Remote Sensing of Environment 183 (2016) 65–81

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Mapping spatial distribution and biomass of coastal wetland vegetation in Indonesian Papua by combining active and passive remotely sensed data

Aslan Aslan [a], Abdullah F. Rahman [b,*], Matthew W. Warren [c], Scott M. Robeson [d]

[a] School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405, USA
[b] Coastal Studies Lab, University of Texas Rio Grande Valley, San Padre Island, TX 78597, USA
[c] Northern Research Station, USDA Forest Service, Durham, NH 03824, USA
[d] Department of Geography, Indiana University, Bloomington, IN 47405, USA

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 13 April 2016
Accepted 30 April 2016
Available online xxxx

Keywords:
Indonesia
Mangroves
Classification
Biomass
Landsat-8
Radar

ABSTRACT

There is ongoing interest to develop remote sensing methods for mapping and monitoring the spatial distribution and biomass of mangroves. In this study, we develop a suite of methods to evaluate the combination of Landsat-8, ALOS PALSAR, and SRTM data for mapping spatial distribution of mangrove composition, canopy height, and aboveground biomass in the wide intertidal zones and coastal plains of Mimika district, Papua, Indonesia. Image segmentation followed by visual interpretation of composite PALSAR images was used to delineate mangrove areas, whereas a flexible statistical rule based classification of spectral signatures from Landsat-8 images was used to classify mangrove associations. The overall accuracy of land cover classification was 94.38% with a kappa coefficient of 0.94 when validated with field inventory data and Google Earth images. Mangrove height and aboveground biomass were mapped using the SRTM DEM, which were calibrated with field-measured data via quantile regression models. There was a strong correlation between the SRTM DEM and the 0.98 quantile of field canopy heights ($H_{.98}$), which was used to represent the tallest trees in each of 196 10 m radius subplots ($r = 0.84$ and $R^2 = 0.804$). Model performance was evaluated through 10,000 bootstrapped simulations, producing a mean absolute error (MAE) of 3.0 m for canopy height estimation over 30 m pixels of SRTM data. Quantile regression revealed a relatively strong non-linear relationship between the SRTM derived canopy height model and aboveground biomass measured in 0.5 ha mangrove inventory plots ($n = 33$, $R^2 = 0.46$). The model results produced estimates of mean standing biomass of 237.52 ± 98.2 Mg/ha in short canopy (*Avicennia*/*Sonneratia*) stands to 353.52 ± 98.43 Mg/ha in mature tall canopy (*Rhizophora*) dominated forest. The model estimates of mangrove biomass were within 90% confidence intervals of area-weighted biomass derived from field measurements. When validated at the landscape scale, the difference between modeled and measured aboveground mangrove biomass was 3.48% with MAE of 105.75 Mg/ha. These results indicate that the approaches developed here are reliable for mapping and monitoring mangrove composition, height, and biomass over large areas of Indonesia.

1. Introduction

Mangroves grow exclusively within the intertidal zones of coastal, estuarine, and riverine landforms of the tropics and subtropics (Giri et al., 2011). The ecological functions of mangroves are critical to the environmental health of near-shore marine environments and adjacent upstream terrestrial systems, as they are transitional ecosystems where ocean, land, and freshwater converge (Kathiresan & Bingham, 2001; Lugo & Snedaker, 1974; Suratman, 2008; Tomlinson, 1986). They provide at least US $1.6 billion each year globally in ecosystem services while supporting the livelihoods of coastal communities (Polidoro et al., 2010). Mangrove diversity and occurrence are highest in Southeast Asia, where nearly 75% of the World's mangrove species occur. Indonesia alone contains about 19% of the World's mangrove forest area, a total of 3.2 million hectares, and 45 of about 70 “true” mangrove species (species which meet physiological criteria and are adapted to occupy saline, hypoxic intertidal habitats; see Bakosurtanal, 2009; FAO, 2007; Tomlinson, 1986). Approximately half of Indonesia's mangroves are located in the Papua and West Papua provinces and remain largely intact, whereas mangroves in other parts of Indonesia have experienced very high deforestation rates in recent decades due to aquaculture and infrastructure development (Ilman, Wibisono, & Suryadiputra, 2011; Rahman, Dragoni, Didan, Barreto-Munoz, & Hutabarat, 2013). A recent assessment suggests Indonesia has lost up to 40% of its original mangrove cover since 1980. Most of these losses

* Corresponding author.

http://dx.doi.org/10.1016/j.rse.2016.04.026

have occurred in Sumatra, Kalimantan, Sulawesi and Java (Ilman et al., 2011; Murdiyarso et al., 2015).

The southern coast of Indonesian Papua contains some of the largest contiguous mangrove forests on Earth, including large tracts on Bintuni Bay and on the wide coastal plains of Mimika and Asmat districts (Fig. 1). An estimated 193,226 ha of mangrove forest cover the coastal lowlands of Mimika, a southern district of Papua Province (MoF, Ministry of Forestry of Indonesia., 2008). These mangroves are mostly pristine and of high ecological value as they support productive near-shore fisheries, harbor unique biodiversity, and are critical sources of food and other natural products to local communities (ARD, 2014). However, despite the importance of Mimika's mangrove forests and coastal wetlands in providing ecosystem services (Barbier, 2012; Clough & Abdullah, 1993; Costanza et al., 1997; Mumby et al., 2004; Vo, Kuenzer, Vo, Moder, & Oppelt, 2012), they are vulnerable to the rapid large-scale conversion and mismanaged deforestation observed elsewhere in Indonesia (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014; Miettinen, Shi, &Liew, 2011; Rahman et al., 2013). As coastal resources of other Indonesian Islands become depleted, it is likely that Papuan mangroves will become more attractive to developers intending to expand aquaculture production and other industries.

In addition to the well-known ecological benefits they provide, mangroves are gaining increasing attention for their capacity to sequester carbon (they are a key component of “Blue Carbon”) and potential involvement in climate change mitigation efforts (Alongi, 2012; Chmura, Anisfeld, Cahoon, & Lynch, 2003; Donato et al., 2011; Murdiyarso, Kauffman, & Verchot, 2013). Mangroves in the Indo-Pacific region are reported to contain carbon stocks exceeding 1000 MgC/ha, mostly stored in buried sediments (Donato et al., 2011; Fujimoto et al., 1999). Per unit area, this capacity to store carbon is several times higher than that of tropical forests on dry land (Donato et al., 2011). Therefore, conservation and improved management of the remaining mangroves provides an avenue to avoid large-scale CO_2 emissions and loss of sequestered C from mangrove conversion. Such Blue Carbon mitigation strategies could contribute substantially to Indonesia's voluntary pledge to reduce greenhouse gas emissions 26% by 2020 (GOI, Government of Indonesia, 2011). However, involving mangrove conservation in climate mitigation programs such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Blue Carbon (McLeod et al., 2011; Pendleton et al., 2012) requires intensive mapping and monitoring to create baseline C stock data and to validate conservation efforts. Such mapping is also needed for improved spatial planning and integrated coastal management.

The goal of this study was to develop a systematic approach for mapping the distribution and biomass of different species and associations of mangroves at a consistent pixel scale by combined use of multispectral and Synthetic Aperture Radar (SAR) remote sensing data. Specific objectives include:

1) To investigate whether improved mapping of mangroves at genus or even species level may be achieved by using images from the recently launched (February 2013) Landsat-8, which has 16-bit

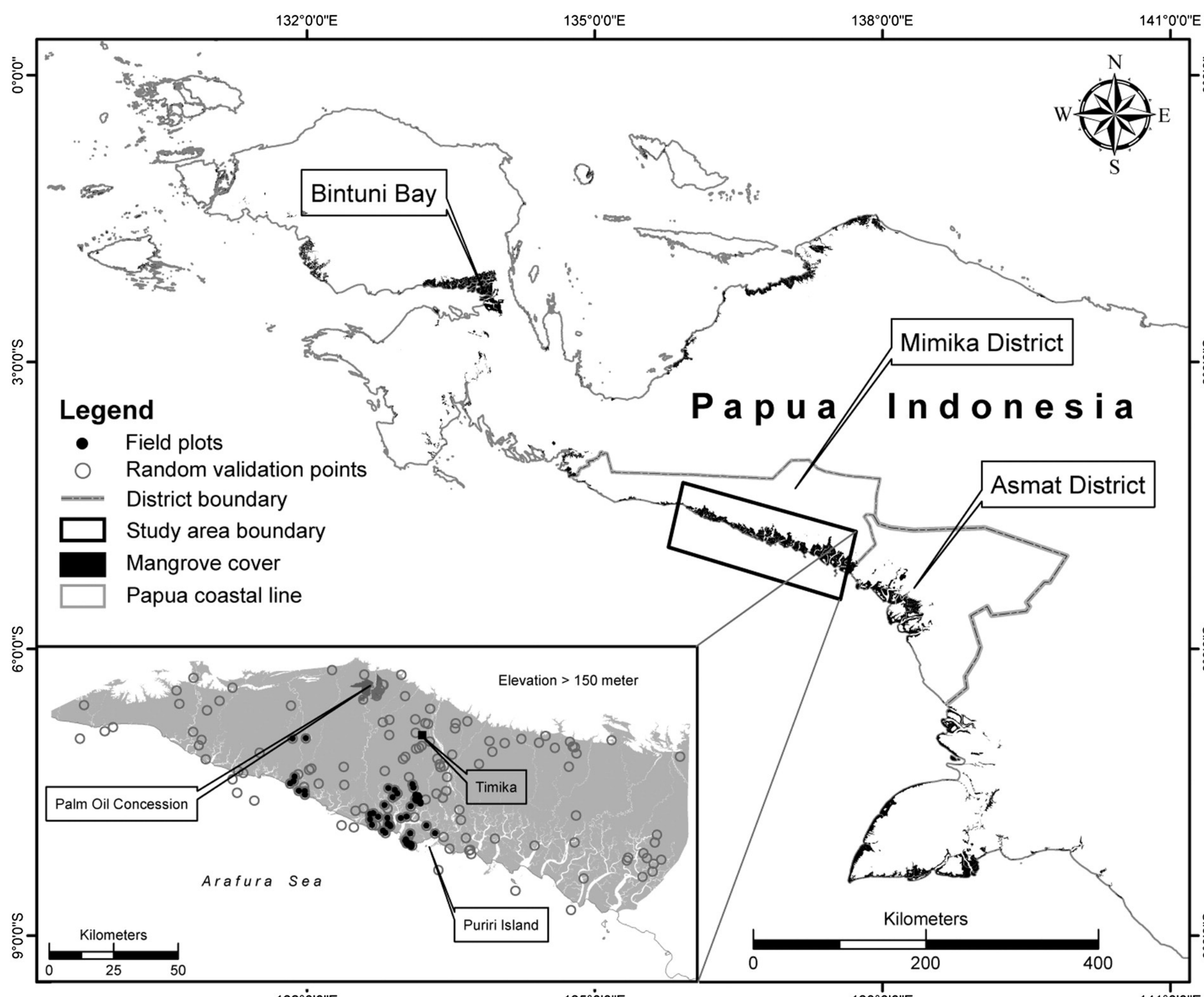

Fig. 1. Map of the study area in the Mimika district of Papua, Indonesia, showing the location of field sampling plots and random validation points bounded between 0 and 150 m ASL elevation.