2013

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Recommended Citation
Cole, Emily Grace, "Estimating Mammalian Densities Using Automated Videography at the Firestone Reserve, Costa Rica" (2013). *Scripps Senior Theses.* Paper 299.
http://scholarship.claremont.edu/scripps_theses/299

Estimating mammalian densities using automated videography at the Firestone Reserve, Costa Rica

*With special reference to Collard Peccaries (*Tayassu tajacu*), Central American Agoutis (*Dasyprocta punctata*), and White-tailed Deer (*Odocoileus virginianus*).*

A Thesis Presented

by

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To the Keck Science Department

Of Claremont McKenna, Pitzer, and Scripps Colleges

In partial fulfillment of

The degree of Bachelor of Arts

Senior Thesis in Organismal Biology

December 10th 2012

Abstract

Camera trapping, a process in which images of organisms are captured through the use of motion and or infrared sensor cameras, is frequently used within the field of biology to estimate species density through the capture-recapture method. Classic physics models of density based on the ideal gas constant, however, can be used to estimate the density of an animal population without the need for recognition of individuals. This study adapts one of these models (Rowclife *et al.* 2008) to the unique data recorded through automated videography or video trapping, and uses it to estimate the population densities of three relatively abundant species on the Firestone Reserve in Costa Rica: Collard Peccaries, Central American Agoutis, and White-tailed Deer. Collard peccaries were found to have a density of 4.93 individuals/km^2, Central American Agoutis were found to have a density of 1.01 individuals/km^2, and white-tailed deer were found to have a density of 0.50 individuals/km^2. The knowledge of species densities can be extremely useful in the context of a reserve. Changes in these estimates can serve as indicators of consequences from poaching, pollution, or climate change, and monitoring them could be very beneficial to the Firestone Reserve.

Introduction

Camera trapping, a process in which images of organisms are captured through the use of motion and or infrared sensor cameras, has been used in recent years within the field of biology (Henschel & Ray 2003; Sanderson & Trolle 2005; Trolle & Kéry 2003). Although video has not been used as frequently, camera traps that can take video sequences, are possible as well. Data from camera traps can be used, among other things, to provide population counts of an individual species, or to provide a species diversity index for a certain area (Henschel & Ray 2003). Camera trapping can also be used to provide reports of species densities. While it is intuitive that the trapping rate of a camera trap inherently provides some information about species density, trapping rate alone does not account for inflation from multiple animals passing as a single individual (Jennelle *et al.* 2002). Often considered necessary for density estimates is the frequently used capture-recapture method (Trolle & Kéry 2003), which requires the ability to recognize and distinguish between individual animals. This is difficult if not impracticable when it comes to small animals and or animals without spots or other distinguishing markings. In their 2008 paper, *Estimating animal density using camera traps without the need for individual recognition* Rowcliffe *et al*. presented and tested a method for estimating animal density that builds on a paper by Huchinson & Waser (2007), on the use of the ideal gas constant within the field of biology. Models that predict molecular collision rates in an ideal gas can be used to predict the movements and collision rates of individual animals in a population, which in turn can be related to the population density (Huchinson & Waser 2007). The method employed by Rowcliffe *et al.* relies on this concept, and executes it through the use of camera trapping. The researchers used estimates of animal speed, radius and angle of camera sensor, trapping rate, and total camera hours to come to a final estimate of species density. They utilized several methods to obtain these estimates that I will not be able to call upon in my post experimental analysis of my camera data for the Firestone Center. However, Rowcliffe *et al* developed their method for camera trapping with still images. In this study, I estimate some of the variables directly from video data and present density estimates for key species of The Firestone Reserve in Costa Rica.

Methods

Study Area

Data were recorded during the months of June and July at the Firestone Reserve in the province of Puntarenas, Costa Rica, which is a property owned by Pitzer College. It is a semi-secluded location bordered by paved roads and a few residences. The climate is tropical, and the reserve primarily consists of secondary forest with pockets of riparian forest, bamboo forest, and banana plantations.

Camera Placement

Fifteen Bushnell Trophy Cam cameras were placed at different points within the Firestone Reserve, on average about 0.5 meters above ground level (Figure 1). Placement was a compromise between opportunistic and dispersive motivations. Cameras were placed by game trails, bodies of water, burrows, or other signs of possible animal presence, but in addition an effort was made to disperse them extensively throughout the reserve. Traps were sometimes baited with puma, warthog, or fisher cat urine, cat food, or weasel bait. The cameras were programmed to take 30 to 15 second videos, with a 30 second delay after each video, during which no additional video could be taken. They were also set to the highest sensitivity option. The cameras were moved if, after 48 to 72 hours, they were not capturing any videos at all, if the videos captured were mainly false triggers, or if it seemed they were capturing the same individuals over and over again. If the animals captured were of increased interest, such as a puma, cameras were kept in the same area for a prolonged period of time.

Camera memory cards were swapped out once every 48 hours and videos of animals were saved and organized by camera number, location, and date. Videos triggered by insects, humans, or other non-animal causes were recorded but deleted.

Data Analysis

A species abundance index was created with values for both “days sighted,” as well as “separate sightings.” Days sighted was defined as the number of days an animal was sighted, regardless of the number of times that animal was sighted per day, while separate sightings was defined as the number of times that animal was seen either on a different day or at a different location.

The video data were then used to estimate the components required for a density calculation based on the methods of Rowcliffe *et al* (2008).

Animal speed was estimated as a sum of straight-line movements on camera, over the time spent on camera. The distance the animal covered was recorded in relation to the average size of the animal, which was obtained from literature sources, to avoid distortions produced by the animal’s being closer or farther from the camera.

The harmonic mean was used as the average speed, which is the appropriate average for speed data given in units of distance over time, when the distance is the fixed variable (Ferger 1931; Rowcliffe *et al.* 2012).

Trapping rate was calculated as the total number of contacts over the total number of camera hours. One contact was defined as a video triggered by an animal that was not in the frame before. In the case of animals that often travel in groups, a new individual entering the frame while other members of the group were still on screen was not defined as new contact. Animals that often travel in groups had their trapping rate multiplied by the measure of their average group size, which was obtained from the video data as well.

The area of the camera's trigger zone and angle of field of view were obtained from data provided by vendors of the camera (Bushnell 2012). The radius of the trigger zone was then calculated using the following equation derived from the equation for the area of a sector:

$$\sqrt{\frac{A(360)}{\pi\theta}} = r$$

Where A= the area of the trigger zone, θ= the angle of the field of view of the trigger zone, and r=the radius of the trigger zone. Although both r and θ may have fluctuated due to environmental conditions and the size of the triggering animal, for this study they were treated as constants.

Total camera hours were calculated as the total sum of hours from the time the first camera was placed to the time the last camera was removed, multiplied by the number of functioning cameras.

Density was then estimated from the following equation developed by Rowcliffe *et al.*:

$$D = \frac{y}{t} \frac{\pi}{vr(2+\theta)}$$

Where y = the total number of contacts, t = the total camera hours, v = the average animal speed, r= the radius of the trigger zone, and θ = the camera sensor field of view.

Results

Abundance

Table 1. Species sightings for the Firestone reserve from 6/7/2012 to 7/28/2012. Number of days sighted refers to the number of unique days an animal was sighted, while number of separate sightings refers to the number of sightings of an animal either on a different day or at a different location.

Animal Name	Scientific Name	Number of Days Sighted	Number of Separate Sightings
Puma	*Puma concolor*	6	10
Ocelot	*Leopardis pardalis*	3	3
White-faced Capuchin Monkey	*Cebus capucinus*	5	5
White-Nosed Coati	*Nasua narica*	8	10
Northern Tamandua	*Tamandua mexicana*	1	1
Unidentified Opossum		12	16
Collard Peccary	*Tayassu tajacu*	35	60
White-tailed Deer	*Odocoileus virginianus*	18	23

Red Brocket Deer	*Mazama temama*	2	2
Raccoon	*Procyon lotor*	1	1
Nine-banded Armadillo	*Dasypus novemcinctus*	4	5
Central American Agouti	*Dasyprocta punctata*	30	38
Unidentified Rat		1	1
Unidentified Cat		1	1
Spotted Paca	*Agouti paca*	25	34

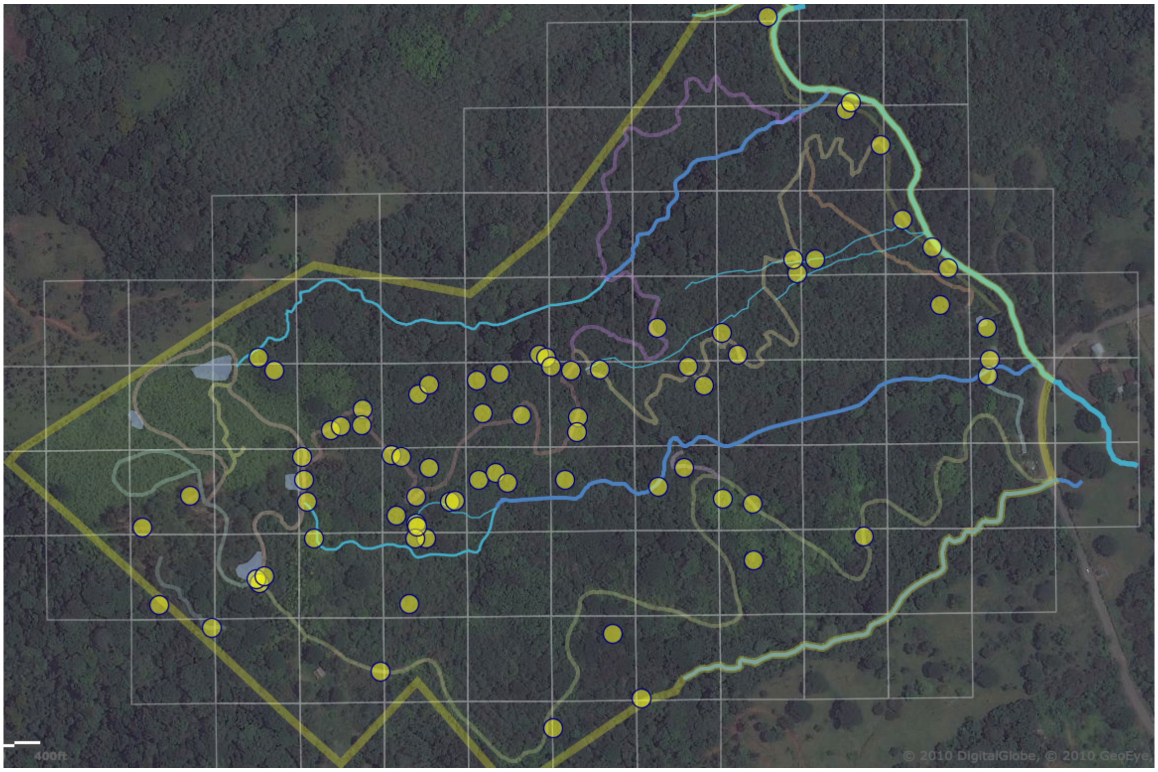

Figure 1. Placements and areas marked for placement of camera traps on the Firestone Reserve, Costa Rica.

Activity

Table 2. Sightings during the day, during the night, and in total, for a subset of mammals of the Firestone Reserve.

	Peccaries	Agoutis	Deer
Total Contacts	85	43	26
Contacts in semi or full daylight	70	39	24
Contacts in Full Darkness	15	4	2

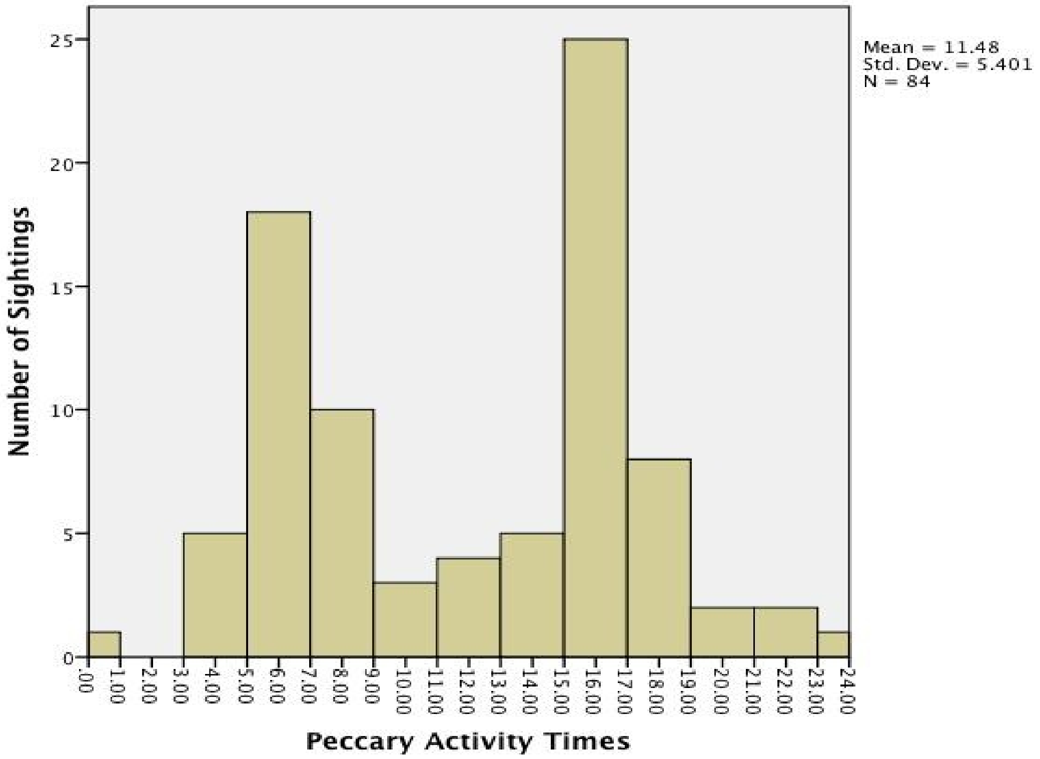

Figure 2. Total number of peccary contacts for every hour of the day.

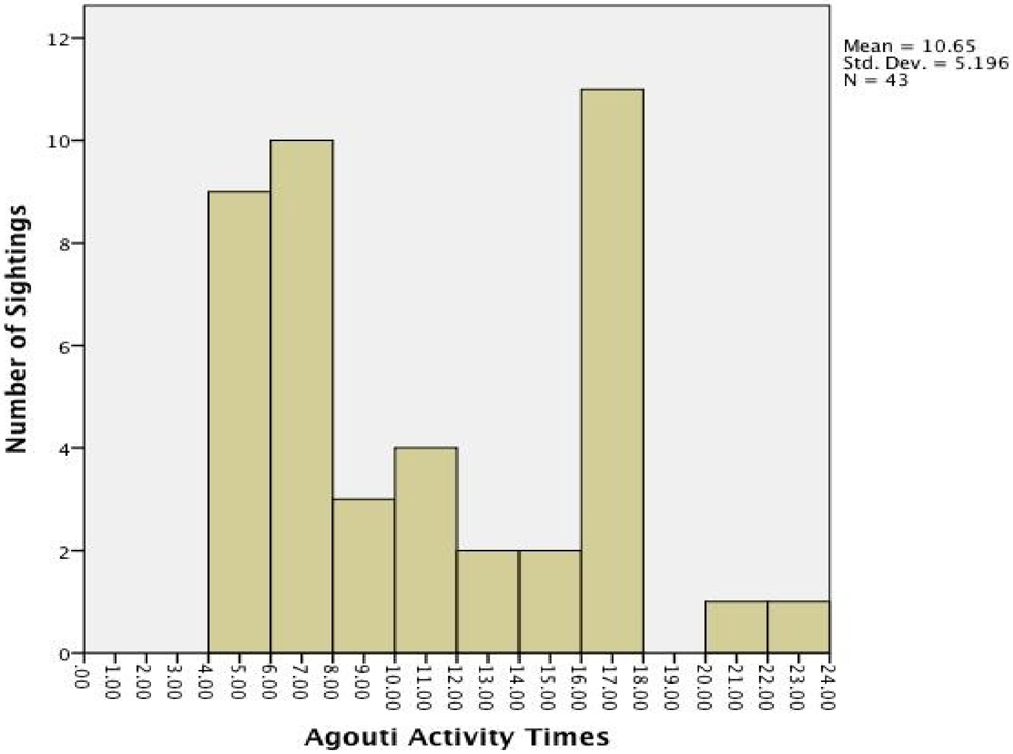

Figure 3. Total number of agouti contacts for every hour of the day.

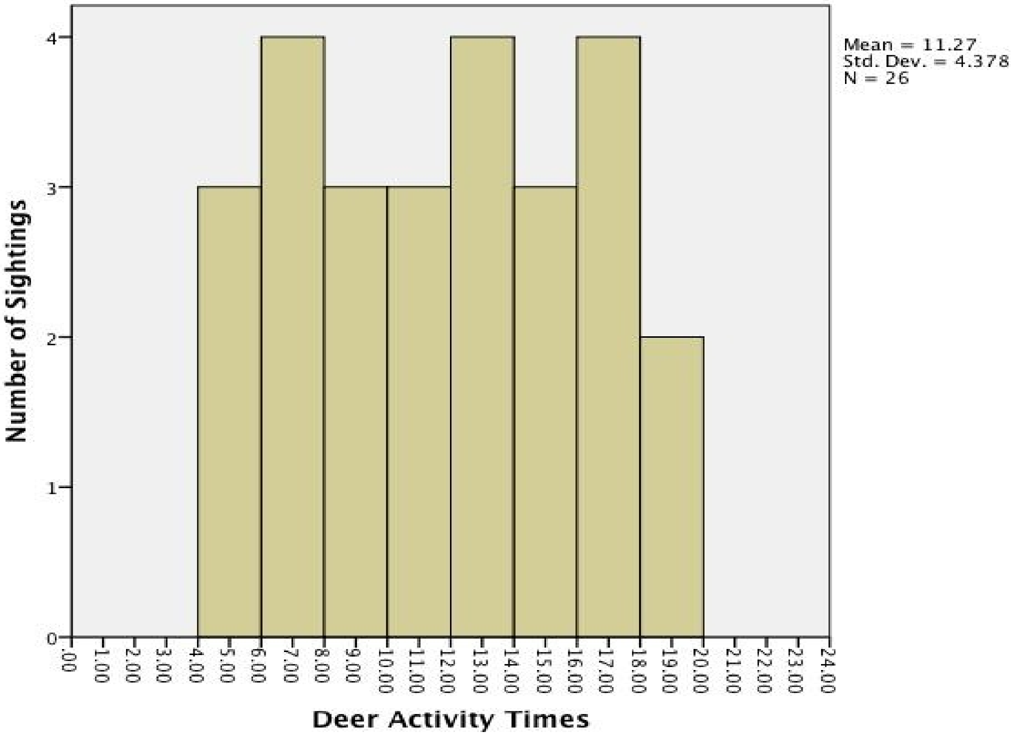

Figure 4. Total number of deer contacts for every hour of the day.

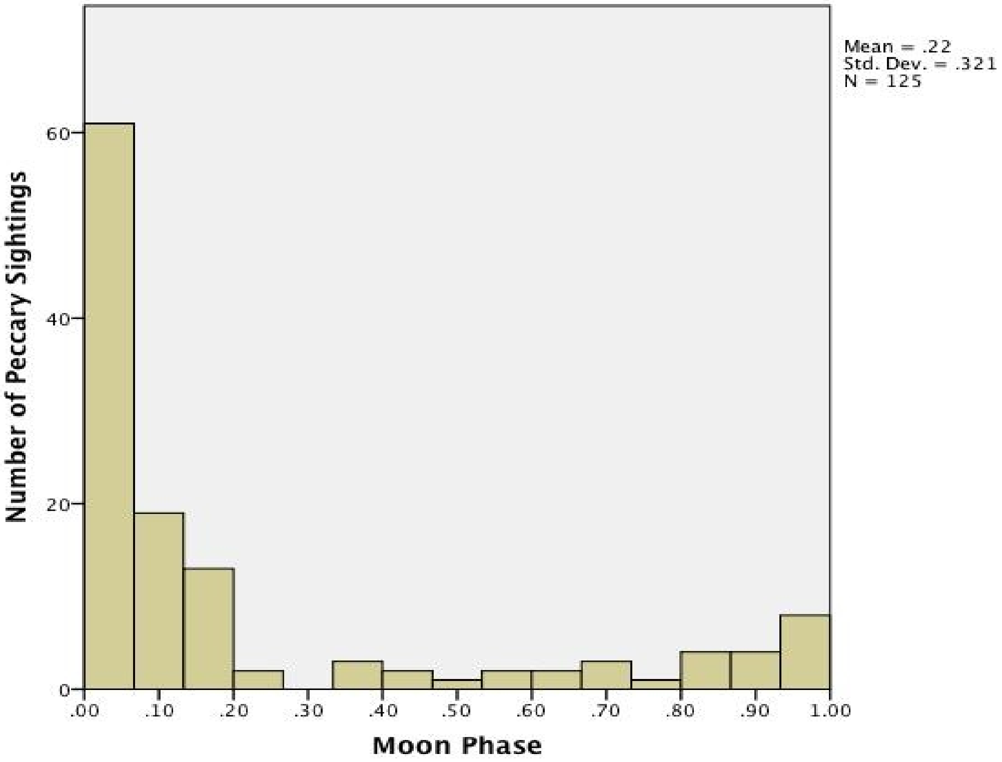

Figure 5. Total number of peccary contacts by moon phase.

Table 3. Results of a linear regression test for moon phase as a predictor of total peccary contacts.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	24.946	1	24.946	3.467	.072[a]
	Residual	237.454	33	7.196		
	Total	262.400	34			

Table 4. Results of a Chi-squared test for frequencies of total peccary contacts for each moon phase.

	MoonPhase
Chi-Square	109.333[a]
df	34
Asymp. Sig.	.000

Table 5. Results of a linear regression test for moon phase as a predictor of peccary contacts in full darkness.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.622	1	.622	1.038	.316[a]
	Residual	19.778	33	.599		
	Total	20.400	34			

Table 6. Results of a Chi Square test for frequencies of peccary contacts in full darkness for each moon phase.

	MoonPhase
Chi-Square	2.714[a]
df	8
Asymp. Sig.	.951

<u>Density</u>

Table 7. Density values for peccaries, agoutis, and deer on the Firestone Reserve and the unique variables they are based on.

	Peccaries	Agoutis	Deer
Density (individuals/km^2)	4.93	1.01	0.50
Mean Speed (harmonic, m/s)	0.15	0.24	0.29
Total Number of Contacts	85	43	26
Average Group Size	1.51	1	1

Table 8. Constant variables used to calculate mammal densities of the Firestone Reserve.

Total Camera Time (Hours)	Camera Angle (Rad)	Camera Radius (m)
16,536	0.70	3.5

Table 9. Alternate estimates of speed for peccaries, agoutis, and deer on the Firestone Reserve.

	Peccaries	Agoutis	Deer
Mean Speed (harmonic, m/s)	0.15	0.24	0.29
Mean Speed with shelter time accounted for (non harmonic, m/s)	0.21	0.23	0.38
Shelter Time (hours)	10	6	8

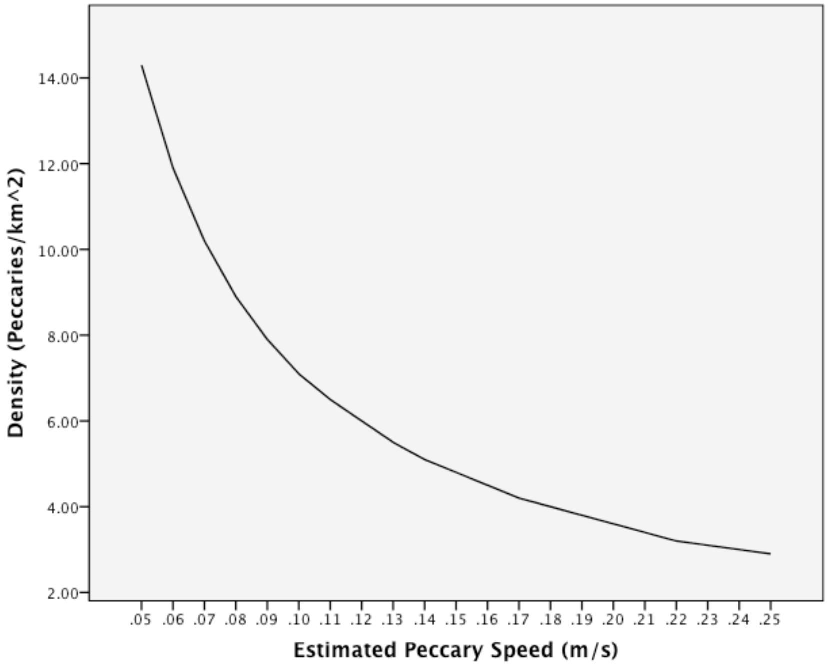

Figure 6. Peccary densities of the Firestone Reserve as determined by estimates of peccary speed.

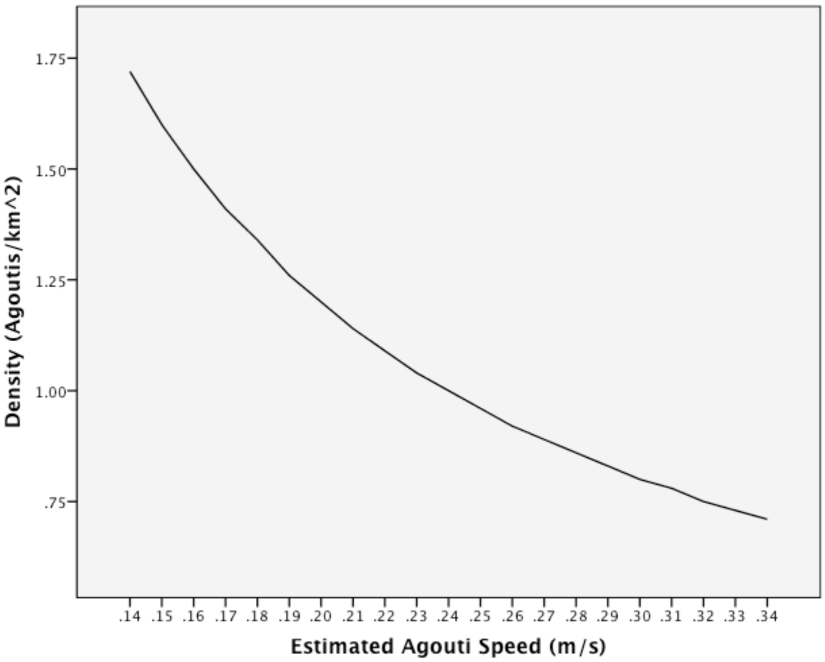

Figure 7. Agouti densities of the Firestone Reserve as determined by estimates of agouti speed.

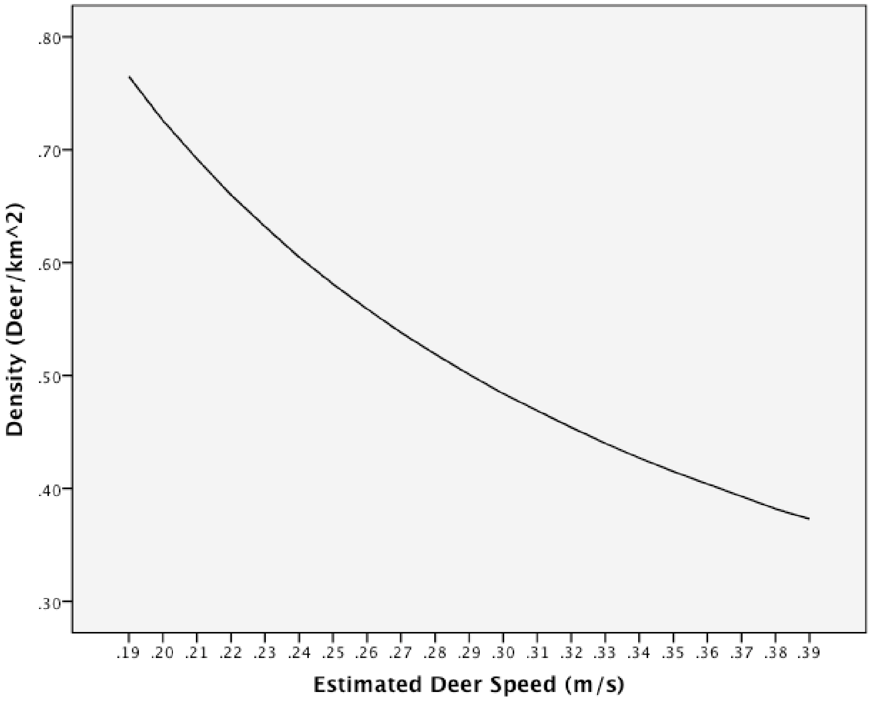

Figure 8. Deer densities of the Firestone Reserve as determined by estimates of deer speed.

Discussion

Abundance

The species abundance index (table 1) provides two different measures of sightings in an attempt to make sure the same individual was not being recorded over and over again. The first measure, “Number of Days Sighted” may be more appropriate for long-range species, such as the puma and ocelot, where multiple camera sightings on the same day are most likely the same individual. The second measure “Separate Sightings” probably provides a more accurate estimate of abundance for smaller animals. Certain groups of species, such as opossums were lumped together in a single index value although several sub species make up that one category. This is because in these cases it was too difficult to consistently identify the correct sub-species from the video data, due to poor video quality, or subtly of distinguishing features.

According to the index, peccaries appear to be the most abundant species on the Firestone Reserve. Rats, Raccoons, and the Northern Tamandua tie for least abundant, however the infrequent appearance of rats is most likely due to the placement of cameras on average 0.5 meters above ground. The one time a rat was recorded it was by a camera that was, unusually, placed directly on the ground. In addition it is worth noting that sightings of arboreal mammals were severely limited by camera placement as well. While White-faced Capuchin monkeys did appear on camera a few times, three-toed sloths, which were sighted in the field during camera placement and maintenance, did not appear on video at all. Other species may have escaped detection all together as well.

Activity

I attempted more advanced scrutiny of the video data for peccaries, agoutis, and deer. These were the species with the highest abundance scores, other than the spotted paca, and thus provided the most data. Although pacas were sighted more often than deer, many of their videos came from camera 9, which was the first camera to capture a puma, and therefore was not moved during the entire study. Most of the paca videos from this camera showed an adult and a juvenile traversing the exact same path, alternating in direction each time. This lead me to believe that they were the same two individuals, and thus may have inflated the paca abundance score. For this reason I chose to focus on deer instead of pacas.

Peccaries, agoutis, and deer were all most active during the daytime (Table 2; Figures 2,3,4). Deer in particular were relatively more active during the day (Figure 4), and did not show a midday decrease in activity that appeared with both peccaries and agoutis (Figures 2,3). This decrease in activity for peccaries and agoutis may have been due to the fact that midday hours are the hottest and least sheltered from the sun. Perhaps because deer are so long-legged and less compact they are better equipped to handle the heat and therefore are more active during the day, less active during the night, and do not need to rest during the hottest portion of the day.

Of these three, the most nocturnally active animals were peccaries (Table 2; Figure 2). In terms of total number of sightings, they seemed to be most active when the moon was least illuminated (Figure 5). A linear regression test of moon phase as a predictor of frequency of peccary sightings resulted in a p value of 0.072, which is not significant, but is close (Table 3). However the residuals of the moon phase values were not normally distributed, which violates one of the assumptions of a linear regression. A Chi-squared test, which is a non-parametric test, showed that the frequency of peccary sightings varied significantly between the different phases of the moon ($p<.001$, Table 4). So peccary activity may be affected by moon phase. Peccary sightings at night did not vary significantly between moon phases ($p= 0.95$, Table 6), but maybe peccary activity increases in general when the moon is less illuminated, because if they do happen to be caught at night during those times, it will be darker, leaving them less susceptible to predation.

Density

I encountered a few difficulties while attempting to appropriate the method for estimating density presented by Rowcliffe *et al.* to the video data obtained from the Firestone Reserve. Possibly most problematic was that my experimental design did not fulfill all of the constraints the researchers claimed for their method. Because the method is based on the ideal gas constant, which models random movements and collisions, it does not allow for opportunistic camera placement or trap baiting. The cameras in this study were placed opportunistically, and at times some of them were baited. These violations constitute a systematic error and may have skewed my results toward a higher density.

Although Rowcliffe *et al.* treat camera sensor radius (r) and camera sensor field of view (θ) as constants in their study, another systematic error most likely resulted from shrinkage or blockage of the camera trigger zone. Some of the cameras were partially obscured by brush or other natural features, meaning the sensors were not functioning at their greatest possible area. In addition, it is known that the infrared sensor is affected by ambient temperature, so the area of the contact zone created by the camera may have fluctuated from day to day (Bushnell 2012). Animal size may have also affected the radius of the trigger zone, as smaller animals generate less heat. All of these issues may have contributed to an overestimate in the values for the area of the trigger zone, biasing the calculated densities toward lower results.

One possibility for future projects would be to attempt to place the cameras in unobscured locations. However since this may conflict with the need to not place cameras opportunistically, the distance to the blockage could be measured, and a better estimate of the amount of the contact zone it was blocking could be obtained. In addition, in order to explore the variability of the sensor, tests of camera sensitivity could be performed on location on particularly hot and cool days, although this is probably a much smaller source of error than that of the obscured trigger zones.

A third systematic error most likely resulted from the estimation of distance an animal covers as a sum of straight-line movements. Obviously animals do not always move in straight lines and the omission of turns and curves from their movements underestimates the distance they are actually covering, which in turn overestimates their speed (Rowcliffe *et al.* 2012). This error is likely to have biased my results toward a lower density, and may have been more impactful than the violations described above.

Rowcliffe *et al*. cited the estimation of animal speed (v) as one of their main sources of error, and although I used a different method, I believe it was my main source of error as well. Within the calculation of animal density presented by Rowcliffe *et al*., animal speed, when multiplied by total camera hours (t), is functioning as an estimate for the total area covered by an individual of the given species in the specified amount of time that the study took place. Therefore (v) is not necessarily the speed of the moving animal, but rather the average speed of the animal over a twenty-four hour period, that takes into account the time the animal spends still, while in it's burrow, eating, etc. Rowcliffe *et al.* dealt with this problem by trailing individuals for a half hour at a time to estimate the species' day range, and then only taking into account their daytime photos, but this method is not ideal.

Analyzing only daytime photos halves the camera hours one is able to use, cutting available data by 50%, which is undesirable. In addition, such a practice does not take into account species movements during the night. For example, although peccaries are thought of as diurnal (Carillo *et al.* 2002), about 18% of peccary contacts were made in full darkness (table 2; Figure 2). This means that peccaries do continue to move about in the night, just less frequently, and excluding the entire data set of their nighttime movements may bias density reports.

Because of this, my method for estimating mean animal speed makes full use of the recorded camera hours, however I have included two different methods of calculating an animal's mean speed (Table 9) due to the error-prone nature of this estimation. The first and possibly most appropriate method was to take the harmonic mean, which is the inverse of the mean of the inverses of all the recorded speeds. The harmonic mean gives more weight to slower speeds and therefore compensates for the fact that faster speeds are more likely to be seen (Ferger 1931; Rowcliffe *et al.* 2012). However, when using the harmonic mean I was unable to include videos in which an animal was simply standing still, as this was recorded as a speed of zero, and I could not take its' inverse.

In contrast to this, the second calculation of average speed takes the mean of the recorded speeds and accounts for the amount of time an animal is likely to spend in it's shelter. In the case of peccaries, which were sighted almost every hour of the day (Figure 2), shelter time was determined through literature sources. For agoutis and deer, shelter time was calculated as the sum of the hours of the day during which there were no sightings of that animal (Figures 3, 4). During the time in its shelter, an animal would have a speed of approximately zero, and would automatically not be within view of a camera, so without accounting for this, its mean speed is drastically inflated. In a future experimental design, a possible strategy could be to place cameras outside animal shelters so as to record the amount of time an animal spends in them. This would be more accurate and could eliminate the dependence on outside literature sources.

Because speed is both an essential and difficult part of this calculation of density, I have included figures that illustrate the resulting density values for both methods of calculating average speed, as well as how the calculated density changes as estimates of speed change, for peccaries, agoutis, and deer (Figures 6, 7, 8).

Finally, it is worth noting that while Rowcliffe *et al.* were using camera traps without video, and thus did not have many other options for estimating animal speed, the use of the video data for estimating speed requires less man-power, and provides far more flexibility in terms of execution, than a series of day-range estimates does. Recent data have also shown that it is comparably accurate (Rowcliffe *et al.* 2012).

The knowledge of a certain species' density can be extremely useful, especially in the context of a reserve. While the Firestone Reserve is somewhat guarded, it is still vulnerable to poaching. Peccaries in particular are at risk, as they are often hunted for their meat. Peccary density reports in similar climates vary widely, such as from 1.4 – 8.1 individuals/km^2 (Fragoso, 1998), but even keeping track of changes in it's own density estimates could be vastly beneficial to the Firestone Reserve. Such changes could serve as indicators of poaching, pollution, or climate change, and could be used to measure the general success of the reserve's protection.

Acknowledgements

I would like to thank Donald A. McFarlane for guiding me through and aiding me with every step of this process, Warren Roberts for his help, both in the field and with GIS, Elise Ferree for offering advice to me throughout my field research, Greddy Arias for enthusiastically helping me with whatever problem arose during my field research, from animal identifications to animals caught in my cameras, Jack Ewig for being continuously willing to provide me with information and for allowing me to work with the guides of his neighboring reserve, Hacienda Baru, the guides of Hacienda Baru for showing me animal trails, wallows, and watering holes throughout the Firestone Reserve, Cheryl Baduini and Cherly Margoluis for helping me to identify ambiguous animals caught on camera, Pitzer College for allowing me use of the Firestone Reserve for this research, and the Keck Science Department for funding it. In addition I am grateful to the Fletcher Bay Foundation for funding the purchase of the trail cameras.

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