STATUS OF DIEBACK OF *JUNIPERUS PROCERA* (AFRICAN PENCIL CEDAR) IN NATURAL STANDS AND PLANTATION IN ALSOUDA HIGHLANDS, SAUDI ARABIA

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Abstract. The natural habitat of *Juniperus procera* is a unique ecosystem in Saudi Arabia. The ecosystem of Aseer highlands is an important habitat for flora and fauna. Alsouda Highlands, situated in the southwestern part of Saudi Arabia, is claimed to be the highest peak in Saudi Arabia. These forests suffered varying degrees of degradation. Juniperus trees in these highlands have experienced widespread decline with substantial dieback for 35 years. The aim of the study is to evaluate the status of *J. procera* dieback in Alsouda natural stands (2400-2950 m). The results showed that >80 % *J. procera* trees within the natural stands had symptoms of dieback but >65% was not severely affected. Tree recovery signs of new lateral shoots, leaves, sprouts and flowering were evidently observed even among the severely affected trees. The plantation showed no symptoms of dieback, but their growth rate was relatively low. The NDVI showed an increasing trend of greenness with time, especially in the seasons with high rainfall. The effect of slope aspect was evident in the severity of dieback and greenness of the vegetation as detected by the NDVI data. The west facing slopes were higher in NDVI values than the east-facing slopes, due to higher precipitation in the west – facing slopes by the southwestern monsoons. The results indicate significant effect of seasonal rainfall with respect to tree health.
Keywords: *African pencil cedar, natural stands, plantations, new regeneration, NDVI, Aseer region*

Introduction

Juniperus procera Hochst. ex. Endl. (Cupressaceae), known as African pencil cedar and Arar in Arabic, is the world's largest juniper, evergreen, dioecious and wind pollinated forest tree species (Farjon, 2005; Couralet and Bakamwesiga, 2007; Negash and Kagnew, 2013). It spreads naturally in the highlands above 1800 m.a.s.l., but can occurs in a broader range of 1000–3500 m.a.s.l., with an average annual temperature range from 5 °C to 20 °C (Couralet and Bakamwesiga, 2007). It is listed in the IUCN red list of the threatened species due to overexploitation and global decline in its populations (Farjon, 2013).

The species is the dominant forest tree in the southwestern highlands of Aseer Region Kingdom of Saudi Arabia (KSA) at elevations from 2000 to 3000 m.a.s.l (El-Juhany et al., 2008; El-Juhany, 2015), and the density decreases in the subsequent lower elevations (El-Juhany and Aref, 2013). In addition to aesthetic values, the Juniper natural stands are important component of the highland ecosystems in Aseer (Aref et al., 2013) as they enhance biodiversity, reduce soil erosion, conserve rainfall water, and provide wood products (Aboulfatih et al., 1989).

Dieback symptoms and low rate of natural regeneration of *J. procera* were observed in Alsouda, Aseer Region during the early 1980's (El-Juhany, 2015). Symptoms were

up to 50% among trees in some parks, in addition to absence of new regeneration (Barth and Horst Strunk, 2000). It was attributed to climate change (Fisher, 1997), soil erosion and water run (Aref et al., 2013; El Atta et al., 2013), deprived eroded-soil from litter and mycorrhiza (Barth and Horst Strunk, 2000) and human interferences (Gardner and Fisher, 1994). Highlands in Aseer region had experienced warming trends (Krishna 2014) and decreasing annual rainfall (Hosny and Almazroui, 2015). Dieback were reported in Juniper ecosystems in the Arabian Peninsula and south-west Asia (Fisher, 1997), and parts of Africa (Borghesio et al., 2004).

Globally, Forest dieback and decline are significant threat to biodiversity in forest ecosystems with serious economic and aesthetic impacts (McKinneya et al., 2014. Climate and weather stresses were identified prime causes for water stresses and tree declines (Auclair, 1993; Rice et al., 2004; Jurskis, 2005). Climate change was reported to l affect *J. procera* future distribution in northern Ethiopia (Abrha et al., 2018). Natural pests and diseases causes can affect managed- forest condition and stability (Freer-Smith, 2007). Biotic factors are generally considered as contributing secondary factors, however they were primary causes for dieback in English woodlands (Woodward and Boa, 2013), Spruce forest (Kana et al., 2013), and Juniper forests (Borghesio et al., 2004). Study in Ethiopia showed that *J. procera* trees were tolerant and less affected by cypress aphid compared to *cupressus lusitanica* (Demeke, 2018).

The Juniper Forest in Asir is the only dense forest in the Kingdom and is particularly important from the point of view of conservation. Of particular concern is the widespread decline of *Juniperus procera* on exposed lower slopes with some stands consisting mainly of dead or dying trees. Hence, the aim of this study was to evaluate the health status of *J. procera* and extent of dieback in southwestern highlands of KSA. The objectives were to determine the severity of dieback within natural stands and plantations in Alsouda area, and temporal trends of tree health using satellite images in relation to annual rainfall and slope aspects.

Materials and methods

Study area

The study was conducted in Alsouda Area in Aseer Region, in the southwestern highlands of KSA, which is an important touristic area with the richest plant biodiversity in Aseer Region and KSA (Vincent, 2008). The study site is elongated in shape and dissected by small valleys with a total area of 291 km² (*Fig. 1*) and dominated by *J. procera* trees. The satellite image of Landsat depicted in FCC (False color composite (RGB) in order to observe the features clearly. The site was delineated based on topography and maximum stocking density of Juniper trees. It is located between latitude of 18° 8' 43.81" N and 18° 27' 32.00" N and longitude of 42° 18' 0.559"E and 42° 28' 58.317"E and elevations 2400 to 2950 m.a.s.l. As part of the Arabian shield in the western part of the Saudi Arabia, the topography is undulating and characterized by natural geological erosion and sedimentation phenomena (Mallick et al., 2014; Youssef et al., 2016). The dominate type of soil classes are loamy sand, sandy loam, and loam (Mallick, 2016). Alsouda receives the highest amount of annual rainfall in KSA by southwestern monsoons, with variable annual patterns (Vincent, 2008). Precipitation is mainly from March to June during spring and summer growing seasons (Wheater et al., 1989), and minimum and maximum temperature are 19.3 °C and 29.70 °C, respectively.
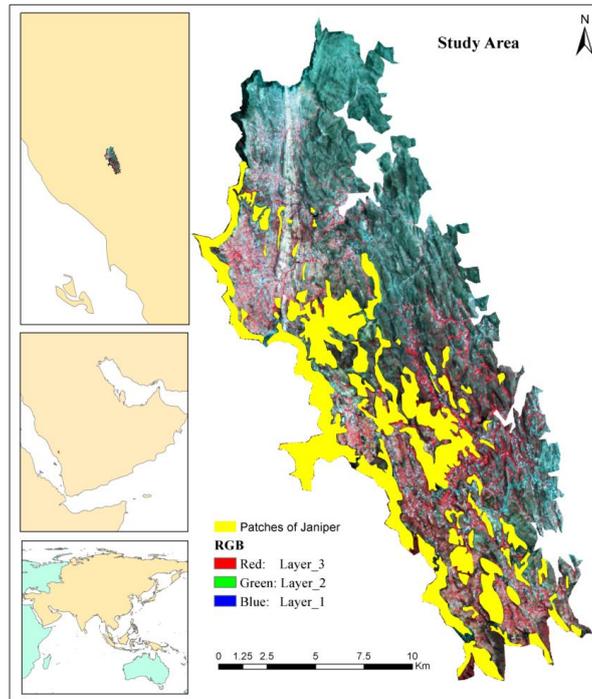
Figure 1. *Study area*

Data collection

Site-based surveys and remote sensing techniques were used as proven valuable tools to vegetation condition across a spatial and temporal range (Vogelmann et al., 2012).

Field survey

Ground surveys were conducted during October 2017 to March 2018 for the *J. procera* natural stands and plantations. According to an initial reconnaissance survey, the natural stands were divided into two aspects as east and west-facing slopes. Systematic random sampling was carried out along six transect lines in each aspect, with a total of 188 trees in the east slope and 201 trees in the west aspect. Tree dieback was evaluated at sampling point by the first author on ordinal scale from "1" healthy tree without obvious symptoms to "6" severely affected or dead tree (*Fig. 2*). Trees in the four plantation plots, numbered from 1 to 4, were measured for dieback symptoms, tree height and crown width. The nursery raised-seedlings were planted in 2006 with a spacing of about 3 m × 3 m. The number of measured trees 51, 73, 33 and 54 in plots 1, 2,3 and 5, respectively.

Figure 2. *Ordinal scale of 1 to 6 (1= healthy, no signs of dieback and 6 = severe or dying)*

Meteorological data

Rainfall data was obtained from the meteorological station situated within the study area (Al-Sooda Station no. 00028, 18° 15' 08" N (latitude) and 42° 24' 15.7" E (longitude). Whereas temperature data, the meteorological station located towards the 20 km of south-west. (Abha Station no. 41112, 18° 14' 25" N (latitude) and 42° 39' 11" E (longitude). The data related to the rainfall and temperature were operated and maintained by Ministry of Environment, Water and Agriculture and Presidency of Meteorology and Environment (PME), Saudi Arabia respectively. The elevation of both meteorological stations is 2585 and 2125 m from the m.s.l. respectively. The rainfall dataset analysed for the period 1965–2017, whereas temperature datasets for 1978-2017.

Remote sensing data processing

Satellite datasets of LANDSAT TM and LANDSAT-8 level-1TP (Level 1TP product contains systematically, radiometrically, geometrically, and topographically corrected using GCPs) over Aseer region were used for the preparation of the Normalized Difference Vegetation Index (NDVI) and Land use and land cover (LULC) maps. Digital number (DN) data converted to at-sensor radiance for LANDSAT data (https://landsat.usgs.gov/landsat-8-l8-data-users-handbook). ENVI-FLASSH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) an atmospheric correction module was used to retrieve spectral reflectance.

Conversion of DNs to physical units

At-sensor radiances measured at a wavelength spectrum which captures the image in DNs values, which have no unit and any physical implication; therefore, it is essential to coverts to radiance and reflectance.

OLI and TIRS at sensor spectral radiance

Satellite images were processed in units of absolute radiance using 32-bit floating-point calculations and the values were converted to 16-bit integer values. It was then converted to spectral radiance using the radiance scaling factors provided in the metadata file of LANDSAT-8 (*Eq. 1*):

$$L_\lambda = M_L * Q_{cal} + A_L \qquad \text{(Eq.1)}$$

where:

L_λ = Spectral radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)

M_L = Radiance multiplicative factor for the band (RADIANCE_MULT_BAND_n from the metadata).

A_L = Radiance additive factor for the band (RADIANCE_ADD_BAND_n from the metadata).

Q_{cal} = Pixel value in DN

Atmospheric correction

ENVI-FLASSH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) an atmospheric correction module was used to retrieve spectral reflectance. The

standard atmospheric (tropical atmosphere) and the geometric parameters (such as aerosol, CO_2, azimuth, zenith angle, square slit, etc.) were calculated using the FLAASH module (Detail could be found in the weblink). The atmospheric parameters (such as water vapor and Aerosol Optical Depth (AOD)) procured from the AERONET (AErosol RObotic NETwork) and incorporated into the FLAASH module.

Normalized difference vegetation index (NDVI)

NDVI is one of the band ratios that are highly correlated with vegetation parameters such as green leaf biomass and green leaf area. It quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). NDVI values ranges from -1 to +1. As shown below, NDVI uses the NIR and red channels in its formula:

$$NDVI = (Infrared - Red)/(Infrared + Red)$$

Moreover, it reduces variation due to surface topography and compensates for variation in radiance as a function of sun elevation for different parts of the scene, which is highly valuable in regional studies. To demonstrate the utility of Landsat data for monitoring vegetation status at the regional scale, random temporal plots are selected and analyzed for the NDVI values. The maximum NDVI is calculated to determine the index of greenness of the vegetation at the time of peak growth season. It is calculated to represent the maximum foliage cover in the study period. Overall, NDVI is a standardized way to measure healthy vegetation, where higher NDVI values indicate healthier vegetation.

Table 1 shows the satellite data acquisition and its related information. The NDVI data were converted into monthly values using the maximum value composite method to reduce cloud disturbance and increase the overall quality of the dataset (Fensholt and Proud, 2012).

Statistical analysis

Trends of annual rainfall and temperature series data were analyzed using Mann-Kendall trend test, and Mann-Whitney U test was used for the dieback ordinal data. Differences among the four plantation plots were analyzed using one-way analysis of variance procedure.

Table 1. *Characteristics of satellite data used in the study*

Satellite/sensor	Date of acquisition	Path/row	Spatial resolution	Information extracted
Landsat TM	1988-06-12	167/47	30 m (Band3 and Band4)	NDVI
Landsat TM	1993-04-07; 1993-06-26	167/47	30 m (Band3 and Band4)	NDVI
Landsat TM	1998-03-20; 1998-04-21; 1998-05-07; 1998-06-08;	167/47	30 m (Band3 and Band4)	NDVI
Landsat TM	2000-03-09; 2000-04-10; 2000-04-26; 2000-05-28; 2000-06-13	167/47	30 m (Band3 and Band4)	NDVI
Landsat-8	2016-03-05; 2016-03-21; 2016-04-06; 2016-04-22; 2016-05-08; 2016-05-24; 2016-06-09	167/47	30 m (Band4 and Band5)	NDVI

Results

Dieback of J. procera in natural stands

Most of the trees in the west and east facing slopes had shown dieback symptoms dieback with varying extent of severity (*Fig 3*). The effect of slope aspect was significant (Pr = 0.03), and the west-facing slopes were less affected than the east-facing slopes. The west-facing slopes had significantly fewer trees with severe dieback symptoms (4%), and more trees without obvious symptoms (17%) compared to the east facing slopes (8% and 11%; respectively) (*Fig. 3*).
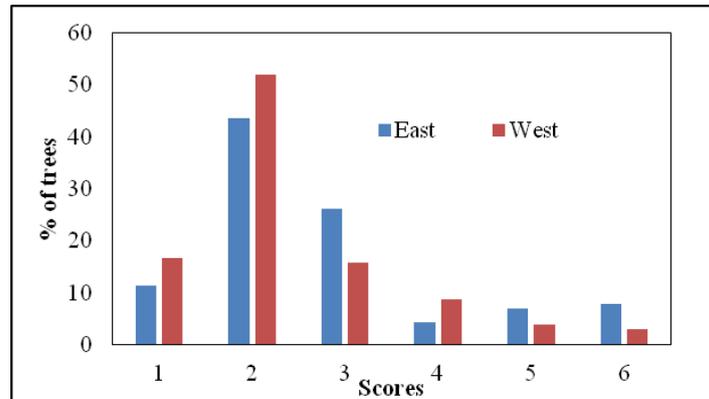

Figure 3. Percent of J. procera according dieback symptoms in the west and east facing slopes in Alsouda (1 = no symptoms to 6 severely affected dying or dead trees, significant difference between east and west facing slopes Pr = 0.03 using Mann-Whitney U test)

All of the trees with scores 2 to 5 and some of severely affected trees showed recovery signs and healthy lateral branches. The recovery signs include new lateral shoots, new needles and flowers at different stages (*Fig. 4*). Also, new regenerates were spotted in the well- stocked Juniper stands.

Figure 4. Recovering J. procera trees from dieback in Alsouda natural stands: A and B) new shoots and leaves C) sprouts and D) new regenerates

J. procera plantation plots

The 12- year's trees showed no signs of dieback symptoms in the four plantation plots in Alsouda (*Fig. 5*). Difference among the four plots was significant (Pr < 0.001) in height and crown diameter, where plot 2 had significantly shorter trees and smaller crown diameters than the other 3 plots plants (*Table 2*).

Table 2. *Tree height and crown width (cm) of 12-years J. procera plantations in Alsouda, Aseer region*

Plot number	Number of trees	Tree height and SE	Crown width and SE	Dieback symptoms
1	51	254 cm ± 9.5 A	191 cm ± 6.9 A	No symptoms
2	73	193 cm ± 7.6 B	153 cm ± 6.6 B	No symptoms
3	33	234 cm ± 12.3 A	173 cm ± 8.8 A	No symptoms
4	97	246 cm ± 8.5 A	180 cm ± 6.7 A	No symptoms

Figure 5. *Row of planted J. procera from nursery raised seedling in 2006, Alsouda National Park, Aseer Region*

Meteorological data

Total annual rainfall was variable among the years from 1965 to 2017, and the trend was not significant (*Fig. 6a*). However, maximum, minimum, and annual temperature showed increasing trend (Pr < 0.01) during the period of 1978 to 2017 (*Fig. 6b*).
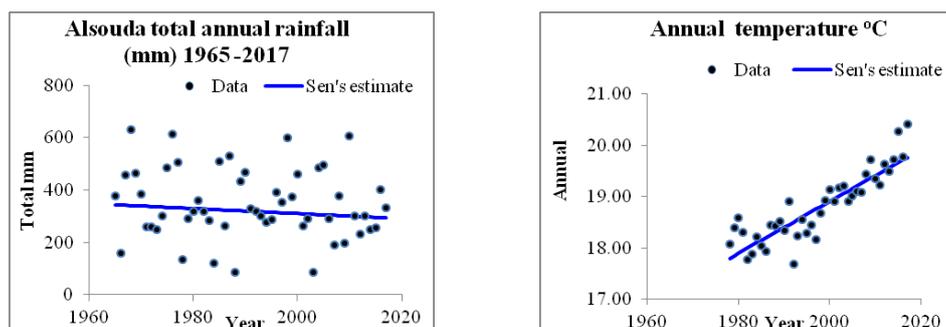

Figure 6. *A) Alsouda annual amount of rainfall during 1965 to 2017 (Pr > 0.05), and B) Abha annual average temperature during 1978 to 2017 (highly significant increasing trend)*

NDVI results

Figures 7 and *8* illustrate an increasing of NDVI values from 1988 to 2016, with a significant drop in 2000 that witnessed drier rainy season. The pattern of NDVI class distribution showed greener narrow western strips *J. procera* (NDVI > 0.51) that extend from south to north with gradual decrease in the NDVI values from west to east. Dissecting the area according to aspect illustrates clear and marked trend of higher values in the west facing slopes (*Tables 3* and *4*).
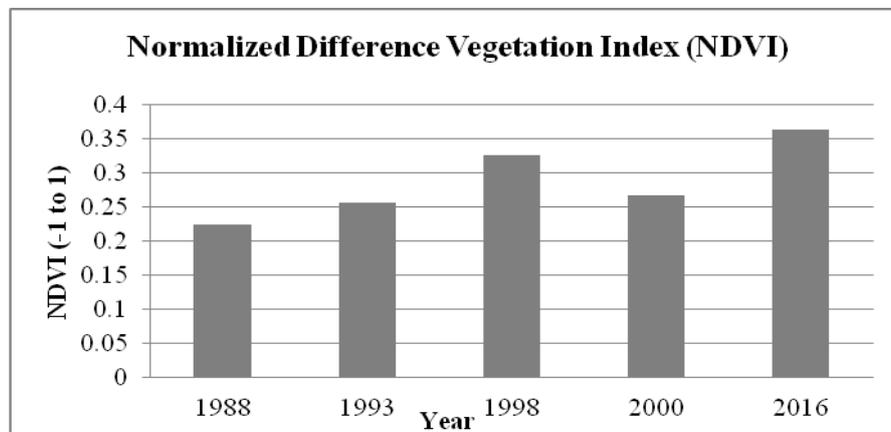

Figure 7. Mean NDVI value of the study area in 1988, 1993, 1988, 2000 and 2016

Discussion

J. procera is the most important indigenous tree species in the forest ecosystems of the southwestern highlands (above 2000 m.a.s.l) KSA for its ecological, economically and aesthetic values. It is an essential component in ecotourism attractions of Alsouda, Aseer Region, which is the most frequented touristic site during summer time (June to August) in KSA.

Tree health and stocking density are of vital importance, and dieback is the main problem facing forest ecosystems in KSA. El-Juhany (2015) estimated that 11.5% of the *J. procera* trees in Aseer were affected by dieback. The results of this study showed that many trees have dieback symptoms (84% and 89% in the West and east facing- aspect, respectively). However, the severely affected trees were 7% and 15% in the west and east facing slopes, respectively. Tree recovery signs were in most of the affected trees with new needled, branches, and sprouts. Unlike (Barth and Horst Strunk, 2000), natural regeneration was detected in the well-stocked and remote slopes, indicating the importance of nursing trees (Senbeta and Teketay, 2001). The NDVI pattern and classes confirmed recovering trends Juniper Natural stands.

The 12-year trees in the four plantation plots were free from dieback symptoms, and reached an average height of 2.0-2.5 m and an average crown diameter of 1.7-1.9 m. Tree height is less than the 7-year old plantation in the highlands of Ethiopia (Negash and Kagnew, 2013). This comparatively slow growth may be due low mean annual rainfall of Alsouda (350) compared to 1140 mm in Ethiopia highlands.

Topography and aspect of slopes have significant influences on the microclimate and soil moisture content. Måren et al. (2015) attributed differences in vegetation of *Pinus* and *Juniperus* species to soil characteristics between slope aspects in high altitude of semiarid environments.

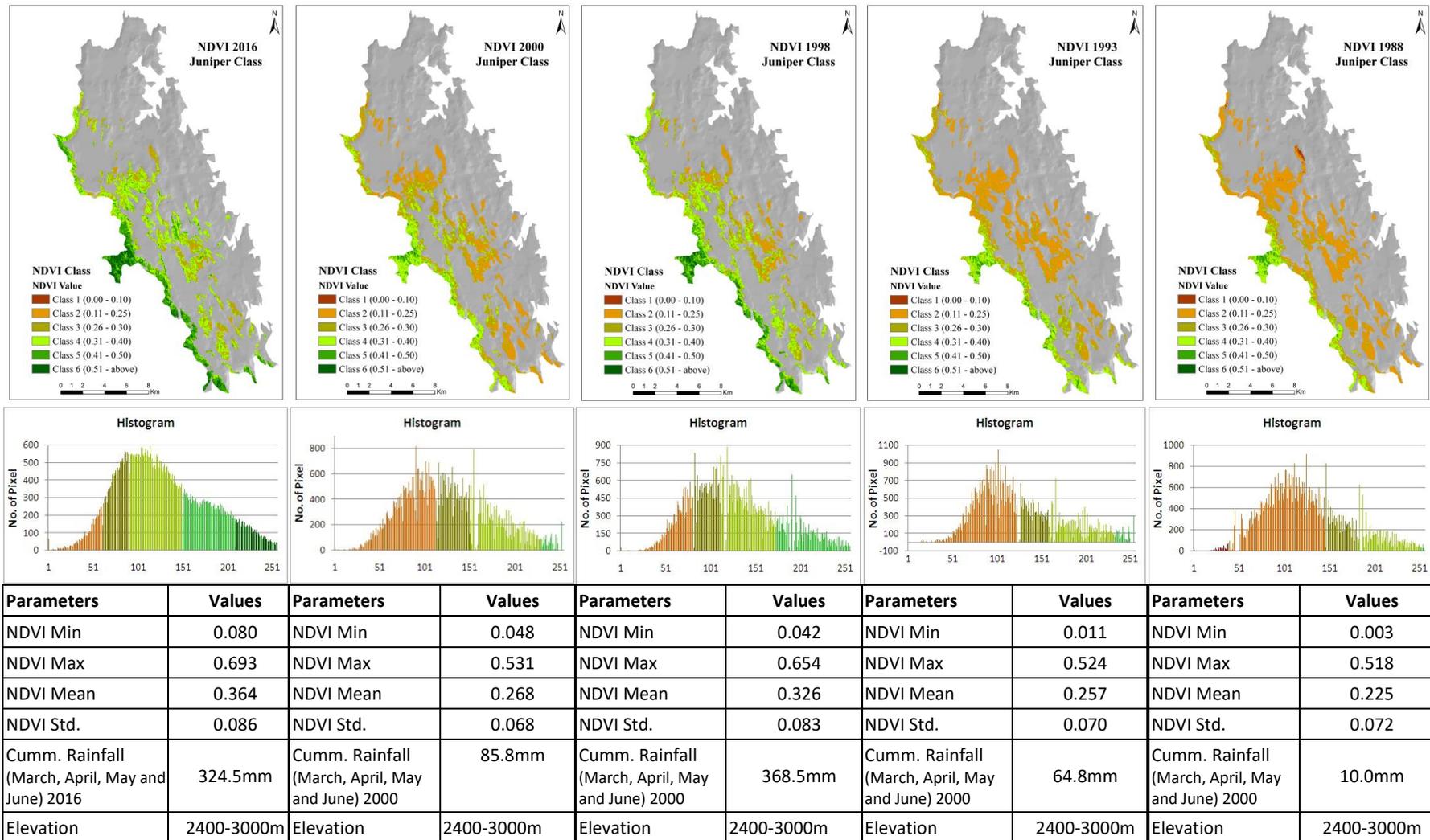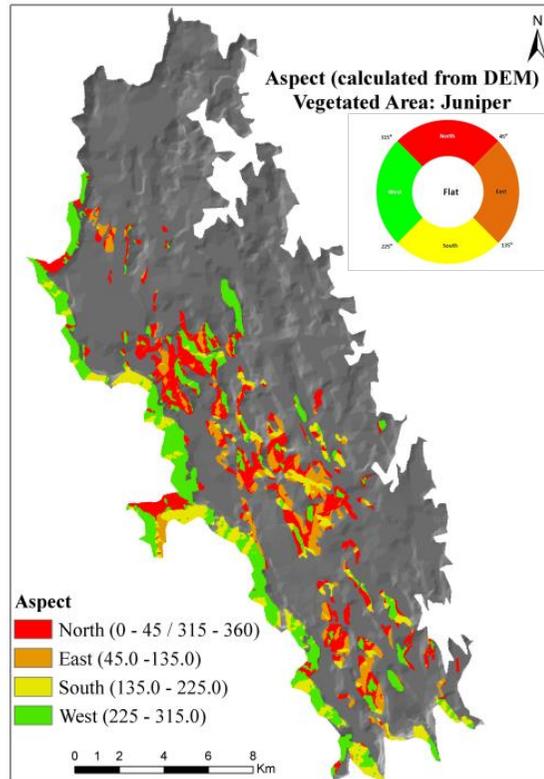| Parameters	Values	Parameters	Values	Parameters	Values	Parameters	Values	Parameters	Values
NDVI Min	0.080	NDVI Min	0.048	NDVI Min	0.042	NDVI Min	0.011	NDVI Min	0.003
NDVI Max	0.693	NDVI Max	0.531	NDVI Max	0.654	NDVI Max	0.524	NDVI Max	0.518
NDVI Mean	0.364	NDVI Mean	0.268	NDVI Mean	0.326	NDVI Mean	0.257	NDVI Mean	0.225
NDVI Std.	0.086	NDVI Std.	0.068	NDVI Std.	0.083	NDVI Std.	0.070	NDVI Std.	0.072
Cumm. Rainfall (March, April, May and June) 2016	324.5mm	Cumm. Rainfall (March, April, May and June) 2000	85.8mm	Cumm. Rainfall (March, April, May and June) 2000	368.5mm	Cumm. Rainfall (March, April, May and June) 2000	64.8mm	Cumm. Rainfall (March, April, May and June) 2000	10.0mm
Elevation	2400-3000m	Elevation	2400-3000m	Elevation	2400-3000m	Elevation	2400-3000m	Elevation	2400-3000m

Figure 8. Analysis of NDVI data (1988, 1993, 1998, 2000 and 2016)

Table 3. *Slope Aspect (calculated from DEM) Juniper Vegetated Area*
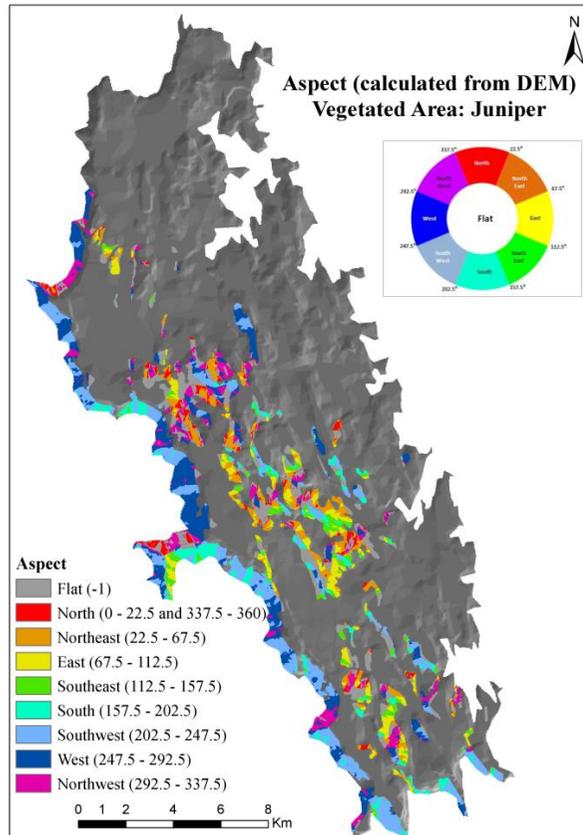
Year	Area	2016		2000		1998		1993		1988	
		Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.
Flat (-1)	11.28	0.336	0.072	0.258	0.060	0.302	0.070	0.235	0.054	0.216	0.064
North (0 - 22.5 and 337.5 - 360)	2.23	**0.376**	0.093	**0.291**	0.073	**0.345**	0.093	**0.275**	0.072	**0.245**	0.090
Northeast (22.5 - 67.5)	5.53	**0.328**	0.061	**0.255**	0.049	**0.299**	0.059	**0.229**	0.045	**0.208**	0.047
East (67.5 - 112.5)	5.01	**0.331**	0.072	**0.251**	0.059	**0.300**	0.071	**0.242**	0.061	**0.214**	0.061
Southeast (112.5 - 157.5)	3.08	0.345	0.087	0.260	0.064	0.308	0.089	0.251	0.076	0.221	0.073
South (157.5 - 202.5)	4.51	0.369	0.092	0.268	0.067	0.333	0.091	0.260	0.081	0.233	0.074
Southwest (202.5 - 247.5)	12.19	**0.396**	0.087	**0.278**	0.066	**0.355**	0.089	**0.285**	0.076	**0.238**	0.070
West (247.5 - 292.5)	11.31	**0.388**	0.088	**0.286**	0.070	**0.347**	0.083	**0.266**	0.068	**0.241**	0.077
Northwest (292.5 - 337.5)	5.39	0.363	0.087	0.275	0.070	0.332	0.087	0.256	0.073	0.234	0.084

Table 4. *Slope Aspect (four side orientation) (calculated from DEM) Juniper Vegetated Area*

Year		2016		2000		1998		1993		1988	
	Area	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.	Mean NDVI	Std. Dev.
North ($0 - 45^0$ and $315 - 360^0$)	18.57	0.343	0.078	0.263	0.063	0.311	0.077	0.240	0.060	0.215	0.071
East ($45^0 - 135^0$)	9.57	0.331	0.071	0.254	0.058	0.300	0.070	0.239	0.059	0.213	0.059
South ($135^0 - 225^0$)	11.23	**0.381**	0.090	**0.271**	0.066	**0.339**	0.092	**0.271**	0.081	**0.233**	0.072
West ($225^0 - 315^0$)	21.15	**0.387**	0.089	**0.282**	0.069	**0.348**	0.085	**0.278**	0.071	**0.239**	0.075

In this study, the west-facing *J. procera* had low impact from dieback and had greener vegetation NDVI classes than the east-facing slopes. The west- facing slopes receive higher rainfall higher by the southwestern monsoons precipitation patterns in Alsouda (Vincent, 2008), and consequently higher soil moisture content than the east-facing slopes. Similarly, El-Atta et al. (2013) demonstrated significantly higher leaf water potential (Ψw), chlorophyll content, and net photosynthetic ability of *J. procera* trees under increased soil moisture content in Alsouda.

Conclusions

Extent and severity of dieback was quantified among *J. procera* natural stands in Alsouda, Aseer Region, which was first reported in the early 1980's. Most of the trees have shown symptoms of dieback (> 80%), however they were not seriously affected and showed recovery signs. The recovery signs include new shouts, leaves and flowering even within the severely affect trees. In addition, the new natural regeneration in the well- stocked slopes indicates the importance of tree nursing effect to enhance restoration of Juniper stands. The 12-years plantations showed no symptoms of dieback, but growth rate is relatively low as compared to plantation in other regions that have higher annual rainfall. The meteorological data showed variable rainfall pattern without significant trend over time, while temperature showed significant increasing trends. The effect of slope aspect was evident in the severity of dieback and greenness of the vegetation as detected by the NDVI data. The west facing slopes were higher in NDVI values (greener vegetation) than the east-facing slopes, which may be due to higher precipitation in the west – facing slopes by the south-western monsoons (Vincent, 2008). The tree recovery, new regeneration and absence of dieback in the plantation plots, in spite of the warming trend and variable rainfall, may indicate that climate change is not the prime cause for the dieback phenomenon in the south-western highlands of KSA. The results indicate the importance of annual rainfall in the general health and greenness of the trees. Further studies are needed to quantify differences in rainfall between east and west-facing slopes, and elucidate effect of nursing trees on enhancing natural regeneration of *J. procera.* It is recommended that the plantations efforts should continue, especially among trees within *natural* stands to benefit from the nursing effect.

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