

**Geospatial movement patterns of yellow-bellied
marmots, *Marmota flaviventris*, and their behavioral
responses to path obstructions**

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ABSTRACT: Yellow-bellied marmots, *Marmota flaviventris*, follow defined runs in moving from one habitat feature to another. In human impacted areas, these paths are regularly disrupted by eroding and shifting rocks or discarded human refuse. To test the response of marmots to this type of habitat disruption, rocks and scrap metal were experimentally placed in marmot runs and their response behaviors were recorded. Marmots deviated more from paths when they were blocked by scrap metal than when they were blocked by rocks or not blocked at all. All but three responses showed that marmots navigated around scrap metal rather than over it. In the three exceptions, marmots traveled around the metal at first, and then, the behavior of all marmots in the sets switches at once and they begin to navigate over the scrap metal instead. Upon further statistical testing, it was concluded that the switch of all marmots' behavior at once was likely the result of one marmot learning to go over the object and the rest of the marmots simply imitating that behavior.

INTRODUCTION

Marmota flaviventris, yellow-bellied marmots are ground-dwelling Sciurid rodents, feeding mainly on green grasses and forbs, and constructing burrows and dens within talus fields (Armitage 1991). Colonies of these marmots can occupy ranges of over 7 hectares, and can grow to more than 20 individuals consisting of one breeding male, females, newborns, and yearlings (Ozgul et al 2006). Marmots spend approximately 78% of a 24-hour day in their burrow, 10% of the day perching, and 12% of the day foraging and moving (Armitage 1991). Marmots have a wide variety of predators, including badgers, coyotes, and other larger carnivores, and thus must be able to escape to safety in their habitat if a threat of predation should arise (Armitage 2004, Blumstein and Pelletier 2005, Runyan and Blumstein 2004). For this reason, along with a necessity to forage as optimally as possible, marmots utilize defined runs to get from point to point in their patchy and open habitats (Ozgul et al. 2006, Griffin et al. 2009, Borrego et al. 2009), similar to the way in which other rodents, such as voles, use defined runs through grasslands (Hanson 1979, Harper and Batzli 1996, Dolby 2001).

Additionally, marmots are able to live in and around areas with human disturbance, including rock falls caused by high use of rock and gravel roads above burrows (Griffin et al. 2007).

Given their propensity toward following defined runs, how would marmots alter their movement patterns in response to blockages presented by manmade disturbances on these runs? I hypothesized that marmots would deviate more from a designated path than expected when presented with an obstacle. Furthermore, would marmots respond differently to a natural blockage versus an artificial one, given the substrate through which the run is routed? I hypothesized that in a route over a rocky substrate, a marmot would walk over a natural rock obstruction, whereas in a grass route, a marmot would most like re-route its run around a natural rock obstruction. I also hypothesized that given a novel, artificial blockage, marmots would walk around the blockage or avoid it altogether, given uncertainty of the nature and origin of the object.

MATERIALS & METHODS

Range Mapping

After discussion with local residents concerning existing marmot populations within the region, the Moiese Hill marmot population was located on June 30, 2009. On the following day, a home range estimate was obtained for the population through basic fecal deposit survey methods. After three days of initial observations to determine baseline activity levels, timing of activity, and relative path usage, gridding began. From July 3 to July 5, 2009, low resolution gridding was conducted over the entire range of marmot activity, determined from the earlier baseline observations. Because of the

aspect and curvature of the hill on which the population's habitat was located, the range was originally broken into three sites, only two of which were ultimately utilized for this study: site 1, which was oriented on a WSW facing slope, and site 2, which was oriented on a WNW facing slope. The area of site 1 was set at 50m wide across the ridge of the hill, and 40m long, perpendicular to the ridge; the area of site 2 was set at 40m wide across the ridge, and 40m long, perpendicular to the ridge. Both sites were gridded at a 10m by 10m resolution, with necessary scaling of widths due to the curvature of the hill, and the corners of each of the 10m squares were marked with marking spray paint. From July 19 to July 21, 2009, high resolution gridding was conducted around paths which were traveled most frequently. Since it was observed that there were two distinct habitat types in the home range of the population (rocky habitat toward the top of the ridge with greater than 90% ground cover composed of rock; and grass habitat as distance from the ridge of the hill increased with less than 5% of ground cover composed of rocks), high resolution gridding efforts were split equally between rock and grass habitats. Four grids of no greater than 10m by 10m were marked at a 1m resolution in rock habitats, and four grids were marked in grass habitats. Again, corners of each of the 1m squares were marked with marking spray paint. One grid in the rock and one grid in the grass were excluded from analyses because they yielded little to no observations.

Field Observation

Control observations occurred from July 23 to July 25, 2009, with data from July 24 excluded because of rain. Sampling efforts were standardized at 7.5 hours per day, split approximately evenly between morning and evening movement observations. Field observations for control consisted of scan sampling for any moving marmot with

binoculars from a distance of approximately 60m away from the habitat. Once a marmot was observed to be moving, on or around a grid, observation methods switched to a focal follow of that individual. A time of movement, accurate to the minute was recorded when the marmot entered into a high resolution grid and its approximate subsequent movements were recorded until that marmot exited that grid. Since the grids were marked with a 1m resolution, and quarters of the grid could easily be estimated by the observer, resolution of movement observations was 50cm. Also recorded were any relevant actions of the marmot while moving through the grid. All of this data was also collected for the first set of treatments, from July 26 to July 29, 2009.

Treatments consisted of placing an obstacle within the main path used in each grid. This obstacle was placed centrally between the entry and exit points of the path to the grid. In addition to the movement data collected in the control, a time of interaction with the blockage, accurate to the minute was recorded, when applicable, and its action in response to that blockage (e.g. did the marmot go over or around the blockage?).

Randomization of the implement of blockage for each treatment was maintained through assigning numbers 1-6 to sites and blockages, and then running a random sequence generator *via* random.org for the assigned numbers for blockages, and matching up the first number in the sequence to site 1, the second to site 2, *et cetera*.

The two different treatments were the placement of a natural blockage, rock, and the placement of an artificial blockage, scrap metal within a designated path on a grid. With regard to the natural blockages, rocks of approximate sizes ranging from 2500 to 3500 cubic centimeters in volume were taken from outside of the marmot home range, so as to avoid any bias which may have been introduced to interaction by previous marmot

scent marking of rocks. These blockages, since they were present in abundance in the rock habitat, were designated as “familiar” features of the environment, but since rocks of this size were not common in the dead grass habitat, they were designated as “novel” features in the environment. The artificial blockages were obtained from a local scrap pile, with items used including: a fuse box, a car battery box, a bucket, an elbow pipe, the head of a vacuum cleaner, and an old, very small engine. These items all fell within the size ranges of the rocks used in the natural blockage treatment. These blockages, since they were not present in any of the grids, were considered “novel” features of the environment for both the rock and dead grass habitat types.

Objects were introduced to the paths in two blocks of time. The first block ran from July 26 to July 29, 2009 and consisted of a natural blockage being placed for 2 days, and then being replaced for the next 2 days with an artificial blockage. After a one day control period between sampling blocks (blocks is the proper word because statistically this is also what they would be), the second block ran from July 31 to August 3, 2009 and consisted of an artificial blockage being placed for 2 days, and then being replaced for the following 2 days with a natural blockage. This alternation of order was used to control for any possible effect that order may have had on the behavioral response of the marmots. The second set of treatments was used only for data concerning interaction with blockages, due to an insufficient amount of corresponding control observation days.

Analysis

R 2.8.1 was utilized for running all one-way and multiway ANOVAs, as well as subsequent Tukey’s HSD post hoc tests. SYSTAT 10 was utilized for running piecemeal regression models. All chi-square and independent t-tests were manually calculated.

RESULTS

Ethographic Narrative

The marmots were found to live in a habitat of high human impact. In this habitat, the rock field used for burrows, interspersed with rebar and other such metal objects, was created to build up an irrigation ditch and road, and the field used for foraging is regularly irrigated. The maximum count of marmots simultaneously active within the range was observed to be 19 individuals; thus total population size, including immatures in dens, was estimated to be greater than 20 individuals. These individuals occupied an estimated home range of 3.325 hectares. Marmots in site 2, with a WNW aspect, were the first to become active in the mornings, usually emerging from burrows approximately one hour after the sun rose over the hill. The marmots in site 1 generally lagged behind those in site 2 by 30 minutes, emerging from burrows approximately one and a half hours after the sun rose over the ridge. This discrepancy was assumed to be due to the orientation of the ridges, with site 2 being the first to receive sunlight, and thus the first to warm up in the morning. The majority of movement in the early morning consisted of perching on top of the ridge and interacting with other marmots in the rock habitat. Toward the late morning, marmots began to move into the dead grass habitat to forage. All activity usually ceased by midday, when the marmots retreated to their burrows, most likely to escape the high heat. Then, movement resumed again in the late afternoon and usually consisted of foraging in the dead grass habitat, with some amount of perching and social interaction in rock habitats occurring. Activity above ground ceased for the day approximately two hours before sunset.

When paths were obstructed with natural blockages, very little attention, if any at all was paid to the blockage. However, when paths were obstructed with artificial blockages, nearly every marmot that passed by the scrap metal would spend at least some time inspecting the item, regardless of habitat type in which the item was placed. Common reactions to artificial blockages were to circumnavigate the object, to sniff the object, to gnaw the object, and to place forepaws on the object. One instance of urinating on the object was also observed. In the rock habitats, one interesting reaction to artificial blockages was to attempt to dig underneath the object, although this behavior was only rarely observed, and was always abandoned in favor of going around the object instead. The two main responses to navigating the obstacles were to go over or around them.

In the rock habitat type, when presented with a natural blockage, the overwhelming response was to travel over the object, whereas the response in the dead grass to natural blockages was to travel around the object. When presented with an artificial blockage in dead grass habitats, the response was always to travel around the object. The initial response in rock habitats to artificial blockages was also to travel around the object. Although this behavior of traveling around the rock was maintained for the full 15 hours of observation in three of six treatment sets, the other three showed an ultimate response of traveling over the rock instead of around it. For each of these three sets in which the marmots eventually went over artificial blockages, the pattern was the same: one marmot decides to travel over the obstacle, and another marmot observes this occurrence and then also travels over the obstacle until all marmots in that grid traveled over the obstacle rather than around it.

Movement Analyses

In a one-way ANOVA, mean observations of marmot movement per hour were found to be greater within rock habitat-type sites (1.072 observations/hour) than within dead grass habitat-type sites (0.322 observations/hour) [$F_{1, 22} = 16.531$, $p = 0.0005$] (Fig. 1). In a two-way ANOVA, with factors of habitat-type and treatment, mean proportions of designated paths used by marmots within grids were found to differ significantly among treatments [$F_{2, 271} = 11.4505$, $p < 0.0001$], but not between habitat-types [$F_{1, 271} = 1.8544$, $p = 0.1744$], and showed no significant interaction [$F_{2, 271} = 0.1960$, $p = 0.8221$] (Fig. 2). Among treatments in the previous ANOVA, a Tukey's HSD post hoc analysis showed that marmots within a grid used lower proportions of designated paths when their paths were obstructed with artificial blockages (0.297) than when the paths were either obstructed with natural blockages (0.431) [$p = 0.0245$], or not obstructed, in the control (0.535) [$p < 0.0001$]; proportions of designated paths utilized did not differ significantly between instances in which paths were obstructed with natural blockages and instances in which paths were not obstructed [$p = 0.1904$]. In a second two-way ANOVA, also with factors of habitat-type and treatment, mean proportions of designated paths used by marmots initiating movement at either of the entry points of the path into a grid were found to be higher in dead grass habitat-types (0.798) than in rock habitat-types (0.615) [$F_{1, 129} = 9.8210$, $p = 0.0021$], but no significant difference was found among treatments [$F_{2, 129} = 2.1304$, $p = 0.1230$], and results showed no significant interaction [$F_{2, 129} = 0.7654$, $p = 0.4673$] (Fig. 3).

Behavioral Analyses

Chi-square tests were used to compare observed distributions of traveling either over or around artificial blockages with expected distributions generated from the distributions of traveling over and around natural blockages. For all observations, distributions of traveling over and around artificial blockages in dead grass habitats did not differ significantly from expected distributions for dead grass habitats [$X^2_{1,27} = 1.8621, p = 0.1724$], however, individuals traveled over artificial blockages in rock habitats less than expected [$X^2_{1,125} = 364.6919, p < 0.0001$] (Fig. 4). Observations were then divided into those in the first day of treatments and those in the second. For the first day of treatments, distributions of traveling over and around artificial blockages in dead grass habitats did not differ significantly from expected distributions for dead grass habitats [$X^2_{1,9} = 0.5625, p = 0.4535$], however, individuals traveled over artificial blockages in rock habitats less than expected from rock habitat distributions [$X^2_{1,60} = 462.9630, p < 0.0001$] (Fig. 5A). For the second day of treatments, distributions of traveling over and around artificial blockages in dead grass habitats did not differ significantly from expected distributions for dead grass habitats [$X^2_{1,18} = 1.3846, p = 0.2393$], however, individuals still traveled over artificial blockages in rock habitats less than expected from rock habitat distributions [$X^2_{1,65} = 52.9459, p < 0.0001$] (Fig. 5B).

Although results showed that observed distributions did not differ from expected distributions on either treatment day in dead grass habits, and that individuals traveled over artificial blockages less than expected on both treatment days in rock habitats, further chi-square tests were run to determine if distributions on day two differed from expected distributions generated from day one in both habitat types. In dead grass

habitats, observed distributions of traveling over and around artificial blockages on day two did not differ significantly from expected distributions generated from day one [$\chi^2_{1,9} = 0.0000$, $p = 0.9999$], however, in rock habitats, individuals traveled over artificial blockages on day two more than expected from expected distributions generated from day one [$\chi^2_{1,60} = 30.0455$, $p < 0.0001$] (Fig. 5A-B). This result was assumed to be due to the observation that three of the six sets of artificial blockages in rock habitat paths showed an ultimate response of traveling over the blockage, whereas the other three ultimately responded in traveling around the blockage. Thus, six further chi-square tests were used to compare expected distributions for traveling over and around blockages generated from natural blockages in both rock and dead grass habitats with observed distributions in rock habitat sets with an ultimate response of traveling over artificial blockages, rock habitat sets with an ultimate response of traveling around artificial blockages, and all dead grass habitats with artificial blockages. Distributions for both dead grass habitats and rock habitat sets showing an ultimate response of traveling around artificial blockages were shown to not be statistically different from expected distributions generated for dead grass habitats, but the rock habitat sets showing an ultimate response of traveling over artificial blockages were shown to be statistically different from expected distributions generated for both dead grass and rock habitats (Table 1).

Since it was also observed in the course of the study that after one individual traveled over an artificial blockage in rock habitats, other individuals also tended to travel over the artificial blockage, the data for traveling over versus around artificial blockages in all three sets showing an ultimate response of traveling over was graphed against time

and showed two distinct segments (Fig. 6). Thus, piecemeal regressions were run for each of the three rock habitat sets showing ultimate responses of traveling over artificial blockages, with observational hours as the independent variable and number of interactions resulting in traveling around the blockage as the dependent variable. The cutoff point for each of these piecemeal models was set to the time of the last instance of traveling around a blockage, and slopes of best fit lines were calculated for the data on either side of the cutoff point. From the error in these best fit lines, a recalculated inflection point with 95% confidence intervals and asymptotic standard error was generated (Fig. 7A-C). Independent t-tests using recalculated inflection points and asymptotic standard errors showed that there were no significant differences between any of the inflection points (Table 2). The mean inflection point of the three data sets was 9.360 ± 0.298 observation hours.

In a one-way ANOVA testing for further differences between ultimately going over an artificial blockage and ultimately going around, mean time between interactions with artificial obstacles in rock habitats was found to be less in sets showing an ultimate response of traveling around artificial blockages (10.299 minutes) than in those showing an ultimate response of traveling around artificial blockages (15.610 minutes) [$F_{1, 116} = 4.0755$, $p = 0.0458$] (Fig. 8).

DISCUSSION

Results confirmed the observation that marmots used rock grids more often than they did dead grass grids (Fig. 1). This combined with the finding that when starting upon a path in the grass, marmots were more likely to follow that same path than they

were to in rocks (Fig. 3) may show that defined runs in grass are used because they are the fastest means of transportation in an open environment. In the grass, there were very few rocks to run to and hide underneath in the event that a predator should arise. A rock run between those two points may be more preferable because it provides more opportunity for protection from predators. Also, the hypothesis that marmots would deviate more from a designated path than expected when presented with an obstacle, was only partially confirmed, in that marmots followed less of the designated paths when paths were obstructed with artificial blockages, but not when they were obstructed with natural ones (Fig. 2).

The second hypothesis was also partially confirmed. The hypothesis that in a route over a rocky substrate, a marmot would walk over a natural rock obstruction, whereas in a grass route, a marmot would most likely re-route its run around a natural rock obstruction was supported with observations. Also, the hypothesis that given a novel, artificial blockage, marmots would walk around the blockage was supported by chi-square tests in all cases but the three in which marmots chose to ultimately navigate over a blockage instead of around it (Table 1). The reasoning behind this hypothesis and why it was mostly supported can be explained by the designations of blockages given in the methods concerning familiar and novel features in the environment. Since natural obstacles in rock habitats were familiar, the marmots had no trouble traveling over them: they recognized that the rock was a rock and that they could travel over it, but as natural obstacles in dead grass habitats were novel, marmots were not used to encountering rocks in a dead grass path, and thus continued on an altered dead grass path around the rock. This same response of traveling around artificial blocks was expected because the

obstacle is a novel feature in both rock and dead grass habitats. Therefore, one would expect, just as with the natural obstacle in the dead grass that marmots would travel around the object, because of uncertainty about the object, this time possibly concerning its nature, origin, or stability. The actions of licking and sniffing the artificial obstacles may hint toward an investigation of the origin or nature of the object, and the action of placing forepaws on top of the obstacle may hint toward an investigation of the stability of the object. However, in the three cases in which marmots did eventually go over the artificial obstacle in the rock habitats, the data for traveling over and around did not fit expected distribution for the familiar or novel response.

The reason that the three cases did not fit the novel or familiar response expectations in their overall distributions was that the data for traveling over and around the artificial obstacle showed two distinct temporal portions, one in which the assumption of the novel feature fit nearly perfectly, and later, one in which the assumption of the familiar feature fit (Fig. 6, Fig. 7A-C). This two-part “piecemeal” response shows that there was a modification in the way that the animals viewed the object, they became acclimated to the artificial object in their environment and began to treat it as just any other rock. However, if each individual became acclimated to the object independently, one would not expect to see such distinct delineation in response. Instead, the exact cutoff point, before which nearly all observations are of going around the object and after which nearly all are of going over the object suggests that the population became acclimated to the object collectively at the same time. In other words, they all “learned” that the object was safe to navigate over top of at the same time. Although there is a very minute chance that this is due entirely to coincidence, the much more logical answer is

that this behavior was learned by one “demonstrator” individual, and then socially transmitted to the rest of the “naïve” population through observation and then imitation. This pattern is documented by Thornton and Malapert (2009), in which certain “demonstrator” meerkats possessing a behavior were placed in populations in which that behavior was absent. All individuals not possessing the behavior, the “naïve” meerkats, picked up the behavior rather quickly through imitation because it provided them with a food reward. The reward which the marmots received was a much more subtle one, it was the shortening of a path between two points by going over a rock versus carefully navigating around.

The clumping of data points around the inflection points of the graphs of the piecemeal regressions (Fig. 7A-C) combined with the finding that instances in which the ultimate result was to travel over an artificial block, mean time between interaction with blockages was lowest (Fig. 8), may suggest that either total frequency of interaction with an obstacle or density of marmots on a grid affects or even predicts time until acclimation to a novel feature. To determine if this were the case, a suggestion for future research on this topic would be to watch more populations of marmots with known differences in population densities for longer periods of time, perhaps 30 or even 60 observation hours per treatment. Also, to determine if certain individuals, such as older marmots are more likely younger marmots to become “demonstrators,” tagging of this population ought to be conducted before more observations are taken.

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TABLES

Table 1. *Chi-square tests comparing observed distributions of traveling over and around artificial blockages with expected distributions generated from natural blockage data.*

Observed			Generated Expected		
Habitat Type	Ultimate Response	n	Dead Grass	Rock	
Rock	Over	82	123.3727	155.1021	χ^2
			< 0.0001	< 0.0001	p
Rock	Around	43	1.2129	235.9854	χ^2
			0.2708	< 0.0001	p
Dead Grass	Around	27	1.862	156.6	χ^2
			0.1724	< 0.0001	p

Table 2. *Pairwise comparisons using independent t-tests to test for significant differences among piecemeal regression inflection points in sets exhibiting ultimate responses of traveling over artificial blockages in rock habitats.*

	t_{calc}	p
1R2_A1 : 1R2_A2	9.82879E-05	0.9999
1R2_A2 : 2R2_A2	0.000202953	0.9998
1R2_A1 : 2R2_A2	3.18134E-06	0.9999

FIGURES

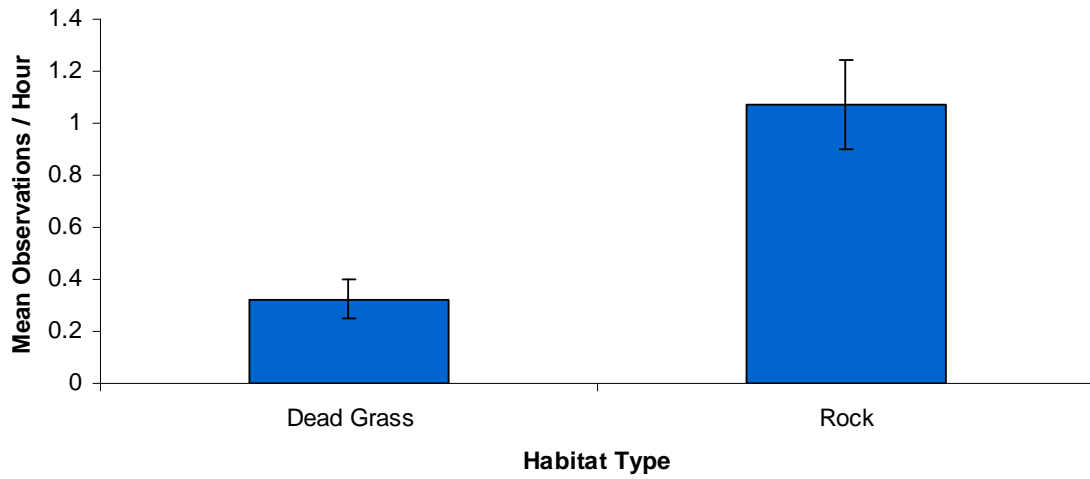


Figure 1. Mean observations per hour (\pm SE) between habitat types for all treatments combined.

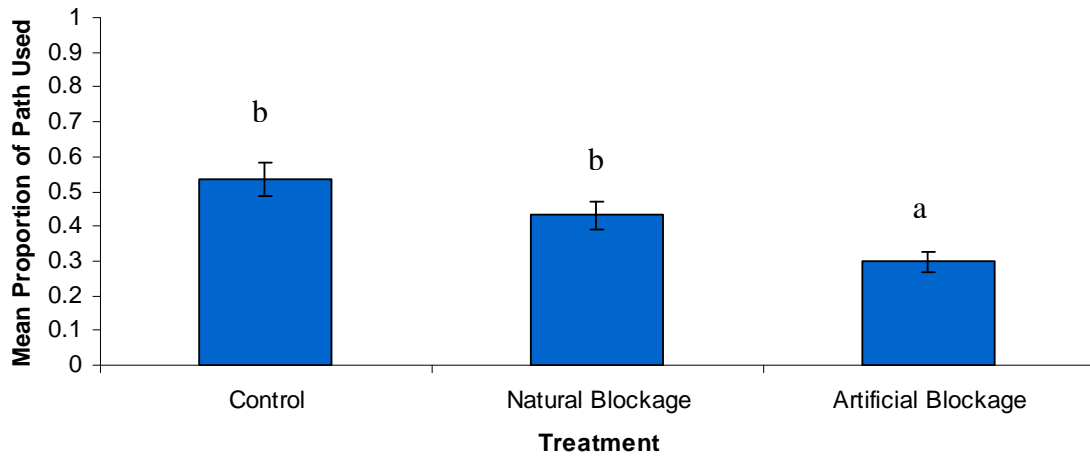


Figure 2. Mean proportion of path used by all marmots in grid (\pm SE) among treatments. Lower-case letters denote statistical difference as determined by Tukey's Honestly Significant Difference test

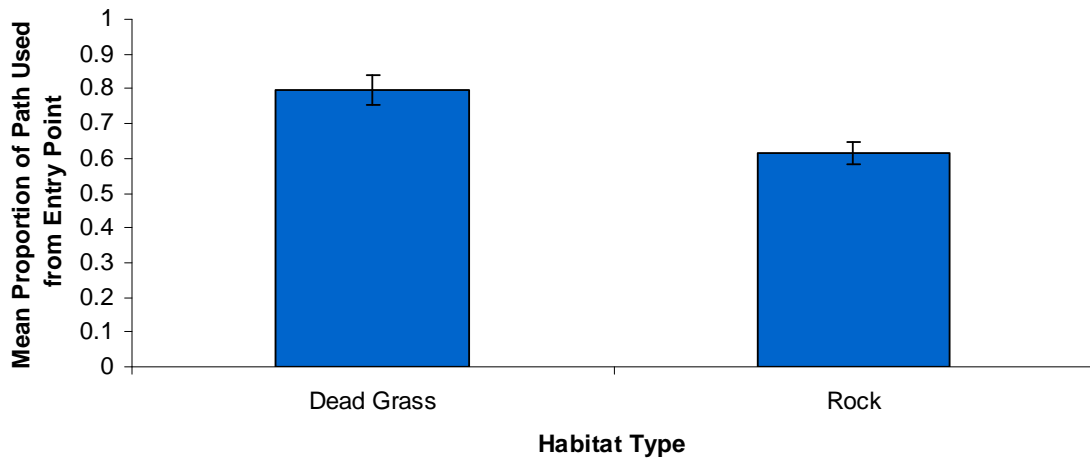


Figure 3. Mean proportion of path used only by marmots beginning at the entry point of a path into a grid (\pm SE) between habitat types.

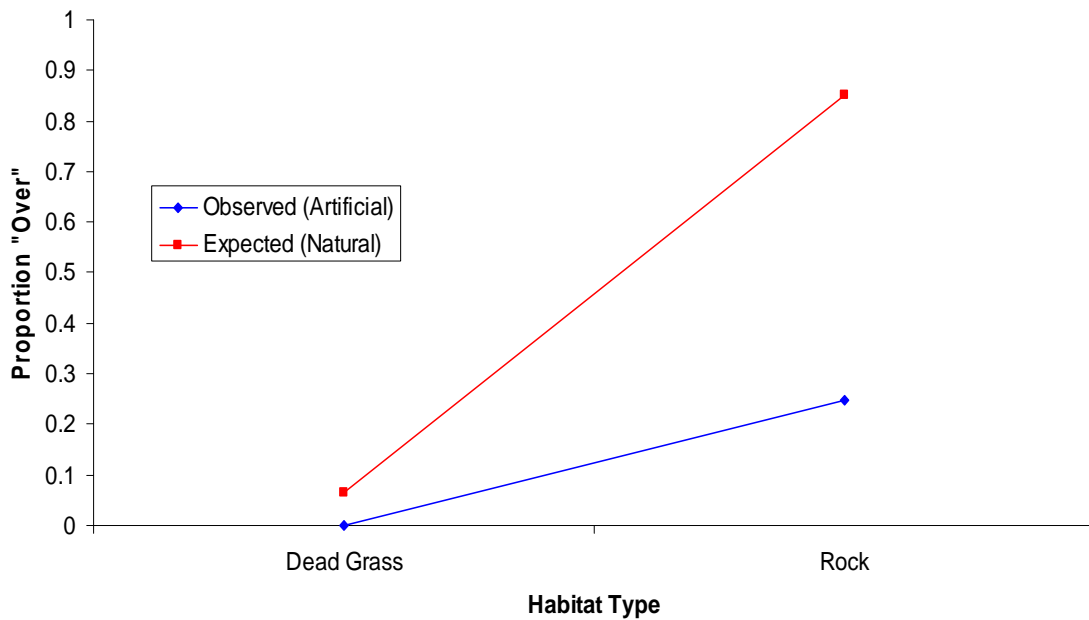


Figure 4. Chi-squares comparing proportions of choosing to go over artificial obstacles versus going around artificial obstacles between habitat types.

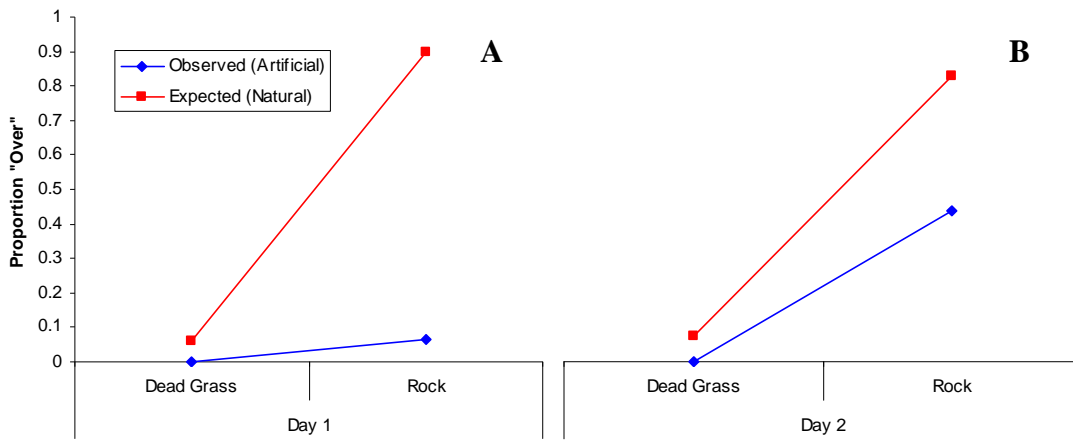


Figure 5. Chi-squares comparing proportions of choosing to go over artificial obstacles versus going around artificial obstacles between habitat types, divided by A.) day one of treatments, and B.) day two of treatments.

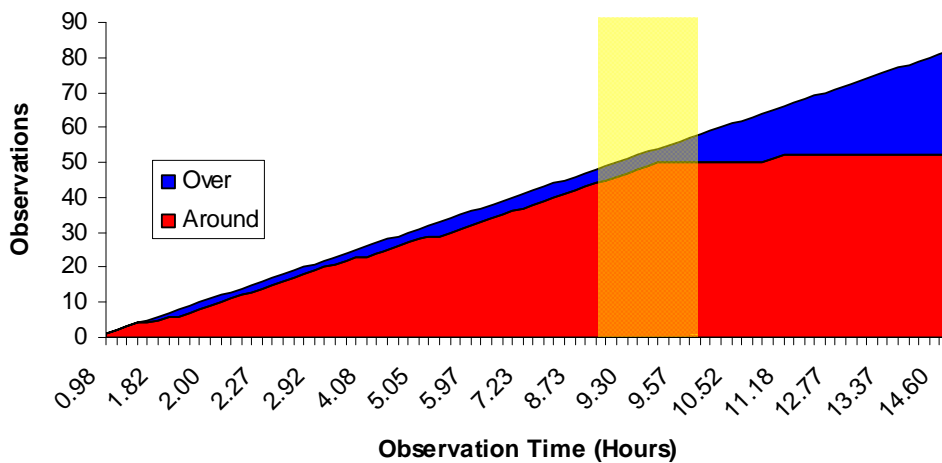


Figure 6. Comparison of total observations of going over and going around plotted against time in observation hours for all instances in which the ultimate response to an artificial blockage in a rock habitat was to go over.

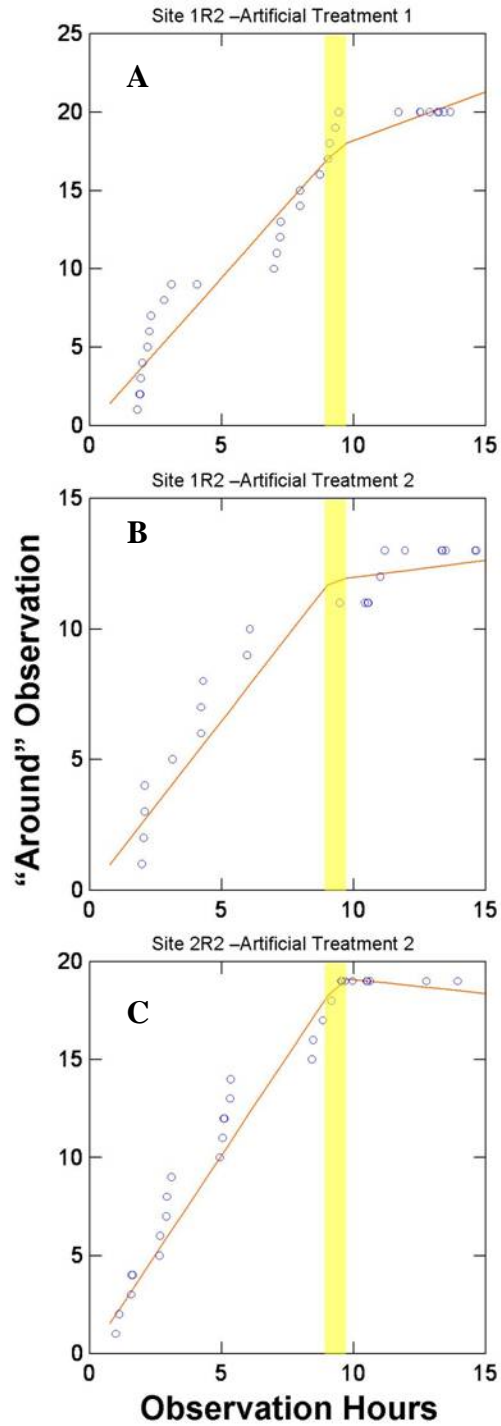


Figure 7. Three piecemeal regressions of total around observations versus observation hours for A.) Site 1R2, Artificial Treatment #1, B.) Site 1R2, Artificial Treatment #2, and C.) Site 2R2, Artificial Treatment #2. The highlighted band shows the overlap of the inflection points of the three graphs.

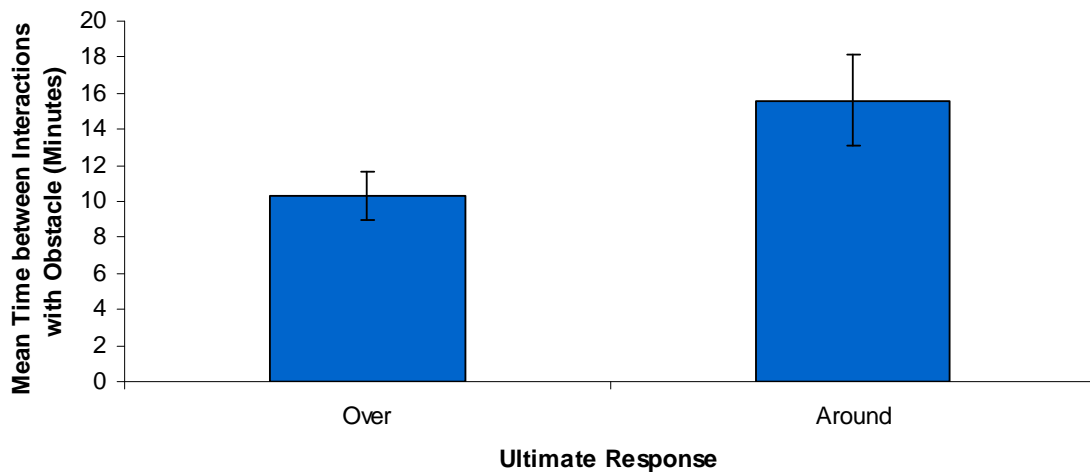


Figure 8. Mean time in minutes ($\pm SE$) between observed interactions with artificial obstacles in rock habitats between ultimate responses of either traveling over or around the obstacle.