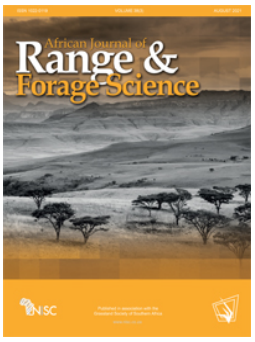

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Assessment of long-term protection on the aboveground biomass and organic carbon content using two non-destructive techniques: case of the Sidi Toui National Park in southern Tunisia

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Long-term protection of arid ecosystems changes the vegetation and soil structures. The quantification of aboveground biomass and carbon content are among the principal indicators to evaluate these changes. Most methods used to quantify these parameters are costly, time consuming and destructive. In this paper, two non-destructive methods were compared: digital image processing and biometric measurements. Aboveground biomass and carbon content of five perennial shrubs were studied inside and outside Sidi Toui National Park, southern Tunisia. The effect of long-term protection on aboveground biomass and carbon content was assessed. The main results indicated that both methods provided similar aboveground biomass and carbon values. Aboveground biomass and carbon content were strongly correlated with canopy cover and biovolume (R^2 > 0.7). Positive linear relationships were found for all the studied species. Apart from the large canopy cover of *Haloxylon schmittianum* and *Haloxylon scoparium*, the obtained results showed that long-term protection had no significant effect on aboveground biomass and carbon content for the other species. These results suggest that digital charting technique is an accurate method for assessing rangeland productivity in a timely and cost-efficient manner and that long-term protection is not always suitable for enhancing carbon content and therefore ecosystem resilience under climate change conditions.

Keywords: arid rangelands, non-destructive methods, photographic monitoring technique, VegMeasure®, rangeland assessment

Introduction

Sustainable rangeland management in arid areas can contribute to the mitigation of climate change and rising atmospheric carbon dioxide concentrations, because they store considerable amounts of carbon both in the aboveground vegetation and in the soils (Derner and Schuman 2007; Yang et al. 2017). In general, plant biomass of rangelands is relatively low at approximately 2–6 kg m^{-2}, compared with other terrestrial ecosystems reaching 10–18 kg m^{-2} (Ruijun et al. 2010), but their large area offers significant potential for carbon sequestration (Chen et al. 2009).

Dryland ecosystems have a sequestration potential of approximately 1 billion tons of carbon per year, accounting for more than 12% of global anthropogenic greenhouse gases emissions (Lal 2004). Some studies indicate that 59% of total carbon storage in Africa is in arid areas (Campbell et al. 2008; UNEP 2008). In these regions, where pastoral activities are dominant, most of the sequestered carbon is stored underground, and is therefore relatively stable (FAO 2002). There is also a substantial amount of aboveground carbon stored in trees, bushes, shrubs and grasses, which are not grazed or are only moderately disturbed by grazing (IPCC 2007; Vashum and Jayakumar 2012). However, it has been suggested that, under current land use management, overgrazing leads to loss of carbon stocks (Tessema et al. 2011). Many rangeland management techniques, such as rehabilitation and grazing enclosures, aim to increase forage production and to consolidate the carbon sequestration potential both in soils and in aboveground vegetation (Homann et al. 2008). National parks and other protected areas have been established to protect biodiversity and maintain ecological stability through restriction of livestock grazing and other human interventions. According to Campbell et al. (2008), 15.2% of global carbon stock is stored within protected areas, which cover 12.2% of total land area, highlighting the importance of protected areas in climate change mitigation.

Long-term protection of such dryland areas increases spatial heterogeneity and vegetation cover and leads to the development of new vegetation units (Tarhouni et al. 2014). This management technique significantly improves aboveground productivity of shrubby plants in arid rangelands and increases their potential to sequester atmospheric carbon (Wu et al. 2009).

Accurate quantification and study of the biomass of ligneous plants is essential in assessing the structure and vegetation production of terrestrial ecosystems and in estimating their potential contribution to carbon sequestration (Yang et al. 2017). Measurement or estimation of woody plant biomass can be done using direct or indirect methods. These methods have evolved over time. Initially, visual estimation was developed for use in grasslands and forblands (Pechanec and Pickford 1937). Later on, Woodroffe (1941) described an adaptation of the technique for shrubs. The most accurate method for estimating plant biomass is the direct method, which involves harvesting all aboveground biomass (Vashum and Jayakumar 2012). This traditional technique is time consuming and requires intense fieldwork. It also destroys vegetation resources and may accentuate the risk of desertification in arid lands (Ketterings et al. 2001; Djomo et al. 2010).

Because of the need for inexpensive and accurate measurements of plant biomass has led to the gradual development of various non-destructive techniques that allow for larger sample sizes at the expense perhaps of less precision at the plot level. For instance, the reference unit method is a semi-destructive technique based on the use of representative samples to reduce harvest of the entire shrub and increase the samples number (Boyda et al. 2015). Moreover, biomass equations were developed to estimate shrub biomass as a function of variables that are correlated with it, such as rainfall. However, this correlation works well with the herbaceous strata and not with other life forms, such as shrubs (Louhaichi et al. 2018a). Similarly, shrub biomass equations were developed as functions of plant dimensions (diameter and height, vegetation cover). The equations are usually species specific because of the variation in shape, size, and vegetative behaviour between species (Louhaichi et al. 2018a). They can be estimated using linear (Flombaum and Sala 2007; Tarhouni et al. 2007; Idi et al. 2009), quadratic (Hughes et al. 1987), and logarithmic regression models with various independent variables, such as stem diameter, height, and crown dimensions (Baskerville 1972; Ohmann et al. 1981). Recently, another non-destructive method, plant canopy cover measurement, has been used as a surrogate for estimating the biomass of woody plants, because these two parameters are believed to be positively correlated (Tarhouni et al. 2016). This technique uses a digital camera and follows a standardized procedure to classify and measure vegetation on the ground. Finally, with the advances in geo-spatial technologies, new biophysical predictors have been identified, which open new venue for developing accurate allometric equations and/or geo-spatial approaches (Louhaichi et al. 2018b; Issa et al. 2020).

Assessing ligneous plants biomass using these tools serves as an indicator of the productivity of rangelands and facilitates the study of carbon sequestration potential in these ecosystems. The huge content of organic carbon in vegetation, produced by photosynthesis, is usually estimated by multiplying the total plant biomass by a corresponding biomass carbon conversion factor (Ma et al. 2018). Although dryland regions occupy 45% of global land area, the amount of carbon stored in the arid and desert ecosystem has been poorly studied (Fusco et al. 2019) and most studies that have estimated carbon stocks have focused mainly on tree species. In fact, carbon uptake by dwarf shrubs accounts for approximately one-third of the total carbon sink, and these life forms represent a large biomass and carbon pool that is usually underestimated in carbon storage assessments (Li et al. 2018). In Tunisia, the estimation of carbon sequestration in vegetation is rarely studied and those studies that have been carried out have been concentrated on forest areas located in the north of the country (Zribi et al. 2016). However, a comprehensive understanding of global carbon stocks must include the study of the carbon sequestration potential of dryland regions through the investigation of the two principal carbon wells, the soils and vegetation biomass of these regions.

This study aimed to investigate the effect of long-term protection of arid rangelands on biomass production and carbon storage for five dominant dwarf shrub species, as well as to develop the best-fit correlation models for predicting the biomass and carbon content of these species. The study took place inside and outside the National Park of Sidi Toui, in the El Ouara natural rangeland area in southern Tunisia where the efficiency of the digital image analysis was compared to the biovolume measurement technique, another non-destructive measurement method.

Materials and methods

Study site

In Tunisia, rangelands occupy approximately 4.5 million ha, of which 45% and 42% are located in arid and desert areas of southern Tunisia, respectively (DGF 2010). Chamaephytes are the dominant life forms of natural vegetation in Tunisian arid rangelands and mostly considered as key ecological species within desert ecosystems (Yang et al. 2017). Projections of climate change in southern Tunisia for 2030–2050 predict a rise in annual and seasonal temperature and decrease in rainfall, with an increased frequency of extreme events, including successive dry years, which can have a significant impact on the perspectives and development of production systems, particularly in these dwarf shrub ecosystems (Ouled Belgacem and Louhaichi 2013; Touhami 2016). Such ecosystems play an important role in reducing the effects of wind erosion and in conserving soil and water (Yang et al. 2017), as well as in generating suitable habitats for the understory plants, animals, and microorganisms specific to this environment (Li et al. 2003).

The current study was carried out inside (ungrazed area) and outside (free grazing) the Sidi Toui National Park in southern Tunisia. Created in 1991 on 6 315 ha, this park is located in Presaharian Tunisia in the El Ouara natural rangelands area (Figure 1). The soil substratum is mainly composed of vast encrusted glacis with a sandy and thin upper layer. The vegetation cover is mainly dominated by shrubby Chamaephytes. Predominant shrubby species include *Anthyllis henoniana* Coss. Ex Batt., *Gymnocarpos decander* Forssk, *Rhanterium suaveolens* Desf., *Haloxylon schmittianum* Pomel and *Haloxylon scoparium*

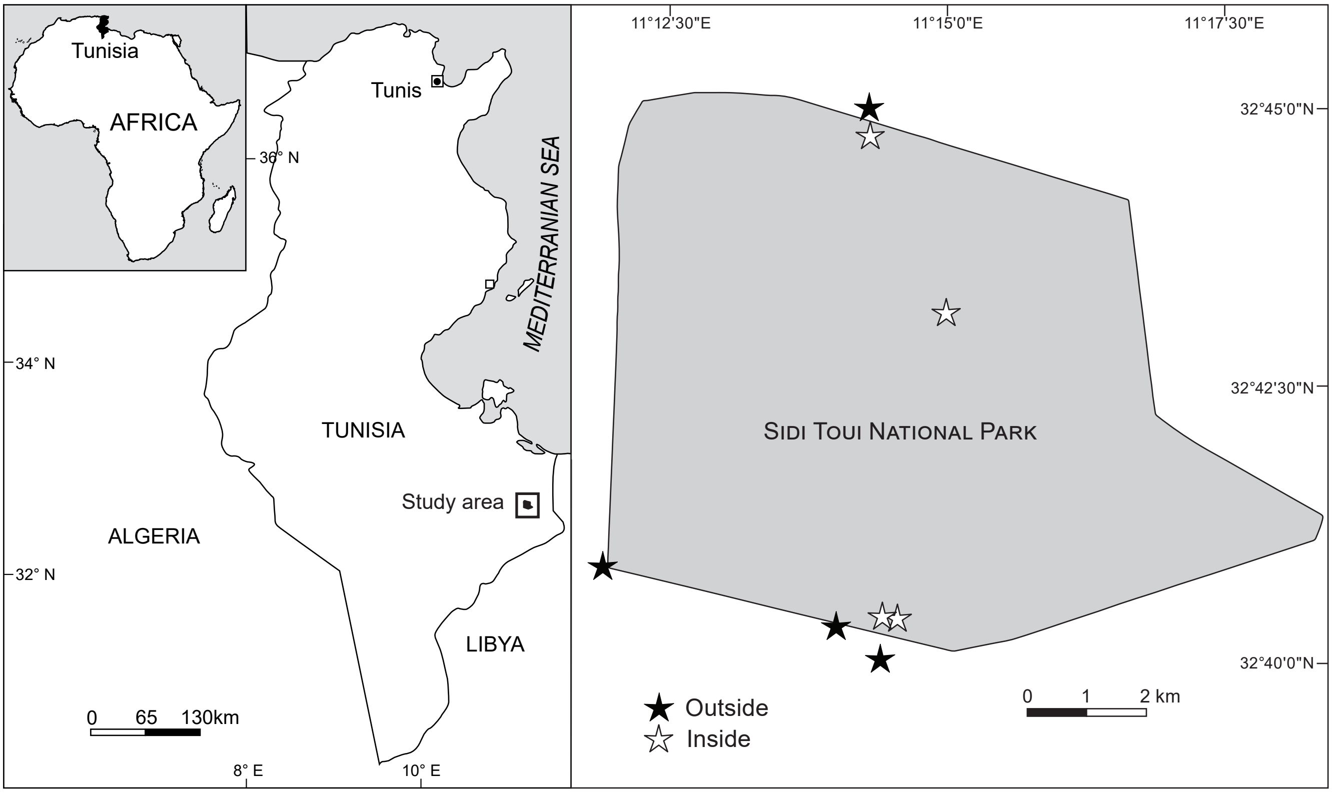

Figure 1: Geographical location of the study area (Sidi Toui National Park)

Table 1: Climate data for the Sidi Toui National Park 2017–2019 (local measurements)

Variables	J	F	M	A	M	J	J	A	S	O	N	D	Annual means
Mean temperature (°C)	13	14	18	20	23	27	30	29	27	23	18	13	21.25
Mean maximum temperature (°C)	18	20	24	26	30	34	37	36	33	28	23	18	27.25
Mean minimum temperature (°C)	8	9	12	15	18	21	24	23	22	18	13	9	16.00
Mean precipitation (mm)	2	1	7	15	1	0	0	0	0	26	56	13	121.00

Pomel. The main land use in the region is livestock grazing and there is a long history of free grazing by small ruminants and camels. Inside the park, grazing is strictly prohibited. Nevertheless, the park is occupied by very small number of wild herbivores, mainly antelopes (*Oryx*, gazelles), ostriches and rabbits.

According to the Köppen-Geiger classification, the climate of the study area is classified as type BWh. The average temperature is 19.6 °C and rainfall is low and sporadic, with mean annual precipitation of approximately 175 mm. The driest month is July and the highest precipitation is recorded in January (https:/fr.climate-data.org, accessed on 7 April 2020). During the experiment period (2017–2019), the mean precipitation recorded in the meteorological station of the Sidi Toui National Park was relatively low (121 mm), compared with the mean annual of the region (Table 1).

Experimental design

Five dominant native perennial species were selected, because they are key species of the five main plant communities in the park and its surrounding (Ould Sidi Mohamed et al. 2002; Tarhouni et al. 2014): *A. henoniana, G. decander, R. suaveolens, H. schmittianum* and *H. scoparium*. The biomass and canopy cover of these species were measured during the spring of 2017, 2018 and 2019, respectively. One hundred and twenty tufts for each species of *A. henoniana* and *R. suaveolens* (60 tufts from inside and 60 from outside the park) and 60 tufts for each species of *G. decander, H. schmittianum* and *H. scoparium* (30 inside and 30 outside the park) were randomly selected for measurement. For each species, two classes of canopy size (big and small) were considered and the size distinction between classes was made by visual observation.

Canopy cover

The selected individuals of each species were photographed with a high-resolution digital camera (Nikon Coolpix AW110, 16 megapixels and the images resolution was 4 608 × 3 456 pixels) before cutting. A consistent camera height above the ground (1.25 m) was maintained during the protocol to ensure the photographed area was the same each time. The camera was pointed vertically downward (ensured by a bubble level) and the direction was determined using a compass. Time of day can interfere with the quality of the photographs taken and, in general, it is recommended to avoid early and late afternoon (Louhaichi et al. 2018b). The obtained images were processed using specialized software 'VegMeasure' (Louhaichi et al. 2010). This software is used to classify the collected digital images and measure plant cover of the targeted species. The canopy cover (CC) was expressed as a percentage of the plant cover in the photographed area.

Biometric measures

For each selected individual plant, the maximum height H (defined as the distance between the ground surface and the highest crown point) and the crown area in two directions (largest diameter of the crown [D1], and its perpendicular diameter [D2]) were measured using a tape with 1 mm accuracy to describe the architectural characteristics. The geometric shapes of the tufts of the selected species were considered as hemispherical. Therefore, the biovolume (BV) was determined using the following formula:

$$\mathrm{BV}\ (\mathrm{m}^3) = ((4/3) \times \pi \times r^3)/2$$

where the average radius is expressed as:

$$r\ (\mathrm{m}) = ((\mathrm{D1} + \mathrm{D2})/2 + \mathrm{H})/2$$

Aboveground biomass and carbon content measurement

The aboveground biomass was obtained by clipping all the aerial parts of the photographed plants. The fresh material from each measured plant was weighed and dried at 105 °C for 24 h to obtain the aerial dry biomass (DM).

The carbon content was measured by the loss on ignition method (ash method) (Chavan and Rasal 2011). Samples from each clipped plant were weighed (M1) then burned in an oven for approximately 4 h at 550 °C. The obtained ash was allowed to cool in a desiccator and then weighed (M2).

The proportion of organic carbon (OC) content for each biomass was calculated by ash weight (M2), primary weight (M1), and the proportion of organic material (OM), using the following formulae (Allen et al. 1986):

$$\mathrm{OM}\ (\%) = (\mathrm{M1} - \mathrm{M2})/\mathrm{M1} \times 100$$

$$\mathrm{OC}\ (\%) = \mathrm{OM}\ (\%) \times 0.58$$

The results expression of both measured parameters was carried out according to the size classes (big canopy and small canopy).

Statistical analysis

After a Shapiro–Wilk test for normality, logarithmic transformations were made for DM and OC content before statistical analysis to ensure homogeneity of variance. One-way analysis of variance (ANOVA) was performed using SPSS software 20.0. Linear regression analyses were used to explore relationships between DM, OC, CC (calculated by VegMeasure), and BV for the selected species. The determination coefficient (R^2) was computed for dependent and independent variables. Univariate regression is described as follows:

$$y = \alpha x + \beta$$

where y is the dependent variable; x is the independent variable; α is the slope and β is a intercept of this function. Linear regressions and calculated models were obtained using Excel software and the intercept was set to 0.

Results

Biomass production and organic carbon content

The mean aboveground biomass (DM) and organic carbon content (OC) for all individual plants, inside and outside the Sidi Toui protected area, of both canopy size classes are shown in Table 2. Inside the protected area, mean DM and OC content were highest in *H. scoparium* (big canopy) weighing 992.45 g ± 507.55 g and 505.72 g ± 273.64 g, respectively. Mean DM and OC content were lowest in *G. decander* (small canopy) weighing 44.25 ± 31.99 g and 22.26 ± 16.18 g, respectively. Outside the protected area (that is, in the grazed area), mean DM and OC content were also highest in *H. scoparium* (big canopy) weighing 599.91 g ± 244.16 g and 306.43 g ± 126.26 g, respectively, and lowest in *G. decander* (small canopy) weighing 39.12 g ± 26.25 g and 18.83 g ± 11.72 g, respectively. The results of ANOVA showed that a long period of protection had no significant effect on biomass production and carbon content for the small canopies of all the studied species and for the big canopies of *A. henoniana, G. decander*, and *R. suaveolens* ($p > 0.05$). However, for the big canopies of the chenopods, a highly significant effect was found for *H. schmittianum* ($p < 0.001$) and a significant effect for *H. scoparium* ($p < 0.05$) for both parameters.

Canopy cover and biovolume

After software processing of the photographs of all the individual species inside and outside the protected area, the highest estimated CC values were attributed to *H. scoparium,* ranging from 0.8 to 41.9% with an average of 12.29%. CC values varied from 0.2 to 38.1% (9.34% on average) for *R. suaveolens* and from 0.5 to 26.3% (7.6% on average) for *A. henoniana*. The lowest CC values were found for *G. decander*, ranging from 0.3 to 20% (6.49% on average), and *H. schmittianum*, ranging from 0.4 to 15.9% (5.47% on average).

Using biometric measurements (second non-destructive method), the results showed that BV varied between 0.001 and 0.63 m^3 for all the studied shrub species. The highest mean canopy BVs were 0.11 ± 0.11 m^3 (range 0.004–0.43 m^3) for *H. scoparium*; 0.11 ± 0.10 m^3 (range 0.008–0.63 m^3) for *R. suaveolens*; and 0.9 ± 0.8 m^3 (range 0.008–0.35 m^3) *for A. henoniana.* The lowest BV values were 0.5 ± 0.4 m^3 (range 0.001–0.23 m^3) for *H. schmittianum* and 0.5 ± 0.5 m^3 (range 0.003–0.29 m^3) for *G. decander.*

Regression analysis

The analysis of photographs by the VegMeasure software (Figure 2) and biometric measurements served

Table 2: Mean ± SD aerial dry biomass (DM) and organic carbon content (OC) of five perennial shrubs inside and outside the Sidi Toui National Park collected in spring over three years (2017– 2019). The canopy size classes are B (big) and S (small), where *n* is the number of measured individuals of each species for each size class inside and outside the park. Asterisks indicate a statistically significant difference between means inside and outside the park, * $p < 0.05$; ** $p < 0.01$

Species (*n*)	Canopy size class	DM (g plant⁻¹)		OC (g plant⁻¹)	
		Inside	Outside	Inside	Outside
Anthyllis henoniana	B	541.1 ± 372.7	513.6 ± 263.6	285.4 ± 200.9	275.4 ± 142.6
(*n* = 30)	S	90.6 ± 54.1	69.5 ± 32.1	46.9 ± 27.9	37.4 ± 17.4
Gymnocarpos decander	B	606.2 ± 291.1	572.7 ± 306.5	295.9 ± 144.6	291.2 ± 155.9
(*n* = 15)	S	44.2 ± 31.9	39.1 ± 26.3	22.3 ± 16.2	18.8 ± 11.7
Rhanterium suaveolens	B	549.1 ± 411.8	424.1 ± 302.8	282.8 ± 218.1	220.4 ± 156.4
(*n* = 30)	S	74.2 ± 61.3	54.7 ± 27.6	38.7 ± 31.6	28.3 ± 15.5
Haloxylon schmittianum	B	648.2 ± 265.3**	403.2 ± 289.8**	314.8 ± 123.2**	192.5 ± 140.0**
(*n* = 15)	S	177.1 ± 101.0	104.1 ± 93.5	81.2 ± 48.2	46.8 ± 41.3
Haloxylon scoparium	B	992.4 ± 507.5*	599.9 ± 244.2*	505.7 ± 273.6*	306.4 ±126.2*
(*n* = 15)	S	139.6 ± 73.9	102.9 ± 90.9	67.5 ± 40.8	51.20 ± 46.3

for estimating the CC and BV and determining their relationships with the measured DM.

The main results of regression analysis showed comparable highly significant ($p < 0.001$) relationship between CC and DM and between BV and DM, with R^2 ranging from 0.72 to 0.82 and from 0.71 to 0.84, respectively, for all studied species inside and outside the Sidi Toui National Park (Table 3, Figure 3). Similarly, OC content was positively and highly significantly ($p < 0.001$) correlated with CC and BV, with R^2 ranging from 0.74 to 0.8 and from 0.72 to 0.82, respectively (Table 3, Figure 4).

For *A. henoniana*, DM and CC were not as closely correlated (R^2 = 0.72) as DM and BV (R^2 = 0.83). The correlations between OC content and CC (R^2 = 0.76) and OC content and BV (R^2 = 0.81) were more similar. Therefore, the estimated CC of *A. henoniana* seemed to be more closely correlated with BV than with DM and OC (Table 3, Figures 3 and 4). Similar correlations were obtained for *R. suaveolens* between DM and CC (R^2 = 0.75), between DM and BV (R^2 = 0.83), between OC content and CC (R^2 = 0.76) and between OC and BV (R^2 = 0.82). The results for *G. decander* suggested that, both non-destructive methods gave very similar estimations of DM and OC content deduced using CC and BV measurements, with R^2 values of 0.73 (DM and CC), 0.74 (DM and BV), 0.75 (OC and CC) and 0.75 (OC and BV). For *H. schmittianum*, R^2 ranged from 0.71 to 0.80 (Table 3, Figures 3 and 4) with the analysis suggesting that DM and OC content were more closely correlated with CC (R^2 = 0.80 and 0.74, respectively) than with BV (R^2 = 0.71 and 0.72, respectively). The strongest correlations were found for *H. scoparium*, with R^2 ranging from 0.80 to 0.83 (Table 3, Figures 3 and 4). These very similar values suggest that both methods produced more accurate calculations of DM and OC content for this species.

Discussion

The quantification of aboveground plant biomass is necessary when estimating net primary productivity and carbon sequestration potential (Keller et al. 2001; Sampaio and Silva 2005; Daryanto et al. 2013). Generally, protected areas play an important role in carbon sequestration in arid regions (Del Rosario et al. 2012; Castro et al. 2015). In particular, the exclusion of livestock from the Sidi Toui National Park has increased biomass production, spatial heterogeneity, and total vegetation cover (Ould Sidi Mohamed et al. 2002; Tarhouni et al. 2014). Zhang (1998) reported that total canopy cover was highest in protected areas, compared with the freely grazed areas, but the short duration of his study meant he was unable to distinguish between the impacts of grazing and/or climate stress as the main cause of this variation. Based on the current results, aboveground dry biomass and organic carbon content increased in the protected area only for the big canopies of the chenopods *H. schmittianum* and *H. scoparium*. These results suggest that, despite the benefits and multiple ecosystem services offered by the protected areas, long-term protection (for >25 years) can negatively affect vegetation dynamics, especially for some perennial species. Likewise, Louhaichi et al. (2012) reported that despite a notable increase in biomass production during short periods of protection, the difference was not significant for perennials. A negative effect of long-term protection on vegetation dynamics was also reported by Ouled Belgacem et al. (2013a) in some degraded rangelands in Qatar. Yayneshet et al. (2009) reported that in semi-arid rangelands in northern Ethiopia, long-term protection reduced the diversity and biomass of herbaceous species and they considered that short-term exclusion seemed better for plant productivity and diversity. Similarly, Abdallah and Chaieb (2014) found that long-term protection reduced biomass production, but also that continuously grazed areas became dominated by less palatable species.

Grazing behaviour (i.e. grazing intensity, livestock species and numbers), climatic conditions, vegetation type, and phenological stages of species are among the main factors influencing biomass production and carbon content. The response of plants to grazing management depends on the combined effects of all these factors (Chen et al. 2012). It should be noted that among the shrubs evaluated in the current study, *A. henoniana* and *G. decander* are reported to be highly palatable species, *R. suaveolens* and *H. scoparium* are less palatable and *H. schmittianum* is occasionally palatable (Le Houerou and Ionesco 1973).

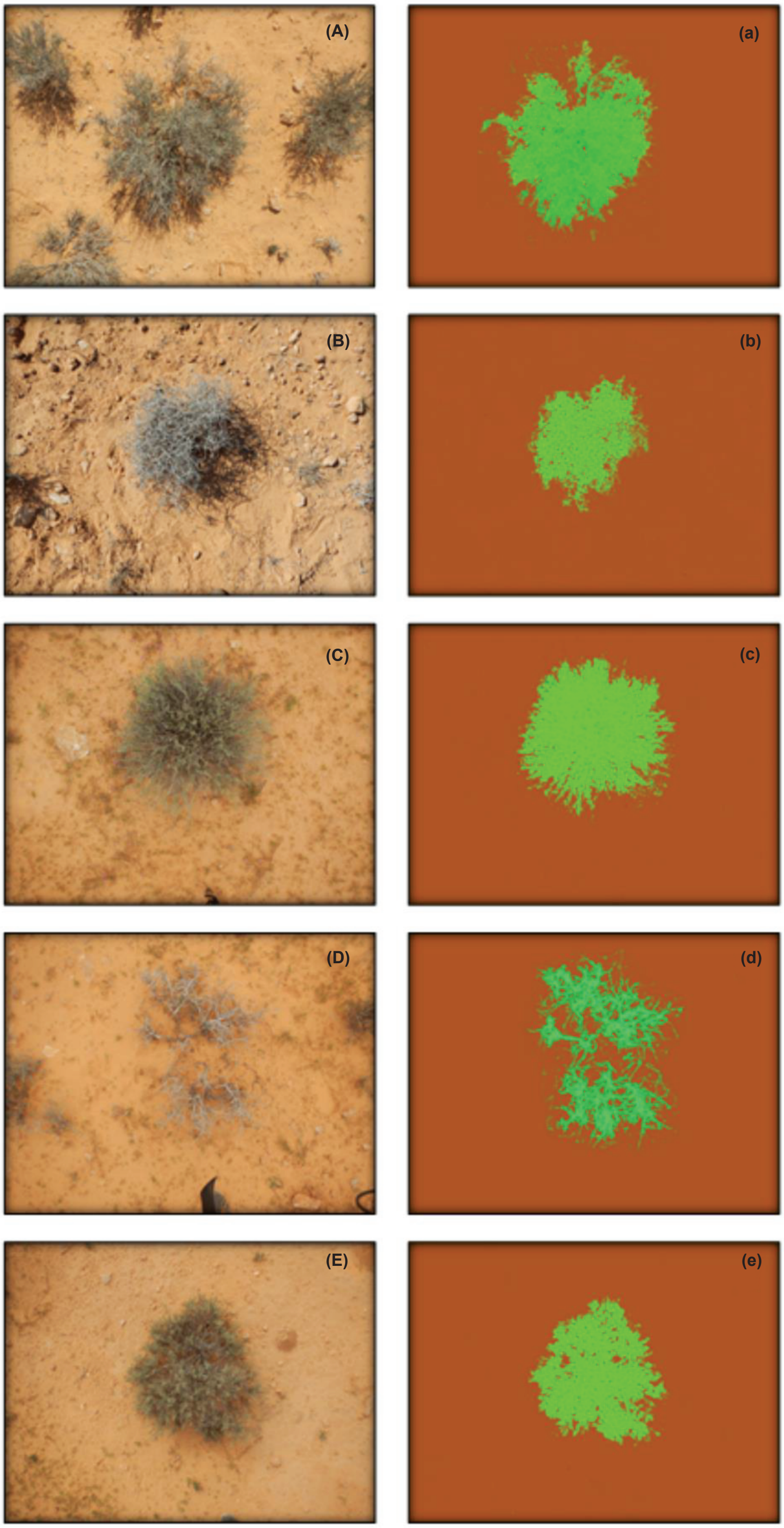

Figure 2: Original (A, B, C, D and E) and VegMeasure software processed images (a, b, c, d and e) of (A, a) *Anthyllis henoniana*, (B, b) *Gymnocarpos decander*, (C, c) *Rhanterium suaveolens*, (D, d) *Arthrophytum schmittianum*, and (E, e) *Arthrophytum scoparium*

Table 3: Regression analysis parameters for the studied plants. DC: aerial dry matter; CC: canopy cover; BV: canopy biovolume; OC: organic carbon content. α is the slope, β is the intercept of the function and R^2 is the coefficient of determination, *** $p < 0.001$

Species		DM*CC	DM*BV	OC*CC	OC*BV
Anthyllis henoniana	α	42.25	3 406.8	23.14	187.1
	β	30.92	25.38	8.11	1 083
	R^2	0.72	0.83	0.76	0.81
	sig	***	***	***	***
Gymnocarpos decander	α	51.29	5 140.9	27.3	2 444.2
	β	16.7	60.1	3.61	30.65
	R^2	0.73	0.74	0.75	0.75
	sig	***	***	***	***
Rhanterium suaveolens	α	33.52	2 993.2	18.6	1 599.1
	β	4.28	−19.5	−5.74	−12.29
	R^2	0.75	0.83	0.76	0.82
	sig	***	***	***	***
Haloxylon schmittianum	α	63.77	6 273.4	31.67	3 033.7
	β	−16.86	10.2	−13.81	13.85
	R^2	0.8	0.71	0.74	0.72
	sig	***	***	***	***
Haloxylon scoparium	α	37.85	3 606	19.51	1 867
	β	−1.38	50.49	−4.56	21.2
	R^2	0.82	0.83	0.8	0.82
	sig	***	***	***	***

It is suggested that this palatability classification, together with the lignification that is characteristic in species of the Amaranthaceae family, explains the higher performance observed in *H. scoparium and H. schmittianum*. This also confirms the finding of Ouled Belgacem and Louhaichi (2013) that these species are of low range value and broad ecological niches, favoured by the impacts of climate change and seemed to be able to survive under future environmental conditions of their adaptation range.

Our results showed that canopy cover and aboveground biovolume measurements were highest for *H. scoparium* and lowest for *G. decander*. These findings suggest that the two non-destructive methods examined (i.e. estimating the canopy cover and the biovolume of the shrub tufts) are strongly related to the aboveground biomass and the carbon content, and highly significant linear relationships were established. The digital imaging method and the size measurement method provided a reasonable estimation of aboveground biomass for the shrub species, giving positive relationships with $R^2 > 0.7$ for all the shrubs studied. This outcome correlates with similar findings in other recent studies in similar arid sites, which confirmed the positive relationship between plant biomass production and vegetation cover (Tarhouni et al. 2016; Louhaichi et al. 2018a), as well as the positive correlation between vegetation biomass and dimensions measurements (Tarhouni et al. 2007; Idi et al. 2009; Yang et al. 2017). The use of vegetation cover and plant dimensions as a tool for studying shrub biomass has the advantage of being non-destructive, easy to use and faster, when compared with the harvest technique (Flombaum and Sala 2007; Idi et al. 2009; Tarhouni et al. 2016; Louhaichi et al. 2018a); and many other researchers have studied the estimation of aboveground biomass carbon through non-destructive methods (Vashum and Jayakumar 2012; Mandal and Joshi 2015).

Accordingly, aboveground biomass can be predicted by measuring only dimensional parameters or by estimating canopy cover. We suggest that these non-destructive methods could be a good alternative to destructive methods for assessing vegetation development or estimating the availability of grazing resources in arid and semi-arid rangelands. They have the added advantage that they can be performed quickly at different times to assess vegetation dynamics for monitoring purposes. In addition, the obtained results are easily archived to ensure maximum data availability for future change analyses (Laliberté et al. 2007; Tarhouni et al. 2016).

For all the species studied, the aboveground organic carbon content for each canopy size class decreased in the grazed site, although this decrease was significant only for *H. schmittianum* and *H. scoparium*. Continuous grazing can decrease vegetation cover, resulting in the loss of aboveground biomass carbon (Li et al. 2018). Therefore, the positive effects of grazing exclusion depend on the widespread degradation of grasslands and the lower baseline of observed indicators (Xiong et al. 2016). Bisigato et al. (2008) reported that several factors, such as climate variations, species composition, degradation threshold, and physical and biological soil conditions, could also lead to the absence of significant changes in carbon levels between grazed and protected sites in some studies. On the other hand, our results corroborate those of Ouled Belgacem et al. (2013b) that palatable species cannot tolerate long-term protection and require moderate grazing to reactivate their growth.

Although these methods offer numerous advantages, they also have some limitations. For example, the digital technique works well for globular or compact shrubs (Louhaichi et al. 2018a), but because the images are taken vertically from above, the aboveground biomass of species

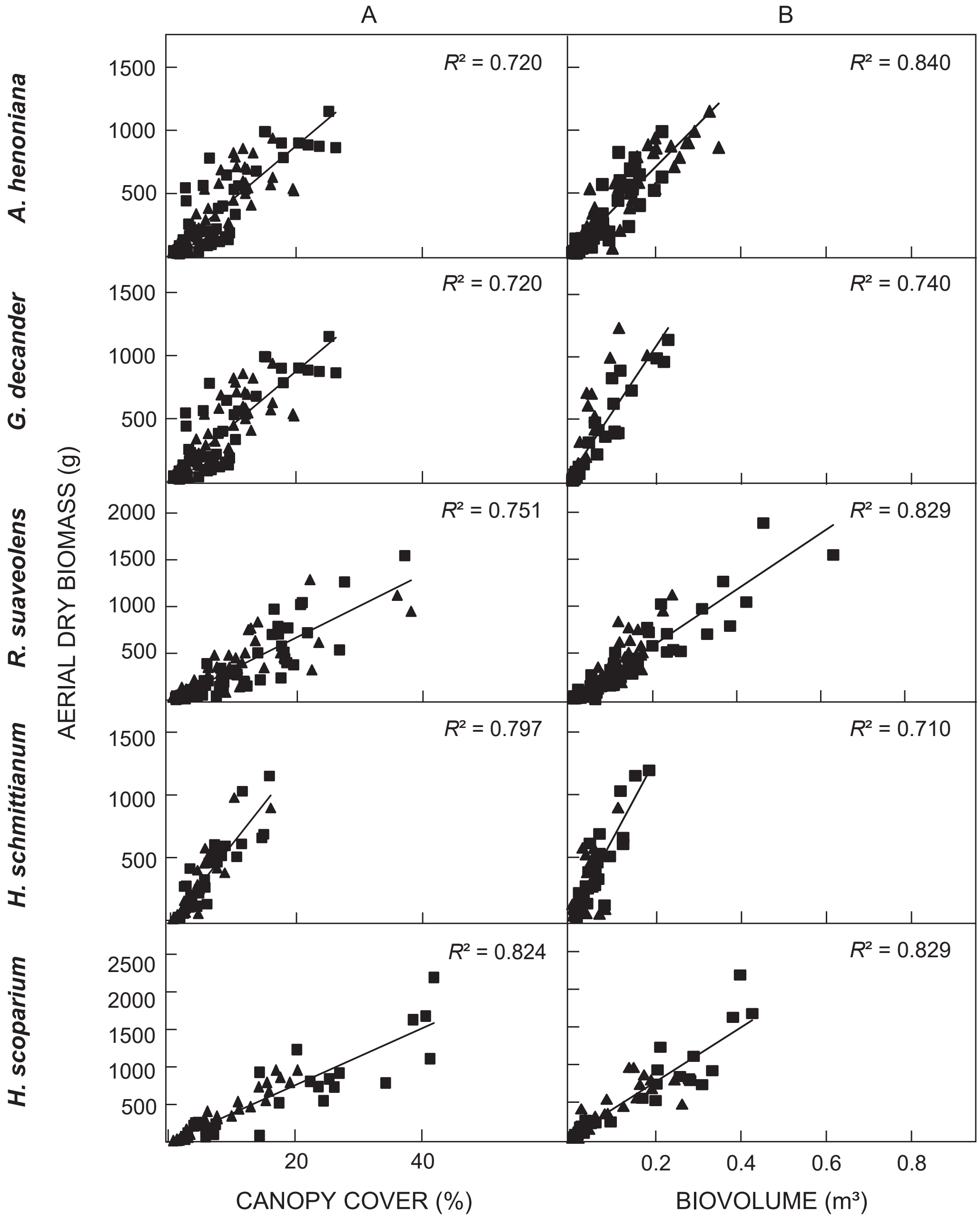

Figure 3: Correlation between (A) aerial dry biomass and canopy cover and (B) aerial dry biomass and biovolume of five abundant species (*Haloxylon schmittianum, Haloxylon scoparium*, and *Gymnocarpos decander* [n = 60] and *Anthyllis henoniana* and *Rhanterium suaveolens* [n = 120]) inside (■) and outside (▲) the Sidi Toui National Park

with a long upright form may be underestimated (Tarhouni et al. 2016). Hence, each species should be separately studied, taking into account the particular growth habit and plant size of each plant community (Hamada et al. 2011).

Conclusion

Assessing the productivity and sustainability of ecological key woody species within arid ecosystems gives an indication of the potential amount of carbon that can be sequestered. The results of this study showed that non-destructive techniques using digital image processing and/or biometric measurement provided a good estimation of aboveground biomass for the shrub species studied, giving positive and significant relationships. Comparison of the aerial biomass and carbon content inside and outside the Sidi Toui National Park indicated a non-significant effect of long-term protection on shrub biomass production and carbon content for the studied species, except of for the big canopies of the low range value chenopods (*H. schmittianum* and *H. scoparium*). Therefore, the results of this study indicate a light grazing regime

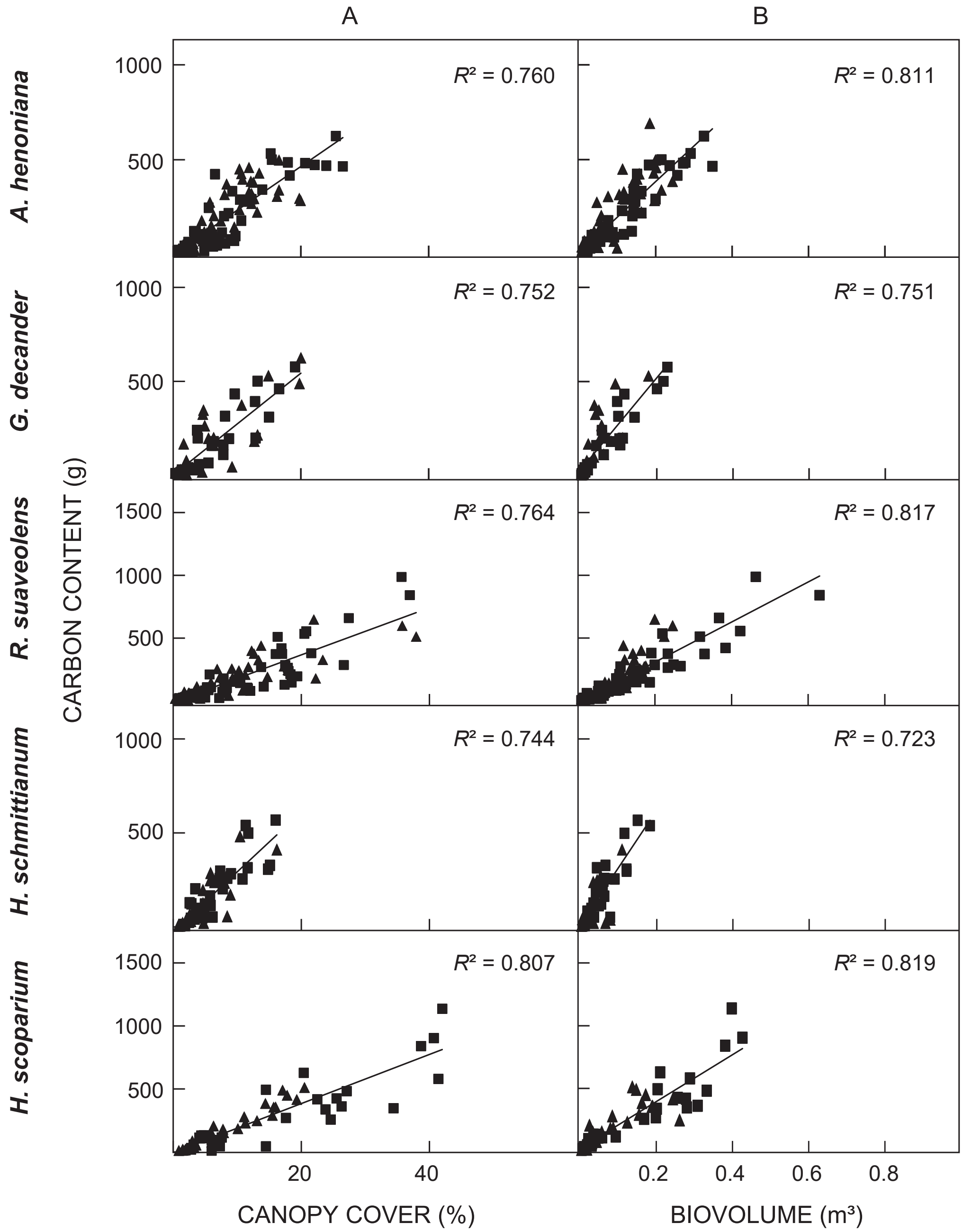

Figure 4: Correlation between (A) carbon content and canopy cover and (B) carbon content and biovolume of five abundant shrub species (*Haloxylon schmittianum, Haloxylon scoparium*, and *Gymnocarpos decander* [n = 60] and *Anthyllis henoniana* and *Rhanterium suaveolens* [n = 120]) inside (■) and outside (▲) the Sidi Toui National Park

of long-term protected areas under arid conditions to reactivate the growth of palatable shrubby vegetation and enhance consequently their resilience and their carbon sequestration potential.

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