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FOOD SUPPLEMENTATION INCREASES MULE DEER (*Odocoileus hemionus eremicus*) RETENTION AT THE RANCHO SAN HUBERTO WILDLIFE CONSERVATION MANAGEMENT UNIT, SONORA, MEXICO

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ABSTRACT

Artificial food and water supplementation programs are common in Wildlife Conservation Management Units (UMAs) in arid northern Mexico to attract and retain mule deer as quality trophies. However, implementing these actions represents a high economic cost, and there is no convincing evidence of their effectiveness. This study evaluated the effect of food and water supplementation by capture-mark-recapture using camera traps at the UMA San Huberto, Sonora, Mexico. During the winter of 2015-2016, male mule deer counts and detection histories were collected at 62 photo-trapping stations spread across four supplementation treatments: 1) water and food, 2) water, 3) food, and 4) no supplementation. In addition, to assess the impact of natural vegetation on trough and feeder utilization on the ranch, the Normalized Difference Vegetation Index was calculated using Landsat 8 satellite images. A log-Poisson regression model for deer counts per photo-trapping station found that food supplementation increased mule deer numbers by 42 % when compared to stations without food supplementation. Vegetation biomass had no effect on the frequency of use of feeders and waterers in any of the treatments. According to the multistate model for detection histories, male mule deer at waterers receiving food-only supplementation are more likely to remain in that treatment than to move to either of the other two treatments (water and feed or water). This finding suggests that food-only supplementation is more effective in retaining male mule deer.

Keywords: capture-mark-recapture, photo-trapping, habitat improvement, UMA.

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INTRODUCTION

The arid zones of northern Mexico are home to the country's most prized game for domestic and foreign trophy hunters: mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), and bighorn sheep (*Ovis canadensis*). In large areas of these ecosystems with low agricultural, livestock, and forestry potential, hunting tourism has become a profitable productive alternative (Villarreal-González, 2012). In particular, the hunting value of the Sonoran mule deer subspecies (*O. hemionus* *eremicus*) has created an industry of such magnitude that a large part of the arid surface of Sonora has been designated for the registration and operation of Management Units for the Conservation of Wildlife (UMA, *sensu* Ley General de Vida Silvestre) for the extractive use of the species.

Mule deer hunting generates an estimated annual economic revenue of between 20 and 30 million dollars in Sonora (Valenzuela-Martínez, 2017). Given its economic importance, it is essential to provide the owners and technical managers of UMAs with habitat management tools to maintain a viable population density of mule deer for a sustainable harvest of the species (Villarreal-González, 2012). In this context, management involves protecting existing habitat, creating new habitat by providing resources that are limiting factors, or restoring it to maintain or increase wildlife abundance (Mannan and Steidl, 2013).

Since the late 1940s and early 1950s, wildlife managers in the southwestern United States and northern Mexico have assumed that water and food are the primary limiting factors for wildlife populations, particularly in desert habitats (Rosenstock *et al*., 1999). Under this assumption, some state wildlife management agencies in the United States established artificial water source programs to maintain or increase the size of wildlife populations, particularly game species (Cain *et al*., 2013). Food and water supplementation practices were subsequently implemented in Mexico and are now common in UMAs in arid northern Mexico, either using traditional livestock food and water supplementation infrastructure (water troughs, dams, alfalferos) or specialized programmable automatic feed supplementers for deer (Villarreal-Gonzalez, 2012).

Scientific evidence on the effects of water and feed supplementation on wildlife has been ambiguous and remains mostly speculative (Simpson *et al*., 2011). However, the positive effects of wildlife water provision are the most frequently documented (Rosenstock *et al*., 1999; Cain *et al*., 2013). Many game and non-game species benefit from water supplementation, but not all water source development projects have had the expected effects on animal distribution and abundance (Rosenstock *et al*., 1999). Some studies suggest that water sources constructed as habitat improvements have not provided the expected benefits for wildlife species, and may even harm them by promoting predation, intraspecific competition, disease transmission (Rosenstock *et al*., 2004), and vegetation degradation (Priesmeyer *et al*., 2012). However, the effectiveness of these practices is rarely evaluated with sufficient scientific rigor to determine their feasibility. Because these practices are costly, short-, medium-, and long-term studies on the efficiency of water and feed supplementation are required to achieve the management objectives of UMAs (Deyoung *et al*., 2019).

Therefore, the objective of this study was to evaluate the impact of artificial water and food sources on male mule deer permanence at the UMA Rancho San Huberto A. C., Municipality of Pitiquito, Sonora, Mexico. This paper tests the hypothesis that artificial supplementation of food and water increases male mule deer stay in the Rancho San Huberto UMA by reducing deer movements in search of these resources (Shields *et al*., 2012; McKee *et al*., 2015).

MATERIALS AND METHODS

The main objectives of the San Huberto UMA (SEMARNAT-UMA-EX-0358-SON) are wildlife conservation and harvesting. Mule deer, white-tailed deer, and collared peccary (*Dicotyles tajacu*) are hunted for sport. This UMA is located in the municipality of Pitiquito, Sonora, and covers an area of 18 083 ha of the Sonoran Coastal Plain. The San Huberto UMA has an arid climate with a winter rainfall regime and an extreme annual thermal oscillation (BWhs (x')(e') *sensu* García-Amaro (2004)) (CONABIO, 1998). Annual precipitation is variable (between 28 and 235 mm), with an average of 101 mm. The average monthly temperature is 21.1 °C (with a range between 13 and 30.2 °C). Sixty-five percent of the UMA's surface is represented by very smooth planes and hills with uniform and complex topography of 0 to 6 % slope. The remaining 35 % of the area is made up of inclined planes, low, medium, and high hills, and hills with complex topography, with slope ranging from 0 to 45 %, falling into the "level" to "very steep" classes. It is located at altitudes ranging from 0 to 900 m. Its formation is alluvial, colluvial, and *in-situ* origin (INEGI, 2004).

Microphilous Desert Scrubland, Sarcocaule Scrubland, and Mezquital are among the vegetation types found in the Rancho San Huberto UMA (INEGI, 2016). Microphilous Desert Scrub is found in the flat, lowlands, and on gentle hillsides. This vegetation type is constituted by an association of low to medium woody shrub species, with simple and compound, small and evergreen leaves such as creosote bush (*Larrea tridentata*), franseria (*Franseria deltoidea*); deciduous species such as ocotillo (*Fouquieria splendens*), and brittlebush (*Encelia farinosa*) associated with tall and short cacti such as sahuaro (*Carnegiea gigantea*), organ-pipe cactus (*Stenocereus thurberi*), and chollas (*Opuntia* spp.).

The lower stratum of the vegetation is made up of annual grasses, such as sixweeks grama (*Bouteloua barbata*). Thorns are present in 20 to 25 % of woody species. Sarcocaule scrub is found on medium, high, and hilly hillsides, and is composed of an association of low and medium-sized soft-stemmed shrubs, such as matacora (*Jatropha cuneata*) and lomboy (*Jatropha cinerea*); also low trees with small deciduous leaves and soft stems such as copal (*Bursera hindsiana*) and elephant tree (*Bursera microphylla*), or woody such as foothill palo verde (*Parkinsonia microphylum*) and ocotillo, associated with low and tall cacti such as jumping cholla (*Opuntia bigelovii*) and cardon cactus (*Pachycereus pringley*); which are slow growing with deep or superficial root systems and reduced or modified foliage. Mezquital is found in intermittent in lowland intermittent streams; it is composed of an association of low to medium and tall shrubs with woody stems, simple and compound leaves, small and evergreen, such as mesquite (*Prosopis glandulosa*), creosote bush, and brittlebush. In the lower stratum, annual grasses such as sixweeks grama and buffel grass (*Cenchrus ciliaris*) prevail (INEGI, 2015).

Food and water supplementation

Prior to this study, as a strategy to improve the habitat in the Rancho San Huberto UMA, its owners established a water distribution network of 62 drinking troughs

(Figure 1). These were distributed according to the existing gaps in the property and were periodically replenished with a 10 000 L tanker truck. Wildlife feeders, known as "alfalferos", were also installed at these locations, where bales of hayed alfalfa were deposited.

Experimental design

The UMA area was divided into four sections or blocks corresponding to the number of cells in a 2×2 factorial design (Berger *et al*., 2018), with the factors *WATER* (levels with and without water supplementation) and *FOOD* (levels with and without food supplementation). The study by Deyoung *et al*. (2019) represents an example of the application of a factorial design to wildlife in the field, used simultaneously to evaluate the effect of food supplementation and population density of white-tailed deer on

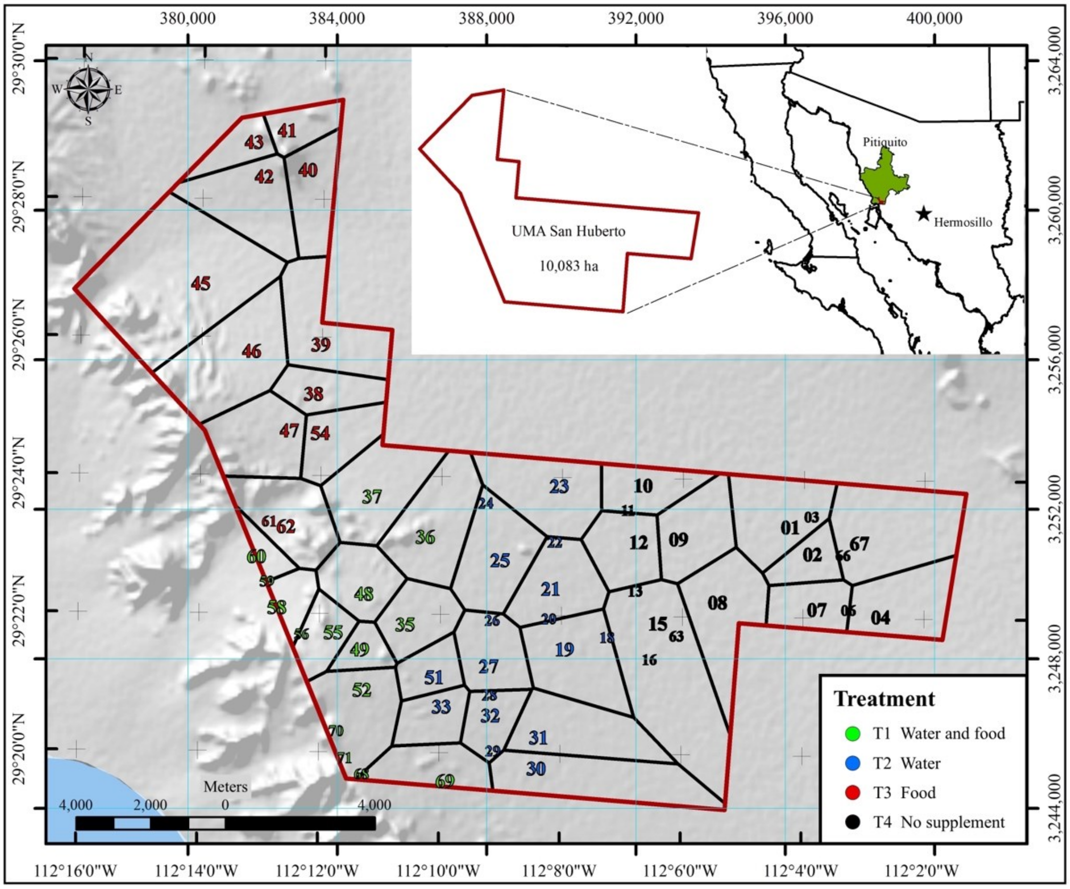

Figure 1. Location of photo-trapping stations and artificial watering trough treatments at the Rancho San Huberto UMA, Sonora, Mexico. Larger numbers denote primary photo-trapping stations used for plotting Thiessen polygons (black lines). Smaller numbers denote secondary photo-trapping stations resulting from the relocation of primary camera-traps. The color of the number denotes the supplemental treatment specified in the legend.

natural vegetation composition in south Texas (USA). Thus, four treatments were applied: Treatment 1) supplement with water and feed; Treatment 2) supplement with water; Treatment 3) supplement with feed, and Treatment 4) no supplement.

As part of the Authorized Management Plan of the UMA Rancho San Huberto, water supplementation in drinking troughs is carried out throughout the year. However, for the purposes of this study, water supplementation was suspended from November 1, 2015 to April 30, 2016 in order to establish Treatments 3 and 4. Similarly, as of November 1, 2015, supplemental food was provided to establish Treatments 1 and 3. The drinking and/or feeding troughs, known as photo-trapping stations, served as the experimental unit in which the treatments were administered. Because only 41 camera-traps were available, 10 photo-trapping stations were initially used in each treatment (11 for Treatment 3), for a total of 41 primary stations. However, due to the operation of the UMA, the total of the 62 photo-trapping stations had to be monitored by moving those 41 camera-traps to secondary photo-trapping stations during the study period (Figure 1).

Camera trap operation

A capture-mark-recapture experiment was used to estimate apparent survival and transition probabilities between treatments by obtaining capture histories of mule deer males visiting the watering troughs. The (photographic) captures were made using 41 automatic detection cameras with two models: Stealth Cam® model STC-I840IRA (USA) and Wildgame Innovations® model i12117c (USA), both equipped with an infrared motion sensor and programmed to take three photographs every two minutes. The cameras were placed in the troughs/feeders according to the experimental design and treatments (Figure 1). Sampling was conducted during the period November 1, 2015 to April 30, 2016, but was variable among photo-trapping stations (Figure 2). Photo-traps were left active 24 h per day for sampling periods established based on technical visits to the ranch.

Photographic files were organized into folders by photo-trapping station and date. Subsequently, each photo was examined and a daily count of male deer per photo-trapping station was taken. Individual males were also identified from the characteristics of their antlers, including size, number of points, shape, symmetry, and pearling, as well as other characteristics such as scars, wounds, and broken antlers. With these data, the capture history of the males was elaborated (Figure 3). If the same individual was photographed twice on the same day, this record was considered as a single capture.

Vegetation analysis

Mule deer population dynamics and movements are affected by the condition of natural vegetation (Hurley *et al*., 2014; Sawyer and Kauffman, 2011), which can mask the effects of water and food supplementation. For this reason, variations in vegetation condition in the study area were analyzed using the Normalized Difference Vegetation

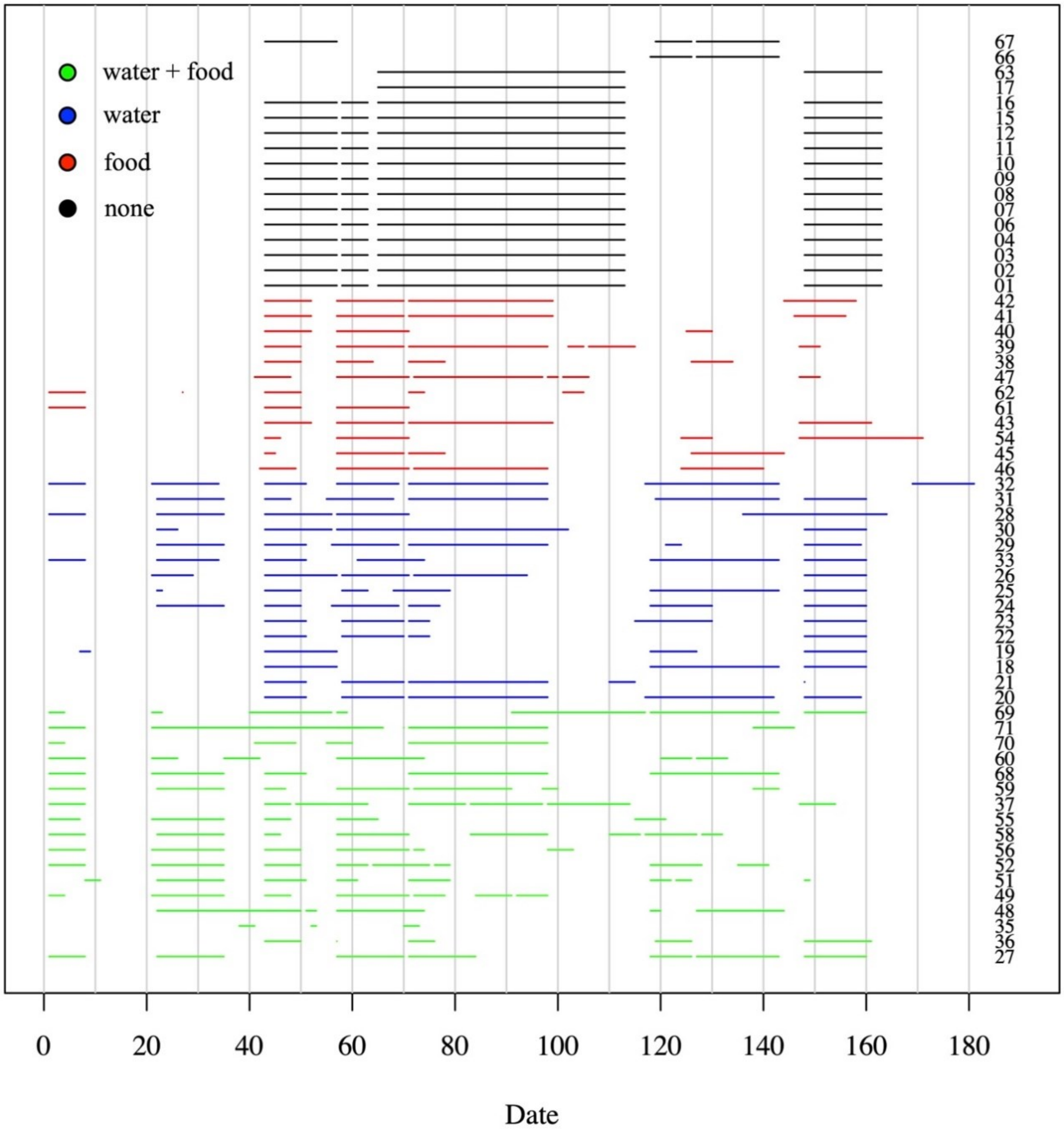

Figure 2. Sampling effort for each camera-trap. Horizontal lines denote sampling periods and color denotes their corresponding treatment. Date (x-axis) value equal to 1 corresponds to November 1, 2015. The numbers on the right denote the photo-trapping stations whose locations are shown (Figure 1).

Index (NDVI), which measures plant vigor, vegetation cover, and biomass from the ratio of reflectance of the red (absorbed by chlorophyll) and near infrared (scattered by the mesophyll of the leaves) spectra (Pettorelli *et al*., 2005).

Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images with a resolution of 250 m were used to estimate NDVI. To assess natural vegetation

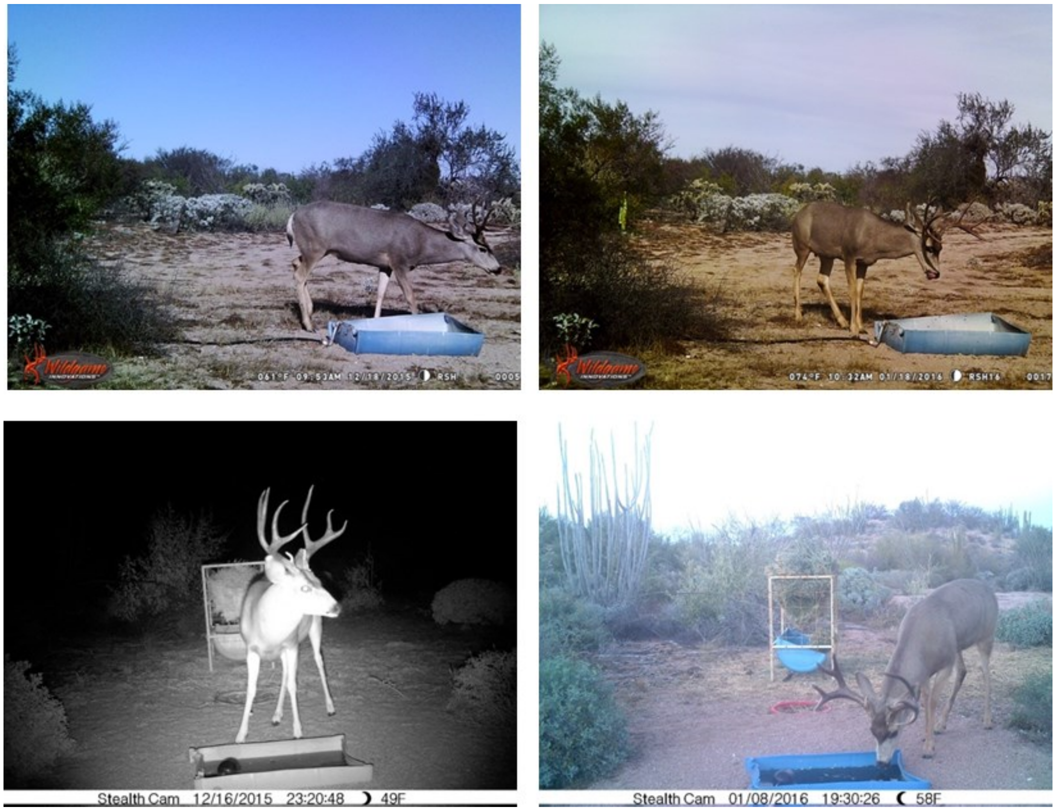

Figure 3. Two individuals of mule deer (*O. hemionus*) detected in camera-traps on different dates and distinguishable by the shape of their antlers.

conditions and changes at the sampling unit level, Thiessen polygons were plotted for the primary photo-trapping stations (Figure 1). The NDVI value assigned to each polygon was the average of the NDVI values of all pixels comprised within the polygon. Secondary photo-trapping stations shared NDVI values with their primary photo-trapping stations. For each photo-trapping station, two monthly satellite images were generated and processed, corresponding to the months of November 2015 to February 2016, and one image for March and April 2016, for a total of 10 images per photo-trapping station (trough-feeder).

Statistical analysis

Two statistical analyses were conducted to determine the effectiveness of the treatments in deer retention. The effect of water supplementation (factor *WATER* with two levels: with and without water), food supplementation (factor *FOOD* with two levels: with and without food), and vegetation biomass (*ndvi*, assessed by NDVI) on the number of counts of male mule deer detected on each sampling day were evaluated using a log-Poisson regression analysis (Dobson and Barnett, 2018) with the stats package of program R (R Core Team, 2022). *Date* and $date^2$ were also added to the model as covariates, where *date* denotes the number of days since November 1, 2015. The variable *date* was included to include the possible effects of physiological changes, since mule deer were in their reproductive season.

A Kruskall-Wallis test (Ramsey and Shafer, 2013) was used to detect differences in the variable *ndvi* among treatments at the beginning of the study period, which could confound the effects of treatments on deer counts. The effect of each variable and interaction was evaluated using a Wald test on each regression coefficient. Statistically significant effects of the factors *WATER* and/or *FOOD* on deer count were expressed as a multiplicative effect (e^b, expressed as a percentage, where b is the regression coefficient associated with the factor) with respect to the reference level (no supplement). The delta method (Faraway, 2016) was used to estimate the sampling variances of the multiplicative effects (Var(e^b)) from the sampling variances of the regression coefficients (Var(b)) and thus estimate the confidence interval for the multiplicative effect.

The implementation of the log-Poisson regression model considered the heterogeneity between the number of camera-traps operating per day per treatment during the study period (Figure 2), using the number of camera-traps for each date as an offset variable. However, it was considered that the extremely low number of total detections in Treatment 4 (without water and feed supplementation) could considerably bias the estimation of the effects of water and feed supplementation. Thus, the above model was evaluated totally excluding the observations in Treatment 4, which resulted in an incomplete design. The exclusion of these data precluded the possibility of estimating the interaction between the factors *WATER* and *FOOD*.

Capture-mark-recapture histories of male mule deer were modeled using a multistate live-capture model (Devineau *et al*., 2014) with program MARK (White and Burnham, 1999). This model estimates the transition probabilities of an individual between two mutually exclusive states A and B (ψ^{AB}), the apparent survival probabilities for each state (S) and the capture probabilities (p) for each state. Our models considered three stages: Treatment 1 (T_1, water and food), Treatment 2 (T_2, water only), and Treatment 3 (T_3, food only). Due to the low number of captures in Treatment 4 (T_4, no supplementation), this treatment was excluded from the modeling. The status of all individuals was defined in 10-day periods from December 11, 2015 through March 20, 2016. Thus, if supplementation with water and feed is effective, the probability of transition to the same state (that a given deer does not switch treatments) is expected to be higher for Treatment 1 than for any other treatment (i.e., $\psi(T_1®T_1) > \psi(T_2®T_2)$, and $\psi(T_1®T_1) > \psi(T_3®T_3)$). For multistate modeling, a model selection process (Cavanaugh and Neath, 2019) was conducted to determine whether treatments influence on mule deer survival and treatment use.

The transition probability (ψ) between all treatments was estimated, as well as the estimated transitions (staying or not staying in the treatment). However, there were some limitations in the variables that could be included. The probability of detection (*p*) could not be evaluated as a function of treatments as it produced high standard errors. Alternatively, the probability was evaluated jointly for the treatments with water supplementation (T_1 and T_2) and without water supplementation (T_3), as well as for the treatments with feed supplementation (T_1 and T_3), and without feed supplementation (T_4). Statistical analyses were performed at a significance level of $a = 0.05$.

It should be clarified that the sections or blocks in which the supplementation treatments were applied were not completely homogeneous. The sections of treatments T_1 and T_3 contain plains, hills, and hillsides, while treatments T_2 and T_4 are located only in flat terrain (Figure 1). This heterogeneity in topographic conditions can potentially confound treatment effects, so the results of the log-Poisson regression analysis and the multistate live-capture model should be interpreted with caution.

RESULTS AND DISCUSSION

Normalized Difference Vegetation Index (NDVI)

The highest NDVI values occurred at the beginning of the study period (November 2015) and decreased steadily towards the end of the study period (April 2016) (Figure 4). There were differences in NDVI values at the beginning of the study period

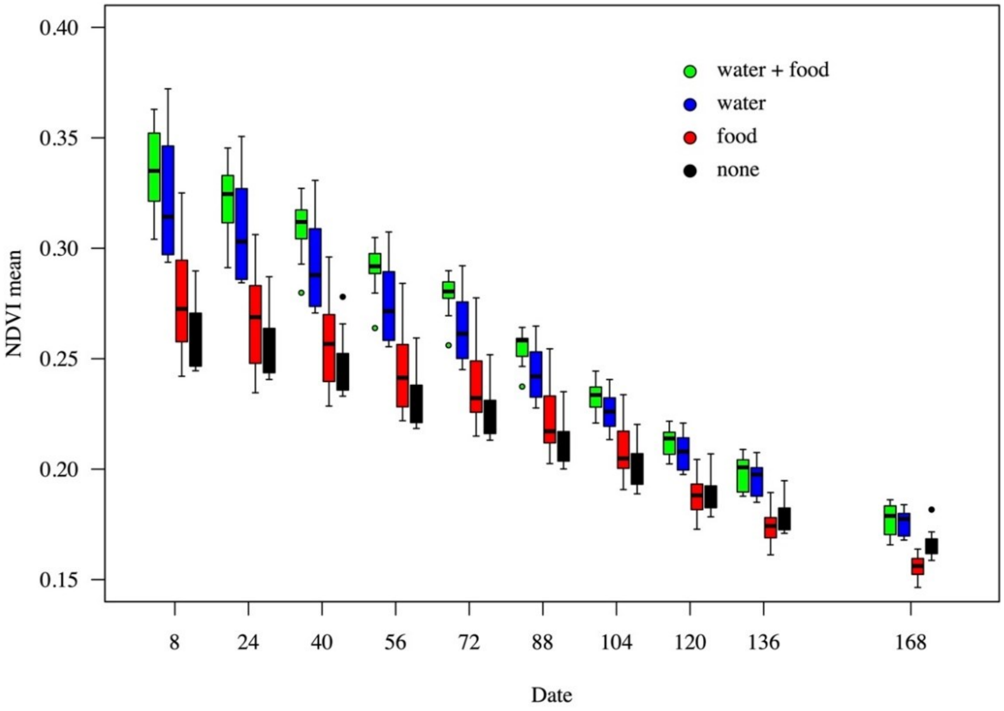

Figure 4. Trend in NDVI values for each treatment during the study period. The Date value (x-axis) equal to 1 corresponds to November 1, 2015.

among supplementation treatments (Kruskall-Wallis test, $c^2 = 26.97$, g.l = 3, $p < 0.001$). This indicates that vegetation biomass was generally higher for the water and food supplementation (T_1) and water only (T_2) treatments, and lower for the food only (T_3) and no supplementation (T_4) treatments.

These differences in NDVI values between treatments, although reduced in magnitude, were maintained at the end of the study period (Figure 4). The division of the UMA into four sections for the random assignment of the four treatments resulted in this relationship between NDVI values and treatments, where each section differed in topography and vegetation type.

The relationship between NDVI values and treatments can lead to confounding the individual effects of these two variables on mule deer retention. In the spatial context, the highest mean NDVI values were recorded on the slopes and hills (0.31–0.38), although towards the end of the study period the highest values were recorded in the valley area, particularly in the streams and lowlands (0.17–0.21).

Effects of water and food supplementation on mule deer retention

We found evidence that food supplementation increases the use frequency of photo-trapping stations by mule deer ($z = 2.299$, $p = 0.021$). Food supplementation is estimated to increase mule deer counts by 42 % (95 % confidence interval = 0–83 %) when compared to stations that did not have food supplementation. These results support the hypothesis that artificial supplementation of water and food sources increase the permanence of male mule deer in the Rancho San Huberto UMA by encouraging their presence at feeders.

There is suggestive, but not conclusive, evidence of a positive linear relationship between date and deer counts in all treatments (Wald test for log-Poisson regression coefficient for the $date^2$ term, $z = 1.680$, $p = 0.093$) (Table 1), indicating that the frequency

Table 1. Effect of the variables date, *ndvi* (biomass of natural vegetation), water supplementation (factor *WATER*, no supplementation as reference level), feed supplementation (factor *FEED*, no supplementation as reference level) on daily deer counts in camera traps per treatment determined by log-Poisson regression. Regression coefficients or effects (*b*) are calculated for the standardized date and *ndvi* variables.

Variable	Effect (*b*)	E.E.(*b*)	*z*	*p*
Intersection	-2.092	0.334	-6.271	>0.001
date	0.921	0.548	1.680	0.093
$date^2$	-0.478	0.323	-1.470	0.141
ndvi	0.501	0.389	1.287	0.198
WATER	0.328	0.351	0.935	0.350
FEED	**0.348**	**0.151**	**2.299**	**0.021**

Eststandard error; *z* and *p*: *z* test statistic and the *p* value of the hypothesis test for no effect (H_0: $b = 0$ vs. H_a: $b \neq 0$). Bolded variables denote statistically significant effects.

of use of waterers and feeders has a continuous increase since the beginning of the study period. In turn, there is no evidence of an effect of NDVI on mule deer counts in camera traps (Wald test for log-Poisson regression coefficient, $z = 1.287$, $p = 0.198$), indicating that vegetation greenness does not influence frequency of use of waterers and feeders (Table 1). There was no evidence that water supplementation increases the frequency of use of photo-trapping stations by mule deer (Wald test for log-Poisson regression coefficient, $z = 0.935$, $p = 0.350$).

The positive effect of food supplementation corroborates that improving habitat characteristics can allow a natural increase in wild populations and increase the probability of locating animals, and encouraging home range reduction or concentrating individuals in certain environments, areas or territories (Larsen *et al*., 2007; Draycott *et al*., 2007; Gaudioso-Lacasa *et al*., 2010).

Contradictorily, the null effect of NDVI on mule deer counts suggests that food available in natural vegetation is not a limiting factor in the study period (November-April). The temporal variation in vegetation biomass observed during the study period was not sufficient to observe a response in deer counts at troughs and feeders. In this regard, Ovalle-Rivera *et al*. (2020) found a positive response in wildlife counts, including white-tailed deer (*O. virginianus*), in artificial troughs in desert shrublands of Coahuila with indicators of plant biomass in the surrounding vegetation (vegetation height and density of dominant woody species) over a 12-month period. In addition, Mandujano-Rodríguez and Hernández (2019) detected a significant increase in the count of *O. virginuanus* in troughs during the season (January-May) with lower rainfall during a three-season study (2016-2018), in a hot semiarid area of Puebla.

It is hypothesized that the higher frequency of mule deer use for the food supplementation treatments (T_1 and T_3) compared to the water only treatment (T_2) is due to males being in the reproductive stage during the winter season, resulting in significant physiological wear and a higher food consumption to meet their energy demands. Olivas-Sánchez *et al*. (2015) state that the foraging behavior of mule deer in the Chihuahuan Desert maximizes the intake of crude protein. Thus, hayed alfalfa provided at feeders is more appealing to mule deer than forage from natural vegetation because of its high crude protein content (Rojas-García *et al*., 2019). In addition, given the phenological stage of the vegetation in which the availability of natural forage is constantly decreasing (Figure 4), mule deer respond more intensely to artificial food supplementation.

Mule deer capture histories (Figure 5) suggest that food-only supplementation (T_3) is more effective in retaining male mule deer. The best multistate model ($w = 0.8437$) had a transition probability as a function of treatment tenure, equal apparent survival between treatments, and a detection probability dependent on water supplementation (Table 2). This model estimates that the probability of a male mule deer to remain in a given treatment is higher for the food-only supplemented treatment ($\psi(T_3 \rightarrow T_3) = 0.816$, IC 95 % ($\psi$)=0.738-0.894) than for the water and food supplemented treatment ($\psi(T_1 \rightarrow T_1) = 0.500$, IC 95 % ($\psi$)=0.363-0.637) (Table 3). The probability of remaining in

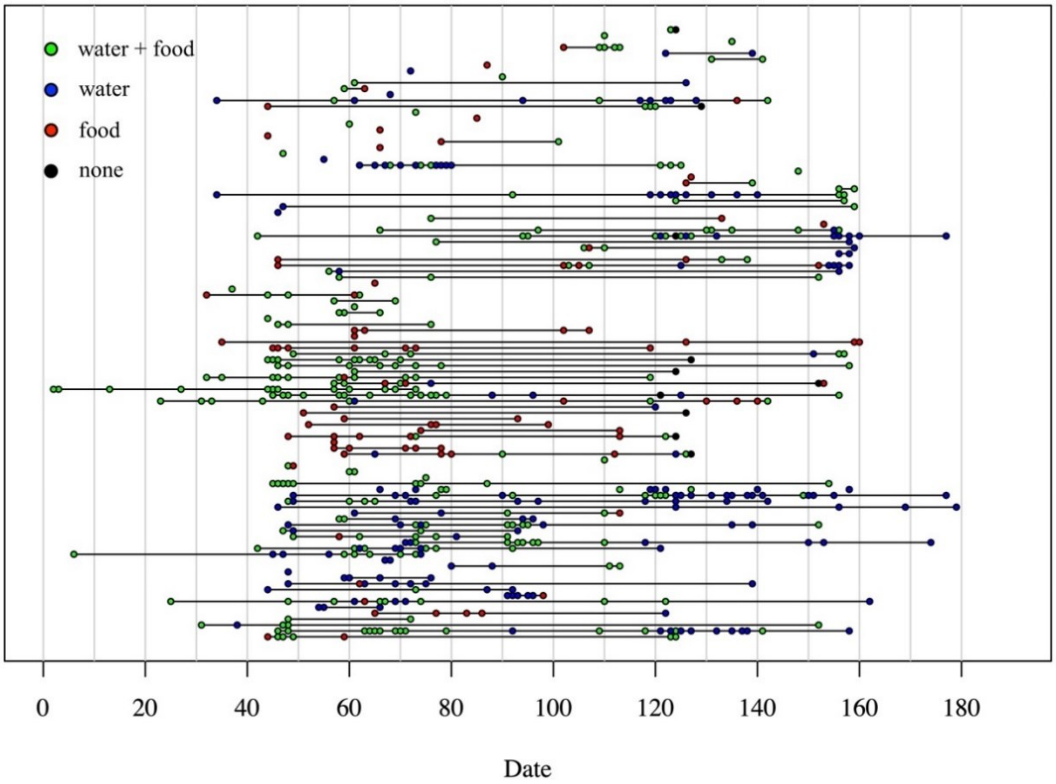

Figure 5. Capture histories of 105 mule deer (*Odocoileus hemionus*) in camera traps in the UMA Rancho San Huberto, Municipality of Pitiquito, Sonora. Dots denote capture dates, and colors denotes the treatment in which the individual was captured.

Table 2. Selection of multistate models estimating the probability of transition between water and food supplementation treatments (ψ), survival (S), and probability of detection (p) in camera traps for *O. hemionus* in the UMA Rancho San Huberto, A. C., Sonora.

Model	*K*	-2 log *L*	AIC$_C$	DAIC$_C$	*w*
$\psi\ (P)\ S(\cdot)\ p(WATER)$	6	828.72	1161.0	0.0	0.8437
$\psi\ (P)\ S(T)\ p(WATER)$	8	827.85	1164.4	3.4	0.1560
$\psi\ (P)\ S(\cdot)\ p(FOOD)$	6	846.53	1178.8	17.8	0.0001
$\psi\ (T)\ S(\cdot)\ p(\cdot)$	8	843.79	1180.3	19.3	0.0001
$\psi\ (P)\ S(T)\ p(FOOD)$	8	844.99	1181.5	20.5	>0.0001
$\psi\ (T)\ S(T)\ p(\cdot)\}$	10	841.16	1182.0	21.0	>0.0001
$\psi\ (\cdot)\ S(\cdot)\ p(\cdot)\}$	3	857.75	1183.8	22.8	>0.0001
$\psi\ (P)\ S(\cdot)\ p(\cdot)$	5	854.50	1184.7	23.7	>0.0001
$\psi\ (P)\ S(T)\ p(\cdot)$	7	851.28	1185.7	24.7	>0.0001

K: number of parameters; -2 log L: deviance ; AIC$_C$: corrected Akaike information criterion; *w*: Akaike weight; $\psi(T)$: models considering all transition probabilities among the three treatments (water and food, water only, and food only); $\psi(P)$: model considering only estimated transitions (staying or not staying in the treatment); $p(WATER)$: estimation of the probability of detection for treatments with water (water and food and water only), and without water; $p(FOOD)$: estimation of the probability of detection for treatments with feed (water and food and food only) and without food; (-): parameter modeled as a constant.

Table 3. Parameter estimates for the best multistate model for live mule deer captures in the UMA Rancho San Huberto, Municipality of Pitiquito, Sonora. Each *state* denotes 1) water and food treatment (T_1), 2) water only treatment (T_2), 3) food only treatment (T_3).

Parameter	Estimator	Standard error	IC 95 %	
			LI	LS
S	0.919	0.019	0.874	0.948
ψ (T_1→T_1)	**0.500**	**0.070**	**0.363**	**0.637**
ψ (T_1→T_2)	0.250	0.035	0.187	0.324
ψ (T_1→T_3)	0.250	0.035	0.187	0.324
ψ (T_2→T_1)	0.188	0.032	0.132	0.259
ψ (T_2→T_2)	**0.624**	**0.064**	**0.499**	**0.749**
ψ (T_2→T_3)	0.188	0.032	0.132	0.259
ψ (T_3→T_1)	0.092	0.020	0.059	0.139
ψ (T_3→T_2)	0.092	0.020	0.059	0.139
ψ (T_3→T_3)	**0.816**	**0.040**	**0.738**	**0.894**
$p(T_1)$	0.556	0.054	0.449	0.659
$p(T_2)$	0.556	0.054	0.449	0.659
$p(T_3)$	0.130	0.027	0.085	0.193

S: probability of apparent survival between 10-day periods; ψ(Tx→Ty): probability of transition from Treatment x to Treatment y; p: probability of detection; LI and LS: lower and upper limits of the 95 % confidence interval (95 % IC), respectively. Bold denotes transition probabilities to the same treatment, ψ(Tx→Tx).

Treatment 2 ($\psi(T_2$→$T_2)$) did not differ from those for Treatment 1 and Treatment 3 since their 95 % ICs overlap (Table 3), although the overlapping with the 95 % IC interval ($\psi(T_3$→$T_3)$) is small and suggests a real difference of Treatment 2 with Treatment 3.

The higher deer retention of the food-only supplementation treatment ($\psi(T_3$→$T_3) = 0.816$) compared to the water and feed supplementation treatment ($\psi(T_1$→$T_1) = 0.500$) is intriguing. Although there is no obvious explanation for this pattern, it is hypothesized that the existence of water increases encounters of male mule deer with other wildlife species that drink water from the troughs but do not consume the alfalfa, especially predators such as coyote, bobcat, and cougar (Rosenstock *et al*., 2004; Esparza-Carlos *et al*., 2019), which are present in the area where the study was conducted. Mule deer water requirements probably decrease during the winter, as water consumption for thermoregulation also decreases, so supplementation with water may not be as attractive to mule deer.

UMA owners and technicians in the arid north of Mexico require technically sound recommendations on water and food supplementation to achieve their management objectives and optimize material, human, and financial resources. Thus, more experimental studies like the current one are needed, but with stricter randomization of trough treatments and a greater spatial (at least three UMAs) and time (at least three years per UMA) representativeness to improve the control of the effect of extraneous variables inherent to any field study.

CONCLUSIONS

This study provides experimental evidence of the effectiveness of artificial food and water supplementation on male mule deer survival in the Sonoran Desert Wildlife Conservation Management Unit during the winter season. Mule deer visit artificial feeders and waterers more frequently and on a regular basis, in contrast to the almost non-existent record of mule deer presence in unsupplemented photo-trapping stations. It is concluded that food supplementation is more effective than water supplementation in retaining male mule deer when there has been a previous and consistent water supplementation. The results suggest that water supplementation during the breeding season does not have a high significant effect on the frequency of water trough use or the deer's permanence when compared to feed-only supplementation.

Finally, spatial and time variation in the state of natural vegetation during the December-March period had no direct effect on the frequency of mule deer use of watering and feeding troughs. However, it is very likely that the condition of the natural vegetation effectively influences the use of waterers and feeders by mule deer on an annual basis, which includes the driest time of year in the region, prior to the summer rainy season (May and June), when natural forage may be most limited.

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