Eco-physiological Implications of Conservation of Dhubs (*Uromastyx aegyptius*) in Kuwait

by

Mohammed Al-Sayegh

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Graduate Supervisory Committee:

Dale Denardo, Chair
Michael Angilletta
Andrew Smith
John Sabo
Qais Majeed

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ABSTRACT

Desert environments provide considerable challenges to organisms because of high temperatures and limited food and water resources. Accordingly, desert species have behavioral and physiological traits that enable them to cope with these constraints. However, continuing human activity as well as anticipated further changes to the climate and the vegetative community pose a great challenge to such balance between an organism and its environment. This is especially true in the Arabian Desert, where climate conditions are extreme and environmental disturbances substantial. This study combined laboratory and field components to enhance our understanding of dhub (*Uromastyx aegyptius*) ecophysiology and determine whether habitat protection influences dhub behavior and physiology.

Results of this study showed that while body mass and body condition consistently diminished as the active season progressed, they were both greater in protected habitats compared to non-protected habitats, regardless of season. Dhubs surface activity and total body water decreased while evaporative water loss and body temperature increased as the active season progressed and ambient temperature got hotter. Total body water was also significantly affected by habitat protection.

Overall, this study revealed that, while habitat protection provided more vegetation, it had little effect on seasonal changes in surface activity. While resource availability in protected areas might allow for larger dhub populations, unprotected areas showed similar body morphometrics, activity, and body temperatures. By developing an understanding of how different coping strategies are linked to particular ecological, morphological, and phylogenetic traits, we will be able to make more accurate predictions regarding the vulnerability of species. By combining previous studies pertaining to conservation of protected species with the results of my study, a number of steps in ecosystem management are recommended to help in the preservation of dhubs in the Kuwaiti desert.

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Team Dhub

Mother Amina

Wife Laila

Late father Taher

All my family members in Kuwait

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Introduction

The sustainability of organisms is largely dependent on their adaptations to the specific conditions of the environment in which they live, and this is compromised by natural and anthropogenic disturbances to the ecosystem (Vennila et al., 2014). Habitat destruction, bio-invasion, desertification, and overexploitation can each dramatically affect the delicate balance that enables an organism to exist in its environment. Climate change has major impacts on biodiversity worldwide (Swim et al., 2011). Irrespective of the disturbance, ecosystems exhibit resistance and can return to normality over time. During the times of environmental flux, animals utilize a balance of behavioral and physiological responses to cope with environmental challenges and eventually adapt to the changes (Noy-Meir, 1973).

Deserts are known for having a harsh environment typically characterized by periods of high temperatures, low water availability, and low energy availability, which leads to a low biodiversity and low spatial heterogeneity (Rathbun & Rathbun, 2007; Almedeij, 2014). As deserts have limited resources and biodiversity, any environmental alteration of desert habitat can drastically alter the fine balance that desert species must have with their environment (Abd El-Wahab, 2016). While the outlook of the impact that anthropomorphic change will have, especially on desert systems, is worrisome, the actual effects of such changes are uncertain. In order to persist under such ecological imbalance, desert species must be well adapted to the specific conditions in which they exist. Due to the demand of this precise balance, desert species can be considered to be among the most sensitive organisms toward any change in their environment. Therefore, for predicting the impact of human disturbances, it is imperative to first acquire knowledge of the means by which a species tolerates its environment and adjusts to variation.

Reptiles are the predominant taxon in desert environments because of their ability to tolerate excessive heat and limited water and energy availability. Reptiles play numerous roles within the food webs of most deserts and the negative impacts of human disturbance on their activity will likely create a negative impact on the entire food web. Activity is vital for the acquisition of critical resources to support physiological function, yet it is highly regulated by environmental conditions (Noy-Meir, 1973). Therefore, the location, timing, and duration of activity are extremely plastic, and variation in activity can have dramatic effects on homeostasis (Tews et al., 2004).

The agamid lizard *Uromastyx aegyptius* in the Kuwait desert provides an exceptional study system for examining the impacts of human disturbance because they are a predominant species in a desert that is under substantial pressure from human disturbances. Intense warfare and heavy land use for recreational (i.e., intense, long-term camping) and economic (overgrazing, petroleum, mining) purposes has greatly degraded the natural environment and vegetation of Kuwait (Al-Awadhi et al., 2005; Al-Awadhi et al., 2014; Uddin, 2014). However, over the past couple of decades Kuwait has established several nature preserves where habitat recovery is progressing alongside unprotected areas where habitat destruction persists.

Dhubs, the common local name for *Uromastyx aegyptius*, are the most conspicuous vertebrate in the open desert habitat of the Arabian Peninsula and surrounding desert areas. They are well adapted to the hot, resource-limited, and homogeneous environment in which they live. Dhubs are active during the spring season when daily high temperature are 39-41^{0}C. During the winter, dhubs hide in their burrows (Sarhan & Al-Qahtani, 2007). They have a high heat tolerance capacity, irrespective of limited water availability and seasonally variable food resources (Sarhan & Al-Qahtani, 2007). Dhubs are herbivores and granivores, and primary productivity in dhub habitats is fairly low and displays robust seasonal and annual differences. Therefore, dhubs have evolved a suite of physiological and behavioral adaptations to survive (Cunningham, 2000). However, environmental changes associated with anthropogenic destruction of the habitat along with anticipated climate changes may likely overwhelm the tolerances of the species. To best predict future impacts on the species, it is crucial to understand current impacts on and tolerances of dhub physiological functions such as thermoregulation, energy balance, and water balance. With such knowledge, habitat protection and conservation plans can be optimized to enhance dhub persistence in Middle Eastern or Gulf desert regions (Arnold, 1984).

With this intent, I examined the impact of environmental quality on seasonal patterns in dhub activity, thermoregulation, and body condition. To achieve this goal, I radio-tracked dhubs for the majority of an active season at two pairs of sites, each pair having adjacent protected and heavily distributed dhub populations. The resulting data provide information on the general impacts of habitat alteration, while the seasonal data provide insight into how dhubs may respond to anticipated increases in temperature associated with global warming.

Materials & Methods

Study area description

Kuwait has a typical arid climate characterized by a long, hot, and dry summer, short winter, wide range of temperature, and low amount of precipitation with a great irregularity in time and space (Abd El-Wahab, 2016). Average temperature in July, which is the peak of summer in Kuwait reaches 38.2°C, while average maximum temperature during the same month reaches 45.6°C. In winter, the average temperature in January, which is the peak of winter in Kuwait, is around 12.7°C, while average minimum temperature during the same month is around 7.5°C as reported by the Environmental Public Authority (EPA) in 2012. Annual rainfall varies between 30 and 250 mm, the vast majority of which falls in winter and spring (Halwagy et al., 1982). The mean annual rainfall for the period 1985–2002 was 128 mm. Relative humidity reaches 60% in winter and 20% in summer. The evaporation rate ranges from 4.6 mm/d in January to 22.9 mm/d in June. Wind is mostly northwest with an annual average speed of 13.6 km/h. Dust and sand storms prevail over the area. About 50% of dust storms occur in May, June, and July (El-Baz & Al Sarawi, 2000; Almedeij, 2014).

The fieldwork was conducted at two paired locations – one pair near Liyah, governorate of Jahra, 80 km northwest of Kuwait City, and one near Kabd, governorate of Farwaniyah, 30 km southwest of Kuwait City. Each pair consisted of complimentary protected and non-protected sites (Illustration 1). While both the Liyah and Kabd protected areas have restricted accessibility, there are differences in the state of their recovery. The Liyah protected area was created in 1996 after serving for many years as a gravel quarry, while the Kabd protected area was established in 1979. The Kabd protected area (Sulaibiya Field Station) is a research station owned and operated by Kuwait Institute for Scientific Research (KISR) where many research projects including agricultural research experiments have been carried out. Due to the extent of destruction prior to the commencement of protective measures, the Kabd protected area has a greater diversity of vegetation cover. In addition, the Liyah protected area has subjected to several cases of intentional trespassing and infringements by local inhabitants particularly herders. Regardless, both protected sites at Liyah (LI) and Kabd (KI) have superior vegetation compared to their non-protected counterpart study sites (LO and KO, respectively). Both un-protected areas show major human disturbance as exemplified by the post-camping season damage including off-road vehicles tracks, burned tires, waste, and physical disruption to the ground. Both unprotected areas also show extensive disturbance from extensive grazing by camels and sheep/goats (shoats). Human disturbance appears to be more severe in the non-protected section of Kabd due to the fact that this area is occupied by camel and shoat pens with very high and consistent human traffic.

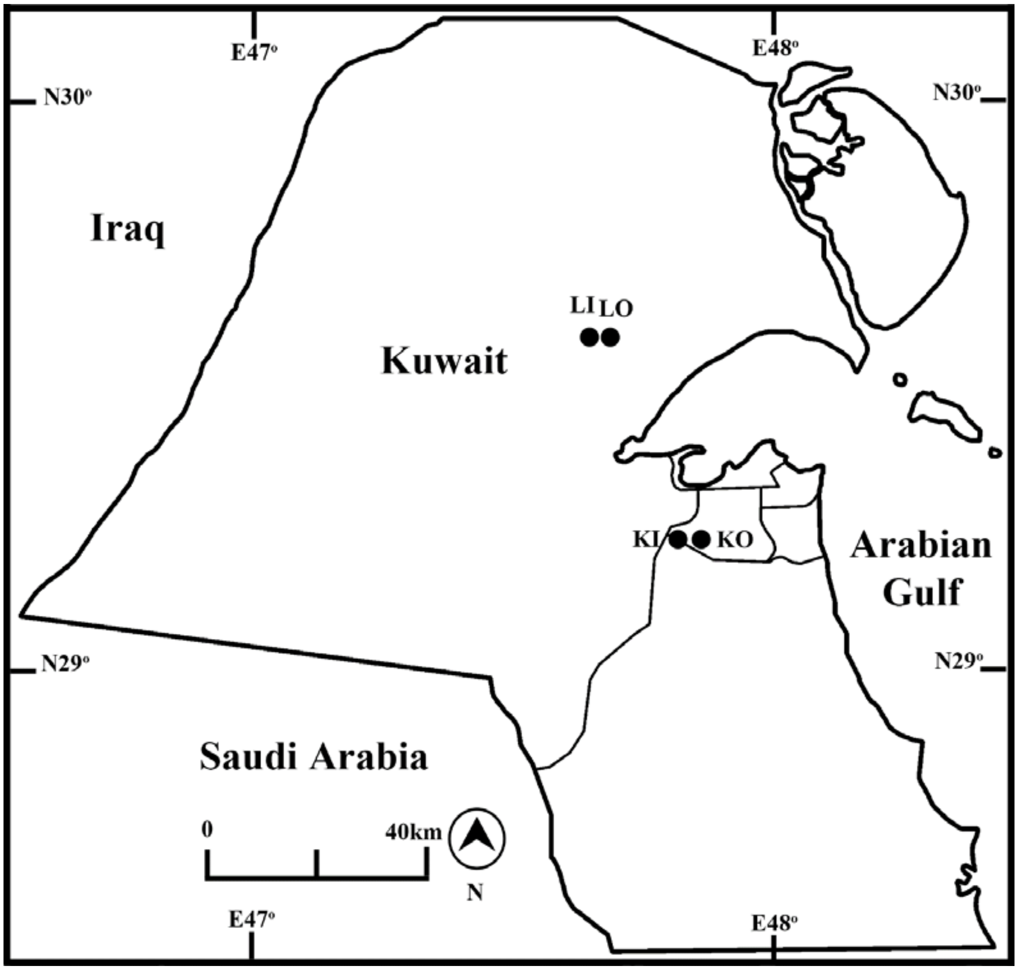

Illustration 1. Map showing study field locations. LI: Liyah protected habitat “Liyah inside”. LO: Liyah non-protected habitat “Liyah outside”. KI: Kabd protected habitat “Kabd Inside”. KO: Kabd unprotected habitat “Kabd Outside” (KO).

The desert in Kuwait ranges from semi-heterogeneous to homogeneous, characterized as open scrub consisting of perennial shrubs that resist drought and annual forbs (Al-Awadhi et al., 2005). In general, the Liyah area is largely covered by a gravel plain, which is mainly attributed to the occurrence of the gravely outcrops in northern Kuwait. Conversely, the Kabd area is covered by a sandy plain composed of smooth and rugged vegetated sand sheets (El-Baz & Al Sarawi, 2000). Sand sheets are sandy plains formed by wind that consist mainly of flat to low angle eolian stratification. They commonly exist on the margins of dune fields or between belts of dunes within a sand sea. Smooth sand sheets have relatively flat surfaces, sometimes covered with a very thin veneer of residual granules. In most cases, they have a unidirectional ripple surface, indicating the northwesterly prevailing wind direction, subsequently covered with some patches of residual gravels (Al-Hurban, 2014). Most of the western and southern parts of Kuwait were covered by rugged vegetated sand sheets, which were developed due to the coalescence of nebkhas or phytogenic mounds. Such areas were distinguished due to their dense to moderate vegetation cover (Khalaf et al., 1984).

The study was conducted from early April to mid-August in 2014 (spring to summer), when dhubs are most active (Sarhan & Al-Qahtani, 2007). The major sites were chosen on the basis of their similar topography and the pairs based on their proximity to each other (separated by 3 km and 7 km, for Liyah and Kabd, respectively, between the closest dhub burrows chosen in the protected and non-protected habitats. Using a paired design, I could assess the effect of protection on seasonal patterns in dhub ecophysiology and surface activity.

Because of the proximity of the paired protected and non-protected habitats and the more secure nature of the protected habitats, I limited air temperature monitoring to the protected habitats. At both protected habitats, shaded air temperature (T_a) one meter above the ground was recorded every half hour using a temperature logger (Thermochron iButton, Maxim, Dallas, TX). To minimize the effect of solar radiation on the loggers, they were placed in a stainless steel mesh tea ball and hung inside an upside down plastic plant pot in a shaded location.

Animal capture and processing

The study was performed in accordance with Arizona State University's (ASU) Institutional Animal Care and Use Committee (IACUC) protocol 12-1244R and was partially funded by Kuwait Foundation for the Advancement of Science (KFAS) under project code "P114-62SL-01". I captured 36 adult dhubs (21 males and 15 females), nine from each of the four habitats. The geographical location of the 36 burrows (latitude, longitude, and elevation) was measured with a global positioning system device (Lowrance iFINDER Explorer, Lowarnace, Tulsa, OK). Dhubs were captured using metal mesh gravity action trigger traps placed at the entrance of a burrow into which a dhub was seen retreating (Photograph 1). A board was then placed on top of the trap to prevent the dhubs from overheating while in the trap. Each captured dhub was marked with a unique identifier number, transferred to a secure transport cage, and taken to our lab at the Basic Education College in Ardiya for processing. At the lab, each dhub was anesthetized with isoflurane, and a 0.4 ml blood sample was drawn from the caudal vein to be used as a part of a complimentary study. Following the procedure described in Taylor et al., (2004), I surgically implanted a 13 g radiotransmitter (SI-2T, Holohil, Carp, Ontario, Canada) and a 3.1 g temperature datalogger (Thermochron iButton, Maxim, Dallas, TX) into the dhubs. Prior to implanting, the dataloggers were programmed for collecting data every half hour and were coated in immunologically inert PlastiDip (PlastiDip International, Blaine, MN). By using an automated temperature logger, I was able to serially sample their body temperatures for an extended period of time at four habitats simultaneously, while avoiding complications associated with non-random sampling (Taylor et al., 2004).

Photograph 1. Dhub in a metal mesh gravity action trigger trap placed at the entrance of the lizard's burrow. The cover board that provided shade has been removed for the picture.

After surgery but before recovery from anesthesia, I measured each dhub's body mass (using an electronic platform scale), snout-vent length (SVL, using a cloth measuring tape) and tail volume (using water displacement). Evaluating the tail volume is significant as it is a good indicator of energy reserves. Unlike body mass, gut contents do not influence tail volume measurements (Pough, 1973). Dhubs were retained for ~12 hours (e.g., overnight) before each was returned to the burrow at which it was captured. However, before release, a second 0.4 ml blood sample was drawn from the tail vein. The entire process was repeated in mid-August to remove the implanted electronics and get end of study morphometric data.

Radiotelemetry and estimates of surface activity

Dhubs were radio tracked twice per week, with the time and GPS coordinates recorded each time to determine the number of burrows utilized by each dhub. Nine animals were lost during the study to mortality, dispersal, or failed transmitters, limiting the end-of-season retrieval of temperature data to 27 dhubs (17 males and 10 females).

Using the ambient and body temperature data, I calculated surface activity based on temperature-based activity estimation (TBAE). TBAE compares ambient and body temperatures using a pre-determined set of criteria to determine whether the animal was active on the surface or in a refuge at each recorded time point (Davis et al., 2008). TBAE is 95% accurate in determining surface activity for another large, burrow-occupying desert lizard (Gila monster, *Heloderma suspectum*; Davis et al., 2008). Using TBAE, I calculated the following variables: proportion of days with surface activity, proportion of days with morning surface activity, proportion of days with afternoon surface activity, proportion of days with both morning and afternoon surface activity, proportion of time surface active, average overall surface activity duration, average surface activity duration during the morning, average surface activity duration during the afternoon, average overall body temperature (T_b), average T_b when surface active, average T_b when in refugia, and average daily maximum T_b. To evaluate seasonal effects on these variables, raw data were grouped into nine two-week periods.

Vegetation Survey

Vegetation surveys were conducted at all four study habitats in April and June of 2014. A total of 115 plots (5m × 5m each) were selected randomly in the study areas close to the active burrows (within a 5-meter radius) and in the interspace areas (at least 30 meters away from active burrows). At each plot, species richness (number of plant species) and abundance (number of individuals of each species) were counted, and density (total number of individuals divided by number of plots) was estimated. Relative density of each species was calculated according to the following equation:

$$Relative\ density\% = \frac{Density\ of\ species}{Total\ densities\ of\ all\ species} \times 100$$

Vegetation cover percentage was estimated visually (0 = no vegetation, <1% = very low vegetation, 1-10% = low vegetation, 10-30% = medium vegetation, >30% = high vegetation). Identification, nomenclature, growth form (annual herb, annual grass, perennial herb, sub-shrub, and shrub), and importance (fodder, fuel-wood, medicinal) of plant species were designated according to Tackholm & Drar (1956), Daoud & Al-Raevi (1985), Boulos (1988), and Omar et al., (2000). The nature of the soil surface was described visually using the following scale: fine sand <0.2mm, coarse sand 0.2-2mm, and gravel 2-7.5 mm (Brady and Weil, 1999).

Human disturbance intensities (e.g., camping, grazing, solid wastes, off-road driving) were recorded for each locality. Quantitative grazing intensity was determined for each locality based on the following grazing scale: 1 = very low grazing; 2 = low grazing, 3 = medium grazing, and 4 = high grazing (overgrazing). Scale assignment was based on the following data collected from each locality: (1) vegetation cover; (2) the ratio of fodder and non-fodder plant species; (3) browsing percentage and (4) camel and shoat feces and their level of moisture content which reflects number of visits.

Statistical Analyses for the Temperature Based Activity Estimates (TBAE)

The effect of status (protected versus non-protected) and sampling period on our various response variables was evaluated by including these main effects along with their interaction as fixed-effects in a linear mixed-effects model. When appropriate (as determined by our model selection procedures, see below), I controlled the sex of the individual dhubs by including sex as a covariate in the fixed-effects component of our models. I also included individual animals as a random effect in our models by conducting repeated measures on each animal. Finally, when the habitat was a significant predictor of the response variables and including it in the random-effects structure provided the most appropriate model for our random-effects structure (see our model selection procedures below), I included a random-effects term where the animals were nested within their habitats. This measure allowed us to control the possible impact of the habitat on our response variables.

Response variables

The response variables for our analyses were the overall time active, hours active daily, hours active AM, hours active PM, T_b overall, T_b while active, T_b while in a refuge, T_b active AM, T_b active PM, T_b max, body mass, and tail volume. As some of the response variables violated the basic assumptions of normality, wherever necessary, I transformed our data using either logarithmic (overall time active), square root (hours active daily and hours active PM), or the reflection of the logarithmic transformations (T_b active AM and T_b active PM) prior to conducting further analyses.

Regression analyses

I performed a preliminary analysis on the impact of fixed-effects, covariates, and potential interactions on the defined response variables. Fixed-effect terms that independently had a significant impact on our response variable were included in our baseline models. This analysis considered only those animals that had a complete data set.

Model selection procedure

Following the approach determined by Zuur et al. (2009), I began the analysis by constructing a linear mixed-effects model with all the possible main effects, covariates, interactions, and random error fitted by restricted maximum likelihood (REML) using the “nlme” library (Pinheiro et al., 2007) of the R statistical package. I then compared this model to a generalized least squares model with all the possible main effects, covariates, and interactions fitted with REML, but without random error. I then refitted the linear mixed-effects model with all the possible main effects, covariates, and interactions as well as the appropriate random-error model structure and refitted the models using maximum likelihood (ML), after which I determined the optimal fixed-effects structure of our models using the MuMIn package (Barton, 2012).

Akiaike's information criterion, corrected for small sample sizes, (AICc, Anderson et al., 2001) was deployed on the linear mixed-effects regression models for identifying the fixed-effects variables that explain our results in the most adequate manner. AICc values were also used to rank models, where the lowest AICc values represented the best fitting models. Using AICc values, I calculated the differences among the AICc values associated to the best model (ΔAICc) and Akaike weights (ωi). Large ΔAICc values indicate that the models are less likely to explain differences in the response variables as compared to the models that have ΔAICc < 10 and are considered as poor models (Burnham and Anderson, 2004). ωi are used to compare models, as they are an approximation of the probability that a given model is the best-fitting model from the observed data. Thus, larger ωi are indicative of better fitting models. AICc analyses were conducted on the models by using the MuMIn package with the optimal random-effects structure fitted with ML in R (Barton, 2012). The models with both the optimal random- and fixed-effects structure were refitted with REML and then the significance tests were conducted by following the procedures laid out in Zuur et al. (2009).

Statistical Analyses for the Body Mass and Tail Volume Estimates (BMTVE)

The effect of status (protected versus non-protected) on initial and final estimates of body mass and tail volume was evaluated by including the effect of status as a factor variable and body mass and tail volume estimates as dependent variables in the one-way multivariate analysis of variance (one-way MANOVA) using SPSS Statistics (version 21). General linear model (GLM) multivariate analysis or one-way MANOVA is used to determine whether there are any differences between independent groups on more than one continuous dependent variable. GLM multivariate analysis provides regression analysis and analysis of variance for multiple dependent variables. A Tukey test was applied for Post-hoc range tests and multiple comparisons.

Results

General description of habitats and disturbance

At both Liyah and Kabd, the ambient temperature consistently increased over time, reflecting expected seasonal changes from spring to summer. In general, variations in air temperature between localities were non-significant. The overall mean daily high temperature was 38.2ºC in Liyah and 37.9ºC in Kabd. Also, the overall mean maximum temperatures per sampling period were 47.3ºC in Liyah and 45.9ºC in Kabd. Total rainfall from April 1 to September 30, 2014, was only 2.27 mm, and, for the entire year, it was 73.69 mm at the Kuwait Meteorological Center located at Kuwait International Airport.

The Liyah protected site (LI) consists of vegetated smooth sand sheets mixed with scattered micro-nebkhas, small mounds of fine sand, silt, and clay formed around few perennials such as *Convolvulus oxyphyllus* and *Rhanterium epapposum*. Some patches in LI are covered by either coarse sand and gravel with medium vegetation or gravel plain with low vegetation. The Liyah non-protected site (LO) is mainly covered by a gravel plain, sometimes mixed with patches covered by coarse sand and gravels. Vegetation cover at LO is mainly very low. Some patches of LO are virtually clear of vegetation. Medium intensity of grazing and camping activities occurred at the LO site (Table 1).

The Kabd protected site (KI) is mainly characterized by high vegetation. Most of the area of KI is covered by fine grain sandy plain mixed in some parts with coarse sand to gravel surface. Calcareous sediments were recognized around some burrows. Sandy plain in some part composed of rugged sand sheets due to abundance of nebkhas formed around shrubs such as *Lycium shawii* and micro-nebkhas around sub-shrubs such as *Cornulaca monacantha, Convolvulus oxyphyllus*, and *Rhanterium epapposum*. The non-protected Kabd site (KO) is covered by smooth sand sheets composed of fine grains, loose sands, and unidirectional ripple surface, indicating the northwesterly prevailing wind direction. Habitats in KO are characterized by low vegetation cover and high intensity of grazing and camping activities (Table 1). The vegetation community of protected habitats was considerably greater in cover than non-protected habitats; however, KI was more diverse than LI. On the other hand, KO was lower in species richness and higher in vegetation cover than LO.

Grazing activity was low in LI and very low in KI, however grazing was higher in KO than LO. Signs of grazing in non-protected areas, particularly KO, included the presence of camels, shoat feces of differing moisture levels and a high percentage of browsing on certain species such as *Cyperus conglomeratus, Moltkiopsis ciliata*, *Rhanterium epapposum,* and *Convolvulus oxyphyllus.* Several signs of high disturbance due to camping activity and solid wastes were also recognized in non-protected habitats (Table 1). The effect of habitat protection on variation in minimal distance between dhub burrows was significant ($F_{3,15}$ = 5.327, p = 0.011). Dhub burrows were located closer to each other in protected habitats, particularly in KI, than in non-protected habitats (Table 1).

Table 1. Variations in disturbance intensity and grazing indicators in protected and non-protected habitats in Liyah and Kabd.

Variable	LI	LO	KI	KO
Total number of recorded plant species	16	16	30	8
Fodder species	13	10	25	7
Non-fodder species	3	4	5	1
Fodder:non-fodder	4.3	2.5	5	7
Vegetation cover (%)	30-40%	<1%	50-70%	1-5%
Browsing	very low	medium	very low	high
Camel/shoat feces amount	none	low	none	high
Camel/shoat feces	none	Very dry and	none	Very dry, dry,
Grazing	low	medium	v. low	high
Camping disturbance	none	medium	none	high
Solid wastes	none	medium	none	High
Pens for camels, sheep and	none	medium	none	high
Agricultural research	none	none	medium	Low
Average minimum distance between burrows (m)	240	270	174	238

Plant species composition and relative density

Forty-six plant species, which belong to 17 plant families, were identified in this study. The most representative plant family is Asteraceae (8 species) followed by Poaceae (7 species). Annuals represent 47.8% of the recorded species (Table 2). Perennials consist of four different growth forms; perennial herb (6 species), perennial grass (6 species), sub-shrubs (9 species), and shrubs (2 species).

KI supports a higher diversity of vegetation composition (30 species) than does KO (8 species). While this difference suggests, in general, that protected habitats are rich in vegetation composition compared to unprotected habitats, this was not clear for Liyah where vegetation community consisted of 16 species at both LI and LO.

Based on values of relative density, vegetation communities of protected habitats were characterized by the dominance of *Plantago ciliate* and *Plantago lanceolata* in LI, and *Filago pyramidata* and *Plantago boisseri* in KI (Table 2). In non-protected habitats, the dominant species were *Schismus barbatus, Stipagrostis plumose*, and *Fagonia bruguieri* in LO, and *Ifloga spicata* and *Schismus barbatus* in KO.

Table 2. List of recorded plant species and their growth form, uses, and relative density at all four sites.

No.	Plant Species	Growth Form	Uses*	LI	LO	KI	KO
				Relative Density%			
	Family: Asteraceae						
1	*Atractylis carduus* (Forssk.) C. Chr.	Perennial herb	-	0	0.537	0.035	0
2	*Carduus pycnocephalus* L.	Annual herb	F,O	0	0	0.047	0
3	*Filago pyramidata* L.	Annual herb	F	0	2.326	35.359	4.322
4	*Ifloga spicata* (Forssk.) Sch.Bip.	Annual herb	F	0	7.692	16.501	29.846
5	*Launaea angustifolia* (Desf.) Kuntze.	Annual herb	F	0	0	0.088	0
6	*Launaea mucronata* (Forssk.) Muschl.	Perennial herb	F	0	0.179	0	0
7	*Rhanterium epapposum* Oliv.	Sub-shrub	F, FU	0.165	0	0.495	0.34
8	*Senecio glaucus* L.	Annual herb	F	0.952	0	2.057	0
	Family: Boraginaceae						
9	*Heliotropium bacciferum* Forssk.	Sub-shrub	M, FU	0	0	0	0
10	*Moltkiopsis ciliata* (Frossk.) I.M.Johnston	Perennial herb	F	0	0	0	3.471
	Family: Brassicaceae						

11	*Brassica tournefortii* Gouan	Annual herb	F	3.515	0	0.13	0
12	*Cakile arabica* Velen. & Bornm.	Annual herb	F,O	0	0	0.206	0
13	*Farsetia aegyptia* Turra	Sub-shrub	F	0.051	0	0.041	0
14	*Malcolmia grandiflora* (Bunge.) Kuntze.	Annual herb	F	0	0	0.0295	0
15	*Neotorularia torulosa* (Desf.) Hedge & J. Leonard.	Annual herb	F	0.076	0	0	0
16	*Savignya parviflora* (Delile) Webb.	Annual herb	F	0	0	1.061	0
	Family: Caryophyllaceae						
17	*Gypsophila capillaris* (Forssk.) C.chr	Perennial herb	F	1.231	1.431	0.442	0
18	*Loeflingia hispanica* L.	Annual herb	F	2.601	0	0	0
19	*Polycarpaea repens* (Forssk.) Asch. & Schweinf.	Annual herb	F	0	0	0	0.613
	Family: Chenopodiaceae						
20	*Cornulaca monacantha* Delile.	Sub-shrub	F,M	0	0	0.130	0
21	*Haloxylon salicornicum* (Moq.) Bunge ex Boiss.	Shrub	F,M	0	0.179	0	0
22	*Salsola imbricata* Forssk.	Sub-shrub	M	0	0	0.071	0

23	*Suaeda vermiculata* Forssk.ex J.F. Gmel.	Sub-shrub	F	0	0.179	0.012	0
	Family: Cistaceae						
24	*Heliathemum lippii* (L.) Dum. Cours.	Sub-shrub		0.634	0	0	0
	Family: Convolvulaceae						
25	*Convolvulus oxyphyllus* Boiss.	Sub-shrub	F,O,M	0.127	3.041	0	0
	Family: Cyperaceae						
26	*Cyperus conglomeratus* Rottb.	Perennial grass	F	0	0	0	2.185
	Family: Fabaceae						
27	*Astragalus annularis* Forssk.	Annual herb	F	0	0	0	0.007
28	*Astragalus spinosus* (Forssk.) Muschl.	Sub-shrub	O	0.076	0.537	0	0
	Family: Liliaceae						
29	*Asphodelus tenuifolius* Cav. Baker	Annual herb	O	0	0	0.006	0
	Family: Malvaceae						
30	*Malva parviflora* L.	Perennial herb	F	0	0	0.018	0
	Family: Neuradaceae						
31	*Neurada procumbens* L.	Annual herb	F	0	0	0.707	0
	Family: Orobanchaceae						

32	*Cistanche tubulosa* (Schrenk.) Wight	Annual herb	M	0	0	0.024	0
	Family: Plantaginaceae						
33	*Plantago boissieri* Hausskn. & Bornm.	Annual herb	F	0	0.895	34.769	0
34	*Plantago ciliata* Desf.	Annual herb	F	35.376	0.895	0	0
35	*Plantago coronopus* L.	Annual herb	F	16.470	4.293	0.501	0
36	*Plantago lanceolata* L.	Perennial herb	F	25.378	0	0	0
	Family: Poaceae						
37	*Cenchrus ciliaris* L.	Perennial grass	F,O	0	0	0.589	0
38	*Cenchrus setigerus* Vahl.	Perennial grass	F,O	0	0	0.589	0
39	*Panicum turgidum* Forssk.	Perennial grass	F	0	0	0.006	0
40	*Pennisetum divisum* (Gmel.) Henrard.	Perennial grass	F	0	0	0.707	0
41	*Schismus barbatus* (L.) Thell.	Annual grass	F	0.749	24.329	4.715	59.216
42	*Stipa capensis* Thunb.	Annual grass	F	0	0	0.324	0
43	*Stipagrostis plumosa* (L.) Munro ex T. Anders.	Perennial grass	F	5.152	28.623	0.336	0
	Family: Solanaceae						

44	*Lycium shawii* Roem. & Schult	Shrub	F	0	0	0.006	0
	Family: Zygophyllaceae						
45	*Fagonia bruguieri* DC.	Sub-shrub	m	7.448	24.508	0	0
46	*Tribulus terrestris* L.	Annual herb	M	0	0.358	0	0

*: F= fodder, FU = fuel wood, O = ornamental, M = medicinal.

Body Condition

Tail volume (TV)

The differences in TV between protected and non-protected habitats were significant (Table 3). Average values of initial and final TV of dhubs were higher in protected habitats compared to non-protected ones. However, initial and final TV values between LI and KI, and between LO and KO were non-significant (Table 3).

There was a significant effect of both SVL and period (period *p*-value < 0.01; SVL *p*-value < 0.01) on tail volume. Analysis showed no significant effect of habitat, sex, or the interaction between sampling period and habitat on tail volume. TV percentage loss at LO was less than TV percentage loss at LI (15.3% for LO vs. 28.7% for LI), and TV percentage loss at KO was less than TV percentage loss at KI (18.5% for KO vs. 21% for KI). However these variations were not significant according to analysis of variance (Table 3). As expected, TV was significantly affected by SVL with longer dhubs having greater tail volume (Figure 1). Data analysis controlling for SVL using residuals of a SVL-tail volume regression revealed that the initial tail volume was significantly higher than the final tail volume.

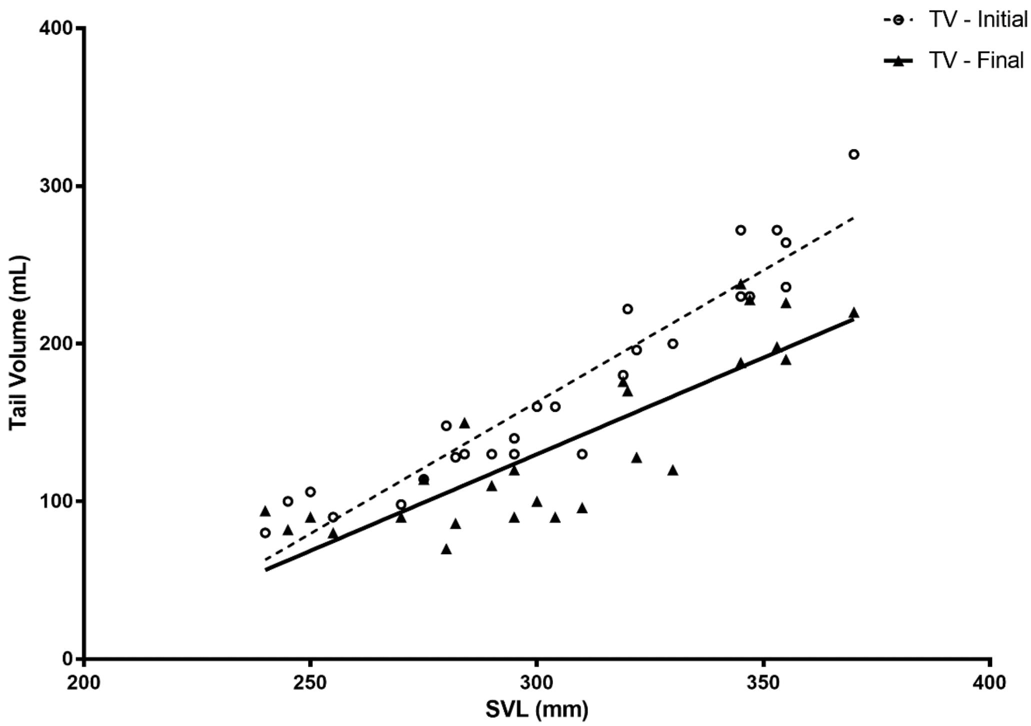

Figure 1: Effects of SVL and period on tail volume. Initial tail volume was significantly higher than final tail volume.

Body mass

Differences in body mass between protected and non-protected habitats were significant (Table 3). Average values of initial and final body mass of dhubs were higher in protected habitats compared to non-protected ones. percentage mass loss at LO was less than percentage mass loss at LI (28% for LO vs. 40% for LI) and percentage mass loss at KO was less than percentage mass loss at KI (28% for KO vs. 30% for KI).

There was a significant effect of sex, SVL, and period on body mass (period p-value < 0.01, SVL p-value < 0.01, sex p-value <0.027) (Figure 2). Even with controlling for SVL, males had greater mass than females. The starting mass of dhubs was significantly higher than their final mass at both protected and non-protected sites. Also, the starting body mass of dhubs in protected areas was higher than those in the non-protected area. The body mass of dhubs in protected areas experienced a higher rate of decrease as compared to dhubs in non-protected areas. Therefore, the habitat of dhubs has a significant overall impact on body mass.

The results of a one-way MANOVA showed that there was a statistically significant difference in body mass and tail volume based on protected and non-protected habitats , F (12, 47.9) = 3.25, p = 0.002; Wilk's Λ = 0.207.

Table 3. Average body mass tail volume and total average tail volume loss at the different sites. Similar letters within a given variable indicate no significant variation according to Tukey test.

Variable	LO	LI	KO	KI	$F_{3,21}$	P
Initial body mass (g)	835.6^{a}	1394.2^{b}	911.2^{a}	1511.9^{b}	10.341	< 0.0005
Final body mass (g)	585.4^{a}	$826.6b^{c}$	649.8^{ab}	1050.4^{c}	8.031	0.001
Initial tail volume (ml)	122.0^{a}	202.4^{b}	125.0^{a}	245.7^{b}	14.933	< 0.0005
Final tail volume (ml)	104.0^{a}	146.8^{ab}	103.3^{a}	193.1^{b}	7.085	0.002
% TV Loss (Average)	15.3	28.7	18.5	21	0.840	0.486

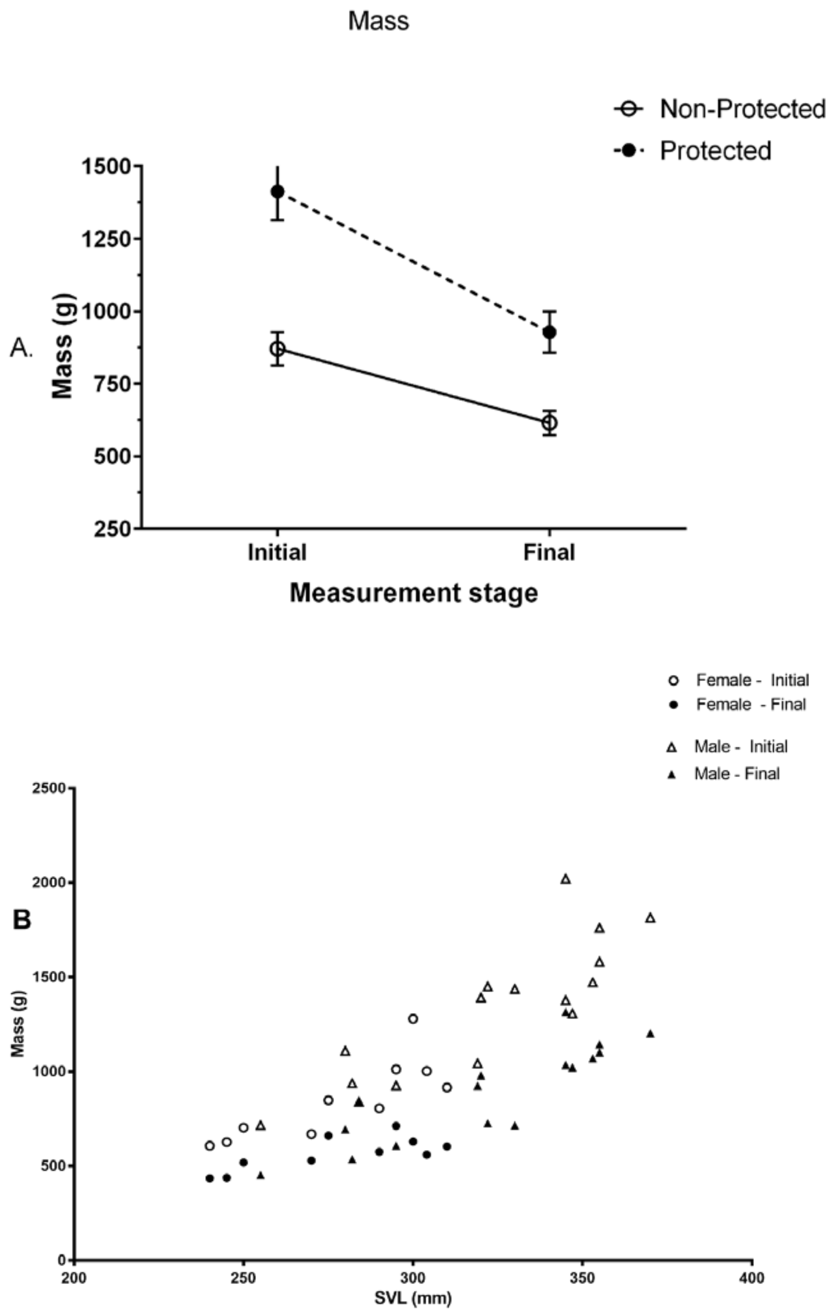

Figure 2: (A) The effects of period and habitat protection on dhub mass. The dhubs lost mass over time, and there was a significant effect of habitat on body mass. Dhubs inside a protected area started with higher body mass when compared with dhubs from non-protected area. (B) The effects of sex, SVL, and period (period p-value < 0.01; SVL p-value < 0.01; sex p-value <0.027) on mass. On average, males are larger and heavier than females and initial mass was significantly higher than final mass.

Surface activity

Overall, dhubs were active 17.8% of the time from April to August. There was a significant effect of period ($F_{8,175}$ = 44.39, *p*-value < 0.01), but no effect of habitat ($F_{1,2}$ = 2.32, *p*-value = 0.27), on all 10 different variables of dhub's activity (Figure 3). Dhubs were more active in the early period of the season (from April to May) than the late period (from May to August).

Detailed statistical analysis within different habitats in Kabd and Liyah area showed significant effect of protection on three variables of surface activity Overall Time Active (OTA), Average Daily Activity (ADA), and Average AM Activity (AAA) (Table 4).

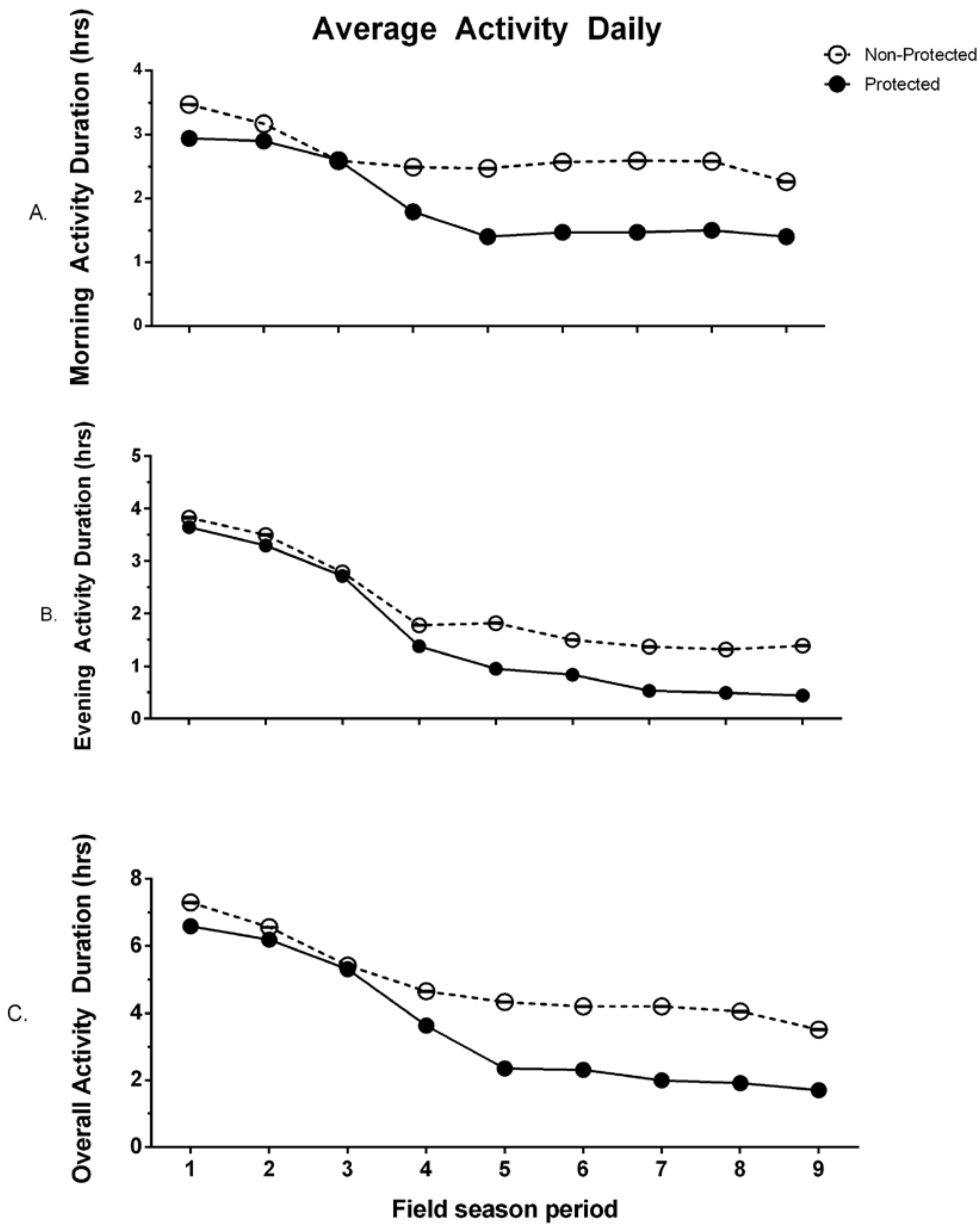

Figure 3: The effect of season on average activity duration. Graphs A & B show the average duration that dhubs were active during the mornings and evenings, respectively. As season progressed, the activity times stabilized and remained constant. Graph C shows the overall time active. Over the course of the field season, dhubs inside the protected areas decreased their overall activity time more than dhubs in non-protected area.

Table 4. Variations in average values of different activity time variables of dhubs in different habitats based on statistical analysis. Similar letters within a given variable indicate no significant variation according to Tukey test.

Variable	LO	LI	KO	KI	$F_{3,48}$	*P*
OTA	68.21^{b}	58.16^{ab}	63.87^{b}	38.16^{a}	4.738	0.006
ADA	5.191^{b}	4.42^{ab}	4.82^{b}	2.90^{a}	5.183	0.003
AAA	2.91^{b}	2.3^{b}	2.47^{b}	1.63^{a}	11.170	<0.0005

When considering all four sites, dhubs typically had bimodal activity with early morning and late afternoon bouts of activity. During April (early season), the time at which dhubs started their daily activity ranged between 0700 and 0800. During August (end of season), morning activity time showed greater variation with activity starting between 0600 and 0800 (Figure 4).

When considering the afternoon activity of dhubs at all the sites, during April (early season) the time at which the dhubs started their activity ranged between 1300 and 1400. During August (end of season), this afternoon activity start time shifted to 1500 to 1600 (Figure 5). Therefore, it can be inferred that, as the season progressed into summer, activity starting times shifted earlier in the morning and later in the afternoon.

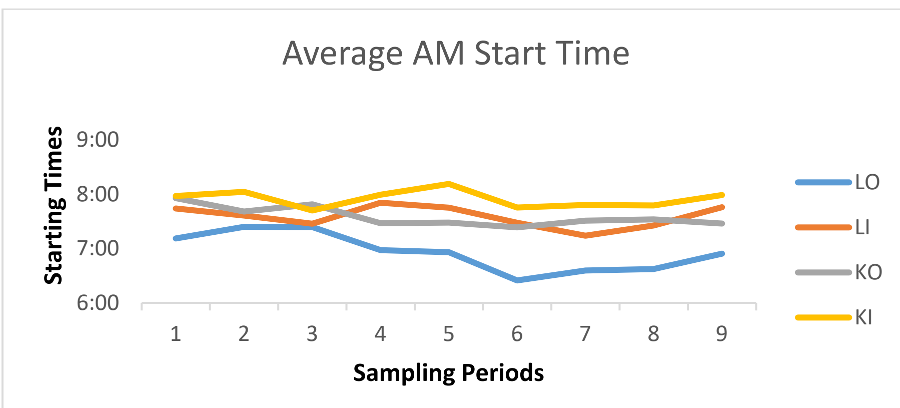

Figure 4: Morning start time of dhub activity. In the morning, dhubs began activity between 0700-0800 during the early parts of the season. As the season progressed, the dhubs began activity between 0600-0800.

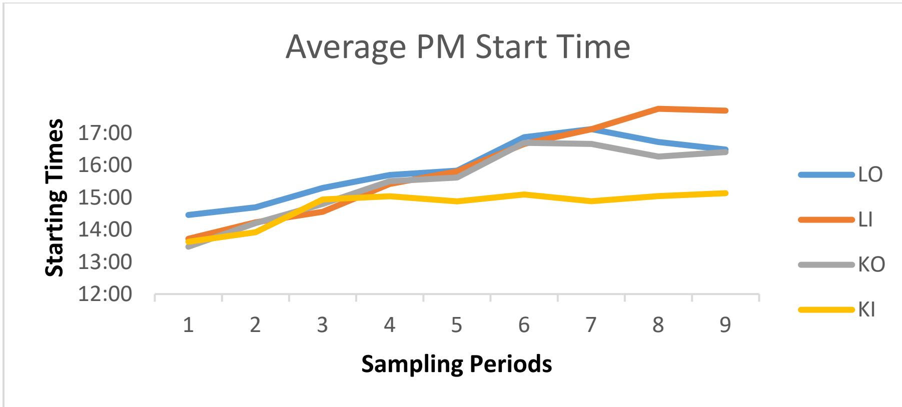

Figure 5: Evening start time of dhub activity at LI, LO, KI and KO. In the afternoon, dhubs were active after 1300-1400 at the start of the season. As the season progressed, dhubs were active after 1500-1700.

Body temperature

I found a significant effect of period ($F_{8,179}$ = 57.55, *p*-value < 0.01), but not habitat ($F_{1,179}$ = 0.01, *p*-value = 0.93), on body temperature (Figure 6). However *t*- test showed significance effect of habitat protection on Average Tb Max (ATBM) only (Table 5). Body temperature increased as the season progressed, both while the dhubs were surface active and in a refuge. Post hoc analyses revealed average body temperatures were significantly lower during the early sampling periods as compared to the later sampling periods; however body temperature during the early sampling periods (approximately sampling periods 1 through 4 and 1 through 5 for the non-protected and protected habitats, respectively) were similar. A similar stable pattern over time was observed for sampling periods 5 through 9 and 6 through 9 for the non-protected and protected habitats, respectively. The average daily maximum body temperature was higher in non-protected habitats (during sampling period 5 to 9) compared to the protected habitat.

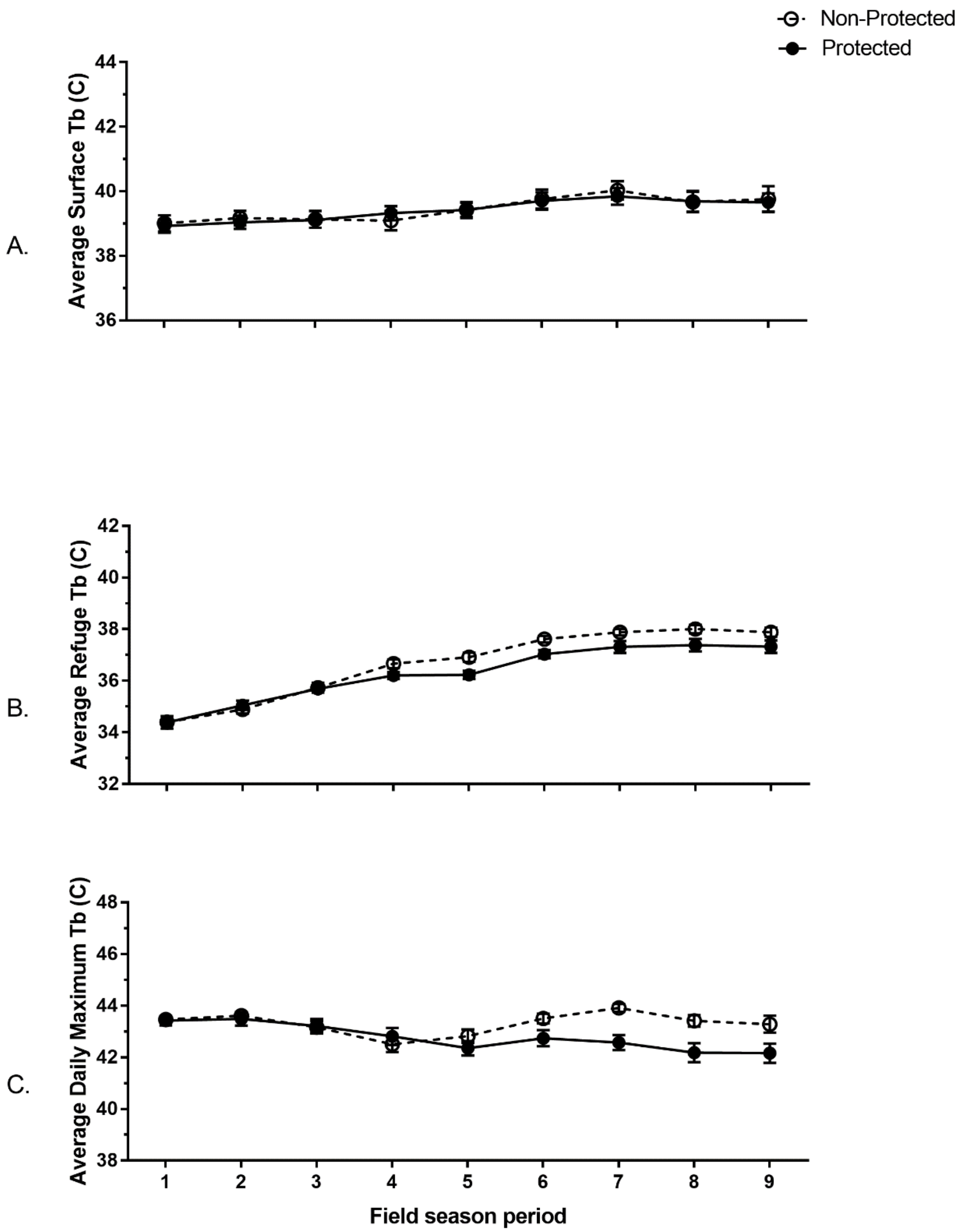

Figure 6: Effect of season on dhub body temperature. A) average dhub body temperature when surface active; B) average body temperature when dhubs are in their burrows; C) average daily maximum body temperature of dhubs. Body temperature increases as the season progresses, both while surface active and in a refuge.

Table 5. Variations in average body temperature (Tb) variables between protected and non-protected habitats. Statistical t-test and its significance value are given. OATB; Overall Average Tb. ATBA; Average Tb Active. ATBR; Average Tb Refuge. ATBAPM; Average Tb Active AM. ATBAPM; Average Tb Active PM. ATBM; Average Tb Max.

Variable	Protected	Non-protected	*t*	*P*
OATB	36.8917	37.2788	-1.717	0.092
ATBA	39.3878	39.4151	-.112	0.911
ATBR	36.3376	36.6108	-.813	0.420
ATBAAM	39.3960	38.9398	1.357	0.181
ATBAPM	39.5402	40.0679	-1.807	0.077
ATBM	42.7901	43.2848	-2.399	0.020

Discussion

Vegetation, Habitat, Disturbance & Climate: The Kuwait desert is characterized by long hot and dry summers, short winters, low amount of rainfall, active Aeolian processes, and severe human disturbances due to camping, grazing, off road vehicles, solid wastes and other human activities (Omar 1991, Brown 2003, Abd El-Wahab, 2016). These conditions have a great impact on plant and animal life particularly in non-protected habitats. Vegetation is mainly composed of annuals, perennial herbs, perennial grasses, and sub-shrubs (El-Ghareeb & Rezk 1989; Omar et al., 2000). Biswas & Mallik (2010) found that disturbance-habitat-stability coupling may have significant effect on particular life forms. Low-abundance of shrubs and almost lack of tree species are indicators of low amount of moisture and high intensity of disturbance. Several studies showed that intensive human disturbance has direct consequences primarily on the loss of trees and shrubs in arid and hyperarid ecosystems, where rarity of rainfall exacerbates the impacts of urbanization and decreases the chance of recovery (Batanouny 1983; Richer 2009; Al-Awadhi et al., 2014). Protected habitats support higher vegetation cover than non-protected habitats, suggesting greater food availability to herbivores and granivores inside the reserves. However, plant species diversity was higher only in protected habitats in Kabd, whereas in Liyah protected and non-protected habitats were similar in the total number of recorded species. This inconsistency between the localities indicates that further research is necessary to better understand the general impact of protection on plant diversity along with the influential factors involved. However, several trespasses or infringements either due to direct grazing activity or severe collecting of *Rhanterium epapposum,* and *Convolvulus oxyphyllus* as a fodder were observed in the Liyah protected area. Grazing is among the most important effects on desert habitats, ranking perhaps second to the moisture factor (Kassas, 1954). Several signs of grazing were recognized in non-protected areas particularly in KO. The high percentage of browsing on certain species such as *Cyperus conglomeratus, Moltkiopsis ciliata*, *Rhanterium epapposum,* and *Convolvulus oxyphyllus* may indicate that these species are characterized by high palatability and nutritional values for livestock and wild animals including dhubs (Robinson, 1995). In a study conducted on dhubs in Qatar, it was found that dhubs feed on at least 37 distinct plant species. *Savignya parviflora* and *Oligomeris linifolia* were the most frequently eaten species. Some of the other plants consumed by the dhubs were *Neurada procumbens, Schismus, Fagonia*, and *Astragalus eremophilus* (Castilla et al., 2014). Dhub burrows were located closer to each other in protected habitats particularly in KI, than in non-protected habitats. This may be due to the low competition on food resources in protected habitats, which support higher vegetation cover and species composition compared to non-protected habitats. Thomas et al., (2009) found that the lizards selected their burrows on the basis of vegetation coverage and the type of soil.

Body Condition: Likely as a result of the greater vegetation resources inside the protected areas, the dhubs residing inside those areas started out with a higher body mass and tail volume when compared to the dhubs in the non-protected areas. The plant species that were heavily grazed were generally found in the non-protected areas at both Kabd and Liyah, indicating that protection decrease overgrazing. Moreover, habitat protection did not alter the seasonal changes in the physiology of the species. On the other hand, seasonality affected body condition more than the habitat did. Overall, our findings agree with a similar study conducted in a protected park in Saudia Arabia where dhub body mass indicies were found to be higher in Spring when compared to Summer which is expected due to the increase in temperature limiting plant productivity and dhub activity (Wilms et al., 2010). The same was found in Gila monsters studied in the Sonoran Desert, where female and male body mass and tail volume generally decreased from Spring to Summer (Davis & DeNardo, 2010).

Surface Activity: The seasonal comparison of the daily activity of dhubs demonstrates crepuscular behavior, where they are active during the mornings and later in the evenings (both periods when temperatures are lower). As the season progressed, the dhubs living in both protected and non-protected areas changed and aligned their behavior and physiology according to the increasing environmental temperatures. This revelation is in alignment with the studies conducted by Cunningham (2000) and Cunningham (2001) in the United Arab Emirates, where the activities of lizards were observed during mornings and evenings and with the findings of Wilms et al. (2010) who found that dhubs follow a bimodal pattern in spring and early summer (our field work period). In spring and early summer, Wilms et al. found that dhubs were visible above ground between 1030 and 1100 and in the afternoon between 1700 and 1730. In our study, dhubs spent a similar amount of time above ground (9.3%) compared Gila monsters (8%) during the same period (April – September) (Davis & DeNardo, 2010), despite the differences in diet (herbivore vs. carnivore) and the more lush environment of the Sonoran Desert in which Gila monsters are native. Thomas et al., (2009) studied the seasonal differences in activity of dhubs in Saudi Arabia and found that the lizards were highly seasonal and exhibited bimodal activity in spring and summer. Also, their activity is low in the autumn. Al-Johany (2003) conducted a study in Riyadh to observe the activity pattern of dhubs and found that they exhibit unimodal activity structure in spring season, where they emerge during the morning and evening. Das et al., (2013) observed the activity pattern and habitats of the Indian spiny-tailed lizard, *Uromastyx hardwickii*, in the Rajasthan region during the monsoon season. The activity pattern was found to be bimodal, which changes with weather conditions. The activities of the lizards comprises of eating, basking, chasing each other and resting. The burrows were sealed during the monsoon season, and the diurnal cycle of body color changes in this season.

Body Temperature: Despite the behavioral adjustments, dhubs average body temperature rose in response to the increasing environmental temperatures, regardless of whether they were in a burrow or on the surface. Thus, behavioral shifts cannot fully buffer the effects of ambient temperature on body temperature. These behavioral adjustments agree with the observational findings of Wilms et, al., in 2010 which suggested that due to relatively mild temperatures during spring, dhubs were seen above ground for longer period of times when compared to times dhubs were seen above ground during summer which were shorter in periods and earlier in the day to avoid overheating. This technique of time-shifting (behavioral adjustments) is also utilized by other lizard species. Gila monsters avoid higher ambient temperatures by shifting their activity times. Activity in Gila monsters is diurnal only during mild temperatures in April and May, while, during hotter times from June to September ,they shift to nocturnal activity to avoid overheating (Davis & DeNardo, 2010). The adaptive behavior of lizards corresponds to the regulation of their body temperature as per the external temperature. Several lizards regulate their activity time or shuffle between sunlight and shady regions to control their body temperature (Pianka, 2017). In the current study, perhaps as a result of limited surface thermal heterogeneity, the lizards regulate their activity time to adjust to high temperatures and maintain adequate body temperature.

Menaker and Wisner (1983) found that the studied *Anolis carolinensis*'s circadian system maintained a constant melatonin production that was compensated by temperature. The implications suggest that the physiology of the creature compensates for both active and non-active states by having a temperature-steady state (Menaker & Wisner, 1983). As dhubs bask in the sun during the day, skin color becomes lighter - beginning dark and turning yellow as it warms, thus allowing them to absorb more energy when cool and reflect excess energy when warm. As they enter refugia night, this absorbed energy allows them to be active and react normally to the changes in light and dark. This indicates that the circadian system is tied to the behavioral nature of the creature, by creating a feedback loop where melatonin production impacts the dhub's behavioral response to sunlight and absence of sunlight. This system allows the dhubs to live in a harsh, hot environment by conserving and storing heat during the day and maintaining it into the cooler night hours (Moore & Menaker, 2012). Other survivalist behavior is seen in lizards, as reported by Artacho et al., (2015) who looked at the thermal issues in their behavior along with energy metabolism in the lizards.

Conclusion

This study revealed that while habitat protection provided more vegetation and refuge to the dhubs, it had little effect on seasonal changes in surface activity times of dhubs. However, the protected habitat might confer a significant effect on body mass by providing greater vegetation abundance. While resource availability might allow for larger dhub populations, based on the observed and measured minimal distance between burrows, the unprotected areas showed similar body morphometrics, activity, and body temperatures.

Future directions

1. Future studies should further investigate what plants are the most valuable for dhubs and ways to promote the growth of such plants.
2. The surface activity assessment did not study in details the actual activities performed by dhubs during the time on surface, it only showed the total times dhubs were above or below ground. Future studies should investigate the actual activities performed by the dhubs during their surface activity time and the proportion of time spent on each.
3. This study only examines the behavioral changes, body temperature, and body mass of dhubs in the Kuwait desert on the basis of its seasonal activities at two primary locations. Future studies should include research on the effect of habitat protection on dhub population support including fecundity, mortality, mating, and survival rate. Also, studies should include investigating the immune system of dhubs and if habitat protection could provide the needed resources for such species to maintain healthy immune status during the different seasons (Hussein et al., 1979).
4. The need for investigating the role of human activities and climate changes on the sustenance of dhubs has been realized. Most human disturbances resulting into sporadic climate changes alters local to landscape-scale habitats that may further endanger the species such as dhubs. Therefore, it is essential to comprehend the impact of climate

changes on the adaptive variations and sustainability of dhubs.

5. Lastly, conservation plans and models must be developed for preserving the populations of dhubs. Emphasis should be laid on maximizing the efficiency of habitats with adequate food availability, for which, taxonomic and systematic studies must be carried on.

Chapter 2

Use of thermal sensitivity of evaporative water loss to predict seasonal water loss in free-ranging dhubs, *Uromastyx aegyptia*

Introduction

Deserts are water-limited ecosystems, and water balance in desert species is further challenged by high temperatures, dehydrating winds, and solar radiation (Nagy, 2004). When rainfall does occur, there is typically little to no surface storage of water, as light rainfall quickly soaks into the sandy substrate and heavy rainfall often causes flash floods that distribute the water elsewhere. While energy availability is also necessary to sustain life, water limitations create a more immediate threat to survival because, unlike energy, water is rarely stored internally (Telford et al., 2012). Further exacerbating the challenge of maintaining water balance is the limited heterogeneity of most deserts (Cox & Cox, 2015). In order to thrive, animals in arid climes must utilize behavioral, physiological, and morphological adaptions that enable them to cope with the challenges that deserts pose to water balance (Williams et al., 2001).

While environments are prone to change over time, such change typically occurs at a rate that enables residents to adapt. However, current projections for global climate change indicate that the rate of climate change will exceed the potential for evolutionary adaptation for many species. Thus, in order to forecast impacts of rapid environmental change, it is critical to understand how organisms cope with current resource limitations and to what extent they buffer themselves from alterations in environmental conditions. One means by which such assessment can be made is to evaluate how a species copes with changing environmental conditions associated with seasonality. While examination of seasonal responses are not an absolute proxy for the tolerance of future climate change, they can provide insight into coping mechanisms, their plasticity, and their potential to buffer an organism from environmental shifts.

The dhub, *Uromastyx aegyptia*, is a predominant lizard of the extreme deserts of northern Africa and the Middle East. While possessing numerous adaptations for inhabiting such a harsh environment, dhubs must cope with the progressively increasing ambient temperatures during the active season. This challenge is likely exacerbated by habitat destruction as a result of the Gulf War, excessive recreational use, and overgrazing.

We used flow-through hygrometry in the laboratory to determine the thermal sensitivity of evaporative water loss in dhubs, and then applied this relationship to field body temperatures of dhubs to estimate water loss across much of the activity season at both protected and non-protected sites. We then compared these estimates to field measurements of changes in total body water. These results further our understanding of how desert species cope with extreme arid conditions and how increasing environmental temperatures influence key metrics associated with water balance. The results will also provide valuable insight into how habitat protection influences water balance and thus provide some guidance for developing conservation strategies for the species.

Materials & Methods

All study components (lab and field work) were performed in accordance with Arizona State University's (ASU) Institutional Animal Care and Use Committee (IACUC) protocol 12-1244R and was partially funded by the Kuwait Foundation for the Advancement of Science (KFAS) under project code "P114-62SL-01".

Lab study — thermal sensitivity of evaporative water loss

This study was conducted in the fall of 2013 using eight dhubs (four males and four females; mean initial mass = 657 g) that were imported to ASU from Kuwait in spring 2013. During experimental trials, each dhub was isolated in an oval, minimally hygroscopic metabolic container that was placed inside an environmental chamber in complete darkness, resembling the inactive state when dhubs are inside a burrow. The containers were opaque except that the tops were made of glass for periodic observation. The glass lids were lined at the edges with closed cell foam to guarantee an air-tight seal. To assure a post-absorptive state, the dhubs were not provided with food or water for 48 hours prior to trials, and they were allowed to adjust to the chamber environment for at least two hours before recording any data.

Two dhubs, each in its own container, were sequentially run through trials. Using minimally hygroscopic tubing (Bev-A-Line, Thermoplastic Processes Inc., Stirling, NJ), compressed outside air was delivered through a desiccant and then the flow was bifurcated with one air stream passing through a mass flow controller (MFC) (UNIT Instruments, Yorba Linda, CA, USA) and the other air stream through a 20 L capacity rotameter. While the MFC delivered air to the container that was being sampled, the rotameter assured approximate air flow rates to the animal waiting to be sampled. Two-way solenoid valves were used and controlled by a data logger (23X micrologger, Campbell Scientific, Logan, UT, USA) to sequentially deliver the supply air from the MFC to each of the containers housing a dhub.

Efferent air from each of the metabolic containers flowed into spill tubes. A peristaltic pump was used to pull air through an array of one-way solenoid valves to subsample from the spill tubes. Both the supply air and effluent air solenoids were controlled so that the container that was being sub-sampled received its supply air from the MFC. The peristaltic pump delivered the air to a hygrometer (RH-300 water vapor analyzer, Sable Systems International, Las Vegas, NV, USA), through a column of Drierite, and then through the oxygen analyzer (FC-1B oxygen analyzer, Sable Systems International, Las Vegas, NV, USA), which was always calibrated with outside air prior to each use.

Parameters that were recorded and continually monitored with a 23X datalogger were barometric pressure, environmental chamber air temperature, MFC flow rate, the status of each solenoid valve, and the effluent air's dew point and percent oxygen. The environmental chamber's air temperature was monitored with two type-T thermocouples that were placed at two different heights within the environmental chamber, and there was a fan running continually to prevent stratification. The two temperature readings were averaged to determine the temperature of the environmental chamber. Baseline water and O_2 contents of the supply air were determined prior to each trial by having the flow stream from the MFC bypass the dhub chambers. Oxygen consumption and evaporative water loss (EWL) was determined for each dhub at four environmental chamber air temperatures – 22, 32, 37, and 42°C – that reflected the natural range in environmental temperature experienced by dhubs during their active season.

Field study – seasonal body temperature and total body water content

A field study was conducted in the Kuwaiti desert, where, in general, weather conditions are extremely hot and dry during the summer and mild with minimal rainfall during winter. The desert in Kuwait is semi-heterogeneous to almost homogeneous, characterized as open scrub consisting of perennial shrubs, grasses that resist drought, and annual forbs (Al-Awadhi et al., 2005). The fieldwork was conducted at two paired locations – one pair near Liyah, governorate of Jahra, 80 km northwest of Kuwait City, and one near Kabd, governorate of Farwaniyah, 30 km southwest of Kuwait City. Each pair consisted of complimentary protected and non-protected sites (Illustration 1). While both the Liyah and Kabd protected areas have restricted accessibility, there are differences in the state of their recovery. The Liyah protected area was created in 1996 after serving for many years as a gravel quarry, while the Kabd protected area was established in 1979. The Kabd protected area is a research station (Sulaibiya Field Station) owned and operated by the Kuwait Institute for Scientific Research (KISR). Due to difference in the extent of destruction prior to the commencement of protective measures, the Kabd protected area has a greater diversity of vegetation cover than does the protected site at Liyah. In addition, the Liyah protected area has been subjected to periodic trespassing and infringements by local inhabitants, particularly herders. Regardless, both the protected sites at Liyah (LI) and Kabd (KI) have superior vegetation compared to their non-protected counterpart study sites (LO and KO, respectively). Both unprotected areas show major human disturbance as exemplified by post camping season damage including off-road vehicles tracks, burned tires, waste, and physical disruption to the ground. Both unprotected areas also show extensive disturbance from over-grazing by camels and sheep-goat hybrids (sometimes referred to as shoats). Human disturbance appears to be more severe in the non-protected section of Kabd due to the fact that this area is occupied by camel and shoat pens with very high and consistent human traffic.

We captured 36 adult dhubs (21M : 15F), nine at each of the four sites, by placing a mesh gravity-action trigger trap at the entrance of a burrow into which a dhub was seen retreating (Photograph 1). Traps were covered with a board to prevent the dhubs from overheating after capture. At capture, each dhub was marked with a unique identifier number, transferred to a secure transport cage, and taken to our lab in Ardiya for processing. At the lab, we surgically implanted a 13 g radio transmitter (SI-2T, Holohil, Carp, Ontario, Canada) and a 3.1 g temperature datalogger (Thermochron, iButtons, Maxim, Dallas, TX) by following the procedure described in Taylor et al., (2004).

Once the dhub was anesthetized and before initiation of surgery, 0.4 ml of blood was collected from the caudal vein of the dhub as the baseline sample for determining initial total body water. Plasma was separated by centrifugation, flame-sealed within glass microcapillary tubes, and stored in a refrigerator at 4°C until later isotope analysis. After surgery, dhubs were weighed (using a standard platform scale), snout-vent length (SVL) measured (using a measuring tape), and tail volume (TV) determined using water displacement to estimate energy stores. After the surgical procedure and measurements, the dhub was injected with 0.4 ml (16 units) of heavy labeled water mixture (1:4 deuterium oxide:Nanopure water) into their coelomic cavity. To allow the heavy water to equilibrate within the body, the dhubs were retained for ~12 hrs (e.g., overnight) before taking them to their point of capture for release. Just prior to release, a second blood sample was collected for the total body water assessment.

The dhubs were tracked twice weekly. Nine transmitters failed over the course of the study, limiting retrieval at the end of the study to 27 dhubs. After the experiment, the dhubs were recaptured, processed, and sampled as described above, except the implanted devices were removed. Data obtained from the temperature loggers were downloaded and stored in an Excel file.

Isotope analysis

Total body water (TBW) was determined using the heavy water dilution technique. Using cryogenic vacuum distillation (Ehleringer, 1989), isotopic water samples were separated from plasma samples. Once extracted, isotopic samples were processed using a water isotope analyzer (DLT-100, Los Gatos Research, Mountain View, CA, USA) to determine deuterium isotopic ratios. For each dhub, four samples were analyzed – a pre- and post-injection sample for both the beginning and the end of the field season. Total body water was determined using the exact amount of deuterium given and the change in concentration of deuterium in the plasma after equilibration of the injectate (McKechnie et al., 2004).

Statistical Analyses

To evaluate seasonal effects on EWL & TBW, raw data were grouped into eight periods (two-weeks each) as follows; 1: April 21 - May 4, 2: May 5 - May 18, 3: May 19 - June 1, 4: June 2 - June 15, 5: June 16 - June 29, 6: June 30 - July 13, 7: July 14 - July 27, and 8: July 28 - August 10. The effect of habitat status (protected versus non-protected sites) and sampling period on the various response variables of the study were evaluated. The interactions between these components were assessed by including these main effects along with their interaction as fixed-effects in a linear mixed-effects model. The sex of the individual dhubs was included as a covariate in the fixed-effects component of our models. Repeated measurements of the individual dhubs were a random effect in our model. Also, a random effect where the animals were nested within their site was included in the analysis when the site was a significant predictor of our response variables. We included fixed effects in the full model for sex, TV, and mass as covariates to control for potential differences among animals.

Field EWL was estimated for each two-week period by first creating a regression of evaporative water and temperature from the laboratory data, replacing each half-hourly body temprature of the field study dhubs with the corresponding evaporative water loss from the regression, and then summing the hourly water loss for the two-week periods.

The response variables for our analyses were evaporative water loss (EWL), EWL total by site, EWL total by period, EWL for thermal sensitivity, average mass, temperature, and total body water (TBW). As some of the response variables violated the basic assumptions of normality, wherever necessary, we transformed our data using either square root or the reflection of the logarithmic transformations prior to conducting our analyses.

We performed a preliminary analysis on the impact of each fixed-effects, covariates, and potential interactions on the defined response variables. Fixed-effect terms that independently had a significant impact on our response variable were included in our baseline models. This analysis considered only those animals that had a complete data set.

Following the approach of Zuur et al., (2009), we began our analysis by constructing a linear mixed-effects model with all the possible main effects, covariates, interactions, and random error fitted by restricted maximum likelihood (REML) using the “nlme” library (Pinheiro et al., 2015) of the R statistical package. We then compared this model to a generalized least squares model with all the possible main effects, covariates, and interactions fitted with REML, but without random error. We then refitted the linear mixed-effects model with all the possible main effects, covariates, and interactions as well as the appropriate random-error model structure and refitted the models using maximum likelihood (ML), after which we determined the optimal fixed-effects structure of our models using the MuMIn package (Barton, 2012).

Akiaike’s information criterion, corrected for small sample sizes, (AICc) (Anderson et al., 2001) was deployed on the linear mixed-effects regression models for identifying the fixed-effects variables that explain our results in the most adequate manner. AICc values were also used to rank models, where the lowest AICc values represented the best fitting models. Using AICc values, we calculated the differences among the AICc values associated to the best model (ΔAICc) and Akaike weights (ωi). Large ΔAICc values indicate that the models are less likely to explain differences in the response variables as compared to the models that have $\Delta \text{AICc} > 10$ and are considered as poor models (Burnham and Anderson, 2004). ωi are used to compare models, as they are an approximation of the probability that a given model is the best-fitting model from the observed data. Thus, larger ωi are indicative of better fitting models. AICc analyses were conducted on the models by using the MuMIn package with the optimal random-effects structure fitted with ML in R (Barton, 2012). The models with both the optimal random- and fixed-effects structure were refitted with REML and then the significance tests were conducted by following the procedures laid out in Zuur et al., (2009).

Results

EWL

Based on results of thermal sensitivity of evaporative water loss experiments that were done in the lab, it was shown that as temperature increased, evaporative water loss of the dhubs increased (r = 0.768, p < 0.001, Figure 7).

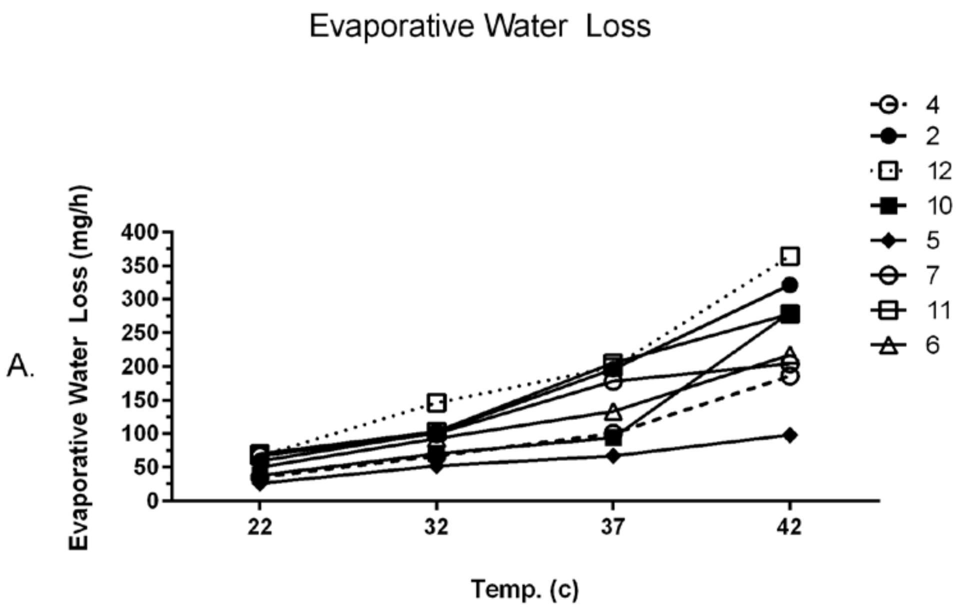

Figure 7. Thermal sensitivity of EWL in each dhub increased as temperature increased. Line equation: EWL = $(0.0136e^{0.0765Tb})$(Mass/2), where Tb means dhub body temperature.

Using the line equation (Figure 7) and the body temperatures downloaded from the implanted loggers, we estimated EWL in 2-week increments over the course of the field season (Figure 8).

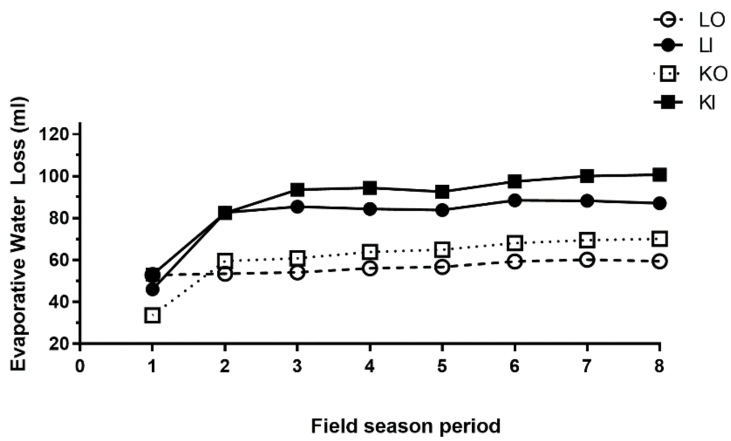

Figure 8. EWL estimates for dhubs by site during different seasonal periods.

There was a significant effect of habitat on dhubs evaporative water loss (EWL) ($F_{3, 226}$ =31.4, p <0.0001). Tukey test showed that dhubs in none protected areas had less EWL than dhubs in protected areas (Table 6). Also seasonal periods (time) had the same significant effect on EWL (*p-value* < 0.0001, Figure 8). The lowest EWL amount was during the first period (April to May, EWL about 46ml). The average of EWL during the rest of the periods reached about 76ml.

Table 6. Variations in average values of evaporative water loss (EWL) and Total body water (TBW) of dhubs in different habitats. Similar letters within a given variable indicate no significant variation according to Tukey test.

Variable	LO	LI	KO	KI	*F*	*P*
EWL ml	53.729[a]	76.561[b]	58.322[a]	86.755[b]	31.396	< 0.0001
TBW ml	687.34[a]	926.23[b]	689.27[a]	922.39[b]	7.406	< 0.0001

TBW

There was a significant effect of habitat protection on TBW ($F_{3, 44}$=7.406, p < 0.0001). Tukey test showed that dhubs in protected areas; KI and LI had a significantly higher TBW than dhubs in none protected habitats; KO & LO (Table 6, Figure 9). There was a significant positive correlation between body mass and TBW ($r = 0.912$, $p < 0.001$), and between tail volume and TBW ($r = 0.825$, $p < 0.001$).

According to the *t*-test, there was a significant effect of time on total body water ($t = 4.685$, *p-value* < 0.0001). Also, the results showed that males had higher total body water than females, as demonstrated in Figure 10, yet, this difference was not significant as well as the interaction between habitat and sex.

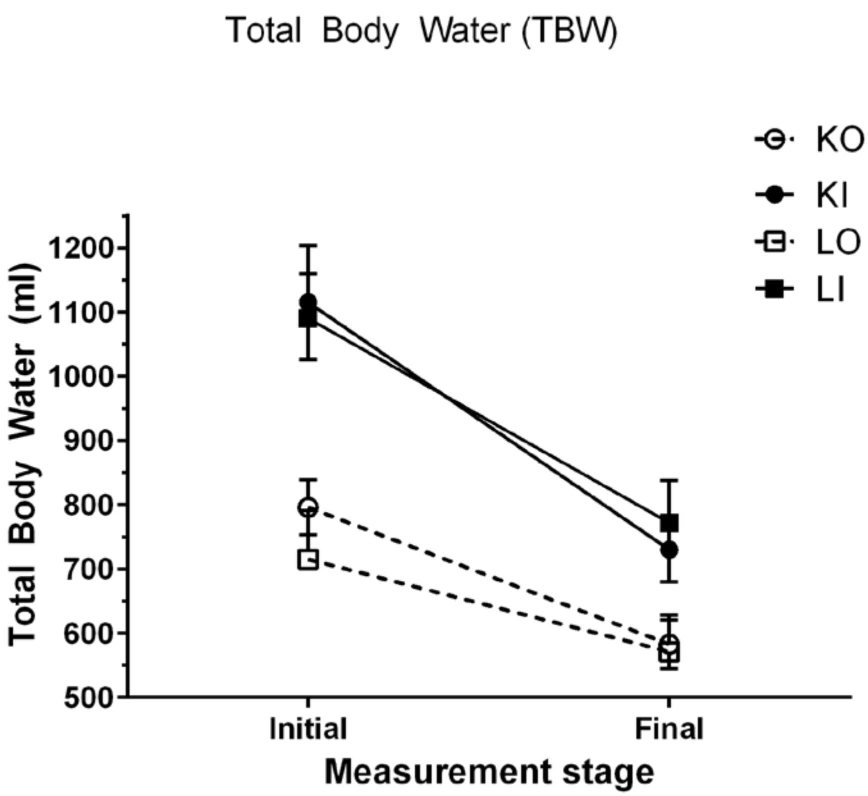

Figure 9. Effect of habitat protection on dhub total body water at initial and final stages.

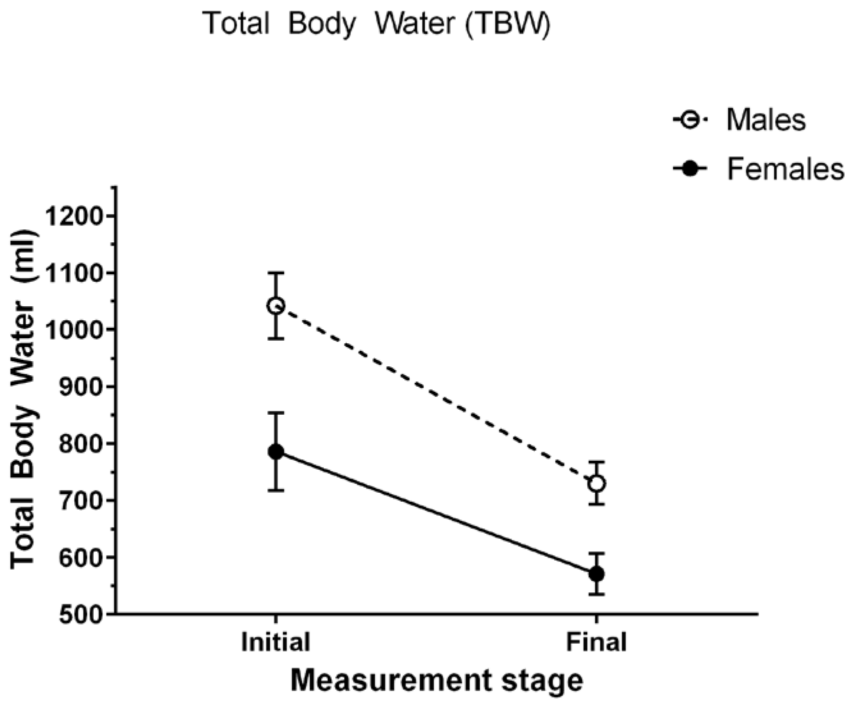

Figure 10. Average total body water for males and females at initial and final stages.

Discussion

Evaporative water loss in ectotherms living in arid environments is a physiologically-regulated trait that ensures survival in harsh conditions (Stevenson, 1985). Dhubs are no different, in my study, dhubs showed the same response to increasing ambient temperatures as they increased in evaporative water loss yet managed to survive behaviorally. Gila monsters (*Heloderma suspectum*), a xeric lizard species in which water balance has been best studied, used both physiological and behavioral adaptations to survive in the arid conditions (Stahlschmidt et al., 2011). Interestingly, in the sensitivity of EWL to temperature, Gila monsters changed slope dramatically with an inflection point when temperatures reach the upper 30's °C. The majority of water loss at high temperatures (>35°C) was attributable to dramatic changes in cloacal evaporative water loss. This increase in EWL corresponded with a lowering of body temperature relative to ambient temperature, and thus likely serves as a mechanism to cope with threateningly high body temperatures (DeNardo et al., 2004). Cloacal evaporative water loss associated with high temperatures has also been reported in a desert bird (Hoffman et al., 2007).

We did not observe a similar EWL inflection point in dhubs, suggesting no such emergency evaporative water loss response occurs in this species, at least across the temperatures examined in this study. Also, despite having relatively low, among lizard, EWL and no emergency evaporative water loss response, dhubs still had increasing EWL as the active season heated up. Thus, despite having a water-conserving EWL rate, water intake did not keep up with water expenditures, This is not overly surprising since food stuffs during the summer have limited water content and standing water is non-existent (Spotila & Berman 1976).

Dhubs total body water (TBW) was affected as time passed by during the season. As temperature increased, TBW decreased. Gila monsters also experience a net water loss across the hot, dry season (Davis and DeNardo, 2010), but they utilize their urinary bladder as a water reservoir (Davis and DeNardo, 2007) much like tortoises and toads do. This adaptation buffers against hypovolemia and hyperosmotic conditions. Dhubs avoid hypervolemia using a different approach; they possess nasal salt glands to excrete excess salts (Norris & Dawson, 1964, Bradshaw et al., 1984); however, it is unknown whether hypovolemia is avoided through the use of an internal reservoir or physiologically tolerated.

Overall, while dhubs and Gila monsters have evolved a suite of physiological and behavioral mechanisms that enable them to cope with hot, dry conditions, the specific strategies employed cannot be generalized across lizard species. Thus, common generalizations regarding the expected impacts of climate change on lizards (e.g., Sinervo et al., 2010) are likely heavily flawed and therefore of limited value. Instead, by developing an understanding of how different coping strategies are linked to particular ecological, morphological, and phylogenetic traits, we will more likely be able to make useful predictions regarding the vulnerability of species to climate change.

Chapter 3
The use of physiological ecology in informing dhub conservation

Introduction

Conservation policies reflect the position of a country in terms of implementing management measures to protect species and biological diversity. To assist these efforts, biologists strive to provide comprehensive data on conservation topics to the legal actors and conservation managers who make the political decisions that govern conversation policy. However, conservation management is fraught with political controversy. While ecological studies traditionally form the major foundation of conservation research, some researchers profess the requisite need to include investigations of the physiological basis of the reaction of the species to their surroundings, comprising their capacities and tolerances (Joseph, 1987). For developing the most effective conservation strategies against species decline, it is imperative to comprehend the physiological responses of target organisms in relation to environmental changes. Such information can be efficient in assessing conservation problems and repercussions of conservation actions. This paper discusses the environmental management history of Kuwait to show the progression of conservation and protection measures toward the natural environment and its challenges. Comprehending the geography and climate of Kuwait is essential for understanding current levels of environmental protection and their future implications. Moreover, the current paper explores how physiological ecology can contribute to building conservation strategies of dhubs (*Uromastyx aegyptia*) by assessing how environmental changes impact their ecosystems and evolutionary responses. The threats to the sustainability of sensitive species have underlying physiological mechanisms that are best understood through the discipline of physiological ecology.

Dhubs inhabit the Arabian Desert and exhibit adaptation related to the dynamic seasonality and availability of food in the region (Wilms, et al. 2010). The activity of dhubs is influenced by the interplay of their physiological capabilities with the physical environment. This interaction influences their individual growth, survivorship, and reproduction, thus determining the dynamics of the population. Therefore, my research attempts to understand physiological adaptability and uncover issues that have led to the ecological devastation of dhubs in Kuwait, including the impacts of camping, over-grazing, and, notably, war. The research presented in Chapters 1 & 2, which examines the activity and sustainability of dhubs in relation to habitat protection, seasonality and evaporative water loss is reviewed and integrated to assist the future environmental management decisions among policy makers, non-profits, communities, and society. Also, comparisons with the conservation management methods adopted by other countries to protect their biological diversity are made. This includes addressing issues concerned with policy design, reserve design, and goals that are political, economic, and social in nature. Based on my research, published work by others, and an understanding of the Kuwait political environment, recommendations for Kuwait are presented to best promote dhub survival in a changing environment by adopting an ecosystem management perspective for dhubs and biodiversity in general.

Kuwait- History, Topography, and Climate

History

Though founded in the 18th century, Kuwait has been home to human civilization since 3000 B.C. As a key trade route, it may have traded with other early and important civilizations (Singh, 2016). Kuwait City was founded by the Anizah tribe and became a sheikdom whose descendants still rule Kuwait to this day. During the 18th century, the city prospered and was entitled as a major commercial hub for transporting goods between India, Arabia, Baghdad, and other regions. As a key trade route, it attracted merchants from all over the world and was most popular in the trading of pearls. In the second half of the 18th century, Kuwait achieved high economic growth that was facilitated by regional geopolitical shifts. In the 1920s, the economy of Kuwait encountered a major setback and, due to its small size and a weakened economy, neighboring countries tried to claim its parts. Several countries such as Iraq and Saudi Arabia invaded the borders of Kuwait and attempted to occupy it, but were stopped by British forces (Bishop, 2003). With the prosperous trade in oil, Kuwait regained its economy in the 1950s and became one of the world's largest oil exporter. In 1961, Kuwait gained its independence from British rule and was recognized as an independent nation.

Topography

In terms of its geography, Kuwait is considered part of the Middle East region (West Asia), occupying a crucial position at the northern end of the Persian Gulf. Iraq lies at its northern border and Saudi Arabia lies on the western and southern borders. Most of the nation is composed of the low-lying desert, with a predominantly sandy terrain and sparse vegetation. Its total land area is 17820 km^2, making it a relatively small nation (Almedeij, 2014; Abdullah, 2016). Natural resources of the area include petroleum, natural gas, fish, and shrimp.

Climate

Kuwait is characterized by intensely hot summers and cool winters, with a huge temperature difference between the seasons (Bishop, 2003). Comprising an arid climate, rainfall in Kuwait ranges from 75 to 150 millimeters per year. Heavy sudden rains occurring from October to April and sand and dust storms occurring between March and August are major natural hazards in Kuwait. The country has limited natural freshwater resources and relies on advanced desalination techniques to provide most of the needed water supply (Abdullah, 2016). The country has developed several political international agreements on environmental issues, including Biodiversity, Kyoto Protocol, Endangered Species, Environmental Modification, and more. Due to its strategic reliance upon marine resources, it is also party to the Law of the Sea and is considering Marine Dumping (Singh, 2016).

Biodiversity

Kuwait's flora and fauna have adapted to the environment for a much longer time than having its politics or people. This is what makes ecological and environmental issues so pressing. People and institutions tend to think in terms of short-term gain rather than long-term sustainability. Without understanding the requisite role of the environment in building the culture and society, efforts at conservation and management may be undermined by political and economic lobbying and profiteering (Artacho et al., 2015; Singh, 2016).

The War and its Environmental Consequences

Kuwait had a major conflict with Iraq that led to an invasion of Iraq in August 1990 that lasted until the US army intervened seven months later. The Iraqis retreated, but only after leaving over 600 Kuwaiti oil wells in flames (Humphreys, 2005). The fires, along with the extensive alteration of the terrain from vehicular travel and the creation of large and widespread bunkers, resulted in the most destructive environmental disaster in Kuwait history (Singh, 2016). The war has been postulated to be a reason for the bad weather in the region, due to the emissions from depleted uranium-tipped missiles deployed by the Iraqis. The harmful emissions from these projectiles poisoned the Arabian Desert's ground and water with radioactive isotopes. The gradual harmful release of gasses from the oil fires in Kuwait had serious implications on habitation in the region. The fires' smoke climbed more than 4 km into the sky, blocking out the sunlight for days. The Iraqi troops also opened up oil valves and barrels that spilled oil freely into the desert and Persian Gulf. The resulting oil sludge was absorbed by the desert, causing great damage to the environment, including poisoned underground water that risked the lives of multiple species. The number of aquatic birds alone that were killed is estimated at 240,000 (Abdullah, 2016; Singh, 2016). The oil leaks created a new surface layer called tartrate on the soil, which is a mix of gravel and oil, reaching a depth of 9feet. All the vegetation underneath the layer was killed and is unlikely to grow again (Singh, 2016). The devastating effects of war on the environment and desert land will have harmful lasting effects on the existing habitats. Therefore, the conservation and protection of habitat is a crucial step in the right direction to facilitate the sustainability of species, yet a more holistic approach is needed.

Physiological Ecology

Attributed to the fact that the precipitation and ambient temperature dramatically affect the diversity of species on an inter-annual basis in any desert environment (Almedeij, 2014), the arid environment of deserts presents regular thermal environment fluctuations with dynamic vegetation and rainfall. These fluctuations can impose threats to the native species and their diversity (Chapman et al., 2010). As an example of physiological ecology, some plants rely on the digestive juices of the species consuming them to facilitate evacuation and eventual germination of the seeds (Artachoet et al., 2015). Understanding such symbiotic relationships has been recognized by several studies as critical to establishing meaningful environmental management and conservation efforts.

In the Arabian Peninsula, there are ~3500 species enduring rapid depletion in their numbers. The causes of species decimation include desertification, overgrazing, and environmental destruction from human activities, even camping (Abdullah, 2016). Kuwait has native vegetation of low growing shrubs and grasses (Hussein et al., 1978). It is evident that given the climate, geography, and environmental issues, dhubs would be highly affected by any change in the vegetation (Almedeij, 2014).

Outcome of the Study

My study revealed that as the season progressed, dhubs living in both protected and non-protected areas changed and aligned their behavior and physiology according to the increasing environmental temperatures. However, habitat protection did not alter the seasonal changes in the physiology of the species. On the other hand, seasonality affected the body conditions according to protection status of the habitat. Habitat protection along with the relative abundance of vegetation provided a safe place for the dhubs to exist and maintain good body status when compared to individuals living in non-protected habitats. As resource availability inside the protected sites might allow for larger dhub population, the same cannot be said about dhubs living in the unprotected habitat as some of the traps and dhubs were lost during the course of the investigation, which serves as evidence that unprotected populations are vulnerable to exploitation. The higher protection of dhubs in the protected habitat is an important consideration in the development of management plans for this species and likely others.

The causes of the environmental degradation have come under debate, though generally, the reasons that emerge for the mass desertification include not only seasonal fluctuations in the weather, but also human interference such as over-grazing, over-cultivating land, quarrying of land, off-road use of land, and irresponsible operations of the oil production industry, a major economic stronghold of the nation (Abdullah, 2016; Singh, 2016). Given the small size of the nation, the intense human-led activities for subsistence and economic growth, and the already harsh climate, species diversity in vegetation could, without protection, have significant impacts upon lizard species like the dhubs.

In the current study, the harsh summer climate led to physiological and behavioral adjustments by dhubs to survive in the extreme conditions. Dhubs changed their activity time during periods of extreme heat, yet total evaporative water loss increased with the increasing temperature. The higher evaporative water loss is a detriment to a desert-dwelling ectotherm like dhubs, especially considering the high ambient temperatures and low availability of water resources in the deserts. As mentioned above, the protected habitat of dhubs had a higher availability of resources, which works as a valuable asset in high temperatures. The conservation management and preservation measures can be built on such basis.

Other Species Experiences

As stipulated by Adler (2007), the protection of species through the protection of habitats is not a complete answer to save either one. However, it is a beginning, and, given the nature of humans to mine resources from the environment for their own use, science can help develop conservation models, which may be different for each area. If a non-profit group had unlimited resources to establish species and habitat protection, difficulties would still emerge, such as gaining the support of the relevant political establishments, the corporate establishment, and convincing the people that the endangered species must be offered space and protection to live in a harsh and fragile environment that is witnessing degradation (Adler, 2007).

Different preservation methods and environmental management models have been developed across the globe for the purpose of conserving varied species and their diversity. Numerous studies have been conducted to inform these efforts. One study revealed that the Mangabey monkey in Kenya is protected by conservation methods (Oluput, 2000). Findings on habitat and diet of these monkeys are relatable to the findings from our studies. Oluput (2000) looked at conservation efforts and discussed them in relation to understanding how rainforest habitat disturbances affect the population of the monkey. The study looked at a 2-year period where 31 adult male grey-cheeked Mangabeys were captured and radio-tagged in both logged forest and unlogged forest in Uganda. Body mass differed in the two groups, which may be due to the habitat or diet. The researcher proposed that the logging practices may be manipulated to allow for better biomass of the species, through providing sufficient diet and habitat (Olupot, 2000).

In another study, the Mangabey population in Kibale National Park in Uganda was investigated (Chapman et al., 2010). The respective investigation is a longitudinal study, covering a period of 26 to 36 years that examined the causes of population density changes for five different species of primates. The national park was subjected to variable land use intensities during the 1960's. Mangabey group density increased while others decreased or remained stable. There were no major food changes over the course of the investigation. The study implied that there is a need to optimize the regional protection for conservation efforts in order to compensate for declining habitat and food sources in some areas while also increasing in other areas (Chapman et al., 2010).

In yet another example of the effect of habitat disturbance, Mbora & McPeek (2009) examined habitat fragmentation on primates. This study noted that the habitat loss and forest fragmentation were the major causes of the loss of species diversity. Additional threats from parasitic diseases are reported to further stress primate populations. Mangabeys in fragmented areas show higher parasitism rates than the other non-forested regions. The study revealed that the conservation mechanisms must be built while considering the human-infused habitat loss and the resulting death of species by parasitism (Mbora & McPeek, 2009). The variation in the research approaches in these studies provides strengths that offset the individual weaknesses of each study. The integration of the varied approaches accentuates a better understanding of the current problem scenario from all aspects. It is contemplated to incorporate cross-sectional as well as longitudinal research approaches to enhance the current research.

Apart from the Mangabeys, Mojave Desert tortoise (*Gopherus agassizii*) is another species which occurs in the desert of California, Arizona, and Utah. There is a need of proper protection and conservation plan of these species since they have declined almost by 90% and therefore, were listed as threatened, under the US ESA. Many investigations have been done on the species to understand threats that they face and decide on the best conservation plans. *Gopherus agassizii* has declined dramatically for the last several decades due to the threats of the human activities in the deserts (Murphy et al., 2011). The researchers have noted that the military and urban development; use of off-road vehicles, overgrazing, mining and the agricultural development can be counted as the major reasons for such a decline. Other than that, it has been evaluated that urban enhancement to the deserts where the tortoises lived or moved to lead to the increase of their natural enemy population. It was found that coyotes/ravens increased nearby human populated areas where more resources became available to these natural predator (Esque et al., 2010).

In the US serious actions have been made in collaboration between many land and wildlife agencies for the goal of conserving this endangered species (Averill-Murray et al., 2012). The military bases have been asked to protect the tortoises by monitoring their health and conducting training exercises away from the areas where these tortoises live. Relocation efforts for the tortoise have been attempted so that they are protected and many studies have been conducted in regard of the species ecology and behavior; adult tortoises preferred annual plants to forge on in the spring following a successful winter precipitation (Berry et al., 2013). Fluctuating rainfall leads to less food for these animals, therefore, it is essential as part of the conservation plan to making the proper availability of forage plants so that the species can continue recovering. A structured approach along with the participation of the broad stakeholders is necessary to save the species. Also, the release of the captive pet tortoises of deserts has been considered as the detrimental.

On the other hand, Texas horned lizards (*Phrynosoma cornutum*) are another species which can be counted under dhubs protection and conservation. These species are mainly found in Central, East and North Texas (Hellgren et al., 2010). The disturbance caused due to urbanization and habitat restoration threatens the population of these sensitive wildlife species. As per the investigations made by the researchers on these species, it has been noted that there are changes in the spatial distribution, population size, survival rates and the density for the last years. The main causes of the loss of these lizards are related to urbanization and agricultural factors (Wolf et al., 2013). Overharvesting for illegal rare species trades can be counted as other causes for the population decline.

Since these lizards are decreasing in numbers, many concerned residents from Texas and Oklahoma formed teams along with wildlife biologists for the order of saving the lizards and promoting its survival in its natural habitat (Fair & Henke, 2016). A Horned Lizard Conservation Society has been formed in Austin, TX in 1990 to save the lizards. In this context, the homeowners are requested not to spray pesticides on the harvester ant mound which may affect these lizards which hibernate under the woodpiles, rocks and the burrows. Henceforth, it is essential to develop an ecosystem management so that these species can be conserved and protected, rather than they disappear from the world (Dearborn & Kark, 2010).

Conservation and Protection Model – Ecosystem Management

A growing and rather established movement in the protection and conservation of the natural environment is the model of ecosystem management. Ecosystem management combines processes to conserve species and provide essential resources for promoting biological diversity. This is a holistic model, which sees that all organisms are parts of a larger whole. Impacts on one small system will impact the larger system it belongs to and vice versa. Usually, in these models, a sentinel biological model is selected to study the effects of environmental changes on the species. Studying sentinel models when applying the concepts of ecosystem management, will inform science (and hence, stakeholders) about how to best utilize a conceptual management model while comprehending all the given inputs and facts. Hence, the existence of dhubs, which are listed as vulnerable on the International Union for Conservation of Nature (IUCN) Red List, can serve as a sentinel for Kuwait’s deserts as the challenges reveal that dhubs are highly affected by many factors such as poaching for medicinal purposes and a source of dietary protein.

Ecosystem management is an evolving concept in environmental management. It incorporates knowledge of ecological relationships and sociopolitical views for the long-term purpose of protecting the integrity of native ecosystems (Willard & Cronin, 2007). Ecosystem management recognizes that the protection of air, land, and water resources requires an integrated approach with cumulative efforts of different agencies. It also entails the coordination of efforts among separate agencies and departments that work toward controlling the effects of cross-media pollution (Humphreys, 2005). It involves a variety of innovations, the survival of which must be weighed against administrative efficiency and political endurance (Carter-Finn et al., 2009). Kuwait and the other members of the Gulf Cooperation Council (GCC) have pursued the tightening of ecological regulations to protect their environments (Kannan, 2012).

As previously noted, Kuwait has set aside protected areas or habitats to promote biodiversity. The findings from my study show that there was a difference in body condition of dhubs living in protected and unprotected areas, and the protected habitats were found to be rich in vegetation, a valuable refuge and food resource for the dhubs. As Kuwait is still experiencing fallout from the wars as well as the unsustainable policies of mining, drilling, cultivating, and grazing, setting aside protected habitats is a critical move for species protection.

The influences of mankind on the environment and different species have been evident from previous research and the Iraq-Kuwait war itself. The protection of habitat is an initiation of ecosystem management, which further needs effective processes and measurements to conserve the population of dhubs in Kuwait as a protected species that may considerably change an ecosystem. By reviewing the studies pertaining to conservation of endangered creatures, along with the results of my current study, I recommend a few steps for ecosystem management that can help in the preservation of dhubs in the Kuwaiti desert:

1. The Parliament should produce legislation to further control human activities in the Kuwaiti desert. Extended recreational camping in the desert must be regulated, where the people leave the surroundings as it was when they arrived, without interfering with the natural setting of the environment. Moreover, camping locations must be restricted so as to minimize the impact of mankind on the environment and the residing species. The government should enforce all laws with no exceptions. According to the Environmental Democracy Index (EDI), which ranks countries using 75 legal environmental indicators

based on objective and internationally recognized standards established by the United Nations Environment Programme's (UNEP) on how a country enforcing laws to protect healthy environment, countries such as Lithuania, Latvia, and Russia were the top three nations out of 70 countries, where legal systems highly support the environment (Al-Abdulghani et al., 2013). Unfortunately, Kuwait was unable to secure any rank. However, ascribed to a myriad of concerns and developmental projects being undertaken by the Kuwaiti government simultaneously, it may be uncertain about implementing strict rules to protect the environment.

2. The government and non-profit organizations should start major public awareness programs to educate people of the importance of the environment in general and the role of endangered animals in the balance of the ecosystem, in this case, dhubs specifically. The pink ribbon, which was first introduced in a race for breast cancer in New York City in 1991, is a great example of how public awareness can make a difference and change political views of a given issue. While the authorities may be successful in executing this campaign, the public may or may not heed this matter.
3. As vegetation and food availability is at its greatest in the protected habitats, the region, and boundaries of such areas must be extended to further the availability of plant shelters for protecting dhubs from high temperatures. The plant shelters can reduce the water loss in the area by providing a relatively cooler microhabitat (Yates et al., 2000). This would also increase the humidity of the environment. However, desert reforestation may be considerably tedious because of the expensive and capital-intensive methods.
4. Not only must camping sites be limited and restricted, the habitat of dhubs and other species must be extended with no interruption (establishment of corridors to avoid fragmentation) to allow for gene flow in case of a disaster (Mader, 1984). Due to the effects of war and poaching, these creatures are at a threat of extinction. While imposing these restrictions is easy, the implementation by the general public must emanate from within for conservation of the ecosystem and partake in this contribution.

5. Parliament should impose a new law which requires all oil companies operating in Kuwait to get an ecological permit before drilling. These permits will make sure that drilling will not be detrimental to the biodiversity and ecology of Kuwait (Rena, 2008). This aspect can be positively implemented by the oil companies since oil is the major contributor of Kuwait's economy and there are a considerable amount of oil companies that are necessary for the economy. Also, bearing in mind the steps of conservation initiated by other GCC nations, Kuwait must incorporate these approaches to stay in the lead in conservation. The Government must establish a council for dispensing the permit before a company could start the drilling work. Accountable to this, the area to be drilled should be monitored thoroughly (Rena, 2008) and the decision to permit the drill must be made in accordance with the ecological impacts.
6. Conservation models and laws are one of the best means to protect wildlife, yet their success is dependent on a thorough understanding of the ecology of the target organisms as well as their physiological tolerances and sensitivities. In this context, the present study has put forth the relevance of examining the adaptation of dhub's physiology toward the surrounding environment, which will not only assist in developing conservation laws but also help in designing protected habitats or reserves. A better understanding of whether physiological indices can be used as short-term proxies for long-term fitness is needed. Another valuable path of investigation would be an examination of population and landscape genetics in order to maximize the efficient placement of natural reserves. Genetics and genomics are valuable assets in offering key knowledge pertaining to the identification of genetic mixing among populations, genetic variation, and genes that control the key life traits of the species (Shaffer et al., 2015). Genetic analysis can, therefore, offer insight into how ecological reserves can be efficiently designed through the comprehension of ecological and evolutionary processes that affects biodiversity. At last, long-term monitoring studies should be conducted to determine the efficacy of the reserves in conserving dhubs and other species within their boundaries and across Kuwait.

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