Acacia koa forest classification and productivity assessment across environmental gradients in Hawaii using fine resolution remotely sensed imagery

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Acacia koa (koa) is a native Hawaiian tree species of high economic and ecological value adapted to a wide range of elevation (600-2300 m asl) and precipitation (850-5000 mm) gradients. This study developed methodologies to differentiate these forests using fine resolution remote sensing and related image metrics to field measurements of forest productivity across these gradients. The calculation of 7 vegetation indices (VIs) from IKONOS satellite imagery allowed classification of various koa forest types into micro-regions in leeward and windward gradient locations. Image texture metrics and VIs were strongly related with tree height, specific leaf area (SLA), leaf nitrogen and phosphorus concentration, but less strongly related with leaf area index (LAI) and basal area (BA). These statistical models could be used to spatially predict these measurements at landscape and regional scales and to evaluate forest productivity responses to forest management practices.

Objectives

- To use high-resolution satellite imagery to classify koa forest types across elevation and rainfall gradients.
- To determine meaningful statistical models using spatial and spectral metrics and on-the-ground measurements of forest productivity.
- To analyze potential of models for spatial prediction of field measurements at landscape and regional scales.

Materials and Methods

Location and field measurements

- Koa forests (~30 yrs-old) were selected at 2 locations in Hawaii (Fig. 1).
- Along Mauna Loa Road at Hawaii Volcanoes National Park (HAVO).
- At the Honomalino forest tract of the Kona Hema Preserve (HONO).

- Monotypic stands at different elevation (sites) selected at each location.
- 3 plots (20 x 20 m) were established at each site.

- Tree height and stem diameter (DBH) measured in the field.
- Basal area (BA) and leaf area index (LAI) calculated from DBH.
- Specific leaf area (SLA) and foliar nitrogen (%N) and phosphorus (%P) from Idol et al. (2007).

Image Classification

- IKONOS-2 satellite imagery (1-m panchromatic (Pan) and 4-m multispectral (Ms) in the blue, green, red, and NIR obtained for both locations.

- Extraction of image metrics
- 7 VIs were calculated from the 4-m Ms imagery:

NDVI	Normalized Difference Vegetation Index
EVI	Enhanced Vegetation Index
SAVI	Soil Adjusted Vegetation Index
MSAVI	Modified Soil Adjusted Vegetation Index
ARVI	Atmospherically Resistant Vegetation Index
SR	Simple Ratio
MSR	Modified Simple Ratio

- Five texture measures were derived from the 1-m Pan.
- Canonical Discriminant Analysis (CDA) used to separate sites (Fig. 2).
- Three supervised classification methods used to classify sites into micro-regions:
- Maximum Likelihood Classifier (MLC) in ENVI.
- Canonical Discriminant Analysis (CDA) in MatLab.
- Classification and Regression Trees (CART) in MatLab.
- Two plots from each site used for image training before classification.
- One plot used to validate the classified image using a confusion matrix (Table 1).

Relationship of image metrics to koa forest productivity

- Anova was carried out using ARVI to compare reflectance at HAVO and HONO.
- Anova and means comparison of field measurements were carried out among micro-regions.
- At each location, all image metrics were regressed against field measurements and best models selected.

Site Location

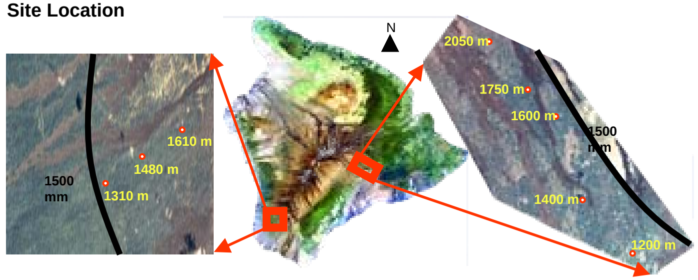

Figure 1. Study site locations and elevation. Black lines and numbers indicate mean annual rainfall isohyets.

Results

- A combination of 6 VIs allowed separation of the 5 sites at HAVO (Fig. 2). Only SR was not important.
- Similar trends were observed at HONO on VI contributions to separate the 3 gradient sites (data not shown).
- ARVI gradually decreased as elevation increased (Fig. 3), indicating spectral separation among gradient sites.

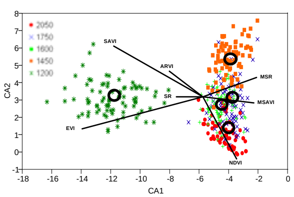

Figure 2. Spectral separability between gradient sites at HAVO using CDA.

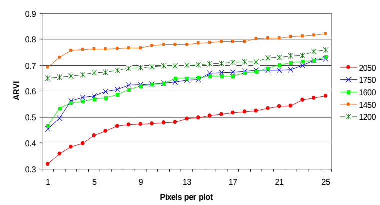

Figure 3. Distribution of ARVI values among gradient sites at HAVO. Similar results found at HONO.

- MLC provided the best image classification for both gradient locations (Table 1).
- 3 main koa micro-regions were differentiated at HAVO (Fig. 4): upper (2050 m), intermediate (1750 and 1600m) and lower (1450 and 1200 m).
- 2 main koa micro-regions were classified at HONO (Fig. 5).
- Anova from ARVI showed that reflectance was significantly different between HAVO and HONO indicating the need to develop models for each gradient location.

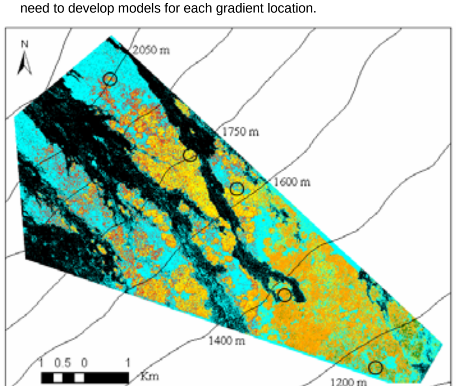

Figure 4. Classified image showing 3 main koa micro-regions at HAVO (cyan and black represent grasses and lava).

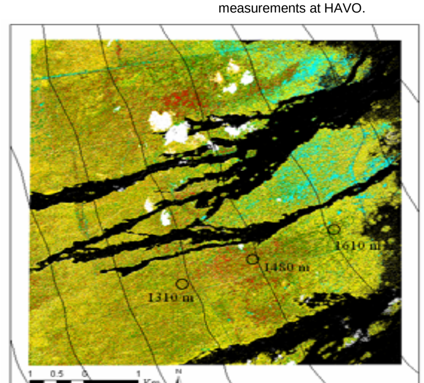

Figure 5. Classified image showing 2 main koa micro-regions at HONO (yellow and cyan represent ohia and grasses).

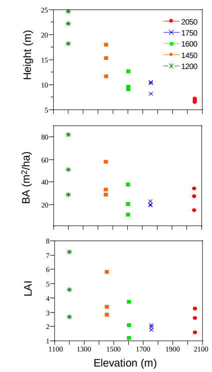

Figure 6. Plot level measurements of koa productivity at HAVO.

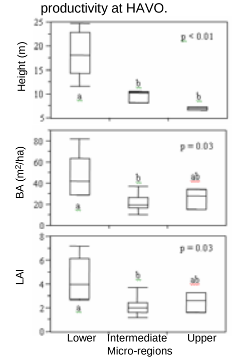

Figure 7. Anova and means comparison of field measurements at HAVO.

Testing Sites

Gradient Class	2050	1750	1600	1450	1200
2050	**79**	8	8.5	0	16
1750	21	**70**	**73**	0	3
1600	0	0	10	0	0
1450	0	22	8.5	**100**	**58**
1200	0	0	0	0	23

Table 1. Class overlap (%) among sites at HAVO using MLC classification (columns sum to 100%).

- VI increments (Fig. 3) corresponded well to increments in height, LAI and BA as elevation decreased at HAVO (Fig. 6).
- The lower micro-region was significantly different from the intermediate and upper micro-regions (Fig. 7) indicating potential for statistical modeling.
- Strong relationships were found between most field measurements and SAVI, MSAVI, EVI, but they were weaker than with most texture measures.
- Tree height, leaf N, leaf P, and SLA were significantly correlated with the mean texture measure (Table 2).
- Non significant differences were found at HONO, and only tree height had a strong relationship with ARVI.

Linear Model	R^2
HAVO	
Log Height = 0.2427 + 0.0032 Mean Texture	0.81
Leaf P = -0.0346 + 0.00039 Mean Texture	0.77
SLA = 1.4188 + 0.01172 Mean Texture	0.74
Leaf N = 0.6495 + 0.00499 Mean Texture	0.62
HONO	
Log Height = 0.2018874 + 1.5253288 ARVI	0.63

Discussion

- Due to larger forest canopy gaps, SAVI and MSAVI were important to classify upper and intermediate koa stands.
- Due to greater sensitivity to higher forest biomass, ARVI and EVI were most important in classifying the more productive lower koa stands.
- Since NDVI saturates at high biomass, this VI was only helpful to classify upper koa stands.
- Since texture provides a description of detailed tonal variations within individual bands, these metrics were better related to field measurements.
- Tree height and leaf P were most strongly related to texture metrics.

Conclusions

- VIs were able to differentiate koa forest from other land cover types and classify koa forests across environmental gradients into significantly different micro-regions.
- Tree height and leaf characteristics were better indicators of productivity than basal area or LAI.
- This could be used for landscape-scale assessments of land cover and productivity, and for site-specific management.

Future Directions

- Use of finer resolution imagery from the GeoEye1 satellite (0.5 m pixel) for:
- Forest health assessment at individual tree scale.
- Landscape-scale assessments of land cover and productivity, and for site-specific management.

Selected Reference

Idol, T., Baker, P.J., & Meason, D. (2007). Indicators of forest ecosystem productivity and nutrient status across precipitation and temperature gradients in Hawaii. *Journal of Tropical Ecology*, 23, 693–704.