Remote Sensing of Environment 200 (2017) 368–377

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Radar polarization and ecological pattern properties across Mediterranean-to-arid transition zone

Jisung Chang*, Maxim Shoshany

Faculty of Civil and Environmental Engineering, Technion-Israel Institute of Technology, Haifa, 32000, Israel

A R T I C L E I N F O

Keywords:
ALOS-PALSAR
Biomass remote sensing
Degree of polarization
Dryland ecosystem
Mediterranean
NDVI
Shrubland biomass
Polarimetric

A B S T R A C T

Full polarimetric L-band PALSAR data facilitated one of the first empirical assessments of the relationships between radar polarization properties (RPPs) and ecological pattern properties (EPPs) in desert fringe ecosystems. Correlations between radar parameters (polarized backscattering intensities, their ratios, entropy, and degrees of polarization) and remotely sensed ecological parameters (shrub cover, edge parameter, average shrub height, and biomass information) were analyzed for 52 least-disturbed sites along a climatic gradient between semi-arid and arid zones in the south-eastern Mediterranean. The degree of horizontal polarization (DOHP) was the RPP that was most highly correlated with all EPPs, while NDVIR biomass (NDVI multiplied by relative rainfall) was the EPP most highly correlated with all RPPs. Combinations of NDVIR biomass and DOHP data exhibited consistent inverse relationships for both the 52 least-disturbed sites as well as for the entire gradient. Mapping these combinations along the transition zone enabled differentiation of desert fringe areas and dense shrub and tree areas, with three transition typologies between the two. Although DOHP is instrumental in detecting changes in tall shrub coverage, it was found to be insufficiently sensitive to surface conditions in areas with dwarf shrubs and shrubs of biomass lower than 0.7 kg/m^2 at the end of the summer. Differentiation between the desert, desert fringe, and semi-arid margins of high DOHP values ($>$ 0.9) was facilitated by differences in their NDVIR biomass. Areas of high anthropogenic influence on the landscape, i.e. abandoned terraces and low-density pine plantations, deviate significantly from the inverse DOHP and NDVIR biomass relationship, as both were characterized by low values in these parameterizations. The wide extent of DOHP and NDVIR combinations representing desert fringe ecosystems and arid lands indicated a continuation of degradation processes in areas with rainfalls $>$ 500 mm/year. The technique developed, which utilizes DOHP, provides new means for mapping desert fringe ecosystems and for exploring desertification over wide regions.

1. Introduction

The south-eastern Mediterranean is a hot-spot of climate change and desertification. Hoerling et al. (2012) identified it as a hot spot of dry winters between 1971 and 2010, while the United Nations' Office for Disaster Risk Reduction reported on the decline of ecosystems in this region owing to a water deficit of about 651 million m^3 during the years 1995–2005 caused by an increase in drought frequency (Erian et al., 2013). Mariotti et al. (2008) predicted further warming and drying of this region until the end of this century as did Kafle and Bruins (2009), who claimed that the desert in this region is becoming drier. Since early in human history, ecosystems in this region have been subjected to growing pressure due to expanding build-up and infrastructure areas, overgrazing, frequent fires, and wood cutting following socio-economic changes and political instability. High topographic, lithologic, and soil variability combined with natural and anthropogenic influences resulted in a “mosaic of innumerable variants of different degradation and regeneration stages” (Walter, 1968; Naveh and Lieberman, 1973). In such a complex mosaic, it is difficult to extract information about an ecosystem's response to climate change. Developing remote sensing methods for the identification of characteristic shrub patterns and the assessment of their modes of change across climatic transitions is one way of advancing this field. The use of sensor systems that are sensitive to vegetation and soil properties in areas of varying habitat conditions is instrumental for this purpose.

Numerous remote sensing studies were carried out with the aim of mapping the Mediterranean and arid environments and the changes they undergo (e.g., Otterman, 1981; Shoshany et al., 1996; Schmidt and Karnieli, 2000; Bolle et al., 2002; Shoshany and Svoray, 2002; Hill et al., 2008). Most of these studies used remote sensing in the optical wavelength domain. Limitations on the information content of optical sensor data regarding inner vegetation layers, shrub understory, and

* Corresponding author.
E-mail address: cjisung@campus.technion.ac.il (J. Chang).

http://dx.doi.org/10.1016/j.rse.2017.08.032
Received 1 September 2016; Received in revised form 6 February 2017; Accepted 22 August 2017
Available online 30 August 2017

sub-surface soil properties are well recognized by researchers in this field. Since the launch of the ERS-1 by ESA (1992), the JERS-1 by Japan Aerospace Exploration Agency (1992), and the RADARSAT system by the Canadian Space Agency (1995), radar sensor data have facilitated improvements in the monitoring of biomass and soil moisture across the arid margins of Mediterranean regions (e.g., Svoray and Shoshany, 2002; Svoray and Shoshany, 2004; Wang and Qu, 2009; Eisfelder et al., 2012). Radar L-band systems with quad-polarization measurements (HH, VV, HV and VH), which have been available since 2004, have further improved the potential extraction of volumetric information by remote sensing (Chen et al., 2009; Le Toan et al., 2011; Neumann et al., 2012; Bourgeau-Chavez et al., 2013; Hamdan et al., 2014). Much of the successful experience using polarized radar sensor data was reported for relatively homogeneous vegetation cover such as that observed in forests and agricultural areas (Ghasemi et al., 2011; Neumann et al., 2012; Robinson et al., 2013; Sinha et al., 2015), while use of polarimetric radar in highly heterogeneous landscapes is quite limited (see Mathieu et al., 2013 and Tanase et al., 2014 among the few existing studies). Our hypothesis is that polarimetric radar parameterizations will add significant information regarding ecological properties along transition zones containing varying combinations of shrubs, dwarf shrubs, rocks and bare soil patches. Such spatial complexity may, however, hamper ecological information extraction due to the diverse forms of polarized radar signal response to surface roughness, soil moisture, topography, and shrub biomass. Assessing relationships between radar polarization and shrubland pattern properties will therefore be instrumental in the development of efficient monitoring systems and their implementation for mapping these highly heterogeneous transition zones. To this end, we will first analyze relationships between radar polarization properties (RPPs) and remotely sensed ecosystems pattern properties (EPPs) as derived from ortho-rectified air-photographs at sites representing minimal disturbance along the climatic gradient between semi-arid and arid zones in the south-eastern Mediterranean basin. Then, based on this analysis, we select the combination of parameters that is best suited for broad mapping of surface conditions. After mapping these parameter combinations, we assess the patterns that emerge in the context of land degradation and desertification.

2. The study area within the context of Mediterranean climate transition

Shrublands occupy vast areas across semi-arid to arid transition zones around the world (e.g., Evenari et al., 1985; Peinado et al., 1995). Among these zones are areas at the arid margins of the five Mediterranean regions characterized by hot dry summers and cold wet winters (Trewartha, 1954; Bennett et al., 1998; Lionello et al., 2006). Their generalized form of transition concern a typical shift from steppe woodland or Mattoral (Chapparal, Maquis) into Semidesert (dwarf-shrubs) and Desert (Chamaephyte), along a north to south or west to east gradients in rainfall between 600 and 100 mm/year (e.g., Shmida, 1981). Plant associations of these regions are highly similar in terms of physiogenomy and morphology (Raven, 1973). Human disturbance due to grazing, wood cutting and fire (e.g., Rundel, 1998) are threatening biodiversity following the increase in population growth across the five Mediterranean regions (e.g., Underwood et al., 2009). Common climate change trends concerning decreasing precipitation and increasing atmospheric temperatures (e.g., Lionello et al., 2006; Seager et al., 2007; Mariotti et al., 2008; Philandras et al., 2011) are further deteriorating habitat conditions and increasing potential desertification. Our study area in the south eastern Mediterranean, represents a typical Mediterranean to arid transition zone undergoing such human disturbance and climate change threats. It extends (Fig. 1) from the Judean Mountains (reaching above 500 mm/year rainfall) to the Judean Desert in the east and the Negev Desert in the south (reaching rainfall levels below 200 mm/year). The phyto-ecological units that characterize this

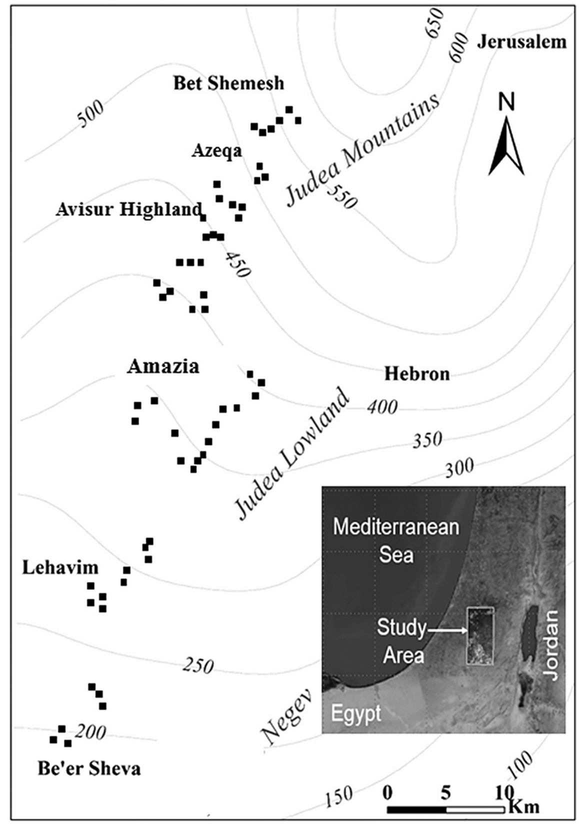

Fig. 1. The study area, from Lehavim (250 mm/year) in the south, through Amazia (350 mm/year) and Avisur Highland (450 mm/year), to Azeqa in the north (550 mm/year).

transition zone are (Danin, 1992):

- Woodlands and shrublands in areas with rainfall > 350 mm/year, which are populated by three associations: Quercus calliprinos and *Pistacia lentiscus*, Ceratonia silliqua and *Pistacia lentiscus*, and Rhamnus palaestinus.
- Highly disturbed shrublands, which are populated by a mix of the aforementioned shrub associations and herbaceous plants of the *Hyparrhenia hirta* community together with the a Sarcopoterium spinosum batha.
- Desert fringe batha in areas with < 350 mm/year rainfall, which is dominated by the Sarcopoterium spinosum and the Thymelaea hirsuta dwarf shrubs.

During the past 40 years, this transition zone has attracted significant attention within the broad framework of studying spatial ecosystem responses to change in climate conditions as indication of future responses to temporal changes in these conditions. These studies included climatological research on annual and seasonal rainfall variations (e.g., Aviad et al., 2004), ecological research concerning species distribution in the northern Negev and the Judean Desert (Danin et al., 1975), human effects on the flora (e.g., Holzapfel et al., 1992), rainfall effects on plants diversity (Kutiel et al., 2000; Rysavy et al., 2014), biomass differences between semi-arid and desert fringe sites (Sternberg and Shoshany 2001a & 2001b) and studies of degradation and erosion (Cerda 1998a & 1998b). Most of this body of research was conducted along the west-to-east transect where human disturbances reached highest levels. The North-to-south transect has lower levels of human disturbance with protected sites and sites of controlled grazing, allowing better understanding of the vegetation's dependence on rainfall. Most of the existing ecological studies of the climatic gradients of the Judean mountains are based on a small number of small sites