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GIS ANALYSIS OF INVASIVE *PROSOPIS JULIFLORA* DYNAMICS IN TWO SELECTED SITES FROM THE UNITED ARAB EMIRATES

*Salem Issa and Bassam Dohai
Department of Geology, College of Science, United Arab Emirates University
P O Box 17551, AL AIN, UAE

ABSTRACT

High resolution digital aerial photographs were used to rate the change and to evaluate the woody *Prosopis juliflora* dynamics in northern Unite Arab Emirates, Filayah (untreated) and Khut (treated). A time series of three different dates: 1986, 1996, and 2005 were chosen. On-screen digitizing of plant communities was conducted using interpretative elements such as shape, tone texture and shadow; production of final maps was achieved with acceptable accuracy. We built a geo-database containing layers representing different dates for both sites. We performed statistical analysis to rate changes of the following four spatial attributes: percent cover, patch density, patch size, and mean patch shape index. Finally, we conducted a GIS Overlay analysis to visualize plant dynamics and to explore possible spatial associations. Results confirm that *Prosopis juliflora* is a very active and dynamic invader which has the potential to threaten the local environment; as its percent cover as well as its patch density increased noticeably during the study period (1986-2005). We concluded that *Prosopis juliflora* seems to go through phases of expansion. First, an accelerated expansion earlier in the establishment period, then the distribution reaches a plateau. This plateau may be an optimum density of *Prosopis juliflora* in that region. The time period for such optimum is suggested to be 10 years from invasion.

Keywords: Aerial photographs, *Prosopis juliflora*, UAE, optimum density, GIS overlay analysis, remote sensing.

INTRODUCTION

It is necessary to study dynamics of invasive woody plant encroachment in the United Arab Emirates to determine its rate of expansion and to map its spatial distribution. The invasive woody plant *Prosopis juliflora* (Sw.) DC., which is an evergreen tree native to North and South America (Pasiecznik *et al.*, 2004; Shiferaw *et al.*, 2004) is currently escaping the artificial forests of the UAE where it was first introduced more than twenty years ago. The argument used was its resistivity to the harsh climatic conditions of the country and as a stabilizer of sand dunes (Ghazanfar, 1996; Western, 1989). Complaints of *Prosopis juliflora* range from invading large urban and agricultural areas, to forming shelters to dangerous insects, mice and reptile as well as being allergenic to people (AL Bayan, 1998). A new study of the impact of *Prosopis juliflora* in the UAE showed a great depressive effect on the number, density and frequency of the associated species, particularly its invasion to native vegetation such as *Prosopis Cineraria* (Tiwari, 1999; El-keblawy, 2002; Awatif, 2004). It is being combated by many municipalities including the municipality of Dubai (Awatef, 2004). Long-term changes in cover and density of the *Prosopis Juliflora*, on specific sites of the UAE are not well quantified. Much of the information includes either non-quantitative map comparisons (Marijcke and Jongbloed, 2003) or descriptive studies in which *P. juliflora* is being described from biotic, environmental and/or economic views (Awatef, 2004). This is probably the first attempt to use GIS and remote sensing technologies to map dynamics of the plant in the area.

Previous studies showed that *P. juliflora* is performing better under drought stresses compared to native species. High seed germination rates gives *P. juliflora* great opportunities to grow faster and better and makes it a more adapted to drought conditions compared to other native species. In their study in Oman, (Al –Rawahy *et al.*, 2003) concluded that the number of *P. juliflora* seeds in seed banks is greater than the seeds of native tree species. *P. juliflora* accumulates long-lived dormant but viable seeds in the soil serving as sources of regeneration of new Prosopis plants in the event of disturbance that might eliminate the aboveground stands. Shiferaw *et al*. (2004) found that even under optimal conditions only a portion of the seeds will germinate at any one time [in their experiments only few seeds (21%) germinated, suggesting that the seeds have high dormancy caused by the hard seed coat]. This is particularly important for species survival in arid environments characterized by their spatial and temporal unpredictability in rainfalls (El-Keblawy and Al-Rawai, 2006). This phenomenon is referred to as (opportunistic behaviour) of *P. juliflora* comprising two main ecological factors: seed ecology of *P. juliflora* (Al –Rawahy *et al.*, 2003; El-Keblawy and Al-Rawai, 2006; Shiferaw *et al.*, 2004) and Allelophatic effects of *P. juliflora* to other species (Noor *et al.*, 1995; Warrage and Al-Humaid, 1998). They all reported that *P. juliflora* plants possess allelochemicals that inhibit the

*Corresponding author email: salem.essa@uaeu.ac.ae

germination and spread of other plant species. This mechanism, combined with drought conditions, can inhabit other species and eliminate any kind of competition. Our objectives are to map the dynamics and quantify the rates at which *P. juliflora* increased over a 19 years period (1986 to 2005). We selected two sites to compare the dynamics of *P. juliflora* between, previously farmed land with nearly zero *P. juliflora* percent cover, considered in this research as treated site, and an untreated site.

The United Arab Emirates is located in south-west Asia, east of Saudi Arabia, with a coast line approaching 600 km on the Arabian Gulf and another 100 km to the east on the Indian Ocean (Fig. 1). Its area approximates 83,000 square km (Ministry of Information, 2003). The sand and gravel desert dominates most of the country, with steep mountains in the north and northeastern parts. The weather is warm and sunny in winter, and hot humid in summer. Two sites from Ras AL Khaimah (RAK) are selected to conduct this study after field visits to the sites between June and December 2004 (the selection was based on their high density, high canopy cover and their homogeneity on the aerial photographs).

The two sites are located south of RAK (25°44'N, 55° 59'W; elevation = 10m) for Filayah site and (25°36'N, 55° 58'W; elevation = 22m) for Khut site (Fig. 1). Mean annual rainfall is 147 mm (Fig. 2). Rainfall pattern in the study area is illustrated by data analysis from the rainfall station at RAK airport station in operation since 1979. Most precipitation falls between December and March. It is cited in many references (Al –Rawahy *et al.* 2003; Elfadl and Luukkanen, 2006) that rainfall amount and distribution throughout the year is a major factor influencing growth and dynamics of *P. juliflora*. The researchers found that precipitation was above normal in the first period (1986-1996) and below normal in the second period (1996-2005). Soils are level and uniform throughout the study area, consisting of deep soils with high quantities of silt, sand and clay of more than 60 cm thickness (AlBarshmgy, 2006).

Vegetation is a mixture of native trees and grasses dominated by *Prosopis juliflora*. Major *Prosopis juliflora* communities are mainly found along the northern coast of the UAE (Awatef, 2004), occupying old farms with no apparent agricultural management.

MATERIALS AND METHODS

Study area

The study area (Fig. 1) encloses the two sites selected in our study; Filayah to the north with an estimated area of about 93.94 ha, and Khut to the south, near RAK airport with an estimated area of about 15.81 ha. Focusing on this part of the country for the studying of *P. juliflora* gained its importance from the fact that the greatest vegetation diversity occurs in the northern mountains of the country which host more than 70% of the total species distribution in the country (Erwda, 2003).

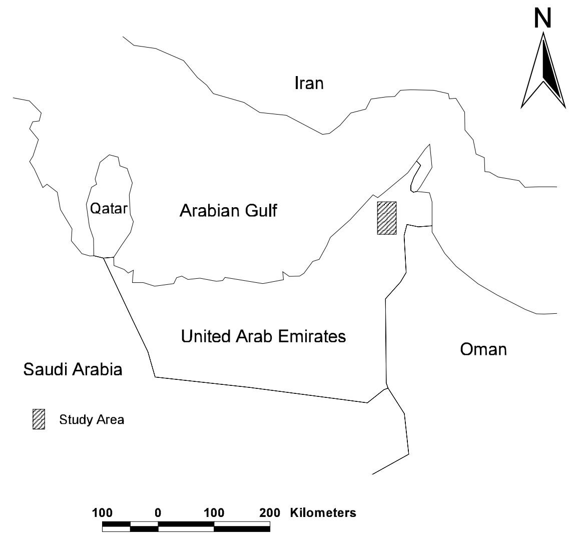

Fig. 1. Location of the study area in Northern Emirates.

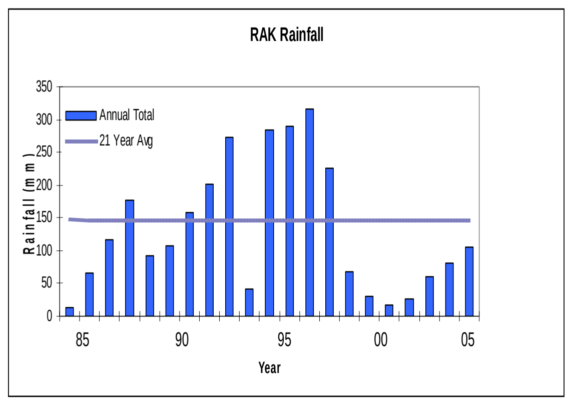

Fig. 2. Annual rainfall at the research sites south of RAK, North UAE from 1986 to 2005 compared to the 21 years average.

MATERIALS

A temporal series of remote sensing data was provided by the MSD (Military Survey Department) for the study area which was composed of B/W as well as colour aerial photographs from 1986, 1996, and 2005 (Fig. 3). Nominal scales for the aerial photographs were 1:30,000, 1:60,000 and 1:30,000, respectively. Softwares used include ERDAS Imagine 8.4 for georectification and image processing, ESRI Arc View 3.2 software for digitization, production of vector GIS layers and for performing GIS analysis, MS Excel for statistical analysis, whereas the hardware includes PC Pentium IV

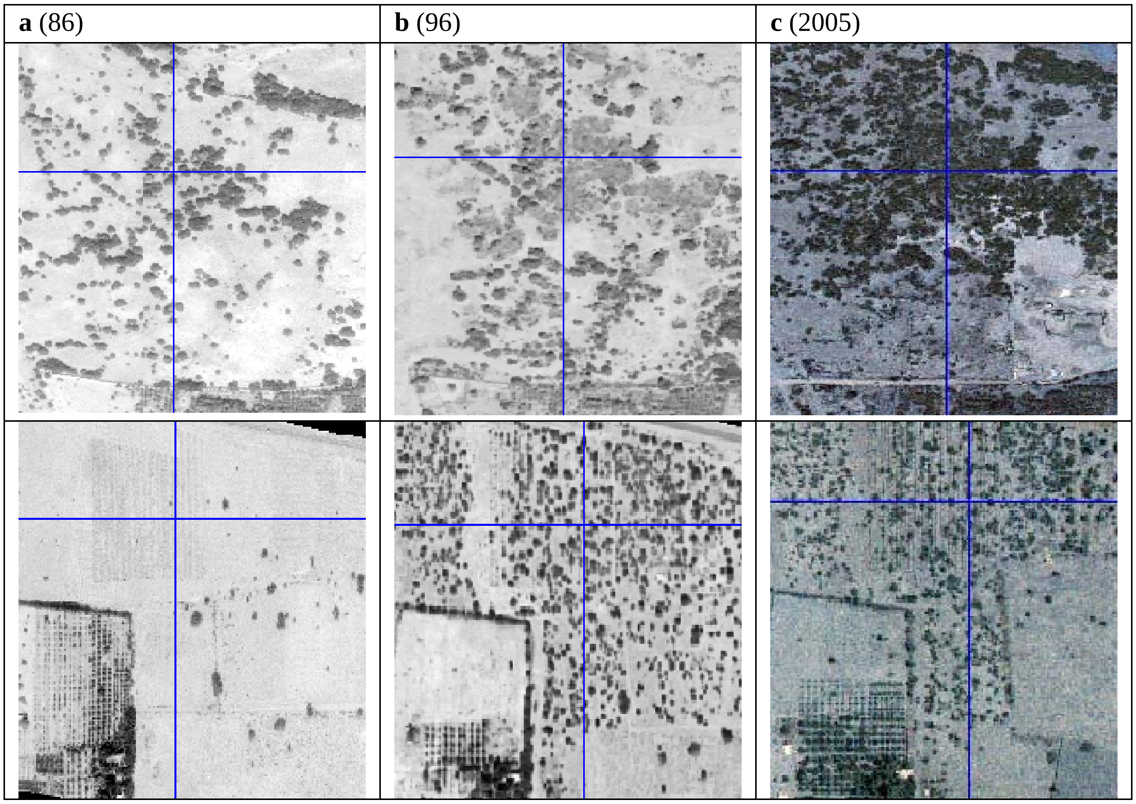

Fig. 3. Time series of multi-temporal aerial photographs: **a** (86), **b** (96), and **c** (2005); For Filayah (top) and Khut (bottom).

3.2 GH speed. The selection of data used in this study was largely governed by availability and accessibility of archived data especially at the MSD archives while the selection of hardware and software was governed by both budget limitation and UAEU geology department's facilities.

All aerial photographs were scanned at a resolution of 600dpi, at the Military Survey Department. We applied the nearest neighbour method of grey-level interpolation and obtained a pixel resolution of 2m. As a reference for data georectification we used the aerial photograph of 2005, found on the e-government web site (www.rak.ae) of Ras Al Khaimah! It is important to note that before proceeding in the georectification process we conducted a visit to the RAK municipality site-planning section, who confirmed that the photograph was accurate, geo-referenced and resampled to 25 cm x 25 cm pixel resolution. Therefore, we used this aerial photograph, which was already projected to the UTM_Zone 40N, to register the 2005-photo of our dataset using an image-to-image registration. We were able to collect 16 ground control points (GCPs) for Khut site and another 10 points for the Filaya site. The resulting 2005-rectified photo was subsequently used as a reference for the 1996 and 1986 aerial photographs repeating the same procedure for each dataset. GCPs represented buildings and man made features edges, however due to difficulties in finding suitable features, especially in the 1986 Filaya site, permanent old trees centres, e.g. *Prosopis cineraria* centres were used instead. A second degree polynomial transformation was used for projection and we could achieve a total Root Mean Square (RMS) less than 0.5 pixel for all photos. Finally, in order to unify the spatial resolution for all datasets we resampled the resulting aerial photographs and got a final pixel size of 2m for all datasets.

METHODOLOGY

GIS has been used to capture and map spatial distributions of plant dynamics in the study area (two sites). The methodology used pursues the following generic procedure:

- Selecting and delineating the two sites borders on aerial photographs of three different dates,
- Image sharpening to enhance contrast between target and background and/or surroundings,
- On-screen digitizing and creation of *P. juliflora* layers within each site using ArcView GIS (ESRI, 1998); all patches of *P. juliflora* are digitized and GIS layers are created for all three dates.

- Exclusion of areas with high level of human disturbance from the analysis. These areas are defined as those areas that have their land cover changed due to change in land use in, at least, one date during the study period;
- For each site, comparisons are made between the following four spatial attributes: percent cover, patch density, patch size, and mean patch shape index.
- Conducting and applying statistical and GIS Overlay analysis functions to evaluate and visualize *P. juliflora* dynamics for both sites.

We estimate canopy percent cover by dividing canopy area coverage (sum of polygon areas) by total site area, patch density is calculated by dividing the number of patches (number of polygons in ArcView) at each site by area in ha, patch sizes and mean patch size are calculated automatically by ArcView software, and finally we determine mean patch shape index as the output of three attributes calculation in ArcView. We consider canopy cover as synonymous with "aerial crown cover", and represents the percentage of land surface area occupied by *Prosopis juliflora* canopies as viewed from above (Ansley *et al.*, 2001). Using enhancement and digitizing methods, and guided by a newly acquired aerial photograph with 25cm × 25cm resolution, we were able to visually exclude most shaded soil areas in all dates. It was possible to differentiate *Prosopis juliflora* from native *P. cineraria* trees using difference in tone and colour on large scale aerial photographs (*P. cineraria* trees show more greyish and less dark tone on aerial photographs), (Figure 4). Furthermore, the persistence of the *P. cineraria* tree over time is taken as indicator of a *P. cineraria* tree rather than a *P. juliflora* patch, as the former is respected, protected and preserved by local authorities, population and farmers (Brown, 2004).

Prosopis juliflora patches are defined as discrete areas of *P. juliflora* canopy consisting of one or more individuals with visually connected canopies. Patch density is defined as the number of discrete *P. juliflora* areas per ha; mean patch size is the average area of the patches (m^2). The mean patch shape index is used to quantify the average shape complexity of the patches in a site. The shape index of a *P. juliflora* patch is defined as $0.25*P/A^{1/2}$, where P is the perimeter and A is the area of the patch (McGarigal and Marks, 1995). The shape index equals one for a patch with the simplest raster shape, a square or a circle, and increases when the shape of a patch becomes more complex.

The rate of change in percent cover from an earlier year to a later year is determined by subtracting the cover value of the earlier year from that of the later year and dividing this amount by the number of years between the two dates.

To discard external factors influencing our analysis of the *P. juliflora* dynamics in the two sites, we build a GIS database containing GIS layers for all land cover types in the study areas. A GIS Mask is defined in this study as a GIS layer representing all areas subjected to change in land cover and depicted in at least one date; they are identified as areas of high human disturbance. Main land cover changes occurring in the area and being included in the mask layer are: cleared land, land converted to farms, buildings and quarries. To extract undisturbed *P. juliflora* areas the following procedure is implemented:

1) On-screen digitizing of cleared land, farmed land, buildings and quarries on all dates. To assemble together all land cover types, as not all of these land cover types are present on all dates, applying union operation procedure is necessary to ensure that all disturbed areas are included in the mask;
2) Dissolving adjacent polygons to eliminate inter-boundaries between similar polygons in the same land cover type;
3) Subtracting the mask layer from the *Prosopis juliflora* layer created during the first phase of the study to produce undisturbed *P. juliflora* areas only. This is achieved by applying the 'Select by Theme Function', then Intersect with the Mask layer features, then Switch Selection, then apply the 'convert to shape file function'. The output file contains *P. juliflora* areas that are recognized as undisturbed.

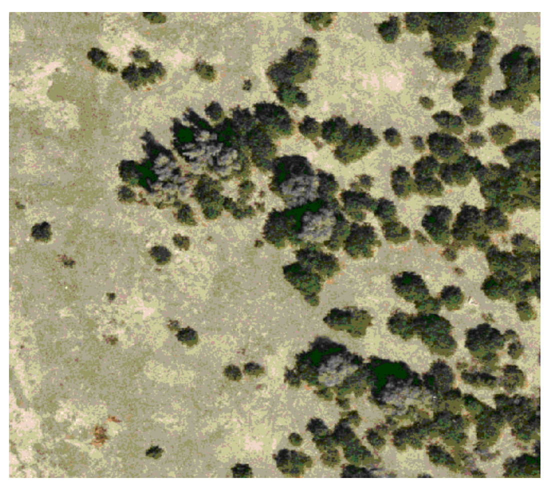

Fig. 4. *Prosopis cineraria* trees showing more grayish and less dark tone than *Prosopis juliflora* trees on aerial photographs.

RESULTS AND DISCUSSION

During the 19-year period (1986 to 2005), 12 years had below average precipitation and 7 were above average (Fig. 2). Average annual precipitation for all 19 years was 158 mm, or 7.5% above normal. Average annual precipitation from 1986 to 1996 was 18.4 % above normal at 174 mm per year. Annual precipitation from 1997 to 2005 was 4.1 % below normal at 141 mm per year. More than 60 hours were required to finish the on-screen digitizing and create the GIS layers of the *P. juliflora* canopies on the 6 site images (2 per year × 3 sample years). *P. juliflora* canopy cover in Filayah area increased from 10.48 to 16.17% during the 19-year period, an average of 0.3 % percentage units per year (Fig. 5). *P. juliflora* cover increased from 10.48 to 15.48 % during the 10-year sub-period (1986 to 1996), an average of 0.5 % percentage units per year, which was about double the average of the 19-year study period, this was mainly caused by the above average annual rainfall of 18.4 % during this sub-period. *P. juliflora* cover slowed down but continues to increase from 15.48 to 16.17 % during the 9-year sub-period (1996 to 2005), an average of 0.08 %. This was mainly caused by the below normal average annual rainfall of 4.1 % during the second period and saturation conditions as the area may have reached its maximum carrying capacity at the end of this period.

For the Khut area, *P. juliflora* canopy cover increased from 1.19 to 32.48 % during the 19-year period, an average of 1.65 (percentage units per year) was significantly higher than in Filayah area as *P. juliflora* starts from seeds or little seedlings (Fig. 5). *P. juliflora* cover increased from 1.19 to 39.43 % during the 10-year sub-period (1986 to 1996), an average of 3.8 (percentage units per year), which was more than doubling the average of the 19 years study period. Initially treated land and above average annual rainfall of 18.4 % during the same period played an important role. During the second 9 years sub-period (1996 to 2005), *P. juliflora* cover decreased from 39.43 to 32.48 %, an average of 0.77 %, this was mainly caused by the below normal average annual rainfall of 4.1% recorded during the second period and saturation conditions as the area may have reached its maximum carrying capacity.

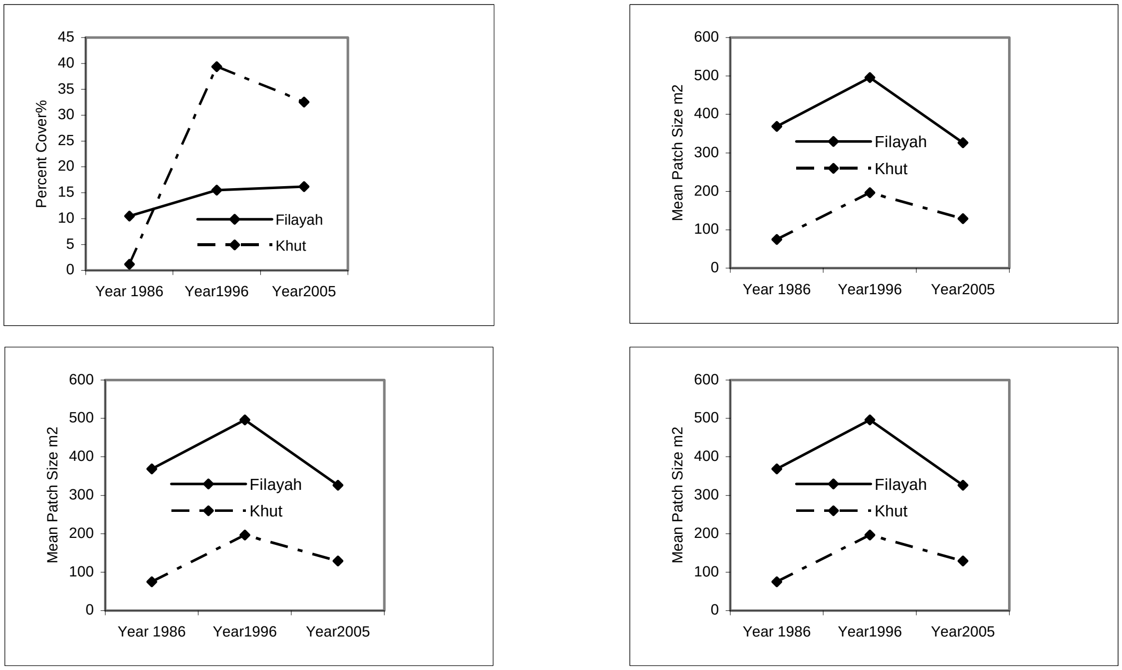

Fig. 5. *Prosopis juliflor*a percent cover, patch density, mean patch size and mean patch shape index, in Filayah and Khut areas near RAK, northern UAE from 1986 to 2005.

Spatial Attributes

In addition to the changes in canopy cover, there had been complex changes in the spatial attributes of *P. juliflora* patches, which provided additional insights into the dynamics of the systems. Three processes can influence changes in *P. juliflora* patch density: recruitment of new *P. juliflora* plants or patches, coalescing of expanding *P. juliflora* patches, and mortality of *P. juliflora* trees (Ansley *et al*., 2001). In Filayah area, patch density of *P. juliflora* increased continuously from 2.84 in 1986 to 3.12 in 1996 and to 4.96 patches/ha in 2005 (Fig. 5), with more increase in the second period (1996 to 2005). This was explained by the recruitment of more new small patches during this below-rainfall average period, as it was reported that *P. juliflora* perform better than other species during harsh weather conditions (Al –Rawahy *et al*., 2003). Coalescence and very low rate of new patches recruitment balanced each other and stabilized patch density in the period (1986 to 1996). Mean patch size variation was negligible during the whole study period (Fig. 5) because coalescence and recruitment of new patches balance each other, as either coalescing (increased shape complexity) or recruitment (more small patches) would change the shape index. High coalescing was observed between 1986 and 1996 however this was balanced by real recruitment of new patches during the same period. Recruitment of new patches has increased in the second period between 1996 and 2005 balanced by mortality of larger old patches.

For Khut area, patch density increased continuously from 1.58 in 1986 to 20.06 in 1996 and to 25.05 patch/ha in 2005 (Fig. 5) with more increase in the first period due to increase in recruitment as this was a treated area starting from seeds or little seedlings. Mean patch size increased in the first period then decreased because of recruitment of new patches in the second dry period (1996 to 2005). The mean patch shape index increased significantly (1986 to 1996) (Fig. 5) then declined between 1996 and 2005. There was high rate of new recruitment of *P. juliflora* patches as well as high coalescing occurring between 1986 and 1996 which increased significantly the mean shape index, and then there was little coalescing which balanced the effect of recruitment of new *P. juliflora* from 1996 and 2005, this was attributed to low rainfall amount between 1996 and 2005.

Researchers noticed that both canopy percent cover and patch density in the treated site (Khut) reached higher values compared with the untreated site (Filayah). We explained this by the fact that the treated area was previously used for farming; consequently there was abundance of fertilizers and moisture in the soil favouring the growth of *P. juliflora*.

Comparisons between the two sites

For Filayah site (untreated), the first period testified sharp increase in canopy cover because of the above average rainfall (Fig. 2), then the curve slowed down in the second period because of the decrease in rainfall (Fig. 2). Same observation goes for the mean patch size; while patch density followed an inverse trend, as it was almost stable during the first period although the rainfall was above average then it started to increase in the second, below average rainfall, period. As mentioned in section one above, this was explained by the opportunistic behaviour of *P. juliflora* (Al –Rawahy *et al.*, 2003; El-Keblawy and Al-Rawai 2006; Shiferaw *et al.*, 2004; Noor *et al.*, 1995; Warrage and Al-Humaid, 1998) which, combined with drought conditions, can inhibit other species and eliminate any kind of competition.

For Khut site (treated), the first period testified very sharp increase in canopy percent cover because of two reasons; first *P. juliflora* started from seeds or little seedling; second rainfall was above average during this period (Fig. 2). In the second period the curve went down mainly because of drought. Mean patch size followed same trend as with Filayah while patch density followed an increased trend (1986 to 2005) with a slower slope in the second period.

Saturation conditions in the area play an important role in the expansion process of *Prosopis juliflora*. We think that these conditions, which are rapidly reached in the region considering the environmental factors within each site, are another factor affecting percent cover as well as mean patch size. Mean shape index increased sharply in the first period because of new recruitment then slowed down because of little coalescence in the second period caused by less rainfall amounts.

In summary, the treated site was invaded aggressively in the first period with sharp increase in canopy percent cover and patch density; however both sites showed same behaviour in the second period while *P. juliflora* reached climax conditions. In addition, as mentioned above, plant growth in the treated (Khut) site reached higher percentages compared with the untreated (Filayah) site because of abundance of fertilizers and soil moisture. In conclusion, *P. juliflora* was a real invader that should be continuously combated by local authorities and farmers alike, as even previously controlled areas started to be invaded rapidly after abandonment.

Significance of the study

Large-scale aerial photographs were efficient in differentiating between patches of *Prosopis juliflora* and other species especially *Prosopis Cineraria*. One of our objectives was to find a fast, reliable and timeliness way to track *Prosopis juliflora*. Remotely sensed data such as large scale aerial photographs could decrease the amount of field work, as we were able to digitize and capture practically most, if not all, *Prosopis juliflora* patches during our study. Overlay analysis was useful in showing dynamics between years. Researchers were able, using these techniques, to visualize eight different dynamics categories during this study (Fig. 6).

- patches appearing in 1986 only (not visible in 1996 or 2005);
- patches appearing in 1986 and 1996 only (patches appear in 1986 and 1996 then disappear in 2005);
- patches consistent between 1986 and 2005 (appear on all dates and thus considered as the core of the *Prosopis juliflora* colony);
- patches appearing in 1996 only (new recruitments between 1986 and 1996);

- patches appearing in 1996 and 2005 (recruited in 1996 and continue to exist in 2005);
- patches appearing in 2005 only (newly recruited in 2005);
- areas without patches during the study period;
- Patches appearing in 1986, disappearing in 1996 then, appearing in 2005.

Comparison between treated and untreated sites was attempted; it was difficult to distinguish between the two, as we found that once treatment stopped then the invasion restarted vigorously so that after a period of about 10 years, *Prosopis juliflora* behaves more or less the same for both areas.

GIS methods were capable of capturing, mapping and spatially analyzing and visualizing all species-related spatial attributes in time; same procedures can be used and applied for other spatially distributed features.

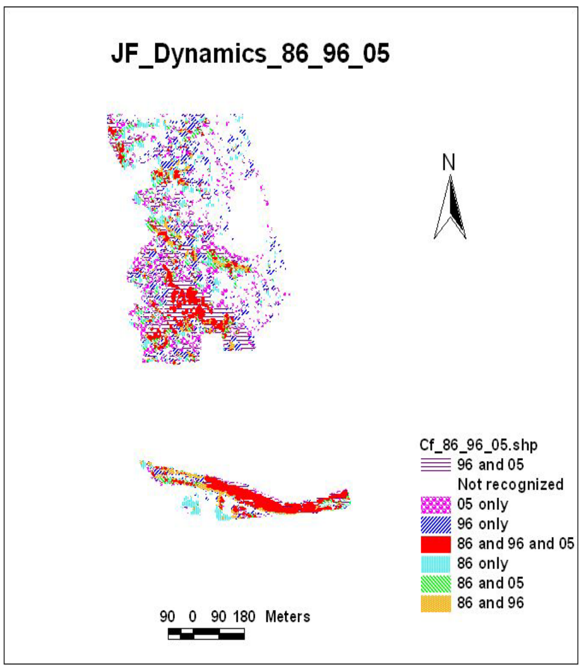

Fig. 6. Overlay analysis results showing dynamics of *Prosopis cineraria* in Filayah area (undisturbed areas only) near RAK, northern UAE from 1986 to 2005.

CONCLUSION

Remote sensing and GIS technologies have proved their usefulness in studying invading plants dynamics in arid land conditions. Large scale aerial photographs were found to be very useful in differentiating and mapping even small patches of *Prosopis juliflora*. GIS proved to be very useful in building the geo-database containing *Prosopis juliflora* as well as other layers and very helpful in evaluating and visualizing plant dynamics. It was proved that *Prosopis juliflora* represented real threat to the local farming activities, as its percentage cover increased during the 19 years period from 10.48 to 16.17 % in Filayah area (untreated) and from 1.19 to 32.48 % in Khut area (treated). Patch density also increased continuously from 2.84 in 1986 to 3.12 in 1996 and to 4.96 patch/ha in 2005 for Filayah area and from 1.58 in 1986 to 20.06 in 1996 and to 25.05 patch/ha in 2005 for Khut area. We found that *Prosopis juliflora* goes through phases of expansion. First an accelerated expansion earlier in the establishment period, in the present study this was observed between 1986 and 1995. Then the distribution reaches a plateau which was observed 1996 – 2005 in our study. This plateau may be an optimum density of *Prosopis juliflora* in that region. This optimum is affected by the environmental factors within each site. The time period for such optimum is suggested to be 10 years from invasion or after treatment for sites that were subjected to some kind of control (chemical and mechanical).

For future studies the technique used and the methodology developed can be applied to other areas in the country to track and model other species dynamics. This will provide decision makers as well as planners with a powerful tool to improve monitoring methods and help protecting and planning the environment in near real time. Future work will focus on monitoring dynamics of native species (e.g. *Prosopis Cineraria*) present in the site and thought to be endangered by this invader; existing spatial relationships will be captured and analyzed to estimate the vigour of the impact of the invader on the local native species.

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