Tropical Forests Mapping of Bioko Island Using Remote Sensing Techniques

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Abstract. Forest sustainable management requires basically adequate vegetation mapping. Remote sensing techniques delivers reliable classification scheme of medicinal species *Prunus africana* located in Bioko Island -Equatorial Guinea. *Prunus africana* sustainable management relies principally on the population's quantification of the sustainable trade volume. Unsupervised and supervised image classifications techniques were implemented on Landsat OLI-8 (Operational Land Imager-8) to produce *P. africana* thematic maps on Bioko. Primarily, Support Vector Machine classification algorithm realized overall accuracy of 82.01%, with kappa coefficient of 0.79. Forests misclassification was mainly confined between two interconnected classes of Guineo-Congolian/ Afromontane forest classes and lowland forest classes. Therefore an extra rule of determent altitude (>1400 m) was added to the classification decision rule to improve the classification accuracies to be estimated as overall accuracy of 80.01% and a kappa coefficient of 0.81. Regular ground truth data collection from nine transects found that both of *P. africana* and *Schefflera* sp. were dominantly the two arboreal species located in Bioko's forests. Thematic classification maps illustrated in the conducted research is an essential data for the sustainable management of *P. africana* bark extraction. These results may also be valuable for various future studies ranging from primate research to genetic variation of *P. africana* on Bioko Island.

Keywords: Afromontane forests, Landsat OLI-8, Non-Timber Forest Products, *Prunus africana*, Tropical forests.

1. Introduction

The tropical ecosystems are composed of mosaics of forest of different sizes and in distinct phases of natural regeneration (Whitmore, 1991; Martinez-Ramos, 1994). Many explanations of the high diversity of species in the tropical systems have been

concentrated in the study of natural disturbances and the generation of heterogeneous conditions which facilitate the dispersion, germination, establishment and growth of seedlings in the clear zones beneath the canopy of the forest (Ricklefs, 1987). The species of the study: *P. africana* (Hook, f.) Walkman (= *Pygeum africanum*), enjoys its

greatest distribution in African and Malagasy forests found at higher altitudes, above the Guineo-Congolian rain forests.

On nearly all African mountains, the forest diminishes in structure and complexity from the lower slopes to the summit, yet this regularity is modified by local features of aspect, exposure, incidence of frost, depth of soil, and by overall patterns of climate which depend on the size and configuration of the mountain in relation to distance from the sea (White, 1983).

P. africana is a forest species of great importance to African traditional medicine for its use in the treatment of chest pains, malaria, and feverish symptoms. Commercial exploitation of the species began for its timber at the beginning of the 20th century in South Africa and Kenya. In 1966, a bark extract from the species was patented as a treatment for prostate ailments (Cunningham and Mbenkum, 1993), with bark extraction beginning in Cameroon in 1972.

The market for *P. africana* is global. The exploitation of its bark has severely reduced natural populations of *P. africana*. In 2000, the international consumption of *P. africana* bark was estimated at more than 4000 t, of which Cameroon produced two thirds (Toney et al, 2000). Large-scale exploitation of *P. africana* bark has diversified toward other countries such as Madagascar, Democratic Republic Congo, and Kenya.

The Mount Cameroon region and the mountain ecosystems of Bioko have been grouped together to form a part of the Afromontane floristic region (White, 1983). The Afromontane habitats are isolated from each other, as is the case on the volcanic island of Bioko which belongs to the Gulf of Guinea Islands group (composed of Sao Tomé, Principe and Annobón). *P. africana* exists on

Sao Tomé and within three zones on Bioko: Pico Basilé, Caldera de Luba, and Lago Biao (Thibaut Kaptué, *et al.*, 2011).

P. africana is at risk of unsustainable bark extraction or being felled for both bark and timber (Zafra-Calvo, *et al.*, 2010). Every population lost to forest clearance or unsustainable bark harvesting reduces the genetic diversity of this species and negatively affects surrounding flora and fauna. Previous study of diversity among the geographically disjunct *P. africana* populations considers that diversity and differences exist among populations of *P. africana* (Simons and Leakey, 2004). Crown dieback and eventual tree death due to improper bark harvesting techniques have been documented on Bioko (Sunderland and Tako, 1999). It is not certain that these trees will recover and reproduce the bark taken during these first extractions. Improper bark extraction continues and existing populations have remained both unqualified and unmapped (Bussmann, 2006 and Zafra-Calvo, *et al.*, 2010).

Changes in species composition and stand structure are accompanied by similar changes in spectral properties. Successional status in tropical ecosystems, characterized by species composition, biomass, and distribution of heights and diameters has been used to indicate relationships between forest successional stages and spectral properties of Landsat TM data (Vieira, *et al.*, 2003). The ability to identify different regenerating forest classes was investigated with Landsat TM data at a test site near Manaus, Brazil (Foody and Hill, 1996).

Tropical forest types differ in species composition, canopy height, and understory vegetation. Some of these studies have tried to classify forests among stand age, while others have relied on species composition, edaphic conditions (Foody and Hill, 1996) or

hyperspectral sensors (Thenkabail, *et al.*, 2003) and presented better results. In this study, field observations concerning ecosystem type, species composition, and distributions of heights and diameters will be used to classify the forest types of Bioko.

Authors have stated that the use of the near (NIR) and mid infrared (MIR) bands improves the accuracy of vegetation mapping (Salovaara, *et al.*, 2005; Thenkabail, *et al.*, 2004). Young secondary vegetation typically shows the highest reflectance in Landsat band 4, with other more mature forests reflecting relatively less. The MIR band of the ETM+ improved the strength of regressions used to explain variation in stem density and basal area of rainforests (Thenkabail, *et al.*, 2003). This approach was used in the detection of floristic structure across different topographic and moisture gradients in a mixed species Central African forest.

The aim of this study is to first develop a detailed vegetation map of Bioko (Equatorial Guinea) based on the classification of Landsat OLI-8 imagery, and then a second vegetation map detailing Afromontane vegetation. The Afromontane vegetation map will be created by combining data collected from systematic inventory plots with remote sensing techniques.

2. Materials and Methods

2.1. Study area

Bioko Island (3°48'-3°12"N; 8°25' 8°57'E) is located in the Gulf of Guinea, 32 km from the Cameroon coast. The island (Figure 1) is rectangular in shape (69 x 32 km) and has an area of 2017 km². Geologically, Bioko is a part of the African continental platform. The island is divided into two administrative zones:

Bioko Norte and Bioko Sur. The islands of the Gulf of Guinea (Bioko, Príncipe, Sao Tomé, and Annabón) form part of the Cameroon line of volcanoes. These volcanoes, including Mt. Cameroon and its highlands, were formed as a result of volcanic eruptions during the Lower Tertiary and early Quaternary period. Geological studies have suggested that these volcanoes developed along a fracture stretching NE-SW from Mounts Kupe and Manenguba (Cameroon) all the way to St Helena Island located in the South Atlantic (Juste and Fa, 1994). The island is composed of two main volcanic massifs: Pico Basilé (3011 m) in the north, and the southern volcanic peaks of Pico Biao (2009 m) and Caldera de Luba (2261 m). Pico Basilé, having developed from basaltic lava flows, presents a gentle, yet steady incline on the north-eastern and south-western slopes. Travelling north-west from the peak lies the 5 km wide Caldera de Bonyoma which offers a change in altitude of over 1000 m within a horizontal distance of less than 1 km. A series of cinder cones follow this depression, along with other such cones found on the lower slopes of P. Basilé. Three eruptions have taken place on the south eastern flank of P. Basilé, in 1898, 1903, and 1923 (Global Volcanism Program, Smithsonian Institution, 2005). Fa (1991) reports latent volcanic activity on Bioko, with eruptions in 1880 and 1900 and seismic activity noted in 1922. A central depression on Bioko separates the volcanic massif of P. Basilé from the southern massif dominated by the Caldera de Luba (2261 m). The caldera has a diameter of approximately 5 km. The rivers on the island drain radially from the main volcanic massifs of Pico Basilé, Biao and the Caldera de Luba. The river Tiburones descends the southern slopes of P. Basilé and empties into the bay of Luba.

Fig. 1. Study area location.

2.2. Sampling design and data collection

The potential distribution of *P. africana* lies within an area of 31,969 hectares in the island of Bioko. 16,000 hectares are within the National Park of P. Basile and the rest are in the zones of Moka and the Western region of the Caldera de Luba. No *P. africana* were found below 1400 m, as a result it was decided that the study zone to be restricted between 1400 m and 2400 m altitude. Extraction of *P. africana* bark in the Moka region takes place in two distinct areas: in secondary forest west of Moka village and around Lago Biao.

The inventory design selected was a stratified inventory with systematic collection points every 10 minutes (approximately 100 meters) following already existing trails of extraction. In Pico Basilé and Lago Biao, the only accessible entrances into the forest are trails maintained by hunters and those who

extract *P. africana* bark, and those trails were selected as transects for study of *P. africana*.

Data collected from systematic inventory plots was used to validate the supervised classification maps and to characterize forests with the presence of *P. africana*.

2.3. Image processing

The following methodology will recount the steps conducted during the production of the thematic maps of vegetation types found on Bioko. These maps will be based on supervised classifications of Bioko vegetative cover. The supervised classification was created through bibliographic references, field observations, and in part from the unsupervised classification derived from satellite imagery. Another forthcoming result based on forest inventories carried out on Pico Basilé, village of Moka, and Lago Biao will

yield a description of the forests which contain *P. africana*.

2.3.1. Image preprocessing

Digital sensors mounted on satellites record the intensity of electromagnetic radiation from each spot viewed on the Earth's surface as a digital number (DN). A major characteristic of such sensors is that they record the DN for several different wavelengths of electromagnetic energy. The exact range of DN that a sensor utilizes depends on the sensor used, Boyd and Duane 2001.

Radiance had to be converted to exatmospheric reflectance. Reflectance does not have units and is measured on a scale from 0 to 1 (or 0-100%). In order to achieve this conversion, a standardization equation was applied to every pixel in the image. This equation converts the image's digital numbers (DN, or voltage measurements) to at-sensor radiance and computes at-sensor reflectance while normalizing solar elevation angle, Richards, 1993:

$$\rho_P = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos \theta_S}$$

Where:

ρ_P is the at-satellite exo-atmospheric reflectance,

L_λ is the radiance ($\text{W m}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$)

d is the earth to sun distance in astronomic units at the acquisition date

$ESUN_\lambda$ is the mean solar exoatmospheric irradiance ($\text{W m}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$)

θ_S is the solar zenith angle in degrees

2.3.2. Unsupervised classification

An unsupervised classification was the first step in understanding Bioko's vegetation and land cover. The unsupervised classification is

a method in which the pixels in an image are assigned to spectral classes without the user being aware of the existence or names of these classes (Richards, 1993). This method is most useful for determining spectral class composition prior to detailed analysis through supervised classification.

The unsupervised classification performed here was created using the ISODATA module from Erdas 2014 software. The classification of satellite images generally involves the assignment of a particular class value to every pixel. ISODATA classification is referred as quantitative analysis because of its ability to identify pixels according to numerical properties in order to minimize the Mean Squared Error (MSE). Basically, the unsupervised classification is a method by which the labels may be attached to pixels in view of their spectral character (Jensen, 1996):

$$MSE = \frac{\sum_{v \in x} [x - C(x)]^2}{(N - c)b}$$

Where

N is the number of pixels,

c indicates the number of clusters,

b is the number of spectral bands

2.3.3. Supervised classification

The supervised classification is the procedure most often used for quantitative analysis of remote sensing image data. One of the most important factors regarding supervised classification is the selection of an appropriate algorithm which will label pixels according to ground cover types, or in this case, vegetation classes. The steps for supervised classification are summarized by Richards (1993).

Georeferenced ground information used for supervised classification training areas were of

three types: georeferenced observations, *P. africana* observations, and systematic inventory field plots. These observations served as representative pixels for the training areas of the supervised classifications. Systematic field inventories and *P. africana* observations took place above the 1400 m altitudinal limit, which was considered the *P. africana* field work study zone.

Because of the complexity of vegetation cover of Bioko, the reflectance ranges of the land cover classes at times overlapped. As a result, it was decided that Support Vector Machine classification would be more suitable (Elhag, *et al.*, 2013). With this classifier, training data is used only to distinguish the categories upon margin maximization of a decision surface between the categories based on sigmoidal function equation (Richards, 1993):

$$K(x_i, x_j) = \tanh(gx_i^T x_j + r)$$

Where:

g is the gamma term in the kernel function for all kernel types except linear

r is the bias term in the kernel function for the polynomial and sigmoid kernels.

2.4. Accuracy assessment

An error matrix was determined and the producer's Accuracy (a measure of omission error), user's Accuracy (a measure of commission error) and the kappa coefficient of agreement were calculated for each class and for both supervised classifications. The method is a simple cross-tabulation of the mapped class label against that observed in the ground or reference data for a sample of cases at specified locations (Foody, 2002).

In digital image analysis is the assessment of the accuracy of the computer derived

classification results is the final step. Producers, users and Overall accuracy were derived from a Matrix. These results often articulated in plane form, known as a confusion matrix. The Kappa examination is distinct multivariate method used in accuracy assessment to specify statically whether one error matrix is significantly different to another (Cohen, 1960). The accuracy assessment was carried out following Congalton and Mead (1983) and Congalton (1991) to estimate K_{hat} for different the employed classification algorithms:

$$K_{hat} = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{ij} \times x_{ji})}{N^2 - \sum_{i=1}^r (x_{ij} \times x_{ji})} \quad \text{Eq. 7}$$

Where

r is number of rows in the error matrix;

x_{ii} is number of observations in row i and column i (the diagonal cells);

x_{i+} is total observations of row i ;

x_{+j} is total observations of column j ;

N is total of observations in the matrix

K_{hat} value of 0.80 and higher indicates strong agreement and a value between 0.40 and 0.80 indicates moderate agreement. Accuracy assessment using the kappa coefficient was performed on both of the thematic maps produced through the supervised classification.

3. Results

3.1. Unsupervised classification

The unsupervised cluster classification of 14 classes was named and analyzed (Figure 2). Classes described consist of coastal evergreen forest (HGC), primary lowland forest (GCPRIM), corresponding lowland rain forest secondary formations depending on date and type of anthropogenic disturbance (LLDEG,

GCCC, OSECGC, YSECGC, CULT) mixed lowland and Afromontane forests and corresponding secondary formations (MIXGC, SECMIX), Afromontane forests and corresponding secondary formations (UAFR, AFRH, SECAFR, SECGRAS), and finally higher altitude formations of ericaceous shrub land (ERIC).

Table 1 displays the spectral relationships by indicating the Euclidean distance between classes. This Euclidean distance was based on average reflectance values per class for Landsat bands 2 through 5 and band 7. The unsupervised classification spectral separability measure shows that the HGC vegetation class had the highest separability value, making it the most unique class. It should also be noted that the SECGRAS class may be considered as having a high separability value.

Figure 3 shows the results of this classification. Vegetation types presented consist of classes recognized through the unsupervised classification and classes recognized during field work. Vegetation classes generally follow an altitudinal distribution with corresponding secondary formations included. Low altitude vegetation classes include primary rain forest (GCPRIM) along with secondary formations which may be attributed to different anthropogenic influences such as areas surrounding rural populations (SECRURAL), areas currently or in the past used for agricultural purposes (OSECGC, GCCC) and natural resources extraction (GCDEG).

3.2. Supervised classification

Table 2 is a description of training areas used in supervised classification of Bioko. 15

georeferenced observation points per class were used as training areas on which to base class spectral signatures. 30 points per class were reserved for accuracy assessment. Descriptions of the individual classes are composed of notes taken during field observations on Bioko. Bibliographic references combined with analysis of the unsupervised classification have assisted in the description of inaccessible sites.

3.3. Accuracy assessment

Accuracy assessment (Table 3) was performed in order to evaluate the classification results and the overall accuracy for the classification process. A global accuracy of 82.01% was achieved with a kappa coefficient of 0.79. Individual class accuracies were moderately good for classes within the Afromontane vegetation zone (AFALP, ERIC, PAST, SECAFR, ARAL). Distinct patches of primary forest and areas subject to timber exploitation (GCPRIM, GCDEG) achieved high classification accuracies. Lowland secondary vegetation classes (SECRURAL and GCCC) were often misclassified with mixed forest (MIXGC) and Afromontane forest humid type.

The classes with the lowest average separability included GCCC and MIXGC, both of which contain affinities with other vegetation classes. Based on the results of the unsupervised classification it was decided that some classes would be merged for the supervised classification. This was done with the YSECGC and CULT, whose separability values indicated strong spectral similarities between these classes.

Table 1. Spectral Separability of Land Cover Classes derived from Cluster Unsupervised Classification of Bioko vegetation.

Land Cover Class	HGC	GCPRIM	ERIC	UAFR	LLDEG	AFRH	GCCC	OSECGC	YSECGC	MIXGC	SECAFR	SECMIX	CULT	SECGRAS
HGC	0.000	0.042	0.060	0.095	0.065	0.076	0.085	0.082	0.104	0.101	0.121	0.120	0.126	0.144
GCPRIM	0.042	0.000	0.035	0.062	0.023	0.037	0.044	0.042	0.063	0.061	0.082	0.079	0.085	0.103
ERIC	0.060	0.035	0.000	0.039	0.039	0.031	0.051	0.058	0.071	0.058	0.071	0.078	0.092	0.097
UAFR	0.095	0.062	0.039	0.000	0.050	0.030	0.043	0.058	0.058	0.036	0.036	0.053	0.074	0.065
LLDEG	0.065	0.023	0.039	0.050	0.000	0.021	0.022	0.020	0.040	0.039	0.061	0.056	0.062	0.081
AFRH	0.076	0.037	0.031	0.030	0.021	0.000	0.023	0.032	0.041	0.029	0.047	0.049	0.062	0.070
GCCC	0.085	0.044	0.051	0.043	0.022	0.023	0.000	0.018	0.023	0.019	0.043	0.035	0.045	0.061
OSECGC	0.082	0.042	0.058	0.058	0.020	0.032	0.018	0.000	0.023	0.033	0.057	0.044	0.044	0.070
YSECGC	0.104	0.063	0.071	0.058	0.040	0.041	0.023	0.023	0.000	0.023	0.043	0.023	0.023	0.049
MIXGC	0.101	0.061	0.058	0.036	0.039	0.029	0.019	0.033	0.023	0.000	0.025	0.020	0.038	0.043
SECAFR	0.121	0.082	0.071	0.036	0.061	0.047	0.043	0.057	0.043	0.025	0.000	0.025	0.048	0.029
SECMIX	0.120	0.079	0.078	0.053	0.056	0.049	0.035	0.044	0.023	0.020	0.025	0.000	0.024	0.027
CULT	0.126	0.085	0.092	0.074	0.062	0.062	0.045	0.044	0.023	0.038	0.048	0.024	0.000	0.039
SECGRAS	0.144	0.103	0.097	0.065	0.081	0.070	0.061	0.070	0.049	0.043	0.029	0.027	0.039	0.000
Av. Class Separability	0.078	0.054	0.056	0.050	0.041	0.039	0.036	0.042	0.042	0.038	0.049	0.045	0.054	0.063
Global Separability	0.049													

MIXGC: Guineo-Congolian rain forest with Afromontane elements, AFRH: Afromontane forest humid type, AFALP: Afro-alpine vegetation, ERIC: Ericaceous shrubland, PAST: Pastures, SECAFR: Secondary Afromontane forest, SECGRAS: Secondary Afromontane grassland, ARAL: Afromontane forest Araliaceae type, GCDEG: Guineo-Congolian rain forest degraded, SECRRAL: Secondary rural complex, OSECGC: Old secondary Guineo-Congolian rain forest, GCPRIM: Primary Guineo-Congolian rain forest, HGC: Hygrophilous coastal evergreen rain forest, GCCC: Degraded Guineo-Congolian forest mixed with cacao and palm.

Table 2. Training areas used in supervised classification of Bioko land cover.

Land Cover Class*	Number of observ./class	Training area description
MIXGC	15	Similar to Guineo-Congolian rain forest in species composition, but smaller and mixed with Afromontane species.
AFRH	15	Shorter canopy than G.C. rain forest, species with relatively small diameters, tree ferns, epiphytes and some lichens.
AFLAP	15	Well-draining soils on ancient volcanic peak of P. Basilé provide habitat for temperate herbaceous species.
ERIC	15	Individuals of the Ericacea family (among other characteristic species) form dense thickets up to 6 m tall.
PAST	15	Abandoned cattle pasture south of Moka village, grass fields with Afromontane forest and tree ferns between fields.
SECAFR	15	20-25 m canopy height, middle arboreal stratum present, thin understory vegetation, tree ferns in valleys and canopy gaps.
SECGRAS	15	Originally cleared for animal pasture, fields of bracken fern are mixed with shrubs familiar from the ERIC land cover class.
ARAL	15	Primary afromontane forest, tall canopy up to 40 m, uneven canopy coverage results in 2-3 m tall understory vegetation.
GCDEG	15	Areas subjected to timber extraction, particularly on the southern slopes of Bioko around the village of Ureka.
SECRURAL	15	Secondary forest intermixed with rural settlements, gardens, and agricultural production.
OSECGC	15	Mature Guineo-Congolian secondary forest with tall canopy up to 40 m, very dense understory.
GCPRIM	15	Remaining primary lowland forest, monsoon forest of southern Bioko, extremely dense rain forest, epiphytes, lianas.
HGC	15	Coastal forest with coconut palms, and Cacsalpinaceae.
GCCC	15	Areas of cacao, coffee, and palm oil production had retained large canopy trees and are now abandoned in many parts of Bioko.

*MIXGC: Guineo-Congolian rain forest with Afromontane elements, AFRH: Afromontane forest humid type, AFLAP: Afro-alpine vegetation, ERIC: Ericaceous shrubland, PAST: Pastures, SECAFR: Secondary Afromontane forest, SECGRAS: Secondary Afromontane grassland, ARAL: Afromontane forest Araliaceae type, GCDEG: Guineo-Congolian rain forest degraded, SECRURAL: Secondary rural complex, OSECGC: Old secondary Guineo-Congolian rain forest, GCPRIM: Primary Guineo-Congolian rain forest, HGC: Hygrophilous coastal evergreen rain forest, GCCC: Degraded Guineo-Congolian forest mixed with cacao and palm.

Table 3. Confusion Matrix from supervised classification of Bioko vegetation.

Actual Class	Predicted class															Producer's Accuracy
	MIXGC	AFRH	AFLAP	ERIC	PAST	SECAFR	SECGRAS	ARAL	GCDEG	SECRURAL	OSECGC	GCPRIM	HGC	GCCC	Σ	
MIXGC	21	0	0	0	0	2	1	0	1	5	0	0	0	0	30	70.00
AFRH	5	6	0	0	0	6	1	0	0	11	0	1	0	0	30	20.00
AFLAP	0	1	17	10	1	0	0	0	0	0	0	0	0	0	30	58.62
ERIC	0	0	0	23	0	0	0	4	0	0	0	3	0	0	30	76.67
PAST	0	0	0	0	30	0	0	0	0	0	0	0	0	0	30	100
SECAFR	0	0	0	0	0	25	4	1	0	0	0	0	0	0	30	83.33
SECGRAS	1	2	0	0	7	2	17	0	0	0	0	0	0	0	30	58.62
ARAL	1	0	0	0	0	1	0	28	0	0	0	0	0	0	30	93.33
GCDEG	0	1	0	0	0	0	0	0	29	0	0	0	0	0	30	96.67
SECRURAL	4	0	0	0	0	1	2	0	0	17	3	0	0	3	30	56.67
OSECGC	0	0	0	0	0	0	0	0	5	1	16	1	0	7	30	53.33
GCPRIM	0	0	0	0	0	0	0	0	1	0	0	29	0	0	30	96.67
HGC	0	0	0	0	0	0	0	0	0	0	0	0	30	0	30	100
GCCC	12	1	0	0	0	0	1	2	0	1	0	0	0	13	30	43.33
Σ	44	11	17	33	38	37	26	35	36	35	19	34	30	23		
User's Accuracy	47.73	54.55	100	69.70	78.95	67.57	65.38	80.00	80.56	48.57	84.21	85.29	100	56.52		

Overall percentage correct allocation was 82.01%, the kappa coefficient was 0.79. The Global Producer's Accuracy was 81.95% and the Global User's Accuracy was 82.79%.

MIXGC: Guineo-Congolian rain forest with Afromontane elements, AFRH: Afromontane forest humid type, AFLAP: Afro-alpine vegetation, ERIC: Ericaceous shrubland, PAST: Pastures, SECAFR: Secondary Afromontane forest, SECGRAS: Secondary Afromontane grassland, ARAL: Afromontane forest Araliaceae type, GCDEG: Guineo-Congolian rain forest degraded, SECRURAL: Secondary rural complex, OSECGC: Old secondary Guineo-Congolian rain forest, GCPRIM: Primary Guineo-Congolian rain forest, HGC: Hygrophilous coastal evergreen rain forest, GCCC: Degraded Guineo-Congolian forest mixed with cacao and palm.

Fig. 2. ISODATA unsupervised classification of Bioko Island.

Fig. 3. SVM supervised classification of Bioko Island.

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4. Discussion

Analysis of remotely sensed data aided by field inventories is commonly used to classify land cover. In this case, the identification of forest types and the species composition of African tropical forests were undertaken to produce thematic maps. These thematic maps along with the description of such classes contribute toward the assessment of natural resources located within the forests of Bioko.

Firstly, unsupervised classification was produced to investigate the spectral properties of Bioko land cover. This classification served to provide preliminary information concerning the reflectance values of Guineo-Congolian and Afromontane forest. Collection of forest measurements and species composition from systematic inventory plots within various montane forest types on Bioko was essential for an accurate classification. A relationship between forest types and pixel reflectance had to be established in order to generate a thematic map with high user accuracy. Similar classification techniques have been used to show that changes in species composition and stand structure are accompanied by similar changes in the spectral properties of tropical forest Vieira, *et al.*, 2003.

Successful combination of spectral data from Landsat OLI-8 imagery with field measurement of forest attributes indicates the continuing potential for applications of remote sensing to the study of tropical forests. In this work and other studies, there are clear indications that carefully selected narrow portions of the wavebands, spread across the visible, near-infrared, and mid-infrared (400-2500 nm) will be required for continued improvement in the study of forest structure (basal area, stem density) and species compositions, Vieira, *et al.*, 2003; Thenkabail, *et al.*, 2003.

Results of the two supervised classifications indicate agreement between field observations and remotely sensed data of Bioko Island. Among the Afromontane forest types presented exist structural differences which may be observed through species composition and physiographic variables collected during field sampling. Further, the combination of data collected on Bioko with the results of the field inventories indicate the diverse ecosystems in which the endangered species *P. africana* is found.

Classification results have accurately presented the various vegetation classes and defined the spatial extension of such classes. An interpretation and explanation of these vegetation classes is necessary in order to clearly frame the distribution of the medicinal plant *P. africana* on Bioko. *P. africana* occurs in varying quantities according to vegetation type, Vancutsem, *et al.*, 2009. It must be stated directly that *P. africana* constitutes a major part of the climax montane forest of Bioko. This tree can be found in Araliaceae forests in great size and distribution forming up to 60% of the forest canopy in some areas (Hill, 1999). This species is also found in great numbers in secondary forests, which having been left to regenerate may soon be considered part of Bioko's Araliaceae forest, rather than secondary forest. *P. africana* should not be considered a secondary forest species on Bioko, but instead an indicator of maturity and successional age of these forests. *P. africana* occurs along with *Schefflera* sp., the arboreal species which typifies the Araliaceae type Afromontane forests of Bioko.

The distribution of Afromontane forests on Bioko is clearly due to a number of factors, particularly the oceanic cooling effect and monsoon phenomena which affect this island. Bioko provides a suitable habitat for *P. africana*, which has been associated with cooler temperatures (Hall, *et al.*, 2000) and

other species found on the highest mountains of continental Africa. The particular environmental conditions of Bioko do not only influence the distribution of this Afromontane species, but also other vegetation formations found on this island. A discussion of the vegetation classes derived from the supervised classifications of Bioko Landsat OLI-8 data will make the effects of these factors more evident, Song, *et al.*, 2001.

5. Conclusion

The detection of individual species in tropical forests is a common objective, yet also a limitation when working with remotely sensed tropical forest data. Humid tropical forest types have low spectral separability in Landsat OLI-8 data due to highly textured reflectance patterns at the 30 m spatial resolution. Various methods of reducing spectral variation, low-pass spatial filtering and image segmentation exist. The Landsat image used in this study was not filtered before classification. Considering the relatively small surface area of Bioko (2017 km²), it was decided that local spectral variation was insignificant and explainable. Within the context of the Bioko montane classification, some areas which were represented by a mix of classified pixels were interpreted to be at a successional stage not specified by the supervised classification training areas. Secondly, the field work methodology was designed with the intention of applying field observations (systematic vegetation inventories as well as *P. africana* and other observations) to individual pixels for use during the supervised classification. Nonetheless, the ability to derive these tropical forest classes allows for greater use of classified imagery in conservation planning and future studies of Bioko. The supervised classification has produced an accurate classification of Bioko's vegetation types. Besides this, floristic and structural data

recorded during field observations indicate differences between forest structures. These differences have been presented in the supervised classification of Afromontane vegetation. Results from the confusion matrix derived during the accuracy assessment may be attributed to factors which include methodological choices, and morphologic and structural characteristics among vegetation classes. It is quite important that the confusion matrix be examined not solely as a measure of the producer accuracy, but also in order to optimize the impression given to the user during analysis of the final thematic map. The errors of commission indicate similarities among vegetation classes which also elaborate the discussion of these vegetation types.

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رسم خرائط الغابات الاستوائية في جزيرة بيوكو باستخدام تقنيات الاستشعار عن بعد

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المستخلص. تتطلب الإدارة المستدامة للغابات الاستوائية إلى خرائط الغطاء النباتي الملائمة. وتقنيات الاستشعار عن بعد توفر نظام تصنيف موثوق به للأنواع الطيبة الممثلة في *Prunus africana* الذي يتواجد في جزيرة بيوكو - غينيا- الاستوائية.

تعتمد الإدارة المستدامة أساساً على القياس الكمي لمجموعات *Prunus africana* لتحديد حجم التجارة المستدامة. نفذت تقنيات تصنيف الصور الفضائية غير الخاضعة للرقابة والخاضعة للرقابة على لاندسات OLI-8 (أرض التشغيلي تصوير-٨) لإنتاج خرائط موضوعية لـ *Prunus africana* على جزيرة بيوكو.

إن خوارزمية التصنيف المعتمدة على آلية تصنيف المتجهات بدقة إجمالية ٨٢,٠١٪، مع معامل كابتا ٠,٧٩، اقتصر الخطأ في تصنيف الغابات أساساً على فئتين من فئات مترابطة الغابات جنين-الكونغولية / وإفرومونتانا في الطبقات المنخفضة من الغابات. لذلك تم بإضافة قاعدة إضافية إلى حكم قرار التصنيف لتحسين الدقة، والتصنيف باستخدام الارتفاع عن سطح البحر (< ٤٠٠ م) وارتفعت دقة التصنيف الإجمالي إلى ٨٠,٠١٪ ومعامل كابتا إلى ٠,٨١.

تم جمع البيانات الأرضية من تسعة مقاطع عرضية لكلا من *Prunus africana* و *Schefflera*. ويغلب اثنين من الأنواع الشجرية الموجودة في الغابات بيوكو على باقي الأصناف الموجودة. إن خرائط التصنيف الموضوعية التي أجريت هي البيانات الأساسية للإدارة المستدامة لـ *Prunus africana*.

قد تكون هذه النتائج أيضاً ذات قيمة لمختلف الدراسات المستقبلية التي تشتمل على الاختلافات البيئية من *Prunus africana* في جزيرة بيوكو.

الكلمات الدالة: غابات الإفرومونتانا، لانسات - ٨، إنتاج الأخشاب، غابات استوائية، *Prunus Africana*.