Guam Vegetation Mapping Using Very High Spatial Resolution Imagery 2006

Methodology

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Introduction

The USDA Forest Service Pacific Southwest Region, Forest Health Protection (FHP) and the Pacific Northwest Research Station, Forest Inventory and Analysis (FIA) Programs are leading a collaborative effort to acquire recurring high spatial resolution satellite imagery and develop detailed vegetation maps for the U.S. affiliated Pacific Basin islands. The long-term goal of the program is to provide environmental scientists and resource managers with up-to-date information on land cover and its change through time. This report provides detailed documentation of the methods and techniques used to create the vegetation map for Guam.

Project Area

Guam is an unincorporated territory of the United States located at 13.48-degree-North in latitude and144.45-degree-East in longitude. It is about 900 miles north of the Equator in the Western Pacific, 3,800 miles west of Honolulu, and 1,500 miles south of Japan. The island spans approximately four to eight miles in width, is almost 32 miles long, and covers a land area of approximately 135,000 acres making it the largest island of the Marianas archipelago. Guam is the southernmost island in the Marianas group (Figure 1).

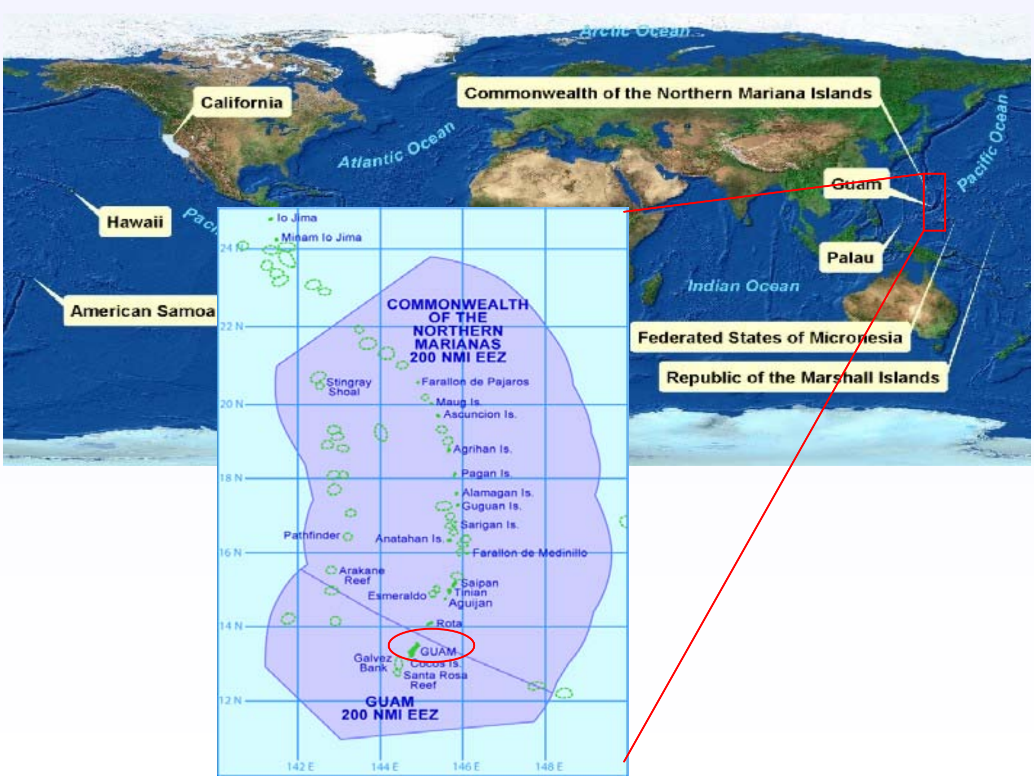


Figure 1. Geographic Location of Guam

The population of Guam is estimated to be around 166,000, with approximately 37% being Chamorros, Guam's original inhabitants, 26% Filipinos, 10% Caucasian, and 27% other ethnic groups (Guam Visitors Bureau, 2006). The capital of Guam is Hagatna (Agana). Official languages are Chamorro and English.

Guam is warm throughout the year, averaging 29 degrees Celsius (85 degrees Fahrenheit) varying between 21 to 32 degree Celsius (70 – 90 degrees Fahrenheit). Rainfall is relatively seasonal typically lasting from June through December. September and October are the wettest months, receiving an average of 355 millimeters or 14 inches of rainfall (Guam Visitors Bureau, 2006). However, it is rather dry from January to May. The highest point on the island is Mt. Lamlam 406 meters or 1,332 feet. The northern half of the island is dominated by a large limestone plateau with three small volcanic exposures protruding through it. The southern half, in sharp contrast, is composed of ancient deeply weathered volcanic material with patches of limestone here and there (Mueller-Dombois and Fosberg, 1998).

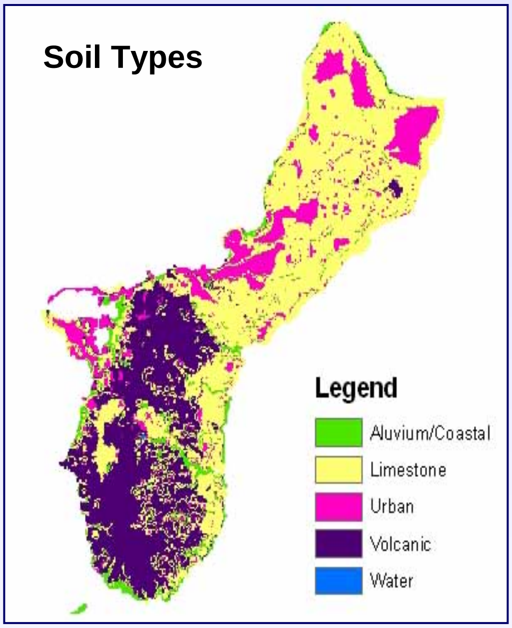


Figure 2. Soil Types of Guam

Guam hosts a diversity-rich collection of over 600 species of vascular plants, with more than 100 species of trees. The distribution of vegetation is influenced by two main factors, the sharply contrasting soil types between the north and south, and disturbances both anthropogenic (e.g. urban development and fire) and natural (i.e. windthrow from hurricanes).

The last comprehensive study on Guam's vegetation is documented in ***Vegetation of the Tropical Pacific Islands*** by Mueller-Dombois and Fosberg (1998). Based on studies done by Fosberg in the 1940s and early 1950s, the greater part of the island was forested with substantial areas of grasses, especially in the south. Moreover, he described that the majority of the island was covered by small patches of extremely varied vegetation types. Forests appeared to be mostly second growth.

According to the "Reconnaissance Map of the Vegetation of Guam" originally created in 1954 by Dr. F. R. Fosberg (FDR) and updated in 1995 by Dr. Harley I. Manner (University of Guam), Guam's vegetation was classified into nine groups. These groups laid the framework for establishing an updated classification scheme for this mapping project:

1. Forest on elevated limestone plateaus and cliffs;
2. Savanna Complex;
3. Swamp Forest Complex, including Mangroves;
4. Ravine Forest on Volcanic Soil and on Limestone Outcrops in Valleys;
5. Secondary Thickets and Partially Cultivated Scrub Forest;
6. Coconut Plantation;
7. Predominantly Open Ground and Pastures;
8. Urban Vegetation around military installations and cities; and
9. Reed Marsh (Fosberg, 1998).

Classification Scheme

Establishing a proper classification scheme (target classes), is critical to the success of any mapping project. A proper vegetation classification scheme is not only defined by what the established project goals are, but also determined by the existing knowledge about the project area's vegetation, and in this case, limited by what can be discerned from optical remotely sensed imagery.

The main goal of this project was to produce a timely baseline vegetation map for Guam. However, determining the best classification scheme was difficult for three reasons. First, the only historic data available was the reconnaissance map by Dr. F. R. Fosberg in paper print. Secondly, mapping tropical vegetation using very-high spatial resolution remote sensing imagery at detailed levels is still in its infancy and not many peer-reviewed journal articles were available at the initial stage of the project. Finally, tropical vegetation systems are very complex. The plant species are so rich and many vegetation communities share a great number of same species.

A classification scheme was drafted and modeled after the categories used by the FDR reconnaissance map. The draft scheme was modified during the initial classifications due to limitations of the satellite data. The classification scheme was further refined after two field visits and meetings with local experts including David Limtiaco, Chief of Forestry from the Department of Forestry & Soil Resources, Guam. The final classification scheme for Guam is shown in Table 1. Note that the system also includes non-vegetation classes.

Class	Land Use/Land Cover
Limestone Forest	Forest Land
Ravine Forest	Forest Land
Palma Brava Grove	Forest Land
Scrub Forest	Forest Land
Leucaena Stand	Forest Land
Casuarina Thicket	Forest Land
Acacia Plantation	Forest Land
Savanna Complex	Rangeland
Strand Vegetation	Rangeland
Other Shrub/Grass	Rangeland
Coconut Plantation	Agricultural Land
Agriculture Field	Agricultural Land
Urban Builtup	Urban or Built-up Land
Urban Cultivated	Urban or Built-up Land
Mangrove Swamp	Wetland
Marsh Land	Wetland
Wetland	Wetland
Bad Land	Barren Land
Sand Beach/Bare Rocks	Barren Land
Barren	Barren Land
Water	Water

Table 1. Classification Scheme of Guam

Vegetation Class Description:

Forest Land

- **Limestone Forest**

  Forest on elevated limestone plateaus and cliffs. "Basically moist, broadleaved evergreen forest, mostly dominated by dugdug or wild breadfruit (*Artocarpus*) and nunu or banyan (*Ficus*), in some large areas by screw pine (*Pandanus*), locally by other species. This forest varies to a dense scrub on edges and faces of cliffs and near the sea" (Mueller-Dombois and Fosberg, 1998. p.272).

- **Ravine Forest**

  - Ravine Forest

    "Basically moist, broad-leaved evergreen forest, dominated locally by pago (Hibiscus) or screw pine (*Pandanus*), rarely by dugdug (*Artocarpus*). This forest is usually very mixed, commonly containing betel palm (*Areca*) and with dugdug scarce or absent. It frequently varies to a dense scrub of limon de china (*Triphasia*) or to patches of reed marsh and patches of hibiscus scrub. Coconuts are occasional to "locally common" (Mueller-Dombois and Fosberg, 1998. p.274). Dominant tree species in Ravine Forest listed by Fosberg include *Hibiscus tiliaceaus*, *Pandanus tectorius*, *Pandanus dubius*, *Ficus prolixa*, *Glochidion marriannensis*, and *Premna serratifolia*.

- o Palma Brava Grove

  Groves of forest in ravines and slopes of central Guam dominated by *Heterospathe elata* (Palma Brava). Also can be found in these stands are Pandus and Hibiscus. Palma Brava is listed by Space and Falanruw (1999) under the category of native and naturalized species exhibiting aggressive behavior, and was described as palms that "continue to spread in ravines and slopes of central Guam" (p.5).

- **Scrub Forest**

  Named as Secondary Thickets and Partially Cultivated Scrub Forest by Fosberg. It is "extremely variable vegetation, resulting from long-continued human disturbance, usually on argillaceous limestone. It makes a fine mosaic of patches of forest, usually dominated by breadfruit (*Artocarpus*), coconut groves, bamboo clumps, patches of scrub or scrub forest, home sites, small cultivated fields and patches, pastures, and very large areas of Tanantangan (*Leucaena leucocephala*) thickets" (Mueller-Dombois and Fosberg, 1998. p.274).

- **Leucaena Stand**

  Continuous canopy of Tangantangan (Leucaena leucocephala). Large areas of Leucaena have become widespread since WWII. It was described as "introduced species that are invasive elsewhere and are also invasive in Micronesia" (Space and Falanruw, 1999).

- **Casuarina Thicket**

  Casuarina equisetifolia, commonly called "Ironwood" or "Australian Pine", fairly distinctive on IKONOS image and aerial photograph. This species grows well on the savanna but scattered in many parts, locally forming sparse woodland. Casuarina also occurs along the coast in bands usually too narrow to be separately delineated.

- **Acacia Plantation**

  Acacia confuse, an introduced species widely planted by Guam Forestry on the Savanna areas as a measure to revegetate these disturbed lands and to prevent soil erosion. They form small forest stands on the flat area and gentle slopes among the savanna grassland. Acacia was also listed by Space and Falanruw (1999, p.4) as a "species that are mentioned or listed as weedy or invasive elsewhere and are common or weedy in Micronesia."

Rangeland

- **Savanna Complex**

  "Mosaic of several kinds of grassland and herbaceous vegetation intermixed with erosion scars with shrubs and tangled ferns" (Mueller-Dombois and Fosberg, 1998. p.274). It covers a large portion of the island's volcanic surface and continuous from the middle to the south end. Savanna Complex is dominated by Swordrass (*Miscnthus floridulus*),

- **Strand Vegetation**

  Strand Vegetation refers to vegetations along the coasts growing in the immediate vicinity of the sea, generally too narrow to be separated.

- **Other Shrub and Grass**

  Areas where the natural vegetation has been disturbed and replaced by fast growing grass, shrub and weedy species

Agricultural Land

- **Coconut Plantation**

  Dense groves of coconut trees (*Cocos nucifera*) originally planted for commercial purposes. Most of these plantations have been abandoned since WWII. Some are still in relatively good condition especially along the flat coasts on the northwest, and in the ravines on the southwest and south coasts. Coconut tree is also common in the Urban Cultivated areas, and is an important indicator and a dominant species for the Scrub Forest.

- **Agriculture (Crop) Field**

  Areas of cultivated lands, cropland, very limited existence in Guam. Common vegetables include tomatoes, green onions, eggplant and cucumbers.

Urban or Built-up Land

- **Urban Builtup**

  Urban buildup land: buildings, roads, et al.

- **Urban Cultivated**

  Vegetation around military installations and cities, usually well maintained, e.g. golf courses, lawns, soccer and baseball fields, etc.

Wetland

- **Mangrove Swamp**

  Rather poorly represented on Guam but is readily accessible. There are two mangrove species in Guam: *Bruguiera gymnorhiza* and *Rhizophora mucronata*.

- **Marsh Land**

  Areas of grasses, sedges, and herbs growing in standing water most of the year, usually dominated by the tall reed *Phragmites karka*.

- **Wet Land**

  Unidentified Wetland

Barren Land

- **Bad Land**

  Exposed bare soils caused by erosions, a serious problem in the central and southern Savanna areas. Fire and the increasing prevalence of cross-country motorcycling are causing widespread erosion and damage to the vegetation.

- **Sand Beach and Bare Rocks**

  Sand Beach and Bare Rocks with no or minimum vegetation coverage.

- **Barren**

  Unidentified Barren Land

Water

Water of all types

Imagery Data

IKONOS (*Space Imaging ®)* was used as the source data for image processing and classification. Acquiring satellite imagery over the tropical islands is challenging due to heavy cloud cover which is year-round in some areas. IKONOS 4-meter-resolution multispectral (Blue, Green, Red, Near-Infrared) and 1-meter-resolution panchromatic mosaic images for Guam were provided by the USDA - USFS Pacific Northwest Research Station Forest Inventory and Analysis program (FIA) (http://www.fs.fed.us/pnw/fia/). Table 2 shows the spectral specifications of the imagery.

Band	Bandwidth (nm)	Center Wavelength (nm)
Panchromatic	403	727.1
Blue	71.3	480.3
Green	88.6	550.7
Red	65.8	664.8
Near-Infrared	95.4	805.0

Table 2. IKONOS Spectral Band Characteristics (Space Imaging)

Two IKONOS multispectral mosaics created in 2003 and 2004 respectively were used for image processing and classification. Figure 3 shows the initial 2003 mosaic used for classification and Figure 4 shows the 2004 mosaic used to provide data for areas covered under clouds/shadow in the 2003 mosaic. Metadata indicated the 2004 mosaic was created using 13 different IKONOS scenes, dated 2002/11/11, 2003/01/05, 2003/01/16, 2003/11/14, 2003/05/14, and 2004/01/08. Unfortunately, precise dates for the 2003 mosaic were not provided.

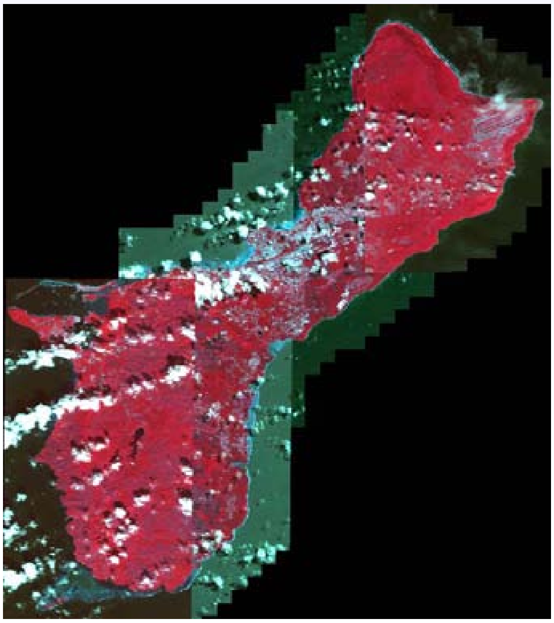


Figure 3. 2003 IKONOS Mosaic

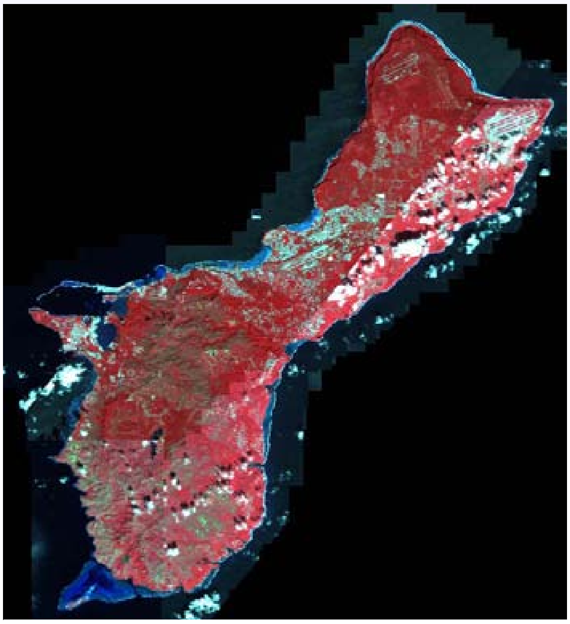


Figure 4. 2004 IKONOS Mosaic

Image Processing and Classification

The image processing and classification in this project took three phases:

1. Image preparation;
2. Creating the 5-Class landcover map; and,
3. Generating detailed vegetation classes.

Image Preparation

Image preparation involved two tasks including removal of cloud/shadow pixels and stratifying the image by landcover types. Both tasks are performed to improve the classification efficiency and accuracy. Cloud/shadow pixel clusters were digitized and masked out of the mosaic as Areas of Interest (AOIs) in ERDAS IMAGINE 8.6 (Leica Geosystems ®). Figure 5 shows the 2003 IKONOS mosaic after the cloud and shadows were removed. With its histogram manually stretched this image also revealed or rather enhanced, three relatively color-distinctive sections (defined by red polygons). These variations resulted from mosaicking together multiple IKONOS scenes acquired from different dates and view angles. Although the 2003 mosaic actually contained more than three scenes, we only stratified it into these three clearly separable regions due to the lack of sufficient metadata. Subsequent classifications were performed separately on each of these three regions.

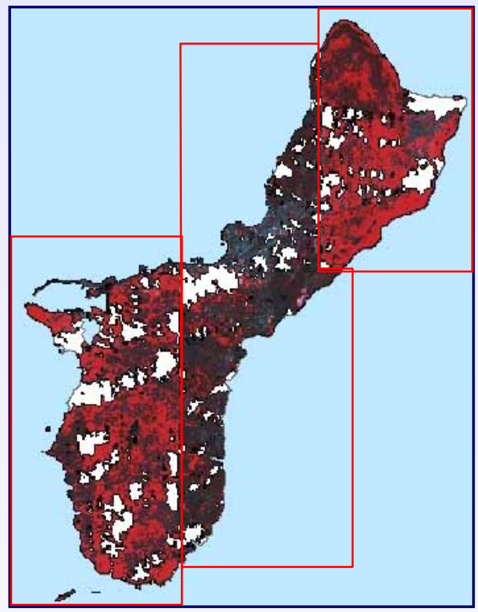


Figure 5. 2003 Mosaic without Cloud/Shadow

Creating the 5-Class Landcover map

Unsupervised classifications using Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm were performed to create the 5-Class landcover map. The ISODATA algorithm uses minimum spectral distance to assign a class for each pixel. It repeatedly performs an entire classification and recalculates statistics until all criteria are met (ERDAS Field Guide). There are three parameters for ISODATA clustering:

- N – the maximum number of clusters/classes to be formed;
- T – a convergence threshold that refers to the maximum percentage of pixels whose class values are allowed to be unchanged between iterations;
- M – the maximum number of iterations.(ERDAS Field Guide).

Using ERDAS IMAGINE's Unsupervised Classification function, twenty (N) initial classes were generated from the ISODATA clustering process (T = 96%; M = 20). Each class was either attached to one of the five landcover classes or given a "confused class" label. A confused class label indicates pixels belonging to two or more classes. These confused classes were isolated and re-run through ISODATA clustering again (N = 10; T = 96%; M = 20). These two steps iterated until there were no confused classes left. Figure 6 illustrates this iterative process. All classification results were then merged together into one 5-class landcover image (Figure 7).

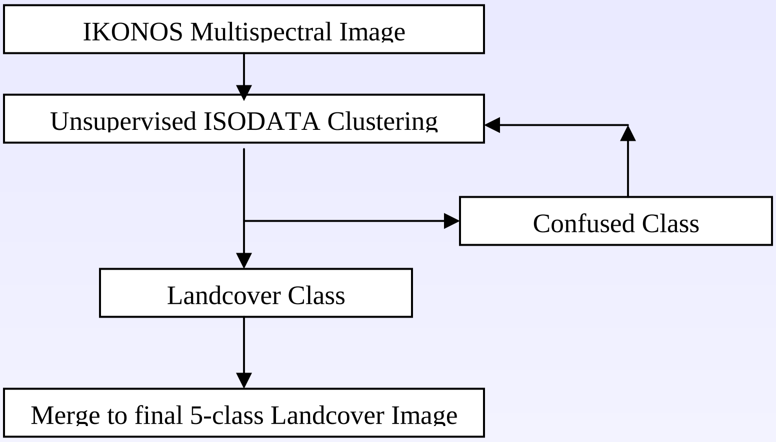


Figure 6. Creating 5-class Landcover Map

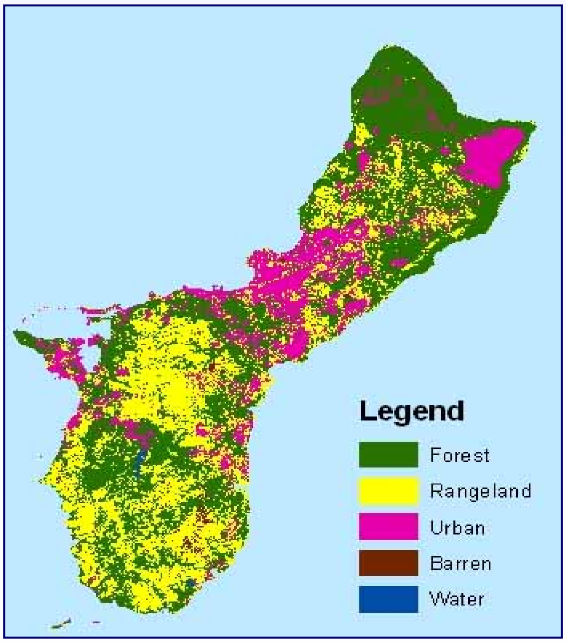


Figure 7. Guam 5-Class Landcover

Generating detailed vegetation classes

Generating the detailed classes for forest types were more difficult than initially anticipated even when classifications were performed on each landcover stratum. We first attempted to use a supervised classification method to develop the detailed vegetation classes. Supervised classification, in contrast to unsupervised clustering, requires direct involvement of and is closely controlled by the analyst. Basically, the analyst selects pixels that represent defined feature classes and then instructs the computer to identify pixels with similar characteristics.

To perform a supervised classification the first step is to select training sites. There were two sources for training data for this project, existing data – the FDR paper map, and results from the preliminary unsupervised classification. We created several independently selected training sets from both sources. Then trained and applied the classifier to the entire image. In searching for a better result this process was applied to not only the original IKONOS multispectral image, but also various combinations of the original bands; the Normalized Difference Vegetation Index (NDVI) and the Tasseled Cap transformation image. Unfortunately the results were less than what we expected. Limited by available tools and time we decided to manually assign labels to clusters of detailed classes based on visual interpretation of the image with reference to the FDR Map. We also used the preliminary unsupervised classification results as a guide. The finished product represents the first draft of the detailed vegetation map for Guam.

During the classification process, field visits were made to Guam in June 2004 and March 2005. In the first visit, local experts from the Department of Forestry & Soil Resources reviewed the draft map and provided valuable suggestions that helped to fine-tune the classification scheme and to improve the map. During the 2005 fieldwork, we presented a second draft map and received more comments and advice. Additional field data (digital photo/video and field observation notes) were collected for refining classes and to conduct accuracy assessment. With these newly available field data, we applied a great deal of editing to the map.

In order to improve efficiency, we performed the actual editing on a polygon layer using customized labeling tools developed in Visual Basic 6.0 (Microsoft ®) for ArcMap 9.1 (ESRI ®). The polygon layer was created by segmenting the 2004 IKONOS multispectral mosaic image using eCognition Professional 3.4 (Definiens ®). eCognition breaks a continuous image into discrete segments/polygons by analyzing the pixel's spectral and textural characteristics. For this project, we set the segmentation's scale factor, a parameter that determines the average size of output segments, to 50 after comparing results from several trails. Polygons were first assigned class labels from the draft map based on location. Then all polygons were checked against available field data. If an error was identified, the correct class label was assigned.

After editing was completed, all polygons smaller than 0.2-acres, the minimum mapping unit (MMU) used by this project, were eliminated using the “eliminate” command from ArcGIS 9.1 Workstation (ESRI ®). These polygons were merged into neighboring large polygons based on majority rule.

The map was edited after each field visit. The main objective for the 2005 fieldwork was to collect data for accuracy assessment which was actually conducted before the map received additional editing. It is important to note that the main goal of this project was to produce a baseline vegetation map. Therefore, the map will be continually updated as new information becomes available.

Accuracy Assessment

Accuracy assessment of a landcover mapping project is crucial because it measures the overall reliability of the map, identifies classes or areas that do not meet the accuracy objectives, and identifies where additional efforts will be required when the map is updated.

Reference Data

Reference data were collected through two separate field trips: one in March, 2005; and a previous trip in June 2004.

During the 2004 fieldwork, aerial reconnaissance was conducted onboard a small fixed-wing aircraft. One hundred and fourteen aerial photos of the ground vegetation were taken using a Canon PowerShot A80 digital camera (Figure 8). We also visited the naval reservation area around Fena Valley Reservoir, where the original vegetation is well preserved

Figure 8. Aerial photo of native vegetation

In the 2005 field visit, 73 locations were sampled. Forty six of these sites were high-elevation points and were selected to achieve the widest coverage of the island’s vegetation. The other 27 sites were random stops along the roads. At each site, the geographic coordinates (Lat/Lon, WGS 84 Datum) were recorded using a Trimble GeoExplorer 3 GPS receiver. Detailed vegetation descriptions including species composition for each site and the areas within visible range (using 10-by-4 Nikon binoculars) were recorded. Photographs were taken using a Canon PowerShot A80 digital camera. In total, we collected over 700 high-resolution digital photos that covered most of the landcover types on Guam.

Sampling Strategy

In addition to the 73 ground reference sites, we used the Accuracy Assessment module in ERDAS IMAGINE to generate 236 random points. A stratified random sampling scheme was implemented in order to obtain representations for all vegetation types.

Reference class labels were assigned to these random points based on available field data. 17 sites were dropped due to insufficient information, reducing the total number of random sites to 219.

The 219 randomly generated points together with the 73 ground reference locations created an accuracy assessment sample base of 292 sites.

Analysis

The techniques used to calculate the accuracy statistics were based on ***Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*** (Congalton and Green, 1999). Here are the key definitions and calculation formulas.

The Error Matrix

Row: Classified (*j=1,2,…,k*) Column: Reference (*i=1,2,…,k*)

	CLASS 1	CLASS 2	…	CLASS $_i$
CLASS 1	N_{11}	N_{12}	$N_{1...}$	N_{1i}
CLASS 2	N_{21}	N_{22}	$N_{2...}$	N_{2i}
…	$N_{..}$	$N_{...2}$	$N_{...}$	$N_{...i}$
CLASS $_J$	N_{j1}	N_{j2}	$N_{j...}$	N_{ji}

Overall Accuracy

$$\mathbf{A} = \sum_{i=1}^{k} N_{ii} \Big/ \mathbf{N}$$

A: Overall Accuracy

$\sum_{i=1}^{k} N_{ii}$: total number of accurately classified samples

N: total number of samples assessed

Kappa Index

The Kappa analysis is a discrete multivariate technique used in accuracy assessment for remote sensing image classification to measure the difference between the actual agreement in the error matrix and the chance agreement that might occur by random guessing. In other words, Kappa tests if a classification is meaningful and significantly better than just a random classification/guessing.

Kappa values range from 0 to 1. The closer Kappa is to 1.0 the better the accuracy, however it is generally considered satisfactory when greater than 0.7.

$$K = \left(N^* \sum_{i=1}^{k} N_{ii} - \sum_{i=1}^{k} N_i * N_j \right) \Big/ \left(N^2 - \sum_{i=1}^{k} N_i * N_j \right)$$

K: Kappa Index

In addition to these two numbers that measures the overall accuracy of a classification, the producer's and user's accuracies which are ways of representing individual category accuracies were also calculated.

Producer's Accuracy

Producer's accuracy is a reference-based accuracy that estimates the probability of an actual class being correctly identified.

$$PA_i = N_{ii} \Big/ \sum_{j=1}^{k} N_{ji}$$

User's Accuracy

User's accuracy is a map-based accuracy that estimates the probability of a class as shown on the map being actually correct.

$$UA_j = N_{jj} \Big/ \sum_{i=1}^{k} N_{ji}$$

A standard error matrix was created using the 292 reference samples (Table 3). Overall accuracy, kappa index, and the producer's and user's accuracy for each class are calculated.

Table 3. Error Matrix

Class Name	1	2	3	4	5	6	7	8	9	10	11	Total
Ravine Forest	22	0	1	0	0	0	0	0	0	0	0	23
Limestone Forest	1	12	2	12	0	0	0	0	0	0	0	27
Savanna Complex	2	0	27	0	0	0	0	0	0	0	0	29
Scrub Forest	2	0	1	31	1	0	0	0	0	1	2	38
Limestone Scrub Forest	1	0	1	4	17	0	1	0	0	0	0	24
Urban	0	0	0	0	0	28	4	1	0	0	0	33
Urban Cultivated	1	0	1	3	2	1	29	0	0	1	0	38
Barren	0	0	2	0	1	0	2	16	0	1	0	22
Water	0	0	0	0	0	0	0	1	20	0	0	21
Wetlands	0	0	0	0	0	0	0	0	0	19	0	19
Plantations	0	0	0	0	0	0	0	0	0	0	18	18
Total	29	12	35	50	21	29	36	18	20	22	20	292

Overall Map Accuracy: 81.8%

Kappa Index: 0.80

Producer's and User's Accuracies:

Class Name	Producer's Accuracy	User's Accuracy
Ravine Forest	75.9%	95.7%
Limestone Forest	100.0%	44.4%
Savanna Complex	77.1%	93.1%
Scrub Forest	62.0%	81.6%
Limestone Scrub Forest	81.0%	70.8%
Urban	96.6%	84.8%
Urban Cultivated	80.6%	76.3%
Barren	88.9%	72.7%
Water	100.0%	95.2%
Wetlands	86.4%	100.0%
Plantations	90.0%	100.0%

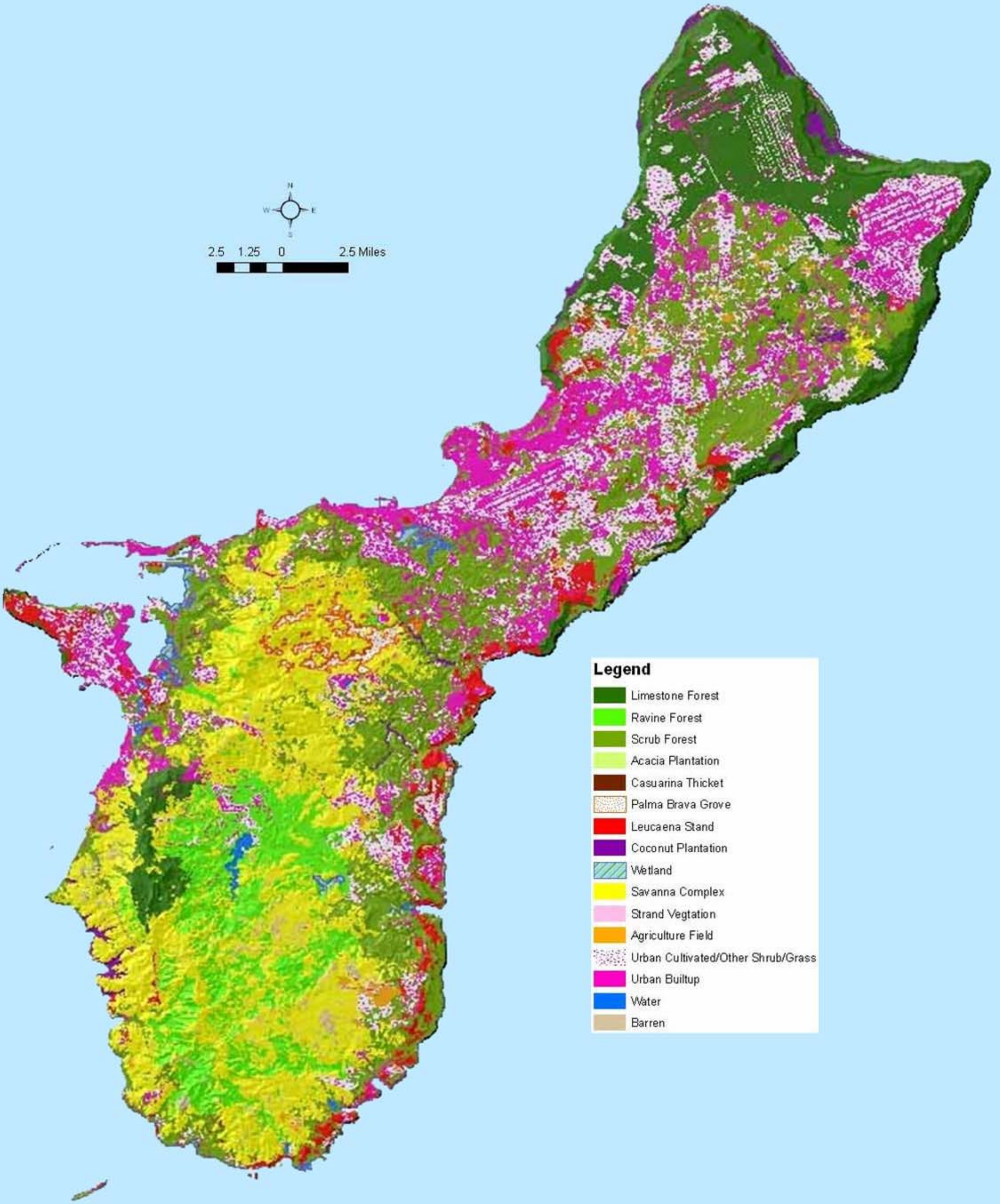
Summary

In summary, this effort to create a relatively detailed baseline vegetation map for the island of Guam was successful. The project showed that mapping using very-high-spatial-resolution satellite imagery is promising. Using newly available segmentation software such as eCognition can really take advantage of the very high spatial resolution. Possibly the most challenging issue encountered is the constant heavy cloud cover over the islands. Continued data acquisitions and coordinating these acquisitions with other agencies may help improved this situation. In the long run, we aim to establish a standard, efficient, and generally applicable methodology for mapping the vegetation across the Pacific Basin islands.

Data Distribution

Data is release in Vector format. The vector layer was checked for topology errors and corrected if detected. The attribute table was standardized. Only two non-spatial attributes were kept: *Class* and *Acres*. A sample symbology layer for displaying the data in ArcMap was created. Sample maps were produced. An FGDC-standard metadata using tools provided in ArcCatalog 9.1 (ESRI ®) was produced. The final distribution package that includes the data and documents listed above is shipped to recipients via FedEx and is also downloadable through the FHP website (http://www.fs.fed.us/r5/spf/fhp).

Detailed Vegetation of Guam



Acknowlegments

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References

Congalton and Green. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices,

ERDAS Field Guild ™ Seventh Edition. Leica Geosystems.

Moore P. H., and Mcmakin, P. D. 1979. Plants of Guam. University of Guam, Collecge of Agriculture and Life Science Cooperative Extension Service.

Mueller-Dombois, D., and Fosberg, F. R. 1998. Ecological Studies 132: Vegetation of the Tropical Pacific Islands. Springer-Verlag New York, Inc.

Space Imaging. http://www.spaceimaging.com/products/ikonos/spectral.htm

Space J. C., and Falanruw M. 1999. Observations on Invasive Species in Micronesia. (Perpared for the meeting of the Pacific Islands Committee, Council of Western State Foresters, Majuro, Republic of the Marshall Islands, February 22-26, 1999). www.hear.org/pier/reports/mreport.htm.