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Rehabilitating degraded drylands by creating woodland islets: Assessing long-term effects on aboveground productivity and soil fertility

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ABSTRACT

We evaluated the effects of *Acacia victoriae* islets planted in 1993 in the Negev drylands on the productivity of the native herbaceous vegetation and soil fertility. Biomass, mineral-P, N and K and soil organic matter were measured from the planted and an adjacent unplanted area. The satellite-derived Normalized Difference Vegetation Index (NDVI) from MODIS was used to expand the timespan of the analysis after calibration with field data. Results showed an average improvement in biomass and rain use efficiency (RUE) of 40% compared to the unplanted area. Improvement was also observed in all nutrients concentrations and organic matter. Biomass was highly related to precipitation ($R^2 = 0.90$, $p < 0.001$), gradually declining from 2001 to 2009. Although declining with precipitation, RUE was maintained constantly higher in the planted area with respect to the unplanted lands even in dry years. The total biomass gained since plantation was estimated at 60 g m^{-2} yr^{-1} (i.e. 12 t ha^{-1}) for a 20-year period. Our results suggest that planting woodland islets may significantly improve soil quality and biomass productivity of the native vegetation in drylands in a relatively short time.

1. Introduction

Land degradation, defined as the long-term decline in biomass productivity, is an environmental problem affecting almost one quarter of the World's arable lands (Bai et al., 2008). It has severe economic implications for agricultural (Girt, 1986) and grazing managements (Oba et al., 2000). In drylands, land degradation may severely affect the local population, which is highly dependent on such services. For these reasons rehabilitating the native vegetation in terms of productivity and improving soil fertility in drylands is of a primary importance. However, it is not straightforward and several solutions were proposed (Le Houérou, 2000). The more active operations suggested are full forestation (Malagnoux et al., 2008) or limited planting of trees as "islets" in extensive areas (Benayas et al., 2008). The latter is suggested as more economic method to drive passive rehabilitation over much larger areas.

The effects of afforestation or tree planting in drylands have been investigated in terms of carbon sequestration (Tal and Gordon, 2010), landscape restoration (Ginsberg, 2000) and changes in rivers stream flows (Herron et al., 2002). However, little attention has been given to the effects on the native vegetation at large-spatial and long-term scales. Many studies explored the effect of trees on the native vegetation and soil nutrient content only in the subcanopy zone (Belsky et al., 1993; Moustakas et al., 2013; Weltzin and Coughenour, 1990). In general, trees interact with herbaceous vegetation through positive (facilitative) and negative (competition) mechanisms. The net effect will be facilitative or competitive depending on many factors that could be changed in time and space and are difficult to model (Scholes and Archer, 1997).

Several specific environmental conditions regulate such interactions. For example, it was found that in dryer semiarid regions trees have net facilitative effects on the herbaceous vegetation (Moustakas et al., 2013). Dense herbaceous layer would develop in subcanopy areas benefiting from the tree shade and water uplift in these dry places. Such effect will become net competitive in more mesic sites (Dohn et al., 2013). Trees also affect soil nutrient content and organic matter at the subcanopy level in arid (Abdallah et al., 2008) and warm temperate (Eldridge and Wong, 2005)

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environments. Improvement in soil organic matter increase the rain use efficiency (RUE), which is the ratio of biomass production to total precipitation (Yang et al., 2010).

RUE is a key factor in ecosystem productivity because it indicates the capacity of vegetation to transform water (and nutrients) to biomass (Hein and De Ridder, 2006). It usually exhibits a unimodal pattern along precipitation amounts in semiarid environments, increasing with low to moderate precipitation, and decreasing with higher precipitation (Hein and De Ridder, 2006). This decrease is due to the increased runoff in these environments when precipitation amount exceeds by far the average. The maximum RUE could be extended when soils' water holding capacity improves through the increase of soil organic matter (Franzluebbers, 2002).

From all the above, it would be expected that a rehabilitated dryland through tree plantations will have increased RUE and productivity together with improved soil quality enriched in nutrients and organic matter. However, little is known about the degree of stability of these parameters in the new rehabilitated system. Moreover, the long-term effect of the planted trees on the native herbaceous vegetation is unclear, especially when significant changes in water supply occur.

The drylands of the Northern Negev have undergone historically intensive exploitation for grazing and cultivation causing degradation. Therefore, *Acacia victoriae* trees were planted as several islets during 1993 for rehabilitation purposes (Fig. 1). The *A. victoriae*, an evergreen tree from the Australian savannas, was used due to its rapid growth rate under semiarid conditions (Maslin and McDonald, 2006) and its high N-fixation capacity (Thomson et al., 1994). The specific aims of these plantings were to rehabilitate the native herbaceous vegetation in terms of productivity for grazing purposes, and to improve soil quality for agricultural practices. It presents an opportunity to test the effects of woodland islets planted in drylands, on interannual variability and long-term (20 years) trends in biomass productivity.

Our specific goals in this study were (i) to develop a method for scaling field measurements of aboveground biomass to an area represented by long-term, remotely sensed data; (ii) to test whether planting *Acacia* trees in the Negev drylands improved the herbaceous productivity and soil fertility; (iii) to test how interannual variability in precipitation affect RUE in the planted area compared to the adjacent, unplanted area; and (iv) to estimate the total biomass production of the native herbaceous vegetation that was gained through creating woodland islets.

To achieve these goals we first estimated aboveground biomass (AGB), soil organic matter (SOM) and nutrients concentrations (N, P, K) in several plots in field. Then, we used this data to calibrate satellite data in order to expand the timespan of the analysis. It allowed us to monitor the effects of interannual variability in precipitation on ABG and RUE during the last thirteen years (2001–2013). Moreover, AGB and RUE measurements were scaled to a larger, more spatially representative area in this manner. Finally, we used the calibrated satellite data and the relationship between precipitation and AGB to estimate the total biomass gained in the planted area during the 20 years since plantation.

2. Data and methods

2.1. The study area

Our study area is located in the Northern Negev drylands of Israel (31°19′25″ N, 34°59′10″ E, 460 m). Climate is arid to semiarid with an aridity index (P/PET) of 0.2 (Kafle and Bruins, 2009). The long-term (40 years) mean annual precipitation is 230 mm y^{-1} with interannual variability of 30%. Rainfall mostly occurs during fall, winter and early spring (October–April). Soils in the study area are sandy loam/sandy clay loam type. Native vegetation consists of scattered dwarf shrubs and patches of annual herbaceous vegetation appearing shortly after the first rains. Predominant functional

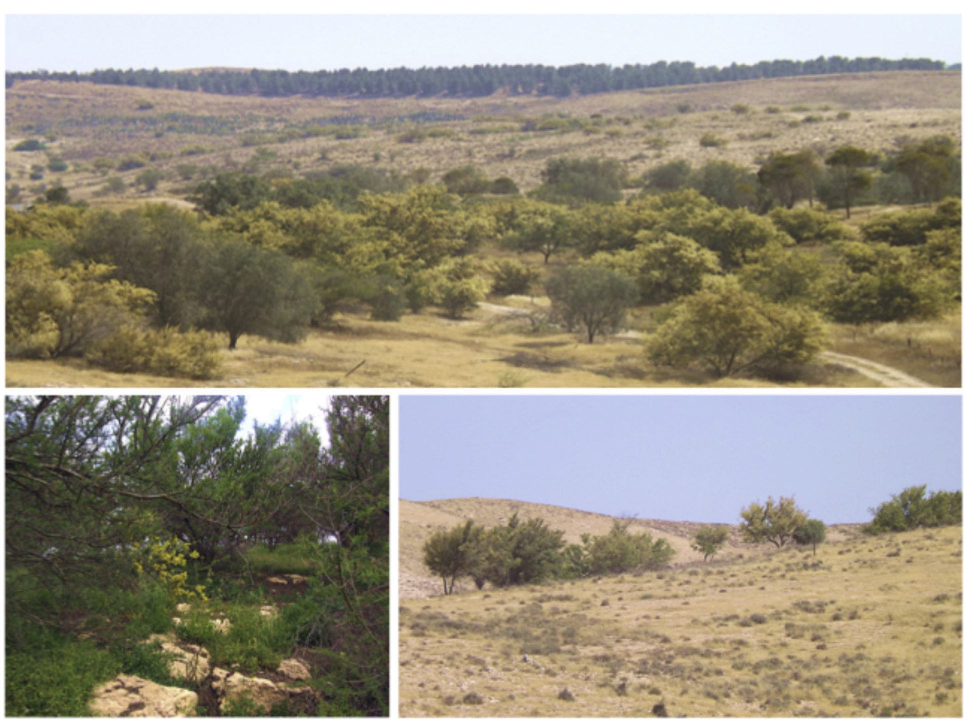

Fig. 1. (Upper) View of the *Acacia victoriae* islets planted in the Northern Negev drylands, with Yatir, the largest planted pine-forest of Israel in the background – two different approaches to rehabilitate degraded drylands. (Lower left) Closer look at the high biomass production of the herbaceous vegetation within the woodland surroundings after the winter rain. (Lower right) A partial view of the *Acacia victoriae* islets planted in the middle of the Negev drylands.
Photos credit: Amir Mussery (2013).