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Persistence of mule deer pellet groups on Chihuahuan Desert

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The persistence of fecal or pellet groups is indispensable when using the pellet group counting technique to estimate population densities and relative abundances of deer, as well as other herbivores. This technique is widely employed worldwide, and in México, the majority of deer abundance estimates have been made using this tool. However, for mule deer (*Odocoileus hemonious*) in México, there is no data on the persistence of pellet groups, and there is only one study on white-tailed deer. The pellet group counting technique has two main methods: a) "Fecal Standing Crop," where the accumulated pellet groups in plots are counted in a single visit, and b) "Fecal Accumulation Rate," which estimates density based on the accumulation of new fecal groups between two sampling periods, initially requiring the removal of all fecal groups from plots and counting again after some time. Both methods require knowing the pellet group disappearance rate during the pellet group accumulation period. This information is fundamental to understanding the ecology and making precise decisions in the management and conservation of mammals, such as mule deer, a species that is declining in some regions of México. Due to the lack of studies on the persistence of pellet group of mule deer in México, the aim of this study was to determine the persistence of mule deer fecal groups and their color changes over time, to establish pellet accumulation periods for estimating population abundances without biases when using this technique in arid habitats. We monitored 102 fecal groups for four years in the Chihuahuan Desert, finding that pellet groups are only lost during the summer rainy season. All pellet groups deposited between October and May were present, and all pellet groups turned white only after the first summer rainy season. The persistence of pellet groups was similar across seasons (fall, winter, spring) and deposition years (2004 to 2006). Some pellet groups persisted for over four years. The data suggest that the only source of degradation of pellet groups is summer rains, and no degradation by biological agents, such as fungi or insects, was observed. In summary, in arid areas, to estimate deer use or density throughout the entire dry season through pellet group counting, it is suggested that only two visits with either of the mentioned techniques are needed. If "Fecal Standing Crop" is used, there is now certainty that all non-white pellets are post the summer rainy season. If the "Fecal Accumulation Rate" technique is used, there is certainty that there will be no loss of pellets groups between the accumulation period of the entire dry season, approximately 7.5 months later. By reducing the number of visits, it allows us to cover more sampling sites, expand the study area, and obtain more precise estimates that will help understand ecological aspects and make management decisions.

La persistencia de excretas o grupos fecales es indispensable al utilizar la técnica de conteo de grupos fecales para estimar densidades poblacionales y abundancias relativas de venados, así como de otros herbívoros. Esta técnica es ampliamente empleada a nivel mundial; y en México la mayoría de estimaciones de abundancias de venados que se han realizado utilizan esta herramienta. Sin embargo, para el venado bura *(Odocoileus hemonious*), en México no existen datos sobre permanencia de grupos fecales y solo hay un estudio en venado cola blanca. La técnica de conteo de grupos fecales tiene dos métodos principales: a) "Fecal standing Crop", dónde se cuentan los grupos de pellets acumulados en parcelas en una sola visita, y b) "Fecal Acumulation Rate", que estima la densidad a partir de la acumulación de grupos fecales nuevos entre dos periodos de muestreo, requiere inicialmente remover todos los grupos fecales de las parcelas y volver a contar después de un tiempo. Ambos métodos requieren saber tasa de desaparición de grupos fecales durante el periodo de acumulación de pellets. Esta información es fundamental para entender la ecología, tomar decisiones precisas en la gestión y conservación, de mamíferos, como el venado bura, especialmente en regiones de México en las cuales están disminuyendo sus poblaciones. Debido a la falta de estudios sobre la tasa de desaparición de grupos fecales de venado bura, el objetivo de este estudio fue determinar el tiempo de permanencia de grupos fecales de venado bura y sus cambios de color a través del tiempo, con el fin de establecer periodos de acumulación de pellets, para estimar las abundancias poblacionales sin sesgos cuando se utiliza esta técnica en hábitats áridos. Se monitorearon 102 grupos fecales durante cuatro años en Desierto Chihuahuense y se encontró que sólo se pierden grupos fecales durante la temporada de lluvias de verano. Todos los grupos fecales depositados entre octubre - mayo estaban presentes y todos los grupos fecales se volvían blancos sólo después de la primera temporada de lluvias de verano. La permanencia de grupos fecales fue similar a lo a largo de las estaciones (otoño, invierno, primavera) y los años de deposición (2004 a 2006). Algunos grupos fecales persistieron hasta después de cuatro años. Los datos sugieren que la única fuente de degradación de los grupos fecales es por las lluvias de verano, y no se observó degradación por agentes biológicos, como hongos o insectos. En resumen, en zonas áridas, para estimar el uso o densidad de venado a lo largo de toda la época seca mediante el conteo de grupos fecales, se sugiere que solo se necesitan dos visitas con cualquiera de las técnicas mencionadas. Si se utiliza "Fecal standing Crop", ahora se tiene la certeza que todos los pellets que no son blancos, son posteriores a la época de lluvias de verano. Si se utiliza la técnica "Fecal Acummulation Rate", está la certeza, que no habrá pérdida de pellets entre el periodo de acumulación de toda la época seca, aproximadamente 7.5 meses después. Al reducir el número de visitas, nos permite abarcar más sitios de muestreo, ampliar el área de estudio y tener estimaciones más precisas que servirán para entender aspectos ecológicos y tomar decisiones de manejo.

Keywords: Mapimí Biosphere Reserve; *Odocoileus hemionus*; pellet group counting; relative abundance.

Introduction

Estimating the abundance of wild mammal populations and evaluating their changes over time or between habitats is essential for understanding species ecology and for effective sustainable management: utilization, conservation, and control (Harestad and Bunnell 1987; Laing *et al.* 2003; Mandujano 2014). To estimate the population density of herbivores, both direct and indirect counting methods have been employed. Direct methods are recommended in areas where deer are abundant and have good visibility in their habitat, and are not easily frightened by humans (Mandujano 2014). However, for many wildlife species, it can be challenging to estimate abundance directly, such as through visual counts, due to factors like low abundance, poor habitat visibility due to bushes, trees, uneven terrain, elusive species, etc., and the potential influence of weather conditions and observer bias (Ezcurra and Gallina 1981; Galindo-Leal and Weber 1998; Hibert *et al.* 2011). Additionally, this method can be costly, and noise from land or air vehicles may disturb the animals, potentially introducing observer bias and fatigue.

When herbivore abundances are low, and the animals are difficult to detect, indirect methods can be a good option. For example, track counts, pellet counts (Harestad and Bunnell 1987; Gallina-Tessaro 1990; Hibert *et al.* 2011; Mandujano 2014). Pellet counting is an attractive option due to its ease of application, non-invasiveness, the potential for adequate sample sizes (Mandujano 2014), minimal training requirements, and cost-effectiveness. This technique provides persistent records of the presence of deer (Ezcurra and Gallina 1981) or other herbivores.

For herbivores, fecal group counting can be used to estimate relative abundances or population density (Lioy *et al.* 2015). To determine population density, the number of individuals in a population, or their distribution, three variables are required: the number of pellet groups or droppings over an area (km^2), the daily deposition rate of feces, and the rate of disappearance of feces or pellet groups for the species under study (Ezcurra and Gallina 1981; Barnes and Barnes 1992; Camargo-Sanabria and Mandujano 2011).

The main techniques used for pellet group counting are: 1) FSC (Fecal Standing Crop), which estimates density by counting all feces or pellet groups accumulated in randomly selected sampling plots. It requires knowledge of the persistence time or disappearance rate of these groups. 2) FAR (Fecal Accumulation Rate). This method estimates density based on the accumulation of new feces between two sampling periods. It initially requires removing all feces from the plots and returning after a fixed time to count how many have accumulated. During this time, there should be no disappearance of feces or pellet groups. Both methods require the daily defecation rate to estimate the population density of the herbivore (Laing *et al.* 2003; Torres *et al.* 2013; Mandujano 2014; Lioy *et al.* 2015).

Additionally, pellet group counting can be employed as an index of abundance, which can be useful for monitoring the same population, detecting changes in populations over time, or comparing populations (Torres *et al.* 2013; Mandujano 2014). Pellet group counts are a good indicator of the relative habitat use (Leopold *et al.* 1984; Loft and Kie 1988; Galindo-Leal and Weber 1998; Sánchez-Rojas and Gallina 2000b; Esparza-Carlos *et al.* 2011; Mandujano 2014). It has been estimated that habitat use measured with different techniques by ungulates and pellet counts is similar in different ecosystems, for example: mule deer, as determined by telemetry and pellet group counts in temperate forest (Loft and Kie 1988); as is the case with Gray Brocket Deer (*Mazama gouazoubira*) the habitat use estimates using GPS and feces did not differ in tropical deciduous forest, savannas and grasslands (Peres *et al.* 2023). It was also similar between habitat use by telemetry and domestic livestock feces (Hernandez *et al.* 1999). Moreover, white-tailed deer abundance estimates have been found to be similar in aerial surveys using thermal cameras and stratified transect pellet group counts (McMahon *et al.* 2021).

The pellet counting technique has been widely extensively employed for herbivores such as cervids, bovids, and leporids in various ecosystems in North America (Harestad and Bunnell 1987; Gallina-Tessaro *et al.* 1991; Hernandez *et al.* 1999; Sánchez-Rojas and Gallina 2000a; Arias-Del Razo *et al.* 2012; Esparza-Carlos *et al.* 2016), as well as in Europe (Gallina-Tessaro 1990; Torres *et al.* 2013, Lioy *et al.* 2015). This method has also been employed in Africa for elephants (Barnes and Barnes 1992) and different ungulate species (Hibert *et. al.* 2011), suggesting that it is a technique applicable for estimate the abundance for any herbivore species.

In México, the technique of pellet group counting to estimate population densities of herbivores began to be used with white-tailed deer (*Odocoileus virginianus*) in Michilía, Durango, in pine-oak forests (Ezcurra and Gallina 1981) and tropical dry frorest for (*O. virginianus*; Mandujano y Gallina 1993; Camargo-Sanabria and Mandujano 2011). The technique was also applied to mule deer in pine-oak forests (Gallina *et al.* 1991) and in the Chihuahuan Desert (Sánchez-Rojas and Gallina 2000a, b). Fecal counting has also been used to assess the relative abundance of cattle (Hernandez *et al.* 1999).

To estimate population densities using pellet groups, there are three main methods used: 1) Transects with circular plots, especially in areas with medium to high deer abundances (Ezcurra and Gallina 1981; Galindo-Leal and Weber 1998; Sánchez-Rojas and Gallina 2000b; Mandujano 2014). An assumption of this technique is that these pellet groups persist throughout the measurement period (Harestad and Bunnell 1987). To determine persistence, the plots are cleaned, or existing pellet groups are marked; which can be a time-consuming process and, at times, impractical for large areas (Harestad and Bunnell 1987; Hibert *et al.* 2011). 2) Strip transects, which in are used in areas with medium to low abundances. 3) Line transects in this method, variable-length transects are used, and the perpendicular distance from the pellet group to the transect is measured (Mandujano 2014). 4) Quadrant Transects (Laing *et al.* 2003, Esparza-Carlos *et al.* 2011), which have been employed to estimate relative abundance in arid regions, pellet group censuses for mule deer are carried out within 1 km^2 (Esparza-Carlos *et al.* 2011).

The pellet group counting technique is recommended primarily during the dry season because, during this period, it is unlikely for pellet groups to be lost due to heavy rain wash (Wallmo *et al.* 1962; Hibert *et al.* 2011). Humidity is a key factor in pellet loss due to the development of fungi (Delisle *et al.* 2022) and consumption by insects (Neff 1968; Ezcurra and Gallina 1981; Harestad and Bunnell 1987; Hibert *et al.* 2011); sun and wind also influences in pellet decay in boreal ecosystem (Jung and Kukka 2016). For example, pellet loss is lower in drier sites, such as open areas and coniferous forests, than in deciduous forests, where humidity is higher, and dung beetles and saprophagous invertebrates play a significant role (Torres *et al.* 2013). Other factors related to the loss of pellet groups include concealment by leaf litter (Harestad and Bunnell 1987; Delisle *et al.* 2022), as well as unintentional removal or trampling by domestic or wild mammals. However, in semiarid ecosystem the pellet group decay increases as number or rains increases too (Wallmo *et al.* 1962).

Understanding the persistence or disappearance rates of pellets is crucial for estimating abundances through pellet groups or feces counting (Camargo-Sanabria and Mandujano 2011; Delisle *et al.* 2022). Despite the widespread use of this technique in México and the USA, based on a literature review, we found a lack of pellet group persistence studies for mule deer in México. The existing data in the United States is also outdated. A similar situation exists for white-tailed deer, although we did find one study for México and another for the United States in the last 12 years.

For mule deer, pellet groups have been observed to last from one to two years on steep slopes and bare ground; however, in areas with vegetation cover, leaves, and litter, they can persist for up to five years (Neff *et al.* 1968). In semiarid ecosystems, pellet groups deposited during the rainy season typically decay within two to four months (Wallmo *et al.* 1962). In a savanna ecosystem, during the dry season, the decay percentage of pellets from different ungulate species varies between 2 to 14 %, with insects identified as the primary cause of decomposition, followed by dispersion, scattering, and embrittlement; the trends in the decay and ageing of pellet groups were similar, although the five species differed in size and feeding habits (Hibert *et al.* 2011). In boreal forest elk pellets decay by 69 % after the first growing season, 74 % after the second, and 76 % after the third (Jung and Kukka 2016). In temperate forests, white-tailed deer pellets generally disappear within an average of 70 to 120 days (Delisle *et al.* 2022). In México, where the technique has been widely used, we found only one study estimating the persistence of white-tailed deer pellet groups in deciduous tropical forest, reporting pellets being lost in 123 days (Camargo-Sanabria and Mandujano 2011).

The lack of data on the permanence or decomposition of pellet groups for mule deer or white-tailed deer in various ecosystems or habitats necessitates cleaning study plots at the start of the study. Moreover, it demands regular visits to reduce pellet loss, assuming no pellet groups are lost during this period, incurring significant costs and labor intensity. In the case FSC, white pellets may be considered old, but time deposition remains uncertain. Hence, the objectives of this study is to ascertain the persistence of mule deer pellet groups in the Chihuahuan Desert, document changes in color over time, and record structural characteristics of the pellets. This aims to minimize the bias of abundance estimates for mule deer. Understanding the pellet groups permanence time and identifying pellet groups age based on color will enable us to establish suitable periods for pellet groups deposition without loss; which affect abundance estimates. This is crucial for FSC studies, as it requires knowledge of the persistence time or disappearance rate of these groups. Additionally, for FAR, time periods for counting and recounting plots are established, assuming no pellet groups are lost. Hence understanding pellet group persistence is crucial to estimate mule deer abundances through the pellet group technique. The, mule deer holds significant ecological importance, as one of the great wild herbivores, serving as the main prey of larger carnivores such as the cougar (Gallina-Tessaro *et. al.* 2019). It also pays a vital role as food resource for rural communities and stands as one the most important game species in México (Gallina-Tessaro *et. al.* 2019). Although the mule deer is currently globally classified as a species of least concern in terms of conservation (Sánchez Rojas and Gallina-Tessaro 2016), the specie has disappeared from the southernmost parts of its distribution, and is experiencing a decline in population numbers and reduction in distribution areas, resulting in local extinctions in regions in the northeastern of México (Martínez-Muñoz *et al.* 2003; Gallina *et al.* 2019b). Therefore, understanding the persistence times of pellet groups is crucial for improving abundance estimates of mule deer through pellet group counting, especially in these arid regions where populations are declining. This information is vital for informed management and conservation decisions.

Methods and materials

Study area. The study was conducted in the Mapimí Biosphere Reserve (MBR), located between 26° 41' 17'' to 26° 39' 23'' N and -103° 44' 02'' to -103° 45' 49'' W, at the intersection of the states of Durango, Chihuahua, and Coahuila, México. The MBR is situated in a closed basin characterized by extensive flat areas, small hills, and isolated mountains, with San Ignacio Mountain being the highest and the focus of this study. The climate is arid, with cool winters and warm summers, with mean temperatures of 15 °C and

26 °C, respectively; the annual mean temperature is 21 °C. The average annual precipitation is 287 mm, ranging from 122 mm to 716 mm. Sixty-four percent of this precipitation is concentrated between June and September (summer rains), and 10 % between December and February (winter rains are highly variable annually; data from the weather station, Laboratorio del Desierto Climate Station, Instituto de Ecología A. C. [INECOL]). The terrain where the study was conducted is relatively flat with a uniform slope ranging from 0 to 4°.

The study was conducted in the area known as the "upper bajadas," which is a part of the landscape element of bajadas and hills of igneous and sedimentary origin (37 % of the area). This area is primarily inhabited by mule deer (Sánchez-Rojas and Gallina 2000a, b). The "Upper Bajadas" are characterized by dominant vegetation such as creosote bush (*Larrea tridentata*), ocotillo (*Fouqueria splendens*), prickly pear (*Opuntia rastrera*), yucca (*Yucca rigida*), and agaves (*Agave scabra, A. lechuguilla*; Montaña and Breimer 1988). The diet of mule deer in this area primarily consists of shrubs (43 % of the annual diet), herbs (34 %, mainly in summer), succulents (13 %), and grasses (10 %; Guth 1987). The only agricultural activity in the area is extensive cattle ranching with minimal management. Human population density in the region is 0.12 inhabitants per square kilometer (Esparza-Carlos 2011).

Data collection. After the rainy season, approximately in October of any year, mule deer start to concentrate in the "Bajadas," and pellet groups begin to accumulate. Deer stay there until the next June when the rainy season begins (personal observation), at which time many of them expand their distribution, likely moving to other areas to feed on newly growing vegetation. Specifically, in the "Upper Bajadas" where the study was conducted, most of the terrain features bare soil, spaced-out shrubs, and few patches of grass; herbs only appear during the summer or winter rainy seasons (Personal observation). Therefore, the detection of mule deer pellet groups is easy.

To determine the persistence of pellet groups and relate color to the time of deposition, in one study of mule deer habitat use and predation risk following FSC, a free search for mule deer pellet groups was conducted in one area of 178 ha (Esparza-Carlos *et al.* 2011, 2016). In total, 102 pellet groups were monitored during various climatic seasons and years, excluding the summer rainy season: a) Group 2004, registered on October 12, 2004, with 15 pellet groups recorded. b) Group 2005a, deposited between February 7 and March 11, 2005, with 17 pellet groups. c) Group 2005b, deposited between November 14 and December 3, 2005, with 40 pellet groups. d) Group 2006, deposited between May 14 and May 23, 2006, with 30 pellet groups.

Once the pellet groups were found, their coordinates were recorded using a Garmin 12XL® GPS device. Photographs were taken of each group, and a description of their color and appearance was made. To identify the pellet group during subsequent visits, the area where they were located was marked with three metal rods or green-painted stones. All pellet groups had been deposited for a few hours (except for the Group 2004, which were recent, but the exact day of deposition was not known).

The persistence of the pellet groups, that is, whether it is still considered present, was assessed in two ways: a) Persistence of the pellet group: it was considered that the group was no longer active when there were fewer than 15 pellets left or when the pellets were mixed with others, making it impossible to identify them as a group (n = 1). b) Persistence of the last pellet of the original pellet group. With the aim of describing the aging process, investigating the causes of decay, and determining when pellets turned completely white (as suspected to occur after a year during each visit), we recorded the color and physical characteristics of the pellets. This included factors such as smoothness, the appearance of cracks, pellet rounding, and so forth (Hibert *et al.* 2011). Initially, visits were conducted every 2 to 4 months, but as no pellets were lost, the visit periods were spaced out: a) February 9 to 16, 2005 (Group 2004); b) April 29 to 30, 2005 (Groups 2004 and 2005a); c) December 1 to 3, 2005 (Groups 2004 and 2005a); d) May 10 to 11, 2006 (Group 2005b); e) June 12 to 26, 2006 (start of the rainy season; Groups 2004, 2005a, and 2005b). The remaining visits included all groups: f) April 17 to 20, 2007; g) May 1 to 27, 2008; h) June 2 to 3, 2009. During the study, the feces were exposed to both rainy and dry years: between May 2004 and May 2005, it was a very rainy year. During the summer rainy season, it received 291 mm of rainfall, which is above the annual average. In contrast, 2005 to 2006 was a dry year. During 2006 to 2007, it was rainy again. For 2008 (January-December), we only have the annual precipitation data, which was 277 mm, close to the annual average, and we do not have the precipitation data for 2009 (Table 1).

Analysis. To determine the persistence of mule deer pellet groups, descriptive analyses were conducted with the number and percentage of pellet groups over time. To assess if the persistence rate of pellet groups was similar among the different groups recorded in various seasons and years, a Generalized Linear Model with a binomial distribution type ANCOVA (Analysis of Covariance) was conducted. The independent variable was the proportion of pellet groups present, and the explanatory variables were time, measured in days, and the set of pellet groups classified by year and the date on which they were found. The assumptions of normality and homogeneity of variances were met. Subsequently, a post-hoc test was performed using the "gmodels" package to determine if the slope differed among the categories of mule deer pellet groups. All analyses were conducted using the R programming language (R Core Team 2021).

Results

All pellet groups (n = 102) turned white after the first rainy season, regardless of the month and year they were depos-

Table 1. Precipitation by Season. The rainy season typically begins in late May or early June and ends in September or early October. The dry season spans from October to May. In some years, there might be winter precipitation.

Time period	Precipitation rainy season	Precipitation dry season	Total
June 2004 – May 2005	291		291
June 2005 – May 2006	138	6	144
June 2006 – May 2007	261	132	393
June 2007 – September 2007	147		147
October – December 2007		6.5	
January – December 2008			277

[1] For the year 2008, we only have the total precipitation data, and we do not have the precipitation data for 2009.

ited by the mule deer (Figures 1 to 3). Freshly excreted pellet groups are olive green in color, with a soft consistency due to moisture, and a smooth, moist outer layer. After a few hours or a day of being deposited, they generally turn a dark brown color, although there can be variations in shades of light brown, brown-yellow, to dark brown or black. However, apart from the tracking described here, we have observed dry pellets of other colors, including pink, white-pink, and yellow-white. As the months pass, some begin to lose color and gradually whiten. Additionally, small white cracks appear in the pellets, which widen and grow as the months go by. The smooth cuticle may peel off in small sections of the outer layer, especially those that have been exposed for more months (Figures 1 to 3).

The color of the pellets starts to fade rapidly with the first summer rains, initially turning from green-white, until becoming a uniform white color after the first summer rainy season. After the first summer rainy season, the outer layers of the pellets become less smooth, and as rainier seasons (years) pass, the outer layers of the pellets lose their smoothness, becoming micro-granular, and the pointed ends (top of the pellet) are lost. The pellets turn a sandy-white color with black spots, and the pellets start to fragment (Figures 1 to 3).

In our study area, all pellet groups remained during the dry season (October to May) for any measured year, even though in 2 years there were rains of 91 and 132 mm during this period (Figure 4, Table 1), which was slightly less than the summer rains during the dry years (138, 147 mm). Pellet groups were only lost after the summer rainy seasons (June-September).

The first set of pellet groups marked in October 2004 was visited in February and April 2005, and no groups were lost. The set of 2005b pellet groups, marked in November 2005, was measured in May, and no losses were detected either (Table 2). However, all sets lost pellet groups during the first rainy season they were exposed to. Even in 2006, at the beginning of the rainy season, several pellet groups from most sets were lost.

During the first rainy season, an average of 47 % of the pellet groups were lost (range 20 to 63 %). For the second rainy season, the cumulative loss of pellet groups was 85 % (range 71 to 93 %). In the third rainy season, the cumulative

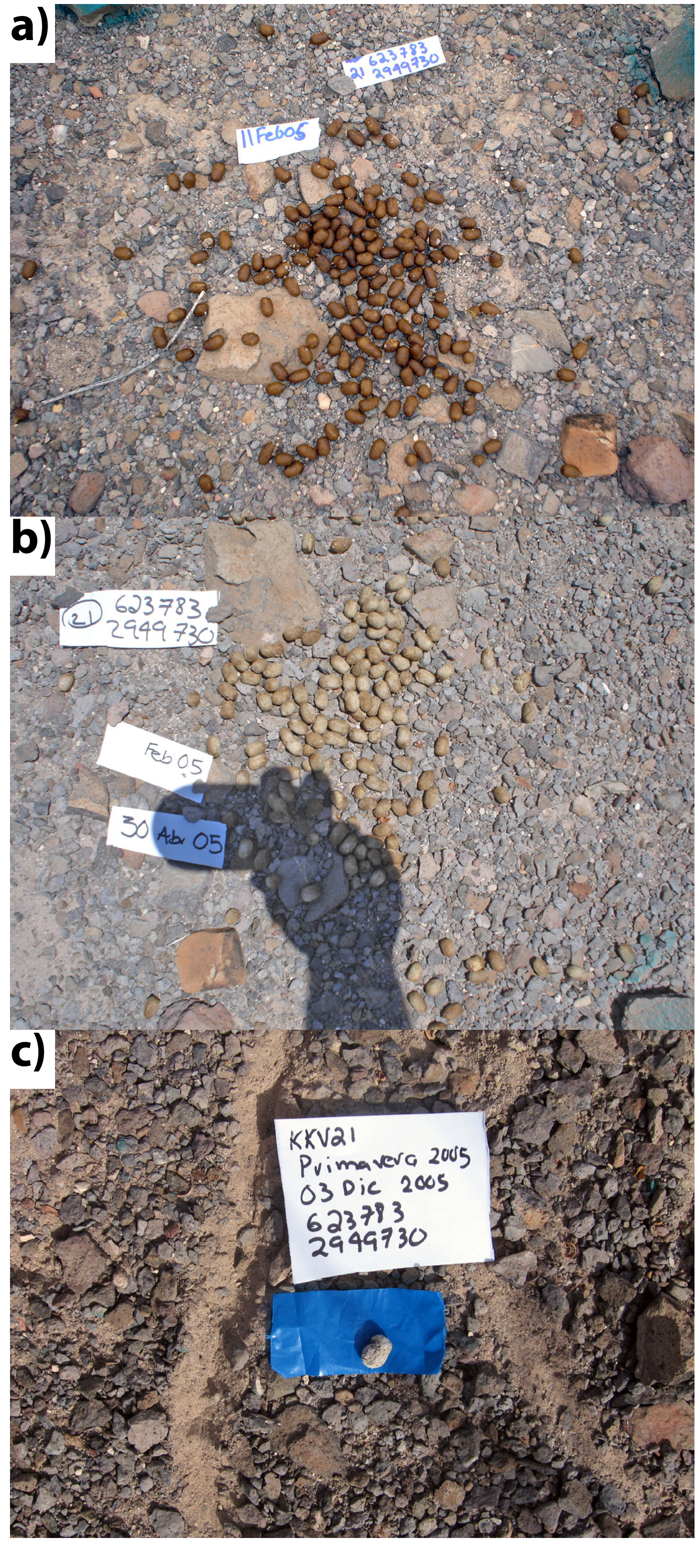

Figure 1. Mule deer pellet group: a) fresh. b) 2 months after being deposited. c) 10 months after the first rainy season, only one white pellet with dark specks like sand remained, with noticeable wear on the edges.

average was 95 % (range 82 to 100 %), and for the two sets of groups measured at the beginning of the fourth rainy season, 97.1 % were lost (94 % and 100 %; Figures 4 and 5; Table 2).

Regarding the total loss of all pellets and pellet groups, the results were similar, although, obviously, they are lost slightly less than the pellet groups. During the first sum-

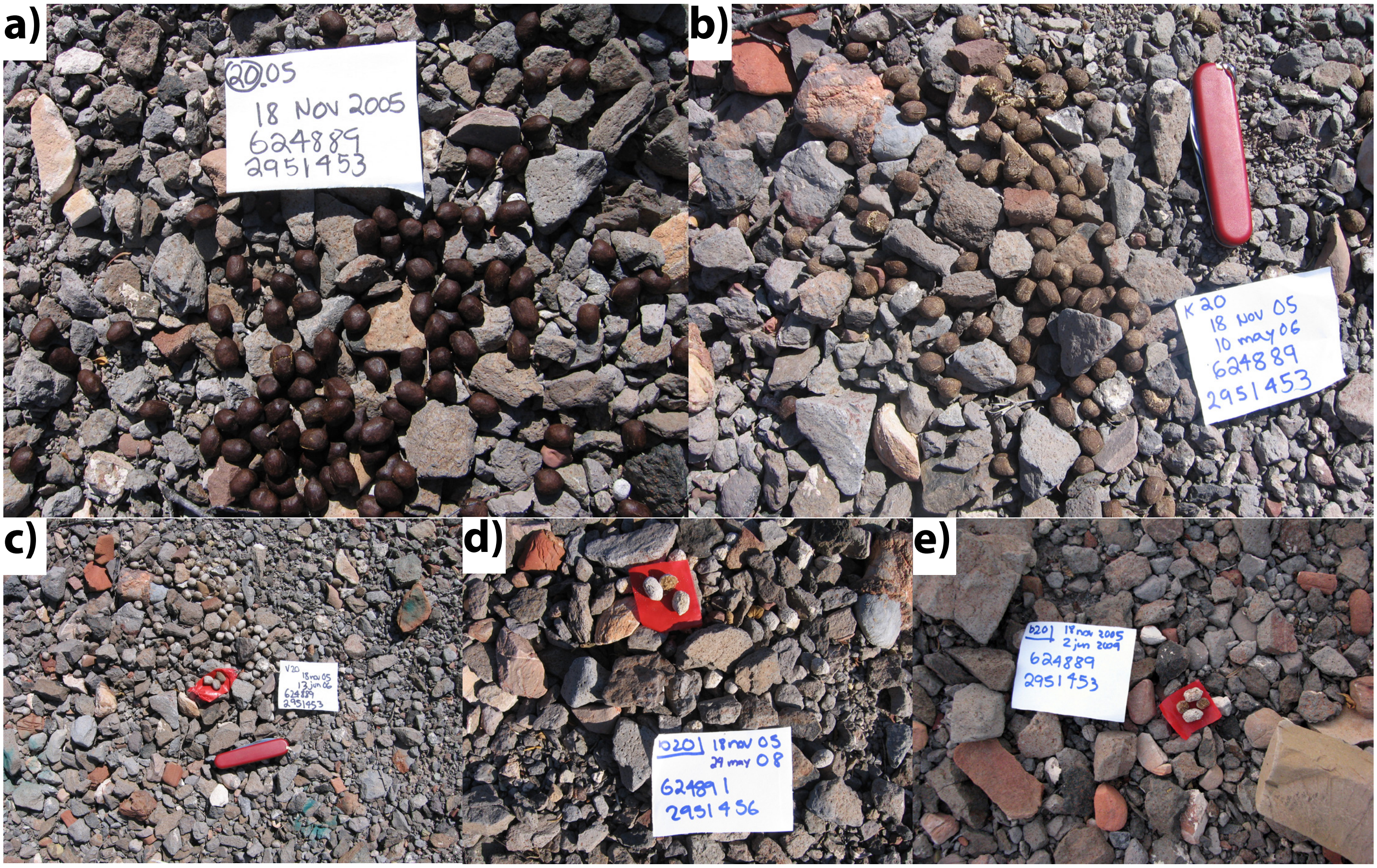

Figure 2. Mule deer pellet group. a) fresh. b) 7 months after being deposited, has lost its color and cracks have appeared. c) 8 months after the first rains. d) 2 years and 7 months later, only a few white pellets with edge wear remain, but they still retain color on the inside. e) some pellets from the original group persisted for at least 3 years and 8 months, which was the last time they were checked.

mer rainy season, an average of 33 % of all pellets were lost (range 20 to 55 %). For the second season, the cumulative loss was 67 % (range 59 to 78 %). In the third summer rainy season, the cumulative loss was 89 % (range 77 to 100 %). Finally, for the two sets of groups measured at the beginning of the fourth rainy season (2004 and 2005a), 97 % were lost (94 % and 100 %; Figures 4 and 5, Table 2).

Although there was no systematic record, we observed that the groups that are lost first are those deposited in micro-channels where water apparently flowed during one or more precipitation events. Those that tend to persist longer are the ones found among gravel, stones, and plants. After the first rainy season, the remaining pellets could be distinguished based on their shape, size, and color. However, after two rainy seasons, it becomes difficult to track the pellets and determine their origin to a specific pellet group. The pellets start to disperse to more than 1 m, and they lose their shape, becoming rounded. All the pellets from various pellet groups turn white with black spots. Identifying their origin becomes challenging, especially after the second rainy season. Some pellet groups, before completely disappearing, leave fewer than 15 pellets (Figures 4 and 5).

The probability of persistence of pellet groups decreases over time, reaching zero or nearly zero around 1000 days (third and the beginning of the fourth rainy seasons) as per the generalized linear model type ANCOVA ($P < 0.001$, $Xi^2_{13} = 30.52$, $df = 13$, explained deviance = 0.92; Table 3 and Figure 5). The *post-hoc* multiple comparison test between pairs of slopes showed that the disappearance rate was similar among all pellet group categories collected in different seasons and years, except for the 2005a category, which was

Table 2. Mule deer pellet group persistence in Chihuahuan Desert. In the Chihuahuan Desert, some sets of mule deer pellet groups persisted for up to 4.1 years. Individual pellets remaining slightly more.

Pellet group categories	Month of deposition	Season of deposition	n	Pellet groups in 2009 (n)	Individual pellets in 2009 (n)	Monitored years (n)
2004	October	Autumn	15	0	0	4.6
2005a	February	Winter	17	1	1	4.3
2005b	November	Autumn	40	1	5	3.5
2006	May	Spring	30	0	3	3.1

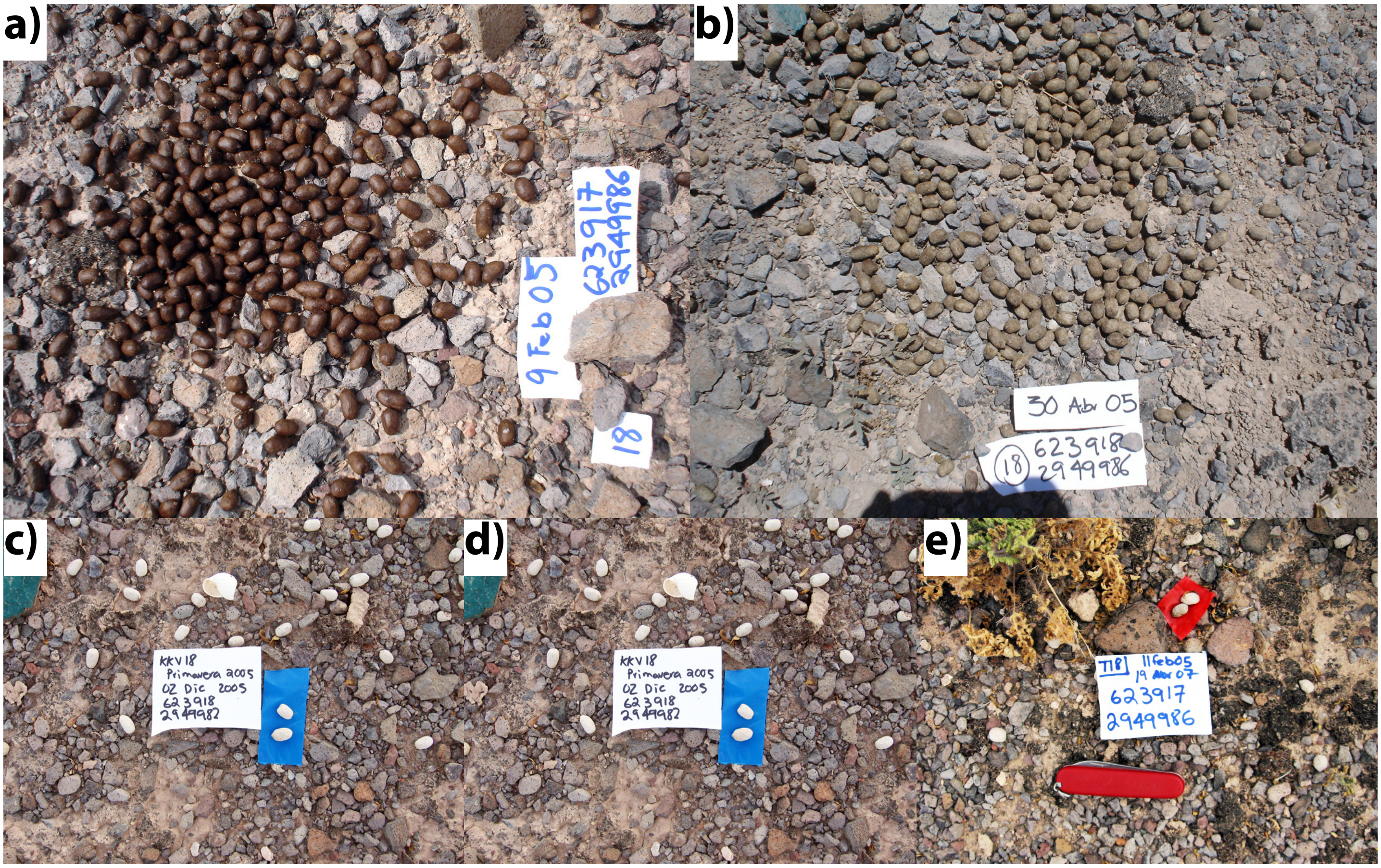

Figure 3. Deer pellet groups a) fresh. b) 2 months after being deposited, they have faded a bit. c) 10 months after the first rains, they are completely white, the pellets have scattered, and the edges have worn out. d) 1 year and 4 months later, at the beginning of the second rainy season, the same pellets remain, only a few white pellets with worn edges, but they still retain their color inside. e) after two rainy seasons, many of the pellets have been lost.

different from the rest (2004, 2005b, 2006), with a slightly higher probability of permanency over time (Table 4; Figure 5). For instance, within categories 2004, 2005b, and 2006, after 713 to 915 days since deposition, 7 to 13% of the pellet groups remained, while for category 2005a, 29 % persisted. After 1114 to 1295 days, the first three categories retained 0 to 3 % of pellet groups, whereas the 2005a category retained 18 %.

Regarding pellet persistence (when the pellet group had < 15 pellets), it decreased over time, according to the generalized linear model type ANCOVA ($P< 0.001$, $Xi^2_{13} = 107.74$, $df = 19$, explained deviance = 0.90; Table 3 and Figure 5). Pellet persistence was slightly higher than that of pellet groups but was similar across all categories. After 1292 days, 13 % of the 2005b category persisted, 6 % of the 2005a category after 1,570 days, and 10 % of the 2006 category after 1,114 days, but 0 % remained after 1,692 days for the 2004 category (Figure 5).

Discussion

The first significant finding of this study is that all pellet groups deposited after summer rainy season, remain until the last of dry season. Furthermore, all pellet groups turn white after being exposed to a summer rainy season in the

Table 3. Results of the generalized linear binomial model type ANCOVA analysis, for the persistence of mule deer pellet groups (top) and pellets (bottom) in the Chihuahuan Desert, Mexico. df = Degrees of freedom.

Category	Deviance change	*df*	Residual Deviance	Deviance Explained (%)	*P*
Groups					
Null		20	361.4		
Pellet groups	2.1	17	359.3	0.6	0.557
Days	318.4	16	40.9	88.1	< 0.001
Pellet groups: days	13.3	13	27.6	3.7	< 0.001
Pellet					
Null		20	294.4		
Days	264.2	19	30.1	89.9	< 0.001

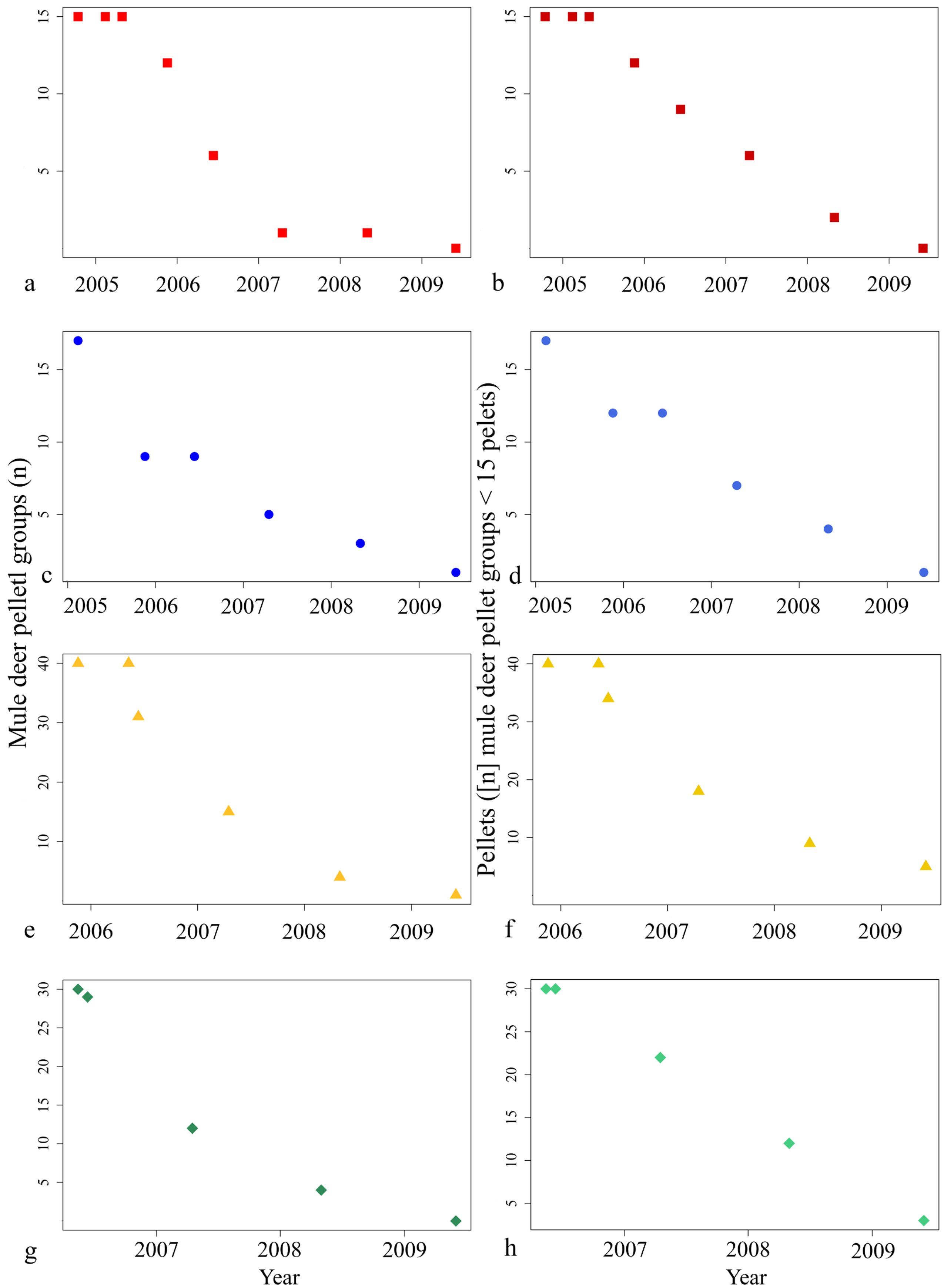

Figure 4. Number of mule deer pellet groups over time. Pellet groups only disappear after the summer rainy seasons. On the left side, mule deer pellet groups (>15 pellets), on the right side, pellets from these (1 - 15) that were no longer considered as pellet groups. Red squares: pellet groups started in October 2004; blue circle: pellet groups started in February 2005; yellow triangle: pellet groups started in November 2005; green rhombus: pellet groups started in May 2006.

Table 4. Post-hoc analysis comparing categories of mule deer pellet groups (top) and pellets (bottom) between different disappearance periods in the Chihuahuan Desert, Mexico. In all cases, degrees of freedom = 1.

Pellet groups categories	**Estimate**	**Standard Error**	**Xi^2 Value**	***P***
2004 - 2005a	- 0.0032	0.00156	4.24	0.040
2004 - 2005b	- 0.0006	0.00163	0.12	0.734
2004 - 2006	0.0011	0.00197	0.30	0.581
2005a - 2005b	0.0027	0.00098	7.35	0.007
2005a - 2006	0.0043	0.00149	8.37	0.004
2005b - 2006	0.0016	0.00155	1.12	0.291

Chihuahuan Desert. This is vital information for using pellet group counting techniques in any approach during the autumn, winter, and spring seasons (excluding the rainy season in summer). For example, if the technique is going to be used as an index of relative abundance or for estimating population density using a single visit Fecal Standing Crop (FSC) in arid areas like the Chihuahuan Desert. This finding relieves us from the need to estimate the pellet disappearance rate over time (Torres *et al.* 2013). This assures us that all colored pellets are subsequent to the summer rainy season and allows us to discard the white-colored ones.

The second important finding is that for the Chihuahuan Desert and possibly other arid areas, the periods of pellet accumulation can be extended according to the study objectives when using the Fecal Accumulation Rate (FAR) technique, which involves two visits. The first visit is to clean all previously deposited pellet groups, and after some time the second to count how many were deposited after some time. With this technique it is suggested that the period between visits to recount pellet groups should be brief to avoid pellet loss (Laing *et al.* 2003). For example, in deciduous tropical forests, white-tailed deer pellet groups disappear after 123 days (Camargo-Sanabria and Mandujano 2011), and in the Chihuahuan Desert, it has been used a period of 90 to 120 month without knowing the pellet disappearance rates (Sánchez-Rojas and Gallina 2000a, b). However, this study demonstrates that in the Chihuahuan Desert, this period can be up to 7.5 months, as no pellet groups was lost between October and May throughout the observation years from 2004 to 2009. For instance, only two visits can be made to determine population density throughout the dry season or habitat use intensity: The first at the end of the summer rainy season, in early October, you can clean the plots and return to count in mid to late May, before the start of the rainy season. This ensures that all pellet groups correspond to the deposition that occurred during this period of time, roughly 7.5 months, have the certainty that no pellet groups will be lost, and none will turn white (this allows us to distinguish them from the dry season of the previous year). Although it had previously been suggested that pellet groups counting should be done during the dry season due to the low likelihood of pellet loss (Wallmo *et al.* 1962; Neff 1968; Ezcurra and Gallina 1981; Mandujano 2014). This work confirms that, at least in the Chihuahuan Desert, no loss of pellet groups occurs during the dry season. In fact, some pellet groups or individual pellets persisted until the end of their monitoring after 3 or 4 years. The percentages of permanence were slightly from elk in boreal forest. After the first growing season the permanence of in this study was 47 compared to 31%; the second growing season was 15 % this study vs 26 %; the third growing season was 5 % vs 24 % (Jung and Kukka 2016). There was no evidence indicating losses due to biological agents such as fungi, insects, or other invertebrates. In savanna ecosystem the principal cause of decay loss was attributed to ants and termites, followed by scattering and embrittlement; however, Bohor reedbuck (*Redunca redunca*) droppings, never were attacked by insects (Hibert *et al.* 2011). The observations consistently point to water runoff during the rainy season (June to September) as the sole cause of pellet group loss. Notably, even when exposed to rain in the supposedly "dry" months of two years with about 50 % of the rainfall of the rainy season,

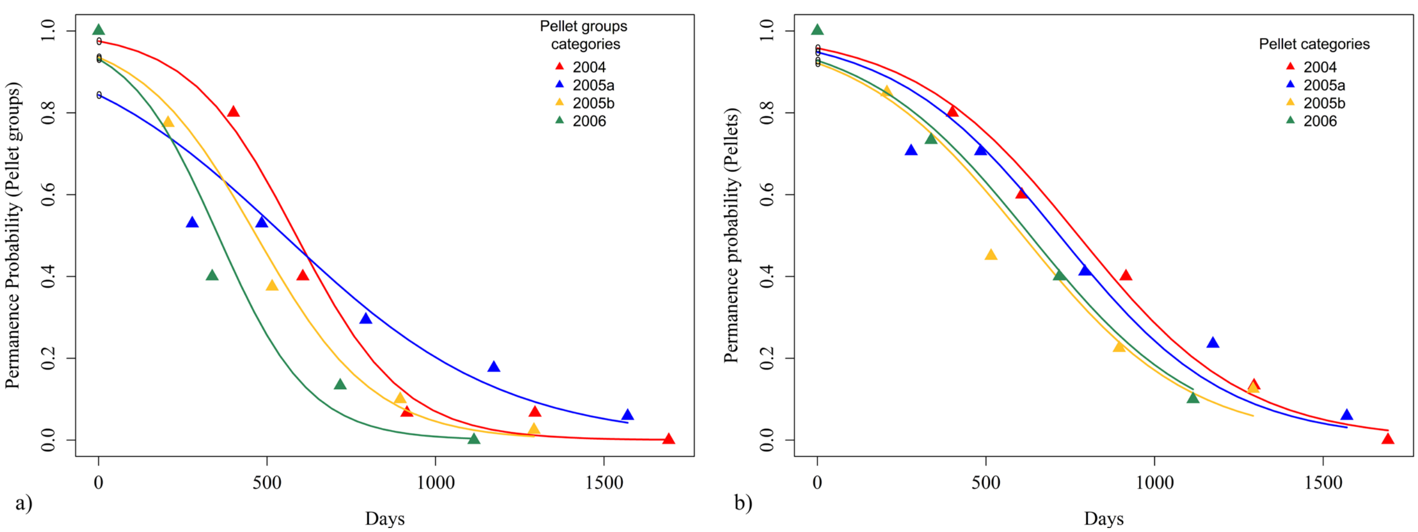

Figure 5. Results of the generalized linear model binomial type ANCOVA on the persistence of: a) pellet groups (left). b) Pellets (Mule deer pellet groups with fewer than 15 pellets) in the Chihuahuan Desert (right) over time. Pellet groups deposited in October 2004 (red), pellet groups deposited in February 2005 (blue), pellet groups deposited in November 2005 (yellow), pellet groups deposited in May 2006 (green).

no pellet groups were lost or turned white. This aligns with findings in other arid areas, where heavy rainfall is identified as the primary cause of mule deer pellet group losses, washing them away (Wallmo *et al.* 1962; Hibert *et al.* 2011). The pellets are dispersed and washed away by run-off or degraded and overed over by seedling vegetation (Hibert *et al.* 2011). This is in agreement with those found in other ecosystems where precipitation and warmer temperatures are the main causes of pellet loss (Delisle *et al.* 2022). It has also been found that in forest ecosystem, pellet groups take longer to disappear in drier habitats, presumably because they dry out faster and become harder compared to more humid habitats (Torres *et al.* 2013); contrary, in boreal forest, Elk (*Cervus Canadensis*) pellets decays more rapidly in drier open habitats, due to exposure to wind and sun (Jung and Kukka 2016). For instance, hare and rabbit pellets start to disappear one month after deposition, while others may take between 4.4 to 9.5 years to vanish, this disappearance is correlated with environmental humidity and precipitation (Flinders and Crawford 1977).

These results have practical implications for estimating deer densities or relative deer abundance using pellet group counting. It is now known with certainty that visiting the study area twice is sufficient when using the Fecal Accumulation Rate method. This can save on costs and time. It also makes it more feasible to cover a larger sampling area since two visits are sufficient, eliminating the need for revisiting the same plots or transects multiple times during the dry season. It is important to note that this applies to the Chihuahuan Desert, and perhaps the Sonoran Desert and some other arid areas. Once in other ecosystems, the rate of pellet loss varies by season (Torres *et al.* 2013). Additionally, in temperate forests or areas with more vegetation, fallen leaves on the forest floor can conceal fecal groups, making them difficult to detect, and in some areas, after a year, only about 10 % of pellet groups are visible for example (Harestad and Bunnell 1987). We assume that in moister areas with more vegetation, such as tropical rainforests, biological decomposition might be significant. Therefore, we suggest conducting studies on the persistence of deer pellet groups in other ecosystems to determine the longevity of pellets. This will help establish the optimal time for revisiting plots without a significant loss of pellet groups or estimating their disappearance rate.

However, there could be potential disturbance factors that might affect the persistence of pellet groups, which were not discussed here but should be considered in other areas. For example, if the study area has a high density of domestic livestock or is frequently used by humans, these factors might lead to pellet loss through mechanical disturbance, such as trampling or bedding areas. In our study area, although there is some livestock use, we believe it is not excessive, especially when compared to areas near water sources.

This result is also significant because it suggests that in certain arid areas, there are very few or no biological agents degrading herbivore feces. In other ecosystems, it has been observed that as humidity increases, more pellet groups are lost because humidity promotes the growth of fungi and the presence of invertebrates that break down feces (Ezcurra and Gallina 1981; Harestad and Bunnell 1987; Torres *et al.* 2013). Throughout all the years of monitoring deer feces groups, there was no evidence of losses due to biological agents. Additionally, during five years of working in the area, conducting deer ecology studies, we never observed any dung beetle or insects in deer pellets (even though we recorded > 20,000 pellet groups (Esparza-Carlos *et al.* 2011, 2016). We also do not recall seeing these in cow dung, which is abundant. This suggests that the abundance of dung beetles is very low or non-existent because dung beetles that consume herbivore dung are polyphagous, and although they have preferences for certain species, they colonize feces from many domestic and wild vertebrates. Furthermore, they prefer feces in open habitats (pastures) over forests (Dormont *et al.* 2007). Therefore, the primary or nearly exclusive means of nutrient reintroduction into the ecosystem in the region, is through the disintegration of pellet pellets, a process facilitated by rain. It is well-documented that white-tailed deer play a significant role in the distribution of nitrogen within ecosystems, such as grasslands, where the nitrogen concentration is higher in deer feces than in Bison feces (*Bison bison*; Pruszenski and Hernández 2020). In our study area, due to the persistence of the pellets, our data suggests that nutrients release may be delayed for several years, and perhaps the distribution of these nutrients is concentrated where water flows, as it appears to be the only or nearly the only source of pellet disintegration. To understand the role of mule deer in nutrients distribution in Chihuahuan Desert, it is recommended to conduct studies on nitrogen and nutrients concentration and release in mule deer pellet groups.

Regarding the color of the pellets, all groups deposited from October to the end of dry season, lose their color gradually, but quickly and become white after the rain season. Therefore, we assume that pellet groups deposited during the rainy season also lose their color after it ends. However, it is uncertain what color feces that were deposited at the end of the rainy season, for example, those exposed to just 1 to 4 rains, would turn to. If we are interested in applying the pellet group counting technique during the summer rainy season, it is recommended to conduct studies of pellet group persistence during this season. Visit the pellet groups every 7 or 15 days and record their persistence and color changes during this period. This approach will allow you to suggest an effective visitation interval for plots with minimal loss of pellet groups during this period. As well as determining if it is a threshold number of rains that causes the pellets to change color or remain the same at the end of the summer rainy season. Furthermore, it would be possible to assess whether, during the rainy season, some pellet groups are lost due to dung beetles or other biological agents, once we were not present for most of the summer rainy season (July to September). Furthermore, for dry season improving color tracking and pellet characteristics could enhance the precision of age assignment to the pellet. Our observations of color and physical changes in pellets offer a broad overview during the dry season. Hence, we propose a more systematic study involving monthly visits. This approach aims to establish age categories based on pellet color and physical changes, documented with photographs and descriptions. The outcome of this systematic study could serve as a guide for estimating pellet age, which may assist in estimating pellet age in a single visit, once appears to be the most useful criterion for dating pellets in five ungulate studied species (Hibert *et al.* 2011). Conducting such studies can provide valuable insights into the dynamics of pellet group persistence and color change during the dry and wet season.

On the other hand, this study further supports the crucial role of mule deer as a significant seed disperser for plant species in the Chihuahuan Desert. Deer groups are recognized as important consumers and dispersers of seeds. For instance, white-tailed deer are known seed dispersers in North America, as they disperse seeds over long distances, and the decay of their pellets facilitates germination for many of plant species (Myers *et al.* 2004; Blyth *et al.* 2013). Previous research in the same area identified mule deer as highly effective dispersers of *Opuntia rastrera* seeds, a common cactus plant in the Chihuahuan Desert (Mandujano *et al.* 1997). Experiments revealed that these seeds require more than a year of dormancy for germination, with mule deer exhibiting the highest germination rates: 0 % for fresh seeds, 58 % after one year, and 85 % after two years, comparable to the control group. The study suggests that being in pellets protects the seeds from predation, and the extensive movements of mule deer contribute to their dispersal over significant distances, enriching the seed bank (Mandujano *et al.* 1997). This study sheds light on this natural process, revealing that pellets decay one to four years after deposition, allowing seeds to be released gradually. This dynamic increases the germination percentage of *O. rastrera* and possibly other species. It underscores the critical role of deer pellets in seed dynamic, acting as potential seed bank in this arid zone where the soil is bare. Therefore, it would be interesting to analyze the germination and disperse role of other seeds species of Chihuahuan Desert.

In summary, mule deer pellet groups exhibit prolonged persistence in the Chihuahuan Desert. Although approximately 40 to 62 % are lost during the initial summer rainy season, some pellets can endure up to 1,700 days (until the beginning of the fourth rainy season). To my knowledge, this is the first published study in México on the persistence of mule deer (*Odocoileus hemionus*). This study also reveals, that All pellet groups deposited during the dry season persist and retain their color until the end. Pellet groups that persist after the rainy season uniformly turn white. This insight enables a reduction in the number of visits for estimating mule deer abundances, when employing mule deer pellet group counting in arid areas, outside of the summer rainy season. This adjustment could help UMAS technicians, CONANP (National Commission of Natural Protected Areas) personnel, and researchers minimize costs associated with the technique by decreasing the required samplings for estimating mule deer abundance. Finally, we recommend conducting persistence studies in diverse ecosystems to determine pellet group disappearance times and establish pellet accumulation periods that enhance optimal pellet group accumulation periods that enhance visit efficiency without losing pellet groups. Such studies may necessitate multiple years of observation due to variations in precipitation and temperature between year.

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