Testing Some Elements of the Hunters' Folklore: Are White-Tailed Deer, *Odocoileus virginianus* (Zimmermann, 1780) (Mammalia: Artiodactyla: Cervidae), Movements Correlated with Meteorological or Astronomical Events?[1]

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Abstract: This study investigated some elements of the folklore surrounding white-tailed deer hunting and determined if one or more of those elements can be scientifically falsified. To address this goal, we combined time-stamped images of moving white tailed deer, *Odocoileus virginianus* (Zimmermann, 1780) (Mammalia: Artiodactyla: Cervidae) generated by trigger cameras placed in a rural site in Effort, Pennsylvania, and meteorological data from an Automated Surface Observing System (ASOS) station located at the Lehigh Valley International Airport (Hanover Township, Lehigh County) some 40 km south. The only element of the hunter's myths supported is that deer tend to move more at milder temperatures (0-10ºC and 20ºC). We also found that deer move more at a slightly below normal mean sea level pressure (1013.25 mbar, 29.92 inches of mercury), during a new and full moon, and when there are calm to mild winds.

Key Words: White-Tailed Deer, *Odocoileus virginianus*, Mammalia, Artiodactyla, Cervidae, movements, camera traps, folklore, hunters' folklore, testing myths, northeastern Pennsylvania, USA

Introduction

There is a significant body of folklore in the hunters' culture and literature concerning white-tailed deer, *O. virginianus* (Zimmermann, 1780) (Mammalia: Artiodactyla: Cervidae). Firmly held ideas within the outdoor sportsperson community includes beliefs that deer movement is influenced by meteorological or astronomical events or, in contrast, that deer move more out of biological necessity, such as finding food, breeding, or seeking shelter (Amenrud 2018). Numerous studies have been conducted to explore if there is a correlation between deer movement and weather events, but most of them have taken place in the southern United States (Anonymous 2018, Winand 2019). Other papers, however, have reached conclusions based on personal experiences (Nelson 2011, Phillips 2017, and Carpenteri 2010).

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Figure 1. A male white-tailed deer, *Odocoileus virginianus* (Zimmermann, 1780). Painting by Anne Dixon.

Hunter's beliefs, often published in well-known hunters' magazines, tend to report results of their seasonal observations using game (also known as motion-sensitive, trigger, or trail) cameras as well as anecdotal reports of weather during the days deer were (or were not) harvested (Carpenteri 2010, Phillips 2017). However, most of these papers do not present evidence, such as data and statistical analyses. In contrast, there are very few scientific studies to support these assertions. Hellickson (2006), Strickland (cited in Anonymous 2018), and Lashley (cited in Winand 2019) conducted studies on factors that influence deer movement and found no relationship between movement and meteorological or astronomical events. These studies will be detailed in the discussion section.

Deer movement is biologically driven by the need to find food and reproduce (Hellickson 2002, Stephen et al. 2010). Earlier studies have shown an increase in male activity before the rut when bucks need to establish dominance hierarches (Hellickson 2002). A decrease in buck movement has been reported in the early rut because dominant-subordinate relationships have already been developed (Hellickson 2002). Deer must feed every four to six hours to support the rumen microbiome (Hellickson 2006).

Animal movement is most often influenced by the imperatives of survival, such as the need for food, shelter, and avoidance of predators, as well as the drive for reproduction. These basic survival necessities of life are often superseded by reproduction drives, such as those present during the rut (mating season). White-tailed deer, *O. virginianus*, a generalist herbivore, are no different from other animals. Their movements are eagerly followed by deer hunters, whose folklore is prevalent in deer-hunting literature (Carpenteri 2010, Nelson 2011, Phillips 2017). One element of this folklore suggests that *O. virginianus* moves in response to weather phenomena, such as temperature, barometric pressure, etc. (Carpenteri 2010, Nelson 2011, Phillips 2017, Ridenour 2017, Winand 2019). Other factors, such as the presence of predators, food availability, and areas of protection are also reportedly important predicators of deer movement (Amenrud 2018). During the winter, in temperate and boreal regions, deer seek refuge from strong winds, cold, and predators (Amenrud 2018). Dr. Bronson Strickland, co-Director of the Deer Ecology and Management Laboratory at Mississippi State University, has found that deer will remain near food sources until breeding season if the likelihood of predation remains low (Webb et at. 2010, Anonymous 2018). Additionally, Abernathy et al. (2019) analyzed the impact of "extreme climatic events", such as Hurricane Irma, on white-tailed deer and how it impacts their movement patterns. The study, following the rut, deer traveled to seek out higher elevation and areas of dense forest (Abernathy et al. 2019).Additionally, they also found that, during the storm, the movement patterns between sexes became more similar than the day before or after the storm.

Our study looked at associations between deer movement and meteorological conditions, such as temperature, wind, barometric pressure, precipitation, as well as astronomical phenomena, such as moon phase, and how they may correlate with deer movement for approximately 13 months (February 18, 2020 to February 19, 2021). We tested some of the claims about deer movement in the hunting community, such as lack of activity on hot days, and relationship between barometric pressure and deer movement. The null hypothesis is that deer movement is unrelated to any of the astronomical or meteorological conditions. Alternative hypotheses include that deer movement occurs within a narrow range within eachvariable (e.g., influenced by extreme meteorological events, such as heavy rains, strong winds, and heavy snow).

Methods

We used four motion-sensitive cameras in the study site from February 15-18, 2021, to capture deer movement and activity patterns. Data from the nearest (38.43 km) high-quality weather observation site, an Automated Surface Observing System (ASOS; latitude 40.6514338, longitude -75.4460202) unit, was used to record hourly temperature, dew point, humidity, wind direction, wind speed, wind gust, pressure,precipitation, and cloud coverage. The ASOS site is located at the Lehigh Valley International Airport (KABE), about 5-6 km northeast of Allentown, Pennsylvania. The weather data was retrieved from Weather Underground (Weather Underground, n.d.).

The data were recorded in an Excel spreadsheet. The study was conductedin a semi-rural area of the unincorporated community of Effort (also known as Mount Effort) located in Monroe County, northeastern Pennsylvania, USA conveniently located close to author's JD residence. Deer movement was documented with movement-sensitive cameras that capture the number of deer, time, and the activity of animals. Details of the study site, variables, instrumentation, camera data analyses, and statistical analyses follow.

Study Site. Deer movement data for this project was collected in a semi-rural village in Effort located in northeastern Pennsylvania. It has a human population of 2,269 (CityData.com 2020) at an elevation of approximately 400 meters above sea level. Figure 2 represents the location of the study in the context of the United States. The study site, a two-hectare residential private property (latitude 40.9969920, longitude -75.4342160), is surrounded by wilderness, including state of Pennsylvania game lands, the latter located approximately five kilometers away. Utilizing images captured from August 30 – September 9, 2020, author JD estimated that the local deer population was approximately 20 individuals. Deer were sorted into groups of bucks, does, and fawns (any deer under a year), each image was counted unless the deer could not be clearly identified. Based on antler patterns, the number of unique bucks were identified. The QDMA's Trail-Camera Survey Computation Form[4] (Thomas 2010, p. 242) was used to determine the local population of 20 and that the area's population is approximately 6.4 deer per

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[4] https://deerassociation.com/wp-content/uploads/2019/07/QDMA_trail_cam_survey_computation.pdf (Thomas 2010).

square mile (2.5 deer per kilometer square). The form that was utilized can be seen in the Appendix (A1). According to Hamrick et al. (2013, p. 6), a single camera over 100 acres will capture 90% of the local deer population. We are aware that relatively inexpensive methods of estimating population size, such as distance sampling (Buckland et al. 2001, 2004), are available. Our questions, however, gravitated primarily around issues of the relationship, if any, between deer movement and environmental cues, not how many deer there were.

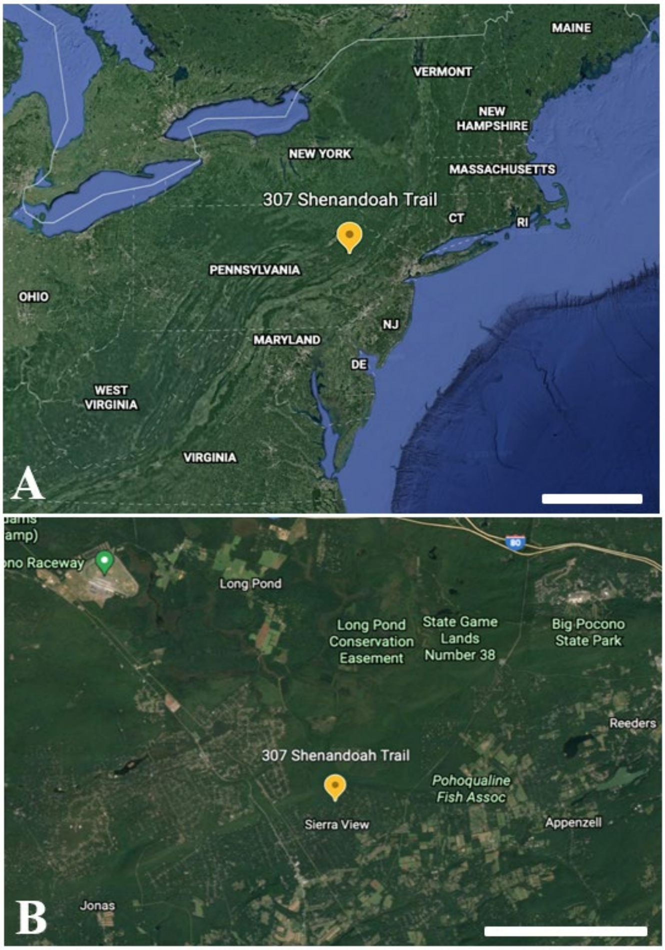

Figure 2. Location of the study is noted with a yellow balloon. Images displayed in Figures 1 and 2 were retrieved from Google Earth, https://about.google/brand-resource-center/products-and-services/geo-guidelines/#google-earth . On panel A, the scale bar represents 200 km; on panel B, scale bar represents 5 km.

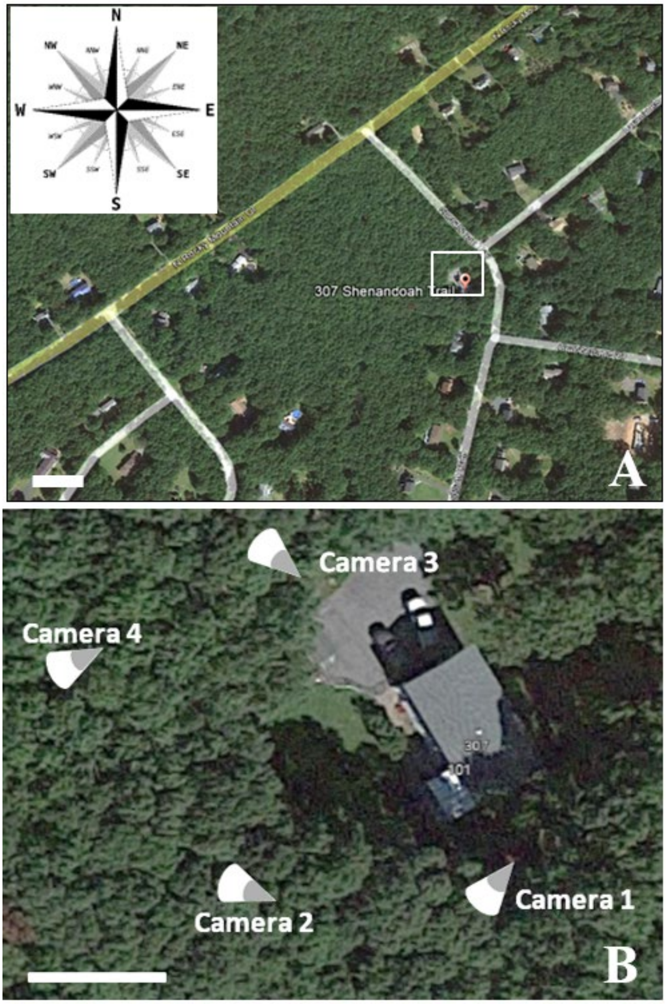

Figure 3. A. Overall view of the suburban community, located in Effort, Pennsylvania (latitude 40.9969920, longitude -75.4342160), where the study took place. The scale bar represents 200 feet (or 60.96 m). B. Enlargement of the boxed area on panel A. Area of the study and the approximate location of the four camera traps. The scale bar represents 50 feet (or 15.24 m). The GPS coordinates of the cameras follow: Camera 1 (40.99697, -75.43404), Camera 2 (40.99638, -75.43409), Camera 3 (40.99734, -75.43454), Camera 4 (40.99709, -75.43409). The approximate area captured during the day by each camera is 1042.42 m^2 (noted in white); at night, 274.32 m^2 (noted in black), or approximately 26% of the day's viewing area. Maps retrieved from Google Earth. Camera 1 is located between two occupied homes, located approximately 43.9 meters apart; camera 3 is located approximately 22.25 meters from an occupied home. The remaining cameras, 2 and 4, were located in the forest, away from the occupied homes and the roadway and they were also facing the forest.

Although in some circumstances it is possible to identify individual deer with camera traps, individual deer identification was out of the scope of this study. More precise identification would require more expensive technology, such as tagging or DNA analysis, and they present some logistical barriers (PGC 2011). The Pennsylvania Game commission (PGC) determines the deer population size based on a model that receives data from hunters, harvested and researched deer, as well as hunter surveys (PGC 2011). For other cervids, such as the row deer, *Capreolus capreolus* (Linnaeus, 1758), in Europe, counts of fecal pellet groups are used to estimate local populations (Tsaparis et. al. 2007, 2008).

The site where the study was conducted is a semi-evergreen forest where white oaks, *Quercus alba* Linneaus (Fagaceae); red maples, *Acer rubrum* Linnaeus (Sapindaceae), mountain laurels; *Kalmia latifolia* Linnaeus (Ericaceae); and *Sassafras albidum* (Nuttall) Nees (Lauraceae). The understory in the study site is dominated by patches of wild blueberries, *Vaccinium* sp.; black huckleberry, *Gaylussacia baccata* (Wangenheim) K. Koch (Ericaceae); hay-scented ferns, *Dennstaedtia punctilobula* (Michaux) T. Moore (Dennstaedtiaceae); garlic-mustard, *Alliaria petiolata* (Marschall von Bieberstein) Cavara and Grande, and sweet vernal grass, *Anthoxanthum odoratum* Linnaeus (the latter two in the Poaceae).

The area has a mean average temperature of 11.7ºCelsius (53.1ºFahrenheit, mean average minimum temperature of 6.0ºC (42.8ºF) and a mean maximum temperature of 17.4ºC (63.3 ºF). The mean annual snowfall from 1944 to 2020 was an average of 83.1 cm (32.7 inches, personal communication for Dr. Imhoff 2021).

Figure 4. Area captured by the camera: A. Camera 1 (photo taken on June 16, 2020, at 7:39:37, temperature 7ºC, waning moon). B. Camera 2 (photo taken on June 11, 2020, at 20:10:21, temperature 18ºC). Camera 3 (photo taken on June 15, 2020, at 6:43:16, temperature 6ºC, waning moon). Camera 4 (photo taken on June 25, 2020, at 8:22:41, temperature 14ºC, waxing moon). Camera numbers refer to Figure 3B.

Variables: The weather data used in this study (i.e., temperature, dew point, humidity, wind speed, wind gust, pressure, precipitation, and cloud conditions) were retrieved from the website Weather Underground[5] from February 18, 2020 to February 19, 2021. The data were collected from Lehigh Valley International Airport Station, which utilizes an Automated Surface Observing System (ASOS). The ASOS site reports observations hourly at fifty-one minutes past the hour (Weather Underground, n.d.). When there are periods of inclement weather, or weather events that could impact air travel, additional readings, called "special reports'', are reported sporadically in between the standard hourly observation times (NOAA 1998). To ensure equal treatment of all the variables and maintain twenty-four weather reports per day, along with the nature of the meteorological variables of interest to this study, special weather events were not used for this analysis (Imhoff, personal communication to the authors, March 23, 2021). Weather Underground includes a plethora of weather observation platforms that span from lower-quality personal weather stations to the highest-quality, highly regulated weather observation systems like the ASOS network. The weather station that was used for this study is an ASOS unit which supports essential aviation activities and is regulated by the National Weather Service (NWS), The Federal Aviation Administration (FAA), and the Department of Defense (DoD) (NOAA 1998).

Weather Underground reports temperature and dew point in ºFahrenheit, which were converted by us to ºCelsius. The dew point is the temperature that air needs to be cooled to where it can no longer hold water in a gas form. At the dew point, water vapor will come out in the liquid form as fog or precipitation (NOAA 2015a). The dew point is the air's temperature needs to be cooled for the atmosphere to reach saturation. When the air is cooled to the dew point, water molecules will begin to condense onto cooler surface at a rate higher than evaporation of other molecules, referred to as "net condensation". When the temperature reaches the dew point, fog and precipitation are likely to form because of net condensation. The dew point was recorded as part of the data, but it is not presented in the results because the graphical analyses closely resembled what is herein presented for temperature. Relative humidity measures the difference between the air temperature and the dew point, reported as a percentage (NOAA 2015a).

Wind speed, wind gust, and cardinal wind direction were retrieved from Weather Underground. Wind speed measurements from ASOS units are representative of sustained wind speed using the most recent 2-minute average of 1-second instantaneous wind measurements. Wind direction is also measured using a 2-minute average. Wind gust speeds are calculated using the greatest 5-second average wind speed taken from the 1-second raw data. Gust speeds are

[5] https://www.wunderground.com/history/daily/KABE/date/2021-2-1 (Weather Underground 2020).

only reported if the highest 5-second average wind speed is above a particular threshold compared to the sustained wind speed (NOAA 1998).

The wind direction was retrieved from the Pennsylvania State Climatologist website[6]. The data were retrieved from the same weather station located at the Allentown International Airport, but were presented in compass degrees, with north being 0. Weather Underground[7] displays the data in cardinal direction. The wind direction was used to assess whether deer seem to prefer a particular wind direction.

The barometric pressure was also obtained from Weather Underground[8]. It is important to understand what type of pressure reading is being reported when comparing findings to other studies (Imhoff, personal communication to the authors, March 23, 2021). Pressure can be reported as station pressure, altimeter setting pressure, and mean sea level pressure[9]. We used mean sea level pressure[10] for the study period (15 Feb 2020 – 19 Feb 2021) as an index of barometric pressure. The change in barometric pressure was then calculated by subtracting the previous recording to the following reading. This change in hourly barometric pressure was used to explore whether deer movement was related to changes in barometric pressure.

Precipitation amounts were retrieved from Weather Underground and is the amount of water that falls to the ground. Any frozen or freezing precipitation is included as a melted, liquid-equivalent total that is reported along with any rainfall in the precipitation amount total. The data was reported in inches and were converted to centimeters for the study. ASOS reports also include information related to sky coverage, precipitation type, precipitation intensity, and obstructions to visibility.

The final variables analyzed were moon phase and astronomical season, it was retrieved from NASA's Horizon database and the astronomical seasons were received from the National Oceanic and Atmospheric Administration (NOAA)[11], respectively. Astronomical seasons are based on Earth's natural rotation around

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6 http://climate.met.psu.edu/data/ida/index.php?t=3&x=faa_raw&id=KABE (Pennsylvania State Climatologist, no date).

7 https://www.wunderground.com/history/daily/KABE/date/2021-2-1. Weather Underground (2021).

8 Pressure is presented in inches of mercury on Weather Underground but was converted to millibars. The formula used is (inches of mercury * 33.864 = millibars).

9 The station pressure is the pressure observed at a specific elevation and is the true barometric pressure for a station (or site) location (NOAA 2015b). Altimeter setting is the pressure reading often given on radio and news reports. It is not the true barometric pressure, and it is reduced to mean sea level by using a temperature profile of the "standard" atmosphere (NOAA 2015b). Standard atmosphere conditions in the United States are based off the average conditions at 40ºN. Finally, mean sea level pressure is the pressure that is commonly used by meteorologists to track weather systems (NOAA 2015b). This pressure represents what the mean sea level pressure would be directly below the station by using a temperature profile based on the temperatures that exist at the station (NOAA 2015b).

10 Conversion from mean sea level pressure to altimeter pressure can be found in this link: https://www.weather.gov/epz/wxcalc_altimetersetting (National Weather Service, no date).

11 https://ssd.jpl.nasa.gov/horizons.cgi#top (Park and Chamberlin, no date).

the sun and define the season with two solstices and two equinoxes whereas the meteorological seasons are broken down into groups of three months based on the annual temperature cycle (NOAA 2021). We used astronomical season instead of meteorological season to test several myths involving the moon's influence on deer movement. Although NASA's Horizon database supplies a variety of astronomical data, only the percentage of the moon illuminated was used. When using this variable, NASA's Horizon database does not factor in waxing or waning conditions.

Instrumentation. Movement-sensitive (also known as game, trail, or trigger) cameras are relatively inexpensive tools that are used for studying relative numbers of animals for extended periods of time (Hamrick 2013). Four cameras (Victure Mini Trail Game Camera, were used in the study. This model offers a 0.4-second trigger timing once motion is detected. The camera has 26 infrared LEDs (Light Emitting Diodes) to supply flawless nighttime shots. There is a 30 second time delay between each photograph required for the image to be written to the memory card.

The four cameras were placed no more than one meter away from sites meeting all the following criteria: identified game trails, deer are commonly seen, and recent deer scat is readily seen. Cameras 1 and 3 were located in semi-forested areas facing the forest. The semi-forested area contains a drainage ditch that often has flowing water following any significant rain event. This is important because water is limited in the study area, increasing the likelihood of imaging deer (Figure 5).

Figure 5. An area in the field of view of camera 1 showing the ephemeral presence of water. A. Drainage ditch during periods of heavy rain and flooding. B. Dry drainage ditch that is seen throughout most of the year.

The cameras have a smaller area of coverage at night due to technical limitations common to many optical instruments (Figure 6). The area of camera coverage was calculated by finding the maximum length and width points that it can detect motion. This difference was calculated by walking at various distances and marking the locations of detection during night and day conditions.

Camera data analyses: Images from the camera were analyzed and the time of capture, number, activity, as well as camera location were recorded. Deer were divided into three categories (fawn; young; and adult). A fawn is categorized as a deer that has spots for this study. At the four camera locations, tape and reflective tacks (bright eyes) were placed on trees surrounding the camera at 53 cm and 45 cm to help with identification. These two heights were chosen because they are the average height of adult white-tailed deer and yearlings, respectively (Pennsylvania Game Commission 2021). A young deer is a deer that has lost its spots but does not meet the height of an adult deer. An adult deer is a deer that meets the average height of an adult deer.

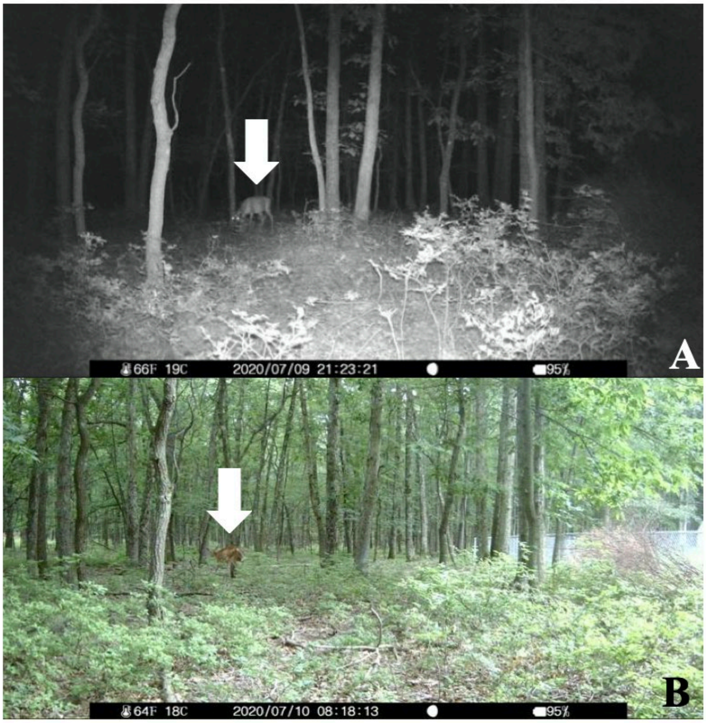


Figure 6. Difference in camera depth of field between day and night. Photo taken site 1. Note that foreground, as shown by the tree trunks, are almost identical; deer are shown by a white arrow. A. Area captured by the camera trap during the night. Note the outline produced by the flashlight's cone (see also Figure 3) and the reduction of area captured due to the limited light sources at night. B. Area captured by the camera trap during the day.

The images from the four cameras were analyzed sequentially to ensure that there was no overlap in counting instances of deer movement on different cameras. If movement was captured within five minutes of each other on different cameras, the images were analyzed to address the direction of movement and the number of deer observed. If it was concluded to be the same instance of movement, the deer were only recorded once using the first location detected.

Once all the instances of movement were recorded, the data were partitioned to the nearest hour (Figure 7). To ensure that the closest weather reading was assigned to the movement, the time of the reading, ##:51, was identified as the middle of the hour (example presented in Figure A2 of the Appendix). This method was not applied to the precipitation analysis because totals are presented in the following hour.

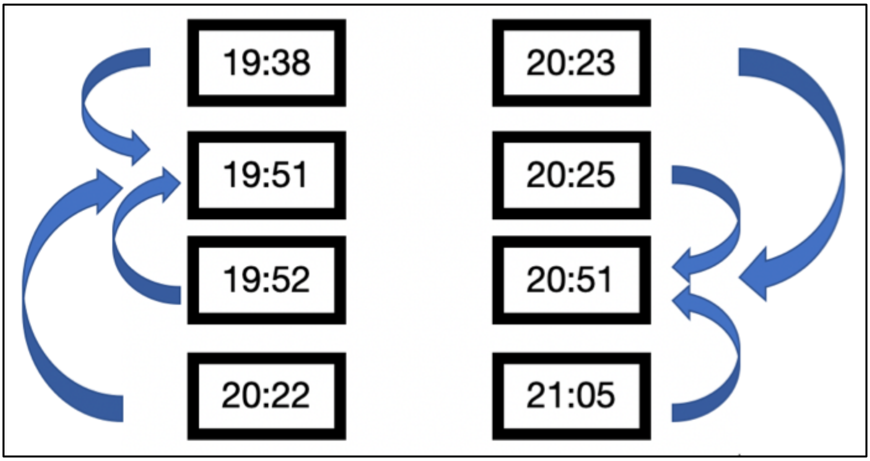


Figure 7. Shows how deer movement photographic captures were recorded to match the hourly data of Weather Underground. The arrows in the figure above show how the deer observation would be distributed into the hourly readings from Weather Underground. Movement occurring 30 minutes before the 51 and 29 minutes after the 51 was recorded on the hour, including the 51. When there were multiple instances of deer movement capture, they were totaled and apportioned to the corresponding hour.

Statistical Analyses. All variables were analyzed individually and assessed for trends. Thereafter, all weather data (i.e., temperature, humidity, wind speed, wind direction, pressure), was relativized to ensure that the contributions (or weight) of each meteorological value was weighed proportionally to its frequency. For example, if the temperature were -10ºC was present only 8 of the total 8860 observations (0.09%), the number of deer observations could be unfairly diminished by the relatively small frequency of the temperature -10ºC, not necessarily by deer movement having anything to do with the temperature.

The data were relativized in Excel by using PivotTables. A pivot table was created for each variable to include the count of the variable and the sum of total of deer captured. An example of a pivot table used can be seen in Table 1.

Table. 1. Example of a pivot table used to relativize each weather variable and sum total of deer movement.

Row Labels	Count of Temperature (C)	Sum of Total number of deer
-17.78	1	0
-13.89	2	0
-12.78	1	0
-12.22	2	0
-11.67	3	0
-11.11	4	0
-10.56	4	1
-10.00	8	0
-9.45	8	0
-8.89	17	4
-8.33	7	3
-7.78	14	0
-7.22	32	7
-6.67	48	0
-6.11	72	8
-5.56	51	44
-5.00	91	18
-4.44	78	24

The data were relativized by using the following formula: ((count of variable (e.g., temperature, Table 1)/grand total of variable(e.g., temperature, Table 1)) * the sum of total number of deer). The relativized data were then examined for trends. Astronomical data were not relativized because every month the lunar cycle provides equal frequencies of each of its phases.

The statistical software XLSTAT[12], a proprietary add-on package for Excel (Addinsoft; Paris, France) was used to perform the Kruskal-Wallis and Dunn tests on all the variables of interest separately. The Kruskal-Wallis, also known as the one-way ANOVA on ranks, is a rank-based non-parametric test that determines if there is a significant difference amongst the user-created groups. For each variable, the relativized data were divided into groups (or ‘‘bins’’) that were used

[12] https://www.xlstat.com/en/ (Addinsoft 2021).

as targets of the analyses. Non-parametric tests were used because the assumptions of parametric tests (Zar 1999), in this case, namely, independence of the observations (with no covariates, almost certainly deer revisited the study site), normality of the distributions (with no outliers), and equal variances (homoscedasticity) could not be supported, either by our knowledge of the organisms being studied or by inspection of the data plots.

Results

Author JD collected a total of 8873 hourly, combined observations on deer (see Methods for an explanation of how data were condensed). Below, we summarize the statistically significant results and analyses by meteorological (i.e., temperature, barometric pressure, wind direction and speed as well as precipitation) or astronomical variable (i.e., moon phase).

Temperature. One of the folklore elements surrounding deer hunting is that deer do not move during days with warmer temperatures (Phillips 2017, Kenyon 2020, McKean 2010, Ridenour 2017). Bob Shepperd, a medical doctor, conducted a study on deer movement and meteorological events determining that temperature is one of the most critical factors influencing deer movement (Phillips 2017). In the graphical analyses of relativized temperature, there are two peaks of preferred temperatures (Figure 8). The first peak is located around colder temperatures (0-10ºC) and the second around milder temperatures (circa 20ºC).

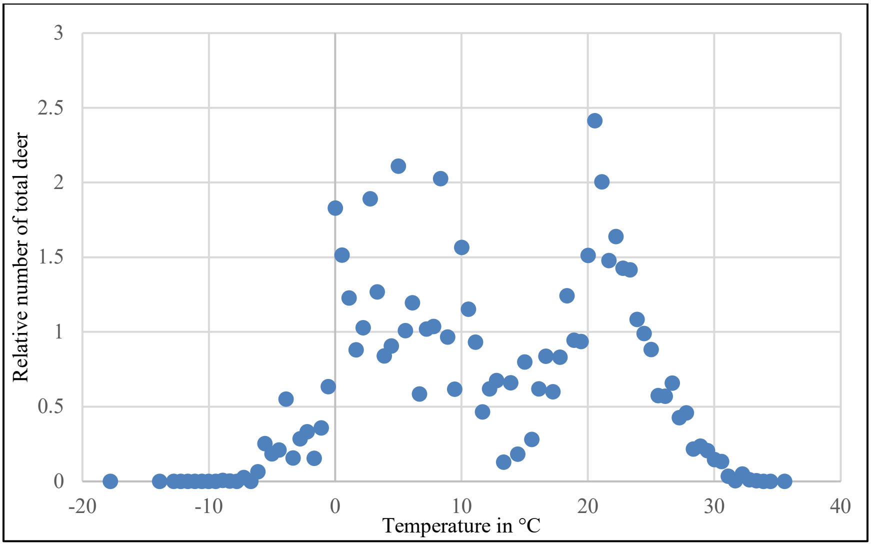
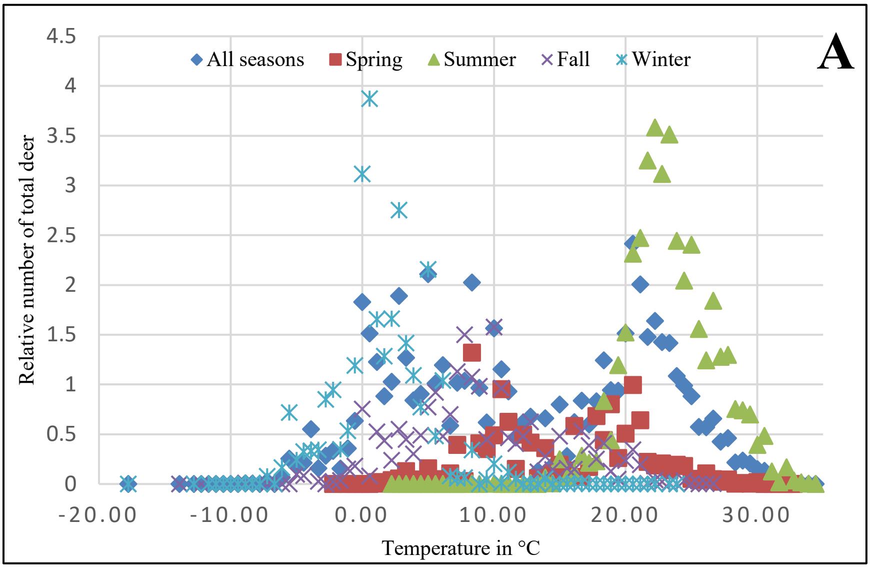


Figure 8. Temperature, in ºC, vs relative number of deer in the study (arithmetic average 10.51, standard deviation 14.46, and 8873 number of observations, including those where deer were not photographed).

Figure 9A displays temperatures sorted out by the annual season. The broad peak at 0-10ºC corresponds mostly to the fall and winter months; the peak at 20ºC corresponds to the summer months. Figure 9B shows all temperatures vs the relative number of deer compared to the months associated with fawning and the rut (breeding). A peak at 10ºC can be seen during the rut.



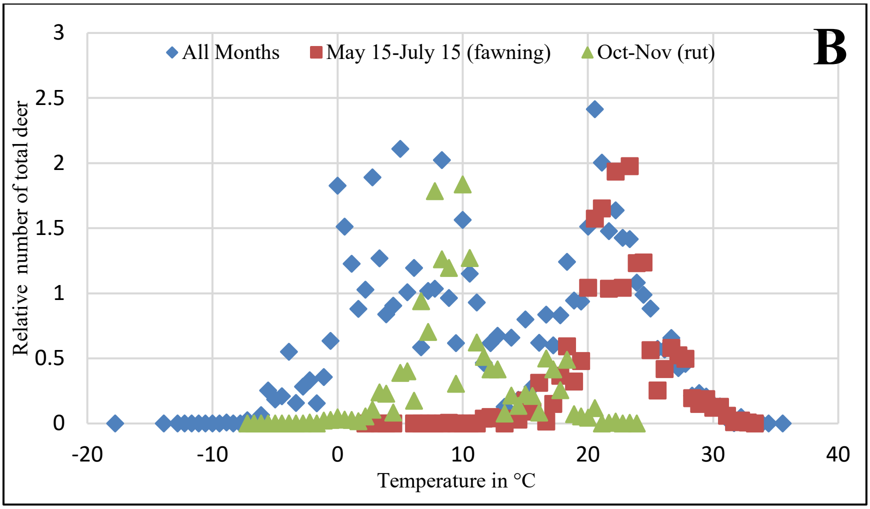


Figure 9. A. Temperature (in ºCelsius) versus relative number of total deer for all season's individual and the relative total number of deer. B. All temperature data and the data from May 15 – July 15, fawning time, and October - November, which is the time of rut.

A difference in the number of points (observations) in Figure 8 (relative number of total deer) and the bottom graph of Figure 9 (relative number of total deer by age group) can be noted. There are more points in the bottom graph of Figure 9 because in Figure 8 the three age groups are totaled for the recorded observation to create one point, while each age group per observation is accounted for in Figure 10.

Figure 10 displays the relative number of deer based on age category. For this study, any deer with spots was determined to be a fawn. Once the spots were lost with the growth of their first winter coat, they were categorized as young deer. As expected from the age groupings of the study, Figure 10 shows a peak in fawn movement during warmer (late spring and summer), and less movement in colder weather. However, there is a peek in young movement in the colder months, this in suspected to be seen because this year's fawns would be classified as young deer from when their spots are lost (approximately September) until they reach the size of an adult deer (approximately May).

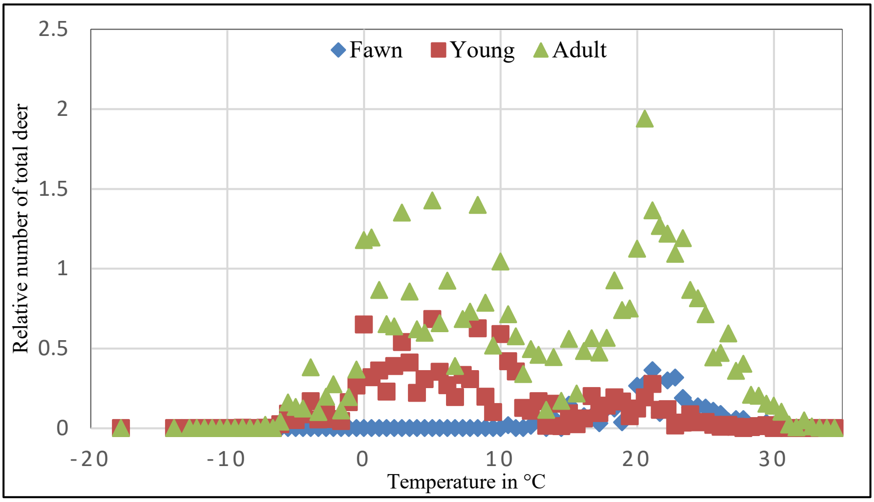


Figure 10. Temperature and the relative number of deer for each age group fawns (only deer with spots), young (deer without spots but not the height of adult deer), and adult. Fawn: arithmetic average 21.11, standard deviation 6.22, and 109 number of observations. Young: arithmetic average 12.04, standard deviation 10.08, and 388 number of observations. Adult: arithmetic average 12.04, standard deviation 10.08, and 1146 number of observations.

Temperatures were separated into six groups, with each group containing a range of 10ºC. A Kruskal-Wallis followed by Dunn statistical tests were performed for this variable (Table 2). Based on Kruskal-Wallis and Dunn statistical test, we found that there is a significant different ($p < 0.0001$) in frequency of movement at different temperatures. The Dunn test showed that there was a significant difference between the relative number of deer movement captures that occurred between the two groups of temperature ranges (1, 6, and 2 and groups 4, 5, and 3). In our study site, deer move less at more extreme temperatures (less than 0ºC and more than 29ºC, Group A); deer move more at milder temperatures (0ºC to 29ºC, Group B).

Table 2. Results of the multiple pairwise comparisons using Dunn's test. Two-tailed test for temperature variable.

Sample (ºC)	**Frequency**	**Sum of ranks**	**Mean of ranks**	**Groups**	
1(-20 to –11)	7	52.000	7.429	A	
6 (30 to 35)	10	173.000	17.300	A	
2 (-10 to –1)	18	462.000	25.667	A	
4 (10 to 19)	18	970.000	53.889		B
5 (20 to 29)	18	1089.000	60.500		B
3 (0 to 9)	18	1259.000	69.944		B

Movement during the rut (October – November) closely mirrors the peak of colder temperatures (0-10ºC). McKean[13] (2010) noted that during increased temperatures deer will bed down even during the rut. Our results suggest that deer move less in temperatures below -5ºC and above 30ºC. In this study, the reported average temperature during the rut was 10.48ºC. The location and period of our study does not allow us to explore how more extreme temperatures influence movement or the impacts of warmer temperature on the rut.

Barometric pressure. Nelson (2010) "collected barometric pressure data from around the country for years through logbook entries from trail cameras, hunters and private studies" and found that barometric is the most important factor influencing deer movement. He also determined that right before the peak of rising pressure is the best time to spot a buck. Our relativized data (Figure 11) show that deer seem to move preferentially at a barometric pressure of approximately 1001.36 millibars (approximately 29.57 inches of mercury).

[13] It is unclear to us whether McKean (2010) is referring to males, females, or both.

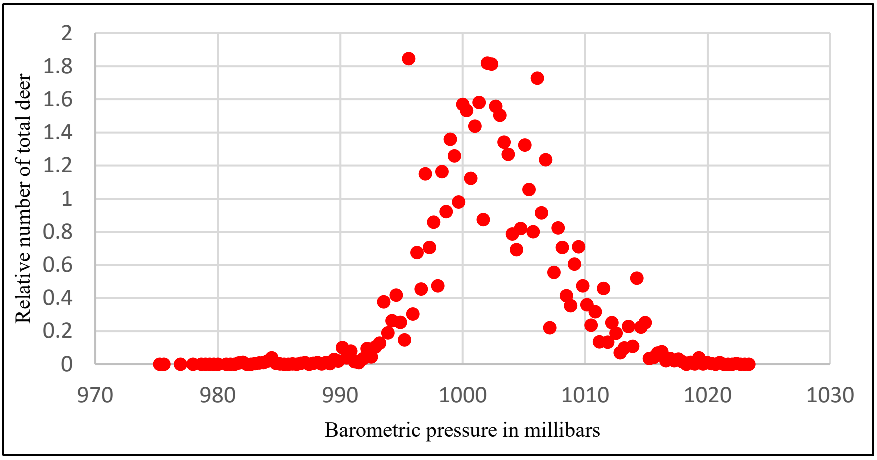


Figure 11. Relative number of total deer vs barometric pressure (millibars) (arithmetic average 999.76, standard deviation 13.49, and 8873 observations, including those where deer were not photographed).

The graphical analyses shows that deer were more active during a mean sea level pressure of 998.99 millibars (approximately 29.6 inches of mercury), which is considered low barometric pressure (normal barometric pressure is 1013.25 mbar or 29.92 inches of mercury). Kruskal-Wallis and Dunn tests were performed supporting the assertion that there is a significant difference within the groups. The p-value from the Kruskal-Wallis test was < 0.0001.

Table 3. Multiple pairwise comparisons of deer movement at different groupings of barometric pressure using Dunn's test, two-tails.

Sample	Frequency	Sum of ranks	Mean of ranks	Groups		
1 (965 - 979)	9	120.000	13.333	A		
4 (1013 -1029)	28	1233.000	44.036	A	B	
2 (980 - 995)	49	2615.000	53.367		B	
3 (996 -1012)	49	5212.000	106.367			C

The barometric pressure was subdivided into four groups with a range of approximately 15 mbar units each. The results of the Dunn test showed that there was a significant difference between sample groups 1 and 4, sample groups 2 and 4 and sample 3. This supports the graphical analyses observation that there was a peak in movement at approximately 1012 mbar.

Nelson (2011) stated that deer movement is positively associated with rising barometric pressure before its peak. He "collected barometric pressure data from around the country [USA] for years through logbook entries from trail cameras, hunters, and private studies. The results are clear and undisputable." However, we did not see a statistically significant change in deer movement with changes in barometric pressures (Figure 12). Pressure change data show that there were fewer camera trail captures of deer movements when there were larger changes in barometric pressure. Instead, the graph shows that more instances of deer movement were captured when there was a small (< ±0.05 mbar) change or no change in barometric pressure.

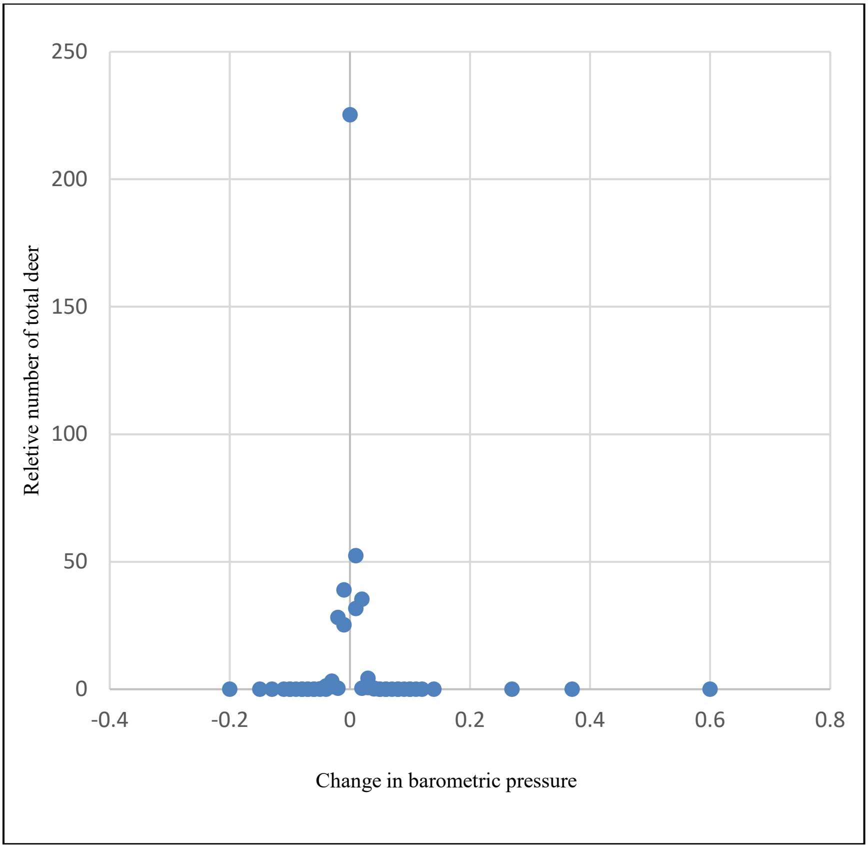


Figure 12. Relative number of total deer vs barometric pressure change and the relative number of total deer.

Figure 13 shows the breakout of the barometric pressure by age groups. Peaks at approximately 1012 mbar can be seen for adult and young age deer.

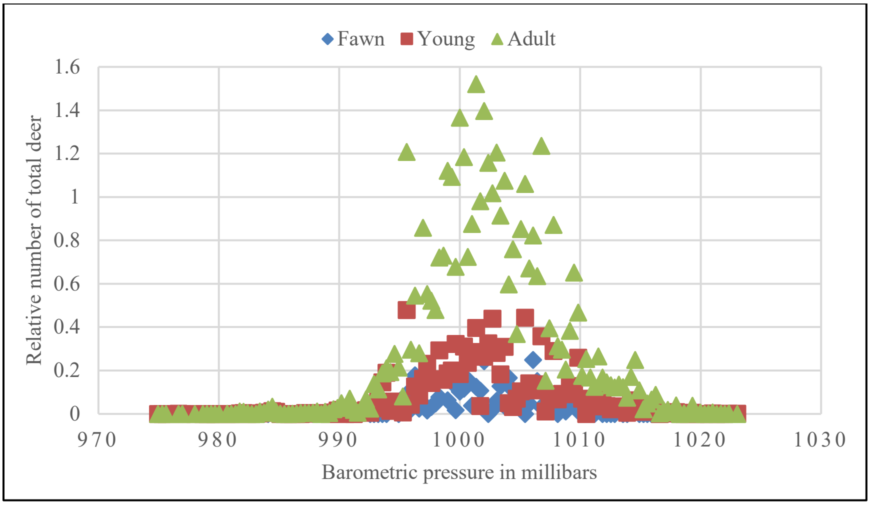


Figure 13. Relative number of deer for each age group fawns (only deer with spots), young (no spots but not the height of adult deer), and adult. Fawn: arithmetic average 1002.30, standard deviation 5.94, and 109 number of observations. Young: arithmetic average 1002.80, standard deviation 7.24, and 388 number of observations. Adult: arithmetic average 1002.80, standard deviation 7.24, and 1146 number of observations.

Wind. Sheppard (in Phillips 2017) and Hepner (2018) found that wind is a critical factor in deer movement and that wind speed is positively associated with deer movement. In contrast, we found an inverse relationship between deer movement (evaluated by camera trap imaging) and wind speed, namely as the wind speed increases, deer movement decreases (Figures 13A and 13B). Additionally, Figure 13B shows that more movement was captured when the wind blew from the west. However, the prevailing wind in the study site, as well as in the continental USA is from west to east (W in Figure 14B).

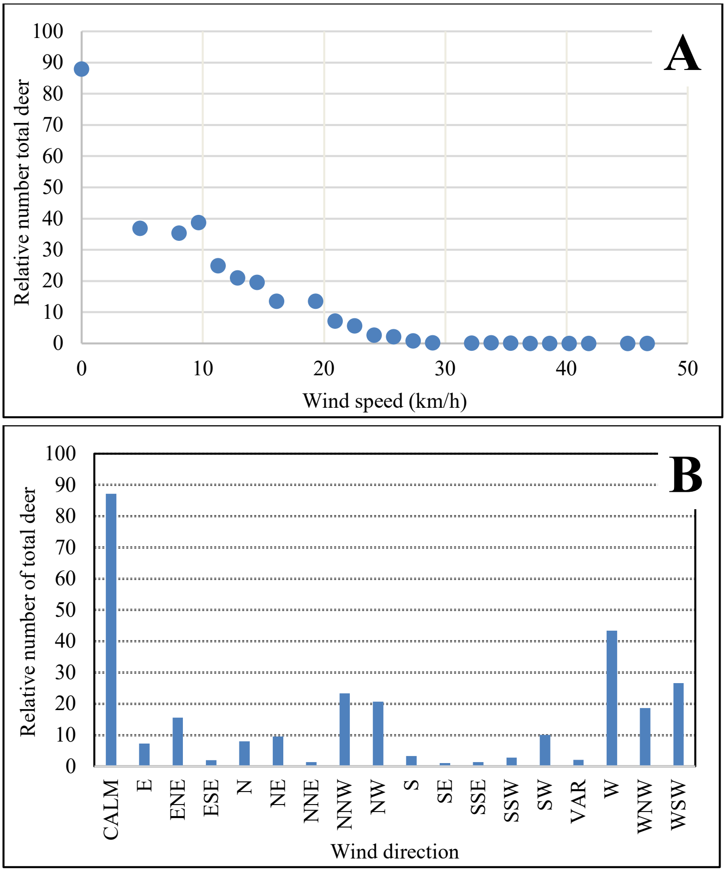


Figure 14. A. Relative number of total deer that were observed at different wind speeds (arithmetic average 24.87, standard deviation13.37, and 8873 observations, including those where deer were not photographed). B. Relative number of total deer that were observed at each wind direction.

Figure 15A shows that most of the wind direction during this study (not only when deer were moving) were from the west and north-northwest. However, Figure 15B shows that there were significantly more instances of deer capture when the wind was blowing from the west. The wind rose (Figures 14A and 14B), show a proportional number of deer capture from the wind direction of west, but non-proportional movements when the wind came from the north-northwest or east-northeast, often associated with storm systems. These results are expected because in the study site the winds blow mostly from the west.

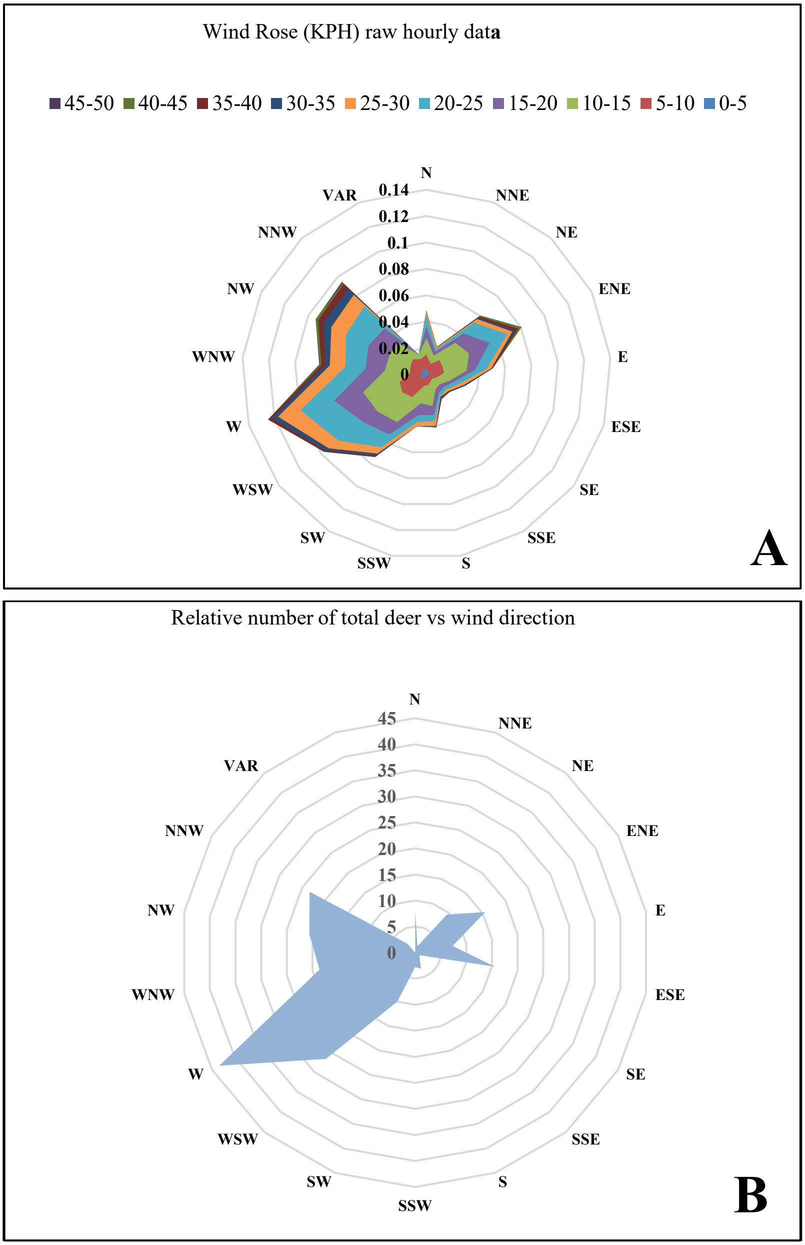


Figure 15. Wind roses. A. Wind rose of the wind direction and wind speeds occurring throughout the duration of the data collection. B. Relative number of deer that was captured at each wind direction. Calm is not included in this panel.

Table 4. Results of the Dunn test for wind speed. There is broad overlap in the groupings.

Sample	**Frequency**	**Sum of Ranks**	**Mean of Ranks**	**Groups**		
5	4	10	2.5	A		
4	5	35	7.0	A	B	
3	6	75	12.5	A	B	C
2	5	90	18.0		B	C
1	3	66	22.0			C

Precipitation. Carpenteri (2010) found that rainfall had a weak association with deer movement. In particular, during rain events, deer seemed less vigilant because the rain acted as sonic camouflage for their movements. In contrast, we found that as rainfall increased, fewer deer were detected (Table 5). The graphical analyses can be seen in Figure 16.

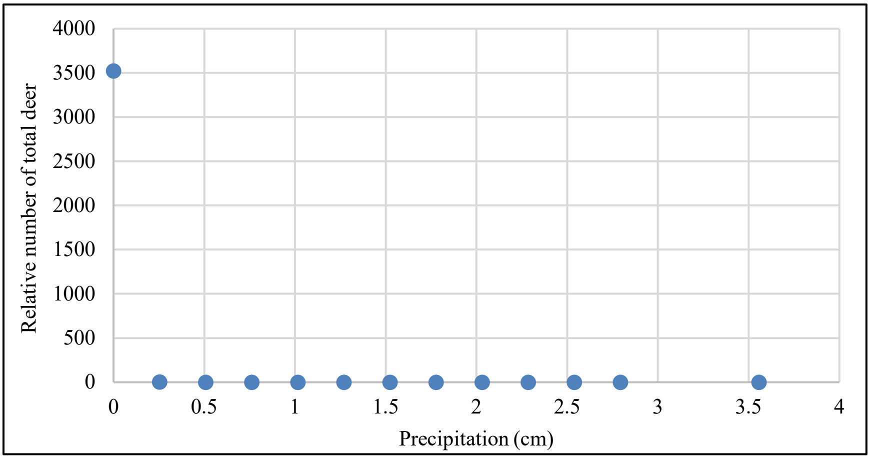
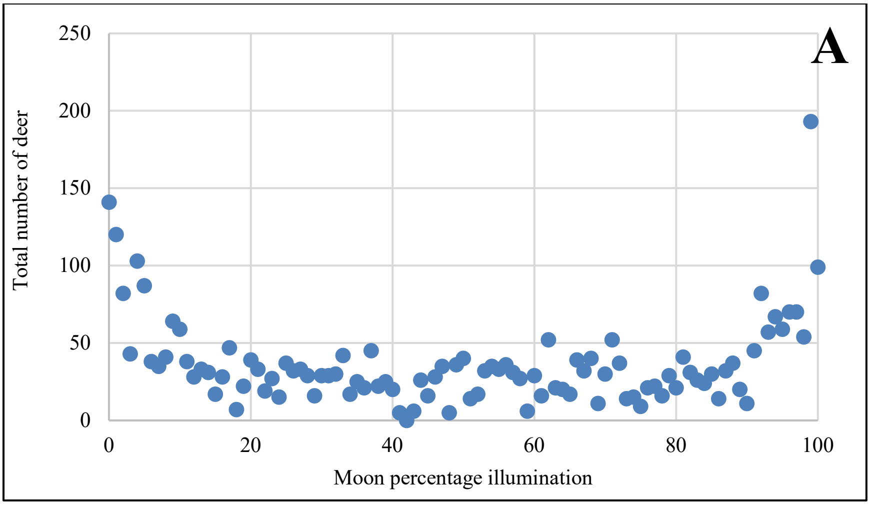


Figure 16. Relative count of deer vs. precipitation (cm). Arithmetic average 1.56, standard deviation 1.06; 8873 observations, including those where deer were not photographed.

Moon phase. There is varying information concerning deer movement and the phase of the moon. Hellickson (2006) found no correlation between moon phase and deer movement during a GPS collar study in Dimmit and Webb counties, Texas. However, according to Winand (2019), Lashley found that there was more midday deer activity during a full moon, but the distance travelled was considered insignificant, so he concluded that the moon phase was not a critical factor.

Our graphical analyses of non-relativized deer activity and moon phase show that there were more instances of deer camera-trailed captures during a new and full moon (Figure 17A).



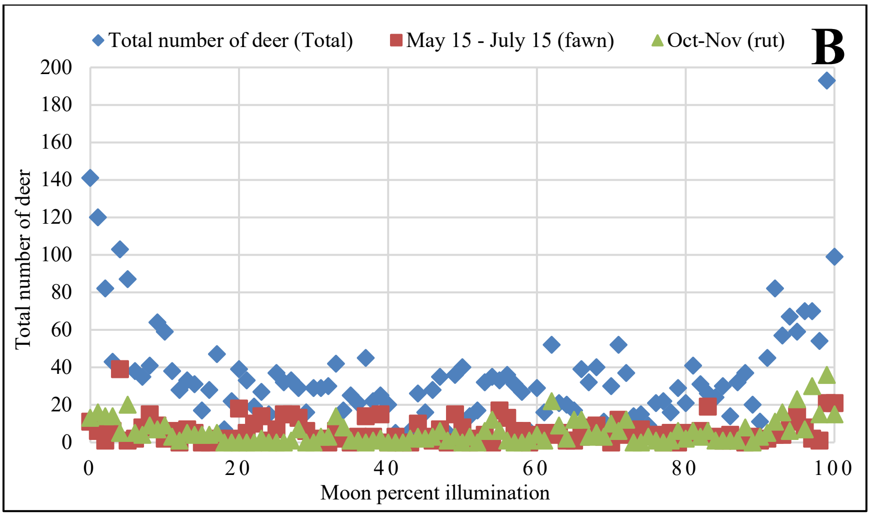


Figure 17. Graphical analyses of the moon phase versus total number of deer. Arithmetic average 50.27, standard deviation 29.76; 8873 observations, including those where deer were not photographed). B. Graphical analyses of the moon phase versus total number of deer, subdivided by major reproductive events, such as fawning and the rut.

Figure 17B shows deer captures and the moon phases of movement captured during fawning and the rut. This is important because during the peak of the rut (October – November 2020), there were two full moons. However, although the graphical analyses do not show the rut having a significant impact on the number of instances captured on the full or new moon, the Kruskal-Wallis resulted in a p-value of < 0.0001. Table 4 shows the results from the Dunn test which showed that there were three distinct categories (A, B, and C) of deer movement as related to moon illumination. However, the analyses also show that there is a broad overlap between these moon illumination categories.

Table 5. Results of the Dunn test. There was broad overlap in the groupings of the phase of the moon. Also, newer moon phases (sample 1, samples 0-9% illuminated) and fuller moon phases (sample 10, 90-100% illuminated) had the highest mean of ranks.

Sample / Percent Illumination	**Frequency**	**Sum of ranks**	**Mean of ranks**	**Groups**		
2 (10-19)	9	247.500	27.500	A		
5 (40-49)	10	275.000	27.500	A		
7 (60-69)	9	247.500	27.500	A		
3 (20-29)	9	340.000	37.778	A		
8 (70-79)	9	391.000	43.444	A	B	
4 (30-39)	9	405.000	45.000	A	B	C
6 (50-59)	9	464.500	51.611	A	B	C
9 (80-89)	10	517.000	51.700	A	B	C
10 (90-100)	11	853.000	77.545		B	C
1 (0-9)	10	819.500	81.950			C

Discussion

Only one of the hunters' myths have survived our statistical analyses, namely deer appear to move more at milder temperatures. As a caveat to all of studies we are aware of, ours included, correlation does not imply causation.

Meteorological Conditions. Several major studies have examined the hunters' myths concerning the meteorological or astronomical factors that may influence deer movement (Hellickson 2002, Stephen et al. 2010) with varied results. For instance, perhaps the most extensive study to-date evaluating the influence of meteorological conditions on deer was performed by Hellickson (2006) on the Faith Ranch in Dimmit and Webb Counties, Texas. GPS motion-sensitive transmitters collars were applied to 43 bucks and 4 years of activity were surveyed to assess empirical support for hunters' folklore. Hellickson found no correlation to deer movement/activity and temperature, humidity, barometric pressure, rainfall, or the moon and concluded that bucks move to breed and feed regardless of the weather conditions. Another study, found in conjunction with hunters at the Bent Creek Lodge, collected data on deer harvest and sightings over the past 20 years to determine what conditions caused the deer to be most active. Their study concluded that temperature was the most critical factor associated with daylight deer movement (Phillips 2017). It seems that Sheppard (in Phillips 2017) is not alone in believing that some meteorological or astronomical factors influence deer movement. White-tailed deer are substantially less likely to move in warmer temperatures during hunting season in November (McKean 2010). According to McKean (2010), Ben Plattner, an Illinois hunting guide, noted that as winter temperatures have been warming, there has been less deer and elk movement because they are seeking shelter in shaded areas. He also noted that during warmer temperatures, bucks are active at dawn but will bed down once it starts to warm up, even during the rut, when male deer, or bucks, typically look for a mate (McKean 2010). This is an unusual behavior because male deer are driven to find a mate, will barely eat during the rut, and can lose up to 20% of their body weight (Brown 1992).

Temperature. Less deer movement in warmer temperatures is expected based on their physiology (Moen 1976). Moen found that deer conserve energy by reducing their degree of activity and seeking level terrain with less snow depth. Deer grow coarse, hollow guard hairs that provide insulation during the winter (University of Georgia's School of Forestry Service 2018). They have fewer guard hairs in their winter coat, but the hairs are twice as thick as their summer coat and a thicker undercoat helps them cope with the colder temperatures. They can puff out their hair in extremely cold temperatures to supply more insulation (University of Georgia's School of Forestry Service 2018). The white-tailed deer's winter coat can overheat during increased winter temperatures. Deer will seek shelter and decrease movement to stay cool during increased winter temperatures (Whittier 2018). Deer in areas that experience harsh winters, such as Michigan, exhibit a distinct winter behavior pattern, involving migration and dense aggregation of animals in forested areas, or yarding (Verme 1973; Van Deelen et al. 1998; Sabine et al. 2001, 2002). Van Deelen et al. (1998) looked at the impact of deer yarding in northern Michigan and found that the distance traveled was highly dependent on age class or sex, and that the two specific deer yards that were observed was spatially isolated during winter. White-tailed deer found in the northern range of New Brunswick (constant severe winter climate) were found to be obligate migrators, traveling to winter range yearly regardless of the winter conditions and remain to spring (Sabine et al. 2002). The deer population located in a southern region of New Brunswick (moderate and variable winter climate) may not migrate to their winter range and may not stay until spring. They are considered conditional migrants because they will migrate if need be (Sabine et al. 2002). The migrations were triggered by snow depth in the south and represent a behavioral response to limiting conditions (Sabine et al. 2002). Snow depth may influence deer movement but was not studied because snow conditions are not commonly mentioned in hunters' folklore.

Barometric pressure. According to Nelson (2011) barometric pressure is the most important predictor of deer movement. Based on weather data, game camera photos, hunter data, and private studies, optimal pressure was determined to be between 1022.7 - 1026.1 mbar (30.20-30.30 inches of mercury). Because Nelson's study did not report the type of pressure they were using, it is unclear if the results are comparable to our findings. Our study utilized sea level pressure and our work suggests that deer in the study site move when the sea level pressure is slightly below normal. Nelson (2011) also found that deer are most active right before the peak of rising barometric pressure. Peak barometric readings occur with winds from the northeast to the northwest. Rising barometric pressure up to the peak is associated with the highest deer activity (Nelson 2011).

Wind. Sheppard's study (cited in Phillips 2017) concluded that wind is a crucial factor in deer movement. Sheppard found that deer move proportionally to wind speed (Phillips 2017). According to Hepner (2018), wind speed is positively correlated with deer movement. More specifically, male deer became more active with light air movement, while female deer activity was not influenced by wind speed (Hepner 2018). This is in contrast to the hypothesis that high winds are associated with less deer movement. These findings are in contrast to ours, which suggest that deer tend to be more active during calm winds.

Precipitation. Rain appears to have a minor impact on deer movement unless there is a torrential downpour (Carpenteri 2010). Hunters have observed that in the rain, deer seem less skittish and more willing to occupy open areas. Carpenteri (2010) attributes the increased activity to the added noises of the rain as it serves as sonic camouflage for the deer movements. Hepner (2018) found that bucks would decrease their movement when it rains and there is little to no wind. The study concluded that a low (less 1 mile per hour or 1.6 km per hour) to no wind and heavy rain combination decreased buck movement the most and the rain/wind combination had no effect on doe movement (Hepner 2018).

Astronomical Conditions. One of the most prevalent myths surrounding deer hunting is that the phase of the moon impacts deer movement. Hellickson (2002, 2006) conducted a two-year study at King Ranch, located close to Kingsville in southern Texas, to analyze the influence of moon phase on white-tailed deer movement. He placed GPS collars on 43 bucks and found that they were most active between 0700-0900 and 1800-1900. Hellickson (2002, 2006) concluded that there was no difference in the movement between a full moon and a new moon. According to Winand (2019), Lashley found that deer in North Carolina were approximately 25% more active midday during a full moon. Lashley determined that this difference in movement was an insignificant amount and concluded that deer are primarily crepuscular. Lastly, another study conducted in Pennsylvania showed that white-tailed deer does move 20 feet (6.1 meters) more per hour during a new moon. This results in approximately 450 feet (circa 137 meters) more of movement throughout the day (Winand 2019). This amount of movement is considered insignificant by most hunters forcing Winand (2019) to conclude that the moon phase has no significant impact on deer movement.

Non-weather-related events. Predation is a non-weather-related event that impacts white-tailed deer, particularly the fawns (Nelson and Mech 1986a, 1991, 2006). One study conducted in central Pennsylvania found that most deer are killed from birth to about 12 weeks (about three months) of age (Vreeland et al.

2004). Bear, *Ursus americanus* (Pallas, 1780); bobcat, *Lynx rufus* (Schreber, 1777); and coyotes, *Canis latrans* (Say, 1823), are the main predators of young deer. The study found that bears and coyotes killed 84% of fawns before nine weeks of age (Vreeland et al. 2004). As deer age, predators have a smaller impact on deer populations. He had a game camera set up in one location that captured 1,200 pictures of white-tailed deer; wild turkeys, *Meleagris gallopavo* (Linnaeus, 1758); raccoons, *Procyon lotor* (Linnaeus, 1758); opossums, *Didelphis virginiana* (Karr, 1792); and eastern gray squirrels, *Sciurus carolinensis* (Gmelin, 1788). When the number of bear images increased (used as an index of regional bear abundance), the number of white-tailed deer photos declined. Garrett (in Anonymous 2014) estimated that the white-tailed deer population decreased as the number of images decreased from 800-900 images per week to approximately 200 per week. Garrett attributed this change to the increase in the bear population. Some studies (e.g., Nelson and Mech 1986b) suggest that in the deep snows of severe winters, predation risk increases because deer are not as able to move as readily, while wolves, a key predator in some northern latitudes, can easily run deer. Although our study recorded black bears, we found that there were no instances of deer movement in the area when bears were detected. However, we did not collect enough data to determine if bear presence had a significant impact on deer movements.

Future Studies

This study supported some of the hunting myths, namely that deer are more likely to move during mild temperatures (0-10ºC and 20ºC), lower-than-normal barometric pressures (1009.14 – 1015.92 millibar), as well as during full and new moons. Hellickson (2002) noted that many studies on white-tailed deer performed in southern USA did not find a correlation to deer movement and weather conditions, but northern studies performed in northern latitudes (Hellickson 2002) have shown that deer shift their activity period to when conditions are most favorable for thermoregulation.

Research using only camera traps, such as this one, have drawbacks, biases, and inaccuracies as well as advantages, such as ease of use and relative low cost (Chitwood et al. 2017). Further studies could employ GPS collars on larger deer populations distributed over several larger areas to better test the hunters' folklore. Nevertheless, the cost ($1,200 - $3,000 per collar) is prohibitive to most scholars interested in movement biology (Cypher et al. 2014).

Because this study is an example of correlation research, further experimental exploration of this question warranted. More longer-term studies using an onsite Automated Surface Observing System (ASOS), GPS (Global Positioning System) tracking collars, and added motion-sensitive cameras to better document deer behavior spread across a more extensive study area could supply more detailed information about the causes of these movements. An experimental, functional ecology approach could pursue answers to the question, "what are the mechanisms by which deer sense the environment?" As our climate continues to change and more extreme weather events occur, long-term studies could show how extreme weather events change and impact deer movement. Other studies have found that deer change their habitat selection during hurricane events (Abernathy et al. 2019). The location of our study and the use of more advanced equipment could provide insights into how deer respond to extreme snow events and warming climates in the northeast.

This study supports the assertion that some meteorological variables are related to deer movement, paving the way for more complex studies on the functional ecology of deer and other large mammals, an area that seem to have been little studied. For example, there have been several studies aiming to understand the impact of pressure changes on other animals, such as fish movement (Udyawer et al. 2013), amphibians' reproduction (Oseen and Wassersug 2002), reptiles, including birds' energy homeostasis (Creagh et al. 2013 and Price-Rees et al. 2014), and mammals, such as humans and their recurrent headaches (Maini and Schuster 2019). Although some of the studies have been inconclusive (snakes, Maini and Schuster 2019), it nevertheless begs the question of the mechanisms by which animals respond to their surroundings.

Importantly, there may be different perspectives between researchers and deer hunters because "researchers are looking for statistically significant and consistent correlations" (Kenyon 2020). In contrast, deer hunters are looking for a "slight edge" concluding that a typical deer hunter would consider a difference of five minutes or 50 yards significant while most scientific studies found these number to be insignificant. These small-scale movements may seem unimportant, but to a person setting in a deer stand could mean the difference in filling a tag, namely harvesting a deer, or going home empty handed.

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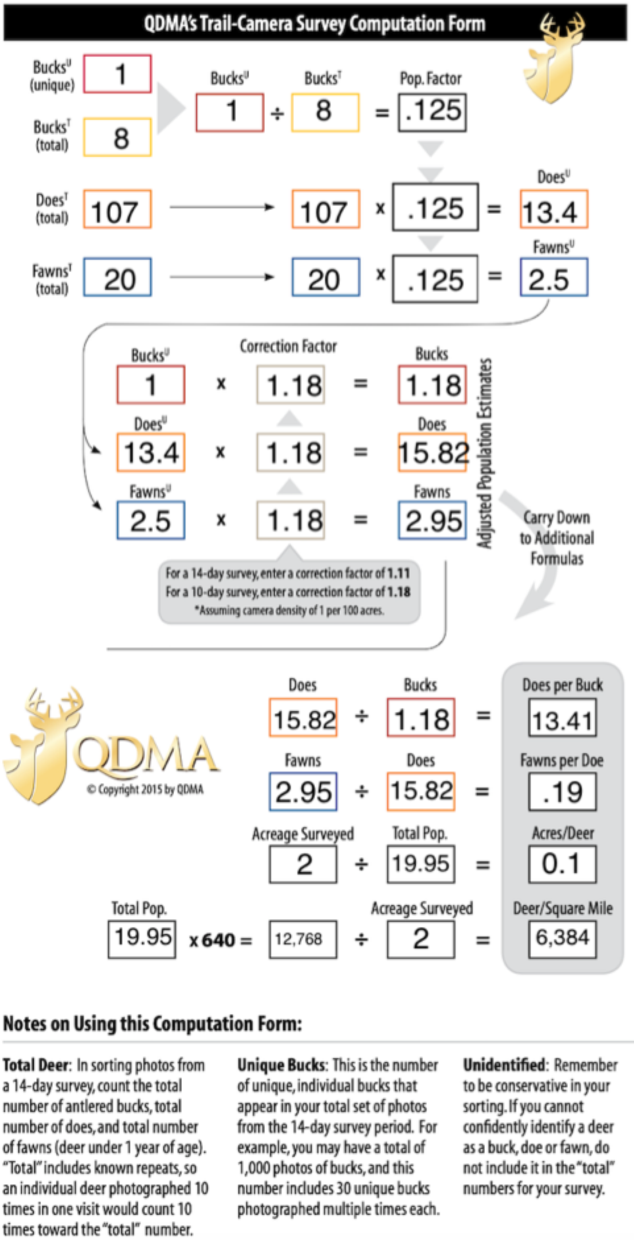
Appendix


QDMA's Trail-Camera Survey Computation Form

Bucks[U] (unique) 1

Bucks[T] (total) 8

Bucks[U] 1 ÷ Bucks[T] 8 = Pop. Factor .125

Does[T] (total) 107 → 107 x .125 = Does[U] 13.4

Fawns[T] (total) 20 → 20 x .125 = Fawns[U] 2.5

Bucks[U] 1 x Correction Factor 1.18 = Bucks 1.18

Does[U] 13.4 x 1.18 = Does 15.82

Fawns[U] 2.5 x 1.18 = Fawns 2.95

Adjusted Population Estimates

For a 14-day survey, enter a correction factor of **1.11**
For a 10-day survey, enter a correction factor of **1.18**
*Assuming camera density of 1 per 100 acres.

Carry Down to Additional Formulas

QDMA
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Does 15.82 ÷ Bucks 1.18 = Does per Buck 13.41

Fawns 2.95 ÷ Does 15.82 = Fawns per Doe .19

Acreage Surveyed 2 ÷ Total Pop. 19.95 = Acres/Deer 0.1

Total Pop. 19.95 **x 640 =** 12,768 ÷ Acreage Surveyed 2 = Deer/Square Mile 6,384

Notes on Using this Computation Form:

Total Deer: In sorting photos from a 14-day survey, count the total number of antlered bucks, total number of does, and total number of fawns (deer under 1 year of age). "Total" includes known repeats, so an individual deer photographed 10 times in one visit would count 10 times toward the "total" number.

Unique Bucks: This is the number of unique, individual bucks that appear in your total set of photos from the 14-day survey period. For example, you may have a total of 1,000 photos of bucks, and this number includes 30 unique bucks photographed multiple times each.

Unidentified: Remember to be conservative in your sorting. If you cannot confidently identify a deer as a buck, doe or fawn, do not include it in the "total" numbers for your survey.

Figure A1. Displays the calculations that were used to estimate the local population. Blank document was retrieved from (Thomas Jr. 2010 p. 242).

1	Date	Julian Date	Astronomical Season	Time	Time Captured on Camera	Temperature (F)	Temperature (C)	Tem
5300	13-Aug	20226	Summer	22:51	0	72	22.22	
5301	13-Aug	20226	Summer	23:51	0	70	21.11	
5302	14-Aug	20227	Summer	0:51	1	71	21.67	
5303	14-Aug	20227	Summer	1:20	1	71	21.67	
5304	14-Aug	20227	Summer	1:23	1	71	21.67	
5305	14-Aug	20227	Summer	1:51	0	68	20.00	
5306	14-Aug	20227	Summer	2:51	0	69	20.56	
5307	14-Aug	20227	Summer	3:51	0	69	20.56	
5308	14-Aug	20227	Summer	4:51	0	68	20.00	
5309	14-Aug	20227	Summer	5:13	6	69	20.56	
5310	14-Aug	20227	Summer	5:41	1	69	20.56	
5311	14-Aug	20227	Summer	5:51	0	69	20.56	
5312	14-Aug	20227	Summer	6:51	0	71	21.67	
5313	14-Aug	20227	Summer	6:52	1	71	21.67	

1	Date	Julian Date	Astronomical Season	Time	Time Captured on Camera	Temperature (F)	Temperature (C)	Temp
5387	16-Aug	20229	Summer	8:51	0	67	19.45	
5388	16-Aug	20229	Summer	9:25	1	67	19.45	
5389	16-Aug	20229	Summer	9:45	1	67	19.45	
5390	16-Aug	20229	Summer	9:50	1	67	19.45	
5391	16-Aug	20229	Summer	9:51	0	67	19.45	
5392	16-Aug	20229	Summer	10:24	0	68	20.00	
5393	16-Aug	20229	Summer	10:51	0	68	20.00	

1	Date	Julian Date	Astronomical Season	Time	Time Captured on Camera	Precip. (in)	Precipitation (cm)	Total number of deer
2845	12-Jun	20164	Spring	16:51	3	0	0	2
2846	12-Jun	20164	Spring	17:51	5	0	0	3
2847	12-Jun	20164	Spring	18:02	3	0	0	1
2848	12-Jun	20164	Spring	18:10	1	0	0	1
2849	12-Jun	20164	Spring	18:15	1	0	0	1
2850	12-Jun	20164	Spring	18:19	1	0	0	1
2851	12-Jun	20164	Spring	18:28	1	0	0	1
2852	12-Jun	20164	Spring	18:33	1	0	0	1
2853	12-Jun	20164	Spring	18:51	0	0	0	0
2854	12-Jun	20164	Spring	19:07	2	0	0	2

Figure A2. Displays how instances of deer movement was recorded to match the hourly weather data and ensure even distribution. The top two rows of data display examples of how the data were partitioned.