ABSTRACT

The spread of alien plant species has long been recognized as one of the most significant environmental changes due to its ability to decrease biodiversity and alter ecosystem processes. In Mākaha Valley, O'ahu, there is a need to evaluate the impact of alien species invasion on local hydrology for sustainable water resource management. A detailed vegetation map depicting the current spatial extent of invasive and native plant species is required. In this study, we assessed the utility of fine resolution satellite imagery in discriminating invasive from native vegetation communities. Two fine resolution images were acquired over Mākaha: a QuickBird (2.4m multi-spectral resolution) and an IKONOS (4m multi-spectral resolution) image. These images were classified using unsupervised classification algorithms and compared with existing vegetation maps. These sensor images were classified into four to five discriminable native- and invasive-dominated vegetation classes whereas most of these classes were labeled as a single “forest” class in the existing vegetation maps. Likewise, spatial distributions of these classes were depicted in much more detail in the image analysis results than in the existing vegetation maps. It was strongly felt that fine resolution imagery is very useful in mapping invasive and native species. Our efforts are continuing to field-identify the species compositions of image classes and to assess the accuracy of classification results.

INTRODUCTION

Invasion of natural communities by nonnative species constitutes a major threat to biodiversity globally (Lodge 1993). Invasive alien species not only compete with natives on a species scale, but some alter the way an ecosystem functions, e.g., primary productivity, decomposition, hydrology, geomorphology, nutrient cycling, and natural disturbance regimes (Vitousek and Walker 1989, Mack et al. 2000).

One of the earliest examples of ecosystem-level change caused by alien plant invasion in Hawai‘i showed that the grass Andropogon virginicus alters rain forest hydrology by preventing normal soil evaporation as well as effective transpiration (Mueller-Dombois 1973). In other research, invasive plants have been known to increase transpiration and evaporation of intercepted rainfall (Versfield and van Wilgen 1986, Gordon 1998). Of particular concern in Hawai‘i are the studies of a common invasive tree, Schinus terebinthifolius. On Lana‘i, Stratton et al. (2000) and Stratton and Goldstein (2001) concluded that, relative to native Hawaiian plants, S. terebinthifolius exhibits high rates of water uptake during the wet season and higher water use efficiency during the dry season.
Mohala i ka Wai, a community group on the island of O‘ahu in Hawai‘i, and the Honolulu Board of Water Supply (HBWS) have a strong interest to determine the impact of *S. terebinthifolius* and other alien species on the hydrological cycle in Mākaha Valley. Located on the dry leeward coast of O‘ahu, more than 60% of Mākaha Valley experiences arid to semi-arid climate with a mean annual rainfall of less than 1800 mm (NCDC 2004). Despite the fact that stream flow rates have declined since the 1960s, the HBWS has pumped water out of Mākaha Valley since 1989. Mohala i ka Wai and the HBWS formed a partnership in September 2000 in order to address community concerns about access to water resources and the preservation of the Mākaha watershed.

Remote sensing has been recognized as a valuable and effective technology with which to detect, monitor, and manage invasive species (Beyers *et al.* 2002, Joshi *et al.* 2004). Although other land use/land cover maps exist for Mākaha Valley, they consist of a limited number of vegetation classes and do not portray fine spatial detail for these classes. This is due in part to the fact that analysis was constrained by remotely sensed data of coarse spatial resolutions (30 – 80m).

In this study, we assessed the effectiveness of fine-resolution (2.5 – 4m) satellite data in delineating native and invasive species communities with the goal of producing a detailed vegetation map over Mākaha Valley.

**MATERIALS AND METHODS**

**Figure 1: Materials and methods used for production of Mākaha Valley vegetation map**

**Materials and study sites**

Accurate detection or discrimination of invasive species often requires high resolution imagery to spatially resolve small patches of invasive species stands or populations and thus to capture their “pure” spectral signatures (Carson *et al.* 1995). Two four-band multi-spectral satellite images were obtained for this project: a November 2001 QuickBird scene and a September 2003 IKONOS scene. QuickBird’s 2.44 m spatial resolution is the highest resolution commercially available. However, the QuickBird image had significant cloud cover and was acquired at a high solar zenith angle. Hence, it had a large amount of both topographic and cloud shadow. The IKONOS image, with 4 m spatial resolution, had minimal cloud cover and was
acquired at a low solar zenith angle. Both images have near-infrared (NIR), red, green, and blue bands.

Two areas of interest were identified and used as classification boundaries. We first concentrated on the back of Mākaha Valley. This area is of great importance due to the large amount of diverse native communities found there which are rapidly being invaded by alien vegetation. However, the area is also challenging to analyze due to its rugged topography which seems to modify the vegetation’s spectral signatures.

The other area of interest is a subwatershed within the valley. The subwatershed delineation is based on the location of the valley’s lowest USGS stream gauge and encompasses the initial area of interest.

**Image analysis methods**

We first produced a NIR false color composite from the QuickBird image for visual inspection. This composite effectively depicted small differences in the reflectance characteristics of vegetation and helped us obtain a general idea of the spatial distribution of different vegetation types.

The ISODATA unsupervised classification algorithm was then applied with 50 classes being the initial number of classes to ensure adequate data representation (Schowengerdt 1999). The classification results were visually evaluated and refined into the number of classes discriminable by the satellite. The Jeffries-Matusita distances were computed and used as a quantitative measure to support and evaluate the class lumping results (Richards and Jia 1999). Classes with an identifiable physical nature were assigned a class label.

The same procedures used for the QuickBird classification were followed for IKONOS analysis. However, two unsupervised classifications were applied to the IKONOS image: one using 50 initial classes and the other using 75 initial classes.

**Field characterization and class identification**

Field reconnaissance was conducted to identify classes resulting from classification and to identify variables that would most likely correlate with satellite signals. GPS points for sites thought to spatially correlate to discriminable classes were collected using a Garmin GPS V Personal Navigator and a Trimble GeoXT. Species and strata composition, slope, and aspect were recorded at each site.

**RESULTS**

The 50 initial classes extracted during the QuickBird unsupervised classification were clustered into six identifiable classes. Four vegetation classes are represented in the back of the valley. The 75 initial classes extracted during the IKONOS unsupervised classification were clustered into nine identifiable classes, five of which represent vegetation communities. Figure 2 shows the QuickBird classification of the back of Mākaha Valley. Figure 3 shows the IKONOS classification of the subwatershed. Agreement between the two analyses is high. It should be noted that Clouds and Shadow are spectrally mixed with the Kukui and ‘Ōhi’a classes in Figure 2. In Figure 3, Clouds contain some spectral confusion with Kukui, ‘Ōhi’a, and Soil.
Field work aided in the general determination of vegetation classes; however, complicated community structures and difficulties in site accessibility were revealed and are proving to be more challenging than initially anticipated. Image analysis indicated a moderate amount of overlap between classes. Part of this is due to shadow and clouds which complicated extraction of classes, especially in the QuickBird image. Solar zenith angle at the time of the image capture is an important factor in the analysis of the topographically rugged area.

Figure 2: QuickBird Image Classification results of the back of Mākaha Valley

Figure 3: Same as Figure 2 but using IKONOS imagery and a subwatershed boundary
DISCUSSION

The vegetation maps produced effectively delineated the dominant native (Metrosideros polymorpha) and alien (Aleurites moluccana) canopy trees. Preliminary field surveys indicated that the pink Unknown vegetation class is primarily alien-dominated vegetation. Although we continue to field-identify the species compositions of the descriminable classes, it is notable that their spatial representation is more detailed than in existing land use/land cover maps (Figure 4).

The 1976 Geographic Information Retrieval and Analysis (GIRAS) map depicts two vegetation classes as existing in the Mākaha Valley subwatershed: Shrub and Brush Rangeland and Evergreen Forest Land. This map is based primarily on manual interpretation of aerial photography (EROS 2005). Coastal Change Analysis Program (C-CAP) land cover map was produced during 2000-2001 using Landsat ETM imagery (30 m spatial resolution). Four vegetation classes (Evergreen Forest, Grassland, Palustrine Forested Wetland, and Scrub/Shrub) in addition to a Bare Land class are delineated on the map. Although the accuracy assessment of this map was 94.9% with a kappa coefficient of agreement equal to 0.94 (NOAA Coastal Services Center 2001), maps based on the higher resolution images produce finer detail (reword).

Figure 4: Existing land use/land cover maps for Mākaha Valley. The lowest gauging station which was used to delineate the subwatershed is represented in both maps.

Although the current IKONOS- and QuickBird-based vegetation maps are useful, more work is desirable in order to refine classification. Initial results of the subwatershed classification indicate that continuing field and image analysis will produce further separation and identification of vegetation classes. Quantitative field work is especially necessary if the vegetation map is to be used to predict the effect of alien communities on Mākaha Valley’s hydrological cycle. Other classification methods of the multi-spectral data may increase the utility of the vegetation maps for this purpose. Alternatively, it may be that the available spectral bands are limiting the detailed discrimination of vegetation communities that is needed and hyper-spectral data would be more suitable for analysis.

Other work includes the classification of Mt. Kaʻala (Palustrine Forested Wetland in the C-CAP map) which is obscured by clouds in our IKONOS image but not in the QuickBird image. Analysis of this area needs to be performed in order to fully depict vegetation communities in the selected subwatershed. Finally, an accuracy assessment of the final classification results will be determined by comparing image sites with field plots. An error matrix will be produced, from which both overall and class-averaged accuracies will be computed (Nishii and Tanaka 1999).
CONCLUSION

In this study, we assessed the utility of fine-resolution satellite imagery in discriminating invasive and native vegetation communities. It was strongly felt that fine resolution satellite imagery is very useful in mapping invasive and native species. Some invasive species were detectable at the species level, and others at the community level. The vegetation maps produced from this study should aid in understanding of the spatial extent of certain native alien and native species within Mākaha Valley. Complications of remote sensing in a tropical environment include the effects of topography and high species diversity; however, much potential exists to increase the accuracy of current vegetation maps.

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