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# The impact of spatial resolution on the classification of plant species and functional types within imaging spectrometer data

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ABSTRACT

Several upcoming hyperspectral satellite sensor missions (e.g., the Hyperspectral Infrared Imager and the Environmental Mapping and Analysis Program) will greatly expand the opportunities for researchers to use imaging spectroscopy data for discriminating and mapping plant species and plant functional types (PFTs; defined in this study as combinations of leaf-type, leaf/plant duration and life form). Accurate knowledge of the spatial distribution of dominant plant species and PFTs is highly valuable to many scientific and management goals, including improved parameterization of ecosystem process and climate models, better invasive species distribution monitoring and forecasting, quantification of human and natural disturbance and recovery processes, and evaluations of terrestrial vegetation response to climate change. Most often, species-level discrimination has been achieved using fine spatial resolution (≤20 m) airborne imagery, but currently proposed spaceborne imaging spectrometers will have coarser spatial resolution (~30 to 60 m). In order to address the impact of coarser spatial resolutions on our ability to spectrally separate species and PFTs, we classified dominant species and PFTs in five contrasting ecosystems over a range of spatial resolutions. Study sites included a temperate broadleaf deciduous forest, a brackish tidal marsh, a mixed conifer/broadleaf montane forest, a temperate rainforest and a Mediterranean climate region encompassing grasslands, oak savanna, oak woodland and shrublands. Data were acquired by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) over each site, and spatially aggregated to 20, 40 and 60 m resolutions. Canonical Discriminant Analysis (CDA) was used to classify species and PFTs at each site and across scales with overall accuracies ranging from 61 to 96% for species and 83–100% for PFTs. The results of this study show accuracy increases at coarser resolutions (≥20 m) across ecosystems, supporting the use of imaging spectroscopy data at spatial resolutions up to 60 m for the purpose of discriminating among plant species and PFTs. In four of the five study sites, the best accuracies were achieved at 40 m resolution. However, at coarser resolutions, some fine-scale species variation is lost and classes that occur only in small patches cannot be mapped. We also demonstrate that spectral libraries developed from fine spatial resolution imagery can be successfully applied as training data to accurately classify coarser resolution data over multiple ecosystems.


## 1. Introduction

Ecosystem- and regional-scale maps of vegetation composition, function and health derived from remote sensing data have played a key role in measuring and monitoring changes in the natural environment across space and time (Kerr & Ostrovsky, 2003; Turner et al., 2003). In particular, these maps are used to characterize the spatial distribution of vegetation types and to monitor land cover change due to climate, natural disasters and human activity. They are also important inputs to ecosystem process and climate models (DeFries, 2008; Turner, Ollinger, & Kimball, 2004). Making these maps on a global scale is quite challenging. Most global data products are derived using coarse spatial resolution (≥500 m), multispectral data. Sensors such as the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectrometer (MODIS) have been used to create several global land cover maps that include vegetation types based primarily on biomes (e.g., evergreen forest, woodlands, open shrublands, etc.) (DeFries, Hansen, Townshend, & Sohlberg, 1998; Friedl et al., 2002; Hansen, DeFries, Townshend, & Sohlberg, 2000; Loveland et al., 2000; Muchoney, Strahler, Hodges, & LoCastro, 1999). While biome-level maps are useful, many applications require more detailed information regarding plant functional type (PFT) composition (Bonan, Levis, Kergoat, & Oleson, 2002), because these classes are more concretely linked to biospheric processes of interest, such as carbon, water and energy fluxes (DeFries et al., 1995). Within remote sensing science, these PFTs are often defined by traits such as leaf type (e.g., broadleaf/needleleaf), leaf longevity (evergreen/deciduous) and life form

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(e.g., tree/shrub/herb). Efforts to derive these products have been successful for the most part (Sun, Liang, Xu, Fang, & Dickinson, 2008; Sun & Liang, 2008), though most PFT data sets have been created using preexisting coarse-grained land cover maps (i.e., biomes). Comparison of existing global and continental classification maps is difficult because most have been made using data acquired by different sensors, or over different time periods, and often do not share the same set of classes. Assessing the accuracy of these coarse-scale maps is also challenging, given the sparseness of validation data. Finer resolution maps of vegetation composition covering smaller regions can provide improved reference data for global products. Such maps have been created using multispectral, finer spatial resolution sensors such as Landsat and SPOT (Goodenough et al., 2003; Göttlicher et al., 2009; Harvey & Hill, 2001; Price, Guo, & Stiles, 2002; Ustin et al., 1986). However, even with the global availability of finer spatial resolution data, such as Landsat (30 m), discrimination of certain PFTs and many species using broadband sensors can be difficult (Clark, Roberts, & Clark, 2005).

The most promising sensors for improving PFT maps, and even discriminating dominant plant species within PFTs, are imaging spectrometers (DeFries, 2008; Schmidtlein, Feilhauer, & Bruelheide, 2012; Ustin & Gamon, 2010; Ustin, Roberts, Gamon, Asner, & Green, 2004). Imaging spectrometers measure reflected radiance in many narrow bands, and thus are sensitive to subtle differences in plant biochemistry, physiology and structure (Kokaly, Asner, Ollinger, Martin, & Wessman, 2009; Schaepman et al., 2009; Ustin et al., 2004). These sensors have been successfully used to discriminate dominant plant species and PFTs over many types of ecosystems (Asner, 2013; Ustin & Gamon, 2010). In temperate forests, studies by Martin, Newman, Aber, and Congalton (1998), Van Aardt and Wynne (2007), and others (e.g., Plourde, Ollinger, Smith, & Martin, 2007) were able to discriminate among a wide variety of broadleaf deciduous and evergreen needleleaf tree species. In the western U.S., Goodenough et al. (2003) mapped similar functional types in a temperate forest. Kokaly, Despain, Clark, and Livo (2003) classified both species and PFTs in a mixed montane conifer forest and the surrounding shrublands, and Schaaf, Dennison, Fryer, Roth, and Roberts (2011) mapped PFTs in a similar montane ecosystem. Tropical forests, some of the most diverse ecosystems on the planet, have also been accurately classified to the species-level in many studies (Clark et al., 2005; Cochrane, 2000; Féret & Asner, 2012; Kalacska, Bohlman, Sanchez-Azofeifa, Castro-Esau, & Caelli, 2007; Somers & Asner, 2013). The successful application of imaging spectroscopy data has not been limited to forests. In Mediterranean climate shrublands, Dennison and Roberts (2003), Underwood, Ustin, and Ramirez (2007) and Roth, Dennison, and Roberts (2012) mapped PFTs and species to accuracies 75% and greater. Li, Ustin, and Lay (2005) and Pengra, Johnston, and Loveland (2007) mapped species in wetland ecosystems, and in urban areas, Zhang and Qiu (2012) and Alonzo, Roth, and Roberts (2013) were able to map single trees to the species-level. Despite these successes, these studies have been done using airborne sensors which collect data at relatively fine spatial resolutions (e.g., 4–20 m) and over limited spatial extents. This limits their applicability for monitoring vegetation on regional to global scales.

Currently, several space-borne imagining spectrometers are under development, which would provide, for the first time, global coverage. In response to data priorities from the National Research Council's Earth Science Decadal Survey (NRC, 2007), NASA's proposed Hyperspectral Infrared Imager (HyspIRI) mission includes a full visible-shortwave infrared (VSWIR) instrument which will collect data at 60 m with a 19 day repeat acquisition time (HyspIRI Team, 2009; Roberts, Quattrochi, Hulley, Hook, & Green, 2012). The German hyperspectral satellite mission Environmental Mapping and Analysis Program (EnMAP) will collect data swaths of 30 km at a ground resolution of 30 m (Kaufmann et al., 2006). Additional missions include Italy's PRecursore IperSpettrale (PRISMA), and both China and Japan are also currently developing spaceborne imaging spectrometers. These missions will greatly increase the availability of imaging spectroscopy data, leading to more comprehensive mapping of PFTs and species. While the spectral and radiometric resolutions of the many of these proposed sensors are based on existing aerial sensors, the proposed spatial resolutions will be coarser. Therefore, it is important to evaluate the impacts of spatial resolution on the discrimination of dominant species and PFTs across a wide range of ecosystems.

Determining the optimal scale for mapping vegetation properties has been an ongoing area of research in remote sensing science (Atkinson & Curran, 1995; Curran & Atkinson, 1999; Woodcock & Strahler, 1987). The scale at which observations are made (i.e., the pixel size) may or may not align well with the scale of biogeophysical processes, and target size (e.g., individual trees, patches of a given species, etc.) will vary across ecosystems and with ecological questions and concerns (Feld et al., 2009; Fisher, 1997; Turner, Neill, Gardner, & Milne, 1989). The implications of this mismatch have been widely considered, and a more in-depth discussion of these can be found in Marceau, Gratton, Fournier, and Fortin (1994), Woodcock and Strahler (1987), and Wu and Li (2009). Most importantly, image spatial resolution will have a significant impact on the ability to accurately characterize surface attributes of interest, such as land cover.

Most scaling studies have been done using data from broadband sensors (Atkinson & Curran, 1997; Chen, Stow, & Gong, 2004; Cohen, Spies, & Bradshaw, 1990; Nelson, McRoberts, Holden, & Bauer, 2009), and few imaging spectroscopy studies have examined the role of spatial scale in discriminating plant species and functional types. Here two types of scale can be considered: physical scale (e.g., leaf vs. branch vs. canopy) and image spatial resolution (i.e., pixel size). Studies by Roberts et al. (2004) in a Pacific Northwest temperate rainforest (the same forest considered in this study) and Clark et al. (2005) in tropical rainforest examined changes in species discrimination across physical scales. These studies are critical because they demonstrate how spectral separability is altered by combinations of leaf structure and biochemistry, crown architecture and canopy structure. They thus provide us a better understanding of the controls on species discrimination. Other studies have examined the impact image resolution has on classification accuracy. Treitz and Howarth (2000) used CASI data to evaluate the spatial scale of variance among forest species associations in a mixed deciduous and coniferous forest. Underwood et al. (2007) compared 4 m and spatially degraded (30 m) AVIRIS data for mapping different vegetation communities with varying levels of invasion by three target species in a mixed chaparral and sage scrub ecosystem. The image was degraded using nearest neighbor resampling, and they report a decrease in overall accuracy from 75% to 58% as resolution became coarser. Schaaf et al. (2011) also spatially degraded 20 m AVIRIS data to 40 m and 60 m for their study on PFT discrimination in a montane ecosystem, but in this case, using spatial averaging to simulate coarser resolution data. Accuracy decreased as spatial resolution was coarsened, but the use of spectral libraries derived at the finer spatial resolution (20 m) improved accuracy over spectral libraries derived at coarser spatial resolutions.

In our study, we sought to expand upon this previous research by assessing the impact of coarsening spatial resolution on the accuracy of PFT and dominant plant species classification with imaging spectroscopy data across a range of North American ecosystems. In particular, we sought to answer the following questions:

1) What effect does spatial resolution have on our ability to spectrally discriminate dominant plant species and PFT composition across a range of ecosystems using imaging spectroscopy, and how do these impacts vary by ecosystem type?
2) Can reference spectral libraries developed from finer resolution (~3–18 m) imagery be used to adequately map dominant plant species and PFTs at coarser scales?

To address these questions, we analyzed imagery acquired by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) over five ecosystems aggregated to a range of spatial resolutions up to 60 m. At each resolution and within each ecosystem, we classified dominant plant species and PFTs using canonical discriminant analysis (CDA). We hypothesized that accuracy metrics, including kappa coefficient, overall