

EXAMINING THE RESPONSE OF DESERT BIGHORN SHEEP TO
BACKCOUNTRY VISITOR USE IN THE PUSCH RIDGE WILDERNESS AREA

by

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DEDICATION

For my beautiful wife Kristin

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ABSTRACT

Many prey species exhibit antipredator responses in the presence of humans. These responses may lead in turn to behavioral modification and spatiotemporal avoidance strategies that may have implications for long term population dynamics. Our research was developed to measure the potential effects of backcountry recreation on the behavior and distribution of desert bighorn sheep in the Pusch Ridge Wilderness Area (PRWA), Arizona, USA. Human use of the PRWA was quantified across the study site using real time observer field counts and modeled use metrics derived from motion activated trail cameras ($n=15$) placed on six US Forest Service trails. We conducted 113 behavioral observations at multiple spatial scales from February of 2015 through May of 2016 to quantify female bighorn activity budgets and responses to human interaction. Bighorn behavior was characterized in a generalized linear model to examine how human use and environmental covariates affect changes in the frequency of behaviors within the bighorn activity budget. Our models indicate that interactions between bighorn and humans are complex. An increase in human activity in the PRWA correlates inversely with bighorn time spent grazing. As a potential trade off bighorn significantly increased the frequency of time bedded. These results suggest that bighorn behavioral responses to human activity may carry costs associated with avoidance, however, behavioral analysis alone is not enough to measure the extent of such costs. This research has management implications where multiple use and high levels of human activity have the potential to negatively influence the behavior of wildlife species.

INTRODUCTION

Examining fine scale interactions between wildlife responses to anthropogenic influence is of increasing importance as the global human population continues to grow. Many prey species react to the presence of humans in a way that mirrors responses to natural predators (Frid and Dill 2002). Paramount in the decision making process of any prey species is the assessment of predation risk associated with a given activity. This risk assessment plays a central role in how wildlife make decisions and allocate time (Walther 1969, Sih 1992, Abrams 1994, Winnie et al. 2006). Wildlife populations subject to high levels of human interaction may experience risk effects associated with long term avoidance strategies that can carry costs at both the individual and population level (Ydenberg and Dill 1986, Lima and Dill 1990). These effects may manifest as generalized changes in resource selection, distribution and spatiotemporal avoidance strategies (Proffitt et al. 2009, Sawyer et al. 2009, Coleman et al. 2013, Longshore et al. 2013, Richard and Côté 2016), increased flight response (Papouchis et al. 2001), a decrease in forage time (Bélanger and Bédard 1990, Lima and Bednekoff 1999) and nutrition (Christianson and Creel 2010), chronic elevated stress levels (Thiel et al. 2008) and potential reduction in survival or recruitment (Creel and Christianson 2008, Creel 2011). These effects may be especially pronounced when human activity poses no direct threat to a species (Peckarsky et al. 2008). As a result the associated predation avoidance strategies likely pose little benefit to the individual given the level of perceived risk is inflated.

These interactions that govern population dynamics are highly complex and derived from a cascade of hierarchical animal responses that, when combined, make it

difficult to isolate the relationship between single factors of influence. While this challenge is inherent in observational study it is still possible to examine the many facets of wildlife responses that collectively dictate ultimate changes in population when we consider these responses in a stepwise fashion. Risk effects for example may be measured as a logical evolution of cause and effect whereby changes in behavior such as foraging time may lead to physiologic response. Physiology may in turn dictate an individual's ability to avoid predation or disease and can be determinant in the production of offspring. The long term cumulative effects of both survival and recruitment then have direct effects on wildlife population dynamics (Creel 2011).

Measuring the response of wildlife behavior to human activity is the first step in this progression. Behavior can be measured on a continuum where a frequency change in the expression of one behavior correlates inversely to a change in one or more of the remaining behaviors that comprise a species total activity budget. Behavioral analysis can isolate the nature of an interaction by providing a real time metric of wildlife responses to a given stimuli. Long term measures of wildlife behavioral responses may highlight potential costs derived from risk avoidance strategies. Behavior itself, however, cannot measure true costs associated with risk effects but instead offers direction and scope when considering next steps in the examination of the ultimate mechanisms that dictate population dynamics. We used behavior to examine the relationship between back country visitor use and a translocated population of desert bighorn sheep (*Ovis canadensis mexicana*) in Arizona.

From 2013-2016 the Arizona Game and Fish Department (AZGFD) released a total of 110 desert bighorn sheep in the Pusch Ridge Wilderness Area (PRWA), Arizona,

USA. The PRWA is unique among many designated wilderness areas given its proximity to a major metropolitan area. Bighorn were released into the PRWA in an effort to re-establish a former endemic population that was extirpated in the mid to late 1990's after experiencing rapid population decline. Reasons for the decline are likely multifactorial, however, urbanization and an associated increase in backcountry recreation within the study area have been cited as likely contributing factors (Harris et al. 1995, Shoenecker and Krausman 2002). Outdoor recreation and backcountry visitor use has increased significantly in recent decades and will likely continue to grow as a result of an increasing global population and technological advance (Hammit et al. 2015). Long term visitor use data of the PRWA is lacking and as a result a detailed comparison of use between current and former conditions within the study area is not possible. It is highly likely, however, that visitor use within the PRWA has increased concomitantly with population growth in the surrounding metropolitan area and is now higher than at the time of the former bighorn population decline. This idea is further corroborated by numerous anecdotal accounts.

Bighorn sheep respond to a variety of anthropogenic influences (Campbell and Remington 1981, Stockwell et al. 1991, Schoenecker and Krausman 2002, Jansen et al. 2006, Keller and Bender 2007). Some populations of bighorn show only limited response or even react favorably to anthropogenic features and human presence (Miller and Smith 1985, Jansen et al. 2007, Longshore et al. 2016) suggesting the potential for habituation. Populations of bighorn subject to infrequent or less predictable human activity are less likely to respond favorably. Human activity may lead to avoidance of needed resources such as waters and natural mineral licks (Campbell and Remington 1981, Keller and

Bender 2007) or avoidance or total abandonment of lambing habitat (Papouchis et al. 2001, Weidmann and Bleich 2014). The effects of hiking appear to have an especially pronounced influence on bighorn vigilance, flight response and spatial distribution (Longshore et al. 2013, Weidmann and Bleich 2014). The elevated response to hiking is likely due in part to a lack of predictability associated with off trail use. These effects may be mitigated, however, when recurring human activity is patterned (Papouchis et al. 2001, Weidmann and Bleich 2014).

Understanding the dynamics of human wildlife interactions bears consequence for both management action and continued ecological study. Despite attempts to mitigate the potential effects of human recreation through management action many of the anthropogenic factors present during the decline of the former PRWA bighorn population still persist. We chose to measure the behavioral responses of desert bighorn sheep as a means to examine (1) if or how bighorn respond to the presence of human activity (2) the level of use at which these responses manifest (3) the scale at which these responses may be measured (4) the potential costs that may be associated with tradeoffs derived from a given behavioral response.

STUDY AREA

Our study site was located within the PRWA located on the southwest side of the Santa Catalina Mountain range of the Coronado National Forest, Arizona, USA. The study site is bordered by the cities of Tucson and Oro Valley to the south and west respectively. In many instances the border of the PRWA itself serves as the boundary between the Coronado National Forest and adjacent residential property of both

municipalities. Elevation in the study area ranges from 854m in the lowland bajadas to 2212 m at the peak of Mt. Kimball. deVos (1983) characterized 8 distinct vegetative communities within the PRWA comprised of three primary ecotones as classified by Brown et al. (1979): Sonoran desert scrub, semi desert grassland and Madrean evergreen woodland. Water availability is highly seasonal and characterized primarily by disjointed ephemeral pools in the larger canyons, small springs, seeps and tinajas throughout. There are multiple check dams and three artificial water sources found within the study area, however, all check dams visited were silted in and only one artificial water source remains functional. Topography varies from mild and undulating draws and ridges of the lowland bajadas to extreme slopes and rugged granitic cliffs and rock spires on Pusch Ridge itself. The study area is dissected by six primary US Forest Service (USFS) trails (Linda Vista/Pusch Peak, Pima Canyon, Finger Rock Canyon, Pontatoc Canyon, Pontatoc Ridge and Ventana Canyon trails). Multiple non-designated or “wildcat” trails are also found throughout.

METHODS

Measurement of Bighorn Activity

I conducted a total of 125 behavioral observations of desert bighorn sheep from February 2015 through May of 2016. All bighorn observations were conducted on a population recently translocated by the Arizona Game and Fish Department in into the PRWA. Bighorn were located via visual scan using binoculars and/or spotting scopes. Visual scans were either (1) deliberate and conducted from a predesignated observation point (OPs) or (2) opportunistic when conducted from any location besides a designated

OP within the study area. I established a total of 10 peripheral and 39 trail OPs ($n=49$) to scan for bighorn. Peripheral OPs were typically located within an urban/suburban setting and designed to allow the observer to locate bighorn that were visible from outside the study area. Peripheral OPs accounted for the majority (57.6%) of bighorn detections. Trail OPs were spaced roughly every 500m on four of the six primary trails (Linda Vista/Pusch Peak, Pima Canyon, Finger Rock and Pontatoc Ridge) within the study site. Pontatoc Canyon trail occupied much of the same viewshed as Pontatoc Ridge trail and was surveyed concurrently from one set of OPs. Bighorn use of Ventana Canyon was highly infrequent and thus no trail OPs were established on this trail. The number of trail OPs ranged from 6 (Pontatoc Ridge) to 14 (Pima Canyon) per trail. We conducted visual scans from trail OPs in succession as we walked each trail as a transect. Visual scans were not conducted from trail OP's on return trips down trail. Trail OPs were visited no less than once monthly in conjunction with routine camera maintenance. Observations from trail OPs accounted for the next highest detection rate of bighorn (22.4%). Opportunistic visual scans at random sites accounted for the remaining (20.0%) observations.

Of the 110 bighorn released by AZGFD into the PRWA 95 were equipped with Lotek Globalstar or Iridium satellite GPS/VHF collars (Lotek Wireless Inc., Newmarket, Ontario, Canada). All collars were scheduled to download a GPS position four times daily (0000, 0600, 1200 and 1800 hours) although true transmission varied by individual collar. GPS collar positions and/or VHF telemetry were used infrequently to locate individuals to minimize bias associated with visual scans. GPS collar positions were used a total of three times (2.4%) to locate bighorn within the study area. These were

individuals that (1) had either not been located after multiple attempts by standard visual scan only or (2) were suspected to occupy remote regions of the study area where detection by standard visual scan would likely be unsuccessful. VHF assisted detections accounted for 11 (8.8%) of the total behavioral observations and were conducted only after a behavioral observation was completed or a viewshed was scanned and no bighorn were detected. If a VHF scan revealed the presence bighorn in a viewshed that had otherwise been undetected a subsequent visual scan was conducted with the assistance of the VHF telemetry to locate the undocumented group(s).

Observations consisted of individual scans of all known bighorn within a group at a 3-5 minute interval depending on group size. Standard observations lasted 60 minutes but ranged from 8 to 129 minutes (mean: 56 minutes). The observer would terminate an observation if all individuals in the group remained out of sight for >3 observation intervals. Several (11.2%) observations were conducted beyond the standard 60 minute time frame, this was done when visibility was sporadic or there was continued direct interaction between recreationists and bighorn observed. We similarly avoided conducting multiple observations on the same group of bighorn within a 48hour period. Exceptions were made when there was a high degree of interaction between recreationists and bighorn observed. These repeat observations were infrequent and accounted for only six (4.8%) of the total observations recorded.

Bighorn observations were classified using a CyberTracker database (CyberTracker Conservation, Louis Liebenberg, Cape Town, South Africa) to record behavior, group composition, location, slope, distance from observer, bearing, weather and a basic habitat description. We used a Newcon Optik LRB 3000PRO (Newcon

International Ltd, Toronto, Ontario, Canada) long range (3,000m) laser rangefinder with built in compass to obtain distance (m), bearing and slope from the observer to each bighorn group observed. Average observation distance was 1,257m with a range of 98 to 3789m (Fig. 1). Observations >2km occurred infrequently (7.2%) and were conducted only when air distortion was minimal, weather conditions were clear and bighorn were unobstructed. When possible the observer tried to close the distance of an observation to within 1500m. The distance, bearing and slope for each bighorn position were plotted against the observers location (UTM, WGS84) to approximate the geographic location for spatial reference. Once a bighorn location was obtained we cross referenced the position using Google Earth as a way to verify the accuracy of each spatial point. The highly variable terrain features of the study area made it possible to accurately relate bighorn positions to distinct landmarks (cliffs, spires, boulders or isolated patches of vegetation) recorded while the observation was being conducted. This approach was used as a way to validate each bighorn location before it was incorporated into our spatial analysis.

We developed a set of hierarchal behavioral codes (Appendix A.) to describe the following seven characteristics of an observation: individual ID, sex and age, class of ram, individual position within the group, lighting, posture and key behaviors. Of bighorn groups observed the majority (50.4%) were composed of all female (ewe) or female and juveniles (lamb), mixed groups of both female and male (ram) were the next most common (40.0%). Observation of male only (bachelor) groups were observed most infrequently (9.6%). Animal posture relates strongly to exhibition of key behaviors and can itself be an indicator of behavioral response. We classified four primary postures:

standing, walking, running or bedded. Key behavior codes were used to further examine fine scale variation in bighorn activity that may manifest in response to changes in the intensity or location of human activity. Key behaviors were classified as: vigilant, vigilant towards observer, grazing, browsing, drinking, fighting, mating, licking, nursing, ruminating, Flehman response and exhibiting no observable behavior. Individuals of a group that were obscured or out of sight were also documented, however, these classifications were omitted from our final models.

A combination of posture and key behavior were used to account for the total breadth (100%) of a bighorns observable activity budget. Classification of key behaviors in our models was exclusive and no two key behaviors were represented within the same model with the exception of foraging which we combined the frequency of observed grazing and browsing to examine the cumulative nutritional response. We pooled posture and key behaviors to develop our seven primary responses. We considered each response hierarchically where the most representative behavior from either category was selected preferentially and quantified accordingly. The seven response variables used within our models are as follows:

Grazing: visibly foraging with head below shoulder height. Grazing was not exclusive to standing as grazing was observed while bighorn were bedded.

Grazing was not exclusive from moving but was categorized hierarchically e.g. walking and grazing was classified grazing.

Browsing: visibly foraging with head above shoulder height. Browsing was not exclusive to standing as browsing was observed while bighorn were bedded.

Browsing was not exclusive from moving but was categorized hierarchically e.g. walking and browsing is classified browsing. *Classification of both grazing and browsing was determined solely as a product of head posture to assess fine scale variation in the perception of risk and was not related to forage use and species consumed.

Vigilant: included both routine and induced vigilance as defined by Blanchard and Fritz (2007) as well as instances of vigilance towards the observer (<1.0%).

Vigilance occurred both while standing and bedded but is exclusive of moving as true routine and induced vigilance cannot be expressed while an individual is in motion.

Moving: occurrence of individuals walking or running. Exclusive of bedded, standing and vigilant and does not include foraging behavior as stated above as foraging was quantified preferentially. Accounts for individuals in motion that express no other observable behavior.

Bedded: occurrence of individuals bedded. Exclusive from moving and standing and did not include limited instances of grazing or browsing as quantified above e.g. bedded and grazing was grazing.

Standing: exclusive of all other bighorn behavior (grazing, browsing, vigilant, moving, bedded and other), standing implies an individual is standing but exhibiting no other observable behavior.

Other: remaining behaviors observed but that occurred at a frequency low enough to lack biological significance as a single quantified response (fighting, mating,

licking, nursing, panting, Flehman response and ruminating). Other accounts for all remaining bighorn behaviors that make up an observable activity budget. It is important to note that ruminating occurred at a higher relative frequency than remaining behaviors in other, however, given the potential for both type I and type II error associated with classifying ruminating at a distance beyond 1,250m we opted to include only verifiable occurrences of ruminating in the other category and failed to include instances that otherwise may have occurred. For this reason the metric for ruminating likely underrepresents the true frequency of rumination in the population.

**Foraging*: included as a behavior that encompassed the occurrence of both grazing and browsing as a single response variable and not quantified as a separate class of activity.

Our models examined the behavioral responses cumulatively for adult females only. Final models considered the response of females only (55.3%) given (1) the biological significance and implications of the female population on recruitment and associated population growth (2) female ungulates are likely to be more responsive to perceived risk than are males (Creel and Winnie 2005, Winnie and Creel 2007). Lambs may mimic group behavior and/or exhibit higher rates of vigilance and movement independent of a perceived risk which may in turn lead to an inflated estimate of potential disturbance responses for this reason the behavior of lambs (23.2%) was omitted from our final models.

Measurement of Visitor Use and Environmental Factors

We measured visitor use of the PRWA from December 2014 to May 2016 on all six of the primary trails in the study area using motion activated cameras ($n=15$) (Bushnell Trophy Cam, Bushnell Corporation, Overland Park, Kansas, USA). Three cameras were placed per trail with the exception of Pontatoc Ridge and Pontatoc Canyon where both trails could be adequately monitored using a combination of three cameras total ($n=3$). Camera sites were located near ($\pm 500\text{m}$) the beginning, mid-point and terminus of each trail. Intensity of human use is likely to decline as a function of total distance from each trail head. Using three cameras per trail allowed us to quantify dynamic visitor use as a gradient at multiple spatial points over the length of each trail observed. Each primary trail contained at least one destination area that was located on or easily accessible by the trail itself. Destination areas included overlooks, summits, geologic or water features or other points of interest that may be accessed disproportionately by recreationists (Hammit et al. 2015). Cameras were placed independently of destination areas found on each trail in order to obtain an unbiased estimate of visitor use at each site. All cameras were placed $\sim 70\text{cm}$ above trail height at a bearing between $350\text{-}10^\circ$ to minimize solar exposure and false triggers derived from glare. Each camera captured a three photo burst at an interval of three seconds. The three photo bursts every three seconds was used to ensure larger groups of recreationists were accurately documented. Cameras ran 24 hours daily over the length of the study.

We used the R package Geosphere to determine the nearest camera site to each bighorn observation location. In instances where the nearest camera failed to collect visitor use data for reasons other than no activity (e.g. batteries dead, card full, camera

malfunction) we substituted visitor use data for the next nearest camera site, this occurred for 21 (16.8%) observation days. Responses to real time human interaction by bighorn are likely to manifest differently than a response to long term predictable patterns of visitor use. We developed a real time visitor use metric for each bighorn observation as a product of total human activity at the nearest camera site over a six hour block. Each block was sampled five hours in advance and the hour of each bighorn observation. This method allowed us to quantify the intensity of human activity at the nearest camera site associated with each observation. To limit the potential for over estimating human activity as a product of the three photo burst we subsampled the visitor use data further to account only for total use occurring at a given camera site every for every other five minute interval. We did not differentiate between hikers moving up or down trail. As a result there was potential to count the same party multiple times as they walked up and then back down the trail. Therefore the visitor use metric was a function of total human activity at a site and not a product of total visitor groups documented. Human activity ranged from 0 to 95 recreationists over a six hour block.

Bighorn often select for steep and rugged terrain or *escape terrain* that is used both as a vantage point and a means of predator avoidance (McKinney et al. 2003, Sappington et al. 2007). We incorporated bighorn proximity to escape terrain within our study area as a predictive variable by examining the relationship of each bighorn group location as a product of distance from a minimum value of ruggedness. Distance to rugged terrain was used to measure the strength of the association with potential escape terrain so as to provided a more variable measure than the value of ruggedness at a single bighorn location. Ruggedness values assigned to a single spatial point account for only

the value of that point and will thereby underrepresent the association with proximal escape terrain a bighorn is otherwise selecting for. We used the SAGA-GIS (SAGA-GIS v2.2.5) Morphometry Module Terrain Ruggedness Index (TRI) to render a digital elevation map (DEM) of the study area. We developed a geographic information system (GIS) using ArcMap (10.3.1) to generate the TRI as points in a raster related each bighorn group position using the Nearest List Spatial Analyst Tool. Bighorn distance to trail and distance to nearest camera analysis was performed using the R package Geosphere. We used the (DEM) of the study area at a pixel resolution of 10x10m using ArcMap (10.3.1). Ruggedness was defined by the net difference in elevation from the center 10m pixel and that of the surrounding eight pixels (Riley et al. 1999). A rugged value indicates no change in elevation between any of the nine pixels. Our value of ruggedness was selected to maximize the amount of variation associated with observed bighorn group distribution in the study area. Bighorn distance from the nearest rugged pixel ≥ 6 m elevation change ranged from 0 to 297.3m (mean=46.5m).

We used the mean enhanced vegetation index value (EVI) associated with each bighorn detection to index seasonal variation in forage availability (Pettorelli et al. 2005, Hamel et al. 2009). The EVI value provides a coarse measure of forage availability that may affect bighorn movement and forage time. Temperature can affect intensity of both bighorn and human activity and was therefore incorporated into our models. Temperature was recorded at the beginning and end of each observation using a Kestrel handheld unit. Given the potential for group size effects on bighorn behavior we incorporated total observed group size as a final covariate in our models (Fig. 2)

Analysis

My models analyzed the behavioral responses of female only groups against six distinct independent variables. Independent variables measured variation in short term human activity and related environmental covariates as well as responses to longer term human use patterns and seasonal variation..

I developed a series of generalized linear models (GLM) to examine the mean response of each of the seven dependent variables against the combined effects of the six anthropogenic and environmental covariates selected. GLMs were fit using `glm` function of the `base stats` package in R. All models incorporated dual metrics for measuring response to variation in human activity over temporal scales(log visitor counts at nearest camera) and spatial scales(log distance to the nearest recreational trail). Each model estimated the effects of the independent variables against the mean of only a single response variable with the exception of our *forage* model which incorporated the estimates of both grazing and browsing as a single behavior. Models were fit with assuming a quasi-binomial distribution of the errors. Independent variables were scaled prior to model fitting to allow for a direct comparison of model coefficients. We used 95% Bonferroni simultaneous confidence interval derived from the `qt` function of the `base stats` package in R to represent the standard deviation of the cumulative interactions of the predictor variables on the expected values associated with each of the seven responses in female only models.

RESULTS

Our approach examined potential tradeoffs in the behavioral responses that comprise the total activity budget of bighorn sheep. A total of 35,604 individual behavioral codes were assigned for 2095 individual observations for the 125 groups observed. On average adult females spent the majority of their time foraging (35.8%), however, when considered separately females spent more time grazing (26.2%) over browsing (9.6%). Bedding was observed at the next highest frequency (26.4%) followed by moving (15.0%), vigilance (12.7%), standing (8.8%). All other behaviors accounted for the remaining measurable activity (1.3%) (Fig. 3).

Our results indicate that the bighorn of PRWA modify their behavior in response to changes in human activity. Bighorn significantly reduced the mean time spent grazing in response to increased human activity (Est=-0.281, SE=0.104, $t=-2.705$, $P=0.008$) (Fig. 4). We observed no measurable relationship between mean vigilance and the changes of human activity (Est=-0.123, SE=0.120, $t=-1.030$, $P=0.305$) (Fig. 5) although vigilance did decrease as a product of increased group size (Est=-0.265, SE=0.116, $t=-2.293$, $P=0.023$) (Fig. 6) consistent with group size effects documented in other gregarious ungulates. The mean time female bighorn spent bedded correlated positively with increased human activity (Est= 0.302, SE=0.138, $t=2.197$, $P=0.030$). Interestingly browsing was less responsive to our predictors and did not respond significantly to changes in human activity (Est=0.131, SE=0.139, $t=0.941$, $P=0.348$). The relationship between the mean browse time and human activity is positive and while not statistically significant, the effect size of the coefficient is large enough to suggest low power may be resulting in a Type II error. Mean time spent moving, standing or exhibiting other

behaviors did not respond significantly to changes in human activity (Table 1). We observed no significant effects of female bighorn distance from trail in any of the models run.

DISCUSSION

Our results suggest bighorn sheep of the PRWA modify their behavior in response to changes in the intensity of human activity as a potential means to limit interaction based on assessment of risk. Changes in vigilance are often used as a metric to examine the perception of risk in ungulates (Lima and Dill 1990). Bighorn within the PRWA, however, exhibited no measurable response in mean vigilance related to changes in human activity or proximity to trail as we might have expected if directly influenced by the presence of people. Instead bighorn responded to increased human activity by bedding. Bedding likely decreases the potential for both detection or interaction with humans and would be a more energetically conservative approach to avoidance that may be exhibited in part due the predictable nature of concentrated visitor use on established trails.

Long term visitor use data of the PRWA is limited. A study of the former population of bighorn sheep by Schoenecker and Krausman (2002) found 18% of visitors observed engaged in off trail use between 1994 and 1996. In contrast we documented roughly 1.5% off trail use from January 2015-May 2016 suggesting current human use of the PRWA may be largely confined to established trails. In a similar study Papouchis et al. (2001) found bighorn flight response in Zion National Park (ZNP) increased in response to more stochastic human activity such as off trail hiking while bighorn subject

to high levels of predictable human use in ZNP showed little behavioral response. Prior management action by the USFS Coronado Ranger District focused on restricting human activity in the PRWA both spatially and temporally in an effort to reduce human interaction with bighorn sheep. As a result many non-designated trails were actively removed, domestic dogs (*Canis lupes familiaris*) were prohibited and seasonal off trail restrictions were put in place during lambing season (January 1-April 31). We speculate that the effects of urbanization around the PRWA may have also inadvertently restricted visitor use to established trails by limiting non-designated access points around the base of the study area that were present during the former population.

While bedding may offer an energetically efficient means of avoidance we documented a significant reduction in nutrient consumption as a product of a decrease in time spent grazing (Fig. 7). The mean time bighorn spent bedded is roughly inversely proportional to the reduction in grazing time observed in response to increased human activity. Our models indicate a roughly 30% decrease in mean grazing time from periods of low human use (i.e. no activity) to high use (activity >90 hikers). This decrease in grazing may suggest the potential for nutritional costs if bighorn are unable to compensate for nutritional loss in other ways. Interestingly the presence of only a single hiker accounts for roughly 50% of the entire change in activity for both grazing and bedding suggesting that while the intensity of human activity is an important metric, the mere presence or absence of people on the trail likely has the largest impact on bighorn response.

By contrast browsing responded positively to increased human activity in our models and while this correlation did not bear statistical significance the effect size of the

coefficient does suggest some biological significance indicative of more fine scale differentiation in foraging strategy (Fig. 8). Differentiation of forage strategy may be attributable to the assessment of risk associated with differences in head posture between grazing and browsing. Typical behavioral studies often consider vigilance or head up posture as a response to predation risk but may fail to examine the head up posture associated with increased time browsing as a potential fine scale response. Grazing as defined requires an individual to lower its head below shoulder level, a position often associated with increased vulnerability (FitzGibbon 1989, Krause and Godin 1996). By contrast, browsing is conducted with the head at or above shoulder level and may therefore increase when perceived risk is higher (Berger 1977). Bighorn sheep can be classified as mixed feeders that utilize both graze and browse species though our measure of time grazing (73.18%) was found to be disproportionate to that of browsing (26.82%) in the bighorn of the PRWA. There is potential for additional dietary costs associated with selection lower quality forage as a response to risk. Browse plant species are typically higher in lignin and cell content which may make metabolizing such material less efficient for non-browsing specialists such as bighorn sheep (Gordon 1989, Sanson 2002), however, this idea warrants further study before potential for nutritional costs associated with a change in forage strategy are considered.

Our measured reduction in mean grazing time indicates the strong potential for nutritional costs associated with changes in bighorn behavior that could in turn affect individual physiology by limiting nutrient intake. Unknown, however, are the potential compensatory mechanisms by which bighorn may make up for a reduction in forage time. It is possible for example that bighorn diversify foraging temporally and thereby redeem

any nutritional losses incurred during peak periods of human activity. Behavioral analysis allows for real time examination of responses to human activity but can fail to account for longer term coarse scale changes that may act to buffer potential costs of short term avoidance strategies. This dilemma highlights the need for comprehensive research methodologies that consider the implications of each sub-component of wildlife response rather than a focus on the speculation of potential costs based off behavioral observation alone.

Management Implications

Continued increases in the frequency and diversity of back country recreation are likely to pose challenges to both wildlife and the agencies that manage them. Our results indicate bighorn sheep experience behavioral tradeoffs in response to changes in human activity. Though we are unable to speculate as to the potential costs attributed to these tradeoffs managers should bear in mind that any increase in human interaction will likely act to exacerbate any true costs that may exist and should therefore be wary of practices that increase the potential for human wildlife interaction. Concentration of recreational use may minimize the effects of human activity on wildlife. Seasonal prohibitions of visitor use from sensitive areas might also minimize impacts of human activity. In regions subject to high levels of human activity such as the PRWA managers should work to develop a detailed understanding of the type, frequency and intensity of visitor activities, while also continuing to quantify possible behavioral responses and their demographic consequences in wildlife, to develop recreational management policies that complement wildlife conservation measures.

Conclusions

The purpose of this study was to examine the ways in which wildlife respond to changes in human activity. To do this we observed the interactions of backcountry recreationists and desert bighorn sheep. We wanted to first understand how bighorn may modify their behavioral in response to changes in the levels of human activity. Our results suggest that bighorn respond to perceived risk by decreasing time they spend active. As a result bighorn tend to bed more and forage less when human use is higher. In studying bighorn behavior we also wanted to examine the scale on which behavioral responses may manifest. We found act of bedding may demonstrate a more passive means by which bighorn may limit the potential for human interaction and thereby avoid risk. We also found that bighorn tend to browse more in response to increased human activity. Though the relationship with browsing is not strong it is suggestive of potential fine scale variation associated with forage strategy and head posture. Given the tradeoffs associated with risk assessment we wanted to use the measured behavioral responses of bighorn sheep to highlight any potential costs that may have implications for physiology, individual survival or recruitment and overall population dynamics. There may be nutritional costs connected to both a reduction in forage time or selection of lower quality forage through increased browsing that when sustained could have effects on individual physiology. It is unclear, however, if bighorn recoup a loss in nutrients by foraging more when human activity is lower. Further study is thereby needed to examine (1) how bighorn might redeem nutritional costs through compensatory behavior and (2) what are the potential consequences associated with a significant reduction in forage time if bighorn do not redeem nutritional losses. Further study will fill in existing gaps and inform

the next steps in our understanding of the mechanisms that govern wildlife population dynamics.

Table 1. Modeled coefficients of mean female responses to human activity.

Table does not include output for *Other* category of behavior.

Mean Female Response to Human Activity				
Variable	Estimate	Std. Error	t value	P value
Grazing	-0.281	0.104	-2.705	*0.008
Browsing	0.131	0.139	0.941	0.348
Vigilance	-0.123	0.120	-0.247	0.305
Bedding	0.302	0.137	2.197	*0.030
Moving	-0.116	0.142	-0.811	0.419
Standing	0.008	0.109	0.074	0.941

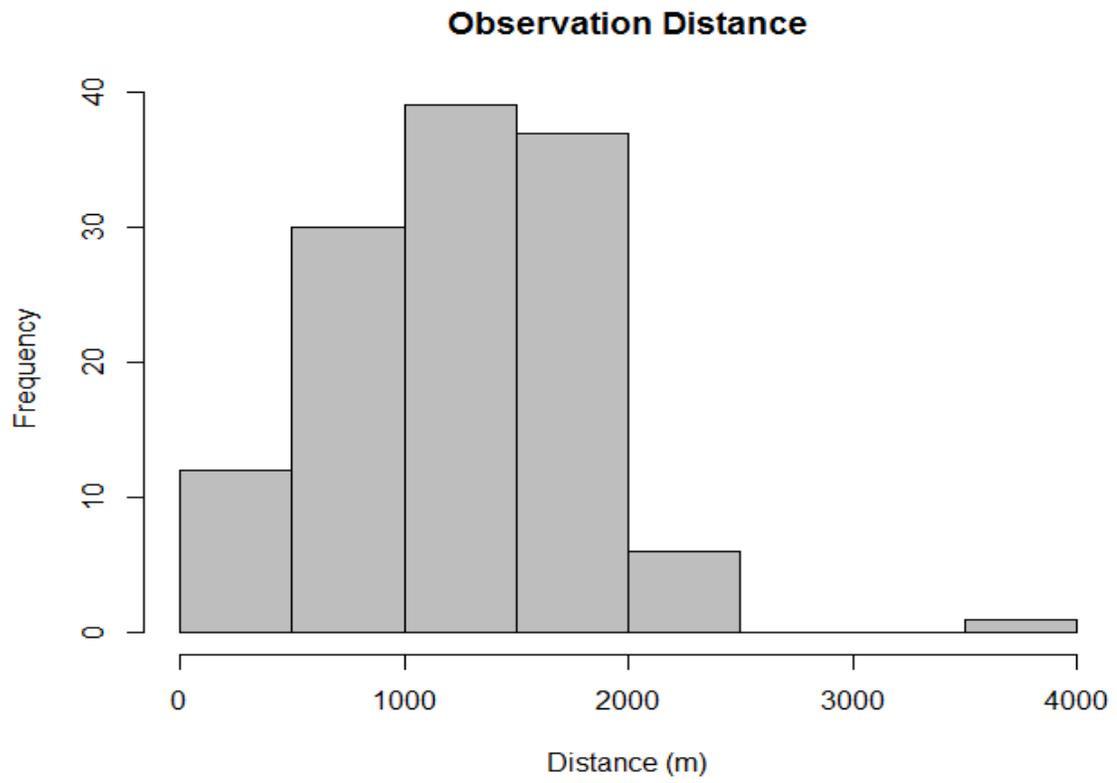
Figure 1.

Figure 2.

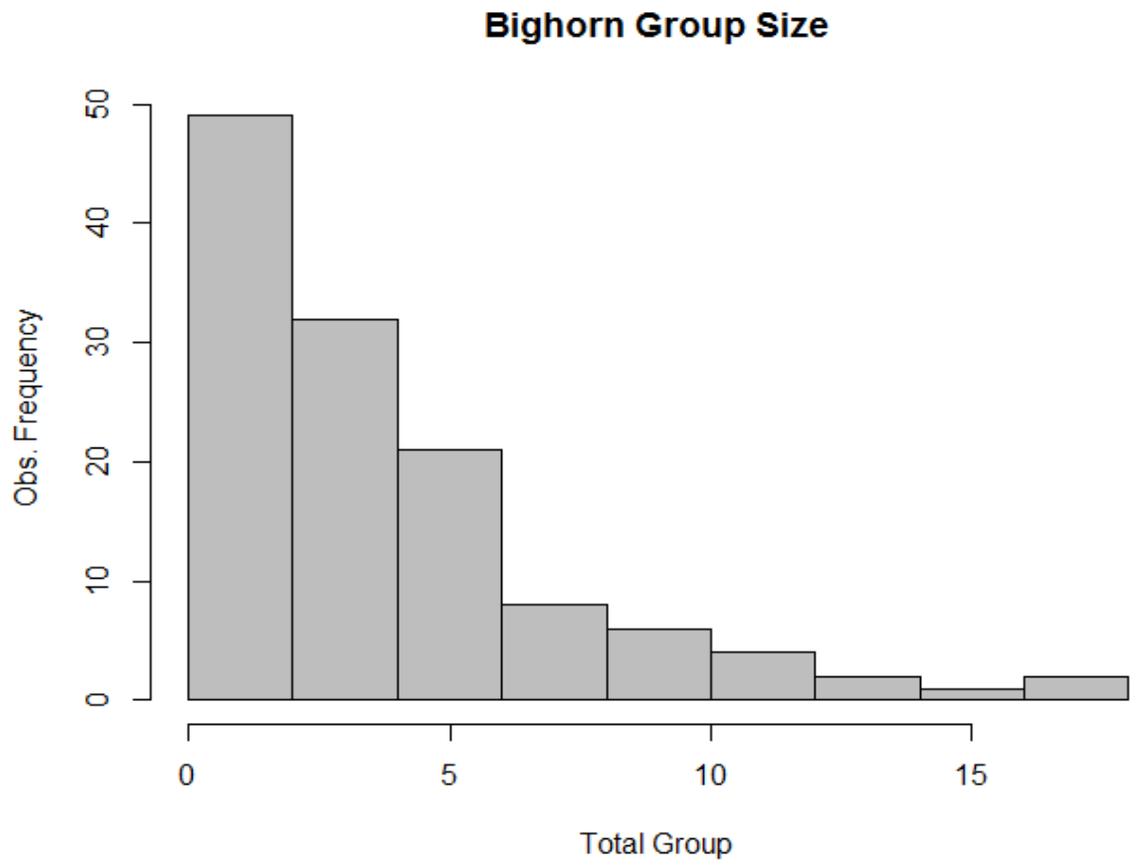


Figure 3.

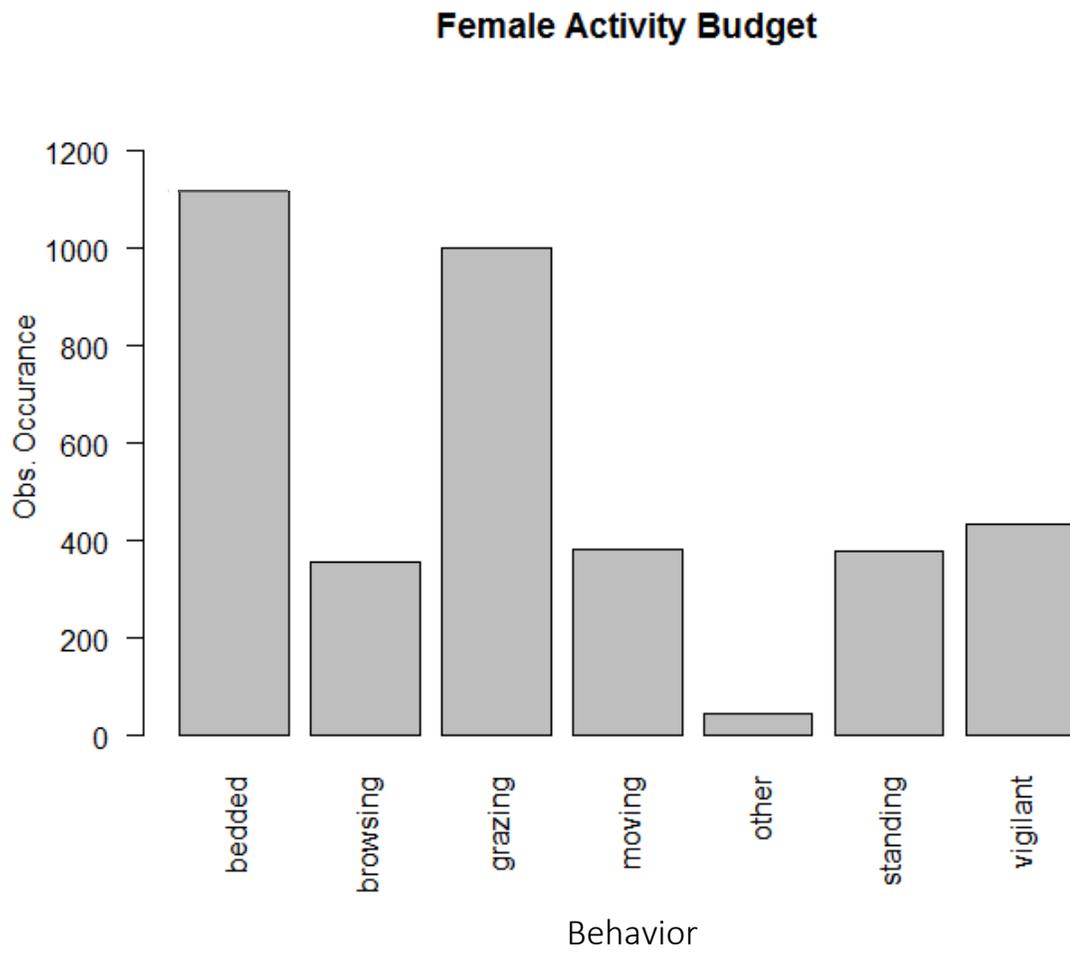


Figure 4.

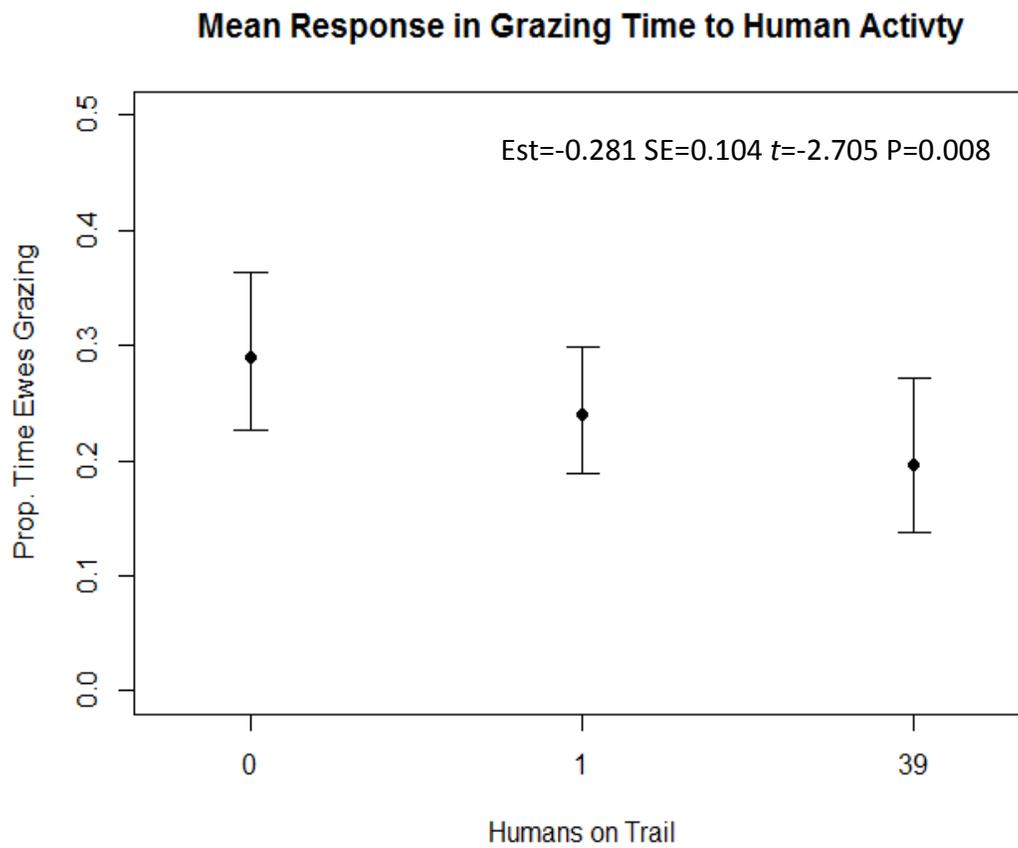


Figure 5.

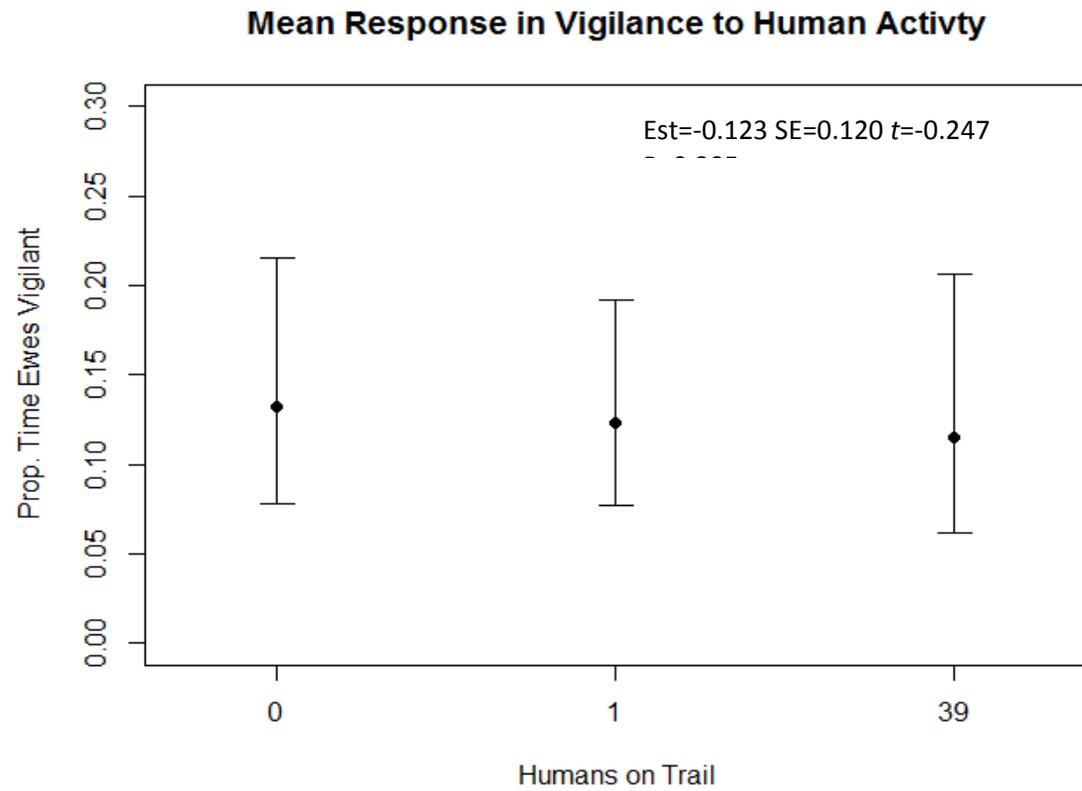


Figure 6.

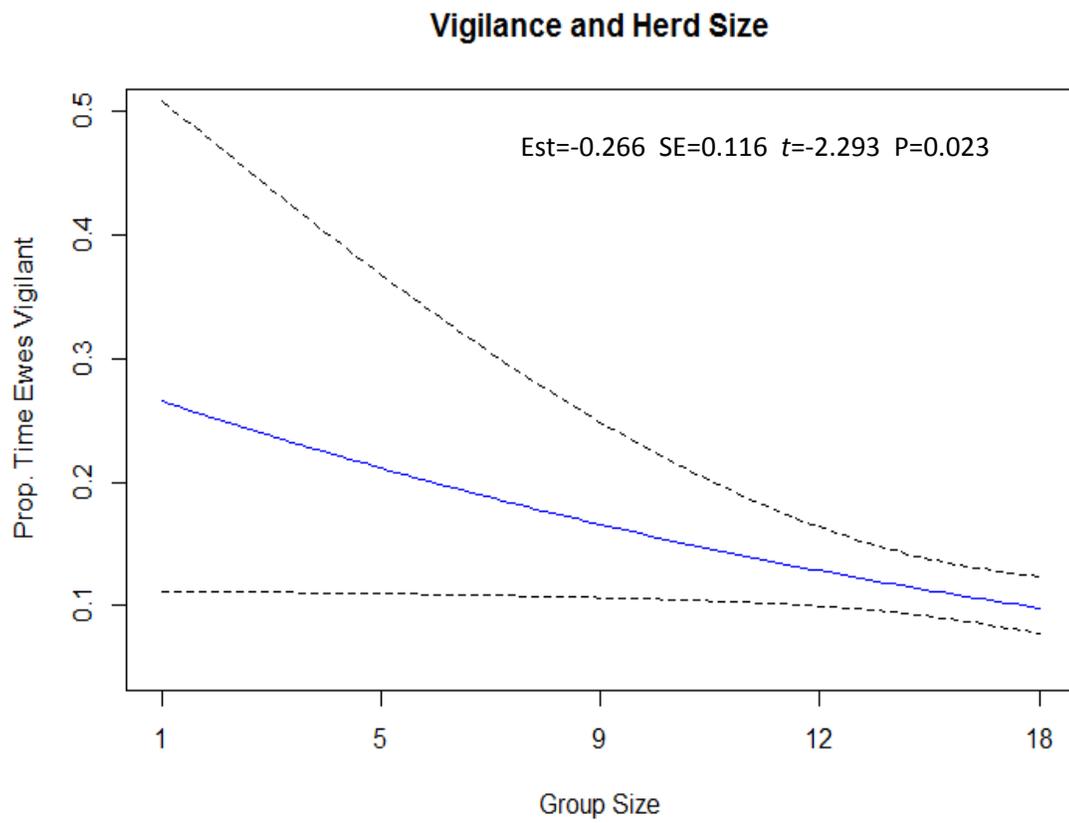


Figure 7.

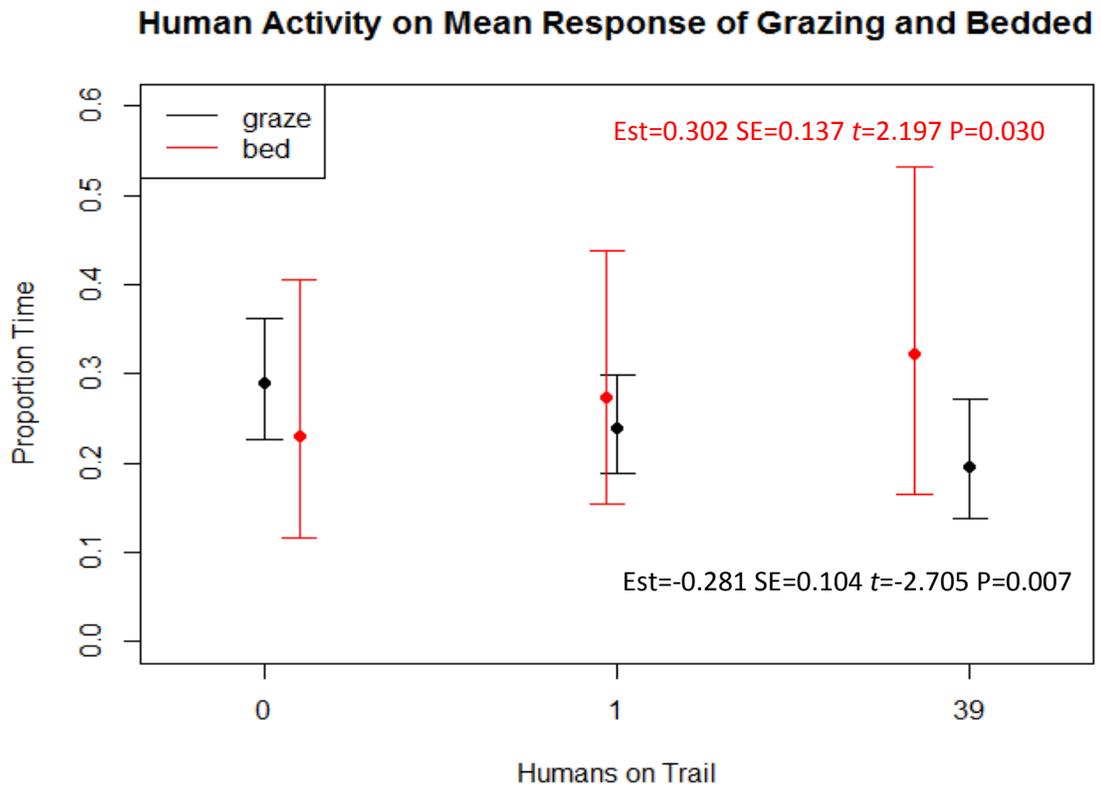


Figure 8.

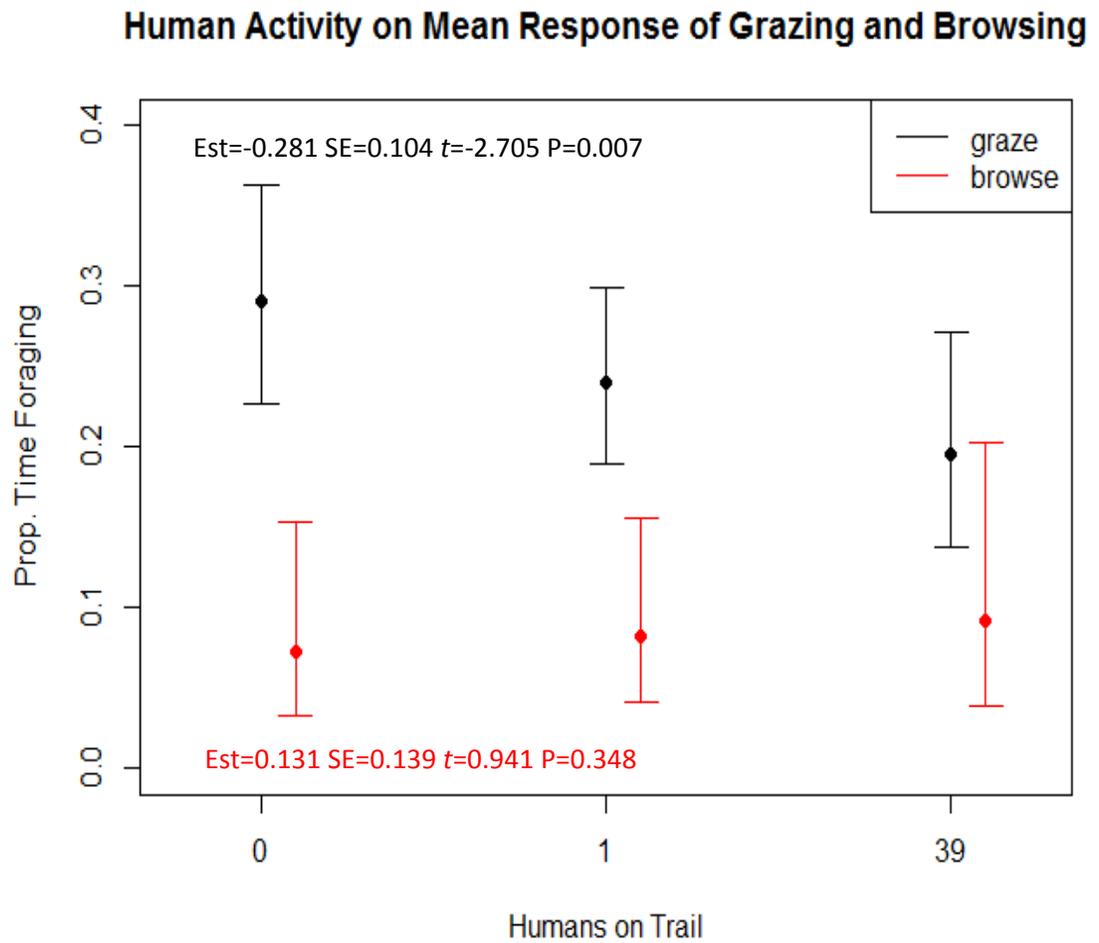


Figure 9. Behavioral code reference sheet used to categorize and quantify bighorn behavior.

T-M-3-E-L-S-Gr

1. Marked	2. Age/Sex	3. Class (Ram only)	4. Herd Position	5. Shading	6. Posture	7. Key Behaviors
U (unmarked)	Y (young)	1	E (exterior)**	L (direct sun)	S (standing)	Vi (vigilant)
C (collared)	A (adult, unknown sex)	2	I (interior)	D (in shade)	W (walking)	Vm (vigilant towards observer)
T (ear tagged)*	M (adult male)	3		O (no shadow b/c dawn, dusk or clouds)	R (running)	Ru (ruminating)
	F (adult female)	4			B (bedded)	Pa (panting or out of breath)
	Z (unknown age and sex)	Q (?/unknown)				Gr (grazing, head down foraging)
		Na (ewe, lamb or juvenile)				Br (browsing, head level or up)
						Dr (drinking)
						Fi (fighting)
						Nu (nursing, mother or fawn)
						Ma (mating)
						Li (licking, grooming or scratching)
						Fr (Flehmen response [see back])
						OS (out of sight)**
						NO (no other behaviors)****

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