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Using high spatial resolution satellite imagery to evaluate the impact of mesquite invasion on desert rangeland at southeastern Egypt

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Key words: Shrub encroachment, Mesquite, WorldView-1, Halaib, Image segmentation, Object-Based Image Analysis.

Abstract

Shalateen–Abou-Ramad-Halaib triangle is located in the south eastern corner of Egypt. It occupies approximately 18000km^2 and has a vital and strategic importance to Egypt. Recently, Mesquite (*Prosopis juliflora*) invasion was reported as a new constrain that negatively impact Halaib rangeland management. The recent development of high spatial resolution satellite imagery in the last decade has opened new opportunities for remote sensing applications in rangeland management. The objectives of this research were to use WorldView-1 satellite imagery to map mesquite distribution and identify areas where mesquite is clearly the dominate species within the study area in the Halaib desert rangelands, and to evaluate the relationship between mesquite canopy cover and perennial grass cover and forb forage production at the Egyptian Southeastern desert rangelands. A WorldView-1 high resolution satellite image with ground resolution of 50cm at the panchromatic band for the study area in October, 2012 was acquired. Image segmentation and object-based classification in the software Cognition were conducted and used to map mesquite shrubs cover. Results indicate that increasing mesquite canopy cover was corresponding with decreasing understory vegetation cover. Under low mesquite cover, *Panicum turgidum*, the most important forage plant in Halaib region from stand point of high nutritive value and palatability, had the highest coverage (5.51%). However, areas with high mesquite cover were associated with lower *Panicum turgidum* coverage (2.48). Results showed that object-based image analysis of high resolution satellite image can provide useful way for detecting and mapping shrub encroachments on arid desert rangelands.

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Introduction

Efforts to increase the resilience of rangeland systems have arrived at a point where truly interdisciplinary efforts are required if the well-being of local communities, and the functioning of the ecosystems on which they depend, are to be improved substantially. Shalateen–Abou-Ramad-Halaib triangle is located in the south eastern corner of the Egyptian Eastern Desert. It occupies approximately 18000km^2 and has a vital and strategic importance to Egypt. Desert rangelands are important for food production and ecosystem services in southeastern Egypt. Rangeland retrogression with heavy grazing, shrub invasion and drought can occur most rapidly under desert rangelands compared to more mesic rangeland types. In addition, vegetation in desert ecosystems changes continuously and it is important to have reliable methods for monitoring the past and present vegetation status. Many researchers have considered mesquite encroachment a major threat to livestock production (Buffington and Herbel (1965), Gibbens *et al.* (1992), Gibbens *et al.* (2005), Fredrickson *et al* (2006). Shackleton *et al.* (2014) stated that mesquite is located in 129 countries around the world and many countries in the world where the mesquite is not registered yet have a suitable environment for mesquite growth. Based on ground survey studies from New Mexico, USA, honey mesquite canopy cover levels above 18–20% appear to negatively impact perennial grass production (Warren *et al.*, (1996), Moliner *et al.*, (2002), Khumalo (2006). In 1985, Mesquite (*Prosopis juliflora*) invasion was reported as a new constrain that negatively impact management of the Egyptian Southeastern Desert Rangeland. Although seed dispersal by livestock is considered to be a primary cause of mesquite encroachment in the region, several other factors including human movement, water movement during rainy season, commercial activities between Egypt and Sudan. Mesquite invasion can negatively impact grazing capacity, spatial livestock distribution, and forage production in Southeastern Desert rangelands.

Evaluation of the impact of shrub encroachment levels on rangeland vegetation using ground surveys is typically time consuming and expensive. Holechek *et al.* (2003) stated that a combined evaluation of precipitation, forage production, shrub cover, grazing intensity, and rangeland condition and trend are needed to develop sound management decisions. However, it is seldom possible to acquire all this information due to limitations of money, time, labor, and technology. Shrub encroachment has been a serious socio-economic challenge for rangeland management in several arid and arid areas of the world. High resolution satellite imageries could be used to accurately estimate the extent of shrub encroachment in rangelands. This technique has been commended as more efficient and less expensive method than the traditional field sampling and survey technique to monitor the vegetation of rangelands. Development of a geospatial model to evaluate effect of mesquite invasion in Egyptian Southeastern Desert ecosystems should increase vegetation monitoring precision because a large breadth of spatial variability could be accounted for. In addition, it would reduce rangeland inventory and monitoring costs.

Geospatial technologies have been widely used for mapping and monitoring rangeland vegetation. Traditional remote sensing data has been used for monitoring vegetation cover (Ramsey *et al.* 2004); establishing stocking rate (Hunt and Miyake 2006); characterizing grassland productivity (Reeves *et al.*, 2006); determining rangeland trend in terms of soil loss, decreased cover, and change vegetation composition (McGlynn and Okin 2006; Washington-Allen *et al.*, 2006). Estimation of rangeland biomass is another successful application of remote sensing data (Anderson *et al.* 1993; Roy and Ravan 1996; Zheng *et al.*, 2004; Tsutumi *et al.*, 2005). High temporal resolution Advanced Very High-Resolution Radiometer (AVHRR) images with conjunction with vegetation indices were used to distinguish shrubland, grassland, and mixed herbaceous and woody vegetation areas (Peters *et al.*, 1997).

The recent development of high spatial resolution satellite imagery in the last decade has opened new opportunities for remote sensing applications in rangeland management.

The exceptionally high spatial resolution data of these satellite images is a promising data source for mapping vegetation change. Many rangeland characteristics can be quantified accurately and precisely using high spatial resolution multispectral satellite imagery (Weber 2006). Studies are available that indicate IKONOS and QuickBird satellite imagery can be useful in distinguishing among woody plant species (Wang *et al.*, 2004); evaluating shrub encroachment (Laliberte *et al.*, 2004); differentiating rangeland vegetation cover types (Everitt *et al.*, 2006); analyzing arid rangeland vegetation (Laliberte *et al.* 2007); mapping woody plants (Everitt *et al.*, 2008); and evaluating honey mesquite shrub cover impact on forage production (Mohamed *et al.*, 2010). Using high resolution satellite images and change detection Mohamed *et al.* (2015) found that Mesquite cover increased from about 0.5% at 2002 to about 2 % at 2012 from the total classified study area at Halaib, Egypt, which represents about 20% of relative vegetation cover in the study area.

Therefore, our objectives were to use WorldView 1 satellite imagery to map mesquite distribution and identify areas where mesquite is clearly the dominate species within the study area in the Halaib desert rangelands and to evaluate the relationship between mesquite canopy cover and perennial grass cover and forb forage production at the Egyptian Southeastern desert rangelands.

Materials and methods

Study area description

The Eastern desert of Egypt is approximately 275000Km2 which represents more than one quarter of the total territorial area of Egypt. It is located between the Red Sea in the east and the Nile River in the west. Shalateen–Abou-Ramad-Halaib triangle is located in the south eastern corner of the Eastern desert which occupies approximately 18000km^2. The region has a vital and strategic importance to Egypt. It looks like a triangle with a bottom side of about 300Km parallel to 22° latitude (The Egyptian-Sudanese borders). The top point of the triangle is located at the Red Sea nearby the Shalateen well.

The triangle region is a mountainous desert with several valleys dissecting mountains. Rainfall sometimes starts from October up to March, but erratic. The area is, also, characterized by high mist and appeared as mist oases, particularly at Elba Mountain and its valleys. It is reflected on growing several plant communities.

There are three little towns in the triangle region. Halaib is one of the new rural, which has an important strategic situation. Abou-Ramad is a little port at the Red sea. Shalateen is considered the main trade center in the triangle region where the camel market is currently the main source of imported camels to Egypt.

World View Very high-resolution satellite image

Based on our ground survey, the study area was located with different mesquite canopy cover (Fig. 1). In this research, the most recent WorldView-1 very high satellite image with 50 cm ground resolution at the panchromatic band (DigitalGlobe Inc., Longmont, CO, USA) was purchased.

The image covers an area of 36km^2. The image was radiometrically and geometrically corrected and projected to the world geodetic survey 1984 (WGS 1984_Zone 37 N) prior to delivery.

Image Segmentation and Object Based Image Analysis

Multi-resolution image segmentation based on the Fractal Net Evolution Approach (FNEA), which is available in eCognition Developer 8.9 Software was used for image segmentation. Two level of image segmentation were used with different parameters i.e. scale, shape, and compactness parameters. Fig. (2) shows an example of WorldView-1 satellite image after performing image segmentation with scale parameter of 20 and 0.5 for shape and compactness.

The second step after image segmentation in the object-based image analysis is image classification, which can be conducting using various information sources and different approaches.

The four land cover classes were considered as the main land cover categories in the study area including mesquite shrubs, grass-mix vegetation, bright soil and building, and dark bare ground and roads. Object-based classification was applied to the segmented images in order to assign a class to each of the related objects. Both fuzzy membership functions and nearest neighbor classifier which are available in eCognition were used to assign class to segmented objects.

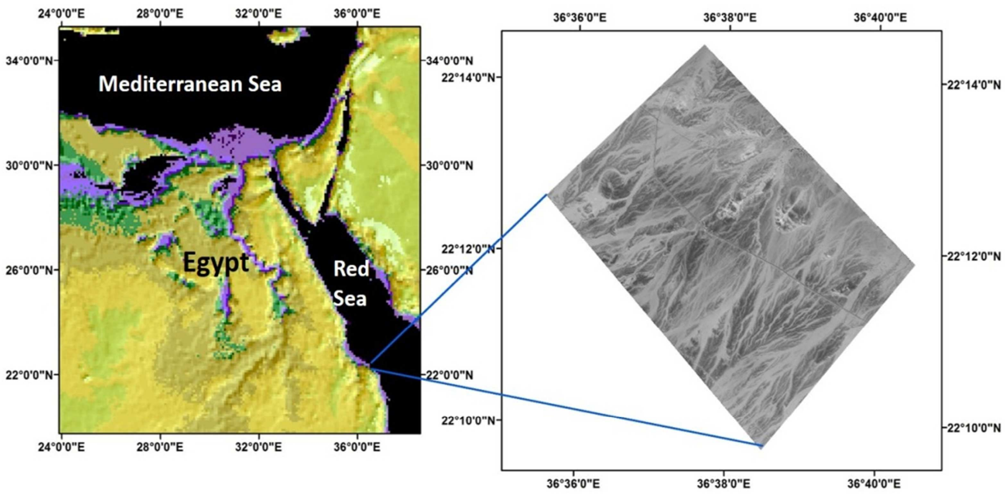

Fig. 1. Location of study area at Halaib region at Southeastern Egypt.

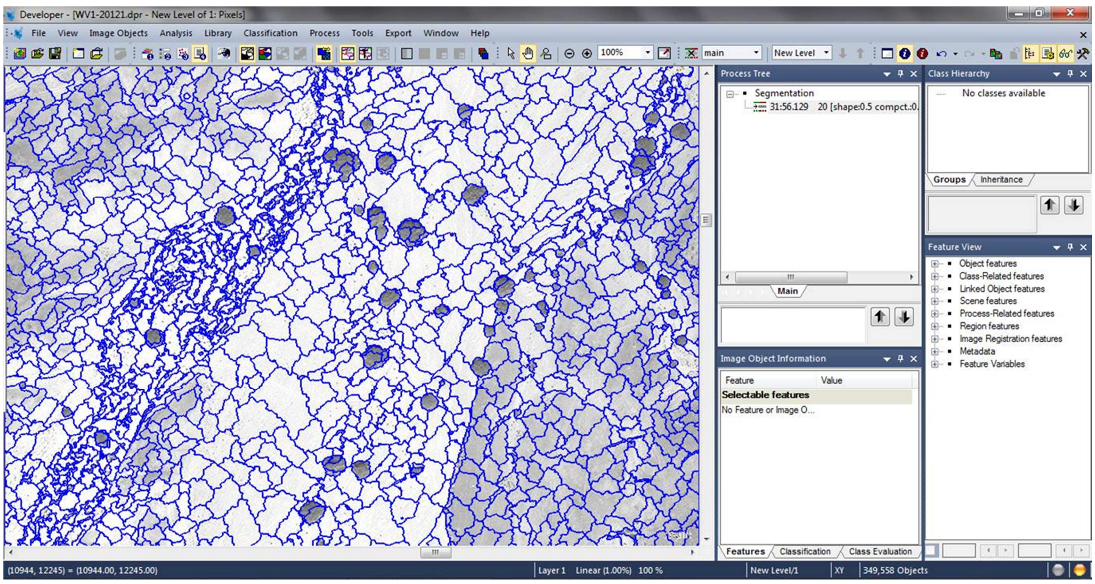

Fig. 2. An example of the first segmentation level was conducted in eCognition and used to identify mesquite shrubs at the study area.

Accuracy Assessment

To determine the accuracy of World View 1 image classification, ERDAS Imagine 10 software used to assign a minimum of 40 points per class from the classified maps of October 21, 2012 in a stratified random pattern. For the error matrix evaluation, the general method described by Jensen (2005) was used to locate a reference test unit and high accurate GPS was used to locate reference points. Accuracy assessment measurements estimated by ERDAS Imagine included; producer's accuracy (errors of omission); user's accuracy (errors of commission).

In addition, overall accuracy (the total number of correct points divided by all points in the entire matrix), and the Kappa Coefficient were calculated.

Evaluation of Mesquite impact on Desert Rangeland vegetation

Twenty different plots, at different mesquite canopy cover sites, each of 20x20m were used within the study area to study vegetation composition; cover percent and plant density were recorded and determined by using list and quadrates.

While transect 100m length ten times for determining plant abundance and frequency percentages. The following measurements were calculated, frequency, abundance, and plant cover as described by Hanson and Churchill (1961) and Mueller-Dombois and Ellenberg (1974). Plant species and families were fully identified to level and named according to Takholm (1974) and updated by Bouls (1995).

Results and discussion

Image Classification Accuracy

The very high resolution of World View-1 satellite imagery combined with the high power of image segmentation using eCognition resulted in most of mesquite shrubs were highly detected. Data regarding accuracy assessment are presented in Table 1.

Overall accuracy of 92.43% and Kappa Coefficient of 0.914 were achieved for Object-based image analysis. Laliberte *et al.* (2004) reported that about 87% of mesquite shrubs were detected and classified using object-based image analysis.

The highest values of user's and producer's accuracies of 94.12% and 96%, respectively were recorded for the bight soil and building class due to they have high brightens value and were easy to classified from other objects. Mesquite shrubs cover had user's and producer's accuracies of more than 90%.

Dark bare ground soil was very common on the study site and for some extents were mixed with mesquite shrubs in image classification as the image used was the only available image for the study area with panchromatic band only. Grass-mix vegetation was also classified with high level of accuracy.

Our finding regarding accuracy assessment values of classified very high-resolution satellite images are in accordance with Mohamed *et al.* (2011) and Kux and Souza (2012).

Table 1. Error matrix generated from classified map and reference data for October 21, 2012 World View 1 image of the study area at Halaib.

Classification data	Reference data					
	Mesquite shrubs	Grass-mix vegetation	Bright soil and Building	Dark bare ground and roads	Total	User's accuracy %
Mesquite shrubs	47	1	0	4	52	90.38
Grass-mix vegetation	0	53	2	2	57	92.98
Bright soil and Building	1	1	48	1	51	94.12
Dark bare ground and roads	3	1	0	41	45	91.11
Total	51	56	50	48	205	
Producer's accuracy %	92.16	94.64	96.00	85.42		

Overall accuracy = 92.43 %; Kappa coefficient = 0.914.

Land Cover Status

Analysis of classified map of the study area (Fig. 3) indicated that the study area was dominated by bright soil followed by dark bare ground soil and the represented about 64.44% and 25.79% from the study area, respectively.

Estimated cover percentages for grass-mix vegetation and mesquite shrubs were 8.05% and 1.72%, respectively. Even though mesquite shrub cover calculated from very high-resolution satellite image analysis for the study area indicated that mesquite cover relatively low compared with the total area, it represents more than 17% of the relative plant cover in the study area. In a desert rangeland at Southwestern United States, image analysis showed that mesquite cover increased from 0.9 in 1937 to 13.1% in 2003 (Laliberte *et al.*, 2004). Grass-mix vegetation cover was impacted negatively by increasing mesquite cover (Fig. 4).

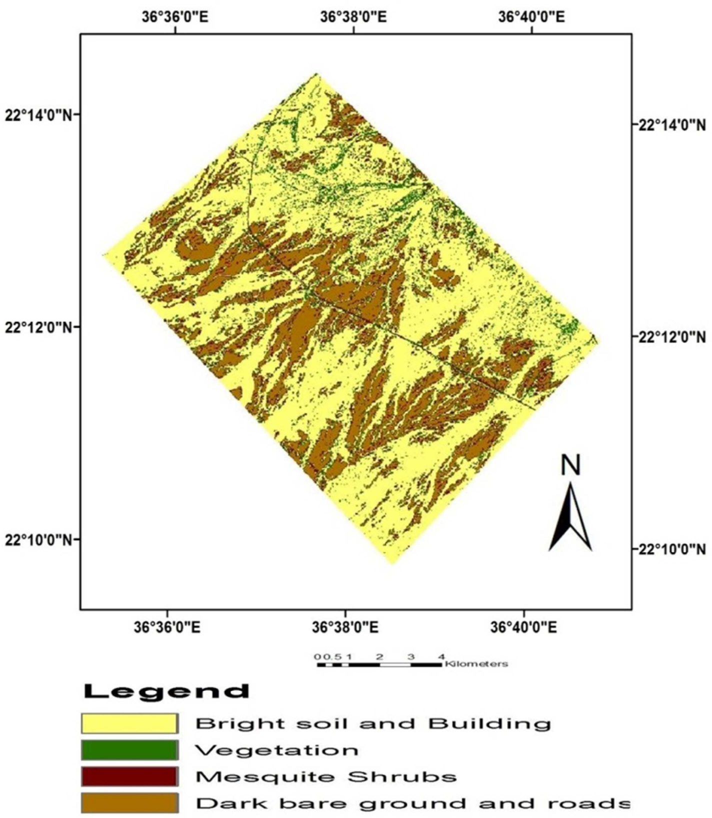

Fig. 3. Classified map of the study area (3600 ha) at Halaib, Southeastern Egypt produced from object-based image analysis of WorldView-1 very high resolution satellite image acquired at October 21, 2012.

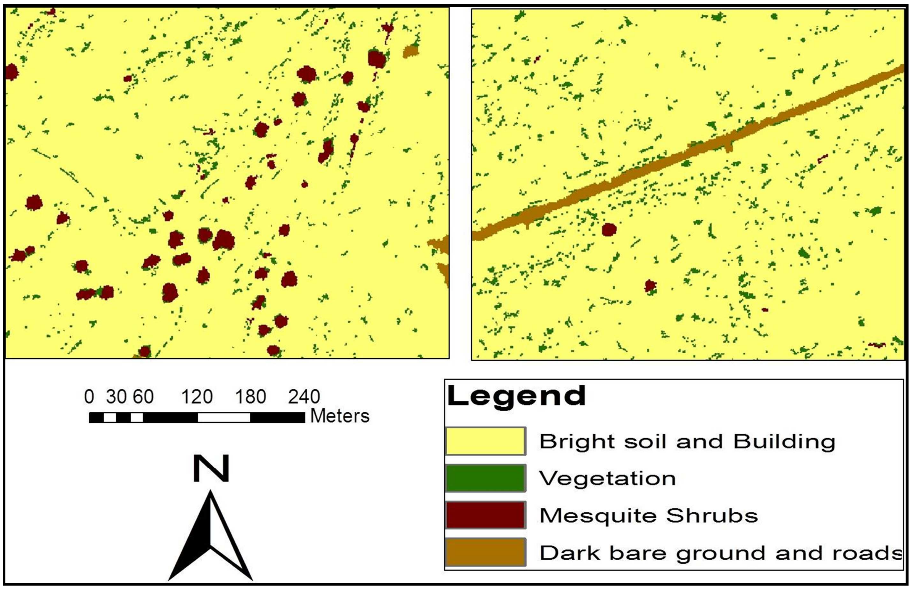

Fig. 4. Two plots from classified map of the study area at Halaib, Southeastern Egypt showing different mesquite shrub and grass-mix vegetation cover.

Mesquite impact on Halaib Desert Rangeland vegetation

Data presented in Tables (2) show the relation between mesquite shrubs canopy cover and the other associated rangeland plant species cover. Preliminary results indicate that increasing mesquite canopy cover was corresponding with decreasing understory vegetation cover. Under low mesquite canopy (19.64%), *Panicum turgidum*, the most important forage plant in Halaib region from stand point of high nutritive value, abundance, and high palatability, had the highest coverage (5.508%).

In contrast, data in table (2) show that high mesquite canopy cover (55.69%) was associated with lower *Panicum turgidum* coverage (2.48%).

In 1985, Mesquite (*Prosopis juliflora*) invasion was reported as a new constrain that negatively impact management of the Egyptian Southeastern Desert Rangeland. Although seed dispersal by livestock is considered to be a primary cause of mesquite encroachment in the region, several other factors including human movement, water movement during rainy season, commercial activities between Egypt and Sudan. Mesquite invasion can negatively impact grazing capacity, spatial livestock distribution, and forage production in Southeastern Desert rangelands. Several sheepherders and local farmers at Halaib were interviewed regarding their view of mesquite encroachment in the region. They all agreed that mesquite brought to Egypt from Sudan whereas some people plant mesquite seedling as a shading tree then they start to distribute it in the region. Another major factor for the rapid mesquite encroachment in Halaib is seed dispersal by livestock. Mesquite produces high amount of pods every year during the summer season. For example, the author collected 15kg of dry pods from only one large mesquite. Sheep and goats prefer feeding on mesquite dry pods particularly at the dry season, where the mesquite pods provide the animals with high amount of protein and energy. Our observations indicate that seed dispersal by sheep and goats is increasing mesquite population at Halaib region very quickly. For instance, the author recorded 25 mesquite seedling of the current year growth in one 20x20m plot. So, the author believes that in order to control mesquite encroachment, it needs to decrease seed dispersal by livestock. I proposed that collecting mesquite pods either before or after maturity and ground mill the pods then include them in sheep and goats' rations would be beneficiary from two sides. First, this will be successful method of keeping mesquite population under control; second it will provide animals with nonconventional cheap protein source. Although increasing mesquite cover would have negative impact on the natural rangeland vegetation in Halaib region, it was mentioned that having some mesquite shrubs on the range has a positive influence in the environments. Mesquite trees provide shading for wildlife including the Dorcas gazelle and wild donkey (*Equus africanus*) and for livestock grazing animals. It is also very important for birds' habitat. However, mesquite cover should be kept under control by using the proper rangeland management practices and monitoring the shrubs cover every three to five years.

Table 2. Effect of mesquite canopy cover on associated rangeland vegetation composition at Halaib in spring 2013.

No	Scientific name	Low mesquite canopy cover			High mesquite canopy cover		
		Density plant/400 m²	Coverage %	Abundance %	Density plant/400 m²	Coverage %	Abundance %
1	*Prosopis juliflora*	0.002	--	1.571	0.01	--	9.5
2	*Panicum turgidum*	0.098	5.508	29.178	0.09	2.48	25.54
3	*Zygophyllum simplex*	0.300	0.953	44.845	0.13	0.60	18.23
4	*Fagonia Arabica*	0.033	0.063	3.080	0.03	0.05	4.38
5	*Indigofera*	--	--	--	0.003	0.14	4.50
6	*Zygophyllum album*	0.010	0.938	20.833	0.01	1.41	19.11
7	*Stipagrostis ciliate*	--	--	--	0.04	0.01	8.07
8	*Acacia raddiana*	--	--	--	0.01	0.94	3.95
9	*Aristida funiculate*	--	--	--	0.03	0.38	6.72
10	*Cassia italic*	0.003	0.005	0.493	--	--	--
Total		0.446	7.467	100	0.353	6.01	100

Conclusion

Shrub encroachment is a serious constrains that negatively impact wide range of arid land ecosystems. Whereas nutrients and water resources are very limited at the desert rangelands, unpalatable shrubs have high ability to compete with the desired natural rangelands vegetation. Mesquite invasion has reported in several rangeland types across the globe. Quantifying its influences in desert ecosystems is needed for sustainable development and management of our natural resources.

This research employed very high spatial resolution satellite imagery to detect and map mesquite cover in an arid desert rangeland at Southeastern Egypt. Object-based image analysis was used to classify the satellite image. Classified map combined with ground rangeland survey were used to evaluate effect of mesquite invasion on Halaib area. Overall accuracy of classified map was 92.43% and more than 90% of mesquite shrubs were detected from image analysis. Results indicate that important native grass spices cover was impacted by high levels of mesquite canopy cover.

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