ERDC/EL SR-23-5

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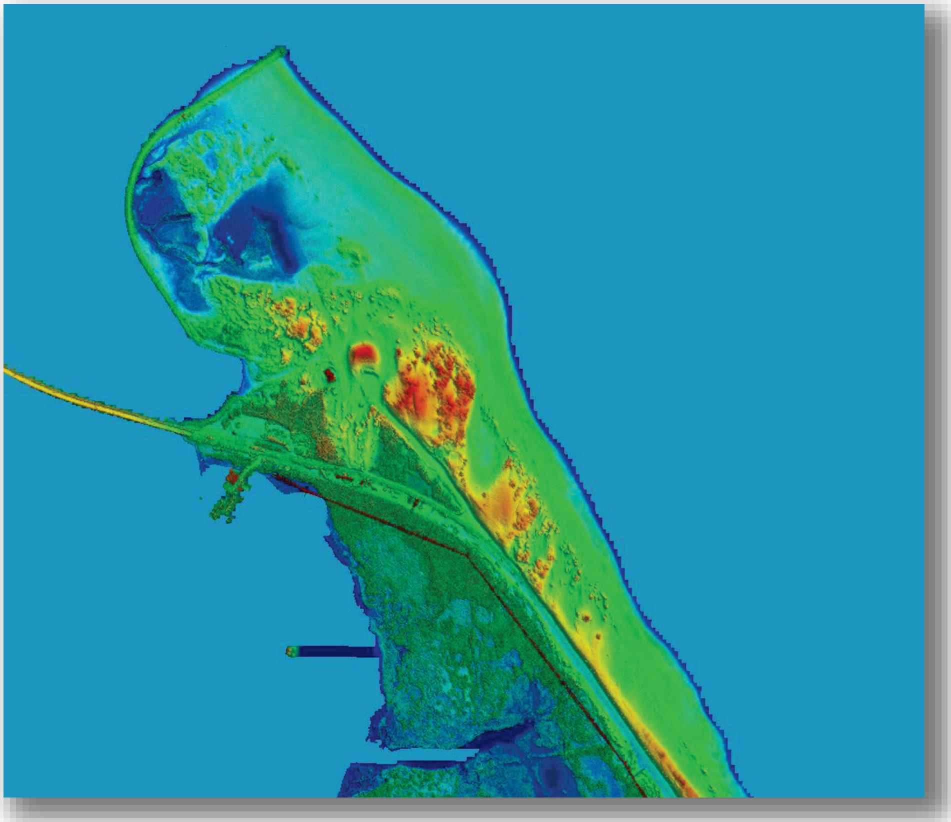
National Coastal Mapping Program

During Nearshore Event Vegetation Gradation (DUNEVEG): Geospatial Tools for Automating Remote Vegetation Extraction

Sam S. Jackson, Christina L. Saltus, Molly K. Reif,
and Glenn M. Suir

September 2023



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Abstract

Monitoring and modeling of coastal vegetation and ecosystems are major challenges, especially when considering environmental response to hazards, disturbances, and management activities. Remote sensing applications can provide alternatives and complementary approaches to the often costly and laborious field-based collection methods traditionally used for coastal ecosystem monitoring. New and improved sensors and data analysis techniques have become available, making remote sensing applications attractive for evaluation and potential use in monitoring coastal vegetation properties and ecosystem conditions and changes. This study involves the extraction of vegetation metrics from airborne lidar and hyperspectral imagery (HSI) collected by the US Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP) to quantify coastal dune vegetation characteristics. A custom geoprocessing toolbox and associated suite of tools were developed to allow inputs of common NCMP lidar and imagery products to help automate the workflow for extracting prioritized dune vegetation metrics in an efficient and repeatable way. This study advances existing coastal ecosystem knowledge and remote sensing techniques by developing new methodologies to classify, quantify, and estimate critical coastal vegetation metrics which will ultimately improve future estimates and predictions of nearshore dynamics and impacts from disturbance events.

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Preface

This study was conducted for the US Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP), "During Nearshore Event Vegetation Gradation (DUNEVEG): Geospatial Tools for Automating Remote Vegetation Extraction" under AMSCO Code 008242 and funding account K5385997The NCMP is sponsored by Headquarters, USACE, and is assigned to the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), Kiln, Mississippi. The NCMP program manager was Mrs. Jennifer M. Wozencraft.

The work was performed by the Environmental Systems Branch of the Ecosystem Evaluation and Engineering Division, Environmental Laboratory (EL), USACE Engineer Research and Development Center (ERDC). Technical peer reviews were conducted by Ms. Charlene S. Sylvester of the JALBTCX and Mr. Scott G. Bourne of the ERDC EL.

At the time of publication, Mr. Mark R. Graves was branch chief of the Environmental Systems Branch; Mr. Mark D. Farr was division chief of the Ecosystem Evaluation and Engineering Division. Mr. Eddie Wiggins was ERDC technical director for Navigation; and the ERDC EL Director was Dr. Edmond J. Russo.

The commander of ERDC was COL Christian Patterson, and the director of ERDC was Dr. David W. Pittman.

1 Introduction

1.1 Background

Coastal landscape features provide benefits ranging from regulating services (floods, drought, and land degradation), supporting services (soil formation and nutrient cycling), and provisioning services (food and freshwater), to maintaining high biological productivity and serving as critical habitat for fish and wildlife. However, dominant coastal features such as beaches, dunes, and wetlands, are dynamic environments, inherently vulnerable and geomorphologically unstable by nature of their position at the interface of land and sea (Charbonneau et al. 2016). Coastal beaches, dunes, and wetlands change in response to wind, waves, and tides, while the effects of climate change, especially large storms and irregular weather patterns, continue to make these systems increasingly susceptible to erosional forces.

Vegetation is a critical biotic component of coastal ecosystems since they have direct and indirect impacts on system stability and resilience (Charbonneau et al. 2016). Plants contribute, both above- and below-ground, to erosion control. High stem densities in aboveground plant shoot mass reduces rain and wave splash impacts, mitigates storm surge, and diminishes near-bed shear stresses, as well as facilitates vertical and horizontal accretion through organic matter accumulation and sediment trapping (Wigand et al. 2017). Belowground root mass increases the sheer strength of the substrate and thereby prevents erosion by resisting structural failure and creating nearshore bathymetric profiles that assist in dissipating wave energy (Sigren et al. 2014). Therefore, vegetation productivity and processes are critical contributors to coastal wetland stability and resilience, especially with anticipated increases in sea level rise and the frequency and intensity of storms and rain events.

Recent efforts have focused on evaluating physical and biological processes and the long-term evolution of coastal systems as functions of natural processes and anthropogenic activities. Though some emphasis has been on coastal vegetation monitoring and influence on erosion potential, fewer studies have directly evaluated correlations to vegetation structural properties (i.e., vegetative densities), presumably due to limited and insufficient data to support these efforts. Despite ongoing improvements, monitoring is still considered a major challenge in anticipating environmental response to hazards, disturbances, and management activities. Remote sensing applications provide alternatives and complementary approaches to the often costly and laborious field-based collection methods traditionally used for coastal ecosystem monitoring. New and improved sensors and data analysis techniques have become available, making remote sensing applications attractive for evaluation and potential use in monitoring coastal vegetation properties (e.g., cover, height, above- and below-ground biomass, and stem density), and ecosystem conditions and changes (Klemas 2013).

Developments in lidar technology have enabled penetration of high-density vegetation cover to obtain estimates of relative heights above ground and detailed vegetation structure parameters (Rosette et al. 2012; Wang et al. 2017). However, lidar data do not contain spectral information, which is required for estimating biomass through vegetation indices (Luo et al. 2017). Fusing lidar data with high resolution multispectral and/or hyperspectral imagery can assist in discriminating plant species, determining biomass distribution, and extracting key coastal dune vegetation metrics. Multispectral imagery captures data within specific wavelengths across the electromagnetic spectrum, which are beyond the visible range (red, green, and blue) and typically includes data in the near-infrared portion of the spectrum. Hyperspectral imagery (HSI) provides an even higher level of spectral information by acquiring more bands in narrower ranges within the full electromagnetic spectrum. The narrow bands are more sensitive to variations in energy wavelengths and have a higher potential to detect vegetation stress or subtle differences in vegetation characteristics, as compared to multispectral imagery. The goal of this project was to extract metrics from lidar and hyperspectral imagery to quantify dune vegetation biological characteristics, thereby working to improve future estimates and predictions of storm processes and impacts as well as other coastal applications. This study also helps to advance existing dune and wetland system knowledge and remote sensing techniques for developing new methodologies to classify, quantify, and estimate critical dune vegetation metrics.

1.2 Objective

The main objective of this work was to develop geospatial methods using routinely collected NCMP imagery and lidar data to extract dune vegetation metrics of interest to coastal managers. A dune vegetation metric survey was conducted and involved participants attending the 2019 Coastal Navigation Research Area Review Group (RARG) meeting to help determine high priority vegetation metrics most important for coastal resilience and coastal storm risk management studies. The metrics were ranked by overall importance and were prioritized to allow for a better understanding of their usefulness for coastal stability during storm events and for coastal dune studies. The highest ranked metrics evaluated for extraction included vegetation presence/absence, health indices (i.e., Normalized Difference Vegetation Index [NDVI]), vegetation density estimates (cover), Leaf Area Index (LAI), canopy height models, and woody stem locations (density, radius, crown height). Another important goal of this study was to develop automated or semiautomated tools to extract these vegetation metrics from the NCMP data. Therefore, a geoprocessing toolbox and associated suite of tools were developed to allow inputs of common NCMP imagery and lidar products to help automate the workflow for extracting prioritized dune vegetation metrics in an efficient and repeatable way.

1.3 Approach

This report describes dune vegetation metric development and analysis as well as associated toolbox automation for quickly extracting the developed metrics. The toolbox uses NCMP input data (lidar and HSI) to generate remotely derived vegetation metrics that help describe vegetated dune characteristics. The user-friendly ArcGIS Pro geoprocessing toolbox was developed and tested for use with ArcGIS Pro (version 2.6) geospatial analysis software in a Windows 10 desktop environment. The custom toolbox was designed with Python programming language and integrates ArcGIS Pro geoprocessing tools with ENVI (Environment for Visualizing Images) image analysis software to extract the metrics (L3Harris Geospatial Solutions, Inc.).[*] Documentation for the toolbox installation, configuration, workflow, and usage are also included in this report.

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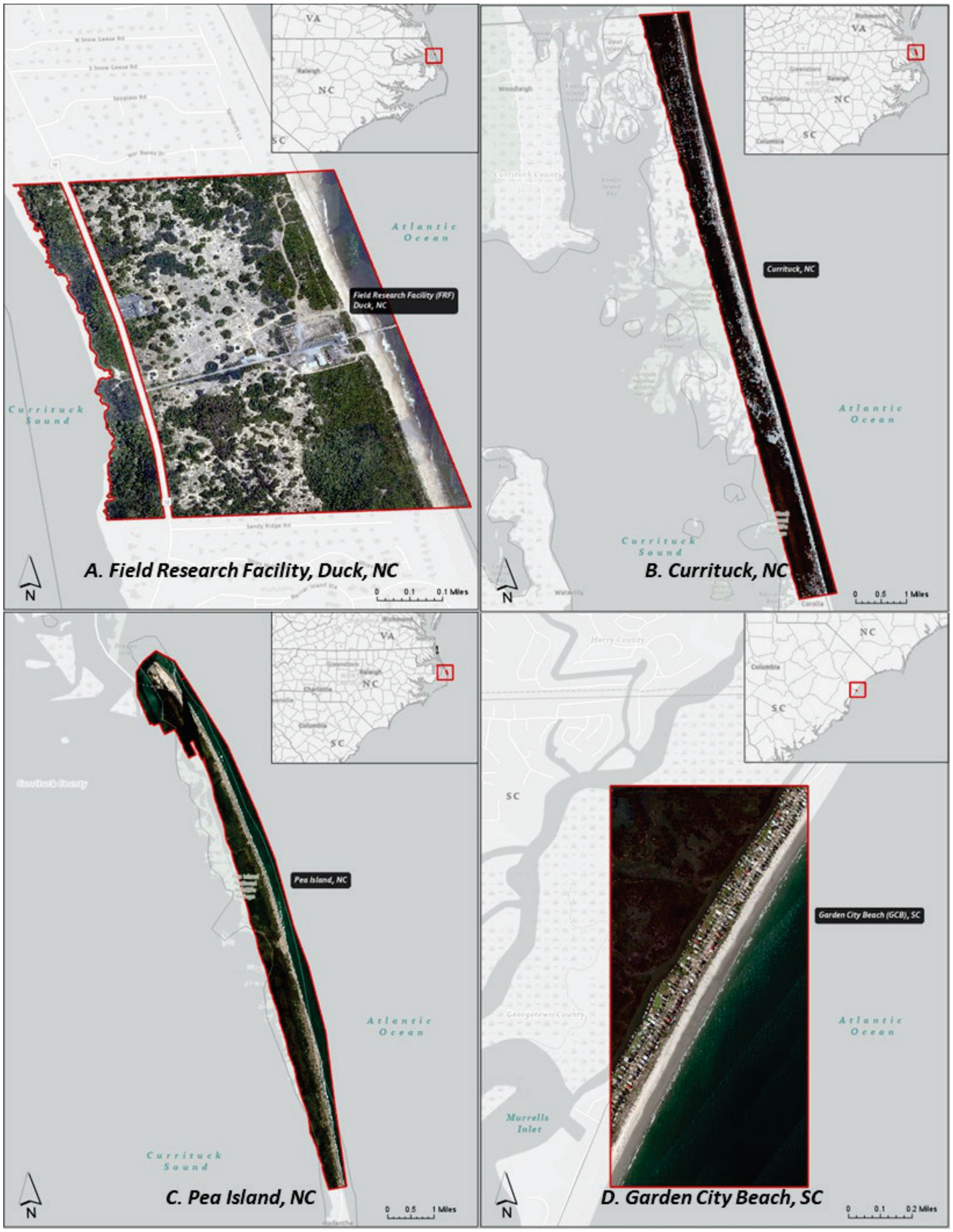
[*] www.harrisgeospatial.com

2 Study Area and Analysis

2.1 Study area

Four sites were chosen to evaluate methods for extracting prioritized dune vegetation metrics and to develop an automated workflow for extraction techniques. The sites were in Duck, North Carolina (ERDC Field Research Facility [FRF]); Currituck, North Carolina; Pea Island, North Carolina; and Garden City Beach, South Carolina (Figure 1). All the sites are current locations for several ongoing coastal research studies including the During Nearshore Event Experiment (DUNEX), which is a multiagency, academia, and stakeholder collaborative community experiment to study nearshore processes during coastal storm events. The multiphase field experiment began in the fall of 2019 with a pilot study and ended with a full experiment in the winter of 2022. It is anticipated that the developed tools and derived vegetation products from this study can aid researchers and prove mutually beneficial for advancing coastal research.

Figure 1. Study sites used to evaluate methods for extracting prioritized dune vegetation metrics and developing an automated workflow. Sites include (*A*) FRF, Duck, NC; (*B*) Currituck, NC; (*C*) Pea Island, NC; and (*D*) Garden City Beach, SC.



2.2 Remote sensing analysis

2.2.1 NCMP source data

This study used coastal HSI and lidar data routinely collected for the USACE National Coastal Mapping Program (NCMP) to evaluate extraction methods of coastal vegetation characteristics. These data are collected by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX 2020) to capture the existing beach and near-shore conditions along the sandy coastlines of the US. The HSI was collected using an Itres Compact Airborne Spectrographic Imager (CASI)-1500, a programmable sensor capable of hundreds of narrow spectral bands, and part of the Coastal Zone Mapping and Imaging Lidar (CZMIL) system. The CZMIL integrates an Optech lidar sensor with topographic (70 kiloHertz [kHz] measurement rate) and bathymetric (10 kHz measurement rate) capabilities, a digital camera, and the CASI-1500 imager on a single remote sensing platform mounted on a fixed wing aircraft.

The integrated system was developed specifically for use in coastal mapping and charting activities and was designed to meet or exceed US Geological Survey Quality Level 2 (QL2) standards for topographic lidar data collections to produce a vertical accuracy ≤10 centimeters (cm) RMSEZ on land surfaces and shallow water (JALBTCX 2020). The CASI-1500 imagery was collected at an altitude of 400 meters (m) with a ground swath of 300 m and has a spatial resolution of 1 m with 48 spectral bands between 380 to 1,050 nanometers (nm). The coordinate system for the data were Universal Transverse Mercator (UTM) referenced to the horizontal North American Datum 1983 (NAD83). Vertical positions from the lidar data were referenced to the NAD83 ellipsoid (GRS 1980) and were converted to NAVD88 orthometric heights using geoid model 12B. The average point density for the topographic lidar at the beach dune interface was ~1 point/square meter (m^2).

Individual image strips were rectified, mosaicked, and atmospherically corrected by the JALBTCX using HydroFusion (Teledyne 2020) airborne bathymetric mapping software prior to data delivery and image analysis, and were delivered in GeoTIFF format. The lidar data were provided in LAS (LASer) format. Multiple data collections from 2016 to 2019 were used for the assessment to ensure repeatability and consistent method development. Some collections, depending on the location, included 4-band multispectral imagery collected from a 60-megapixel Leica RCD30 camera and had a spatial resolution of 5 cm. Where available, the same vegetation metrics were extracted from the 4-band multispectral imagery; however, all methods and tool development were prioritized and implemented using the primary NCMP data products (HSI and lidar), which meet the operational requirements specific to JALBTCX mission directives.

2.2.2 Dune vegetation metric extraction

The software used to develop the steps and methodological framework for subsequent process automation was ENVI version 5.5. All the dune vegetation metrics/products were generated using this software unless otherwise noted. The ENVI Application Programming Interface (API) in IDL was used to customize ENVI functionality for automating metric extraction processes, and the ENVI Py for ArcGIS module allowed for integrated access using ArcGIS Pro (version 2.6) software (ESRI, Redlands, California).[*] The programming tasks, tool automation, and custom toolbox are discussed in the Tool Automation section.

2.2.2.1 Vegetation metric: Normalized Difference Vegetation Index (NDVI)

The NDVI has traditionally been used to assess impacts from anthropogenic, natural, and invasive disturbances (Klemas 2013) and was used in this study as a measure of vegetation health, representing relative biomass of live, green vegetation. NDVI values were generated from the NCMP HSI. Chlorophyll, the pigment in plant leaves, strongly absorbs visible light (from 0.4 to 0.7 micrometers [μm]) for use in photosynthesis. Conversely, the cell structure of the leaves strongly reflects near-infrared light (from 0.7 to 1.1 μm). The more leaves a plant has, the more these wavelengths of light are affected, respectively (Weier and Herring 2000). High spectral resolution imagery acquires data in the visible and near-infrared wavelengths, allowing for differences in plant reflectance to estimate the spatial distribution of vegetation quite well (Myneni et al. 1995). The equation used for calculating the NDVI was a variant of the standard equation (Rouse et al. 1974) and shown in Equation 1:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{1}$$

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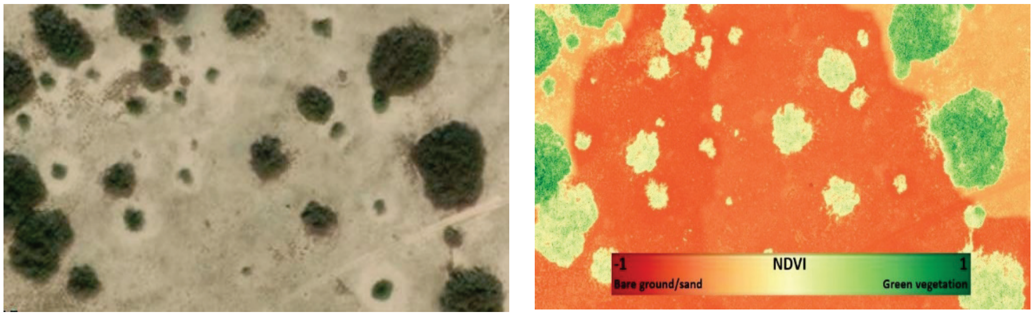
[*] www.esri.com

where NDVI is the Normalized Difference Vegetation Index, NIR is HSI band 35 (856 nm) (the near-infrared spectral band center value), and Red is HSI band 21 (656 nm) (the red spectral band center value).

Band assignments were based on the wavelength closest to the band center within each spectral range according to ENVI software functionality and spectral index requirements (L3Harris Geospatial Solutions, Inc.). NDVI values range from -1 to 1 (Figure 2), where lower values (closer to -1) generally represent nonvegetated features and higher values (closer to 1) tend to represent healthy, green vegetation (Lillesand and Kiefer 1994). Therefore, the higher the NDVI value, the higher the biomass, productivity, and vigor inferred from these calculations. The output raster was 1 m spatial resolution in GeoTIFF file format (32-bit floating point).

Figure 2. National Coastal Mapping Program (NCMP) Hyperspectral Image (a) and the NCMP-derived Normalized Difference Vegetation Index (NDVI) raster image (b), where nonvegetated features such as bare ground and sand have lower NDVI values closer to -1 (red/orange colors) and healthy, green vegetation has values closer to 1 (green color).



(a) (b)

2.2.2.2 Vegetation metric: density estimation (cover)

Coastal dune ecosystems play a complex and vital role in shoreline stability (Sigren et al. 2014); therefore, it is important to quantify the vegetation present at the land-water interface as well as further inland beyond the primary dune. Knowing how vegetation characteristics change from the dune toe to the more elevated and heavily vegetated dunes is an important aspect for understanding dune morphology and associated impacts from coastal processes. Coastal dunes also yield substantial economic benefits by reducing damage to residential and commercial infrastructure during significant storm events. Therefore, many USACE coastal restoration projects focus on dune resiliency to help reduce the risk to coastal communities (USACE 2013).

Delineation of temporal dune vegetation presence and extraction of vegetation density estimates from the atmospherically corrected NCMP HSI were performed using the ENVI Spectral Processing Exploitation and Analysis Resource (SPEAR) vegetation delineation tool. The SPEAR tool performs a density slice method based on NDVI-derived images to generate density categories. NDVI has a strong correlation to aboveground biomass estimation (Moreau et al. 2003; Lillesand and Kiefer 1994). Therefore, inferences can be made on the level of vigor and vegetation density using NDVI value ranges. The density categories (Figure 3) estimated from this method were (1) Dense vegetation, (2) Moderate vegetation, (3) Sparse vegetation, and (4) non-vegetation. Image pixels with NDVI values between 0.70 and 1.0 represent dense vegetation, 0.50 to 0.69 represent moderate vegetation, 0.25 to 0.49 represent sparse vegetation, and values between -1.0 and 0.25 represent non-vegetation.

Figure 3. National Coastal Mapping Program (NCMP) Hyperspectral Image (a) and the NCMP-derived vegetation density data (b), where categories include Dense vegetation (NDVI values 0.70–1.0), Moderate vegetation (NDVI values 0.50––0.69), and Sparse vegetation (NDVI values 0.25––0.49).

(a) (b)

The wavelength band assignments for the NIR and Red bands selected for inputs into the tool were 856 nm (band 35) and 656 nm (band 21), respectively. Again, these assignments represent the wavelength closest to band center and were determined to be the most appropriate for the algorithm. The output format for this analysis were ESRI polygon features (shapefiles) indicative of the NDVI threshold estimates from each vegetation density category. Once the output densities were derived, a spatial merge (geoprocessing task) was used to join the three vegetation densities (Dense, Moderate, and Sparse) into one category representing all vegetation (polygon feature layer). Subsequently, the output of the merge operation represented vegetation presence for the image scene. Likewise, the non-vegetation layer represented vegetation absence. Wetland, submerged, or inundated areas appearing to have brown or dying (nongreen) vegetation were included as non-vegetation for purposes of deriving vegetation density estimates. The resultant product of this analysis is used as a mask layer for subsequent vegetation metric extraction.

2.2.2.3 Vegetation metric: Leaf Area Index (LAI)

A commonly used variable for quantifying vegetation canopy is Leaf Area Index (LAI), which is a measure of green leaf area (m^2) per unit of ground surface area (m^2). In basic terms, it is the estimated (image-derived) or measured (field-derived) amount of foliage in a plant canopy. Leaf surfaces are the primary driver of energy and mass exchange. Therefore, important processes such as canopy interception, evapotranspiration, and photosynthesis are directly proportional to LAI (Fang and Liang 2008). Moreover, the amount of leaf area directly influences net primary productivity and biomass potential, and aboveground biomass can be related to belowground biomass estimates (O’Connell et al. 2015).

For this study, LAI was estimated from optical remote methods using the NCMP HSI and select spectral bands. The calculations were made using ENVI band algebra and a spectral indices tool specifically designed for LAI. The equation used for calculating this vegetation index is shown in Equation 2:

$$\mathrm{LAI} = 3.618 \text{ x } \mathrm{EVI} - 0.118 \tag{2}$$

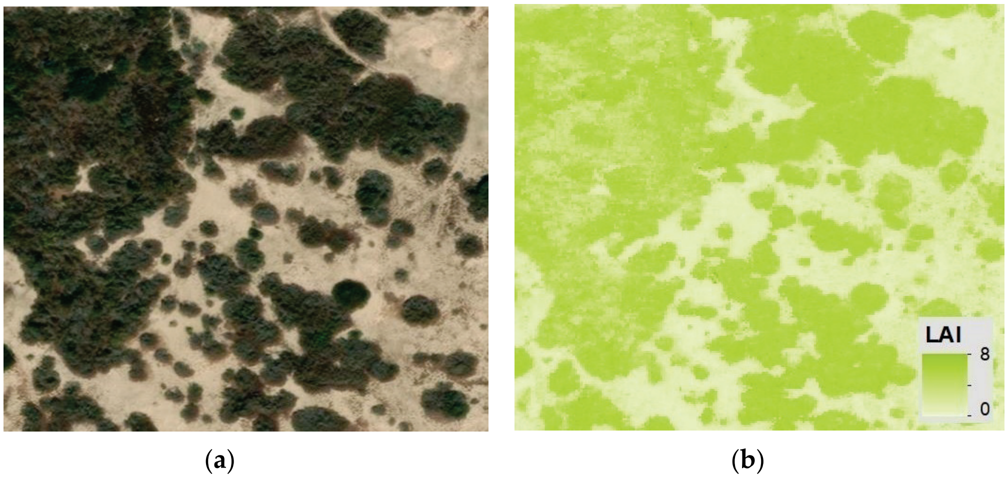
where EVI is the Enhanced Vegetation Index and is an important variable for estimating the LAI using remote sensing methods, especially in areas with high relative biomass. It is a broadband greenness index, and the calculation is shown in Equation 3:

$$\mathrm{EVI} = \mathrm{G} \text{ x } \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{C1} \text{ x } \mathrm{Red} - \mathrm{C2} \text{ x } \mathrm{Blue} + \mathrm{L})} \tag{3}$$

where G is the gain factor (2.5), NIR is HSI band 35 (856 nm) (the near infrared spectral band center value), Red is HSI band 21 (656 nm) (the red spectral band center value), Blue is HSI band 8 (471 nm) (the blue spectral band center value), and the numerical coefficients (C1, C2) and canopy background adjustment (L) are used by ENVI as part of the EVI equation. The spectral bands are the atmospherically corrected surface reflectance values, and the wavelengths must be defined properly in the header file for ENVI to output the correct index values.

The EVI is useful for optimizing the vegetation signal in areas of high LAI (very dense vegetation) and, where NDVI may saturate, can be a limitation of using NDVI alone (Huete et al. 1999). This algorithm makes use of the blue band to correct for soil background signals and to reduce atmospheric influences, including aerosol scattering (L3Harris Geospatial Solutions, Inc.), and is essentially an improved NDVI variable for calculating LAI. The output image for LAI was a 32-bit floating-point data type in GeoTIFF format. The typical range of values for this index was 0 to ~8 for coastal dune vegetation across all sites, and higher values related to higher leaf area (Figure 4).

Figure 4. National Coastal Mapping Program (NCMP) Hyperspectral Image (a) and the NCMP-derived Leaf Area Index (LAI; b). Higher LAI areas appear as darker shades of green and lower LAI areas appear as lighter shades of green.



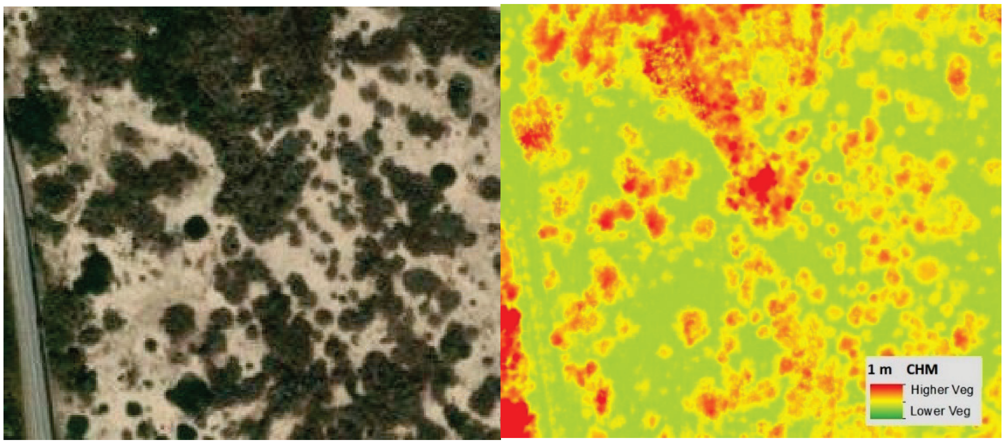
(a) (b)

2.2.2.4 Vegetation metric: Canopy Height Model (CHM)

For each site, the lidar data were processed to generate gridded models of the inland topography and surface features. A 1 m Digital Elevation Model (DEM) was created from points classified as ground returns or assumed last return points from the classified LAS files. A DEM is a regularly spaced raster grid of elevation values of a surface terrain with nonground points removed so the output is a surface representation of bare ground void of vegetation and other above-ground features. A Triangulated Irregular Network (TIN) interpolation method was used with rural area filtering to produce the DEM. A TIN is a digital representation of a continuous surface that consists of triangular facets and used primarily as a discrete global grid in primary elevation models. Similarly, a 1 m Digital Surface Model (DSM) was created from points classified as nonground or from first return points from the classified LAS file. A DSM is a regularly spaced raster grid of surface elevation values that includes vegetation and other above-ground features.

The LAS files were processed using an interpolation method in ENVI that is optimized for vegetation analysis and filters points specifically for extracting vegetation heights. Using the two models, a 1 m vegetation Canopy Height Model (CHM) was created by subtracting the DEM from the DSM to derive a 1 m height model (Figure 5). This subtraction routine was performed using band math in ENVI. The non-vegetation polygon feature (from the density estimate calculation) was used as a mask (geoprocessing task) to exclude non-vegetation and only vegetated areas were output in the CHM. The CHM contains the vegetation canopy height for all areas identified as vegetation within the lidar extent footprint. All the 1 m raster models were output to a 32-bit floating point (GeoTIFF format) with elevations or heights in meters.

Figure 5. National Coastal Mapping Program (NCMP) Hyperspectral Image (a) and the NCMP-derived Canopy Height Model (CHM) (b), where higher vegetation appear red and lower vegetation appear yellow/green.



(a) (b)

2.2.2.5 Vegetation metric: woody stem locations

The woody stem locations were calculated using ENVI lidar version 5.5 and output parameters include stem height (meters), crown radius (meters), and stem locations (*x*-*y* coordinates). An ESRI point feature shapefile was the output format. The algorithm uses the LAS file and resulting DEM (last return) and DSM (first return) to filter the points based on the classified point attributes according to standards published by the American Society for Photogrammetry and Remote Sensing (ASPRS).[*] This process generated maximum vegetation height returns as stem center locations (Figure 3). A minimum height threshold was specified at 1.22 m, which was the expected minimum height of inland dune vegetation. Several minimum heights were evaluated, and the selected value resulted in the most suitable results for woody-type dune vegetation. A minimum crown width was also set to 1.22 m, which after several iterations appeared to be suitable for the type of vegetation present. However, this may need to be adjusted based on the specific size and type of vegetation. The algorithm is designed to select points with dispersal characteristics indicative of trees (woody stems), and due to the lower point density of airborne lidar it was not a suitable algorithm for extracting grass-type dune vegetation. A spatial selection (geoprocessing task) was performed on the stem locations point feature layer using the vegetated areas polygon to select and output stem points in the vegetation area and exclude non-vegetation areas (shown as the white areas in Figure 6).

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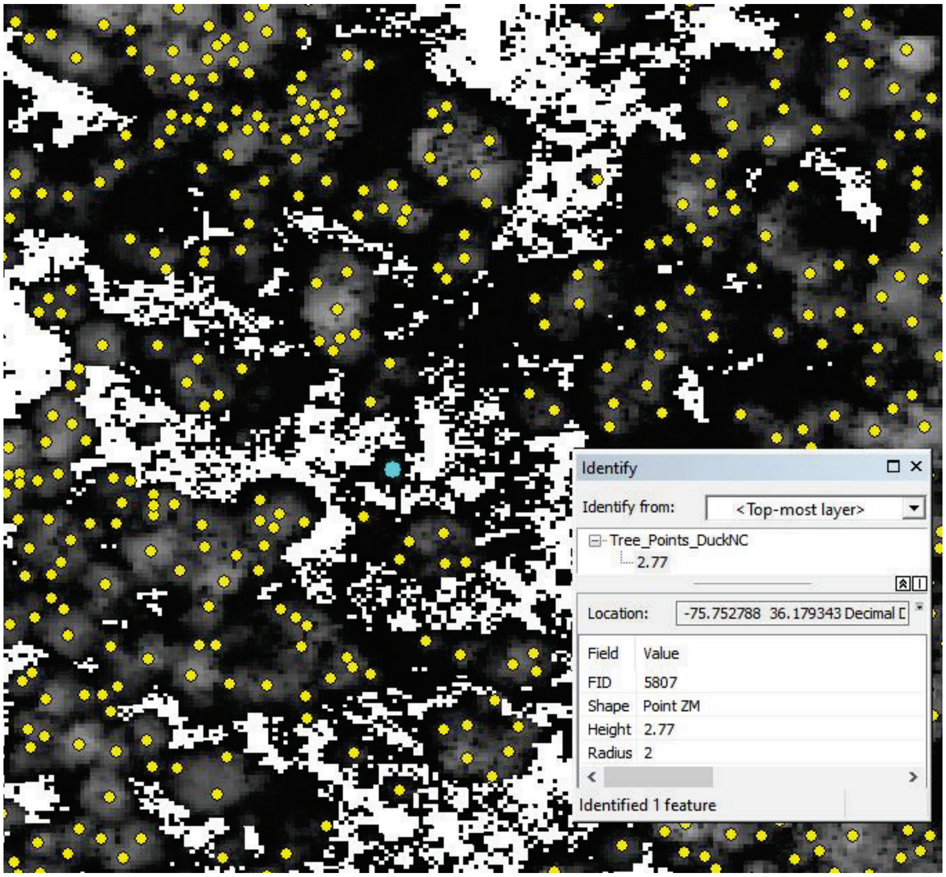
[*] www.asprs.org

Figure 6. Woody stem locations (*yellow points*) with stem height (m) and crown radius (m) attributes with the 1 m Canopy Height Model (CHM) displayed as a base layer in grayscale.



Identify

Identify from: <Top-most layer>

Tree_Points_DuckNC
  2.77

Location: -75.752788 36.179343 Decimal D

Field	Value
FID	5807
Shape	Point ZM
Height	2.77
Radius	2

Identified 1 feature

3 Geoprocessing Toolbox

An ArcGIS Pro geoprocessing toolbox was developed to streamline the implementation of dune vegetation metric extraction methodologies from NCMP hyperspectral imagery and lidar LAS files. The user-friendly toolbox was developed and tested for use in ArcGIS Pro (version 2.6) geospatial analysis software in a Windows 10 desktop environment. The custom toolbox was designed with Python programming language and integrates ArcGIS Pro geoprocessing tools with ENVI image analysis software capabilities to enhance spatial analytics and spectral band math algorithms used to derive the metrics. The tool is intended for moderate to advanced ArcGIS Pro users with knowledge of remote sensing.

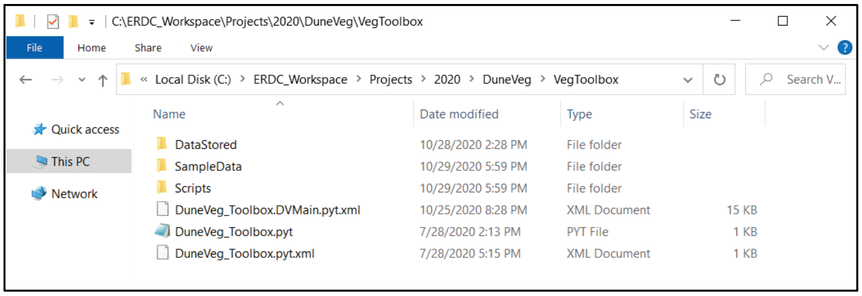
3.1 System requirements

The toolbox requires a Windows 10 operating system environment, an Advanced ArcGIS license with Spatial Analyst Extension, Python version 3.6.10, and ENVI license 5.4 version or greater. Python is automatically installed and available for use with ArcGIS Pro during the default installation, however, additional python client libraries (envipyarc and Cython) are needed for ENVI's full interoperability with ArcGIS.

3.2 Installation and configuration

The toolbox package, stored as a zip file, should be saved locally on the user's desktop computer. Once the necessary files are extracted from the compressed folder, the vegetation tools are available for use and accessible for operation once the ENVI Py module is installed and configured properly. See Figure 7 for an example of the tool file structure and folder contents.

Figure 7. Compiled dune vegetation tool package and associated file structure.

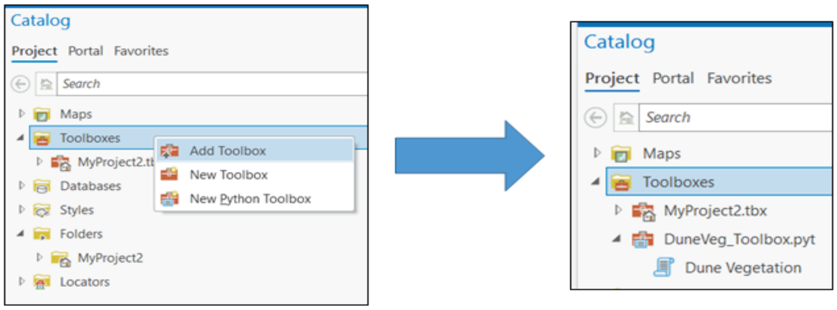


Name	Date modified	Type	Size
DataStored	10/28/2020 2:28 PM	File folder	
SampleData	10/29/2020 5:59 PM	File folder	
Scripts	10/29/2020 5:59 PM	File folder	
DuneVeg_Toolbox.DVMain.pyt.xml	10/25/2020 8:28 PM	XML Document	15 KB
DuneVeg_Toolbox.pyt	7/28/2020 2:13 PM	PYT File	1 KB
DuneVeg_Toolbox.pyt.xml	7/28/2020 5:15 PM	XML Document	1 KB

To install and enable the ENVI Py module for ArcGIS functionality in ArcGIS Pro, the envipyarc and Cython python libraries will need to be installed on the user's computer. First, open the *Python Command Prompt* by right clicking the application located within the ArcGIS suite of tools under the Start Menu and select "run as the administrator." From the prompt, issue the command *pip install envipyarc* to install the ENVI Py module. Once installed, enter the command *pip install Cython* to install the C compiler extension for Python (Cython). Next, follow the instructions for installation and configuration of the envipy module detailed in ENVI Py for ArcGIS document available on L3 Harris Geospatial Solutions website https://envi-py-for-arcgis.readthedocs.io/en/latest/ (L3 Harris 2020).

To add the dune vegetation toolbox to ArcGIS Pro, open the *Catalog* window; right click on *Toolboxes*; and select *Add Toolbox*. Navigate to the location where the dune vegetation toolbox was saved locally. Select the DuneVeg_Toolbox.pyt and click *OK* to add to the *Toolboxes* node (Figure 8). Prior to running the toolbox, ensure the Spatial Analyst Extension is activated and the correct python environment, with ENVI Py installation, is selected in the python package manager.

Figure 8. Load dune vegetation toolbox into ArcGIS Pro.

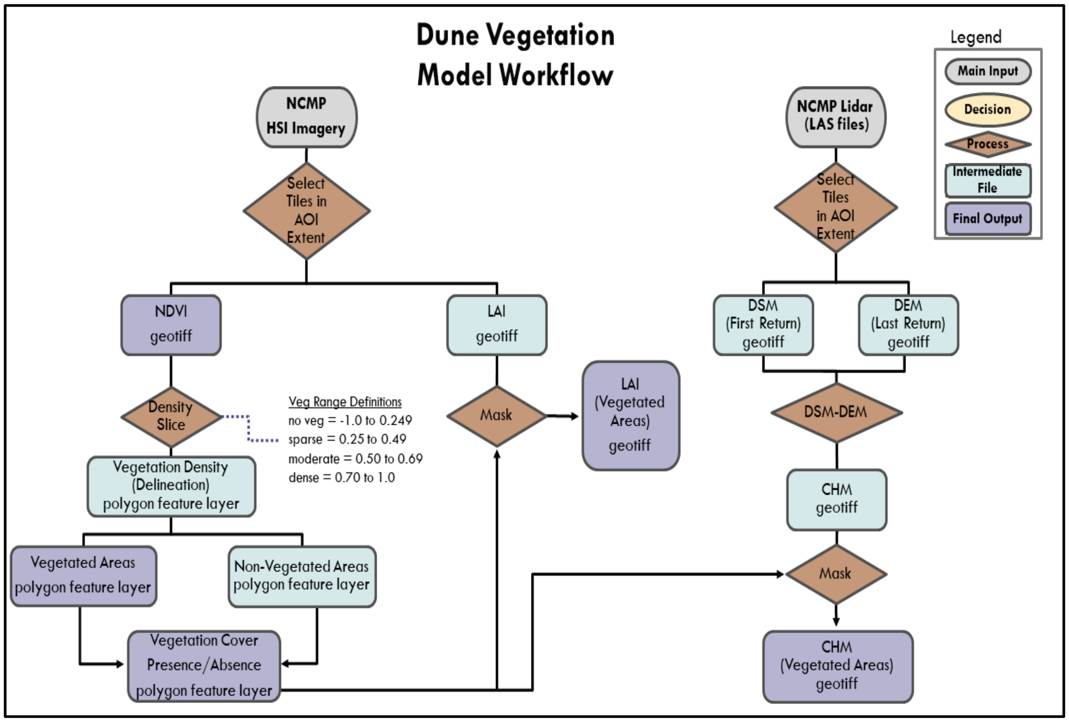


3.3 Toolbox workflow

The goal of the toolbox is to standardize the metric methodologies and automate repetitive tasks. Figure 9 displays the automated geoprocessing tool workflow for extracting dune vegetation metrics using batch processing. Two main inputs accepted into the tool are the NCMP hyperspectral imagery and lidar point cloud data. Each input's workflow creates a list of tiles from a file folder that overlaps the desired area of interest polygon. Then select metrics for each file in the list are generated. The LAI and NDVI files are created from hyperspectral imagery using

ENVI spectral band algorithms. The NDVI imagery is reclassified using ArcGIS Reclassify tool into vegetation densities which is further consolidated into vegetation presence/absence ESRI polygon features. The lidar workflow creates a DSM (first returns) and a DEM (last return/ground [class 2]) using the ArcGIS LAS Dataset to Raster tool with average linear binning interpolation for each file in the lidar point file list. The canopy height model is generated as the difference between the DSM and DEM via ArcGIS Raster Math. Finally, the vegetation presence polygon features are then used as a mask to clip all metric outputs so only vegetated areas are present.

Figure 9. Dune vegetation toolbox workflow.



3.3.1 Toolbox data input

3.3.1.1 Area of Interest polygon (AOI)

The Area of Interest represents the analysis area's spatial extent either drawn onto the map view or added as an ESRI polygon shapefile or geodatabase feature layer. The polygon must have a defined spatial reference. The tool uses the polygon extent to select and create a list of overlapping raster and/or LAS data files from a folder.

3.3.1.2 NCMP hyperspectral image

The NCMP hyperspectral images are multiband data containing 48 spectral bands ranging from 380 to 1,050 nm wavelengths. A header file containing the appropriate band numbers and associated band wavelengths are required for all hyperspectral imagery used in the tool. If the header information is not present, the tool will return an error message to the user. All raster file formats supported by ArcGIS (i.e., geotiff, img, dat, ESRI GRID) are accepted as input. Prior to input, the image must have a defined spatial reference.

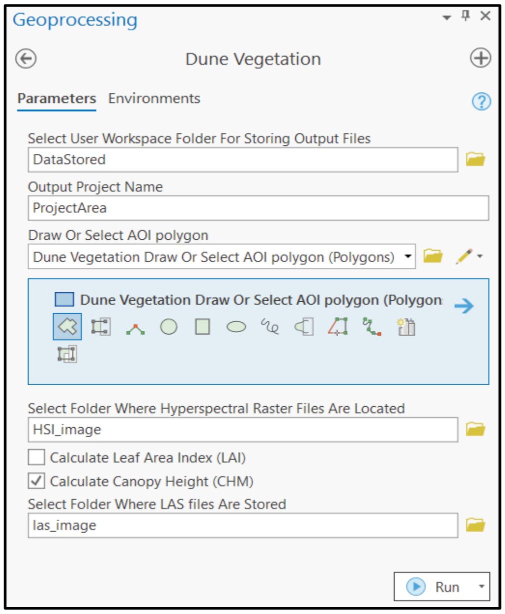
3.3.1.3 NCMP lidar data

The tool uses lidar data stored in a .las file format and contains classified data. Minimum point classification level should be ground and nonground; and include first and last return points. Prior to input, the las data file must have a defined spatial reference.

3.3.2 Toolbox usage

To open the dune vegetation toolbox dialog box, double-click the *Dune Vegetation* tool under the DuneVeg_toolbox.pyt on the *Toolboxes* Node (Figure 10).

Figure 10. Dune vegetation toolbox dialog box.



Select User Workspace Folder For Storing Output Files: DataStored

Output Project Name: ProjectArea

Draw Or Select AOI polygon: Dune Vegetation Draw Or Select AOI polygon (Polygons)

Dune Vegetation Draw Or Select AOI polygon (Polygon

Select Folder Where Hyperspectral Raster Files Are Located: HSI_image

☐ Calculate Leaf Area Index (LAI)

☑ Calculate Canopy Height (CHM)

Select Folder Where LAS files Are Stored: las_image

Next, follow the steps below which describe the inputs and analysis.

1. **Select User Workspace Folder for Storing Output Files:** Select the folder location to store the output dune vegetation metric data. The tool will automatically create the following output folders in this location based on checkboxes selected and if the folders do not already exist: NDVI, VegCover, VegDensity, LAI and ElevModels.
2. **Output Project Name:** Provide a name for your project (i.e., Garden City Beach). In the tool, a geodatabase will be created with the project name (i.e., GardenCityBeachDVprj.gdb). It will automatically remove spaces and special characters from the name. If the project name already exists, an error message will prompt the user to enter a unique name.
3. **Draw or Select Area of Interest (AOI) polygon:** The user must either draw an area of interest on the map view or select an existing polygon feature class. The polygon AOI will be stored in the workspace defined in step 1 within the geodatabase created in step 2. It will also serve as the spatial extent used to create a list of all appropriate overlapping tiles from the hyperspectral imagery and/or lidar las file folders selected in steps 4 and 7.
4. **Select Folder Where Hyperspectral Raster Files are Located:** From the folder icon, browse to and select the folder where the hyperspectral raster files are located. The hyperspectral files must contain a header with band numbers and wavelengths. For each raster file in this folder that overlaps the AOI, a NDVI raster, Veg Density shapefile, and Veg Presence/Absence shapefile are automatically generated. The LAI will be created only if the checkbox in step 5 is selected. The following methods are used to generate output files:
5. NDVI uses ENVI's Spectral Index within the ArcGIS Pro environment where the NIR and Red wavelength bands are automatically selected when generating output with the formula shown in Equation 1.
6. Vegetation densities are generated by reclassifying the NDVI image using ArcGIS Pro's *Reclassify* command. The values ranges are defined as -1.0 to <0.25 as no vegetation, 0.25 to <0.50 as sparse vegetation, 0.50 to <0.70 as moderate vegetation and, 0.70 to 1.0 as dense vegetation. The reclassified file is converted to an ESRI shapefile containing two fields "vegden" (vegetative density) and "vegpa" (vegetation presence/absence).
7. Vegetation presence/absence ESRI shapefile (VegPA.shp) is generated using the ArcGIS Pro's *Dissolve* command on the vegetation density shapefile field name "vegpa". Next, a raster mask is generated from the vegetation presence polygon features in the shapefile using the same

pixel cell size and spatial reference and snapped to the associated NDVI created in steps 4a.

8. The NDVI image is clipped to the vegetation presence mask and stored in the NDVI folder with the filename ending in "NDVI_veg.tif"
9. **Calculate Leaf Area Index (LAI) checkbox:** When the box is checked, the LAI will be calculated on all hyperspectral images under the folder selected in step 4 that overlap the AOI.
10. The LAI used ENVI's Spectral Index, LAI task within the ArcGIS Pro environment where NIR, Red, and Blue wavelength bands are automatically selected through the tool use. Refer to Equations 2 and 3 for more information on how the metric is calculated.
11. For the hyperspectral imagery, the presence/absence raster mask created in step 4c will be used to clip the LAI file so that only LAI for vegetated areas is stored as output. The output raster files are stored in the LAI folder with the filename ending in "LAI_veg.tif".
12. Calculate Canopy Height Model (CHM):
13. When checked, the *Select folder dialog box where LAS files are stored* input will be enabled. This option will allow the DEM, DSM, and CHM raster files to be calculated on all raster images under the folder selected in step 7 that overlaps the AOI.
14. Select Folder Where LAS Files are Stored:
15. From the folder icon, browse and select the folder where the lidar las files are located. For each LAS file in the folder that overlaps the AOI, a DEM, DSM, and CHM are generated and stored in the ElevModels folder under the workspace selected in step 1.
16. DEM uses the ArcGIS Pro *LAS Dataset to Raster* method to create a bare earth raster using the classified LAS point cloud last return features. The average linear binning method creates a gridded raster file where all points that fall within each grid will be averaged to create a bare earth value for each grid cell.
17. DSM uses the ArcGIS Pro *LAS Dataset to Raster* method with using average linear binning interpolation to create a top of surface raster using the first return points from the classified las point cloud.
18. CHM uses the ArcGIS Pro *Raster Math* function to produce the difference between the DSM and DEM.
19. The tile name in the CHM file name is matched to the associated tile name in the dune vegetation presence raster mask created in step 4c and used to clip the CHM file to vegetated areas. The output file is stored in the ElevModels folder with the filename ending in "CHM_veg.tif".

4 Conclusion

Vegetation plays a crucial role for determining how coastal processes affect the land-water interface, in terms of erosion control, dune stability, and overall coastal stability. Therefore, it is important for coastal managers to rapidly and accurately quantify the vegetation present along the coastline. The tools developed as part of this research effort will provide high priority metrics for assessing vegetation presence in a coastal environment. This research also helps coastal managers quantify dune plant biological metrics to improve future estimates and predictions of storm processes and impacts. It will advance existing dune and coastal wetland system knowledge involving remote sensing techniques for developing new methodologies to classify, quantify, and estimate critical dune vegetation metrics.

Many coastal numerical models that study wave dissipation rely on estimates of vegetation metrics like those derived from this research effort. However, very limited data exists that are useful as inputs to these models, particularly for large scale or regional coastal projects, and many models incorporate synthetic vegetation data or constant values as inputs. Wave attention through vegetation is a highly variable function of not only hydrodynamics, but also of general vegetation characteristics. Recent studies have updated models that account for wave interactions using spatially explicit and variable vegetation characteristics as inputs (Anderson et al. 2013). The coastal vegetation metrics generated from the semiautomated tools presented herein will provide some of the necessary data inputs that these models require. Furthermore, refining the numerical model input requirements is important; however, additional research is needed to evaluate these vegetation products with an emphasis on quantifying model performance and accuracy relative to existing data model inputs.

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Monitoring and modeling of coastal vegetation and ecosystems are major challenges, especially when considering environmental response to hazards, disturbances, and management activities. Remote sensing applications can provide alternatives and complementary approaches to the often costly and laborious field-based collection methods traditionally used for coastal ecosystem monitoring. New and improved sensors and data analysis techniques have become available, making remote sensing applications attractive for evaluation and potential use in monitoring coastal vegetation properties and ecosystem conditions and changes. This study involves the extraction of vegetation metrics from airborne lidar and hyperspectral imagery (HSI) collected by the US Army Corps of Engineers (USACE) National Coastal Mapping Program (NCMP) to quantify coastal dune vegetation characteristics. A custom geoprocessing toolbox and associated suite of tools were developed to allow inputs of common NCMP lidar and imagery products to help automate the workflow for extracting prioritized dune vegetation metrics in an efficient and repeatable way. This study advances existing coastal ecosystem knowledge and remote sensing techniques by developing new methodologies to classify, quantify, and estimate critical coastal vegetation metrics which will ultimately improve future estimates and predictions of nearshore dynamics and impacts from disturbance events.

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