion coming from agriculture and forests, built-up areas over the LMAV have increased over time (Karstensen & Sayler, 2009). Studies indicate that the LMAV was predominantly forested but conversion to agriculture and human settlement caused almost 75 % loss of riparian forests by the late twentieth century (Davis, 2016). Furthermore, the construction and operation of flood control structures and reservoirs, surface mining, and urban development have increased the intensity of developed areas (Oswalt, 2013).

The areas of wetland vegetation have shown an increase during the period of study. The establishment of the Wetlands Reserve Program (WRP) has played an important role in protecting and restoring the wetlands on marginal farmland and preventing loss of wetlands (Morgan et al., 2012). Overall, the forest area appears to be increasing over the LMAV since 1992. Research by Oswalt (2013) demonstrated that the total forest area over LMAV has gradually risen in the last three decades. However, the area of cultivation has declined over the study period. The cropland area is lowest in the LMAV than it was known to be before. Our findings are consistent with the study by Yasarer et al., (2020) who demonstrated a decrease in the total area of cropland and harvested cropland from 1969 to 2017.

CONCLUSION

The Lower Mississippi Alluvial Valley is of great importance in terms of biodiversity and ecosystem values. Significant results have been shown in evaluating forest regeneration over LMAV using remote sensing techniques. Determining canopy height over the LMAV region using ICESat-2 data, and analyzing VCT disturbance maps and NLCD land cover maps show a major progression in the restoration process. The findings indicate comparatively high forest canopy over wetlands. The VCT disturbance maps show gradual recovery of the area over period of study. The results show an increase in the forest area and wetlands along with developed areas, whereas a decline in the cultivation area. This study helped to evaluate the restoration process in terms of carbon benefit and overall ecosystem values.

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