ASSESSMENT OF INVASIVE PLANT SPECIES, *OPUNTIA* SPP. (PRICKLY PEAR) IN RAYDAH PROTECTED AREA, ASEER, SAUDI ARABIA

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Abstract. Raydah protected area in an important declared protected area in Aseer area, Kingdom of Saudi Arabia that is rich in biodiversity, and provides habitat for nine of the ten indigenous bird species in the kingdom. Invasive plant *Opuntia* spp. in Raydah could threaten the natural balance among the indigenous species and thereafter affect the biological components of the ecosystem. This study evaluates the prevalence of invasive species and vegetation cover trends in Raydah protected area to identify possible interventions to conserve and protect the protected area. The results provide important and necessary information for the conservation and management of the Raydah Area and the Aseer Area's south-western highlands. The study has demonstrated the potential of sentinel sensor for detection and mapping of invasive species such as *Opuntia* spp. with desirable accuracy. This encouraging result demonstrated the feasibility of developing a semi-automated process for mapping and analysing the distribution of *Opuntia* spp. and found better results compared to multispectral data with very high resolution. Assessment of the current situation of the *Opuntia* spp. in the protected area will provide scientific data base for future management plans to combat and control invasive plants and protect the protected area from their adverse effects.
Keywords: *ecosystem, biodiversity, Sarawat Mountains, Juniperus procera, Sentinel satellite data*

Introduction

Invasive plants pose significant threats to natural ecosystems (Gurevitch and Padilla, 2004), biodiversity (Gaertner et al., 2009), forests (Peerbhay et al., 2016), rangelands and agricultural productivity (Pimentel et al., 2005). In addition, invasive plants are known to reduce the abundance of native plant species (Gaertner et al., 2009), alter soil properties (Pejchar and Mooney, 2009), and homogenize the biodiversity of invaded landscapes (Joshi et al., 2004). Invasive species are the species, subspecies that occur outside their natural range and potential for dispersal, and include any part of those species that may survive and then reproduce (Turlings, 2000). The non-native species invasion process took place in three phases: arrival, establishment and spread.

The southwestern parts of the Kingdom of Saudi Arabia have witnessed negative impacts of invasive species on forest ecosystems over the past few decades. Among them, the *Opuntia* spp. is one of the most serious invasive plant species, colonizing large forest areas in the highlands of the Sarawat Mountains in the southwestern parts of the kingdom. It is rich in dense vegetation as part of the southwest mountain ecosystem of the Sarwat, and constitutes the highest density of vegetation and diversity in the kingdom. The Sarwat southwest mountains' main high altitude species include *Juniperus procera*, the main dominant species with a density of 95 percent at elevations of 2000-3000 m above sea level (Aref et al., 2013). It grows in lower elevations with other tree species, such as *Acacia* spp., *Oleaeuropaea* ssp. Africana (Mill.) P. Green. *Ziziphus spina christi* and *Tamarix aphylla* (El-Juhany and Aref, 2013). El-Juhany and

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Aref (2013) noted that the following species of tree were reported only in the Aseer region: *Dobera glabra, Adenium obesum, Mimusop slaurifolia, Ficussy comorus* and *Tamarindus indica.*

In the southwestern highlands, Thomas et al. (2016) reported many invasive species such as *Opuntia* spp. To evaluate changes in vegetation and the spread of invasive species, it is therefore important to evaluate the status in the Raydah protected area. Invasive species are usually introduced from their native range to new plant species, either intentionally (Surendra et al., 2013) or accidentally, expanding into natural areas and disrupting native plant communities. They are equipped to adapt to new habitats, and with reproductive capacity they can grow aggressively. In the absence of natural enemies, their ability to compete and grow vigorously enables them to expand aggressively. These alien species are usually introduced into an ecosystem through seeds in imported soil, traveller fruits, deliberate introduction of certain species for their products, services or values, dispersal of seeds by natural means, and disposal of waste or soil containing alien plant seeds. Invasive species may have been introduced through human interference in the southwestern highlands of the kingdom and expanded due to clearing vegetation of large areas for road expansion, grazing and felling and removal of endemic forest trees.

Invasive plant expansion Raydah may have catastrophic effects on the habitat of the protected area in terms of overgrowth and displacement of native plants, resulting in disruption of the natural balance of native plant communities. Possible major consequences could include:

- Altering the plant species density and extinction of some species.
- Reducing the genetic base of the endemic species (resulting from biotic and abiotic stresses).
- Impact the balance and composition of endemic plant species - dependent wildlife components.
- Biodiversity reduction can adversely affect wildlife and alter natural processes such as fire or intensity and water flow.

Assessment of the current situation in the Raydah protected area will indicate and reveal the gravity of the situation and indicate possible interventions to control the invasive species Many methods have been developed to control or eradicate invasive species dependent on: available resources, plant species and habitat, and spread severity. These methods include: chemical control of invasive species by systematic herbicides, biological control by imported enemies, mechanical control by machines and hand tools, physical control (hand pulling, water drainage, flooding, burning and shading), or a combination of these methods (Integrated Management). Accordingly, this study address the situation of the invasive species in Raydah, with the general aim of conserving Raydah protected area, as part of an important ecosystem in the southwestern highlands of the kingdom, from their danger and threats. The unique plant association that provides habitat for nine of the ten indigenous bird species of Saudi Arabia should be managed and protected from the aggressiveness of the alien species.

Remote sensing data of high resolution have received considerable attention for invasive species inventory. The multi-date satellite imagery facilitates the monitoring and identification of phenological changes. It may be useful to integrate satellite information with other attributes in GIS to predict the spread of invasive species. Remote sensing of invasive plants has only been successful if the invasive is in a riparian, grassland, desert environment, aquatic and wetland where the lack of a tree cover enables the sensors to see the invasive plant unhindered (Bradley and Mustard, 2006). Thus, hindered invasive poses a challenge. Many researchers used hyperspectral data to detect and map invasive species (Lawrence et al., 2004). A practical advantage of using hyperspectral imagery to map invasive species is its capability to determine relative or unmixed components, which can be particularly useful in determining the percentage of species coverage (Peerbhay et al., 2016; Peerbhay et al., 2015; Curatola Fernandez et al., 2013). As noted above, the success of alien invasion remote sensing depends on their unique spectral signatures being identified, facilitated by differences in biophysical and biochemical characteristics (Matongera et al., 2016). Numerous studies (e.g. Matongera et al., 2016; Peerbhay et al., 2016; Niphadkar and Nagendra, 2016; Rocchini et al., 2015; Bradley, 2014; Boyd and Foody, 2011; Joshi et al., 2004) have explored approaches to remote sensing to optimize AIP detection and mapping.

The study aims to evaluate the prevalence of invasive species and vegetation cover trends in Raydah protected area to identify possible interventions to conserve and protect the protected area. The results may provide important and necessary information for the conservation and management of the Raydah Area and the Aseer Area's southwestern highlands. The specific objectives of this study were: to evaluates the usefulness of Sentinel satellite dataset for *Opuntia* spp. detection and mapping with emphasis on automatic information extraction techniques, establishing a phenological trend for the extraction of understory invasive plant data from temporal Sentinel satellite data (i.e. *Opuntia* spp.), assessing the usefulness of Sentinel sensor for the detection and mapping of *Opuntia* spp.

Literature review

Invasive species are defined as those non-native species that threaten ecosystems, habitats and species (Convention on Biological Diversity, 2008). They have great impact and influence on of the global environmental change (Pysek and Richardson, 2010), seriously affecting ecosystem services that are important to human welfare (Branco et al., 2015; Hejda et al., 2009). Their threats to plant diversity was reported to increase in past decades (Pimentel et al., 2001), due to the increase in exchange of plant material, and consequently their genetic materials among countries (Van Wilgen et al., 2008). Their effect was ranked as second to human interferences in the cause of species endangerment and extinction (IUCN, 2011). The reported hazards include direct threats to human health, and loss or alteration of goods and services regarding fishery, farming, forestry, drinking water, hydrology, climate stabilization, pollination, culture and recreation (McNeely, 2005; Lovell et al., 2006). The invasive species affect and threaten biological diversity by reducing genetic variation and narrowing gene pools to the extinction of endemic species (Sax and Gaines, 2008). Consequently, costs associated with their impacts are very high worldwide.

The management of invasive alien species present a significant challenge for the conservation authorities. The main principles applied to managing invasive species may include: Prevention of invasive species from entering the ecosystem, regular monitoring and rapid response, eradication, and or containment if eradication is not realistic. Some control methods were suggested that range from chemical, biological, physical, manual and integrated management system. Berhanu and Tesfaye (2006) described the dilemma of *Prosopis* dilemma (an aggressive invasive species) and some controlling methods.

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Similarly, invasive species can affect plant diversity in the Kingdom, and reach reaches its woodlands, forests, grasslands, agriculture lands, islands and inhabited areas (Thomas et al., 2016). They may have significant impacts on ecosystems and agriculture areas by eliminating or displacing many native species, particularly the highlands. The prevailing warm climate and the humid areas can enhance their spread in the kingdom by accelerating rapid seedling growth compared to native populations as indicated by Griffith et al. (2014).

Thomas et al. (2016) stated that "Approximately 37 alien plants have been reported from various habitats of southwestern region, majority of which are associated with specific plant associations". They indicated that on the higher elevations (800 to 2700 m) the common exotics according to severity are: "*Opuntia* spp., *N. glauca, Argemone ochroleuca, T. minuta, Verbesina encolioides, Tridax procumbens, Lantana camara, Amaranthus spinosus, Xanthium spinosum, Cenchrus setigerus* and *Bidens aurea"*. Further on, they indicated that six species have increased their distribution range both in the lowlands and highlands, and are therefore considered most troublesome ones in Saudi Arabia. The stated species in a descending order of were "*P. juliflora (Leguminosae), O. dellenii (Cactaceae), N. glauca (Solanaceae), T. portulacastrum (Aizoaceae), O. ficus-indica (Cactaceae) and Argemone ochroleuca (Papaveraceae)*".

The entry of invasive species to the highlands of Aseer Area could be attributed to human interferences like clearance of native plants for roads, as mentioned by Kingston and Waldren (2003). This is evident in the presence of some exotics along road sides in the southwestern high ranges (Thomas, 2016). Also, the highlands of Aseer Area was subjected to overgrazing (Abulfatih et al., 1989) and felling of forest trees that could have contributed to spread of opportunistic invasive species. Economic costs from invasive species include direct costs through reduction of ecosystem productivity and management costs. Indirect costs can occur through reduction in services and revenues. The key to reduce the threats and costs of invasive species damage and management is by early detection and rapid response. Warrag et al., 2019 reported the status of dieback of *Juniperus procera* (African pencil cedar) in natural stands and plantation in Alsouda highlands Saudi Arabia that is near to the studied location. They stated that with time, the NDVI showed a growing trend of greenness, especially in high rainfall seasons. The slope aspect effect was evident in the vegetation's dieback severity and greenness as detected by NDVI data.

Material and methods

Study area and field survey

Raydah watershed area, in an important declared protected area in Aseer area, Kingdom of Saudi Arabia (*Fig. 1*). Among the other protected areas in the kingdom, it has unique plant association and diversity in the highlands of the Sarawat Mountains in the southwestern parts of the kingdom (Mallick, 2016). The studied area is located between latitude of 18°10'50.859"N and 18°13'2.58"N and longitude of 42°21'58.042"E and 42°24'56.197"E and elevations 1330 to 2827 m.a.s.l.

The main features of Raydah protected area is described in Saudi Wildlife Authority as follows:

- It covers an area of 12.17 km^2.

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- It protects dense stands of Juniper (*Juniperus procera)*.
- Its unique plant association provides habitat for nine of the ten indigenous bird species of Saudi Arabia.
- Also, the protected area attracts Caracal Lynx, and Arabian wolf.

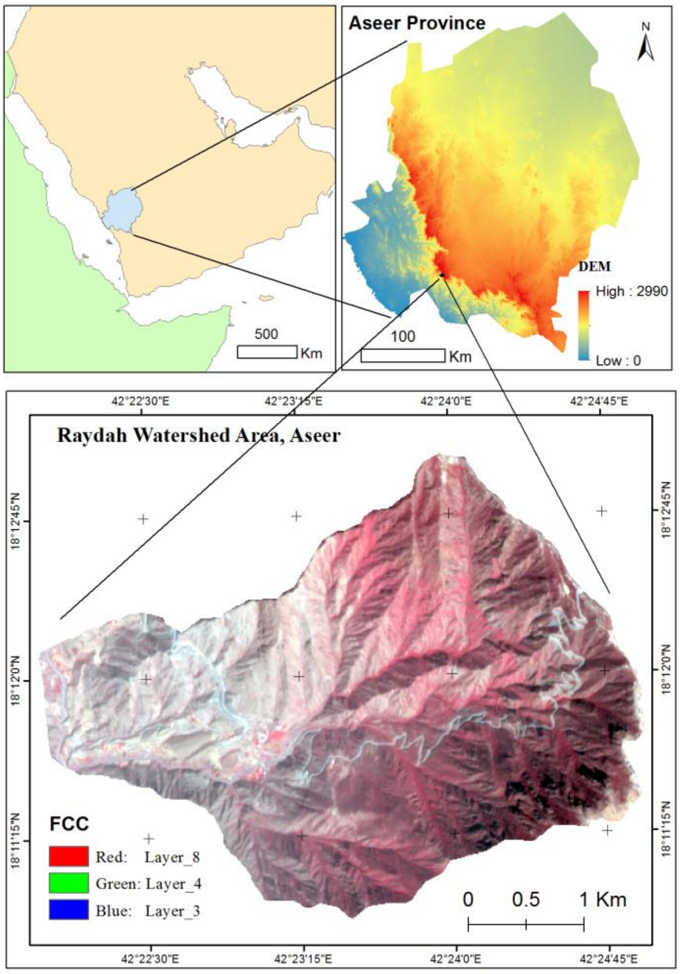

Figure 1. *Study area*

Sarawat Mountains in the south-western parts of the kingdom receives the highest southwestern monsoon annual rainfall in KSA, with variable annual patterns (Vincent, 2008). Precipitation is mainly from March to June during spring and summer growing seasons (Wheater et al., 1989; Mallick et al., 2014), and mean on the minimum of daily average temperature and mean on the maximum of daily average temperature are 19.3 °C and 29.70 °C, respectively. Rainfall data was obtained from the meteorological station situated 8 km northwest of the study area (Al-Sooda Station no. 00028, 18° 15' 08" N (latitude) and 42° 24' 15.7" E (longitude).

Ground surveys were conducted during 9th February 2019 to 23rd February 2019 for the understanding and distribution of vegetation classes and invasive plants. *Figure 2* shows the pictures of important location, in which Juniper procera were severely affected due to *Opuntia* spp. invasive species. The 50 × 50 m size of the sampling areas screened during the field survey.

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Figure 2. *Natural stands status of the Raydah protected area. Opuntia spp. spread and effected Juniperus procera (1-4); Juniperus procera (5-6) and Sidr tree (Ziziphus spina-christi) (7)*

Data processing

The Sentinel-2 level-1C satellite datasets (Level 1C Radiometric and geometric corrections including ortho-rectification and global reference system spatial registration with accuracy of sub-pixels) over the Raydah protected area were used to prepare the Normalized Difference Vegetation Index (NDVI) and Land Use and Land Cover (LULC) maps. The Sentinel-2 L1C product DNs are unsigned integer values of reflectance that that can be multiplied by 10,000 to achieve TOA reflectance values. DEM acquired from ALOS PALSAR Radiometrically Terrain corrected (RTC) DEM. From DEM, elevation (1330-2827 m, with the mean of 2070 m), slope angle (0° to 89.54° with the mean of 29.08°) have been calculated using ArcGIS software. For the generation of texture features, the gray level co-occurrence matrix (GLCM) method (Haralick, 1986) with 3 × 3 pixel window size was used. The NIR band of Sentinel data generated six texture features, mean, variance, contrast, homogeneity, dissimilarity and entropy as input images. The mean, contrast, homogeneity and variance characteristics displayed maximum information and were therefore taken as classification input images. For maximum likelihood classification, the common training sites selected from the sentinel image were used. For classification accuracy assessment, the classified images were field-checked at 152 locations.

Results and discussion

Temporary analysis of September, February and April Sentinel satellite dataset (*Fig. 3*) was conducted to determine a trend in vegetation phenology and to detect changes in the composition and structure of the community. *Juniperus procera* forest maintained significant foliage during the month of June, resulting in high reflectance from the upper canopy and hindering under-story reflection. From June to October, therefore, it was not possible to separate *Opuntia* spp. from the story. Therefore, for

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further analysis, Sentinel images were not used. The *Juniperus procera*, once established, individual trees can survive in hot and dry conditions, but in areas with low rainfall, trees are usually poor in shape and small in size. Where rainfall exceeds *Juniperus procera* dominated forests are gradually replaced by moister types of evergreen forests in which *Juniperus procera* becomes increasingly common. This region has the highest average rainfall in Saudi Arabia distributed over 4-6 months during the spring (Aug and Sept and summer growing seasons (March-June), while negligible rainfall during the rest of the year (Wheater et al., 1989; Mallick et al., 2018). Due to partial leaf shedding in the month of February, the under-story reflection also added to the overall reflection (appearing in light reddish tones on standard false color composite (FCC)).

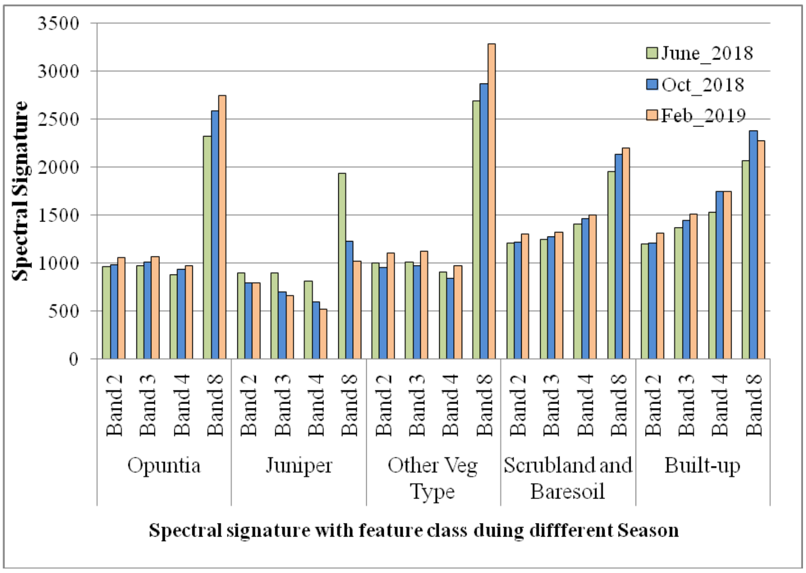

Figure 3. *Spectral reflectance of feature classes in June 2018, Oct. 2018 and Feb. 2019*

Although vegetation was visible in the February image under the story, it was not possible to delineate boundaries. Maximum reflection from vegetation occurred in the month of June - October due to full extent (moister types of evergreen forests) in evergreen tree (Sidr tree (*Ziziphus spina-christi*) and *Juniperus procera* forests (*Fig. 4*). This pattern in reflection showed that the data acquired between February were suitable for detecting *Opuntia* spp in the studied area. Every year, the best month varies due to annual temperature and precipitation differences. Statistically compared the Sentinel satellite data for various vegetation classes (*Table 1*). *Opuntia* spp's CV was slightly higher than *Juniperus procera*, indicating that discrimination against *Opentia* spp was possible to facilitate more accurate discrimination. *Table 2* shows the separability of different classes. In bands 3 and 8 of Sentinel data, the 2000 transformed divergence (TD) value showed very good separability of *Opuntia* spp from *Juniperus procera*. The 1997 and 1998 TD values between *Opuntia* spp and other tree (incl. Sidr tree) in bands 3 and 8 showed good separability, respectively. The texture classification was helpful in distinguishing the *Opuntia* spp from *Juniperus procera* successfully. In the vegetation classes, Band 8 of Sentinel data had the maximum variability compared to the other three bands (*Tables 1* and *2*). Band 8 of Sentinel data was therefore selected to analyze texture to extract *Opuntia* spp.

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Table 1. *Transformed values of divergence (TD) showing separability (higher values mean greater separability)*

Satellite data	**Bands**	**Average**	**Minimum**	**Class pairs**				
				1:2	**1:3**	**1:4**	**2:3**	**2:4**
Sentinel data	Band2	1997	1987	2000	1987	1992	2000	2000
	Band3	2000	1997	2000	1997	2000	2000	2000
	Band4	1876	1257	2000	1257	2000	2000	2000
	Band8	2000	1998	2000	1998	2000	2000	2000

1 *Opuntia*, 2 Juniper, 3 Other tree, 4 Bare soil

Table 2. *Spectral reflectance (DN values) statistical analysis from different feature classes*

Feature class	**Statistical parameters**	**Band1**	**Band2**	**Band3**	**Band4**
Opuntia spp.	Min	1006	1022	914	2304
	Max	1112	1127	1037	2701
	Mean	1060.13	1067.53	975.33	2547.80
	Std. dev	26.402	28.658	35.479	112.579
	CV	2.490	2.684	3.638	4.419
	Skewness	0.129	0.615	0.041	-0.722
	Kurtosis	0.237	-0.301	-0.553	-0.081
Juniperus procera	Min	774	628	491	953
	Max	821	696	561	1168
	Mean	797.14	657.79	520.79	1016.93
	Std. dev	11.446	13.195	16.621	51.270
	CV	1.394	1.896	2.963	4.390
	Skewness	0.161	0.324	0.775	1.624
	Kurtosis	-0.524	1.802	0.834	2.912
Other types (incl. Sidr tree)	Min	1083	1096	943	3124
	Max	1150	1148	1050	3564
	Mean	1109.88	1128.38	974.75	3290.75
	Std. dev	21.457	16.928	34.640	170.984
	CV	1.933	1.500	3.554	5.196
	Skewness	0.011	-0.639	-0.221	0.183
	Kurtosis	0.144	0.411	-0.355	-1.451
Scrubland and bare soil	Min	1247	1248	1397	2108
	Max	1358	1378	1610	2296
	Mean	1305.33	1325.13	1505.40	2200.80
	Std. dev	29.978	35.341	58.261	66.520
	CV	2.297	2.667	3.870	3.023
	Skewness	0.805	-0.897	1.680	1.061
	Kurtosis	0.552	0.624	3.207	-0.467
Built-up	Min	1219	1429	1665	2148
	Max	1410	1572	1796	2342
	Mean	1311.33	1509.00	1750.33	2273.00
	Std. dev	95.657	73.000	73.962	108.448
	CV	7.295	4.838	4.226	4.771
	Skewness	0.297	-0.991	-1.719	-1.704
	Kurtosis	1.023	-1.866	-3.309	4.911

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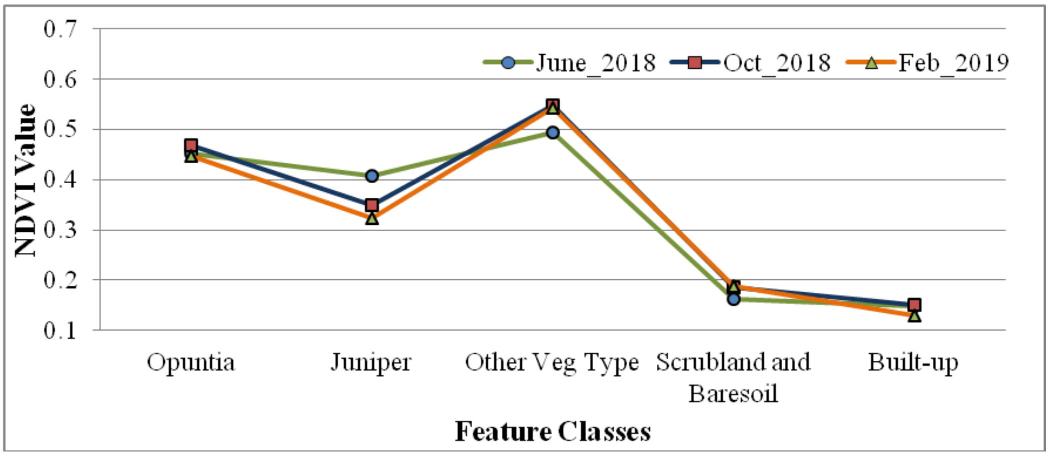

Figure 4. *NDVI value of different feature class over different period*

Taking into account the objectives, Sentinel satellite dataset were used to prepare the feature class map for the study area, i.e. built-up, exposed rocks, scrublands, *Juniperus procera*, *Opuntia* spp. and other tree (incl. Sidr tree). The total area of each category of feature class and percentage was calculated and presented in table. *Figure 5* shows the feature class type and the built - up area that also includes the road network lined from east to west direction and the building is mainly located in the western part of the study area towards the low land area. The *Juniperus procera* (45%) was the most dominant class in 2019, followed by scrublands (30.62%), exposed rocky area (12.66%) and *Opuntia* spp. (9.33%) shown in *Table 3*. Accuracy assessment was also evaluated to study the performance of the Sentinel sensor in feature class detection (specifically *Juniperus procera* and *Opuntia* spp.) for the classified output (*Table 4*).

Table 3. *Area (ha) of feature class estimated from the output of Sentinel sensors*

Sl. No	Feature class	Area in ha	Percent %
1	Built-up	17.70	1.45
2	Exposed rocks	154.93	12.66
3	Scrublands	374.61	30.62
4	*Juniperus procera*	550.54	45.00
5	*Opuntia* spp.	114.13	9.33
6	Other tree (Incl. Sidr)	11.53	0.94
Total area		1223.44	100.00

Table 4. *The producer's and user's accuracies*

Sl. No	Feature class	Producer's accuracy	User's accuracy
1	Built-up	76.52	92.85
2	Exposed rocks	93.15	94.61
3	Scrublands	88.90	92.47
4	*Juniperus procera*	96.14	94.82
5	*Opuntia* spp.	94.69	95.72
6	Other tree (incl. Sidr)	87.65	91.02

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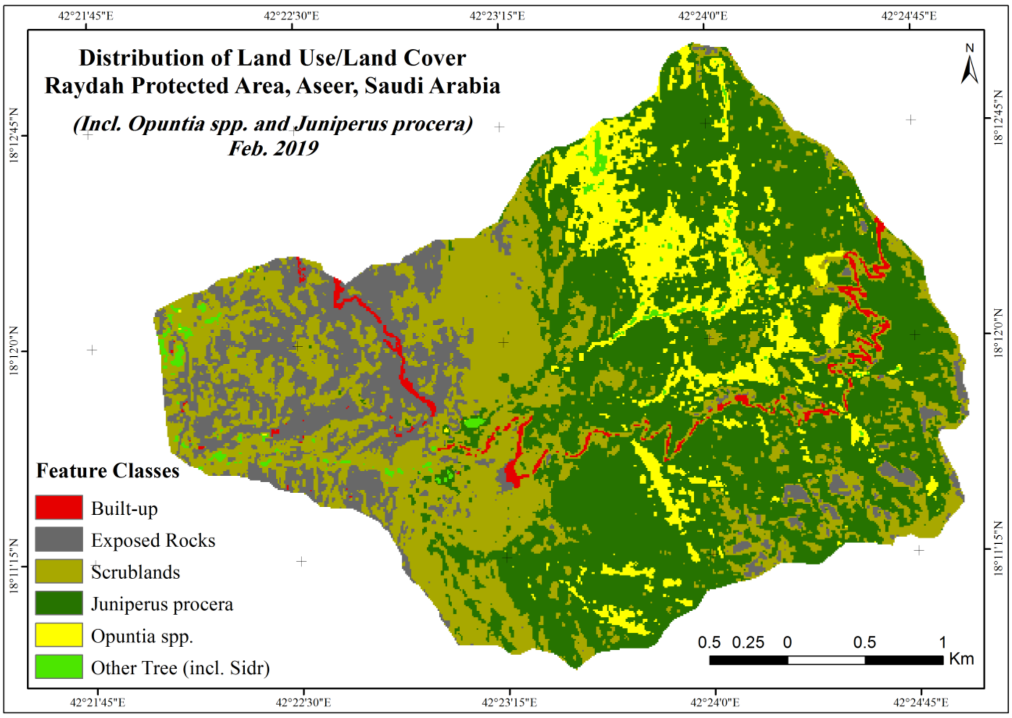

Figure 5. *Distribution of land use/land cover in Raydah protected area, Saudi Arabia*

The relationship between feature class and topography was analyzed using DEM. Figure shows the results of analysis of feature class in 2019 according to elevation (height). According to *Figure 6*, *Juniperus procera* are mostly located in regions with 1951-2827 m of height (Friis, 2009; Negash, 2010). It found as the dominant species in Raydah protected montane vegetation or mixed with other evergreen forests such as Sidr tree (*Ziziphus spina-christi*). The *Opuntia* spp. Mostly located in the regions with 1951-2550 m of height. Similarly, scrubland areas, mainly in regions with height of 1330-1950 m. This may be due to soil depth, week geology, and denuded high slope. With increasing altitude, the rock exposed class decreases.

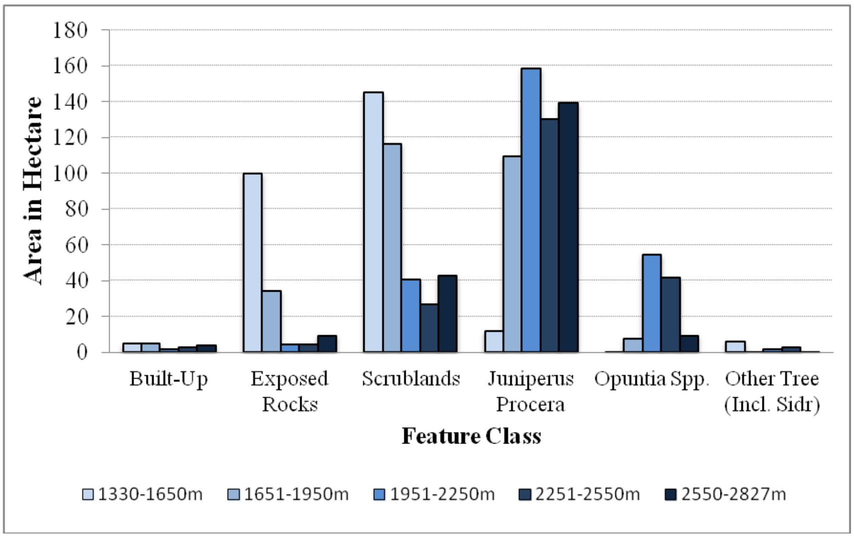

Figure 6. *Feature class according to elevation range*

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The gradient of the slope influences the feature classes distribution in studied area. *Table 5* shows the statistical analysis of slope analysis with feature class at the particular elevation range. The Juniper procera having large variation of slope gradient (ranged approx. 80°) between 1951 and 2827 m of elevation range. Whereas in *Opuntia* spp. It is found that the variation of slope gradient is low (ranged approx. 48°) between 1951 and 2550 m of elevation range. This finding shows that the growth and expansion of *Opuntia* spp. maximum at the moderate slope gradient (*Fig. 7*). It will be noted that the amount of moisture (water) intake tends to slightly decrease with slope increase. On the more gentle slopes, especially the 1.15° slope or less, the largest intake of water was found. That the degree of slope affects the infiltration. Therefore, it can be concluded that the slope factor influences and accelerates the growth and expansion of *Opuntia* spp. in the studied area.

Table 5. *Statistics of feature class according to topography and slope*

	Statistical parameters	**BLT**	**EX**	**SCR**	**Jun. Pro**	**Op. Sp**	**OT**	**Total area**
Class-I Height 1330-1650 m	Area in Ha	4.80	99.88	145.28	11.77	0.23	5.86	267.81
	Min Slope	2.29	1.01	1.09	0.88	7.30	1.15	
	Max Slope	46.14	89.11	89.11	42.49	19.53	38.33	
	Mean Slope	22.13	21.28	21.84	21.1	14.28	14.03	
Class-II Height 1651-1950 m	Area in Ha	4.89	34.5	116.72	109.52	7.44	0.83	273.89
	Min Slope	1.15	2.56	1.81	2.29	9.69	16.39	
	Max Slope	41.54	88.35	67.67	69.25	39.65	35.25	
	Mean Slope	26.77	28.7	30.37	28.57	25.51	23.07	
Class-III Height 1951-2250 m	Area in Ha	1.56	4.39	40.91	158.61	54.64	1.81	261.92
	Min Slope	10.88	11.23	4.13	0.81	7.64	13.34	
	Max Slope	44.16	46.71	89.40	89.42	54.65	50.09	
	Mean Slope	28.64	30.4	33.8	31.89	32.17	30.02	
Class-IV Height 2251-2550m	Area in Ha	2.58	4.59	26.59	130.27	41.59	2.61	208.23
	Min Slope	18.08	17.30	10.89	3.34	9.66	20.24	
	Max Slope	48.24	89.49	89.49	89.48	58.33	46.13	
	Mean Slope	31.71	41.34	35.52	34.24	34.66	32.19	
Class-V Height 2551-2827 m	Area in Ha	3.84	9.39	42.86	139.34	9.42	0.28	205.14
	Min Slope	2.29	0.21	0.94	0.81	5.11	21.04	
	Max Slope	40.15	89.49	89.55	89.54	88.53	44.01	
	Mean Slope	28.05	30.04	25.57	30.84	26.42	30.77	
Total area in hectare								1217.00

BLT = Built-Up; EX = Exposed Rocks; SCR = Scrublands; Jun. Pro = *Juniperus Procera*; Op. Sp = *Opuntia* spp; OT = Other Tree (Incl. Sidr)

Over the past few decades, the southwest part of the Kingdom of Saudi Arabia has experienced negative impacts of invasive species on forest ecosystems, the *Opuntia* spp. among them. It is one of the most severe invasive plant species, colonizing large forest areas in the Sarawat Mountains highlands in the southwestern parts of the Kingdom. Assessing the current situation in the protected area of Raydah will indicate the gravity of the situation and indicate possible interventions to control the invasive species.

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Remote sensing data of high resolution have received considerable attention for invasive species inventory. The image of the multi-date satellite, i.e. Sentinel dataset facilitates phenological change monitoring and identification. In order to predict invasive species spread, it may be useful to integrate satellite information with other attributes in GIS.

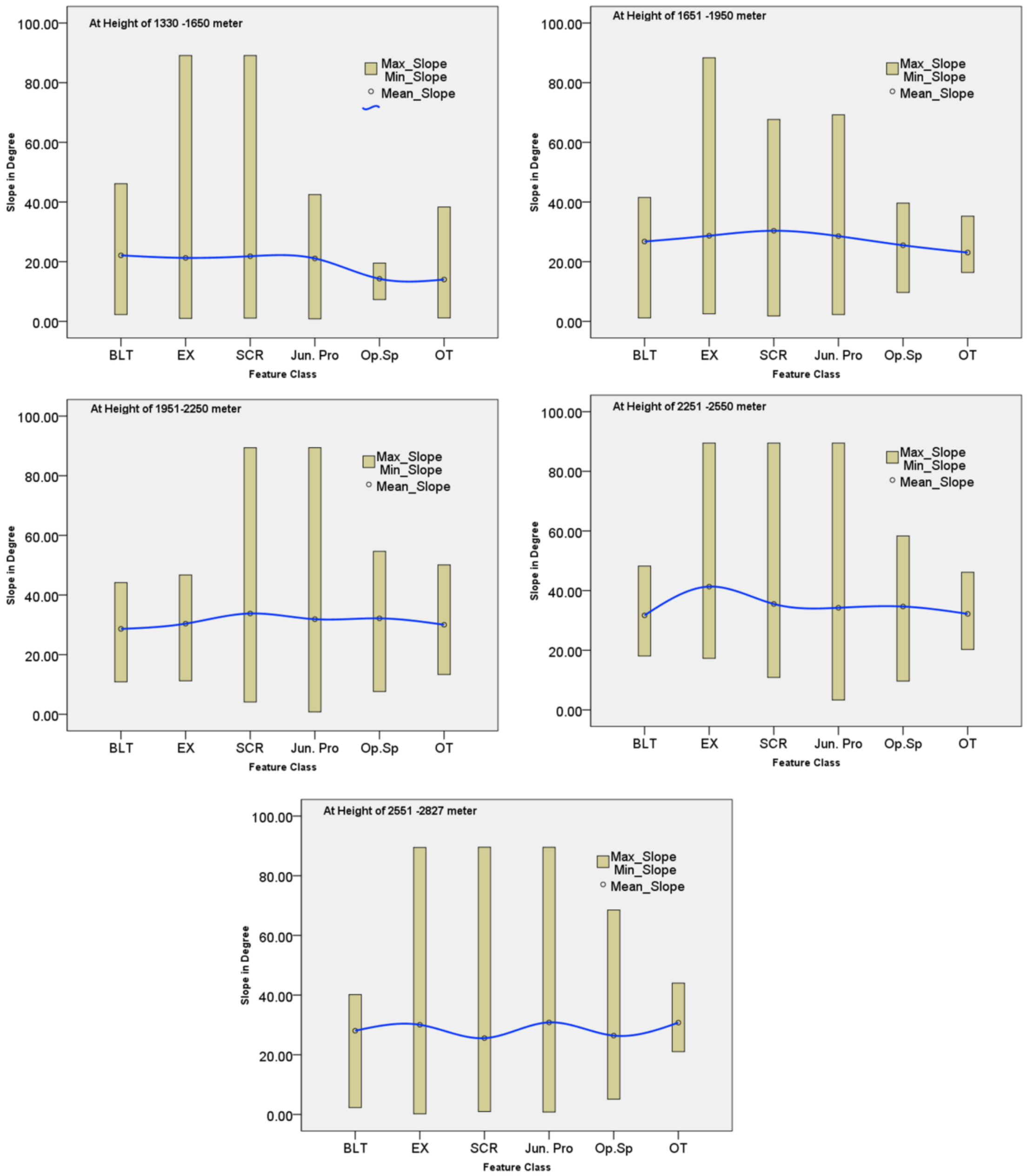

Figure 7. *Graphical representation of slope in degree (min, max and mean) at different feature classes*

The results of this study showed that *Juniperus procera* (45%) was the most dominant class in 2019, followed by scrublands (30.62%), exposed rocky area (12.66%) and *Opuntia* spp. (9.33%). The relationship between feature class and topography was

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also analyzed using DEM. *Juniperus procera* are mostly located in regions with 1951-2827 m of height. It found as the dominant species in Raydah protected montane vegetation or mixed with other evergreen forests such as Sidr tree (*Ziziphus spina-christi*). The *Opuntia* spp. mostly located in the regions with 1951-2550 m of height. Similarly, scrubland areas, mainly in regions with height of 1330-1950 m. This may be due to soil depth, week geology, and denuded high slope. With increasing altitude, the rock exposed class decreases. The gradient of the slope influences the feature classes' distribution in studied area. *Juniper procera* has large variation of slope gradient (ranged approx. 80°) between 1951 and 2827 m of elevation range. Whereas in *Opuntia* spp. It is found that the variation of slope gradient is low (ranged approx. 48°) between 1951 and 2550 m of elevation range. It can be concluded that the slope factor influences and accelerates the growth and expansion of *Opuntia* spp. in the studied area.

Conclusions

Raydah protected area in an important declared protected area in Aseer area - Kingdom of Saudi Arabia that is rich in biodiversity, and provides habitat for nine of the ten indigenous bird species in the kingdom. Invasive plant species in Raydah could threaten the natural balance among the indigenous species and thereafter affect the biological components of the ecosystem. Assessment of the current situation of the invasive plants in the protected area will provide scientific data base for future management plans to combat and control invasive plants and protect the protected area from their adverse effects.

In this study, the temporal data (i.e. June, Oct and February months) were used to establish a trend in vegetation phenology and changes in species community composition and canopy structures. Comparison of the data from these three months revealed that February was adequate month to detect under story *Opuntia* spp. Maximum reflection from vegetation occurred in the month of June - October due to full extent (moister types of evergreen forests) in evergreen tree (Sidr tree (*Ziziphus spina-christi*) and *Juniperus procera* forests where as during February is shows less reflectance over Sidr tree (*Ziziphus spina-christi*) and *Juniperus procera* forests. This pattern in reflection showed that the data acquired between February were suitable for detecting *Opuntia* spp in the studied area. Every year, the best month varies due to annual temperature and precipitation differences. *Opuntia* spp's CV was slightly higher than Juniperus procera, indicating that discrimination against *Opuntia* spp was possible to facilitate more accurate discrimination. The study demonstrated the potential of sentinel sensor for invasive species such as *Opuntia* spp to be detected and mapped with desirable accuracy. This encouraging result demonstrated the feasibility of developing a semi - automated process for mapping and analysing the distribution of *Opuntia* spp in forest areas and found better results compared to multispectral data with very high resolution.

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