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The 2008 Terrestrial Vegetation of Biscayne National Park, FL, USA Derived From Aerial Photography, NDVI, and LiDAR

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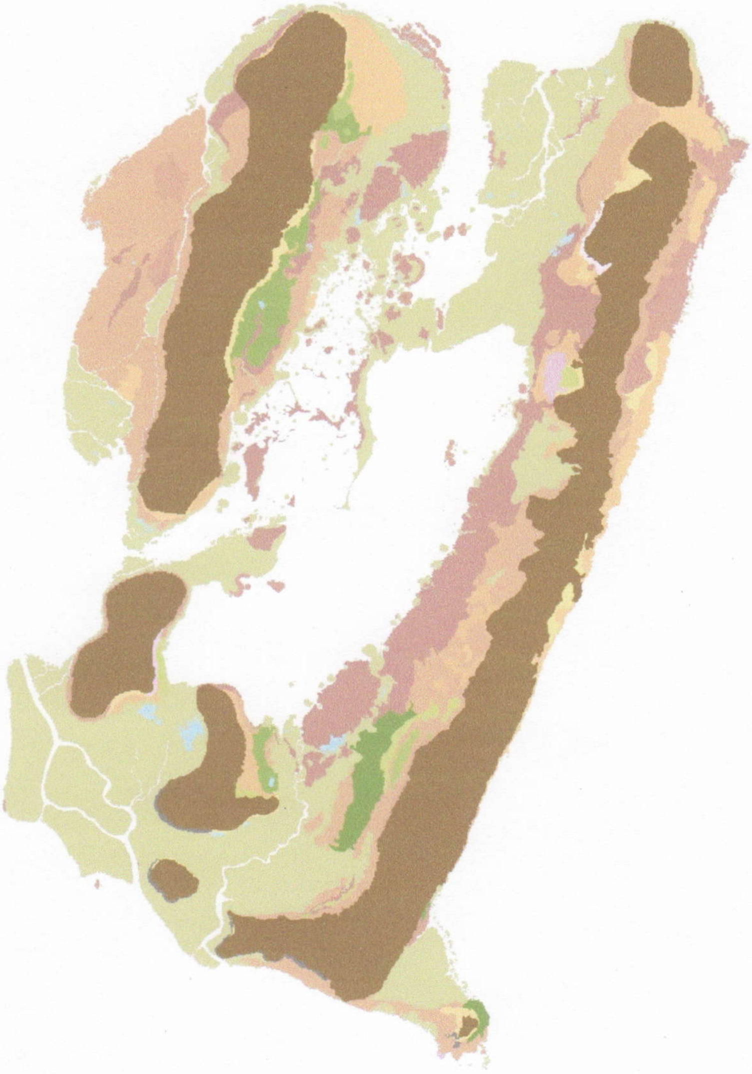

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Executive Summary:

Established as a National Park in 1980, Biscayne National Park (BISC) comprises an area of nearly 700 km^2, of which most is under water. The terrestrial portions of BISC include a coastal strip on the south Florida mainland and a set of Key Largo limestone barrier islands which parallel the mainland several kilometers offshore and define the eastern rim of Biscayne Bay. The upland vegetation component of BISC is embedded within an extensive coastal wetland network, including an archipelago of 42 mangrove-dominated islands with extensive areas of tropical hardwood forests or hammocks. Several databases and vegetation maps describe these terrestrial communities. However, these sources are, for the most part, outdated, incomplete, incompatible, or/and inaccurate. For example, the current, Welch et al. (1999), vegetation map of BISC is nearly 10 years old and represents the conditions of Biscayne National Park shortly after Hurricane Andrew (August 24, 1992). As a result, a new terrestrial vegetation map was commissioned by The National Park Service Inventory and Monitoring Program South Florida / Caribbean Network.

A vector map was developed using: a comprehensive set of 2005 5-band (Red, Green, Blue, NIR, and Pan-Chromatic) 30cm pixel aerial photographs; NDVI (calculated from the 2005 aerials); 2002 LiDAR data, available only for mainland portions of BISC; and over 1,000 ground reference points. In general, NDVI helped delineate low productivity zones (Mangrove Scrub) and Non-Vegetative features from adjacent Shrubland and Forest communities. The availability of LiDAR for the mainland proved invaluable and greatly enhanced the overall map resolution and accuracy. In conjunction with traditional aerial photo-interpretations, *Definiens Professional*® v5 remote sensing software was used to create 1:300 scale shorelines. However, we failed to derive an algorithm in *Definiens Professional*® v5 capable of consistently and accurately segmenting the varied community types found in this region. Vegetation communities were classified to the highest feasible level of resolution within a six-tiered hierarchical vegetation classification system. Level 3 of the hierarchy was the minimum resolution accepted, but some communities were mapped to Level 6. However, not all communities mapped or observed in the field were described in the original classification system. As a result, we modified the classification system, adding previously undescribed units where necessary. Forty-two community types were identified and mapped at Level 3. At Level 6, 90 different community types were mapped. The total area mapped was 35.2 km^2, of which 31 km^2 were within the borders of BISC.

By providing a spatial inventory of the plant communities within the BISC, this map, along with existing data, will allow resource managers to effectively focus their restoration efforts and resources on communities that are indicative of relic or pristine conditions, or communities that are likely to benefit the most from active management. Furthermore, this map, with its 1:300 scale shoreline, serves as a turn-of-the-century baseline for the extent of mangroves within Biscayne National Park and, as a result, can be used to monitor the effects of sea-level rise on the wetlands and forested communities of Biscayne National Park for years to come.

Introduction:

Established as a National Park in 1980, Biscayne National Park (BISC) is the largest marine park in North America. It comprises an area of nearly 700 km^2, of which 95% is under water (Figure 1). The remaining 5% consists of uplands embedded within the Biscayne Bay Coastal Wetlands (BBCW), a network of freshwater and brackish wetlands along the western shore of Biscayne Bay, and within a set of Key Largo limestone (Stephenson & Stephenson 1950) barrier islands that parallel the mainland several kilometers offshore and define the eastern rim of Biscayne Bay (Figure 1). While these terrestrial communities are limited in area, about 31 km^2, they extend over many kilometers and account for a significant portion of the Park's biodiversity, which includes many threatened and endangered species of both flora and fauna. Mangrove communities (forest, woodland, shrubland, and scrub) are by far the most abundant vegetation type found within BISC. Coastal Hardwood Hammocks are another important community type found within BISC, which are often overlooked. However, in contrast to the mangrove communities that are found throughout the Park, Coastal Hardwood Hammocks are restricted to the highest elevations within 11 of 42 mangrove-dominated islands found in BISC.

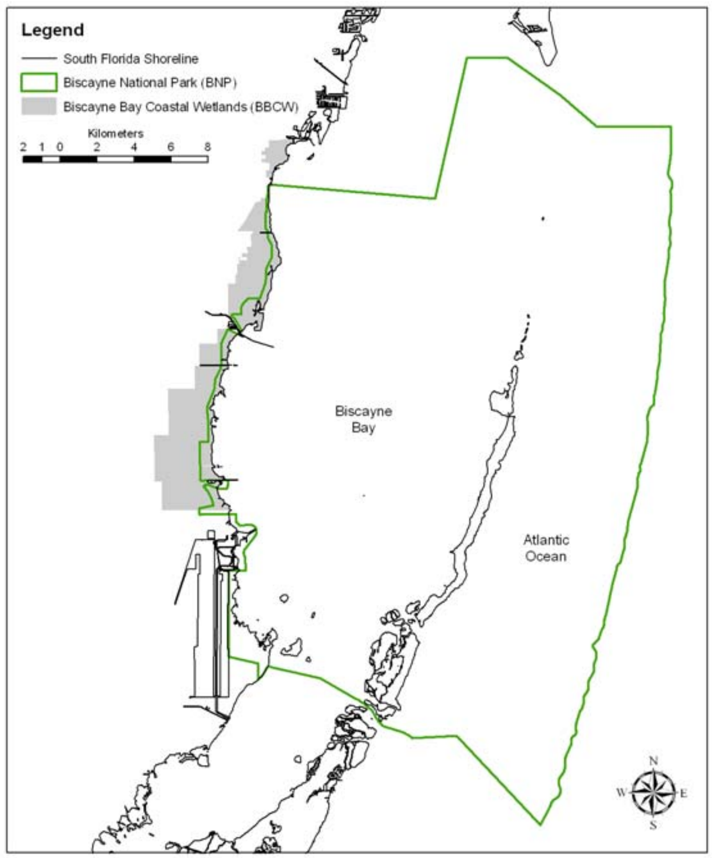

Figure 1: Boundary of Biscayne National Park, Homestead, FL., USA.

Not unlike other natural areas under the stewardship of the National Park System, BISC has endured many years of neglect and abuse by homesteaders and developers who, prior to the establishment of Biscayne National Monument in 1968, had free reign of the area and in many cases successfully drained, cleared, farmed, and developed much of these environmentally sensitive and ecologically important lands. During the latter part of the 1800's, pineapple and lime plantations were common throughout the Florida Keys including many of the islands now part of BISC (Leynes and Cullison 1998). Along with pineapples and limes, other fruits and vegetable were grown on the highly organic and productive soils associated with the Coastal Hardwood Hammock community. As a result, many acres of virgin Coastal Hardwood Hammock were cleared for cultivation and homesteads within BISC (Leynes and Cullison 1998). In the 1920's, Boca Chita, Adams, and Elliott Key were enlarged (Leynes and Cullison 1998) as developers sought to take advantage of the growth and prosperity of Miami Beach and the surrounding areas as a vacation resort. In conjunction with the homesteaders and on the bequest of developers, public works projects dating back to the early 1900's for the purpose of mosquito control, land reclamation, and storm surge protection combined to compartmentalize and further alter the natural vegetation of BISC (Ruiz & Ross 2004).

Fortunately, 28 years of mitigation efforts have significantly improved the conditions of BISC. However, as a consequence of these historical land management practices, Biscayne Bay and the BBCW have become hydrologically isolated from the interior freshwater watershed that once flowed freely by sheet flow from the Everglades through the transverse glades (Ruiz & Ross 2004). As a result, there has been a marked decrease in the volume and kinetics of freshwater runoff into Biscayne Bay via tidal creeks and springs (Gaiser et al. 2005). This, in turn, has altered the natural seasonal variability of surface water salinities throughout the coastal wetland ecotone of BISC (Gaiser et al. 2005). All of these factors, in conjunction with the steady rise in sea level over the last century (2.2 mm/yr, Ross et al. 1994), have yielded large-scale changes in the composition and structure of the vegetation communities within the mainland portions of BISC. The offshore upland communities of BISC have benefited from their general isolation from the mainland and appear to have, for the most part, returned to a natural state. However, there is still clear evidence of historical anthropogenic perturbations throughout these islands.

Topo-lithographic maps of the Park based on 1928 aerial photographs date back to the early 1930's (Figure 2). Though not intended to be used as vegetation maps, these 1:20,000 scale topographic sheets are likely the first comprehensive vegetation maps that exist of BISC. These topographic sheets depict the vegetation of the BBCW and BISC as a mosaic of broad scale community types characterized by deciduous hammocks, high ground deciduous (forests), mangroves, sawgrass on rock, and sloughs and document the extent of anthropogenic alteration in these natural areas for the period. Other maps of BISC include the 1943 and 1967 maps of Davis, the 1999 Florida statewide water management district land cover map, and the 2007 National Wetland Inventory map, among others. Unfortunately, all of these mapping efforts failed to capture the natural complexity and structure of the vegetation communities of the BBCW and BISC, in particular. To date, the only two mapping efforts which have succeeded at capturing the nature of the vegetation within BISC are the 1999 vegetation map of Welch et al. (1999) (Figure 3) and the 2002

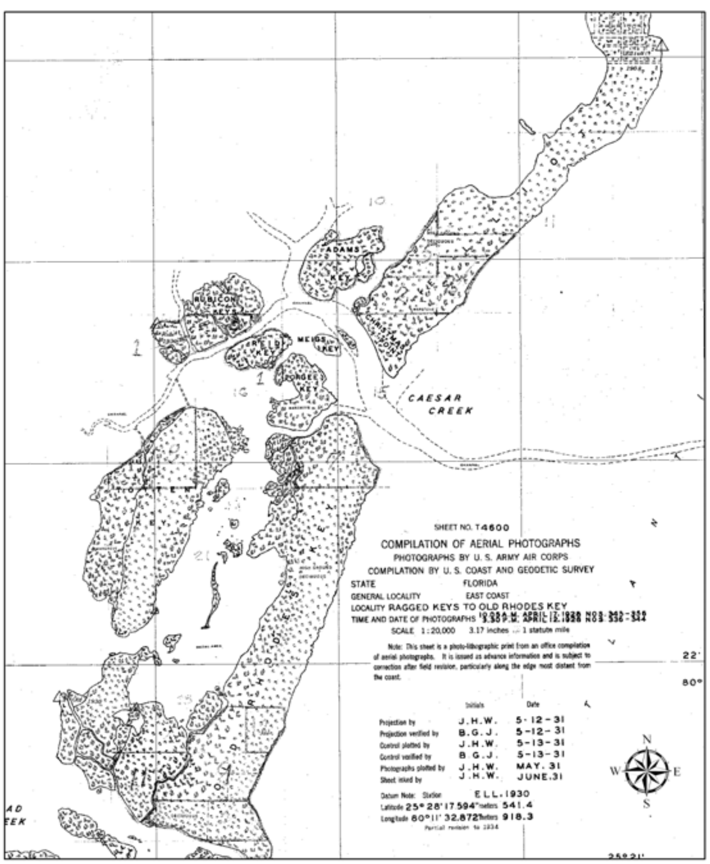

Figure 2: 1931 topo-lithographic sheet of Old Rhodes Key and Totten Key visinity based on 1928 aerial photographs.

vegetation map of Ross and Ruiz (2003) (Figure 4). Unfortunately, the Welch et al (1999) map is plagued with many commission and omission errors, is nearly 10 years old, and represents the conditions of BISC shortly after Hurricane Andrew (August 24, 1992). The 2002 Ross and Ruiz (2003) map, on the other hand, while spatially and thematically accurate, was limited in area and only included a small portion of the Park along its western shore (Figure 4). In 2006, because of the lack of a current, accurate, and useful vegetation map of BISC, the National Park Service Inventory and Monitoring Program South Florida / Caribbean Network commissioned the development of a spatially and thematically accurate vegetation map of BISC. This map, when completed, will provide a spatial inventory of the plant communities within the Park's jurisdiction with a level of accuracy suitable for planning, implementing, and quantifying management decisions and restoration efforts for the next several decades.

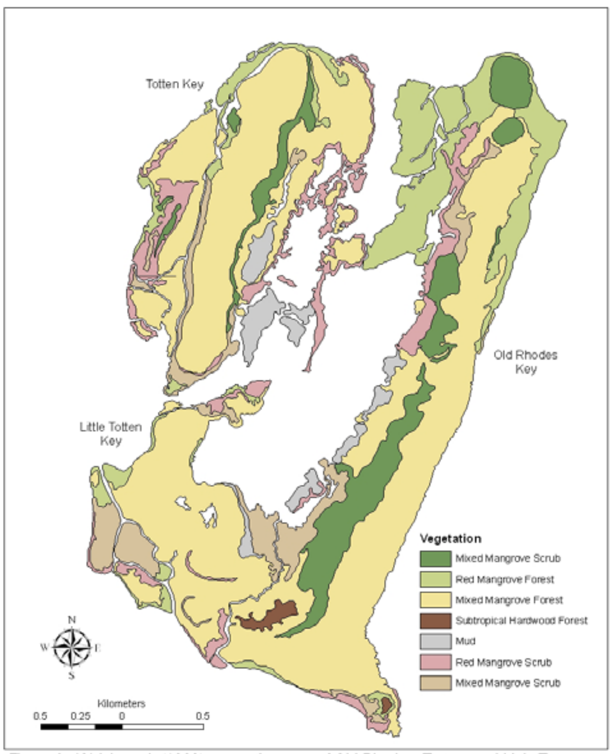

Figure 3: Welch et al. (1999) vegetation map of Old Rhodes, Totten, and Little Totten Keys, Biscayne National Park, Homestead, FL., USA.

Figure 4: Ross and Ruiz (2003) vegetation map of the Biscayne Bay Coastal Wetlands between the Princeton and Mowry Canals, Homestead, FL, USA

Methods:

This project called for the creation of a spatially and thematically accurate vector map of the terrestrial communities of Biscayne National Park. As a result, a map was developed using traditional aerial photo-interpretation techniques, in conjunction with *Definiens Professional*® v5 remote sensing software (Definiens Imaging, 2006), NDVI calculated from the Red and NIR bands of each orthophoto, and LiDAR available for mainland portions of the Park through Florida International University (IHRC 2004). Vegetation communities or polygons were screen-digitized using ESRI® ArcMap™ 9.2 and stored in a Personal Geodatabase. The map is projected to NAD83, UTM Zone 17N (units = meters). The minimum mapping unit was set to 400 m^2, but notable objects smaller than 400 m^2 were sometimes mapped based on the photo-interpreter's discretion. Digitized polygons were classified to the highest feasible level of resolution within the six-tiered hierarchical vegetation classification system developed by Rutchey et al. (2007) v5.22.07. Level 3 of the hierarchy was the minimum resolution required for this mapping project. However, some communities were mapped to Level 6. This map is expected to have a classification accuracy, at Level 3, of no less than 80% with 90% confidence. In addition, the expected minimum positional accuracy for well-defined objects was set at ± 5.0 meters of their actual location.

Imagery:

The Fish and Wildlife Research Institute – Florida Fish and Wildlife Conservation Commission, provided the imagery used in this project. The imagery consists of a set of 316 images taken by Photo Science in May 2005. The images are a 5-band (RGBNIRPan) stacked multispectral orthophoto derived from three separate products. The first consist of a Red-Green-Blue (RGB) product; the second a Color-Infrared (RGNIR) product from which the redundant red and green bands were dropped; and the third a panchromatic (Pan) product. According to the metadata, the images were flown at an averages altitude of 3,142.2 m which produces an image scale of 1:26,185. Each image covers an area of about 10.5 km^2 with an average overlap of approximately 23% between adjacent images. The images are projected to NAD83 UTM Zone 17N and have a spatial resolution of 0.3048 meters. Regrettably, these images are neither spectrally calibrated nor geometrically correct. The calibration issue is the more serious problem in this project, since the lack of spectral correction results in glare and white-outs on bare-ground and water, and in identical vegetation communities having different spectral properties within and across images (Figure 5). The lack of geometric correction caused objects to lean outward from the principal point of the image, even though these images were visually checked against themselves, DOQQs, and different shorelines for planimetric accuracy. As a result, overlapping scenes or pixels from adjacent images were not coincident.

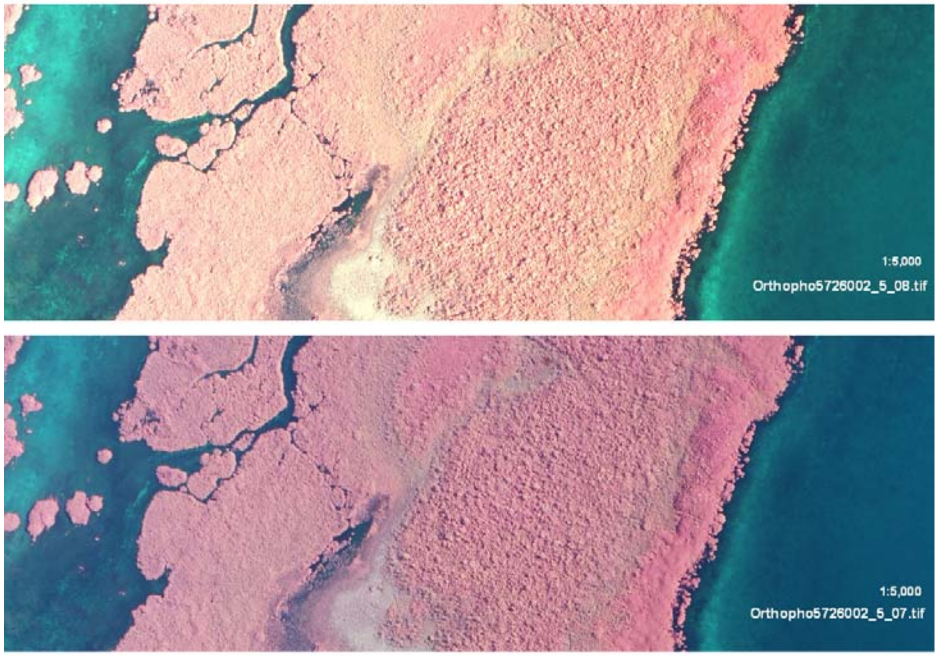

Figure 5: Spectral difference between overlapping adjacent images at 2 standard deviations.

Vegetation Classification System:

Vegetation communities within BISC were classified to the highest feasible level of resolution within the six-tiered hierarchical vegetation classification system developed by Rutchey et al. (2007) v5.22.07. Level 3 (**L3 - Group**) of the hierarchy is the minimum resolution required for this mapping project. However, some communities were mapped to Level 6 (**L6 – Alliance**). Not surprisingly, not all communities registered on the orthophotos, observed in the field, and mapped were listed within this classification system. At the same time, many of the communities listed in the Rutchey et al. (2007) classification system were not observed within the boundaries of BISC. As a result, the classification system used in this project was modified to include all new community types observed and mapped and excluded types not present within the mapping area. Twenty-one new plant community types were added: 7 at Level 3, 5 at Level 4, 8 at Level 5, and 1 at Level 6 (see Appendix 1). Three other modifications were introduced to the Rutchey et al. (2007) classification system.

The first of these was the renaming and restructuring of the original Level 1 *Non-Vegetative* Class to *Other*. This new Level 1 *Other* class was then subdivided into two separate categories at Level 2: *Non-Vegetative* and *Anthropogenic*. This restructuring permits the discrimination, at Level 3, between non-vegetative natural environments (e.g. *Beach*, *Mud*, & *Water*) and environments, either vegetated or not, (e.g. *Lawns & Landscaping*, *Agriculture*, *Parking Lots*, & *Road*) that result from anthropogenic activities. The second modification was the standardization, wherever possible, of Raster ID's so that a species or community type would always be represented by the same number combination. For example, in the Rutchey et al. (2007) classification system, the following Raster ID's 114000, 315000, and 414000 represent the following three red mangrove communities': Forest, Shrubland, and Scrub, respectively.

By standardizing the 4th digit of each Raster ID, in this case to 4, we are able to discern quite easily that the following Raster ID's: 114000, 214000, 314000, and 414000 all represent a community type dominated by red mangrove. The third modification was the removal of blank categories between subordinate levels in the classification system. Aside from these exceptions, the new abridge version of the Rutchey et al. (2007) classification system (Appendix 1) keeps true to the original structure and hierarchy. However, since the Rutchey et al. (2007) classification system was design as an all-encompassing vegetation classification system for Southern Florida it was necessary, in some cases, to append the original community descriptions so that they would be less ambiguous and more relevant to this project (see descriptions below).

At the highest level of the hierarchy, Level 1 (**L1 – Class)**, the new abridged classification system (Appendix 1) has the following structure and requirements:

- **Forest**: High-density stands of trees (>50% tree canopy cover) with heights > 5 meters
- **Woodland**: Low-density stands of trees (10 - 60% tree canopy cover) with heights > 5 meters in a matrix of shrubs, graminoids, and/or herbaceous vegetation.
- **Shrubland**: Stands of small trees and/or shrubs (canopy cover ≥ 50%) with heights < 5 meter tall.
- **Scrub**: Communities of dwarf trees or shrubs typically in a matrix of graminoids, and/or herbaceous vegetation. Canopy cover 10% to 50% but can be as high as 100% for Mangrove. Canopy < 5 meters tall with the exception being for Mangrove which is ≤ 2 meters.
- **Marsh**: Graminoid and/or herbaceous emergent or floating vegetation in shallow water that stands at or above the ground surface for much of the year.
- **Dune**: A ridge of wind blown or windstorm deposited sand or similar material directly inland and parallel to the shoreline which is commonly vegetated by graminoids and/or herbs and sometimes even shrubs.
- **Submerged Aquatic Vegetation**: Vegetation that has evolved the ability to carry out its entire life cycle completely submerged in an aquatic environment.
- **Exotic**: Non-native and invasive vegetation.
- **Other**: Non-vegetative or anthropogenic cover.

The next level in the hierarchy, Level 2 (**L2 – Type)**, modifies the structurally-defined Level 1 with a community designation, for example, *Mangrove Forest* vs *Hammock Forest* or *Mangrove Shrubland* vs *Upland Shrubland*. At Level 3 (**L3 – Group)** the classification system often requires that the previous level (**L2 – Type**) community types be identified by dominant species, such as *Black Mangrove* or *Buttonwood Forest* or *Red Mangrove* or *White*

Mangrove Shrubland, for example. However, this is not always the case. For example, at Level 3, *Hammock Forest* can be subdivided into *Coastal Hardwood Hammocks* or *Coastal Dune Hammocks*. A similar situation occurs within the Level 2 *Salt Marsh* and *Freshwater Marsh* types. At Level 3, these two types are differentiated based on morphological traits like graminoids, herbaceous, or succulent for Salt Marsh or by Marsh or Prairie for Freshwater Marsh. The remaining three levels of the classification system (**L4 - Formation**, **L5 – Alliance**, & **L 6 – Association**) continue to subdivide the previous community types by dominant canopy species composition and than by understory species assemblages; for example, a Level 6 mangrove scrub community might have the following nomenclature *Buttonwood-White Mangrove Scrub-Glasswort*.

Shoreline Segmentation – Definiens Professional® v5:

Definiens Professional® v5 remote sensing software was incorporated into this project as an exploratory methodology for standardizing and automating the digitization of vegetation communities into polygons. For mapping vegetation, *Definiens Professional*® v5 was mostly unproven but offered tremendous benefits as a remote sensing tool. In contrast to traditional remote sensing software in which an image is classified at the pixel level, *Definiens Professional*® v5 classifies images in terms of image objects and their mutual relationships. In other words, pixels with similar brightness values and/or other characteristics are aggregated into image objects. These image objects are then the target of the classification process and not the pixels themselves. Image objects within *Definiens Professional*® v5 are derived by one of three distinct segmentation algorithms: chessboard segmentation; quadtree based segmentation; or multiresolution segmentation. For this project, all image objects were derived using the multiresolution segmentation. This algorithm is a heuristic optimization procedure that locally minimizes the average heterogeneity of image objects for a given resolution (Definiens 2006). Image objects derived from this methodology are created based on three criteria: scale, color, and shape. The scale parameter is an abstract terms that determines the maximum allowed heterogeneity within image objects and their average size (Definiens 2006). Color and shape are mutually exclusive weighted parameters that determine which heterogeneity attributes are minimized during the segmentation process (Definiens 2006). Color emphasizes how brightness values within layers will contribute to the entire homogeneity criterion. On the other hand, shape, composed of two weighted parameters: smoothness and compactness, defines the textural homogeneity of the image objects by either optimizing for smoothness or compactness. Segmentations weighted exclusively towards color result in spectrally homogeneous but spatially heterogeneous image objects, while, segmentations weighted towards shape result in image objects that are spatially homogeneous but spectrally heterogeneous. Regardless of the color weighting, image objects tend to follow natural features more closely when smoothness is emphasized over compactness (Benz et al. 2004).

Multiple exhaustive attempts where made using *Definiens Professional*® v5 to produce image objects that could be classified into distinct vegetation communities. However, it became clear, early on, that these segmentations efforts were accentuating the spectral variability of the imagery and not yielding objects that could be classified into distinctive vegetation communities based on a homogeneous spectral signature. Our efforts, however, showed that the land-water interface could be effectively and consistently segmented into image objects to create fine scale (1:300) shorelines.

Two similar, yet contrasting, methodologies were developed for the delineation of the land-water interface. The first methodology (Appendix 2) is a multifaceted segmentation algorithm modeled from the initial segmentation efforts designed to classify the varied vegetation communities within BISC. This methodology is described in Appendix 2. The second methodology was developed later in the project to: 1) quickly and efficiently recreate shorelines where the original segmentation was based on an image that was no longer deemed appropriate because of planimetric errors or unsuitable color balance; and 2) capture and preserve the fine scale details associated with small irregular mangrove islands or individual trees found on intertidal zones or shallow lagoons. This methodology, described below, while simplistic and straight forward, was as robust as the original segmentation algorithm and minimized the number of image objects needed to consistently segment land and water into image objects.

To minimize file size and processing time, only the Red and NIR spectral bands of each image were imported into *Definiens Professional®* v5. The NIR band was used to define the no data area. Based on the brightness values of the imported two bands the ratio NDVI (see NDVI methods section for equation and description and used of this ratio) was defined as an arithmetic custom feature. This ratio was later used in the sample editor to help classify the image objects. The next step was to define the scale, color, and shape parameters of the multiresolution segmentation. Because of the lack of spectral calibration, the scale parameter for each image segmentation was determined empirically. In general, the larger the scale parameter used the larger the image objects created. At the same time, the larger the scale parameter the fewer image objects created and the less time it takes to run a segmentation. As a result, the initial scale parameter for all segmentations were set to 100. Subsequent segmentations, if needed, were decreased systematically until they reached a minimum value of 10. Scale parameter values < 10 were impractical with this imagery because of the amount of processing time needed to perform the segmentation and the overwhelming number of image objects created, about 260,000 at this scale. In all cases, the Color parameter was set to 0.8, forcing the Shape parameter to 0.2, and the Compactness and Smoothness were set at 0.2 and 0.8, respectively. After the multiresolution segmentation was completed, a spectral difference segmentation was run to merge spectrally similar adjacent objects. In general, values between 2 and 5 were used. Values greater than 5 usually reduce the number of image objects by half but, as a result, merged too many image objects together and thus created many mixed image objects unsuitable for classification. The next step was to classify the image objects. Classification of the image objects was defined through a class hierarchy dialogue similar to Method 1 (Appendix 2). However, only two classes were used: Water and Land. The Water class has an explicit definition (NDVI less than an optimal value determined empirically for each image), whereas the Land class was defined as those image objects not classified as Water. Once the image objects were classified and the classification validated, the image objects were converted to polygons and merged into their respective classes; Water and Land. These merge features were than exported as a vector shapefile for final editing.

Within ESRI® ArcMap™ 9.2 the newly imported shapefile was converted into a grid and then back-converted into a shapefile for final validation and editing at a scale of 1:300. The reasoning behind this double transformation is as follows: Segmented image objects in *Definiens Professional*® v5 tend to be highly fractal (Figure 6a). The transformation to a grid and then back to a polygon has the effect of removing unnecessary vertices from the polygons and thus smoothing the overall shape of the polygons into slightly more realistic and aesthetically pleasing polygons (Figure 6b). Another advantage of this smoothing transformation is that by smoothing the overall shape of the polygons, shoreline errors that would normally have had to be manually corrected are, for the most part, processed automatically, thus saving precious time in the final editing session.

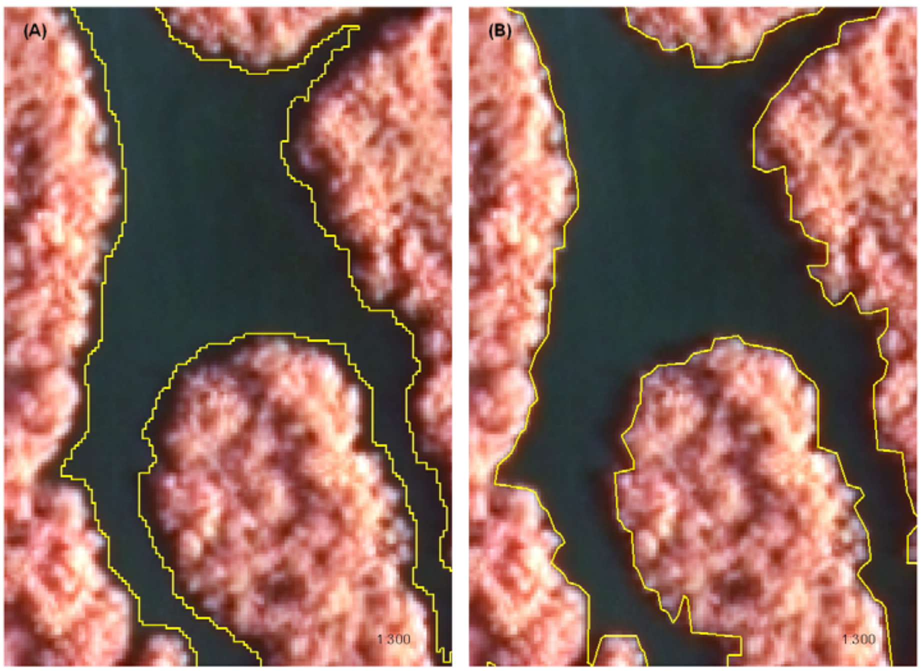

Figure 6: Contrast between shorelines without (A) and with (B) the smoothing transformation. See methods section for methodology.

NDVI:

The Normalized Difference Vegetation Index (NDVI) ratio was calculated for each image as a 1-band gray-scale raster in Erdas Imagine 9.1. NDVI is calculated by subtracting the Red spectral band from the NIR spectral band and than dividing this difference by the sum of the NIR and Red spectral bands (Equation 1).

Equation 1: NDVI = (NIR – Red) / (NIR + Red)

Technically, NDVI should be calculated on the corrected radiant flux of each pixel. However, since none of the imagery was spectrally calibrated NDVI was instead calculated using the original brightness values of each pixel. As a result, community trends in NDVI values could only be applied to the imagery it was derived from and not across all images uniformly. In general, however, NDVI values > 0.3 usually corresponded to heavily vegetated areas with dense canopies characteristic of Shrubland and Forest communities (Figure 7). Scrub communities were usually associated with NDVI values between 0.1 and 0.3 (Figure 7). Soils and bare ground, have a higher reflectance in the near-infrared than in the red and thus exhibited low NDVI values generally between -0.1 – 0.1 (Figure 7). Water, on the other hand, because of its low reflectance in both spectral bands (Red and NIR), tended to have very low NDVI values, usually < -0.1 (Figure 7). Base on these criteria, NDVI helped delineate low productivity zones (Mangrove Scrub) and Non-Vegetative features from adjacent Shrubland and Forest communities. However, NDVI failed to discriminate between the more productive community types (e.g. Hardwood Hammocks, Mangrove Shrublands, and Forest).

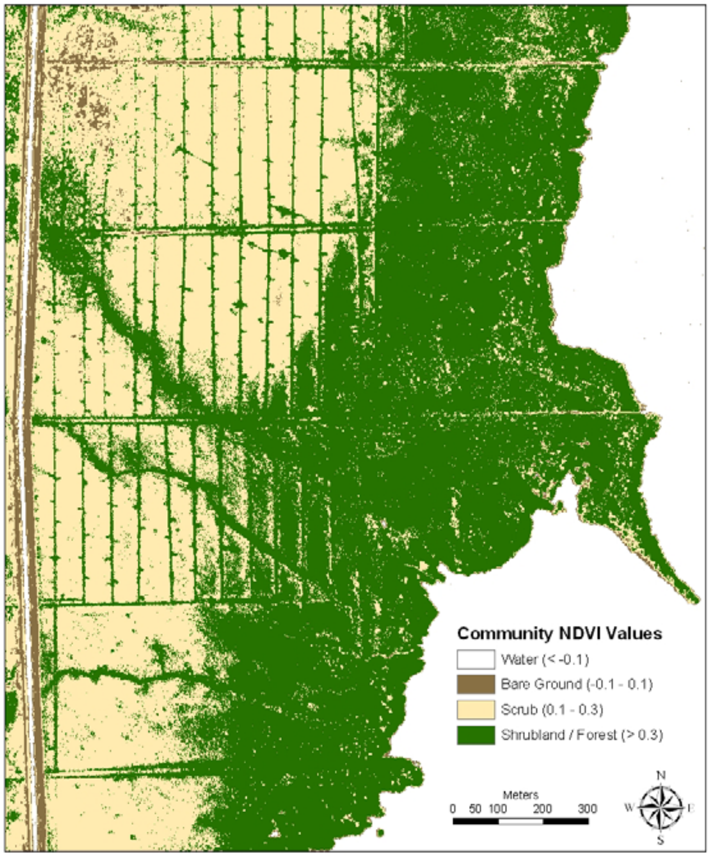

Figure 7: General relationship between community type and NDVI values.

LiDAR:

Light Detection and Ranging (LiDAR) is an active airborne remote sensing technology that uses laser pulses to provide direct and accurate measurements of vegetation structure and topography, among other things. Modern airborne laser systems have demonstrated the ability to: quantify structural changes in mangrove forests following hurricanes (Zhang et al. 2008); provide accurate estimates of forest vertical structure and volume (Zhang et al. 2006, Suárez et al. 2005), and stem diameters (Hyyppä et al. 2001); and have outperformed other remote sensing systems at estimating mean tree height (Lefsky et al. 2001). In recent years, LiDAR has become an invaluable remote sensing tool with many practical applications including land cover classification and mapping (Bork & Su 2007, Hill & Thomson 2005).

The LiDAR used in this project was provided and flown by Florida International University International Hurricane Research Center (IHRC 2004). This data was part of a 2002-2003 survey of Miami-Dade County, Florida. However, the extent of the LiDAR coverage for BISC was, unfortunately, limited to the uplands on the western shore of Biscayne Bay starting just north of Turkey Point and did not include any of the islands within BISC. The flight and laser acquisition parameters (altitude, speed, and scan angle, scan rate, and pulse rate) produced, on average, a 650-meter-wide swath of 30 cm wide laser footprints with a nominal point spacing of 1.5 m (IHRC 2004). The first return (first-stop) data from this survey was interpolated using kriging to produce 5 ft (1.524 meters) resolution top-surface digital elevation models (DEMs) with a vertical accuracy of ± 0.80 ft (24 cm) (IHRC 2004). For BISC, these DEMs represent the mean canopy height (ft) of the vegetation communities sampled in 2002 (Figure 8). The DEMs are projected to State Plane, Florida East Zone, NAD83 (unit = feet) with NAVD88 (feet) as the vertical datum (IHRC 2004).

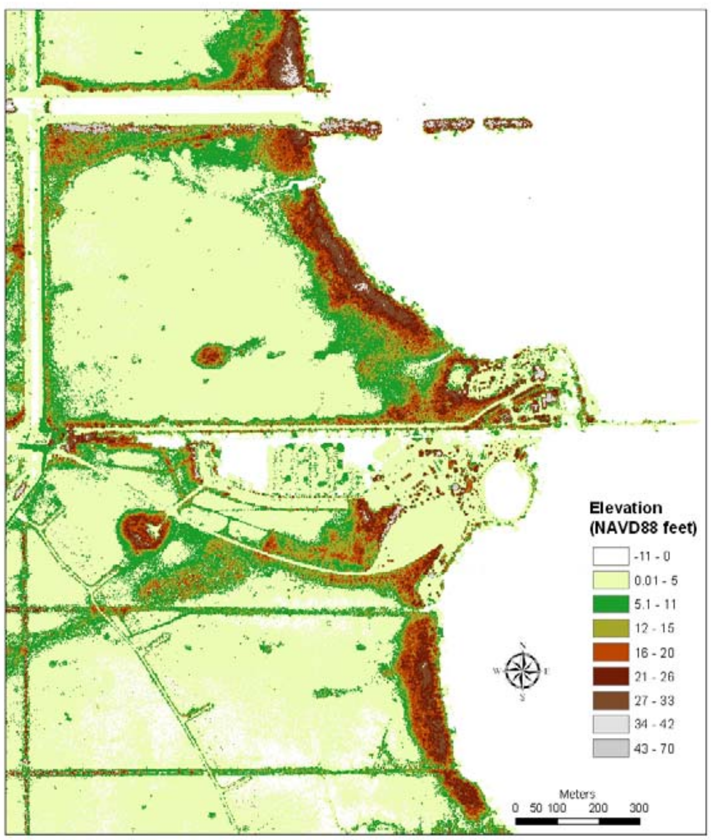

Figure 8: 2002 top-surface digital elevation model (DEM) of LiDAR data for Convoy Point, Homestead, FL.

Since the LiDAR was collected in 2002, the DEMs had to be corrected for canopy height growth between 2002 and 2008 (Table 1). Changes in canopy height were scaled according to community type. Thus, extrapolation of canopy heights was weighted towards the more productive forest community where tree height growth rate can easily reach and exceed 1 m/yr. In contrast, the less productive shrubland and scrub communities would not be expected to have canopy height growth much higher than 20 cm/yr or 5 cm/yr, respectively (Ross et al. unpublished data). The canopy height correction to the DEMs was done in ESRI® ArcMap™ 9.2 as a custom natural breaks classification. Thus, the original DEM values (ft) were reclassified and labeled to show the predicted canopy height in meters for 2008. The classification was saved as a layer file and imported as a symbology each time a new DEM was used.

Table 1: Extrapolation of canopy LiDAR height (m) between 2002 and 2008 used in discriminating between Level 1 community types.

Community Type	2002 LiDAR Height (meters)	2008 Extrapolated LiDAR Height (meters)
Non-Vegetative	< 0	< 0
Scrub	0 – 1.75	0 – 2
	1.75 – 2.1	2 – 2.7
Shrubland	2.1 – 3	2.7 – 3.7
	3 – 3.9	3.7 – 4.9
Forest	> 3.9	> 4.9

Unsupervised Classification:

In an exploratory manner, two independent unsupervised classification methods, pixel based and image-object based, were used in this study to ascertain their potential to classify the vegetation communities of BISC. The area used in this analysis had been previously mapped by Ross and Ruiz (2003) and thus could be use to quantify how well these two methods worked at delineating community boundaries.

In all, three 11-band stacked images were used in this analysis. The 11-band stacked images were derivatives of the original set of images provided for this study and were created using Erdas Imagine 9.1. The first five bands included the Red, Green, Blue, NIR, & Panchromatic bands from the original images, resampled to 0.9 meters. The 6th band was a 3 meter resolution gray-scale NDVI layer. The remaining 5-bands, #'s 7-11, consisted of the five bands from the original images, resampled to 3 meters using a 3x3 fixed window variance filter. Images were cropped to remove areas that contributed excessive glare or were not relevant to the study area. This eliminated unnecessary data from the analysis that might interfere with the classification.

The pixel-based unsupervised classification was carried out using the ISODATA algorithm in Erdas Imagine 9.1. The 11-band image stack described above was resampled to 9 m for this classification, however. A visual inspection of several image resolutions suggested that this scale of resampling preserved the details of the vegetation landscape, while, reducing the 'scatter shot' appearance of individual single pixels of many classes somewhat. The ISODATA algorithm was applied to all 11 bands to produce 40 classes. Subsequently the classification was opened in ESRI® ArcMap™ 9.2, and classes were combined to produce homogeneous areas that best matched the original resolution of the images (0.3048 m) or the Ross and Ruiz (2003) vegetation map.

The image-object unsupervised classification was initiated in *Definiens Professional*® v5 using the same 11-band image stack described above. A multiresolution segmentation was run using 9 of the 11-bands in the image stack and on a shoreline vector layer, previously created in *Definiens Professional*® v5. While adjusting for scale, several segmentation runs were done. Spectral information was weighted over shape by using a shape factor of 0.2. To reduce the appearance of irregular jagged objects, the smoothness parameter was weighted at 0.8 compared to 0.2 for compactness. Several complete analyses indicated that the size of the image objects created in *Definiens Professional*® v5 has a large impact on the quality of the final product. If objects are too small, they only reflect local variation and not the pattern of the vegetation community. The best classification results were seen with approximately 1,800 image-objects using a scale parameter of 200. This segmentation was then exported to a vector polygon file consisting of 30 features representing spectral information, size, shape, and texture.

Many of the exported features were highly correlated. To improve the performance of the subsequent principal components analysis (PCA), features were removed so that correlations between them did not typically exceed 60 percent. Representative features used in the PCA included: area, roundness, compactness, shape index, mean object NDVI pixels in object, mean of variance filtered NIR pixels, mean of variance filtered panchromatic pixels, mean of red pixels in object, mean of green pixels, mean of blue pixels, mean of NIR pixels, mean of panchromatic pixels, SD of NDVI pixels in object, ratio of object length to width, max difference, density and asymmetry.

PCA on the attributes of the exported image objects was carried out using Proc PRINCOMP in SAS v9. Based on previous results, the first 4-5 axes of the PCA usually represent about 80-85% of the total variability. As a result, these axes were used in the subsequent cluster analysis. A cluster analysis was also carried out in SAS using the K-means clustering algorithm, Proc FASTCLUS. Many of the 20-40 classes found represented non-vegetation areas, such as artifacts in the boundaries of the imagery and water areas. In one case, seven of 30 classes representing mixed vegetation were reclassified into 20 additional classes. Once the PCA and cluster analyses were complete, the attribute table was merged back into the object geometry shapefile in ESRI® ArcMap™ v9.2. A visual assessment of the unsupervised classification was done by comparing object boundaries and classes with the Ross and Ruiz (2003) vegetation map and with the original aerial photographs of the study area.

Geodatabase Design & Mapping:

Currently, geodatabases are the most efficient way of editing and storing spatial information. Geodatabases merge traditional GIS data formats and data management tools to create a geospatial environment, which maintains consistency and accuracy by defining how data is stored, accessed, modified, and managed within a single file. For this project, a Personal

Geodatabase, containing 19 feature datasets and 5 feature classes, was created in ESRI® ArcCatalog™ v9.2. All feature datasets and classes within the Geodatabase are projected to NAD83, UTM Zone 17N (unit = meters).

Each feature dataset within the Geodatabase represents an island or region within BISC and contains a topology and two feature classes, *shoreline* and *vegetation*. The naming convention for each topology and feature class is defined by using the feature dataset name as the prefix and the topology and feature class type, *shoreline* or *vegetation*, as the suffix (e.g. , *Adams_Key_Topology*, *Adams_Key_Shoreline* or *Adams_Key_Vegetation*). Within each feature dataset, the topology contains three rules that ensure the proper management of coincident geometry between polygons and the *shoreline* and *vegetation* feature classes. The *shoreline* feature class defines the land-water interface. The structure of this feature class remains consistent throughout all feature datasets and contains the following default ESRI attribute: OBJECTID, SHAPE, SHAPE_Length (m), & SHAPE_Area (m^2). The structure of the *vegetation* feature class is also constant throughout the geodatabase and contains the following attributes for each record: OBJECTID, SHAPE, AUTHOR, QC, RASTER ID, L1, L2, L3, L4, L5, L6, Photo, SHAPE_Length, & SHAPE_Area (Table 2).

Table 2: Description of attributes for vegetation feature class.

Attributes	Description
OBJECTID	ESRI default (ID)
SHAPE	ESRI default (polygon)
AUTHOR	Person responsible for the creation or last edit of that record
QC	Date used to designate when the record was verified in the field or to suggest a high degree of confidence regarding its classification on the day it was digitized
RASTER ID	Numeric string representing the mapped vegetation at the lowest level of the classification
L1	Level 1 classification
L2	Level 2 classification
L3	Level 3 classification
L4	Level 4 classification
L5	Level 5 classification
L6	Level 6 classification
Photo	Orthophoto used to create this record
SHAPE_Length	ESRI default (shape perimeter m)
SHAPE_Area	ESRI default (shape area m^2)

The five, additional, independent feature classes in the geodatabase; i.e. *BISC_Boundary*, *GR_Points*, *OrthoPhoto_Index*, *Shoreline*, & *Vegetation*, represent miscellaneous thematic layers that define the extent of the map, document the data collected, and summarize the spatial information populated within the geodatabase. The *BISC_Boundary* feature class contains one record denoting the 2006 legislative boundary of Biscayne National Park. This feature was acquired directly from The National Park Service Inventory and Monitoring Program South Florida / Caribbean Network. *GR_Points* is a point feature class populated with the 1,081 ground-reference data points collected to assist in the identification of unknown types or regions within the imagery or to ground-truth communities and areas already mapped. This feature class contains both structural and species information. *OrthoPhoto_Index* is a polygon feature class that servers as the photo index for this project. It documents which orthophoto was used to delineate the shoreline and map the vegetation for a particular region. Knowing and documenting this information was crucial because the imagery provided were not geometrically correct, as discussed previously. Consequently, digitized features not paired with the originating orthophoto could have, on average, a spatial offset of 2 meters or more. The last two feature classes, *Shoreline* and *Vegetation* contain all of the data within each of the 19 feature datasets and are the master Shoreline and Vegetation feature classes.

Edits to all feature classes were done within the geodatabase environment in ESRI® ArcMap™ v 9.2. The *Definiens Professional*® v5 shorelines were edited using the 2005 original imagery at a scale of 1:300. The vegetation communities, on the other hand, were delineated (digitized) at a 1:1500 scale using the 2005 imagery. Delineation of the vegetation boundaries was facilitated by overlaying the imagery, with a 25% transparency, over the NDVI raster or the LiDAR DEMs (Figure 9A & 9B, respectively).

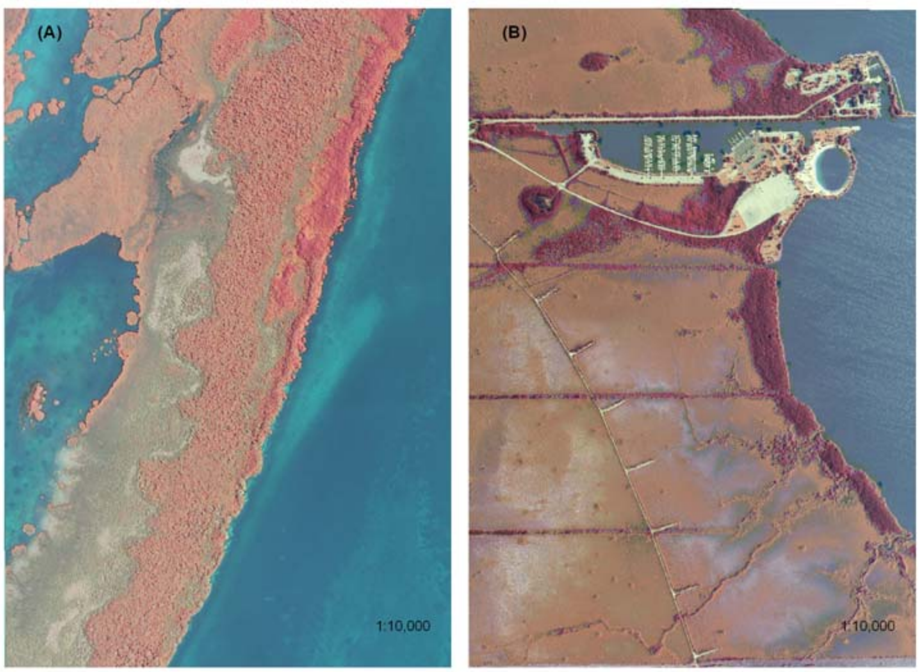

Figure 9: NDVI (A) and LiDAR (B) overtopped by imagery with 25% transparency.

Accuracy Assessment & Ground-truthing:

The accuracy assessment of this map will be subcontracted to an independent contractor within 12 months of project completion. This will ensure that the integrity of the map is not compromised and that the minimum standards set forth by the cooperative agreement between the National Park Service and Florida International University, for this project, are met.

Over 1,000 ground-reference points accessed by helicopter, boat, and on foot (Figure 10) were used to ensure that the map would meet the expected accuracy of 80% with an allowable error of 10% at Level 3 of the classification. On average, 120 individual sites were visited per day. A total of 9 field days were used on this endeavor; four of which were helicopter days. Field observations included, but were not limited to, maximum canopy height, canopy species composition, herbaceous layer species composition, and, on occasion, substrate. The GPS locations of each site visited was recorded directly into a field-book using a handheld GPS or populated into a geodatabase directly via a submeter accurate GIS/GPS integrated system. This information was then used to interpret the spectral signature of unknown types based on the spectral signature of known communities verified by the ground-referencing locations.

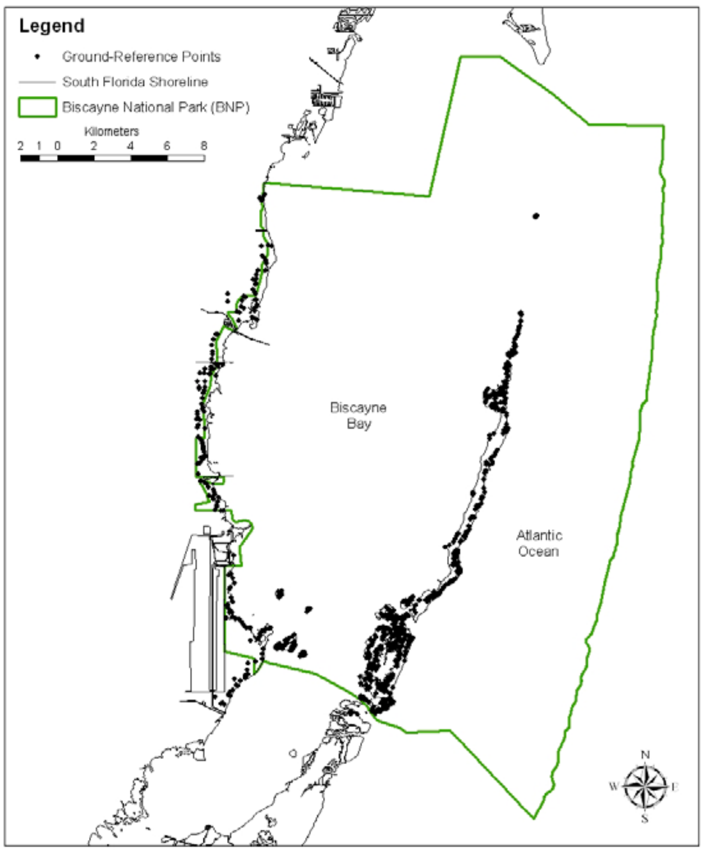

Figure 10: Distribution of ground-reference points used to map Biscayne National Park.

Results & Discussion:

Vegetation Classification System:

One of the unstated goals of this project was to determine the potential and effectiveness of the Rutchey classification system at mapping and capturing the natural complexity and structure of the varied plant communities arrayed along local environmental gradients in BISC. To that end, we found the classification system adequate. However, inherent issues with the classification system, particularly within the mangrove subcategories, created issues that necessarily lead to commission & omission errors. Providing a sound solution to these issues is beyond the scope of this project and report. Nonetheless, the following are worth noting:

- The classification system relies heavily on knowing the following three parameters: height, density, & species composition. Height and density are the most important at the highest level of the hierarchy; i.e. Level 1. Conversely, species composition becomes important at the 3rd level of the classification and thereafter. Height and density are usually difficult and at times impossible to discern from most aerial photography unless one of the following criteria are met: 1) the imagery is of high enough quality and has a spectral resolution that allows for individual crown to be identified; 2) the imagery consists of stereoscopic pairs and a stereoscope is used; or 3) there is enough textural contrast and shadow between communities that their vertical structure can be inferred. As a result, if the imagery, along with the methodology used, fails to recognize and meet the criteria described above, a situation is created where classification errors can occur at a level within the classification system (i.e. Level 1) where they should not be occurring. These errors are problematic since they are then inherited by the subordinate categories. Few can argue that there is a clear solution to this problem. However, the incorporation of LiDAR can mitigate and significantly, if not completely, eliminate classification errors within the 1st Level of this classification system and thus increase the overall accuracy of a map.

- Based on height and density, the Exotic Level 1 Class should be merged into the corresponding 1st Level structural class (i.e. Forest, Woodland, Shrubland, or Scrub). For example, a greater than 5 meter tall stand of Australian Pine with greater than 50% cover should be assigned to the L1 – Class: Forest with the following or similar hierarchical structure:

  L1: Forest
  - L2: Non-Native Forest (or similar description)
    - L3: Australian Pine (*Casuarina* sp.) Forest
      - L4: subcategory if applicable (specific species)
        - L5: subcategory if applicable (treated or not treated)
          - L6: subcategory if applicable

  This reorganization is logically consistent to the overall organization of the Rutchey et al. classification system and is applicable to all non-native community types. Moreover, this hierarchical structure emphasizes the nature and structure of the non-native community. By documenting these communities based on their canopy structure, resource managers are better able to properly ascertain the amount of resources needed for exotic control teams to effectively combat, eradicate, and mitigate these communities.

Co-dominance between native and non-native species and the multi-structural (stratum) characteristics of plant communities are related issues that should be addressed, in general as well as in BISC. For example, it is not uncommon for Australian Pine to be associated with a mixed mangrove community (e.g. Buttonwoods and White mangroves) in a Forest setting in which neither association (i.e. mangroves or non-natives) is dominant. Other examples include dense mixed-mangrove shrublands overtopped by a sparse or full canopy (30-75% cover) of Australian Pine, which are commonly associated with both mosquito & drainage ditches; Australian Pine shrubs or individual trees in a matrix of sawgrass (*Cladium jamaicense*); or mangrove forests (mixed or monotypic) with a dense understory of Brazilian Pepper (*Schinus terebinthifolius*) or Shoebutton Ardisia (*Ardisia elliptica*). These examples may seem like extreme cases rarely seen, but in actuality are commonplace throughout many of the interior wetlands located on the western shore of Biscayne Bay. Unfortunately, deriving a classification which can properly address these complexities is not easy and requires a significant amount of further thought and discussion by the authors and end users of the Rutchey classification system.

- At the 3rd level of the mangrove hierarchy, regardless of class (i.e. Forest, Woodland, Shrubland, Scrub), the cartographer or photo-interpreter is faced with the challenge of identifying mangrove communities at species level (e.g. Black Mangrove Forest, Mixed Mangrove Shrubland, or Red Mangrove Scrub, etc.). In many instances, it is not an easy task to distinguish dominant species (e.g., Black Mangrove, Red Mangrove, Mixed Mangrove), and commission and omission errors are commonplace. In regard to the overall organization of the other community types within the classification system (e.g. the Marsh category, which contains a complete hierarchical structure), it would seem that this species level of detail is better suited for the next lower level (**L4 - Alliance**) or lower within the classification system. The reason for this is two fold. For one, it would eliminate the gap in the mangrove hierarchy that currently exists between Level 3 and Level 5; i.e. there is no Level 4 to transition between many Level 3 (e.g. Red Mangrove Scrub) and Level 5 communities (e.g. Red Mangrove Scrub-Graminoid). The other reason is in the difficulty in determining the mangrove species composition from imagery alone at Level 3, particularly in the Shrubland and Scrub classes. Furthermore, there are many instances when the spectral signature of a lower level community associate like, Saltwort (*Batis maritima*), is readily recognized but the mangrove community associated with it is not (Figure 11). For example, in Figure 11, the succulent understory (yellowish in color) is clearly visible, while the species composition of the overtopping community, if one is present at all, is more difficult, if not impossible to distinguish. Thus, without auxiliary data this community has a high probability of being misclassified based on the overwhelming signature of Saltwort, thereby affecting the thematic accuracy of the map.

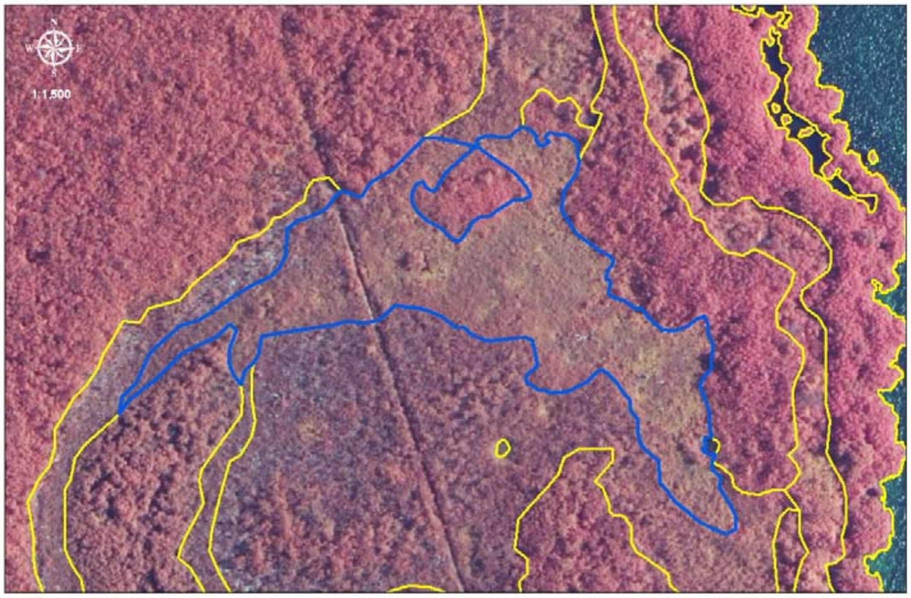

Figure 11: The succulent understory of the community outlined in blue (definable at Level 5 of the classification) is clearly visible, but the structure and species composition of the canopy, defined at Level 3, is difficult to determined. Based on a ground survey, this community was determined to be a Mixed Mangrove (Buttonwood-White Mangrove) Scrub with an understory dominated by Saltwort.

The solution to the two issues discussed in this bullet might be solved with the following modification to the classification system. The example below applies to Mangrove Scrub, but could apply equally well to other Scrub, Shrub, or Woodland categories:

- L2: Mangrove Scrub
  - **L3: Mangrove Scrub-Closed Canopy**
    - L4: Black Mangrove Scrub
    - L4: Mixed Mangrove Scrub
      - L5: Black Mangrove-Red Mangrove Scrub
  - **L3: Mangrove Scrub-Succulent**
    - L4: Mangrove Scrub-Glasswort
      - L5: *White Mangrove Scrub-Glasswort*
    - L4: Mangrove Scrub-Saltwort
      - L5: *Black Mangrove Scrub-Saltwort*
    - L4: Black Mangrove Scrub-Succulent
      - L5: *Black Mangrove Scrub-Saltwort*
    - L4: White Mangrove Scrub-Succulent
      - L5: *White Mangrove Scrub-Glasswort*
    - L4: Mangrove Scrub-Mixed Succulent
    - L4: Mixed Mangrove Scrub-Succulent
      - L5: Buttonwood-White Mangrove-Succulent
        - L6: *Buttonwood-White Mangrove-Saltwort*
      - L5: Mixed Mangrove Scrub-Saltwort
        - L6: *Buttonwood-White Mangrove-Saltwort*
    - L4: Mixed Mangrove Scrub-Mixed Succulent
  - **L3: Mangrove Scrub Graminoid**

While the entire hierarchy is not displayed, the general structure and trend can be followed. By applying this hierarchical structure, the gaps between Level 3 and Level 5 are now gone. Moreover, from a remote sensing perspective, communities or individual plants or groups of plants that are readily discerned but buried deep in the classification hierarchy are now moved up into an appropriate level while communities with a complex and/or ambiguous spectral signature are demoted or grouped logically to minimize commission and omission errors. This restructuring of the classification system provides multiple pathways, at the lower levels of the hierarchy, for specific detailed community types to be arrived at while minimizing community misclassification at higher levels. Multiple pathways might appear problematic, but if the goal is to minimize classification errors and ensure a thematically correct map, while avoiding gaps within subcategories, this may prove to be the best solution within the parameters of the Rutchey et al. (2007) classification system.

NDVI & LiDAR:

As discussed in the methods section, NDVI was instrumental at delineating Non-Vegetative communities and low productivity zones from adjacent more productive communities. However, since the imagery was not spectrally calibrated, the interpretation of NDVI values shifted with each new image used. As a result, the use of NDVI was somewhat impractical because established rule sets had to be confirmed and calibrated each time a new image was used. Nevertheless, the potential of NDVI to distinguish communities along a productivity gradient was demonstrated in this mapping project.

In contrast, by providing direct and accurate seamless estimates of canopy heights for an area, LiDAR overcame the limitations inherent to NDVI and proved superior at distinguishing communities and their boundaries regardless of class and productivity. Consequently, the availability of LiDAR for the mainland portions of the park significantly improved the spatial and thematic accuracy for this section of the map. Moreover, LiDAR notably reduced the amount of time needed to interpret images and digitize plant communities. Furthermore, the multi-dimensionality of LiDAR (i.e. not only does it provide information regarding the mean canopy height for a vegetative community it also possesses information regarding vertical structure, stand volume, basal area, and on topographic relief, among others things.) contributes and enhance our understanding of the spatial and temporal dynamics of plant communities. As such, within the context of resource management, protection, and restoration LiDAR is an invaluable tool, which permits for the quick collection, analysis, and interpretation of large volumes of both spatial and temporal data over large areas without the logistical cost and difficulty associated with ground surveys.

Unsupervised Classification:

Figure 12 shows the pixel-based unsupervised classification using the ISODATA algorithm overlaid with the Ross & Ruiz (2003) vegetation map of the area, for comparison. In general, this classification outlines many of the community boundaries identified by Ross & Ruiz (2003). However, it failed to produce homogeneous areas characterized by one or two pixel classes, which are essential to properly isolate and delineate community types, particularly at the scale of this map. Since many of these classes appear closely related in space, the original 40 classes were consolidated into 10 new cover classes, which are described in Table 3. Taken as a whole, this new classification (Figure 13) matches more closely with the community boundaries drawn by Ross & Ruiz (2003). Nevertheless, the same 'scatter shot' effect which plagued the original classification remains. As a result, most communities still appear as a multi-pixel class aggregate making community delineation very difficult and impractical for this project.

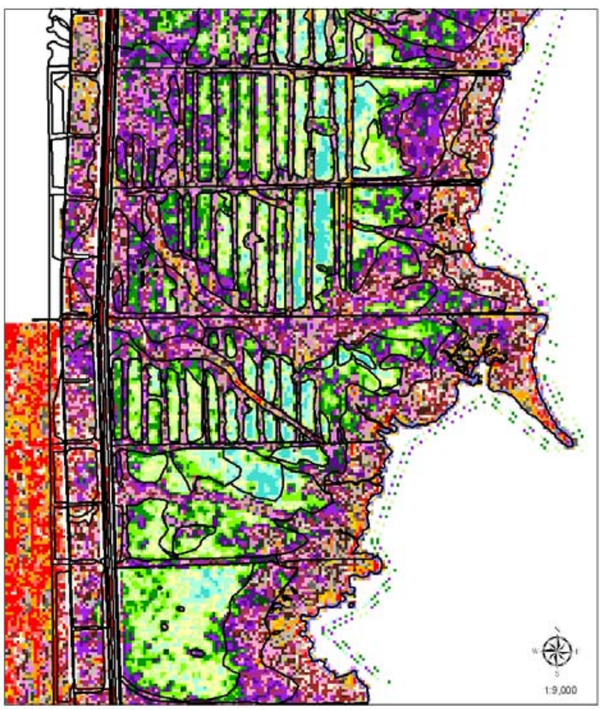

Figure 12: Comparison of unsupervised classification with 40 classes overlaid with the Ruiz & Ross (2004) vegetation boundaries in black.

Figure 13: Comparison of unsupervised classification with 10 classes overlaid with the Ruiz & Ross (2004) vegetation boundaries in black.

Table 3: Description of unsupervised classification cover classes shown on Figure 12.

Class	Color	Description
1	Bright Blue	Water
2	Light Blue	Salt marsh and heavier scrub mangrove in areas between ditches.
3	Yellow	Scrub mangrove in areas of less vegetation west of class shown in light blue.
4	Green	Transitions to denser more textured vegetation.
5	Aqua	Coastal mangrove and some interior non-mangrove areas. This class is picking up areas of rougher texture for coastal and interior areas and when present in the fringe mangrove area is associated with the taller tree canopy.
6	Brown	Associated with rough textured areas near drainage ditches and the border with green and purple areas.
7	Purple	Associated with interior and transitional mangrove areas.
8	Black	Associated with drainage ditches, edges of water bodies, and tree shadows.
9	Red	Main association with *C. equisetifolia* forest in western part of image and coastal bordering fringe mangrove.
10	Orange	Lesser association with *C. equisetifolia* forest.

Image objects created in *Definiens Professional*® v5 containing a 17 factor attribute table were analyzed in SAS v9 using a principal components analysis (PCA) and K-means cluster analysis. The first five axes represented 84% of the variation observed in the data (Table 4). The 17 factors forming the basis of the PCA grouped into four distinct categories based on spectral and textural properties, shape, and a miscellaneous "other" category (Table 5).

Table 4: Eigenvalues for the correlation matrix

PC	Eigenvalue	Difference	Proportion	Cumulative
1	6.195	2.951	0.364	0.364
2	3.244	0.909	0.191	0.555
3	2.335	0.894	0.137	0.693
4	1.441	0.374	0.085	0.777
5	1.067	0.300	0.063	0.840
6	0.768	0.244	0.045	0.885
7	0.524	0.041	0.031	0.916
8	0.483	0.165	0.028	0.945
9	0.317	0.099	0.019	0.963

Based on the eigenvectors (Table 5), PC1 (36%) is a composite of several spectral measures. PC2 (19%) has a negative association with shape (Table 5). PC3 (14%) also appears to have a strong association with the overall shape of each feature. PC4 (9%) and PC5 (6%) are minor components.

Table 5: Eigenvectors (factor scores) computed for the correlation matrix.

Group	Factor	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Spectral	Red	0.286	0.273	-0.187	0.163	0.049
	Green	0.320	0.218	-0.238	0.205	0.002
	Blue	0.235	0.280	-0.251	0.332	0.025
	NIR	0.360	-0.121	-0.119	-0.154	-0.108
	Pan	0.365	0.124	-0.203	0.083	-0.020
	NDVI	0.280	-0.259	-0.093	-0.276	-0.140
Texture	SD NIR	0.151	-0.002	0.196	-0.373	0.500
	VarNIR	0.240	0.228	0.226	-0.296	0.164
	VarPan	0.252	0.266	0.087	-0.217	0.205
Shape	Area	0.146	-0.364	-0.023	0.162	-0.283
	Roundness	0.248	-0.308	0.221	0.225	0.236
	Compactness	0.144	-0.233	0.311	0.426	0.334
	Shape Index	0.252	-0.130	0.424	0.176	-0.113
	Ratio L to W	0.122	0.234	0.341	-0.175	-0.488
	Density	0.083	-0.328	-0.360	-0.314	0.177
	Asymmetry	0.133	0.118	0.314	-0.085	-0.249
Other	Max Diff	-0.263	0.324	0.116	0.124	0.233

In total, 1871 objects were classified into 30 classes using the first five principal components (Table 4) with K-means clustering implemented in Proc FASTCLUS. Seven of the original 30 classes (Class 6, 16, 17, 18, 19, 21 and 27) were found to be a mix of vegetation types that did not separate well into any one class. To improve the separability of these classes, a new cluster analysis was executed on only those objects (712) that grouped into these seven classes.

The results of this second cluster analysis are shown in Figure 14. Out of the 20 new classes, three had to be omitted because they were image artifacts. The results obtained from the remaining 17 classes reveal that the image object boundaries were not following the vegetation patterns visible in the aerial photographs, despite their small size and the inclusion of additional layers to capture texture information (variance filter) and to strengthen the signal (NDVI) between poorly and highly vegetated areas. Possibly, the scale parameter for the multiresolution segmentation was set too large. However, decreasing the scale setting would have created smaller objects that tend to be more jagged and abstract in shape, are heavily influenced by light and shadow, and thus are not representative of the community. In the

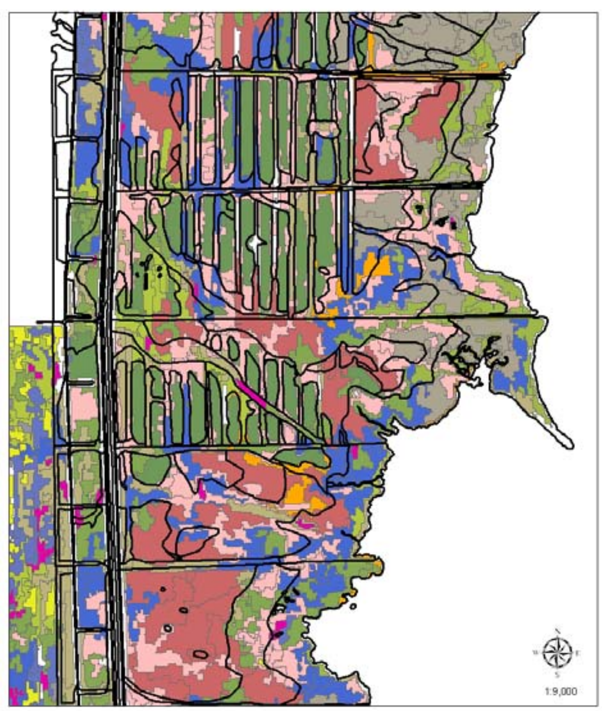

Figure 14: Comparison of object-based unsupervised classification with 17 classes overlaid with the Ruiz & Ross (2004) vegetation boundaries in black.

end, this unsupervised classification method also failed to properly classify and delineate community types within BISC.

In general, computer-based classification methods (pixel-based or object-based) of vegetation require that: 1) the imagery is radiometrically and geometrically corrected and 2) the spectral signature of the vegetation being classified is distinct enough to allow for its classification or separation into separate unique classes or vegetation communities, in this case. If these two parameters are not met, the computer-based classification will tend to have a high degree of commission and omission errors. In the case of this project, the imagery did not meet these standards and the vegetation types being classified did not have exclusive spectral signatures at Level 3 of the classification, the minimum required for this project. At the same time, the classification system applied (Appendix 1) relies heavily on knowing the canopy height and tree density of the area or community being mapped. As a result, without LiDAR (only available for the mainland portions of BISC) or stereo imagery, these parameters become very difficult to establish, thus further diminishing the potential of the computer-based classification to distinguish between communities whose spectral signature are similar or identical but differ only in canopy height (e.g. Red Mangrove Shrubland vs Red Mangrove Forest). As a result, for a project of this size, the logistics of using a computer-based classification was determined to be far less efficient and prone to a higher degree of error than the ocular identification and hand digitizing of vegetation communities.

The Vegetation of Biscayne National Park:

Ideally, mapping efforts should coincide with the acquisition of the imagery being used. In practice, however, this is rarely the case. Realistically because of delays associated in contracting and budgeting, and image acquisition, availability, and/or procurement, it is not uncommon, for most mapping efforts, to be initiated several months to a year or more after the imagery was initially flown. Moreover, the extent, scale, and detail required of a map along with the work force available can extend the temporal separation between the imagery and the final product by several more months or years (see Welch et al. 1999). Luckily, most vegetative communities tend to be relatively inert and resistant to structural and/or compositional change during the lifespan of most mapping projects. However, because of perturbations, both natural and anthropogenic, communities sometimes change rapidly creating conditions on the ground that are no longer coincident with the imagery. This has the unfortunate effect of creating a classification impasse for the cartographer who must decide between mapping what is currently there and known against what might have been prior to the perturbation event. This is also a major problem in the accuracy assessment phase of all mapping project.

For this project, the imagery dated to May 2005 (see methods section), but mapping efforts did not commence until nearly two years later, in March 2007. Consequently, the map (Plate 1) represents the vegetation communities of BISC between March 2007 and June 2008 when the first and last polygons were drawn, respectively, and when ground referencing and truthing efforts ceased, in February 2008. Arguably and reasonably, the point could also be made, based on the image acquisition date, that this map really represents the vegetation of BISC in

2005. However, since all mapping activities were conducted nearly three years after the imagery was taken, and the accuracy assessment won't be complete until nearly a year after map production, it is best to consider it a representation of the vegetation communities of BISC in 2007-08, or for brevity, 2008.

However, ongoing exotic removal and restoration efforts, particularly on Elliott Key and Boca Chita, created conditions on the ground that were no longer coincident with the imagery or definable within the classification system. As a result, on Elliott Key, for example, areas treated for *Thespesia populnea* (Seaside Mahoe) were systematically classified based on the 2005 spectral signature which suggested a monotypic community of this species. These areas could have been classified as Treated Seaside Mahoe. However, conditions on the ground, in 2008, were ambiguous and indicative of a transitional state between treated and non-treated Seaside Mahoe communities with some units completely devoid of vegetation and others showing signs of an emerging mixed mangrove Shrubland, dotted with emerging Seaside Mahoe seedling and saplings, in a succulent herbaceous matrix. Moreover, since the imagery did not allow for the delineation of these new transitional units we had no choice but to map them, by default, based on how they appeared on the imagery. Fortunately, this is an exception and not the norm within the map.

The map created for the project (Plate 1) encompasses a total area of 35.2 km^2 of which 31 km^2 are within the borders of BISC. Nearly 55% (17.0 km^2) of these 31 km^2 correspond to the island habitat alone. The residual 4.2 km^2 (i.e. the difference between the total area mapped and the area mapped corresponding to BISC) consist of sections of the mainland that are adjacent to the park boundary (Figure 1). While not within the legislative jurisdiction of the National Park Service and BISC, these wetlands are an important component of the overall protection and ecological health of the communities that fall within the Park, including Biscayne Bay. As a result, some efforts were directed towards mapping these ecologically important lands. Unfortunately, only a small percentage of the total area in the BBCW were mapped.

Forest communities within BISC; i.e. Mangrove Forest & Hammock Forest, on both the mainland and islands, account for 48.4% of the total area mapped (Table 6). In contrast, the Shrubland and Scrub communities combine for almost 49% of all vegetation area (Table 6). The remaining area was distributed unevenly between Woodland (2%), Marsh (0.2%), Dune (0.03%), and Exotic (0.3%) communities (Table 6).

The total forested area within the Park was greater on the islands than on the mainland, 9.0 km^2 vs 5.7 km^2, respectively (Table 6). However, mangrove forest communities were more abundant on the mainland than on the islands (Table 6). The Coastal Hardwood Hammock community with a total area of 7.023 km^2 (i.e. 22.7% of the total area mapped) was the overall dominant community type present within all of BISC (Table 6) but only occurred on the islands. Woodlands are a minor component of both island and mainland habitats. The distribution of Woodlands were slightly greater on the islands than in the mainland. Red and Mixed Mangrove Shrublands on the islands account for almost 3 times the total area of shrublands of any sort on the mainland (Table 6). In contrast, the scrub mangrove communities of the mainland accounted for almost 4 times the total area of scrub habitat of all types on the islands (Table 6). Marshes, like Woodlands, were a minor component of both island and mainland habitats. However, Marshes were more common on the mainland than on the islands (Table 6). The Dune class was the only class found exclusively on the islands but it only accounted for 0.1% of the total area mapped within the island community. Exotics, at 0.27% of the total area mapped, were a minor component of both the mainland and island habitats.

Descriptively, the vegetation of BISC (Plate 1) consists of a complex mosaic of physiognomically distinct communities distributed along a hydrologic and salinity gradient that, along with nutrient availability and substrate type, ultimately determines plant community composition and productivity. The physiography of the landscape serves as a template controlling hydrology and salinity, and thereby regulating the distribution and structure of the communities. Soil type and depth are equally important, particularly on the mainland portions of BISC where the topographic gradient is subtle (Meeder et al. 2000) and soil depths can reach and exceed 1 m (Gaiser et al. 2006, Meeder et al. 2000). In contrast, soil depth on the upland portions of the islands rarely exceeds a few decimeters, but the topographic gradient between adjacent mangrove and hardwood hammock communities may easily exceed 1 meter. This juxtaposition in topography and substrate (both in type and depth) between the mainland and islands create unique environments that support unique communities within BISC (Table 6). This is particularly true for the Marsh class, where three of the four Level 3 Marsh types documented (e.g. Herbaceous Salt Marsh, Succulent Salt Marsh, and Graminoid Freshwater Prairie) are found exclusively in the island environment but not on the mainland (Table 6). There are other examples of this, most notably, the two Hammock Forest types that are exclusive to the islands (Table 6). Coincidently, both of these hammock communities, though floristically and structurally similar, have distinctive soil characteristics, which sets them apart. Exclusive to the mainland, on the other hand, we find extensive areas of *Rhizophora mangle* dwarf trees (red mangrove scrub) in a matrix of either *Fimbristylis spadicea* (Marsh Fimbry) or *Juncus roemerianus* (Black Rush), as well as isolated Salt Marsh communities dominated by Black Rush. It is worth noting that these Black Rush Salt Marshes are a relic community that is slowly being displaced by the encroachment of mangroves, particularly *R. mangle*.

Table 6: Summary statistics for all **Level – 3** communities, except Exotic (**Level – 1**) identified and mapped within BISC.

Class (L1)	Group (L3)	Area (km^2)			Percent		
		Mainland	Islands	Total	Mainland	Islands	Total
Forest	Black Mangrove Forest	0.0571	0.399	0.457	0.4	2.4	1.47
	Buttonwood Forest	0.0000	0.081	0.081	0.0	0.5	0.26
	White Mangrove Forest	0.0000	0.000	0.000	0.0	0.0	0.00
	Red Mangrove Forest	0.4478	0.319	0.767	3.2	1.9	2.48
	Mixed Mangrove Forest	5.2444	1.110	6.354	37.3	6.6	20.53
	Coastal Hardwood Hammock	0.0000	7.023	7.023	0.0	41.6	22.69
	Coastal Dune Hammock	0.0000	0.034	0.034	0.0	0.2	0.11
Woodland	Black Mangrove Woodland	0.1343	0.185	0.319	1.0	1.1	1.03
	Buttonwood Woodland	0.0000	0.115	0.115	0.0	0.7	0.37
	White Mangrove Woodland	0.0000	0.042	0.042	0.0	0.3	0.14
	Mixed Mangrove Woodland	0.0229	0.097	0.120	0.2	0.6	0.39
	Upland Hardwood Woodland	0.0000	0.027	0.027	0.0	0.2	0.09
Shrubland	Black Mangrove Shrubland	0.0000	0.081	0.081	0.0	0.5	0.26
	Buttonwood Shrubland	0.0000	0.093	0.093	0.0	0.6	0.30
	White Mangrove Shrubland	0.0097	0.011	0.021	0.1	0.1	0.07
	Red Mangrove Shrubland	0.4085	2.525	2.934	2.9	14.9	9.48
	Mixed Mangrove Shrubland	1.6943	3.100	4.794	12.1	18.3	15.49
	Coastal Hardwood Shrubland	0.0000	0.063	0.063	0.0	0.4	0.20
Scrub	Black Mangrove Scrub	0.0000	0.101	0.101	0.0	0.6	0.33
	White Mangrove Scrub	0.0000	0.030	0.030	0.0	0.2	0.10
	Red Mangrove Scrub	4.9972	0.807	5.804	35.5	4.8	18.75
	Mixed Mangrove Scrub	0.5742	0.374	0.948	4.1	2.2	3.06
	Upland Scrub	0.0000	0.002	0.002	0.0	0.0	0.01
	Upland Hardwood Scrub	0.0000	0.015	0.015	0.0	0.1	0.05
Marsh	Graminoid Salt Marsh	0.0341	0.0005	0.035	0.2	0.0	0.11
	Herbaceous Salt Marsh	0.0000	0.001	0.001	0.0	0.0	0.00
	Succulent Salt Marsh	0.0000	0.004	0.004	0.0	0.0	0.01
	Graminoid Freshwater Prairie	0.0000	0.017	0.017	0.0	0.1	0.05
Dune	Mixed Herbaceous Dune	0.0000	0.009	0.009	0.0	0.1	0.03
Exotic	Exotic	0.0314	0.051	0.082	0.2	0.3	0.26
Other	Barren Microkarst	0.0000	0.020	0.020	0.0	0.1	0.06
	Barren Salt Flat	0.0000	0.004	0.004	0.0	0.0	0.01
	Beach	0.0000	0.022	0.022	0.0	0.1	0.07
	Lightning Gap	0.0013	0.0001	0.001	0.0	0.0	0.00
	Littoral Zone	0.0000	0.002	0.002	0.0	0.0	0.01
	Water	0.1738	0.040	0.214	1.2	0.2	0.69
	Anthropogenic	0.2248	0.097	0.322	1.6	0.6	1.04
Total		**14.1 (45.4%)**	**16.9 (54.6%)**	**31.0**	**100**		

Conclusion:

By providing a spatial inventory of the plant communities within BISC, this map, directs managers to focus their attention on relic, rare, and fragmented communities (e.g. *J. roemerianus* salt marshes found on the mainland or mangrove shrublands in a matrix of *Spartina bakeri* found on to Elliott Key) that are generally more vulnerable to anthropogenic and natural perturbations. This is particularly true in the case of the species rich Coastal Hardwood Hammock community. This fragmented upland coastal community serves as refugia for many threatened and endangered species, both flora and fauna. However, since this community is only found on the eastern rim of Biscayne Bay, at a few meters above mean sea level, it is highly vulnerable to the effects of tropical storms and hurricanes and their accompanying storm surge, and, without question, sea-level rise. Moreover, in conjunction with existing data, managers can use this map to isolate communities that are likely to benefit the most from restoration efforts. Finally, this map, with its highly accurate and precise 1:300 scale shoreline, serves as a turn-of-the-21st-century baseline for the extent of mangroves within Biscayne National Park. As a result, it can be useful for monitoring the effects of sea-level rise on the wetlands and forested communities of Biscayne National Park.

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Plate 1

The 2008 Terrestrial Vegetation of Biscayne National Park

THE 2008 TERRESTRIAL VEGETATION OF BISCAYNE NATIONAL PARK

Vegetation

Forest
- Hammock Forest
- Coastal Hardwood Hammock
- Coastal Dune Hammock
- Black Mangrove Forest
- Buttonwood Forest
- White Mangrove Forest
- Red Mangrove Forest
- Mixed Mangrove Forest

Woodland
- Upland Hardwood Woodland
- Black Mangrove Woodland
- Buttonwood Woodland
- White Mangrove Woodland
- Mixed Mangrove Woodland

Shrubland
- Coastal Hardwood Shrubland
- Upland Shrubland
- Black Mangrove Shrubland
- Buttonwood Shrubland
- White Mangrove Shrubland
- Red Mangrove Shrubland
- Mixed Mangrove Shrubland

Scrub
- Upland Scrub
- Upland Hardwood Scrub
- Black Mangrove Scrub
- White Mangrove Scrub
- Red Mangrove Scrub
- Mixed Mangrove Scrub

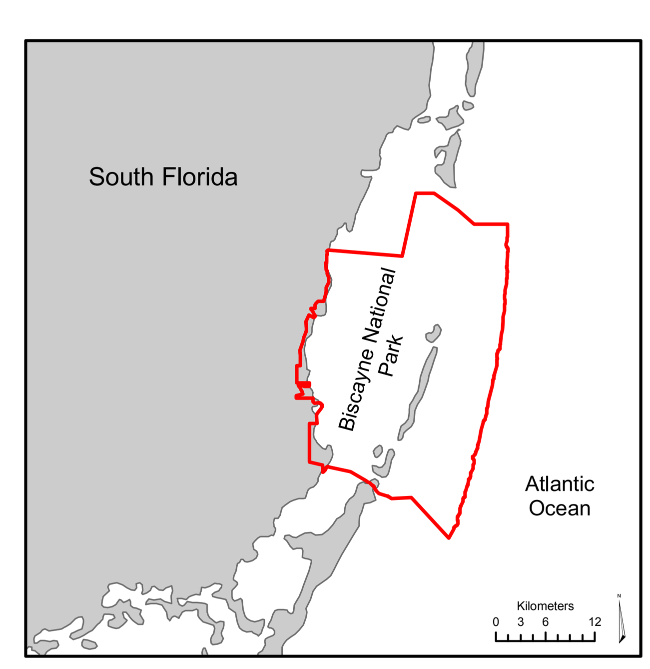
Marsh
- Succulent Salt Marsh
- Herbaceous Salt Marsh
- Graminoid Salt Marsh
- Graminoid Freshwater Prairie
- Graminoid Freshwater Marsh

Dune
- Mixed Herbaceous Dune

Exotic
- Exotic
- Australian Pine
- Treated Australian Pine
- Seaside Mahoe

Other
- Anthropogenic
- Barren Microkarst
- Barren Salt Flat
- Beach
- Lightning Gap
- Littoral Zone
- Inland Lakes or Pools
- Unclassified

Biscayne National Park Boundary



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Authored by: Pablo L Ruiz
Funded by: National Park Service South Florida / Caribbean Network
Date: June 2008
Base Map Source: 2005 Multispectral (RGBNIRPan) Aerial Photos
Datum: NAD83 UTM Zone17N (units = meters)

Appendix 1

Hierarchical Classification System with Community Descriptions

L1 - Class

Class	*Author*	*Raster ID*	*Rutchey ID*
Forest	Rutchey et al.	100000	100000
High-density stands of trees (> 50% tree canopy cover) with heights > 5 meters.			
Woodland	Rutchey et al.	200000	200000
Low-density stands of trees (10 - 60% tree canopy cover) with heights > 5 meters in a matrix of shrubs, graminoids, and/or herbaceous vegetation.			
Shrubland	Rutchey et al.	300000	300000
Stands of small trees and/or shrubs (canopy cover ≥ 50%) with heights < 5 meter tall.			
Scrub	Rutchey et al.	400000	400000
Communities of dwarf trees or shrubs typically in a matrix of graminoids, and/or herbaceous vegetation. Canopy cover 10% to 50% but can be as high as 100% for Mangrove and Cypress classes. Canopy < 5 meters tall with the exception being for Mangrove which is ≤ 2 meters.			
Marsh	Rutchey et al.	500000	500000
Graminoid and/or herbaceous emergent or floating vegetation in shallow water that stands at or above the ground surface for much of the year.			
Dune	Rutchey et al.	600000	600000
A ridge of wind blown or windstorm deposited sand or similar material directly inland and parallel to the shoreline that is commonly vegetated by graminoids and/or herbs and sometimes even shrubs.			
Submerged Aquatic Vegetation	Rutchey et al.	700000	700000
Vegetation that has evolved the ability to carry out its entire life cycle completely submerged in an aquatic environment.			
Exotic	Rutchey et al.	800000	800000
Non-native and invasive vegetation.			
Other	Ruiz & Ross	900000	900000
Non-vegetative or anthropogenic cover.			
Unclassified	Ruiz & Ross	999999	
Unclassified vegetation or land cover.			

L2 - Type

Type	*Author*	*Raster ID*	*Rutchey ID*
Mangrove Forest	Rutchey et al.	110000	110000
Regularly flooded (tidal) forest found along coastal areas dominated by salt tolerant species.			
Hammock Forest	Rutchey et al.	130000	130000
Rarely inundated and well drained forests containing a mixture of tropical and temperate broad-leaved trees.			
Mangrove Woodland	Rutchey et al.	210000	210000
Regularly flooded (tidal) open canopy forest found along coastal areas dominated by salt tolerant species.			
Upland Woodland	Rutchey et al.	230000	230000
Rarely inundated and well drained open canopy forests containing a mixture of tropical and temperate broad-leaved trees.			
Mangrove Shrubland	Rutchey et al.	310000	310000
Regularly flooded (tidal) shrubland found along coastal areas dominated by salt tolerant species			
Upland Shrubland	Rutchey et al.	340000	340000
Rarely inundated and well drained shrublands containing a mixture of tropical and temperate broad-leaved trees.			
Mangrove Scrub	Rutchey et al.	410000	410000
Tidal and seasonally flooded dwarf (< 2 m height) mangrove trees found along coastal areas and in the transition zone between freshwater and marine dominated environments. Canopy densities are generally between 10% - 50% but can be as high as 100%.			
Upland Scrub	Rutchey et al.	430000	430000
Upland graminoid and/or herbaceous dominant communities in a matrix of dwarf (< 2 m height) trees and/or shrubs.			
Salt Marsh	Rutchey et al.	510000	510000
Marsh consisting of salt tolerant (halophilic) graminoid and/or herbaceous vegetation.			
Freshwater Marsh	Rutchey et al.	520000	520000
Marsh consisting of freshwater graminoid and/or herbaceous vegetation.			
Herbaceous Dune	Rutchey et al.	620000	620000
Herbaceous dominated dune.			

L2 - Type	*Author*	*Raster ID*	*Rutchey ID*
Australian Pine	Rutchey et al.	803000	803000

Macrophyte community consisting of River Sheoak (*Casuarina cunninghamiana*), Australian Pine (*C. equisetifolia*), and/or Suckering Australian Pine (*C. glauca*).

Treated Australian Pine	Rutchey et al.	804000	804000

Macrophyte community treated for the presence of River Sheoak (*Casuarina cunninghamiana*), Australian Pine (*C. equisetifolia*), and/or Suckering Australian Pine (*C. glauca*).

Seaside Mahoe	Rutchey et al.	833000	833000

Macrophyte community consisting of *Thespesia populnea*.

Non-Vegetative	Ruiz & Ross	910000	

Non-vegetative coverage

Anthropogenic	Ruiz & Ross	920000	

Non-natural coverage associated with human infrastructure and/or activities.

L3 - Group

Group	Author	Raster ID	Rutchey ID
Black Mangrove Forest	Rutchey et al.	111000	111000
Black Mangrove (*Avicennia germinans*) dominated forest found along the coast.			
Buttonwood Forest	Rutchey et al.	112000	112000
Buttonwood (*Conocarpus erectus*) dominated forest usually found on the landward edge of the coastal mangrove zone.			
White Mangrove Forest	Rutchey et al.	113000	113000
White Mangrove (*Laguncularia racemosa*) dominated forest found along the coast.			
Red Mangrove Forest	Rutchey et al.	114000	114000
Red Mangrove (*Rhizophora mangle*) dominated forest found along the coast.			
Mixed Mangrove Forest	Rutchey et al.	115000	115000
Mixed mangrove forest with no particular species of dominance found along the coast.			
Coastal Hardwood Hammock	Rutchey et al.	131000	131000
Forest containing a mixture of tropical and temperate broad-leaved trees found along coastal areas on rocky substrate overtoped by an organic layer.			
Coastal Dune Hammock	Ruiz & Ross	137000	
Forest containing a mixture of tropical and temperate broad-leaved trees found along coastal areas on a dune (shell mounds excluded).			
Black Mangrove Woodland	Rutchey et al.	211000	212000
Black Mangrove (*Avicennia germinans*) in a matrix composed of salt marsh graminoids, herbs, and/or succulents.			
Buttonwood Woodland	Rutchey et al.	212000	211000
Buttonwood (*Conocarpus erectus*) in a matrix composed of salt marsh graminoids, herbs, and/or succulents.			
White Mangrove Woodland	Ruiz & Ross	213000	
White Mangrove (*Laguncularia racemosa*) in a matrix composed of salt marsh graminoids, herbs, and/or succulents.			
Mixed Mangrove Woodland	Ruiz & Ross	215000	
Mixed assemblage of mangrove tree species in a matrix composed of salt marsh graminoids, herbs, and/or succulents.			

L3 - Group	Author	Raster ID	Rutchey ID
Upland Hardwood Woodland	Rutchey et al.	233000	233000
Woodland containing a mixture of tropical and temperate broad-leaved trees found along coastal areas on rocky substrate with little or no soil.			
Black Mangrove Shrubland	Rutchey et al.	311000	311000
Black Mangrove (*Avicennia germinans*) dominant shrubland predominately found in the upper part of the intertidal zone or on higher elevations.			
Buttonwood Shrubland	Rutchey et al.	312000	313000
Buttonwood (*Conocarpus erectus*) dominant shrubland usually found on the landward edge of the coastal mangrove zone or on the edge of hammocks.			
White Mangrove Shrubland	Rutchey et al.	313000	314000
White Mangrove (*Laguncularia racemosa*) dominant shrubland found throughout the intertidal zone.			
Red Mangrove Shrubland	Rutchey et al.	314000	315000
Red Mangrove (*Rhizophora mangle*) dominant shrubland found on the middle and lower portions of the intertidal and upper subtidal zone.			
Mixed Mangrove Shrubland	Rutchey et al.	315000	316000
Mixed of mangrove shrubland with no particular species of dominance found along the coast.			
Coastal Hardwood Shrubland	Rutchey et al.	342000	342000
Shrubland containing a mixture of tropical and temperate broad-leaved trees found along coastal areas on rocky substrate with little or no soil.			
Black Mangrove Scrub	Rutchey et al.	411000	411000
Black Mangrove (*Avicennia germinans*) dominant scrub predominately found in the upper part of the intertidal zone or on higher elevations.			
White Mangrove Scrub	Rutchey et al.	413000	413000
White Mangrove (*Laguncularia racemosa*) dominant scrub found throughout the intertidal zone.			
Red Mangrove Scrub	Rutchey et al.	414000	414000
Red Mangrove (*Rhizophora mangle*) dominant scrub found on the middle and lower portions of the intertidal and upper subtidal zone.			
Mixed Mangrove Scrub	Rutchey et al.	415000	415000
Mixed of mangrove scrub with no particular species of dominance found along the coast.			
Upland Hardwood Scrub	Rutchey et al.	431000	431000
Scrub containing a mixture of tropical and temperate broad-leaved trees found along coastal areas on rocky substrate with little or no soil.			

L3 - Group	Author	Raster ID	Rutchey ID
Graminoid Salt Marsh	Rutchey et al.	511000	511000
Graminoid dominated salt marsh			
Herbaceous Salt Marsh	Rutchey et al.	512000	512000
Herbaceous dominated salt marsh.			
Succulent Salt Marsh	Rutchey et al.	514000	514000
Succulent dominated salt marsh.			
Graminoid Freshwater Marsh	Rutchey et al.	522000	522000
Graminoid dominated freshwater marsh.			
Graminoid Freshwater Prairie	Rutchey et al.	523000	523000
Short hydroperiod freshwater marsh characterized by a mixture of low-stature grasses and sedges.			
Mixed Herbaceous Dune	Ruiz & Ross	623000	
Mixed herbaceous dominated dune.			
Barren Salt Flat	Rutchey et al.	910010	907000
Barren, generally hypersaline, flats exposed at low tide.			
Beach	Rutchey et al.	910020	901000
Sand and fine shell and coral fragments found along the shoreline.			
Littoral Zone	Ruiz & Ross	910030	
Shoreline that is submerged at high tide and exposed at low tide and is usually devoid of upland vegetation.			
Lightning Gap	Ruiz & Ross	910050	
Canopy gaps created by cloud to ground lightning strikes.			
Mud	Rutchey et al.	910070	903000
Moist or dry open ground.			
Water	Rutchey et al.	910120	904000
Open water areas such as ponds, lakes, rivers, bays, and estuaries.			
Barren Microkarst	Ruiz & Ross	910130	
Karst topography devoid of vegetation usually found around the perimeter of Coastal Hardwood Hammocks.			

L3 - Group	Author	Raster ID	Rutchey ID
Campground	Ruiz & Ross	920010	
Area designated for camping			
Canal	Rutchey et al.	920020	902020
Water bodies specifically designed to direct water from one location to another.			
Dock	Ruiz & Ross	920030	
A place used as a landing place or moorage for boats.			
Lawns & Landscaping	Ruiz & Ross	920040	
Ground that is covered with grass and/or trees and is maintained for its esthetics.			
Levee	Rutchey et al.	920050	902060
Elevated berm, generally with an access road, utilized to contain a body of water such as a lake or marsh			
Parking Lot	Ruiz & Ross	920060	
Area used for the parking of motor vehicles.			
Quarry	Rutchey et al.	920070	902080
Area used for mining rocks, minerals, or other natural resources.			
Road	Rutchey et al.	920080	902100
Paved and unpaved roads other than levees.			
Seawall	Ruiz & Ross	920090	
A wall or embankment to protect the shore from erosion or to act as a breakwater.			
Trail	Ruiz & Ross	920110	
A marked or established path or route designed to be followed.			
Spoil	Rutchey et al.	920120	902110
Earth and rock excavated or dredged.			
Walkway	Ruiz & Ross	920120	
A path, passage, etc. for pedestrians.			
Agriculture	Rutchey et al.	921000	902010
Fields designated for the production of goods or food through the cultivation of plants.			

L3 - Group	Author	Raster ID	Rutchey ID
Building	Ruiz & Ross	922000	
A roofed and walled structure built for permanent use.			
Unknown	Rutchey et al.	929999	908000
Unknown land cover.			

L4 - Formation

Formation	Author	Raster ID	Rutchey ID
Black Mangrove-Buttonwood Forest	Rutchey et al.	115100	115100

Black mangrove (*Avicennia germinans*) and Buttonwood (*Conocarpus erectus*) trees with the cover of either species ranging between 25-75%.

Black Mangrove-White Mangrove Forest	Rutchey et al.	115200	115200

Black mangrove (*Avicennia germinans*) and White Mangrove (*Laguncularia racemosa*) trees with the cover of either species ranging between 25-75%.

Black Mangrove-Red Mangrove Forest	Rutchey et al.	115300	115300

Black mangrove (*Avicennia germinans*) and Red Mangrove (*Rhizophora mangle*) trees with the cover of either species ranging between 25-75%.

Buttonwood-White Mangrove Forest	Rutchey et al.	115400	115400

Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) trees with the cover of either species ranging between 25-75%.

Black Mangrove Woodland-Succulent	Rutchey et al.	211030	211030

Black Mangrove (*Avicennia germinans*) trees in a matrix composed predominately of succulents.

Buttonwood Woodland-Succulent	Rutchey et al.	212030	211030

Buttonwood (*Conocarpus erectus*) trees in a matrix composed predominately of succulents.

Buttonwood-White Mangrove Woodland	Ruiz & Ross	215400	

Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) trees with the cover of either species ranging between 25-75%.

Black Mangrove Shrubland-Succulent	Ruiz & Ross	311040	

Black Mangrove (*Avicennia germinans*) shrubs in a matrix composed predominately of succulents.

Buttonwood Shrubland-Succulent	Ruiz & Ross	312040	

Buttonwood (*Conocarpus erectus*) shrubs in a matrix composed predominately of succulents.

White Mangrove Shrubland-Succulent	Ruiz & Ross	313040	

White Mangrove (*Laguncularia racemosa*) shrubs in a matrix composed predominately of succulents.

Mixed Mangrove Shrubland-Succulent	Ruiz & Ross	315040	

Mixed mangrove shrubs in a matrix composed predominately of succulents.

L4 -Formation	Author	Raster ID	Rutchey ID
Black Mangrove-White Mangrove Shrubland	Rutchey et al.	315200	316200

Black mangrove (*Avicennia germinans*) and White Mangrove (*Laguncularia racemosa*) shrubs with the cover of either species ranging between 25-75%.

Black Mangrove-Red Mangrove Shrubland	Rutchey et al.	315300	316300

Black mangrove (Avicennia germinans) and Red Mangrove (Rhizophora mangle) shrubs with the cover of either species ranging between 25-75%.

Buttonwood-White Mangrove Shrubland	Rutchey et al.	315500	316500

Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) shrubs with the cover of either species ranging between 25-75%.

Buttonwood-Red Mangrove Shrubland	Rutchey et al.	315600	316600

Buttonwood (*Conocarpus erectus*) and Red Mangrove (*Rhizophora mangle*) shrubs with the cover of either species ranging between 25-75%.

White Mangrove-Red Mangrove Shrubland	Rutchey et al.	315700	316700

White Mangrove (*Laguncularia racemosa*) and Red Mangrove (*Rhizophora mangle*) shrubs with the cover of either species ranging between 25-75%.

Black Mangrove Scrub-Succulent	Rutchey et al.	411040	411040

Black Mangrove (*Avicennia germinans*) scrub in a matrix composed predominately of succulents.

White Mangrove Scrub-Succulent	Rutchey et al.	413040	413040

White Mangrove (*Laguncularia racemosa*) scrub in a matrix composed predominately of succulents.

Red Mangrove Scrub-Graminoid	Rutchey et al.	414010	414010

Red Mangrove (*Rhizophora mangle*) scrub in a matrix composed predominately of graminoids.

Red Mangrove Scrub-Open Marsh	Rutchey et al.	414030	414030

Red Mangrove (*Rhizophora mangle*) scrub in a matrix composed predominately of Open Marsh or Open Salt Marsh.

Red Mangrove Scrub-Dominant	Rutchey et al.	414050	414050

Greater than 50% areal coverage of dwarf Red Mangrove (*Rhizophora mangle*) trees.

Mixed Mangrove Scrub-Graminoid	Rutchey et al.	415010	415010

Mixed mangrove scrub in a matrix composed predominately of graminoids.

Mixed Mangrove Scrub-Succulent	Rutchey et al.	415040	415040

Mixed mangrove scrub in a matrix composed predominately of succulents.

L4 -Formation	*Author*	*Raster ID*	*Rutchey ID*
Black Mangrove-White Mangrove Scrub	Rutchey et al.	415200	415200

Black mangrove (*Avicennia germinans*) and White Mangrove (*Laguncularia racemosa*) dwarf trees with the cover of either species ranging between 25-75%.

Black Mangrove-Red Mangrove Scrub	Rutchey et al.	415300	415300

Black mangrove (*Avicennia germinans*) and Red Mangrove (*Rhizophora mangle*) dwarf trees with the cover of either species ranging between 25-75%.

Buttonwood-White Mangrove Scrub	Rutchey et al.	415400	415400

Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) dwarf trees with the cover of either species ranging between 25-75%.

Buttonwood-Red Mangrove Scrub	Rutchey et al.	415500	415500

Buttonwood (*Conocarpus erectus*) and Red Mangrove (*Rhizophora mangle*) dwarf trees with the cover of either species ranging between 25-75%.

White Mangrove-Red Mangrove Scrub	Rutchey et al.	415700	415600

White Mangrove (*Laguncularia racemosa*) and Red Mangrove (*Rhizophora mangle*) dwarf trees with the cover of either species ranging between 25-75%.

Black Rush	Rutchey et al.	511200	511200

Black Rush (*Juncus roemerianus*) dominated salt marsh.

Cordgrass	Rutchey et al.	511400	511400

Sand Cordgrass (*Spartina bakeri*) and/or Gulf Cordgrass (*S. spartinae*) dominated salt marsh.

Glasswort	Rutchey et al.	514200	514200

Glasswort (*Salicornia spp*.) dominated salt marsh.

Sawgrass	Rutchey et al.	522100	522100

Sawgrass (*Cladium jamaicense*) dominated marsh.

Commercial	Ruiz & Ross	922010	

A building or complex housing retail business.

Government	Ruiz & Ross	922020	

A building or complex housing government offices.

Historical	Ruiz & Ross	922030	

A building or complex with historical significances

L4 -Formation	Author	Raster ID	Rutchey ID
Industrial	Ruiz & Ross	922040	
A building or complex housing factories.			
Lighthouse	Ruiz & Ross	922050	
A tower or structure designed to emit light and aid in navigation.			
Pump Station	Rutchey et al.	922060	902040
A Structure used to move water through canals.			
Residential	Ruiz & Ross	922070	
A building or complex used as a permanent dwelling.			

L5 - Alliance

Alliance	*Author*	*Raster ID*	*Rutchey ID*
Black Mangrove Woodland-Saltwort	Ruiz & Ross	211031	
Black Mangrove (*Avicennia germinans*) trees in a matrix composed predominately of Saltwort (Batis maritima).			
Buttonwood-White Mangrove Woodland-Herbaceous	Ruiz & Ross	215420	
Buttonwood *(Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) trees in a matrix composed predominately of herbaceous vegetation.			
Black Mangrove Shrubland-Saltwort	Ruiz & Ross	311041	
Black Mangrove (*Avicennia germinans*) shrubs in a matrix composed predominately of Saltwort (*Batis maritima*).			
Buttonwood Shrubland-Saltwort	Ruiz & Ross	312041	
Buttonwood (*Conocarpus erectus*) shrubs in a matrix composed predominately of Saltwort (*Batis maritima*).			
Black Mangrove-White Mangrove Shrubland-Succulent	Ruiz & Ross	315210	
Black Mangrove (*Avicennia germinans*) and White Mangrove (*Laguncularia racemosa*) shrubs in a matrix composed predominately of succulent vegetation.			
Buttonwood-White Mangrove Shrubland-Succulent	Ruiz & Ross	315510	
Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) shrubs in a matrix composed predominately of succulent vegetation.			
Buttonwood-White Mangrove Shrubland-Graminoid	Ruiz & Ross	315520	
Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) shrubs in a matrix composed predominately of graminoids.			
Black Mangrove Scrub-Saltwort	Rutchey et al.	411041	411041
Black Mangrove (*Avicennia germinans*) dwarf trees in a matrix composed predominately of Saltwort (*Batis maritima*).			
White Mangrove Scrub-Saltwort	Rutchey et al.	413041	413041
White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of Saltwort (*Batis maritima*).			
White Mangrove Scrub-Glasswort	Rutchey et al.	413042	413042
White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of Glasswort (*Salicornia bigelovii*).			
Red Mangrove Scrub-Sawgrass	Rutchey et al.	414011	414011
Red Mangrove (*Rhizophora mangle*) dwarf trees in a matrix composed predominately of Sawgrass (*Cladium jamaicense*).			

L5 -Alliance	***Author***	***Raster ID***	***Rutchey ID***
Red Mangrove Scrub-Frimbry	Rutchey et al.	414014	414014
Red Mangrove (*Rhizophora mangle*) dwarf trees in a matrix composed predominately of Marsh Frimbry (*Fimbristylis spadicea*).			
Red Mangrove Scrub-Black Rush	Rutchey et al.	414015	414015
Red Mangrove (*Rhizophora mangle*) dwarf trees in a matrix composed predominately of Black Rush (Juncus roemerianus).			
Red Mangrove Scrub-Subtidal	Ruiz & Ross	414051	
Red Mangrove (*Rhizophora mangle*) dwarf trees in a subtidal environment.			
Mixed Mangrove Scrub-Black Rush	Rutchey et al.	415015	
Mixed mangrove dwarf trees in a matrix composed predominately of Black Rush (*Juncus roemerianus*).			
Black Mangrove-White Mangrove Scrub-Succulent	Rutchey et al.	415240	415240
Black Mangrove (*Avicennia germinans*) & White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of succulents.			
Buttonwood-White Mangrove Scrub-Graminoid	Rutchey et al.	415410	415410
Buttonwood (*Conocarpus erectus*) & White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of graminoids.			
Buttonwood-White Mangrove Scrub-Succulent	Rutchey et al.	415440	415440
Buttonwood (*Conocarpus erectus*) & White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of succulents.			
Buttonwood-Red Mangrove Scrub-Graminoid	Rutchey et al.	415510	415510
Buttonwood (*Conocarpus erectus*) & Red Mangrove (*Rhizophora mangle*) dwarf trees in a matrix composed predominately of graminoids.			

L6 - Association

Association	*Author*	*Raster ID*	*Rutchey ID*
Buttonwood-White Mangrove Shrubland-Cordgrass	Ruiz & Ross	315521	
Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) shrubs in a matrix composed predominately of Sand Cordgrass (*Spartina bakeri*).			
Black Mangrove-White Mangrove Scrub-Saltwort	Rutchey et al.	415241	415241
Black Mangrove (*Avicennia germinans)* -White Mangrove (*Laguncularia racemosa)* dwarf trees in a matrix composed predominately of Saltwort (*Batis maritima*).			
Buttonwood-White Mangrove Scrub-Cordgrass	Rutchey et al.	415417	415417
Buttonwood (*Conocarpus erectus*) and White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of Sand Cordgrass (*Spartina bakeri*).			
Buttonwood-White Mangrove Scrub-Glasswort	Rutchey et al.	415442	415442
Buttonwood (*Conocarpus erectus*) & White Mangrove (*Laguncularia racemosa*) dwarf trees in a matrix composed predominately of Glasswort (*Salicornia bigelovii*).			
Buttonwood-Red Mangrove Scrub-Sawgrass	Rutchey et al.	415511	415511
Buttonwood (*Conocarpus erectus*) & Red Mangrove (*Rhizophora mangle*) dwarf trees in a matrix composed predominately of Sawgrass (*Cladium jamaicense*).			

Appendix 2

Definiens Professional® v5 Segmentation Algorithm

In *Definiens Professional®* v5, two process trees were created and saved – one for coastal shorelines and one for island shorelines. They are named Land_Water_Boundary_Coast and Land_Water_Boundary_Keys. Both processes contain the same steps, but parameters were altered within the listed functions. Within the Process Tree, processes are grouped into the general areas of Segmentation, Classification, Merge objects and Export. The Process Tree for the Keys is shown in Fig. 1.

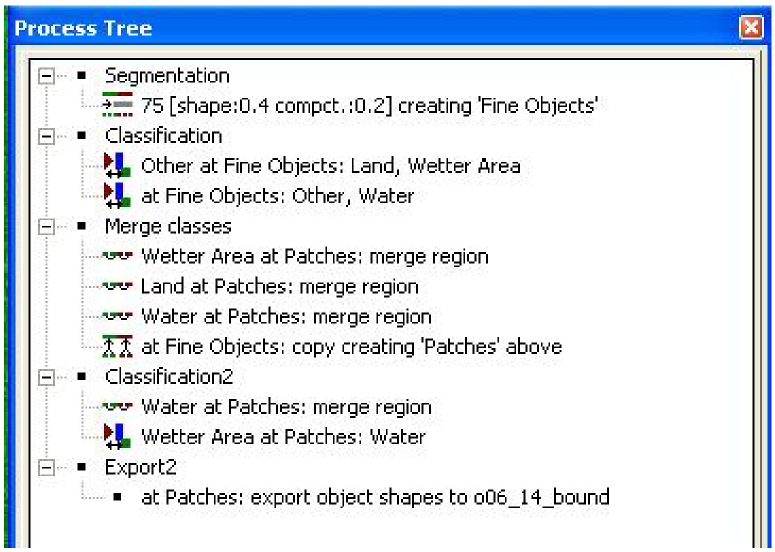


Fig. 1: Process Tree for shoreline creation using *Definiens Professional®* V5. This tree is used for the Keys. The Process Tree used for coastal areas is similar.

To create a project in *Definiens Professional®* v5, we loaded the image of interest, then defined the No Data areas. The near infrared band rarely reads zero in the scene; therefore we use band 4 = 0 as the definition of the No Data area. Next, image objects were created using multiresolution segmentation. In multiresolution segmentation, there are several parameters that can be evaluated. For both the keys and the coastal area, the best segmentation results were seen using only the NIR band 4 of the image and adjusting the Composition of Homogeneity Criteria to 0.6 for color and 0.4 for shape. This ratio refers to the relative importance of spectral input and shape for the image objects. The shape criteria was placed as high as 0.4 to give image objects that were more compact and therefore easier to edit later in ArcGIS as a shapefile.

Fig. 2a & 2b show the segmentation parameters for the coastal area and the keys. Because the coastal area is simpler in vegetation patterns, the scale parameter is 150 rather than 75 in the keys. The scale parameter is used as a threshold for heterogeneity calculations to determine if two objects are similar enough to be merged or kept separate. The remaining parameters are the same in the two multiresolution segmentation processes.

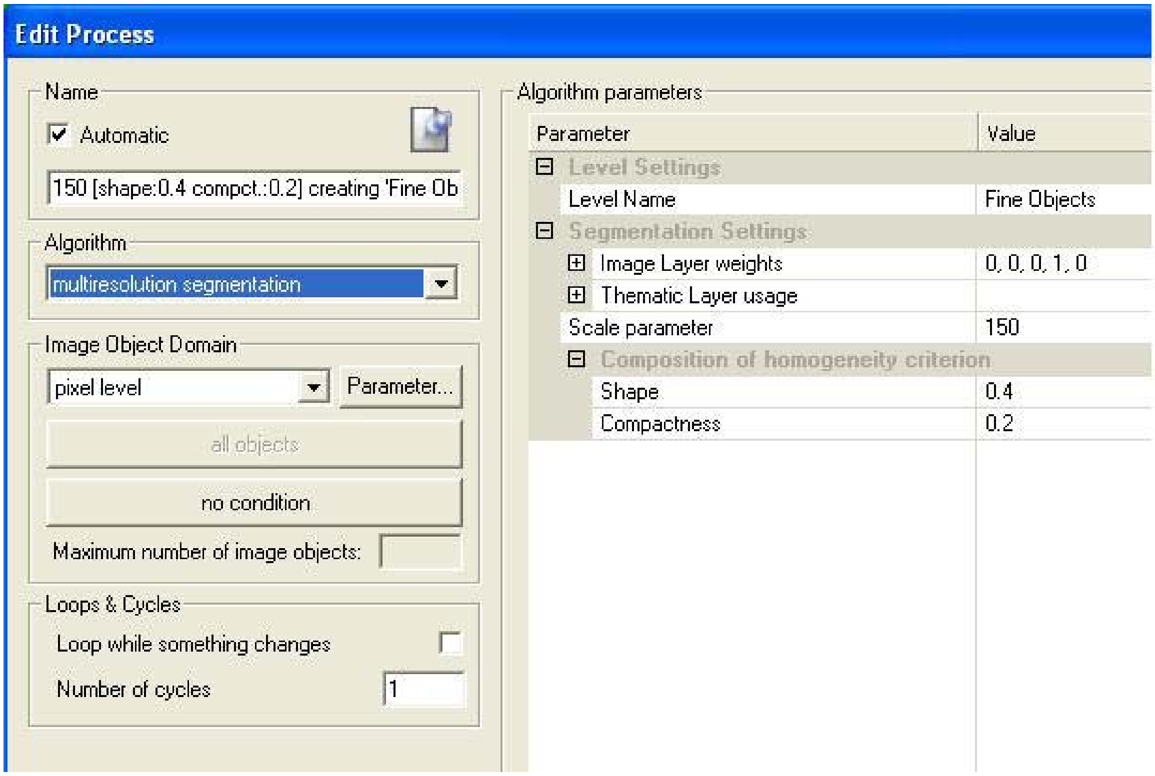


Fig. 2a: Multiresolution segmentation parameters for coastal area.

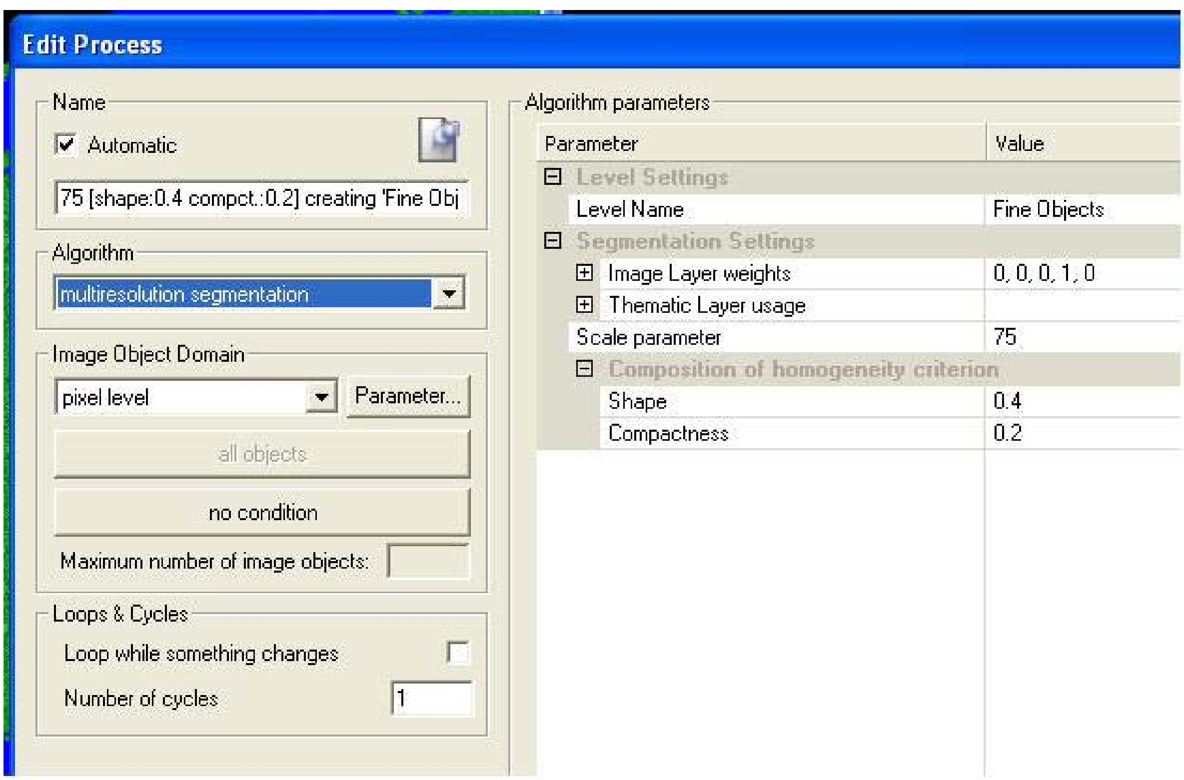


Fig. 2b: Multiresolution segmentation parameters for keys.

Classification of the image objects is defined through the Class Hierarchy. Fig. 3 shows the Class Hierarchy. There are two levels in the hierarchy. In the first level, objects are classified as Water or Other (not water). The Water class has an explicit definition; whereas the Other class is defined as those objects not classed as Water. In the second level, the Other objects are further classified into Wetter Area and Land (not wetter area). Again, here the Wetter Area class has an explicit definition, and the Land Class are those objects not classed as Wetter Area.

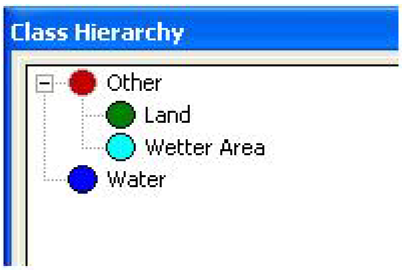


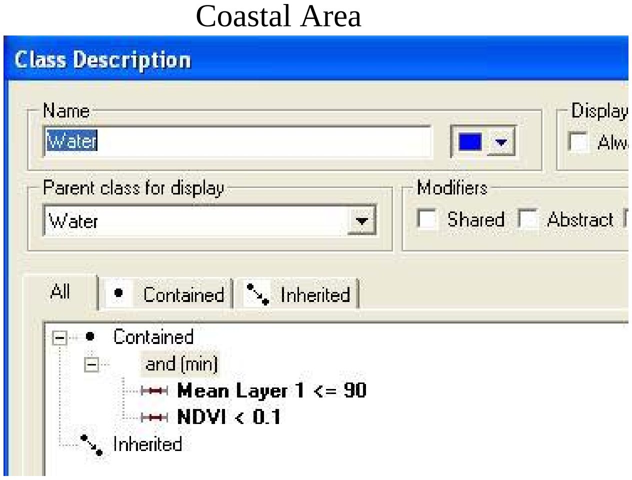
Fig. 3: Class Hierarchy for classification of objects as Land or Water.

To help reduce the influence of the spectral variability of the images in the classification, a ratio, NDVI, was defined as a custom feature using the brightness values:

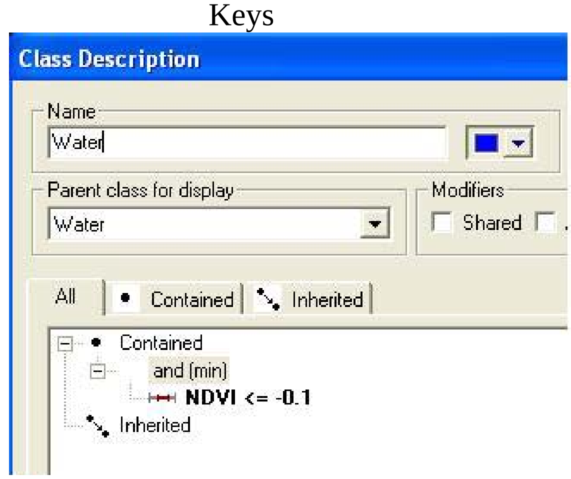
$$NDVI = (NIR - Red)/(NIR + Red) = (Band\ 4 - Band\ 1)/(Band\ 4 + Band\ 1)$$

Classes were than classified as followed (Fig 4.)

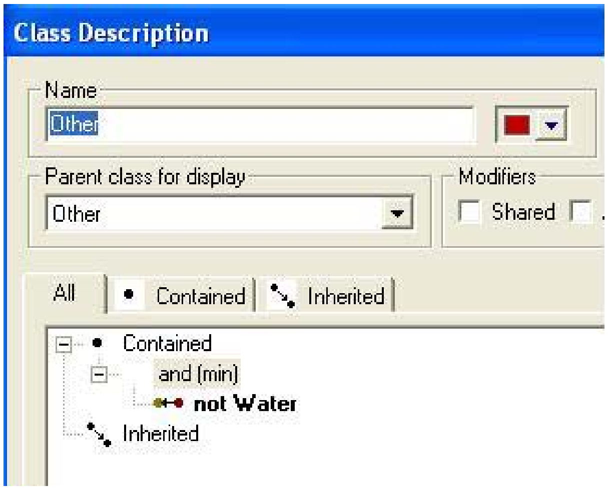
Coastal Area



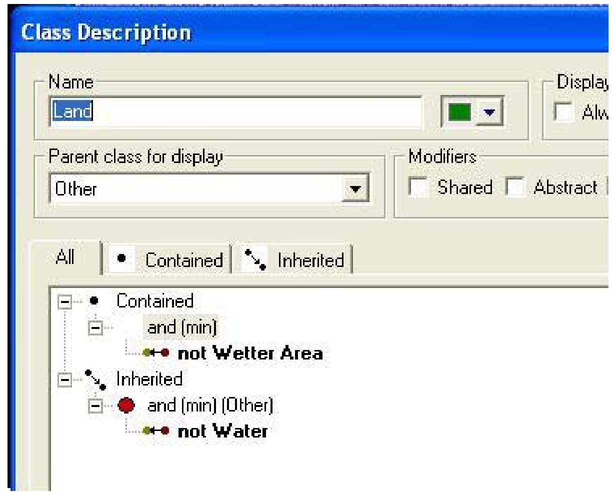
Keys

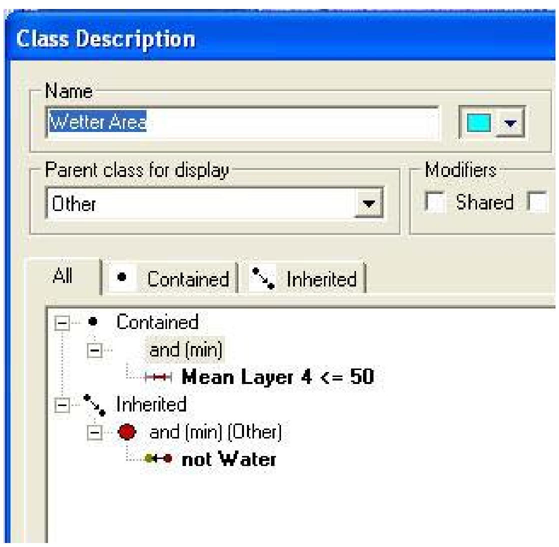


Coastal Area

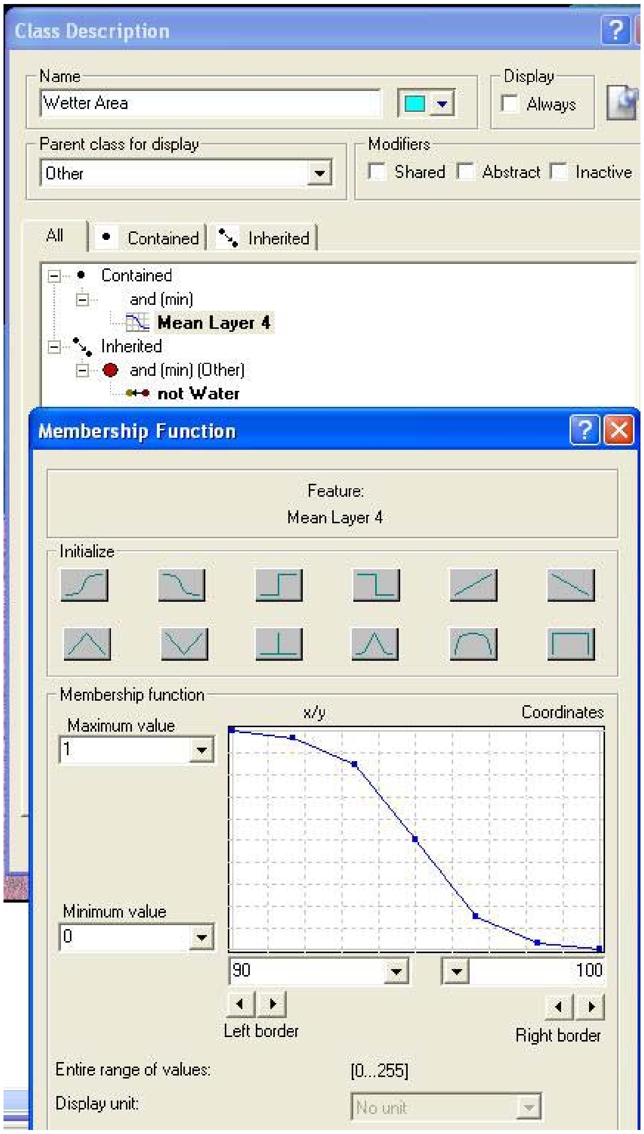


Keys





The Wetter Area class includes areas having shallow water and NDVI just above the cutoff for deeper water. For the coastal area the Wetter Area class is defined as a threshold using NIR (Band 4 <= 50).



In contrast the definition of Wetter Area of the keys is defined by a fuzzy less than function with a mean value of 95.

In general the differences between the keys and the coastal areas are:

Water is defined by a lower threshold for the keys (<=-0.1 vs. <0.1).

Band 1 (Red) is also included in the coastal area.

Wetter Area is defined in the NIR as a threshold <= 50 for the coastal area and fuzzy less than 90-100 for the keys.

Fig 4: class descriptions and functions used for classification.

These class descriptions, which are included with the process tree and rule set, are loaded for each analysis. However, since each scene is different in its spectral properties, it was necessary to alter the rules to get adequate delineation of the shoreline.

It was also necessary to manually change object boundaries and classifications due to the four factors described there. There are a couple of ways to manually assign classes to objects. To get all of the features needed, click on the Manual Editing Toolbar Button (Fig. 5) rather than using the Process Tree. The lower limit for resolving mangrove tree islands was a diameter of about 10 meters, depending on the quality of the photograph.

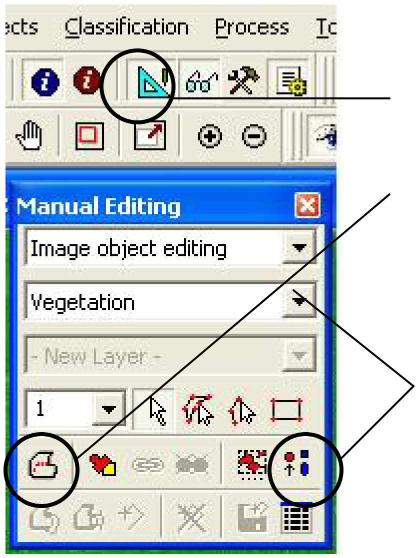


Fig. 5:. Manual Editing Toolbar.

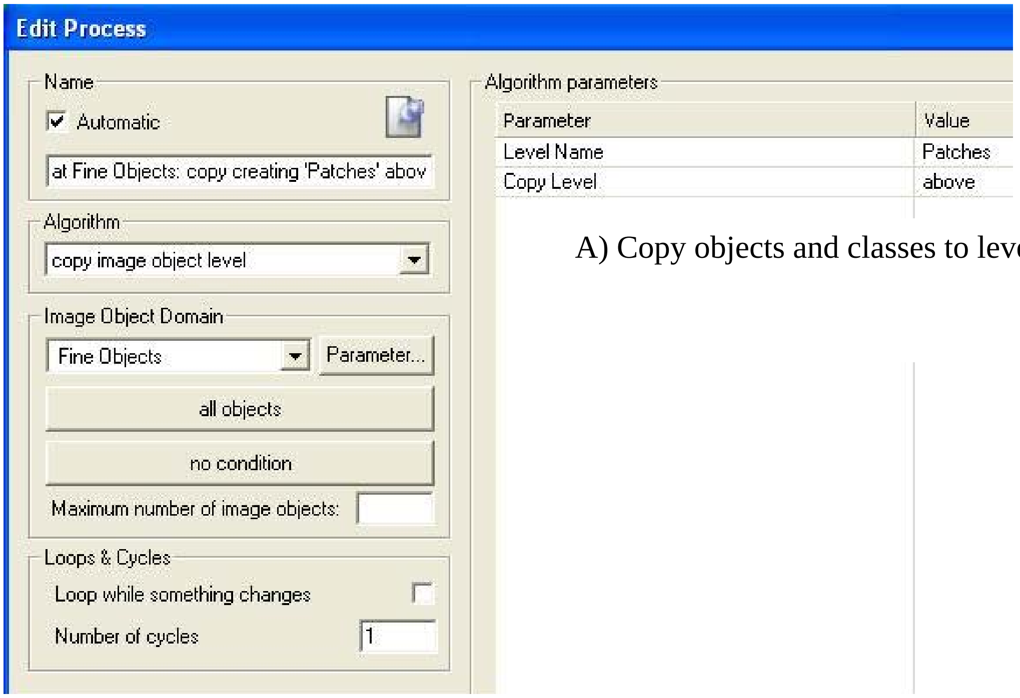
When the objects and classes closely follow the shorelines in the image, then objects can be merged and exported. In V4 (Ecognition), classification based image object fusion could be done in a couple of steps. In V5 the following steps must be done to merge adjoining objects having the same class:

1. Copy all the objects and their classification to a 'higher level'. The image object fusion will be done at this new level while preserving the original segmentation and classification.

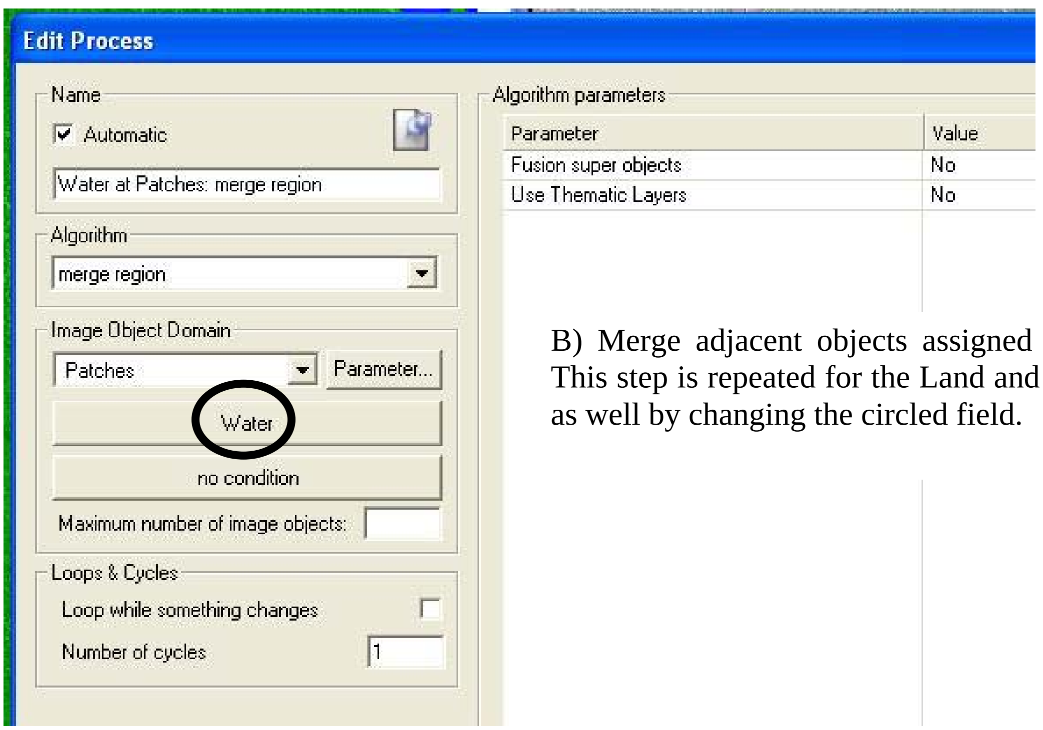
2. Use the Merge Region function for each class individually. This is real important, otherwise the entire image will end up as a single large object. The Merge Classes steps in the Process Tree are shown in Fig. 6, and the individual steps are shown in Fig. 7.

Fig. 6:. Merging objects portion of Process Tree.

Note: The processes nested under each category are read from bottom to top.



A) Copy objects and classes to level above.



B) Merge adjacent objects assigned the class of Water. This step is repeated for the Land and Wetter Area classes as well by changing the circled field.

Fig. 7:. Parameters for copying level and merging objects by class.

At this point, the image has been segmented and the objects classified as Land, Wetter Areas (shallow water) and Water (Deep water). For the purposes of creating shorelines, the project is simplified by changing the class of Wetter Areas to Water then repeating the object fusion. Assigning objects to a particular class is done through the Process Tree (Fig. 8).

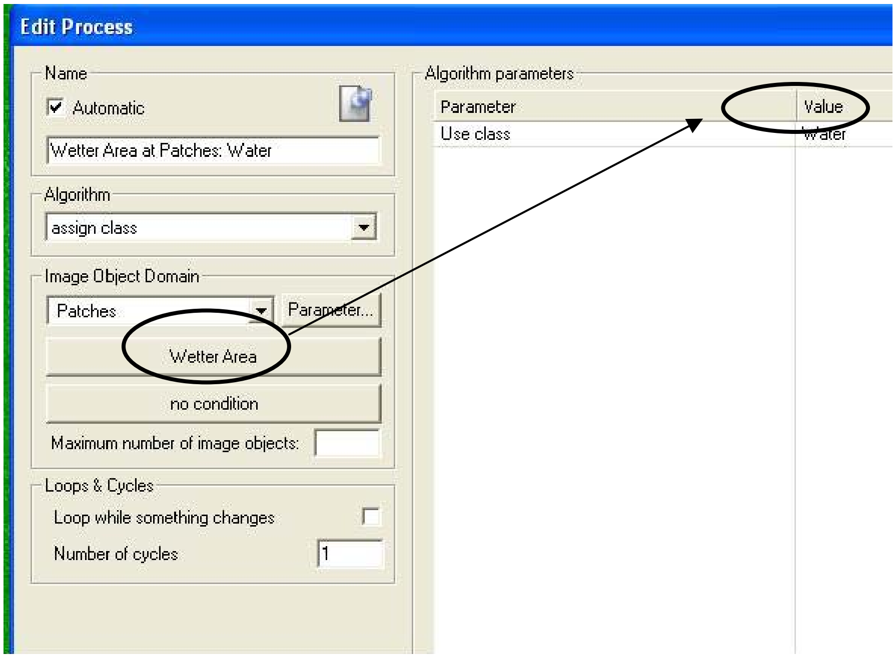


Fig. 8:. Assign class to an object. Here objects classed as Wetter Area are changed to the Water class.

The result of the classification in Fig 9. The green area are objects classified as Land, and the blue areas are classified as water.

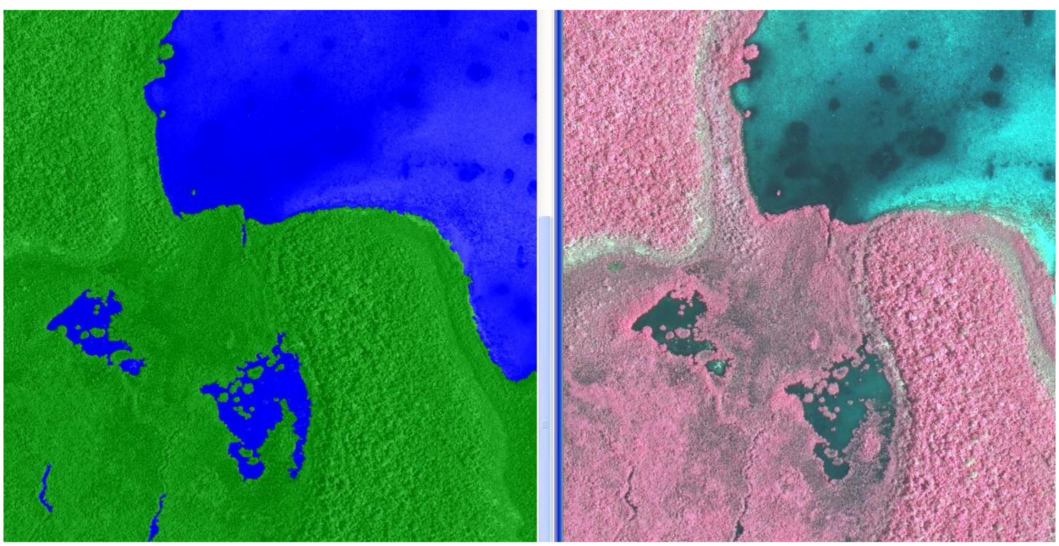


Fig. 9: Results of classification based on algorithm developed.

The last step in the process is to export the objects as a shapefile. The shapefile can be assigned a projection and edited in ArcGIS.