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NRS533

Finale Project

Introduction:

Remote sensing is a powerful tool for understanding how landscape processes create patterns, and in turn how patterns affect processes. Natural disturbances such as fires and storms have a significant impact on landscape patterns. To better understand landscape patterns it is important to understand the impact of these disturbances, this can be done by analyzing landscape indices, or through change detection and analysis. Change detection and analysis is at its most basic the process of identifying differences in the landscape on two or more temporal periods (Hussain et al., 2013). In this study we seek to understand the change to the forested landscape of New England by Hurricane Sandy through change detection and analysis.

Change to the landscape over extended periods of time can be analyzed and identified but the change's cause will be inconclusive. Disturbance events can be analyzed in close proximity to the storm, and the majority of the change can be attributed to the storm event. In some cases, remote sensing has been utilized to identify historical impacts to the forest landscape such as Weishampel et al., which studied impacts of the 1938 hurricane on Harvard forest (2006). That study utilized very high resolution LiDAR to identify canopy heights and areas that changed nearly 65 years prior (Weishampel et al., 2006). Hurricane Sandy, hit the east coast on October 28-31, 2012, the storm had a variety of impacts that can be better understood through remote sensing based change detection. This paper seeks to identify areas of significant change to the forest ecosystem on a regional scale brought about by the hurricane.

Hurricane Sandy was one of the largest storms to hit the northeastern United States in recent times, the storm was active from October 22, 2012-October 31, 2012, economic impacts from inundation, wind and flooding amounted to $50 billion (Blake, 2013). The storm also took 285 people's lives stretching from Haiti to Canada (Blake, 2013). The FEMA map (figure 1) breaks down the area impacted into zones of severity based on wind damage, storm surge, and rain. The map does not take into account forest impacts, in either ecosystem services or board feet. This paper seeks to examine identify where the forest impacts are concentrated, and how the ecological impacts of hurricane Sandy match up with the economic.

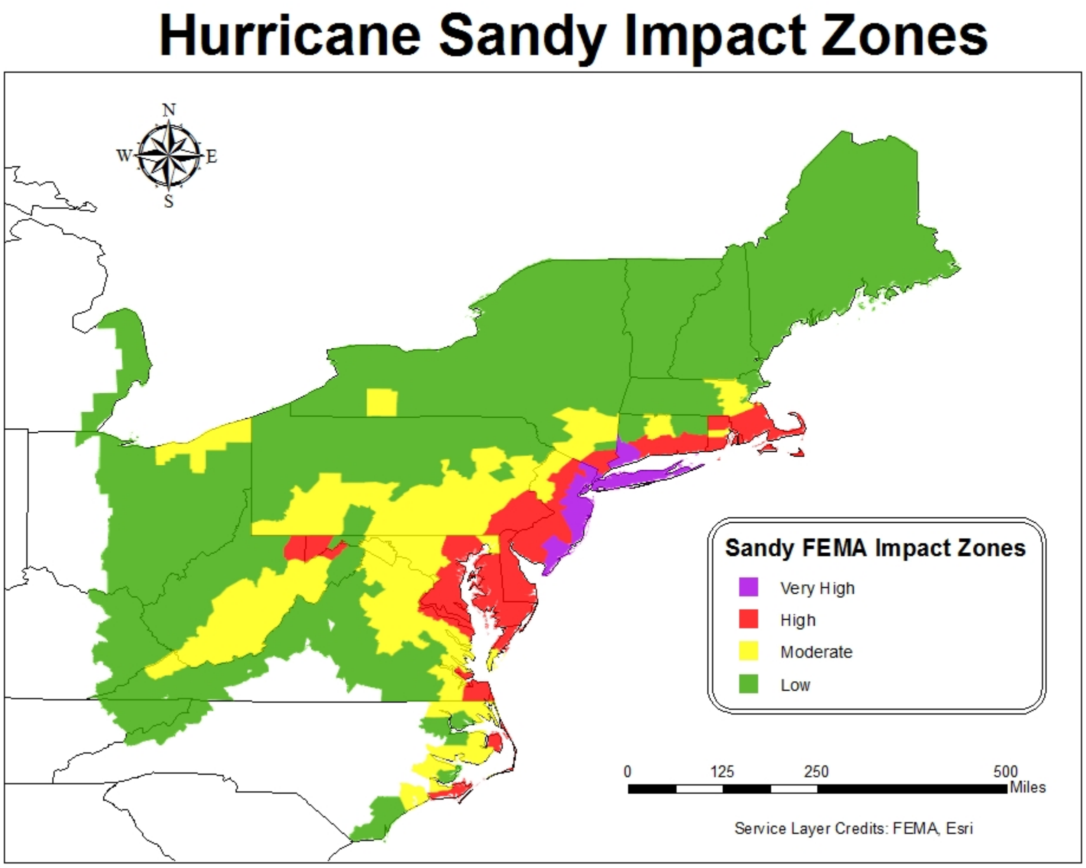

Figure 1 caption: The map shows areas of impact for Hurricane Sandy as delineated by FEMA, these zones were determined by Very High = 10,000 people exposed to storm surge. High = 100 million in wind damage, 500-10,00 exposed to storm surge or >8 in of rain. Moderate= 100-500 exposed to storm surge, 10-100 million in wind damage or 4-8 in of rain. Low impacts were <10 million in wind damage or <4 in of rain.

Stanturf, Goodrick & Outcalt describe the results of “Hurricane force winds, frontal squall lines, and associated tornadoes create a complex pattern of damage at a range of spatial scales” (2007). Sandy’s impacts will be examined with an eye towards spatial scale. Sandy’s wind swath can be seen in figure 2, which shows the study's footprint encompassing the impacted areas of New England. The variety of spatial scales makes it important to utilize data at a different of scales to understand the impacts. The paper utilizes the coarse scale of MODIS 250m spatial resolution data products to understand regional impacts.

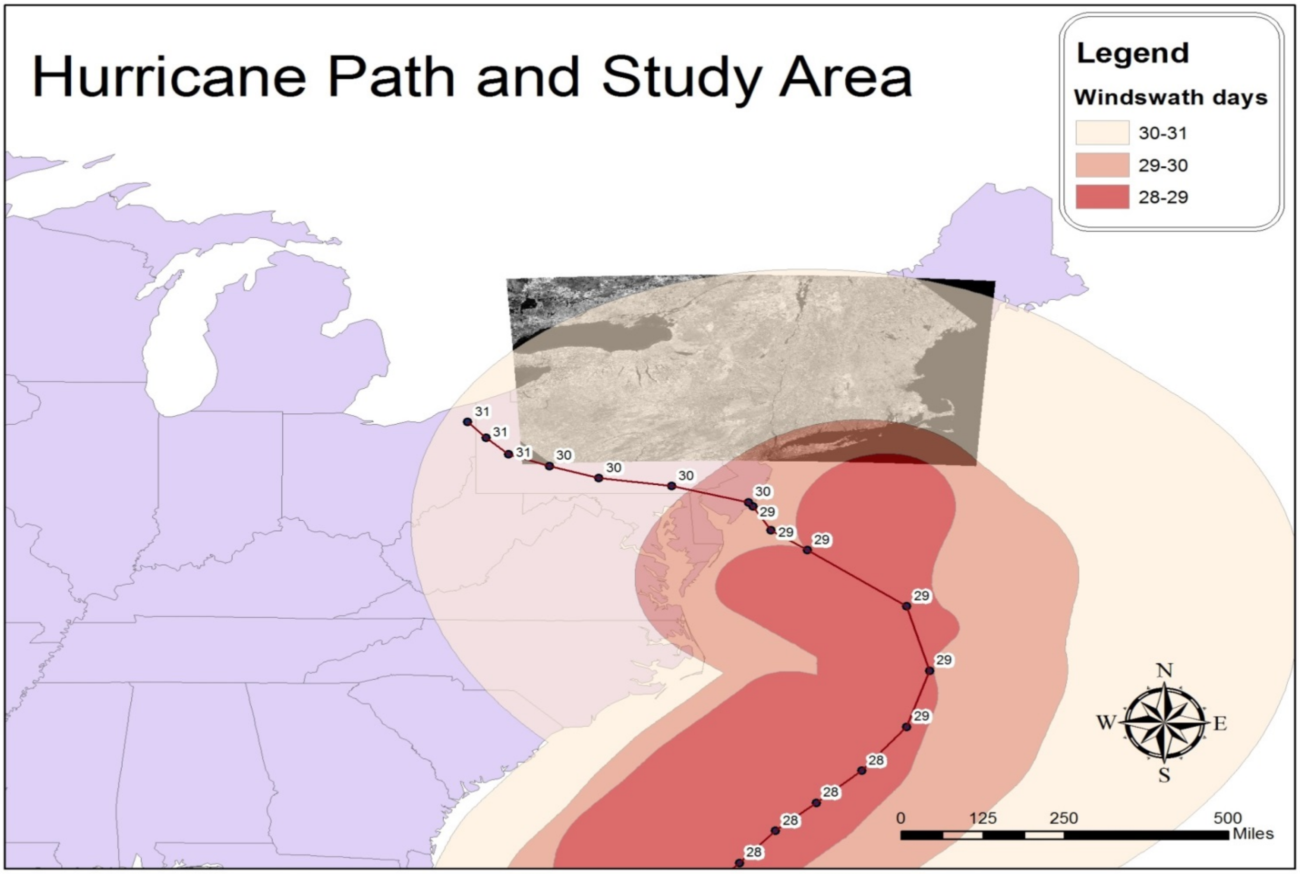

Figure 2 Caption: This map shows the path of Hurricane Sandy including its wind swath and the foot print of the study area.

To better understand hurricane Sandy this paper uses MODIS 13Q1, a 16 day composite image of Normalized Differencing Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). The MOD13Q1 data products are a useful tool when looking at regional vegetation change due to its spatial and temporal resolution (Steyer, Couvillion & Barras, 2013).One change detections analysis will be done with each vegetation index to better understand the various MODIS data products and what they offer to understanding storm impacts on the landscape. MODIS13Q1 utilizes the red and near infrared bands, these two bands have 250 m spatial resolution, MODIS has other spectral bands at 500m and 1 km spatial resolution some of which are utilized to control for atmospheric distortion in MODIS data products (Huete, Justice & Leeuwen, 1999). Red and near infrared spectral bands are important when computing vegetation indices such as NDVI and EVI. Vegetation indices will be utilized to better understand the impact Hurricane Sandy had on the forested landscapes, NDVI has been shown to covary with important vegetation indicators such as Leaf Area Index and green biomass (Phillips, Hansen & Flather, 2008). With increased risk of hurricane events in the near future it is very important to understand the impacts as they may be compounded by storm events in close temporal proximity (Stanturf, Goddick & Outcalt, 2007).

There are a plethora of sensor systems available from the dependable Landsat with over forty years of data collection to the very high resolution topographic information discernible from LiDAR systems. Sensor systems have unique attributes including spectral, spatial, temporal resolutions and ground swath these properties make each sensor system suited for different change detection applications. Jin and Sader found the MODIS13Q1 data product and single date equivalent achieved similar accuracy for classification of forests in the northeastern USA detecting “78% of total change area” when patch size was over 20 ha (2005). The study found MODIS to be an appropriate sensor system for identifying areas of change from logging in Maine (Jin and Sader 2005). Regional disturbances such as hurricanes have also been analyzed utilizing MODIS data products with results ground verified with Forest Service inventory and analysis (Wang et al., 2009). MODIS has been utilized to understand wetland impacts from Hurricane Katarina (Klemas, 2009) (Steyer, Couvillion & Barras, 2013). These studies have shown that MODIS is an important sensor when looking at regional forest and vegetation disturbance and there recovery.

Methodology:

MODIS 13Q1 data products are a 16 day time series of NDVI and EVI derived from the MODIS sensor system. These data products are produced at the 250 m resolution which is important when looking at regional fragmented landscapes. The data provides both NDVI and EVI indices which Wang et al., found could identify hurricane impacts (2009). The change analysis will be done with near annualized data collection periods to reduce the error from radiometric causes, and phenology. Coppin et al., stated the importance of comparable phenological states unless change from phenology is the change being studied (2004). Due to the annual dates of collection, the identical sensor system, and atmospheric correction steps taken with MODIS data products no further correction was done (Huete, Justice & Leeuwen, 1999). MODIS indices are also corrected for angular reflectance, effects of vegetation below the canopy, and vegetation saturation (Huete, Justice & Leeuwen, 1999).

Radiometric correction is highly recommended to reduce noise and increase the overall accuracy of the change detection approach (Coppin et al., 2004). Histogram correction was attempted, to correct the later date to the earlier image, but resulting images were distorted. This could be due to the atmospheric correction already done with the creation of the data product. This is accomplished by using other MODIS sensors with higher spectral resolution to correct for aerosols; the downside is the control sensors have a coarser spatial resolution (Huete, Justice & Leeuwen, 1999). Previous radiometric correction coupled with identical sensors and near annual collection dates make no further correction necessary. The two time series are from 11/24/12 and 11/25/11 and include the sixteen days prior. The study will be done with a univariate image differencing (UID) of both NDVI and EVI, UID was found to be very successful when compared to other methodologies by Wang & Xu (2009).

The sinusoidal projection utilized by MODIS was found to distort the data when interacting with other projections. The images were reprojected to UTM zone 18 with the USGS MODIS Projection tool web interface. This tool was also used to remove areas of Canada that were not within any Sandy impact areas. The resulting study area has West bounding: -79.839, East bounding: -69.0286, North bounding: 45.163 and South bounding: 40.393. The differencing was done with from-to approach as the data will be unclassified, the images will be analyzed for areas of change to the index values.

NDVI has limitations when sensing saturated vegetation cover, low vegetation cover and when sensing areas of bare soil (Phillips, Hansen & Flather, 2008). These issues could make detecting change due to a storm event less accurate due wind throws exposing boles of bare earth that could result in deceiving values. The images are from leaf off season which may cause additional problems with the NDVI differencing due to the low amount of vegetation. Due to the potential error of NDVI we include an analysis of EVI which includes additional spectral information in its calculation including a soil coefficient and two variables that utilize the blue band to control for atmospheric aerosols (Huete, Justice & Leeuwen, 1999). The from-to analysis was done in ERDAS Imagine 9.3, the two images were differenced producing a change map with 10% or greater change, and also an image with all pixel values differenced which was processed with ArcGIS 10.1 to create several map products.

Results:

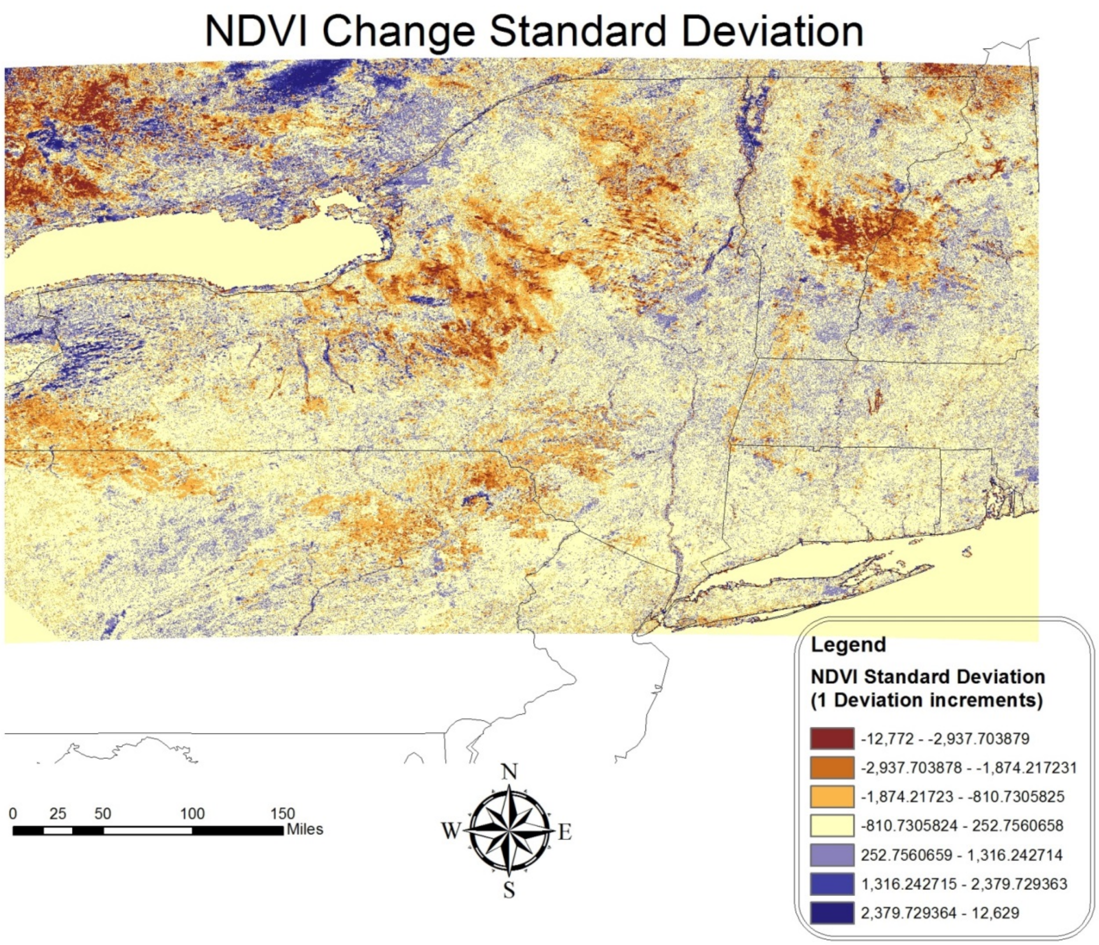

Figure 3 Caption: The map shows change for the study area between 16 day composite images for 11/25/2011 and 11/24/2012. The NDVI was differenced and the results represented in 1 deviation increments.

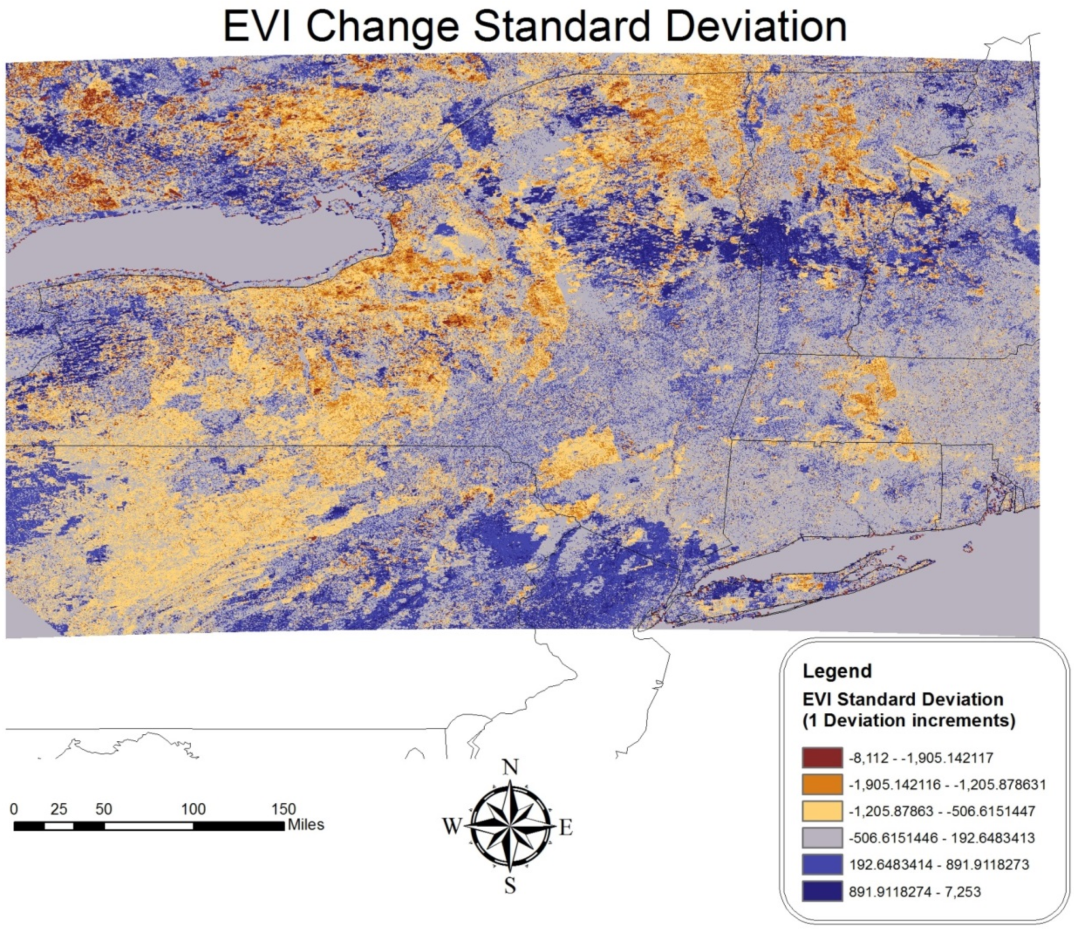

Figure 4 Caption: The map shows change for the study area between 16 day composite images for 11/25/2011 and 11/24/2012. The EVI was differenced and the results represented in 1 deviation increments.

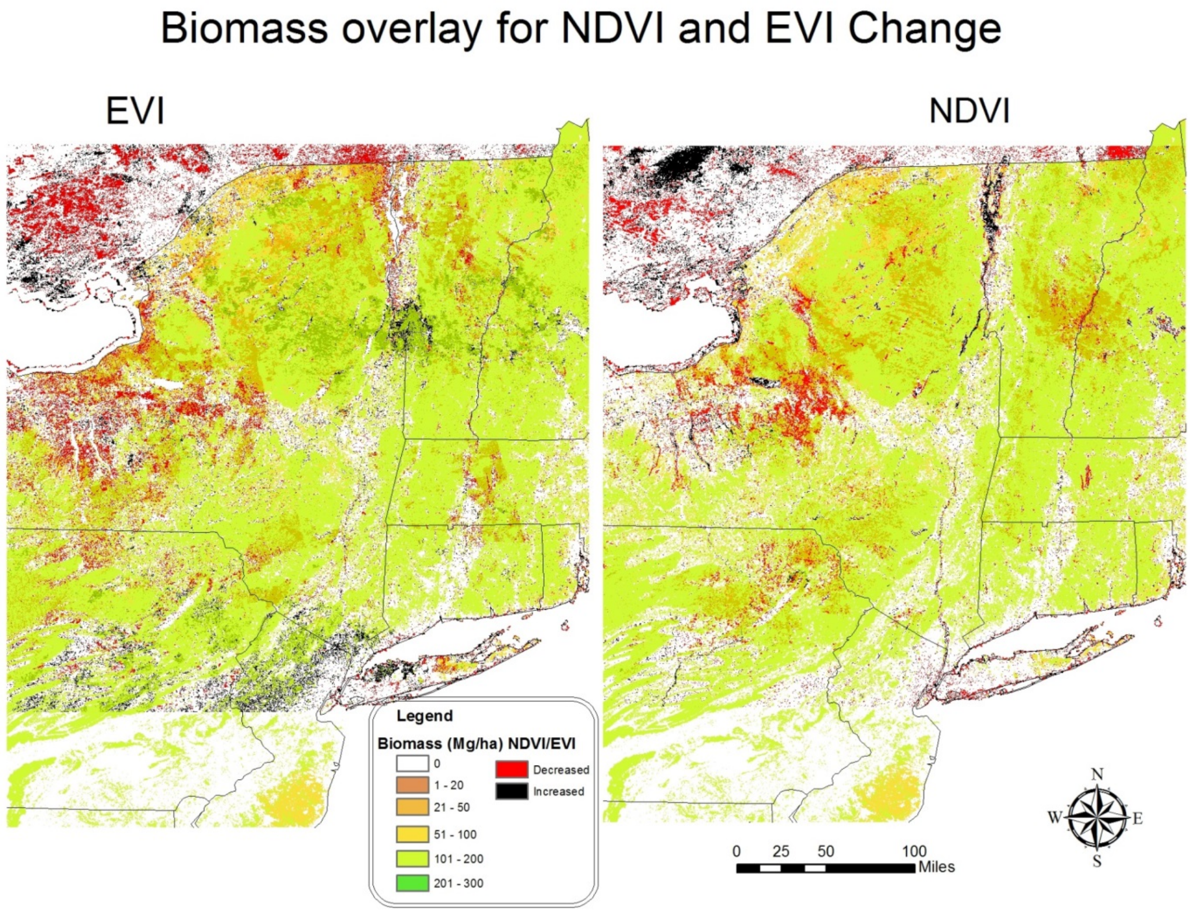

Figure 5 Caption: This figure show a biomass developed from Forest Assessment plots by Blackard et al., overlaying the EVI and NDVI >10% increase and decrease maps (2008).

Table 1 shows that the EVI differencing found more areas of significant change, change >10%, both increasing and decreasing. The areas of significant increase that EVI found were prevelant along northern NJ and PA which is very near the center of Hurricane Sandy and where damage is expected to be severe. The Figure 5, shows several areas of significant change where no forest biomass exists to accomadate this change. This could be due to what little vegetation is in those areas being reduced to create significant change or possibly error from the vegetation indices as it has been previously noted that NDVI has difficulties with accurately representing low vegetation.

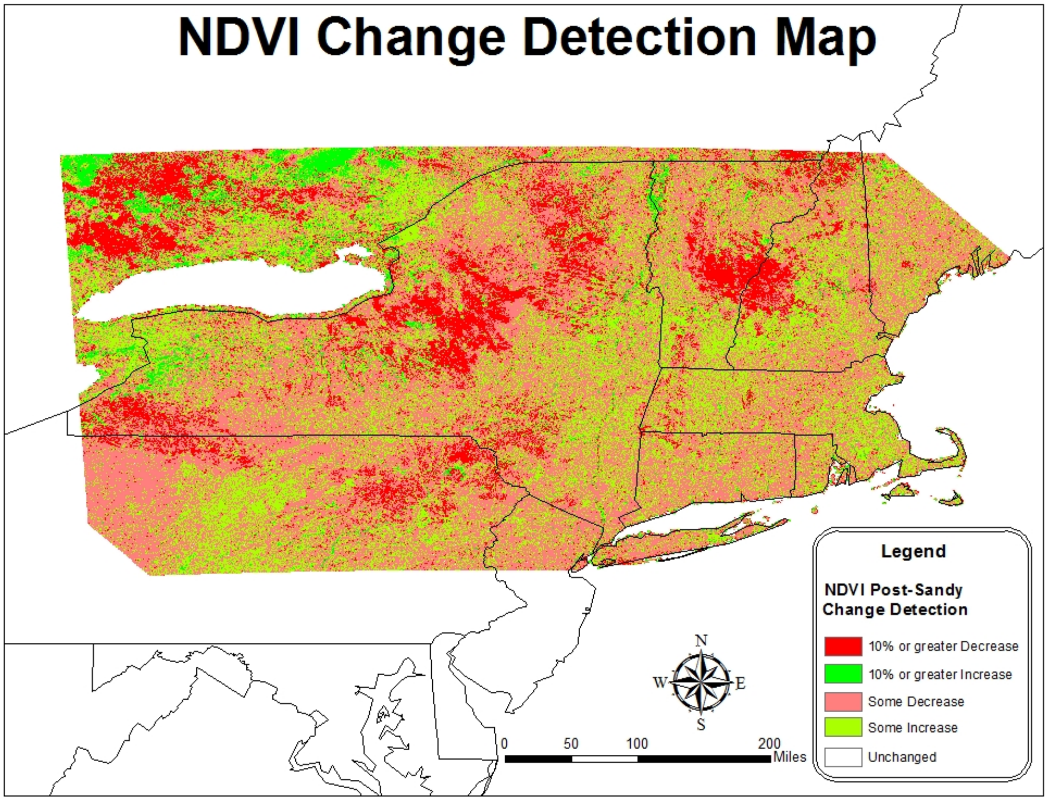

Figure 6 Caption: The map shows NDVI change broken into 4 categories >10% decrease, >10 increase, .1-9.999% increase and .1-9.999% decrease. This map was utilized in creat ion of table 1.

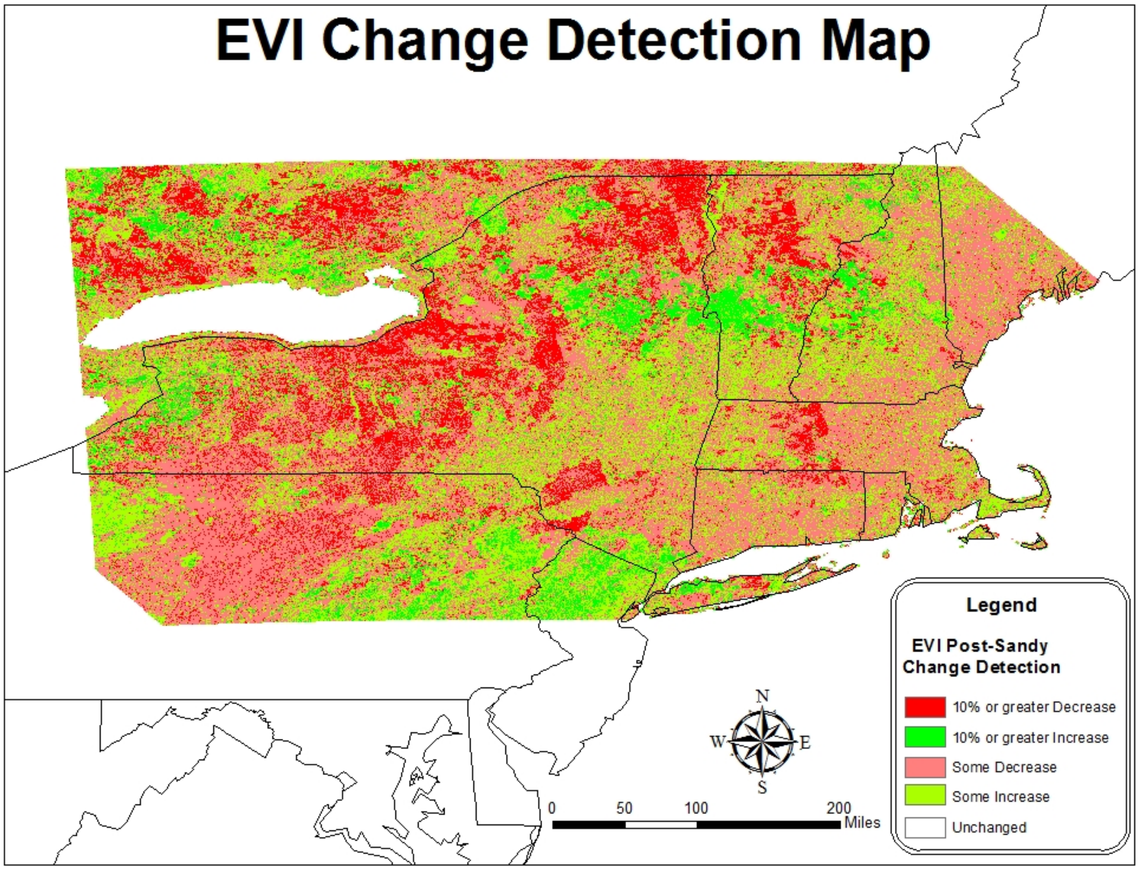

Figure 7 Caption: The map shows EVI change broken into 4 categories >10% decrease, >10 increase, .1-9.999% increase and .1-9.999% decrease. This map was utilized in creation of table 1.

	NDVI Pixels	EVI Pixels	NDVI Area (Km^2)	EVI Area (Km^2)
10% or greater decrease	935,697	1,034,057.00	58,481.06	64,628.56
10% or greater increase	301,640	534,297	18,853	33,393.56
some decrease	3,315,652	3,063,891	207,228	191,493.19
some increase	2,028,525	1,948,386	126,783	121,774.13

Table 1 Caption: Table one shows the pixel counts and km^2 for four categories of change. Some change is between .1-9.999%. Those areas of greater than 10% change are the other categories.

The results are promising for both vegetation indices detecting and identifying areas of change. Additional levels of investigation would be necessary to understand which of the indices found the greatest amount of actual change. Examining the figure 5 shows that both methodologies had difficulties with identifying change in some areas and illustrates how important additional exploration of the forest impacts of Hurricane Sandy is. Figure 3 has few areas of significant increase aside from areas in Canada; the pixel counts show that NDVI did find few areas of significant increase. The patterns of landscape change evident in the NDVI data appear to be more consistent with what would be expected from a storm event. EVI seems inconsistent with areas of significant increases being directly in the path of the hurricane. The two indices offer different possible patterns of disturbance.

Discussion:

Wang & Xu did a comparison of 6 vegetation indices for quantifying hurricane forest impacts post Hurricane Katarina, they found that NDVI had one of the lowest performances the only index with lower detection was the soil adjusted vegetation index (SAVI) (2010). They stated that this was most likely due to there not being significant change in exposed soil before and after Katarina (Wang & Xu, 2010). This does leave concerns that the increased detection evident in the EVI image, which controls for soil exposure, is not an increase in accuracy but rather a reduction. The overlap between the EVI and NDVI results show that MODIS data products are useful starting point for identifying and understanding hurricane impacts. Some areas of change were consistent between the two indices, but additional data would be necessary to understand which index was more accurate. Wang & Xu found that Tasseled Cap wetness was the best indicator of forest impacts post hurricane, unfortunately this index is not able to be computed with the spectral resolution available at 250 m MODIS (2009). The examination of MODIS applications for understanding forest hurricane impacts makes it clear that the biggest limitation for 250m MODIS change detection is not the spatial resolution, but the spectral. With so few bands MODIS cannot identify subtle changes to the forest landscape. The limits of MODIS data products for understanding hurricane forest impacts are evident.

It is clear that even while Hurricane Sandy had its largest impact on urban zones due to storm surge and wind. The wind impacts on the forests are evident through change detection methodology. Storm events are a natural process that have been impacting forests throughout time, and Fischer, Marshall & Camp showed that wind throws that are not managed will recover to create a very similar species composition to those existing before the storm event (2013). Hurricanes are an important process that shape complex landscapes, and only with increased frequency and intensity do they pose a risk to healthy forest ecosystems. It is necessary to understand the extent to which a forest landscape is impacted to better understand how higher frequency storm events may affect the forested ecosystem.

The change detection identified multiple areas that should be investigated further to understand the accuracy of the two vegetation indices, the MODIS sensor and the hurricane impacts. The only accuracy assessment conducted was the use of the biomass overlay (figure 5) which does identify areas to investigate further. Investigating areas with clusters of significant change would be beneficial, and require higher spatial resolution imagery. Additional verification of the areas found to have changed through *in situ* data collection is recommended. These endeavors would be necessary elements of assessing the accuracy of the data. Steyer, Couvillion & Barras, found that the Thematic Mapper sensor added a level of detail to their analysis of MODIS data that complemented its temporal resolution (2013). Steyer, Couvillion & Barras also utilized multiple years of data to establish a baseline which they found beneficial in reducing the effect of anomalous weather conditions in the base year (2013). It has been found that additional accuracy can be imparted on change detection methodologies by utilizing multiple methodologies and then using a decision mechanism such as majority rule to reach a conclusion for whether a pixel has changed (Du et al., 2012). This would have been an interesting approach but required additional indices and methodologies to utilize it fully. These are a few of the areas pertaining to the spectral resolution, indices and methodology that could be improved and became evident when reviewing the literature.

It is likely that in the coming year additional papers studying the regional impacts of Hurricane Sandy will be published bringing further clarity to our understanding of the storm event's impacts. This paper has shown areas that warrant further investigation, starting with areas of significant change with little biomass. These areas should be investigated to determine if the change is due to misinterpretation by the indices or if it is due to change from whatever vegetation is in the areas. With further investigation the accuracy of the indices can be quantified. This exploration would further our understanding of Sandy and MODIS change detection applications. This analysis of the impacts of Hurricane Sandy with MODIS data products has accomplished its goal of bettering the understanding of the environmental impacts of Hurricane Sandy. Change detection and analysis is a developing field with a great deal of additional research being done to improving the accuracy and understanding of the various methodologies.

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