PINEDALE -WHITE-TAILED PRAIRIE DOG SURVEY

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FINAL REPORT

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KEY TO ACRONYMS

BLM-	Bureau of Land Management
BTPD-	Black-tailed Prairie Dog
CIR-	Color Infrared
DEM-	Digital Elevation Map
GL-	Genesis Laboratories, Inc.
J2LA	Jonah II Lease Area
NAPP-	National Aerial Photography Program
PALA-	Pinedale Anticline Lease Area
PFO-	Pinedale Field Office, Bureau of Land Management
SYM-	Symmetry, Inc.
USFWS-	United States Fish and Wildlife Service
USDA-	United States Department of Agriculture
WTPD-	White-tailed Prairie Dog
WyGISC-	Wyoming Geographic Information Center, University of Wyoming, Laramie, WY

EXECUTIVE SUMMARY

A survey of previously mapped (2001) white-tailed prairie dog colonies in the Pinedale Anticline Lease Area of the Pinedale Field Office (PFO) was conducted in late May and early June, 2003. Prairie dog burrows on and near the colonies were mapped by GPS/GIS methods and classified as active or inactive. Prairie dog density and potential reproductive rates at each site were estimated from the field data and values in the literature. Habitat characteristics including slope, aspect, soil texture and soil depth were compared between the original colonies and nearby “ghost” polygons. The ghost polygons were computer generated replicas of the actual colonies that were superimposed on the landscape at randomly chosen locations near each actual colony and within a range that was accessible to the prairie dogs.

The survey found that there has been a dramatic reduction in the number of colonies, with only 15 of 29 colonies surveyed still active. In terms of area, the active colonies we mapped in the vicinity of the 29 original colonies totaled just 71 ha. The original colonies comprised 1407 ha. in 2001.

Out of the 37 newly mapped active colonies, 25 had what is considered a favorable or healthy ratio of active to inactive burrows (> 1.0). Twelve colonies had ratios below 1.0.

The overall loss of numbers and areas occupied since 2001 is cause for concern. The mortality factors which threaten prairie dogs on a large scale include loss of habitat, urbanization, resource development, poisoning, recreational shooting and sylvatic plague (*Yersinia pestis*). While information on the incidence and impact of plague in the study area is lacking, it must be considered as a possible agent impacting the prairie dogs in this study area. Plague is widely considered to be the major threat to most prairie dog populations (Knowles 2002; Wagner 2002).

Topographic exposure, or aspect, was determined by overlaying colony polygons with a GIS derived aspect layer from the 10 meter DEM database. Azimuth data were analyzed using circular statistical methods, in which each datum is defined by it’s length and angle from a defined point on a circle. Additionally, the aspect of the 10m x 10m cell containing each burrow recorded by the GPS was determined, and the results sorted by active or inactive status. Prairie dog colony and burrow site selection may be a response to levels of solar heating over the course of the year. We performed some very preliminary processing and visual graphing of the aspect data in order to characterize burrow locations in direct relation to solar heating.

We found that the mean angle and mean vectors were similar for all three sample sets. Mean angle of all polygons in the three groups were 160° on the base map colonies, 129° among the ghost polygons, and 121° among the currently active colonies. Mean vectors (“evenness” of the dispersion of points around the compass) were 0.556, 0.446 and 0.492, for the base map colonies, ghost polygons, and active colonies, respectively.

The circular graphs display the fact that none of the data sets have any points in the northwest quarter of the compass. The orientation of active and former colonies toward the three quarters of the compass with the earliest daily solar exposure (and likely least exposure to prevailing winds) suggests that solar flux may play a role in site selection. Plots of the energy distribution of the entire landscape in the study area, when compared to the energy distribution of active burrow sites, suggest that the prairie dogs may be selecting sites with greater solar gain. Therefore, it is recommended that future studies include more conclusive and robust statistical analysis of these relationships.

Our comparison of habitat variables between the 2001 colonies and the randomly located ghost polygons did not find significant differences in soil depth (to one meter), or in percent rocks at a depth of 0.5 meter. We had hypothesized that variations in soil depth might affect site selection with regard to the ability to establish hibernacula below the frost line. However, we found soil depth is adequate throughout most of the area and does not seem to be limiting factor. Regarding soil cover, the frequency distribution of mineral particle sizes on the surface was found to be almost identical between colonies and ghost polygons. However there was nearly twice the amount of vegetative cover on colonies as opposed to ghost polygons. Whether this is a cause or result of prairie dog occupancy is unknown.

The evenness of the slope was examined as well. We found the slope variation to be very similar in the 2001 colonies and the ghost polygons. But the slope variation on the currently occupied colonies was on average about half that of the other areas. This supports the hypothesis that evenness of slope may facilitate improved communications and predator detection (Wagner 2002). Again, it is unknown if the prairie dogs preferentially select more even terrain, or if those occupying such terrain are more successful at avoiding predation.

INTRODUCTION

The objectives of this project were to evaluate the utility of aerial photographs for distinguishing white-tailed prairie dog colonies, and to provide a basis for linking prairie dog colonies to land features that might allow modeling of potential habitat. To meet these objectives, the project was designed to ground truth areas identified as white-tailed prairie dog (*Cynomys leucurus* Merriam, 1890) colonies on 1:40000 CIR NAPP photography of the Bureau of Land Management's Pinedale Field Office in western Wyoming. The project also included the assessment of a variety of demographic variables in the identified colonies.

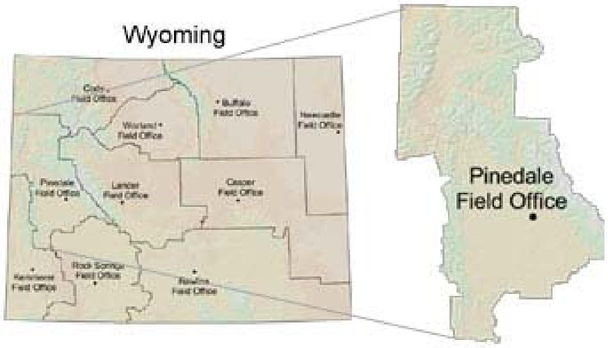


Figure 1. The Pinedale Field Office administrative unit of the Wyoming BLM

During the photo-interpretation process it became apparent that the available imagery would not be adequate to routinely identify colonies. Remote sensing has often been used to map and monitor black-tailed prairie dog (*Cynomys ludovicianus*, Ord, 1815) colonies (Cheatheam 1973; Tietjen et al. 1978; Dalstead et al. 1981; Schenbeck and Myhre 1986; Sidle et al. 2002). Black-tailed prairie dogs (BTPD) establish densely populated colonies in the Great Plains region, and modify the vegetation in a manner that is easily seen on CIR photographs (Biggins et al. 1993). Additionally, the color of the sub-soil excavated to build the characteristic volcano-shaped mounds is often readily distinguished from the darker topsoil on aerial photography or satellite imagery.

In contrast, white-tailed prairie dogs (WTPD) exhibit a looser colonial structure and a relatively low density of burrow entrances (Hoogland 1981). In the Pinedale Field Office (PFO) area, burrows are often interspersed among the shrub cover, which is not drastically modified by the prairie dogs. The mounds are low and broad, and the sub-soil is often similar in color to the meager topsoil. These factors hindered efforts by GIS analysts to identify white-tailed prairie dog colonies in the study area using the available imagery. Biggins et al. (1993), reported that 1:20000 and 1:40000 black and white photography of the Meteetse WTPD complex was adequate to identify some but not all colonies. CIR photography at 1:5000 scale is adequate to distinguish individual WTPD mounds and burrows. Even so, mapping of colonies using 1:5000 CIR imagery "…must be based on the distribution of burrows because there is seldom a noticeable difference in vegetation." (Biggins et al. 1993). Andelt (2003) evaluated the precision of colony area estimates using low level aerial flights over Gunnison's and white-tailed prairie dog colonies in Utah and Colorado. He found that even observers with experience conducting aerial surveys of black-tailed prairie dogs significantly over-estimated colony sizes. Ground-truthing by the observers in conjunction with aerial surveys was recommended as part of the training process.

This project was therefore modified and efforts were directed at assessing demographic variables and habitat characteristics of known colonies in the PFO. Recently compiled GPS maps of WTPD colonies within two mineral leases, the Pinedale Anticline Lease Area (PALA) and Jonah II Lease Area (J2LA) are available. These maps have been generated and updated annually for several years by TRC Mariah Associates, Laramie, WY, as part of an on-going environmental assessment of the mineral leases. The maps are submitted to the BLM when completed each year. The monitoring activity is associated with recent energy exploration and extraction. The two areas contain large reserves of natural gas (Lyon and Anderson 2003). The most recent colony maps available during the planning stages of this survey (early spring of 2003) were those generated by TRC Mariah Associates in the summer of 2001. Approximately 30 colonies had been identified and mapped within the PALA. These colonies (hereafter referred to as the "base map colonies") were selected to study the demographics and habitat characteristics of white-tailed prairie dogs within the PFO.

Prairie dog researchers at a number of agencies and universities were consulted, and a search of the literature was conducted to identify habitat variables that were most likely to have predictive value in building a habitat suitability model. Table 1 lists some of the habitat correlates that have been established for prairie dog species.

The white-tailed prairie dog is classified as a member of the sub-genus *Leucocrossuromys.* Other members of the sub-genus include the Gunnison's and Utah prairie dogs. The other two prairie dog species, the black-tailed and Mexican prairie dogs, are placed in the sub-genus *Cynomys*.

The members of the sub-genus *Leucocrossuromys* may be found at higher elevations than the *Cynomys* sub-genus, and enter true hibernation in the winter. The colonies of *Leucocrossuromys* species are socially less structured than those of the *Cynomys* sub-genus, but all five species have highly developed verbal communications (Slobodchikoff et al. 1986). Predator alert calls are a well known type of call used by prairie dogs. Sounds do not travel well around corners and this may explain why Wagner (2002) found that the evenness of terrain seems to be an important habitat correlate associated with the Gunnison's prairie dog.

Members of sub-genus *Leucocrossuromys* appear to be feeding generalists, as evidenced by their distribution across a wide range of elevations and vegetation types. All prairie dogs are habitat engineers to a greater or lesser extent. Whereas black-tailed prairie dogs modify the habitat extensively including removal of shrubs and tall herbaceous cover, white-tailed prairie dogs are quite tolerant of shrubs and in fact probably modify the local habitat the least of the five species (Knowles 2002). Their activities may influence the quantity and quality of vegetation within the colony, however Menkens and Anderson (1989) concluded that there are no significant correlations between large-scale vegetation characteristics and white-tailed prairie dog population dynamics. Because of this, comparing vegetation within and outside of colonies has little value in predicting the presence or abundance of white-tailed prairie dogs in an area, or in building habitat suitability models (Wagner 2002).

Therefore, our survey concentrated on site factors that may influence the selection of burrow and colony sites and the success of the inhabitants. We can hypothesize that particle size of surface soils may be an tangible indicator of subsurface conditions to prairie dogs, which will affect the energetic costs of building and maintaining burrows. Soils must also be firm enough to maintain burrow integrity, but soft and loose enough to permit burrowing, gas exchange, and drainage. Soil depth must be sufficient to permit construction of hibernacula chambers below the normal frost line. We were unable to find references to the average depth of the frost in the study area, but information from other areas at similar latitudes and elevations suggested that 1 meter (m) is a reasonable estimate. The slope and aspect of the site affect the microclimate of the burrows, as well as plant community composition and productivity. The evenness or uniformity of the slope may affect the visual detection of predators and the efficiency of vocal communications within the colony.

STUDY AREA

The study was conducted in the Pinedale Anticline Lease Area (see 1:100,000 pull-out map in front flap of jacket) of the Pinedale Field Office administrative unit of the Wyoming BLM. The area is part of the Wyoming Basin, which is included in the Intermountain Desert Province ecoregion as classified by the U. S. Forest Service (Driscoll et al. 1984). The area consists of plains interspersed with isolated hills, plateaus and low mountains. The elevation ranges from 6000 – 8000 ft (1800 – 2400 m).

The geology of the area is complex, with uplifted areas of cretaceous rock among widespread exposures of Tertiary shales and sandstones (Munn and Arneson 1998). Sloping alluvial fans at the base of hills and plateaus merge into rolling or flat plains. The lowland soils in the area are classified as alkaline aridisols. Subsoils may contain a layer of lime or gypsum which can develop into a caliche hardpan, often at about 1 m depth (Driscoll et al. 1984; Reid et al. 2002). Winters are cold and the summers are short and hot. Average annual precipitation ranges from 5 to 14 inches (130 to 360 mm), and is fairly evenly distributed throughout the year.

The predominant vegetation community is sagebrush steppe. The sagebrush steppe community is diverse and a variety of descriptive classification schemes have been devised over the years. The sagebrush community systematics have recently been reviewed and unified by Reid et al. (2002). Under the unified scheme the survey area is classified as the Wyoming Big Sagebrush Shrubland Alliance, which is characterized by "…a sparse to moderately dense (20-70% cover) shrub layer that is dominated (or co-dominated with at least 40% relative cover in mixed stands) by *Artemisia tridentata ssp. wyomingensis*. The herbaceous layer is relatively sparse and often dominated by perennial graminoids (<20% cover) that occupy patches in the shrub matrix." (Reid et al. 2002). Other associated vegetation types in the area may include *Atriplex confertifolia, Ericameria* spp. or *Chrysothamnus* spp. shrublands,

The mega-fauna of the area includes pronghorn antelope (*Antilocapra americana*), mountain lion (*Felis concolor*), bobcat (*Lynx rufus*) and coyote (*Canis latrans*). The area is an important wintering ground for pronghorn. Elk (*Cervus canadensis*) and mule deer (*Odecoileus hemiones*) may also winter in the basins. A wide variety of small mammals inhabits the area in addition to white-tailed prairie dogs. Sage grouse (*Centrocercus urophasianus*) are the dominant upland game bird, and a wide variety of hawks and owls, including the burrowing owl, (*Athene culicularia*), are found in the area.

STUDY PERIOD

Field data was acquired during the period from May 21 to June 9, 2003. We met with biologist K. Andrews at the BLM office in Pinedale, WY on May 21, 2003 and reviewed the study plan and maps of the study area, and occurrence of other species of concern in the area. Sage grouse are common in parts of the study area and may still be sitting on nests at that time. Therefore, in such areas we restricted travel with vehicles (trucks and 4-wheel ATV) to established tracks. Off-track survey work was performed on foot. One colony, PDT 12, was dropped from the survey plan altogether because of historic nesting activity by mountain plover (*Charadrius montanus).*

METHODS and MATERIALS

GPS/GIS

Geographic Information System (GIS) support and analysis for the project was provided by Symmetry, Boulder, CO. The BLM PFO supplied digitized maps of the prairie dog colonies within the PALA that were surveyed by TRC Mariah in 2001. Map layers of the prairie dog colonies were overlaid on digitized USGS 1:24000 topographic maps. The Wyoming Geographic Information Science Center at the University of Wyoming (Laramie, WY) generated maps of possible prairie dog colonies in the PFO based on analysis of the CIR NAPP imagery.

In the field, a Global Positioning System (GPS) was used to acquire attribute data on point, line and polygon features. GeoExplorer CE® series handheld GPS units (Trimble Navigation Ltd., Sunnyvale, CA) were used to navigate to sampling sites and to map features in the field. Two GeoExplorer XT® units with sub-meter[2] accuracy were used to acquire most of the field data. A GeoExplorer XM® unit with 2-5 meter[2] accuracy was used to locate some of the soil sampling sites. Data acquired in the field were managed and transferred to a PC platform using Trimble's Terrasync® and Pathfinder® software. Following differential correction, data were exported to an ARC/Info® (Redlands, CA) spatial database for analysis and processing.

NOTE ON NOMENCLATURE

The base map prairie dog colony polygons mapped by TRC Mariah in 2001, are labeled with TRC Mariah's system as PDT 1, PDT 2, …PDT 20. Clusters of associated colonies, or complexes, within this system have a sequential alphabetical identifier appended to the colony number. For example, there is a complex of three colonies labeled PDT 15A, PDT 15B, and PDT 15C. In such cases, there is no PDT 15. The polygons mapped during this survey as active prairie dog colonies are labeled with a lower case “pdt##”. The number assigned is derived from the nearest base map polygon. Clusters or complexes of colonies were labeled with an underscore followed by a sequential number. For example, we mapped six small active colonies in the area of PDT 15C. These new polygons were identified as “pdt15c_1, pdt15c_2,…,pdt15c_6.”

A cluster of small colonies listed on the base maps as PDT 4B, 4C, 4D and 4E, were in close proximity and comprised a total of 4.2 ha. These four colonies were consolidated into a new polygon encompassing all four colonies, which we labeled PDT 4X. Another very small colony, PDT 6B, which was just 0.4 ha in area, was omitted from our survey.

Two other base map colonies were not included in the burrow survey work. PDT 12 was thought to have an active breeding pair of mountain plover, so we avoided this colony entirely. PDT 14 was a very large colony – 303 ha. We collected soil survey data on PDT 14 and the corresponding ghost plot. However, we did not conduct burrow surveys simply because the scale of the plot was so large that the value of an additional active burrow count, which still just contributed a single sample point, was not proportional to the effort to acquire the information. Visits to the colony to collect soil samples indicated it was a very active colony which appears to have expanded to the south of the 2001 boundaries.

IDENTIFYING WHITE-TAILED PRAIRIE DOG BURROWS AND COLONIES

We used the criteria established by Biggins et al. (1993) to identify white-tailed prairie dog burrows and to determine active or inactive status of openings classified as WTPD burrows. Other burrowing animals in the area which might occupy abandoned WTPD burrows or create similar burrows include the burrowing owl, Wyoming ground squirrel (*Spermophilus elegans*), the thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*), and a variety of other rodents, lagomorphs and mustelids. Biggins et al. (1993) suggest that prairie dog burrows be defined as those with an opening diameter of “… at least 7 cm, and so deep that the end is not visible.” Large, badger-reamed burrows were surveyed also, since they may still be occupied by prairie dogs. The only criteria used to establish active status was the presence of fresh prairie dog scat in the opening or within 0.5 m of the opening. Fresh scat is defined as greenish, black or dark brown in color, and not dried hard or bleached white (Biggins et al. 1993).

Active burrows near the periphery of colonies were included in the colony polygon if they were within 50 meters of another active burrow. Collections of burrows were mapped as separate colonies if they were separated by more that 200 meters from other collections of active burrows. Single active burrows more than 50 meters from a colony were mapped as outliers.

PRESENCE/ABSENCE

Colony occupancy (presence/absence) of white-tailed prairie dogs was assessed by visiting the 2001 base map colonies at least once and as many as four times during the period of May 20 to June 9, 2003. Criteria of occupancy were visual sightings of prairie dogs, the distinctive alarm call, or presence of fresh feces within 0.5 meters (m) of a burrow opening (Biggins et al. 1989).

Using these criteria, the presence or absence of prairie dogs can be determined quite easily. We visited the base map colonies up to four times to survey for presence or absence. Once presence was confirmed, no more visits were made exclusively for that purpose. Also, once as colony had been completely surveyed by GPS, no more visits were made to detect presence.

In spite of the ease with which WTPD are usually detected during ground surveys, there is always some probability that prairie dogs are present but not detected. The presence of a focal species will often be under-estimated using the basic equation:

$$\frac{\text{No. of sites where detected}}{\text{Total no. of sites surveyed}} = \text{Probability of detection}$$

By using the change in detection results during repeated visits to the survey sites an improved estimate of the probability that the focal species is present may be calculated. The assumptions and details of the procedure are described by MacKenzie et al. (2002). The program PRESENCE, developed by Proteus Research and Consulting (New Zealand), is available as public domain shareware from the U.S.G.S. (http://www.mps-pwrc.usgs.gov/armi) and was used to calculate the detection probability.

AREAS OF COLONY OCCUPANCY

The current areas of colony occupancy were mapped using GPS/GIS functions. Most of the base map colony boundaries were established in ARC/Info by drawing a line connecting the outermost active burrows recorded. If an active burrow was distal to the emerging polygon and more than 50 m from the nearest neighboring active burrow, the perimeter line was directed back to find the next active burrow toward the centroid. Isolated burrows or tight clusters of burrows more than 50 m from the nearest neighbor were treated as outliers. Clusters of burrows arranged in a linear pattern, or around which a polygon could be created by connecting the outermost points, were treated as separate active polygons. The outer boundaries on a few of the larger colonies, which were surveyed by transects at 60 m intervals, were established by connecting the ends of adjacent transects. Transects started and ended with the outermost active burrows within 50 m of the next active burrows from the core or centroid of the colony. The process is difficult to describe, but quite simple to execute in practice. Figures 3 and 4 in the Results section provide examples.

DEMOGRAPHICS

Population densities of colonies were derived from burrow density estimates. Burrow density was established using two techniques. On a few of the large colonies, burrow density was estimated by sampling about 5% of the colony area. Numbers of burrows were counted along 3 m transects centered at 60 m intervals across colonies (Biggins et al. 1993). On smaller colonies, those less than about 100 hectares (ha), all prairie dog burrows were recorded as features on a GPS data logger. A data dictionary was used to uniquely identify active and inactive burrows. Using the density of active or occupied burrows per unit area, an estimate of the density of WTPD can be derived. The formula is as follows:

WTPD Density = (0.073 x active burrow density)/ 0.495.

This formula has a correlation of r = + 0.95. The correlation between WTPD density and density of all burrows (active + inactive) is not as robust (Biggins et al. 1993).

The ratio of active/inactive burrows was determined for the base map colonies using the same data. This ratio is considered a reliable indictor of colony health, with a ratio of < 1.0 being cause for concern (Biggins et al. 1993).

Reproductive output was estimated by extrapolating from the estimated population density, using values from the literature (Menkens and Anderson 1989). Although the range of reported values is quite large, a typical ratio of adult males to females is 1:2, (≈ 33 ♂: 67 ♀). It is believed that perhaps 90% of the adult females produce litters each year. Based on an estimated average litter size of 5, reproductive output or productivity of the mapped colonies can be estimated with the following formula:

WTPD Density x 0.67 x 0.90 x 5 = Estimated Reproductive Output/Unit Area

WTPD Density is the estimated colony density based on the active burrow counts, 0.67 is the adult female proportion of the colony, 0.90 is the proportion of adult females breeding, and 5 is the average litter size.

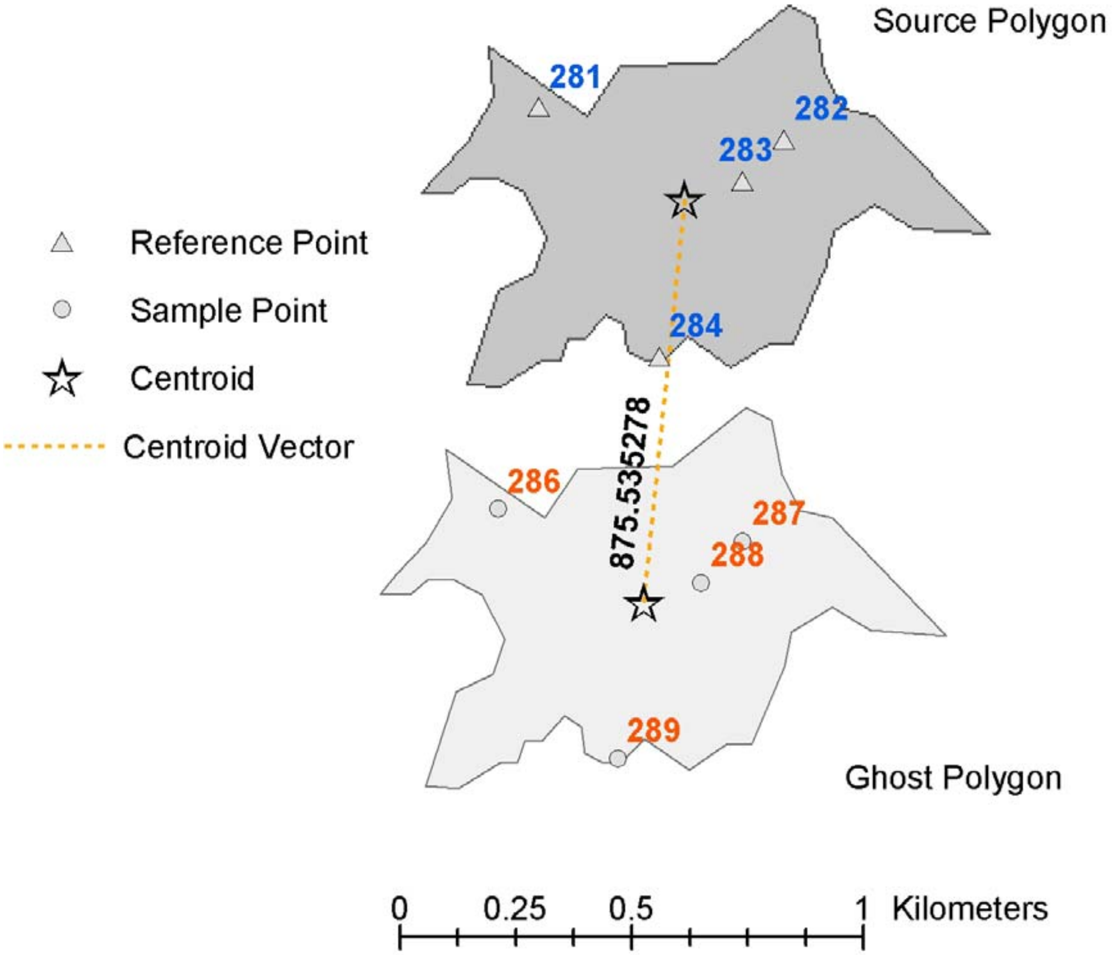
HABITAT CHARACTERISTICS

Physical habitat characteristics were evaluated for the 31 base map prairie dog colonies. In order to compare physical habitat characteristics of WTPD colonies, the same selected traits were evaluated in un-occupied areas near each of the base map colonies. A set of “ghost” polygons were generated using GIS functions. Figure 2 provides an example of the base map colony PDT 6A and the computer generated ghost polygon. The ghost polygons provided randomly selected locations near each colony which were not occupied by WTPD but were within the dispersal range of prairie dogs in the base map colonies. Thus the sites were available and *could* be occupied by WTPD. White-tailed prairie dogs are known to disperse distances of up to 2.7 km (Clark et al. 1971).

A buffer zone of 3 kilometers (km) was mapped around each existing colony. The ghost polygons were created via GIS by making a copy of each base map colony, of the same size, shape and orientation. Using a randomization algorithm, each ghost polygon was overlaid on the buffer zone of the actual colony polygon it represented. The randomization algorithm selected a vector and a distance from the centroid of the base colony. The range of distances from the centroids of base map colonies to the centroids of the corresponding ghost polygons was 501 m to 2288 m. The mean distance between colony and ghost polygon centroids was 1633 m (n = 31).

Figure 2.

Base Map Colony PDT 6A and Ghost Polygon



If a ghost polygon overlapped another mapped prairie dog colony, or if different ghost polygons overlapped, the program was repeated until each ghost colony was isolated. In the field, we checked that the ghost polygon soil sampling sites did not fall within previously or currently occupied prairie dog colonies.

The following features were characterized at base map colonies, and the ghost polygons. PDT 19 and the corresponding ghost colony were omitted from these analyses because the ghost polygon lay partially outside of our 10 m DEM coverage.

Topographic Exposure

Topographic exposure, or aspect, was determined by overlaying colony polygons with a GIS derived aspect layer from the 10 meter DEM database. The aspect values of the base map colonies, the corresponding ghost polygons, and colonies which were surveyed by the transect method were averaged using GIS functions.

In order to determine mean aspects, the DEM source data were transformed. Mean angles were determined using a geometric/trigonometric method to convert source aspect azimuths into component X and Y Cartesian coordinates. For each angle in a collection, the respective X and Y components were summed. The collection sum was then converted back to an angle using the arctangent function and rules applied to convert the resulting angle to an azimuth with positive value. This summing of vectors is widely recognized as a valid representation of "mean" angle or vector. Mean aspect is a function of both direction and magnitude. Magnitude or “length” of a vector is strongly affected by cell counts. In our analysis the term "Beta" was used to represent mean azimuth in all tables.

Azimuth data were analyzed using circular statistical methods, in which each datum is defined by it’s length and angle from a defined point on a circle. Descriptive statistics and graphs of the datasets were generated with the statistical program *statistiXL v. 1.1*© (Roberts and Withers 2003). The mean angle and mean vector for each data set were calculated. The mean angle of the data set is simply the mean of the average azimuth of each of the colonies or polygons making up the set. The “mean vector” of a data set (e.g., ghost polygons) is the length of the vector calculated from the mean angle of the data set, and may range from values of 0 to 1. The mean vector is a measure of the evenness of the dispersion of points around the compass. A mean vector of “0” indicates no mean angle because there is so much dispersion, whereas a value of “1” would indicate all the samples were in the same direction. Rayleigh’s “Z” test was used to test for uniform distribution of the data sets. A probability is associated with the “Z” statistic, and indicates the likelihood that the data were drawn from a uniform distribution.

Additionally, the aspect of the 10m x 10m cell containing each burrow recorded by the GPS was determined, and the results sorted by active or inactive status. There is some overlap in the active and inactive data sets, since both categories of burrows can occur in the same 10 m^2 cell.

Prairie dog colony and burrow site selection may be a response to levels of solar heating over the course of the year. This premise became key to the aspect analysis. Although homeothermic animals are able to physiologically and behaviorally buffer the effects of ambient climatic conditions, they are still constrained within a species specific "climate space" (Gates 1980). Solar heating may also effect herbivorous animals such as prairie dogs indirectly through it's influence on the vegetative community composition and the phenology of each plant species (Daubenmire 1974).

Although examining this topic in any depth is beyond the scope of this project, we performed some very preliminary processing and visual graphing of the aspect data in order to characterize burrow locations in direct relation to solar heating. Programs to measure solar daily duration and cumulative energy measures are available in the public domain. These programs may be obtained from the internet (Rich and Hetrick 2000), and calculate solar duration and cumulative energy measures based on topography, latitude, atmospheric transmittivity and season.

We calculated overall solar heating and duration for the entire study area and for two subsets, the active and inactive burrows. The resolution of the analysis was units of 10 m^2, using the 10 m^2 DEM database as program input. Atmospheric transmittivity was set at 1.0. Duration was set to span a complete solar day for the Julian calendar days of 1, 90, 180 and 270 where the Julian days represent the four seasons of the year – winter, spring, summer and fall, respectively. Outputs included four ARC/Info grids which provide measures of cumulative solar heating. The Arc/Info Grid function 'Mean' was then applied to the four grids to create a grid representing the overall yearly average per 10 m2 cell.

Slope

The slope of base map colonies, ghost polygons and active polygons was evaluated in terms of the variation in slope. The variation in slope is defined as one standard deviation from the mean slope. Slope values were determined by overlaying the colony maps with 10 meter DEM maps. The variations in slope were compared using one way analysis of variance (ANOVA). Prior to the ANOVA, the data sets were evaluated for normal distribution using the chi square goodness-of-fit test (transformed if necessary), and Bartlett's test for homogeneity of variance. Following ANOVA, Bonferroni's t-test was applied as a means separation procedure. Statistical functions in MS Excel (Microsoft, Redmond, WA) and the program TOXSTAT (WEST, Inc., Cheyenne, WY) were used for the analyses.

SOIL CHARACTERISTICS

Three soil attributes were determined in each base map colony and in the corresponding ghost colonies. The attributes were assessed at four sites in each colony or ghost colony. The sites were chosen using a GIS algorithm to randomly selected four 10m x 10m cells within each base map colony. The distance and orientation of each site from the centroid of the polygon was determined, and four corresponding sites were located within each ghost polygon, using the centroid as a reference point.

Soil Surface Particle Size

The first parameter measured was the particle size of soil and minerals on the surface. Standard soil classifications based on particle size were used. Particles were classified as follows:

Sand-Silt-Clay (SSC): < 2 millimeters (mm) diameter;
Gravel (G): 2-4 mm diameter;
Pebbles (P): ≥4 mm and < 64 mm; and
Cobbles (C); ≥ 64 mm.
Any type of plant matter was classed as Vegetation (V).

The point intercept method was used to survey the particle sizes at each site. The point-intercept method employs a sighting device or pin/point frame at selected sites to estimate the cover by type. Optical sighting devices eliminate observer bias when used properly, since the sampling points are selected entirely by procedure. We used an optical sighting device which consisted of a vertical sighting tube with a peep-hole sight at the top end and a glass magnifying lens at the lower end . The sighting tube was attached to the end of a horizontal beam. The beam was mounted on a tripod. When rotated 360 degrees in a horizontal plane on the tripod, the optical sight describes a circle one meter in diameter. The optical sight had a fixed focal length. Readings were made at 30° intervals. Cross-hairs at the center of the magnifying lens pin-pointed each sampling point. Graduation marks scaled to 2 mm intervals at the magnification level used allowed the observer to quickly classify particles by size.

Using the GPS units, we navigated to the sampling site coordinates determined by the GIS program. At each site the optical sighting device was placed on the ground as close to the exact GPS coordinates as possible. If the randomly selected site was on a shrub or within a shrub canopy, the device was moved to one side enough to avoid the shrub. Once in place, the sight was rotated through a complete circle. A reading of the particle size under the cross-hairs was taken at every 30 degrees around the circle. In this manner 12 points were surveyed at each site, and a total of 48 points were surveyed among the four randomly selected sites on each base colony or ghost polygon.

The points surveyed were treated as independent samples. The observed and expected frequency of each cover category in the base colonies and the ghost polygons was calculated. Analysis consisted of a chi square test for a fixed-ratio. In this cases the analysis compared observed versus expected particle size distribution frequency. The ghost polygon data were treated as the expected proportions, with the base colony data the observed proportions.

Percent Rocks in Sub-surface Layers

A sample of soil at a depth of 0.5 meter was collected at each randomly selected site after the soil surface particle size data were collected. Soil samples were collected with a 7 cm diameter bucket auger with a "T" handle (Forestry Supplies, Jackson, MS). The samples were transferred to labeled Ziploc® 1 quart size bags and later transported to Genesis Laboratories in Wellington, CO. There the samples were transferred to open trays and dried for 24 hours at 99.5º F in a Petersime Model 5 incubator (Gettysburg, PA) designed for warming poultry eggs. The incubator maintains an even temperature and is positively ventilated. Following drying, the samples were removed from the incubator and manually ground with a wooden pestle in order to reduce any accretions to their minimum natural particle size. The samples were then weighed before sifting through a ASTM No. 5 sieve (which allows 4 mm particles to pass through). The portions retained by the sieve and passing through the sieve were then weighed separately. Any particle retained by the sieve (greater that 4 mm diameter) were classed as "rocks".

Figure 3. Optical Sighting Device. The device is set as close as possible to the selected coordinates. Cross-hairs on the objective lens in the sighting tube pinpoint the spot for each reading as the apparatus is stopped at 30 degree intervals around the circumference of a one meter circle.

The soil composition data from the base map colonies and the ghost polygons were analyzed using the mean percent "rocks" from the four survey sites at each base map colony or ghost polygon. The data were analyzed first with a chi-square goodness–of-fit test to determine if the data set met was normally distributed. This was followed by Bartlett's test for homogeneity of variance. Since the assumptions of analysis of variance (ANOVA) were satisfied, the data set was analyzed by ANOVA.

Soil Depth

After each soil sample was collected at the 0.5 m depth, boring was continued with the bucket auger, if possible, to a depth of 1.0 m. The depth attained at each site was recorded.

The soil sample data from the base map colonies and the ghost polygons were analyzed using the mean depth from the four survey sites at each base map colony or ghost polygon. The data were analyzed with the Kruskal-Wallis non-parametric ANOVA since the assumptions of ANOVA were not satisfied.

RESULTS and DISCUSSION

PRESENCE/ABSENCE

On the basis of our GPS surveys of 29 colonies mapped in 2001, we found only 15, or 52%, to be occupied currently. Table 2 summarizes the results of presence/absence surveys.

The detection probability as calculated by the program PRESENCE, is 0.9385. That is, under the conditions of this survey the focal species is expected to be detected during a single visit 93.85% of the time.

AREA OF COLONY OCCUPANCY

The areas of the base map colonies are listed in acres and hectares in Table 3. The areas of active burrows found in this survey are shown in Table 4. We observed a significant decline in the number of hectares occupied currently compared with the area occupied in the 2001 survey. We found only 71 ha with active WTPD burrows compared to 1407 ha of active burrows mapped at or near the same sites in 2001. This represents a decline of 95.0% in active burrow acreage in two years. It should be noted that these figures do not include two large colonies surveyed in 2001, PDT 12 (28 ha) and PDT 14 (303 ha). Both of these colonies are still extant but were not surveyed by Genesis in 2003. In addition, Genesis encountered and mapped the perimeter a very active colony not appearing on our 2001 base maps. The colony is to the southwest of PDT 20, and encompasses approximately 50 ha. The boundary was recorded with GPS, and the colony labeled pdtgl20.

Figures 4, 5 and 6 on the following pages show PDT 6A in the southeast section of the PALA. Figure 4 shows the 2001 base map polygon overlaid by the active polygons we delineated in 2003. Figure 5 is the same rendering with the addition of the active burrows. The configuration of the active burrows illustrates the manner in which the outer burrows of a cluster were connected to create the polygon boundaries. Figure 6 shows the same background overlaid this time by the inactive burrows surveyed in 2003. We assume many of these burrows were active in 2001. By connecting selected, now inactive burrows, the boundary of the 2001 polygon emerges.

The dramatic reduction in active colony areas is illustrated by Figures 7 and 8. Figure 7 shows the southwest corner of the PALA, with currently active polygons overlaid on the 2001 base map colonies. Figure 8 shows the same view of colonies in the New American river area in the west central PALA.

With regard to the size of the areas we found with WTPD activity, comparisons between the 2001 survey results with the current survey should be made with care. This survey was completed during the last third of May and the first third of June. The 2001 survey was conducted later in the summer. The young of the year were just emerging during this survey, whereas all newborns would have emerged by mid to late June. Thus a survey in July or August might show more activity due to young of the year. Conversely, later in the summer, estivation of adults may give the appearance that an area or clusters of burrows are no longer active (Knowles 2002). Furthermore, the surveys were carried out by different personnel, and the rules for delineating colony boundaries may be different. We recommend that our results be compared with the TRC Mariah maps generated in 2002, and in the 2003 season, before drawing conclusions about changes in areas occupied by the WTPD.

Figure 4. Shifting Colony Boundaries. Base map colony PDT 6A, as mapped in 2001, overlaid by polygons active in early summer, 2003.

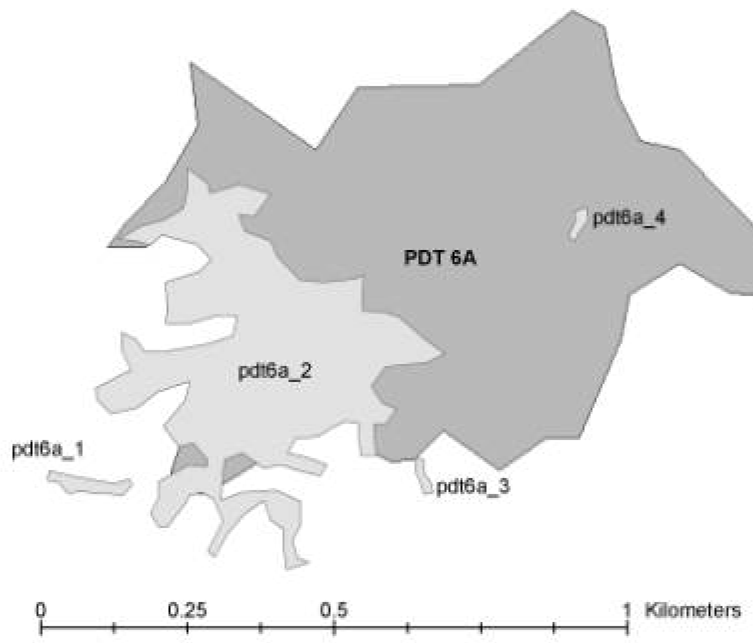


Figure 5. Active Burrows, 2003. Active burrows recorded by GPS in early summer, 2003, overlaid on the colony PDT 6A, mapped in 2001.

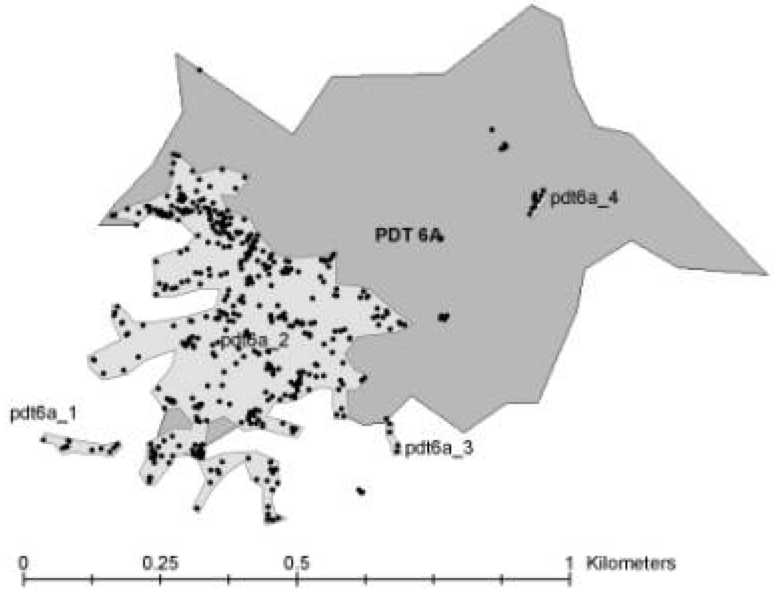


Figure 6. Inactive Burrows, 2003. Inactive burrows recorded by GPS in early summer, 2003, overlaid on the colony PDT 6A, mapped in 2001. The boundaries as drawn in 2001 appear to connect many currently inactive burrows.

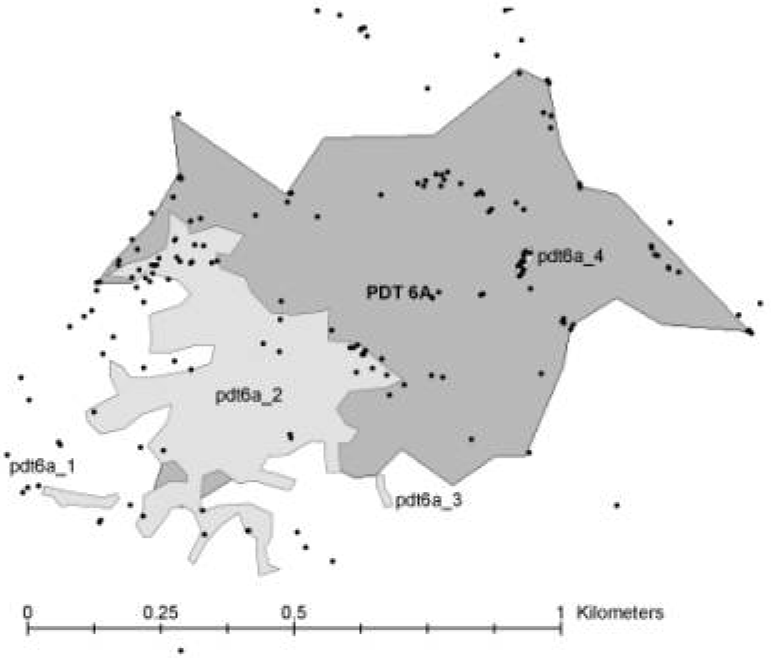


Figure 7. Contracting Colonies in the Southeast Section of the Pinedale Anticline. Areas of white-tailed prairie dog activity mapped in early summer, 2003, in black, are overlaid on the active areas mapped in 2001.

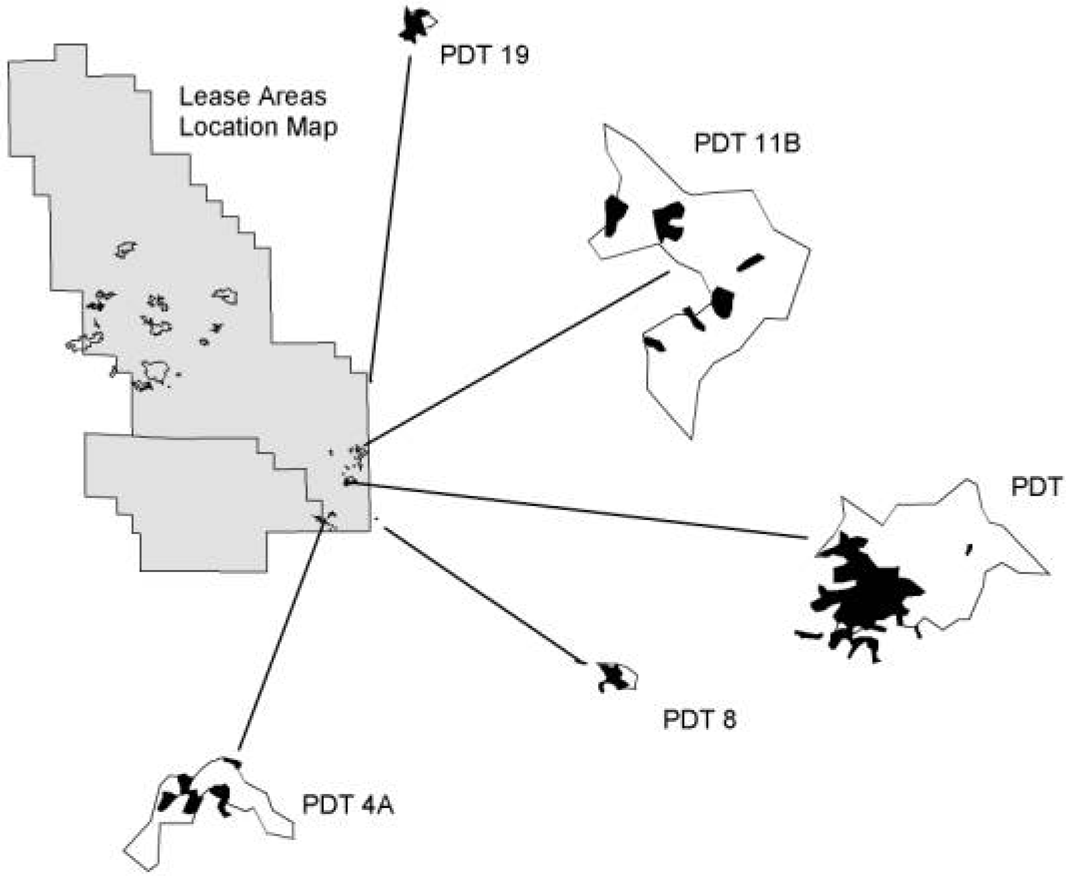
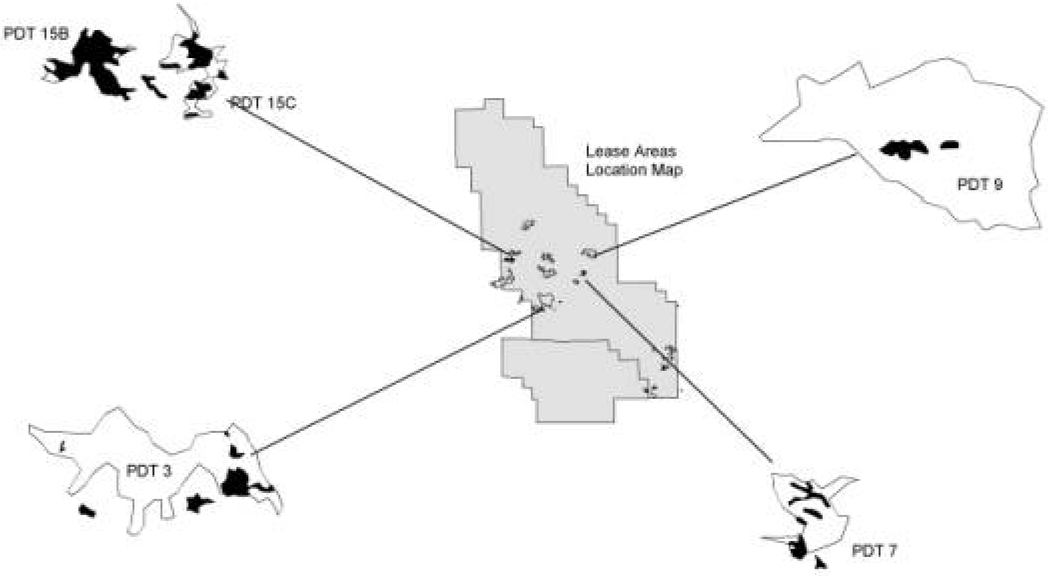


Figure 8. Contracting Colonies in the Central Section of the Pinedale Anticline. Areas of white-tailed prairie dog activity mapped in early summer, 2003, in black, are overlaid on the active areas mapped in 2001.



DEMOGRAPHICS

The density of WTPD per hectare was calculated based on the active burrows per hectare, on the colonies mapped by Genesis Laboratories. The results are shown in Table 5.

The highest density of active burrows, 23 burrows on 0.14 ha (pdt3_1) converts to 167 active burrows per ha. Previously reported numbers range from 9 to 129 per ha (Campbell and Clark 1981). It is assumed that these values in the literature represent both active and inactive burrows. Active burrow density in the colonies we surveyed ranging from about 7 (pdt11b_4) to 167 per hectare, with a mean of 34 per hectare.

Estimates of prairie dog densities were derived from active burrow counts. Most of the densities we recorded fall within the range previously documented, of about 1 – 16 prairie dogs per hectare. Estimates on the colonies we surveyed ranged from about 1 to 25 prairie dogs per hectare, with a mean of 5.0 WTPD per hectare. However, some of the most active areas we mapped are also quite small, e.g., less than 2 ha. On the larger colonies such as pdt6a_2 and pdta5b_1, estimated prairie dog densities were very typical, in the range of about 4 white-tailed prairie dogs per ha. Figure 9 shows the number of active and inactive burrows per colony.

The ratio of active to inactive burrows for each of the active polygons (colonies) surveyed are also shown in Table 5. Twelve of the 36 colonies had ratios below 1.0, indicating poor colony health. Some of these “at risk” colonies form small complexes, i.e., the pdt4a complex, and the pdt15c complex. Figure 10 shows the ratio of active to inactive burrows for each colony.

The estimated reproductive rate, shown in the right column of Table 5, is based on estimated population density and hence on active burrows per unit area, does not correlate with the active:inactive burrow ratio. Some colonies with favorable burrow ratios actually have lower estimated reproductive rates than colonies with “poor” burrow ratios. This survey represents a snapshot of demographic status and therefore the relationships of the burrow ratios and estimated reproductive rates cannot serve as predictors of trend direction in the colonies without more information. Menkens and Anderson (1988) consider white-tailed prairie dogs to be dynamic reproducers which will display a wide range of reproductive output history around the population mean. In fact, they found most demographic traits of the white-tailed prairie dog to be so variable that constructing a life history table for the species is not appropriate. The mean estimated annual reproductive output of colonies we surveyed was 15.1 prairie dogs per hectare.

HABITAT CHARACTERISTICS

Topographic Exposure (Aspect)

Circular plots of the beta terms (mean azimuth) for the base map colonies, ghost polygons, and active colonies mapped in 2003, are presented in Figures 11, 12, and 13, respectively. Each point on the plot represents a colony or polygon. Table 6 lists the mean azimuth and vector length of the base map colonies, ghost polygons, and currently active colonies. Table 7 summarizes the descriptive circular statistics and tests generated for the base map colonies, ghost polygons and the active colonies we mapped.

The mean angle and mean vectors were similar for all three datasets. Mean angles of all polygons in the three groups were: 160°on the base map colonies, 129° among the ghost polygons, and 121° among the currently active colonies. Mean vectors ("evenness" of the dispersion of points around the compass) were 0.556, 0.446 and 0.492, for the base map colonies, ghost polygons, and active colonies, respectively.

Rayleigh's Z statistic was also similar for all three data sets, although the Z values and associated probabilities show the ghost polygons are more uniformly distributed than the former and current active colonies, which display some clustering in the southeast quarter. The circular graphs also demonstrate that none of the sample sets have any points in the northwest quarter of the compass. The orientation of active and former colonies toward the three quarters of the compass with the earliest daily solar exposure (and likely least exposure to prevailing winds) suggests that solar flux may play a role in site selection. The same pattern is apparent in the ghost colonies, but this may be an artifact of the study design. Ghost polygons were not randomly placed anywhere on the landscape, but rather were randomly placed within a fixed radius of existing or former colonies.

Figure 14 plots the energy distributions for the entire area and for the active prairie dog burrows. The frequency distribution curve for the entire area displays a leptokurtic distribution, with values clustered around the mode. The same process applied to the active burrows shows the most frequently occurring value, or mode, is the same but the curve is skewed to the right. We did not compare the two data sets otherwise. But differences between the two distributions raises the possibility that solar heating potential may be a factor in burrow site selection. Therefore, it is recommended that future studies include more robust analyses of these relationships.

Slope

The standard deviations of the slopes in ghost polygons, base map colonies and active polygons were compared. The raw data were not normally distributed, so a square root transformation was applied. The transformed data were normally distributed (chi-square goodness-of fit statistic = 12.1, tabular chi-square = 13.3, alpha = 0.01). Next the data sets were evaluated by Bartlett's test for homogeneity of variance. The transformed data sets met the assumption of homogeneous variance as well.

The mean standard deviations (transformed) of the ghost polygons, base map colonies, and active colonies were 2.83, 2.60, and 1.96, respectively. One-way analysis of variance resulted in a significant F statistic of 14.68 (tabular F = 3.15; alpha 0.05; d.f = 2, 60). Bonnferoni's t-test for means separation was applied, using the original units. The result was that the base map colonies (standard deviation of slope = 7.16) did not differ significantly from the ghost polygons (s.d. = 8.56). However, the active polygons differed significantly from the ghost polygons, with a standard deviation of the slope of 4.38 (calculated t statistic 5.10, tabular value = 1.98; p = 0.05; d.f. = 100, 2).

Summary data of the slope analyses are presented in Table 8.

Comparing the three sample sets, the ghost polygons had the highest maximum slope, the highest mean slope and the highest standard deviation of the mean slope. The standard deviation is a measure of the variability, or evenness of the terrain, regardless of the slope. While the base map colonies, areas that had been occupied recently, had lower values than the ghost colonies in all three measures, the differences were not statistically significant. The active polygons surveyed this year however, had a significantly lower standard deviation than the ghost polygons – about half as much. The maximum slope in the active polygons, and the mean slope, were much lower than the base map polygons or ghost polygons, although these were not analyzed statistically. The results suggest that, with regard to slope, the prairie dogs are not selecting sites randomly from the available landscape. The fact that the base map colony values are much more similar to the ghost polygons than to the active polygons may indicate that the base map colonies encompass favored as well as marginal habitat. The current active polygons may represent preferred habitat selected by the prairie dogs, or habitat which contributes more to the success of white-tailed prairie dogs due to better predator detection, improved communications, or other factors.

SOIL CHARACTERISTICS

Soil Surface Particle Size

The soil surface particle size results are presented in Table 9. Analysis by the chi square test for a fixed ratio, using the ghost polygon data as the expected values, found a highly significant difference in the base map colony results. However, the difference may be in the amount of vegetative cover rather than soil particle size. As seen in Table 9, the values for the different mineral sizes are very similar in both data sets. Indeed in the field we observed that the colonies are found across a very heterogeneous geologic landscape. While large rocks were not common in the soils we sampled, we noted for instance that on PDT 4A, a number of active burrows had been established in very rocky soil, with ejecta of cobbles strewn about the mounds.

The difference in cover attributes appears to be in the vegetative cover. The base map colonies have almost twice as many sampling "hits" on vegetation. Whether the prairie dogs select the sites because of greater vegetative cover, or the cover is a result of the prairie dog activity, is not known. The results are presented graphically in Figure 15.

Percent Rocks in Sub-surface Layers

The rock content at a depth of 0.5 meters was measured for each of four samples from the base map colonies and four samples from the corresponding ghost polygons. The four sample points for each colony or ghost polygon were averaged. The average values were analyzed by ANOVA. Because these results were percentage data a square root transformation was applied first. The transformed data sets passed the chi-square test for normal distribution, and the F-test for equality of variances. The summary data are presented in Table 10. There were no significant differences in the percent rocks at 0.5 m depth between base map colonies and ghost colonies (F= 2.088, Tabular F = 4.08: alpha = 0.05; d.f. = 1,40). This result confirms our casual observations, that the habitat in the study area is very diverse geologically, and prairie dog colonies are scattered across a broad spectrum of soil types and textures.

Soil Depth

The soil depth was determined at each of four samples sites on the base map colonies and the corresponding ghost polygons. The four results for each colony or ghost polygon were averaged. The average values were analyzed by the Kruskal-Wallis non-parametric test because the original data sets did not meet the assumptions of ANOVA. The mean depths were 0.95 m on the ghost polygons, and 0.94 m on the base map colonies. The summary data are presented in Table 12. There were no significant differences in the depth we were able to drill with the hand auger between base map colonies and ghost colonies (calculated H value = 0.009; critical H value = 3.840). Although we occasionally encountered a hardpan layer at less than one meter depth, at the majority of the sample sites we were able to drive the auger at least one meter. To the extent that the hand driven auger corresponds to the ability of prairie dogs to burrow, it would appear that adequate soil depth is not a factor in colony location or success in the study area.

SUMMARY

A survey of 31 previously mapped white-tailed prairie dog colonies in the Pinedale Anticline Lease Area of the Pinedale Field Office was conducted in late May and early June, 2003. Prairie dog burrows on and near the colonies were mapped with GPS/GIS and classified as active or inactive, according to burrow diameter, depth, and the presence or absence of fresh prairie dog droppings. Prairie dog density and potential reproductive rates at each site were calculated from the field data and values in the literature. Habitat characteristics including slope, aspect and soil texture and depth were compared between the original colonies and nearby ghost polygons. The ghost polygons were computer generated replicas of the actual colonies that were superimposed on the landscape at randomly chosen locations near each actual colony and within a range that was accessible to the prairie dogs. The premise was that if the prairie dog were selecting locations in a non-random manner, there would be differences between important habitat features at the actual colonies and ghost polygons.

The survey found that there has been a dramatic reduction in the number of colonies, with only 15 of 29 colonies still active. That is, we found no indication of activity at 14 of the colonies that had been active in 2001. In terms of area, the active colonies we mapped in the vicinity of the 29 original colonies totaled just 71 ha. The original colonies comprised 1407 ha. in 2001. We did not survey two large colonies, PDT 12 and PDT 14, which appear to still be active. We also encountered and mapped the perimeter of a large, active colony not appearing on our 2001 maps. This colony was labeled pdtgl20, and lies to the southwest of PDT 20.

Out of the 37 newly mapped active colonies, 25 had what is considered a favorable or healthy ratio of active to inactive burrows (> 1.0). Twelve colonies had ratios below 1.0
It has been noted that white-tailed prairie dogs colonies are very dynamic, with populations and areas of occupancy fluctuating widely. This pattern may be linked to seasonal and year to year fluctuations in the availability, quantity, and nutritional value of vegetation (Menkens and Anderson 1988).

The apparent overall loss of numbers and areas occupied since 2001 is cause for concern. Even acknowledging normal wide population fluctuations and natural losses to predation, the changes we observed in just two years is striking. The factors which threaten prairie dogs on a large scale include loss of habitat, urbanization, resource development, poisoning, recreational shooting and sylvatic plague (*Yersinia pestis*). Of these, plague must be considered the as a factor in this study area, as well as throughout the range of the white-tailed prairie dog (Knowles 2002). At this time we know of no specific data on the incidence of plague among the prairie dogs in the study area.

Our comparison of habitat variables between the 2001 colonies and the randomly located ghost polygons did not indicate significant differences in soil depth (to one meter), or in percent rocks at a depth of 0.5 meter. We had hypothesized that variations in soil depth might affect site selection with regard to the ability to dig below the frost line. However, we found soil depth is adequate throughout most of the area and does not seem to be limiting factor. Similarly, the “rockiness” of the soil was similar at colonies and ghost polygons. We also observed active burrows in very rocky areas, so again, this does not appear to be a factor affecting colony location or success. Regarding soil cover, the frequency distribution of mineral particle sizes on the surface was found to be almost identical between colonies and ghost polygons. However there was nearly twice the amount of vegetative cover on colonies as opposed to ghost polygons. Whether this is a cause or result of prairie dog occupancy is unknown.

The evenness of the slope was examined as well. We found the slope variation to be very similar in the 2001 colonies and the ghost polygons. But the slope variation on the currently occupied colonies was on average about half that of the other areas examined. The hypothesis that evenness of slope may facilitate improved communications and predator detection cannot be ruled out and deserves further examination.

Regarding solar flux, the analysis demonstrated differences between active burrow and background distribution patterns. This raises the possibility that solar heating potential may be a factor in burrow site selection and it is recommended that future studies include more conclusive and robust statistical analysis of these relationships.

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TABLES AND FIGURES

TABLE 1

Habitat Correlates of Prairie Dog Species

(Compiled and adapted from Belak 2001, and Wagner 2002).

Species	Habitat Features Correlated with Prairie Dog Presence
Black-tailed Prairie Dog (*Cynomys ludovicianus*)	1. Low vegetation height. 2. Grassland . 3. Slope less than 10%. 4. Moderately clayey silt loams. a) Mean % clay of top soil horizon. b) Mean % clay of all soil horizons.
Mexican Prairie Dog (*Cynomys mexicanus*)	1. Grasslands dominated by grass, forbs and bare ground. 2. Loamy soils.
Utah Prairie Dog (*Cynomys parvidens*)	1. Vegetation height. 2. Vegetation composition. 3. Deep, well drained soils.
Gunnison's Prairie Dog (*Cynomys gunnisoni*)	1. Deep soils (provide hibernacula below frost level). 2. Even slope (little variation in slope: thought to improve the ability to detect predators and vocal communications). 3. Comparatively low rock content on the surface and at burrowing depths which may influence costs and benefits of constructing burrows at a site. *4. Mean rock content was not correlated.* *5. Mean clay content was not correlated.* 6. *Mean sand content was not correlated.*
White-tailed Prairie Dog (*Cynomys leucurus*)	No detailed studies have been reported. What information is available indicates that the white-tailed prairie dog is similar to the Gunnison's prairie dog in that both species occupy a wide range of elevations and a variety of vegetation communities.

TABLE 2

Data Collection Matrix, and Results of Presence/Absence Surveys

(“1” indicates a survey task was completed at a site, and a positive result in the presence/absence surveys; “0” indicates a negative result in the presence/absence surveys; "-" indicates missing data at the site indicted)

Count	PLOT ID	PRESENCE/ABSENCE SURVEY(S) 1 = POSITIVE; 0 = NEGATIVE; - = not surveyed				ACTIVE BURROW SURVEY	BURROW SURVEY METHOD	PLOT SOIL SURVEY	GHOST PLOT SOIL SURVEY
		1	2	3	4				
1	1	0	0	0	-	1	Census	1	1
2	2A	0	0	-	-	1	Census	-	1
3	2B	0	0	0	-	1	Census	1	1
4	3	0	0	-	-	1	Census	1	1
5	4A	0	0	-	-	1	Census	1	1
6	4X	0	0	-	-	1	Census	1	1
7	5	1	1	1	-	1	Census	1	1
8	6A	1	1	-	-	1	Census	1	1
9	7	1	-	-	-	1	Census	1	1
10	8	1	-	-	-	1	Census	1	1
11	9	1	-	-	-	1	Biggins	1	1
12	10	1	-	-	-	1	Biggins	1	1
13	11A	0	0	0	-	1	Census	1	1
14	11B	1	-	-	-	1	Census	1	1
15	11C	0	0	-	-	1	Census	1	1
16	11D	0	0	-	-	1	Census	1	1
17	11E	0	0	-	-	1	Census	1	1
18	11F	0	-	-	-	1	Census	1	1
19	12	OMIT - MTN. PLOVER NEST				0	0	-	-
20	13A	0	0	0	-	1	Census	1	1
21	13B	0	0	0	-	1	Biggins	1	1
22	13C	1	-	-	-	1	Census	1	1
24	14	NOT SURVEYED				0	0	1	1
25	15A	1	-	-	-	1	Biggins	1	1
26	15B	1	-	-	-	1	Census	1	1
27	15C	1	-	-	-	1	Census	1	1
28	16	1	-	-	-	1	Census	1	-
29	18	1	-	-	-	1	Census	1	1
29	17	0	1	-	-	1	Census	1	1
30	19	1	-	-	-	1	Census	1	1
31	20	0	0	0	-	1	Census	1	1

TABLE 3

Base Map Colony Areas
(TRC Mariah Survey, 2001)

PDT NUMBER	ACRES	HECTARES
PDT 1	74.48	30.14
PDT 2A	876.11	354.55
PDT 2B	14.80	5.99
PDT 3	213.25	86.30
PDT 4A	38.52	15.59
PDT 4B	6.89	2.79
PDT 4C	1.88	0.76
PDT 4D	0.70	0.28
PDT 4E	1.19	0.48
PDT 5	9.54	3.86
PDT 6A	122.82	49.70
PDT 6B	1.10	0.44
PDT 7	71.37	28.88
PDT8	4.14	1.68
PDT 9	515.83	208.75
PDT 10	460.16	186.22
PDT 11A	18.49	7.48
PDT 11B	176.83	71.56
PCT 11C	1.19	0.48
PDT 11D	7.06	2.86
PDT 11E	3.37	1.37
PDT 11F	25.52	10.33
PDT 12	68.89	27.88
PDT 13A	32.99	13.35
PDT 13B	140.50	56.86
PDT 13C	27.64	11.18
PDT 14	748.86	303.05
PDT 15A	147.51	59.69
PDT 15B	26.68	10.80
PDT 15C	41.50	16.80
PDT 16	351.32	142.17
PDT 17	19.17	7.76
PDT 18	2.21	0.89
PDT 19	2.98	1.20
PCT 20	38.74	15.68
Total Area	4294.25	1737.82

TABLE 4

Active Colonies Areas Surveyed
by Genesis Laboratories May-June, 2003

pdt NUMBER	ACRES	HECTARES
pdt3_1	0.34	0.14
pdt3_2	1.99	0.81
pdt3_3	4.14	1.68
pdt3_4	12.50	5.06
pdt3_5	1.59	0.64
pdt3_6	0.26	0.11
pdt4a_1	3.03	1.23
pdt4a_2	2.11	0.85
pdt4a_3	0.50	0.20
pdt4a_4	1.21	0.49
pdt5_1	1.21	0.49
pdt6_1	1.34	0.54
pdt6a_1	0.74	0.30
pdt6a_2	37.87	15.33
pdt6a_3	0.23	0.09
pdt6a_4	0.24	0.10
pdt6_2	4.54	1.84
pdt6_3	1.63	0.66
pdt6_4	4.72	1.91
pdt6_5	0.81	0.33
pdt8_1	2.43	0.98
pdt9_1	9.88	4.00
pdt9_2	2.05	0.83
pdt11b_1	1.02	0.41
pdt11b_2	1.13	0.46
pdt11b_3	3.33	1.35
pdt11b_4	1.08	0.44
pdt11b_5	5.19	2.10
pdt11b_6	3.64	1.47
pdt15b_1	41.22	16.68
pdt15c_1	2.66	1.08
pdt15c_2	1.39	0.56
pdt15c_3	4.33	1.75
pdt15c_4	0.90	0.36
pdt15c_5	9.75	3.95
pdt15c_6	0.57	0.23
pdt19_1	3.61	1.46
Total Area	175.18	70.91

TABLE 5

Estimated White-tailed Prairie Dog Density and Annual Reproduction on Active Colonies in the Pinedale Anticline Lease Area, May-June 2003.

Colonies with a ratio of active:inactive burrows of <1.0 are in bold face.
Colonies with no inactive burrows (pdt6-2, pdt6_3, pdt6a-1 and pdt6a_3) were assigned a dummy variable of 1 (inactive burrow) in order to calculate the ratio.

Colony (Polygon) I.D.	Active Burrows	Area (ha)	Active Burrow Density per ha	Inactive Burrows	Ratio Active:Inactive Burrows	Estimated WTPD Density per ha	Estimated Annual Reproductive Output per ha
pdt3_1	23	0.14	166.54	9	2.6	24.56	74.05
pdt3_2	39	0.81	48.43	22	1.8	7.14	21.53
pdt3_3	**33**	**1.68**	**19.69**	**43**	**0.8**	**2.9**	**8.76**
pdt3_4	**54**	**5.06**	**10.68**	**61**	**0.9**	**1.57**	**4.75**
pdt3_5	19	0.64	29.51	5	3.8	4.35	13.12
pdt3_6	14	0.11	131.93	4	3.5	19.46	58.66
pdt4a_1	25	1.23	20.37	20	1.3	3	9.06
pdt4a_2	**21**	**0.85**	**24.58**	**46**	**0.5**	**3.62**	**10.93**
pdt4a_3	**6**	**0.2**	**29.63**	**13**	**0.5**	**4.37**	**13.17**
pdt4a_4	7	0.49	14.28	7	1	2.11	6.35
pdt5_1	16	0.49	32.75	11	1.5	4.83	14.56
pdt6_1	6	0.54	11.07	5	1.2	1.63	4.92
pdt6_2	62	1.84	33.71	0(1)	33.7	4.97	14.99
pdt6_3	18	0.66	27.34	0(1)	27.3	4.03	12.16
pdt6_4	41	1.91	21.47	1	41	3.17	9.55
pdt6_5	6	0.33	18.41	4	1.5	2.71	8.19
pdt6a_1	11	0.3	36.55	0(1)	36.55	5.39	16.25
pdt6a_2	430	15.33	28.05	39	11	4.14	12.47
pdt6a_3	4	0.09	42.95	0(1)	42.95	6.33	19.1
pdt6a_4	**10**	**0.1**	**105.11**	**12**	**0.8**	**15.5**	**46.74**
pdt8_1	**25**	**0.98**	**25.4**	**32**	**0.8**	**3.75**	**11.29**
pdt9_1	74	4	18.51	4	18.5	2.73	8.23
pdt9_2	26	0.83	31.3	3	8.7	4.62	13.92
pdt11b_1	12	0.41	29.19	4	3	4.3	12.98
pdt11b_2	6	0.46	13.1	3	2	1.93	5.83
pdt11b_3	**13**	**1.35**	**9.65**	**15**	**0.9**	**1.42**	**4.29**
pdt11b_4	3	0.44	6.86	2	1.5	1.01	3.05
pdt11b_5	21	2.1	10	20	1.1	1.48	4.45
pdt11b_6	14	1.47	9.5	8	1.8	1.4	4.23
pdt15b_1	446	16.68	26.74	106	4.2	3.94	11.89
pdt15c_1	**50**	**1.08**	**46.46**	**81**	**0.6**	**6.85**	**20.66**
pdt15c_2	**36**	**0.56**	**64.13**	**78**	**0.5**	**9.46**	**28.52**
pdt15c_3	**71**	**1.75**	**40.53**	**96**	**0.7**	**5.98**	**18.02**
pdt15c_4	**5**	**0.36**	**13.74**	**14**	**0.4**	**2.03**	**6.11**
pdt15c_5	**32**	**3.95**	**8.11**	**87**	**0.4**	**1.2**	**3.61**
pdt19_1	27	1.46	18.47	6	4.5	2.72	8.21

TABLE 6. Topographic Aspect of Base Map Colonies, Ghost Polygons, and Active Polygons.

POLYGON I.D.	BASE MAP COLONIES		GHOST POLYGONS		POLYGON I.D.	ACTIVE COLONIES	
	Beta	Length	Beta	Length		Beta	Length
PDT 1	129	2625	15	534	pdt3_1	136	14
PDT 2A	129	22482	135	18274	pdt3_2	205	76
PDT 2B	158	480	118	562	pdt3_3	16	168
PDT 3	119	4976	0	4772	pdt3_4	146	278
PDT 4A	144	395	75	884	pdt3_5	157	51
PDT 4X	226	1231	193	2135	pdt3_6	163	9
PDT 5	218	361	186	150	pdt4a_1	91	106
PDT 6A	36	1303	55	3063	pdt4a_2	24	51
PDT 7	126	2383	172	1451	pdt4a_3	22	19
PDT 8	180	155	4	161	pdt4a_4	256	46
PDT 9	203	7923	136	11411	pdt5_1	241	45
PDT 10	210	8435	251	3411	pdt6_1	155	51
PDT 11A	134	356	172	305	pdt6_2	142	159
PDT 11B	5	2848	179	4317	pdt6_3	138	64
PDT 11C	197	41	54	27	pdt6_4	149	171
PDT 11D	224	229	53	132	pdt6_5	148	30
PDT 11E	91	131	195	76	pdt6a_1	23	31
PDT 11F	36	301	107	376	pdt6a_2	55	866
PDT 12	183	705	226	780	pdt6a_3	242	2
PDT 13A	205	703	102	1195	pdt6a_4	55	8
PDT 13B	227	3032	256	2785	pdt8_1	93	88
PDT 13C	230	686	152	570	pdt9_1	172	378
PDT 14	123	20900	160	22603	pdt9_2	160	81
PDT 15A	125	3454	96	3014	pdt11b_1	204	31
PDT 15B	115	893	120	809	pdt11b_2	74	43
PDT 15C	166	1299	25	1075	pdt11b_3	63	116
PDT 16	122	8533	79	3384	pdt11b_4	145	36
PDT 17	227	695	203	662	pdt11b_5	62	101
PDT 18	185	63	163	82	pdt11b_6	36	77
PDT 20	39	969	115	735	pdt15b_1	156	1182
					pdt15c_1	193	105
					pdt15c_2	69	55
					pdt15c_3	153	169
					pdt15c_4	96	33
					pdt15c_5	103	348
					pdt15c_6	50	23
					pdt19_1	127	104

Notes: "Beta" is the mean azimuth of each polygon. Mean aspect is a function of both direction (angle) and vector length or magnitude. Magnitude is strongly affected by cell counts, i.e., larger polygons will tend to have larger vector lengths.

TABLE 7

Summary of Topographic Aspect Analyses

	Base Map Colonies	Ghost Polygons	Currently Active Colonies
Mean Angle	160.1°	128.7°	120.5°
Mean Vector	0.556	0.446	0.492
Rayleigh’s Z	9.572	6.173	8.964
Probability (Z)	0.00003	0.00165	0.00008

Notes:
1. Mean angle is used in the conventional sense, an average of the mean angle of all colonies or polygons in the set.
2. Mean vectors range from zero (0.0) to one (1.0); zero indicating maximum possible dispersion of vectors and one indicating no dispersion.
3. Rayleigh’s Z statistic is a measure of the uniformity of distribution of mean vectors, and the associated probability estimates the likelihood that the data are sampled from a uniform distribution.

TABLE 8. Slope Parameters of Base Map Colonies, Ghost Polygons, and Active Polygons.

MARIAH POLYS				GHOST POLYS			ACTIVE POLYS			
I.D.	Mean Slope	Max. Slope	Standard Deviation	Mean Slope	Max. Slope	Standard Deviation	I.D.	Mean Slope	Max. Slope	Standard Deviation
PDT 1	7.56	16	4.87	12.50	25	7.65	s2pdt_3.cor	16.50	33	9.96
PDT 2A	15.00	30	9.09	29.50	59	17.46	pdt3_1	4.50	6	1.29
PDT 2B	6.00	12	3.89	6.00	11	3.32	pdt3_2	6.50	11	3.03
PDT 3	17.06	36	10.35	10.14	21	6.43	pdt3_3	4.50	7	1.87
PDT 4A	12.77	26	8.00	11.50	23	7.07	pdt3_4	16.24	33	10.00
PDT 4X	19.50	39	11.69	9.00	18	5.63	pdt3_5	4.00	7	2.37
PDT 5	9.94	18	5.15	13.16	26	7.60	pdt3_6	4.00	5	1.00
PDT 6A	9.50	19	5.92	9.00	18	5.63	pdt4a_1	3.63	8	2.67
PDT 7	7.56	16	4.87	8.50	17	5.34	pdt4a_2	3.50	7	2.45
PDT 8	13.05	23	5.72	4.50	7	1.87	pdt4a_3	7.00	9	1.58
PDT 9	14.00	28	8.51	16.50	33	9.96	pdt4a_4	7.71	11	2.56
PDT 10	9.00	18	5.63	8.00	16	5.05	s1pdt5.cor	10.07	18	4.59
PDT 11A	12.00	24	7.36	10.59	22	6.65	pdt5_1	11.08	18	4.03
PDT 11B	15.00	30	9.09	16.53	34	10.01	pdt6_1	2.50	5	1.87
PDT 11C	5.00	8	2.16	17.14	32	7.82	pdt6_2	3.00	6	2.16
PDT 11D	3.00	6	2.16	19.28	42	11.87	pdt6_3	1.50	3	1.29
PDT 11E	8.00	14	3.89	10.76	27	7.56	pdt6_4	1.50	3	1.29
PDT 11F	7.07	15	4.59	5.00	10	3.32	pdt6_5	3.00	5	1.58
PDT 12	4.50	9	3.03	13.00	26	7.94	pdt6a_1	9.50	14	3.03
PDT 13A	7.07	15	4.59	22.60	46	13.60	pdt6a_2	5.00	10	3.32
PDT 13B	12.00	24	7.36	8.12	17	5.24	pdt6a_3	1.50	3	1.29
PDT 13C	6.00	12	3.89	6.50	13	4.18	pdt6a_4	9.00	10	1.00
PDT 14	21.00	42	12.56	21.00	42	12.56	pdt8_1	13.00	23	5.45
PDT 15A	22.00	44	13.13	30.00	60	17.75	s4pdt9.cor	8.00	16	5.05
PDT 15B	17.47	33	9.44	16.00	30	8.51	pdt9_1	4.00	8	2.74
PDT 15C	14.60	30	8.97	21.31	47	13.49	pdt9_2	8.50	12	2.45
PDT 16	24.62	50	14.76	32.02	65	18.93	s2pdt10.cor	9.00	18	5.63
PDT 17	12.04	25	7.02	21.63	44	11.91	pdt11b_1	13.38	21	5.06
PDT 18	5.64	11	3.75	7.00	12	3.32	pdt11b_2	14.63	24	4.99
PDT 20	22.52	46	13.46	16.00	31	9.09	pdt11b_3	9.33	18	5.00
							pdt11b_4	4.11	9	2.93
							pdt11b_5	12.00	23	6.78
							pdt11b_6	13.24	26	7.69
							pdt15b_1	20.55	42	11.78
							pdt15c_1	16.67	28	5.66
							pdt15c_2	10.00	14	2.74
							pdt15c_3	15.56	25	5.62
							pdt15c_4	7.40	12	3.20
							pdt15c_5	6.50	12	3.61
							pdt15c_6	5.00	7	1.58
							s4pdt15a.cor	21.00	42	12.56
							s4pdt16.cor	26.52	54	15.76
							pdt19_1	3.00	6	2.16
							s3pdtgl20-1.cor	16.30	35	10.13

TABLE 9

Summary of Slope Analyses

	Base Map Colonies (degrees)	Ghost Polygons (degrees)	Currently Active Colonies (degrees)
Mean Slope	12.0	14.4	8.94
Maximum Slope	24.0	29.1	16.1
Standard Deviation Of Slope	7.16	8.56	4.38*

* Significantly different from Ghost Polygons.

TABLE 10

Soil Surface Particle Sizes at Base Map Colonies and Ghost Polygons

Category	Base Map Colonies		Ghost Polygons	
	Number	Percent	Number	Percent
Sand/Silt/Clay (< 2 mm)	1045	77.8	1035	77.0
Gravel (2-4 mm)	147	10.9	182	13.5
Pebble (4-64 mm)	67	5.0	77	5.7
Cobble (> 64 mm)	4	0.3	6	0.4
Vegetation	81	6.0	44	3.3
Total	1344	100	1344	100

TABLE 11

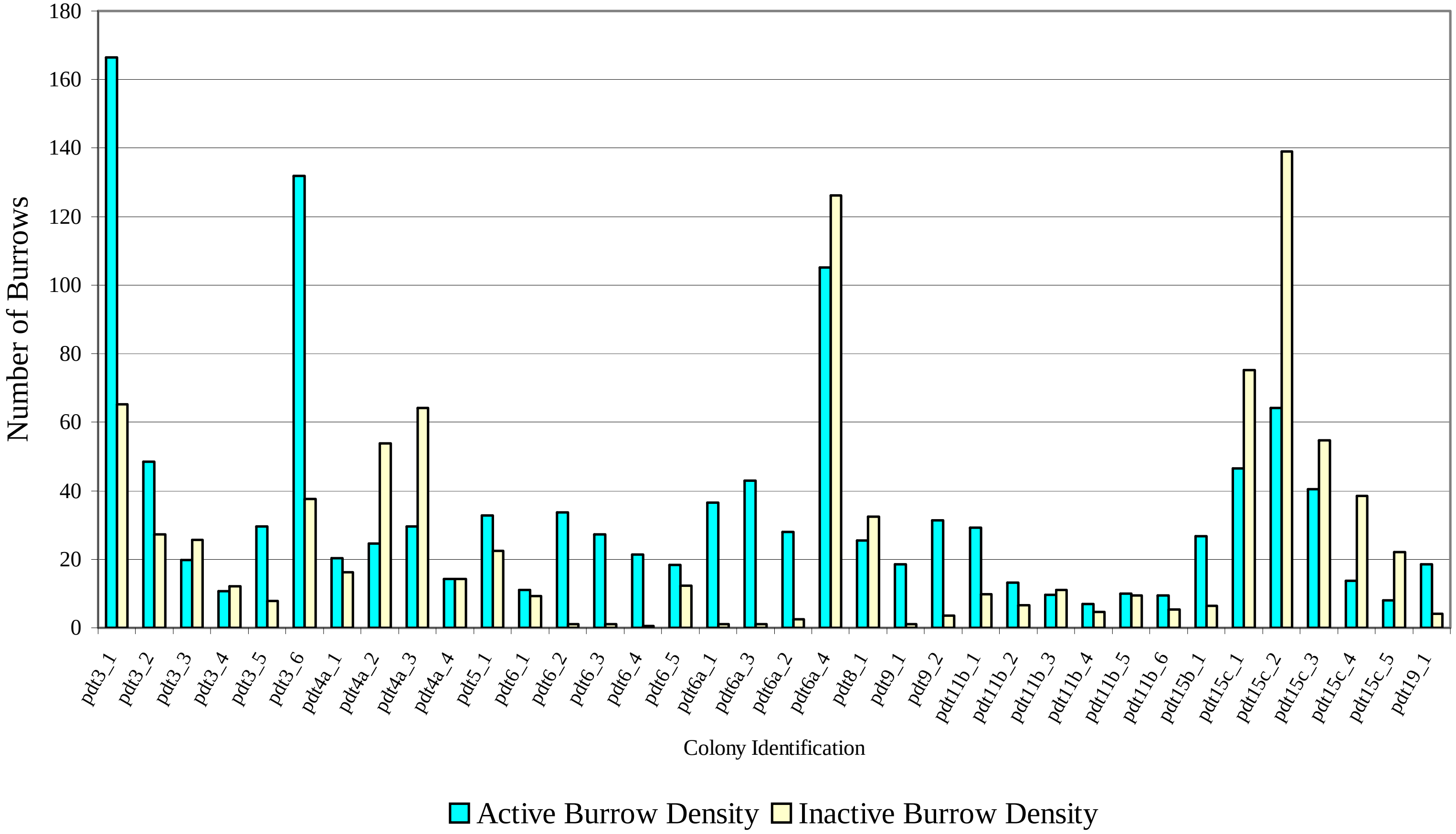
Percent Rocks at 0.5 m depth at Base Map Colonies and Ghost Polygons

Colony ID	Ghost Polygon % Rock	Base Map Colony % Rock
PDT9	0.7	0.0
PDT 15A	0.0	0.0
PDT 13B	0.4	0.0
PDT 13A	0.8	0.0
PDT 15C	0.8	17.2
PDT 13C	3.4	0.0
PDT 15B	14.9	6.5
PDT 10	0.0	0.0
PDT 17	13.0	0.7
PDT 7	1.2	3.0
PDT 1	3.9	0.0
PDT 2B	0.9	1.1
PDT 3	0.6	0.7
PDT 19	2.9	0.1
PDT 18	0.4	1.0
PDT 11B	0.1	1.7
PDT 11A	2.7	1.8
PDT 5	0.2	0.3
PDT 11C	1.4	0.4
PDT 11F	20.0	0.0
PDT 11E	7.6	0.2
PDT 11D	1.2	1.9
PDT 6A	2.5	0.4
PDT 4A	1.8	5.4
PDT 20	0.0	0.8
PDT 8	1.1	0.8
PDT 4X	0.0	1.8
Mean	3.1	1.7

TABLE 12

Maximum Depth Reached with Auger at Ghost Polygons and Base Map Colonies

Colony ID	Ghost Polygons (m)	Base Map Colonies (m)
PDT 1	1.00	1.00
PDT 2B	1.00	1.00
PDT 3	1.00	1.00
PDT 4A	1.00	1.00
PDT 4X	1.00	0.84
PDT 5	1.00	1.00
PDT 6A	1.00	1.00
PDT 7	1.00	1.00
PDT 8	1.00	1.00
PDT 9	1.00	1.00
PDT 10	1.00	1.00
PDT 11A	1.00	1.00
PDT 11B	1.00	1.00
PDT 11C	1.00	1.00
PDT 11D	1.00	1.00
PDT 11E	1.00	1.00
PDT 11F	1.00	1.00
PDT 13A	0.88	1.00
PDT 13B	1.00	1.00
PDT 13C	1.00	1.00
PDT 14	0.61	0.30
PDT 15A	0.95	0.94
PDT 15B	0.13	0.88
PDT 15C	1.00	0.81
PDT 17	0.95	0.64
PDT 18	1.00	1.00
PDT 19	1.00	1.00
PDT 20	0.98	1.00
Mean	0.95	0.94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140
120
100
80
60
40
20
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pdt3_5
pdt3_6
pdt4a_1
pdt4a_2
pdt4a_3
pdt4a_4
pdt5_1
pdt6_1
pdt6_2
pdt6_3
pdt6_4
pdt6_5
pdt6a_1
pdt6a_3
pdt6a_2
pdt6a_4
pdt8_1
pdt9_1
pdt9_2
pdt11b_1
pdt11b_2
pdt11b_3
pdt11b_4
pdt11b_5
pdt11b_6
pdt15b_1
pdt15c_1
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pdt15c_4
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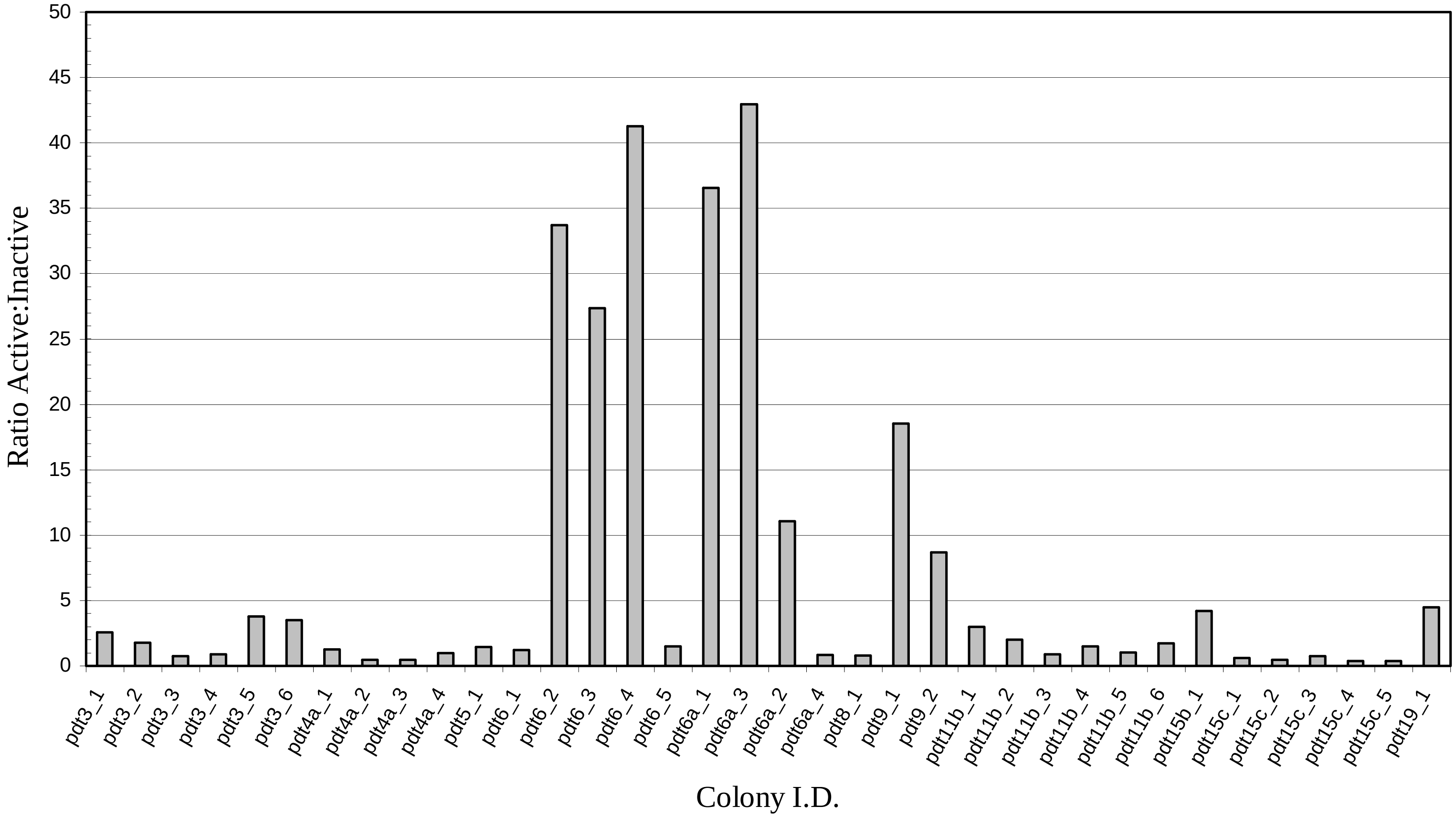
pdt19_1
Colony Identification
Active Burrow Density
Inactive Burrow Density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40
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25
20
15
10
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pdt11b_2
pdt11b_3
pdt11b_4
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pdt11b_6
pdt15b_1
pdt15c_1
pdt15c_2
pdt15c_3
pdt15c_4
pdt15c_5
pdt19_1
Colony I.D.

FIGURE 11

Mean Azimuth of Base Map Colonies

The grand mean azimuth for all base map colonies is 160°.

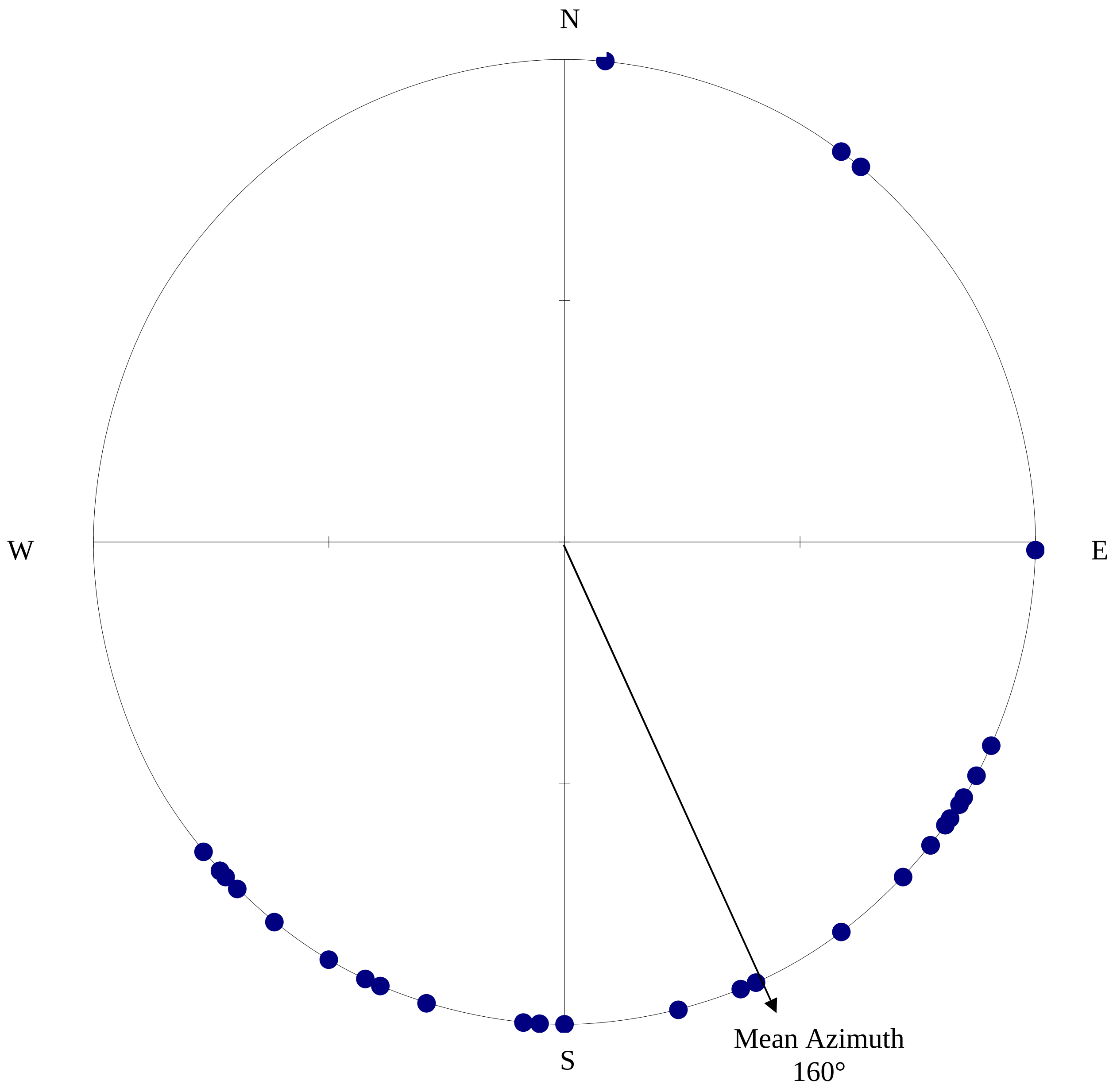


FIGURE 12

Mean Azimuth of Ghost Polygons

The grand mean azimuth for all ghost polygons is 129°.

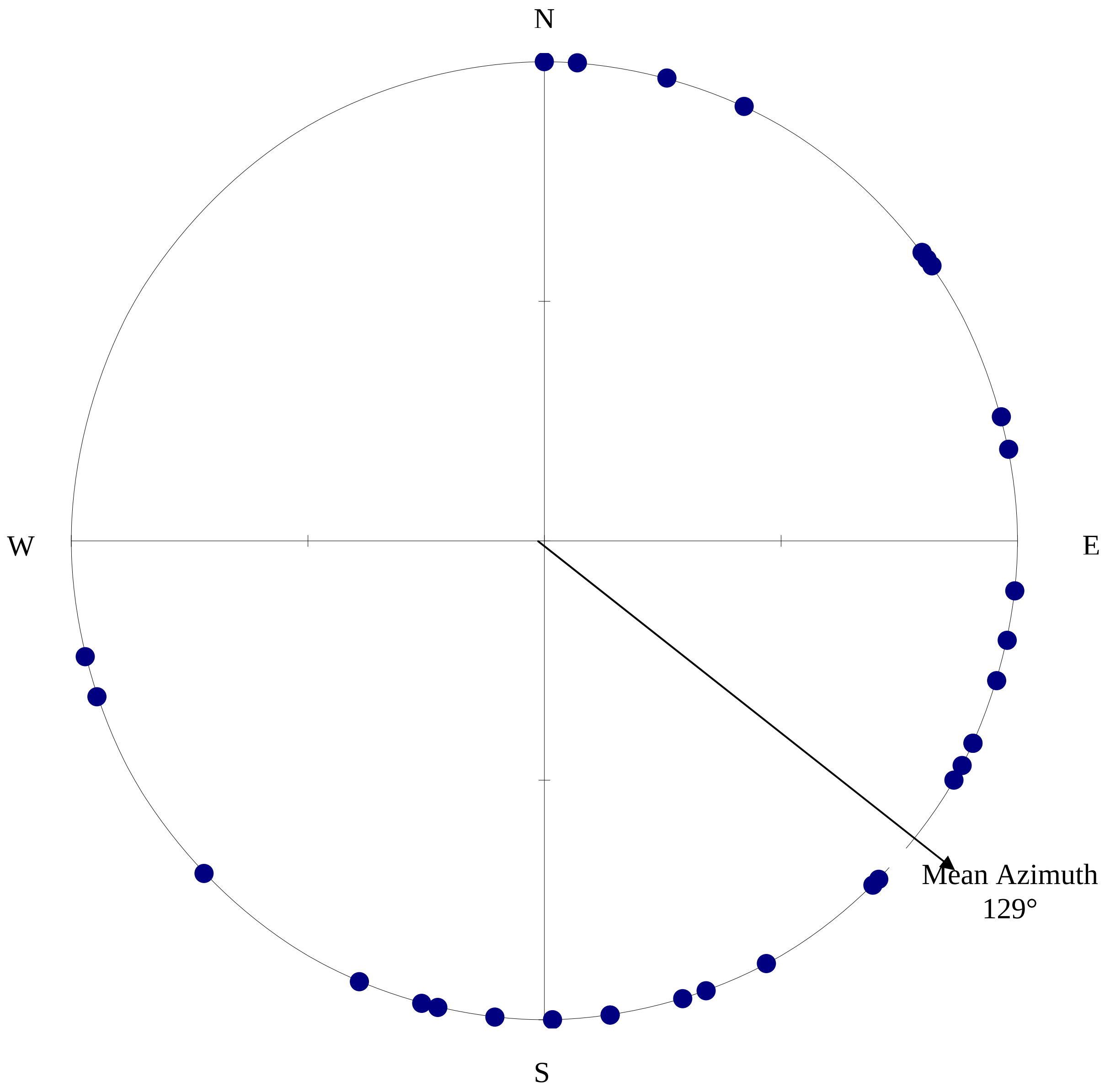


FIGURE 13

Mean Azimuth of Active Colonies Surveyed May-June 2003.

The grand mean azimuth for all active colonies is 121°.

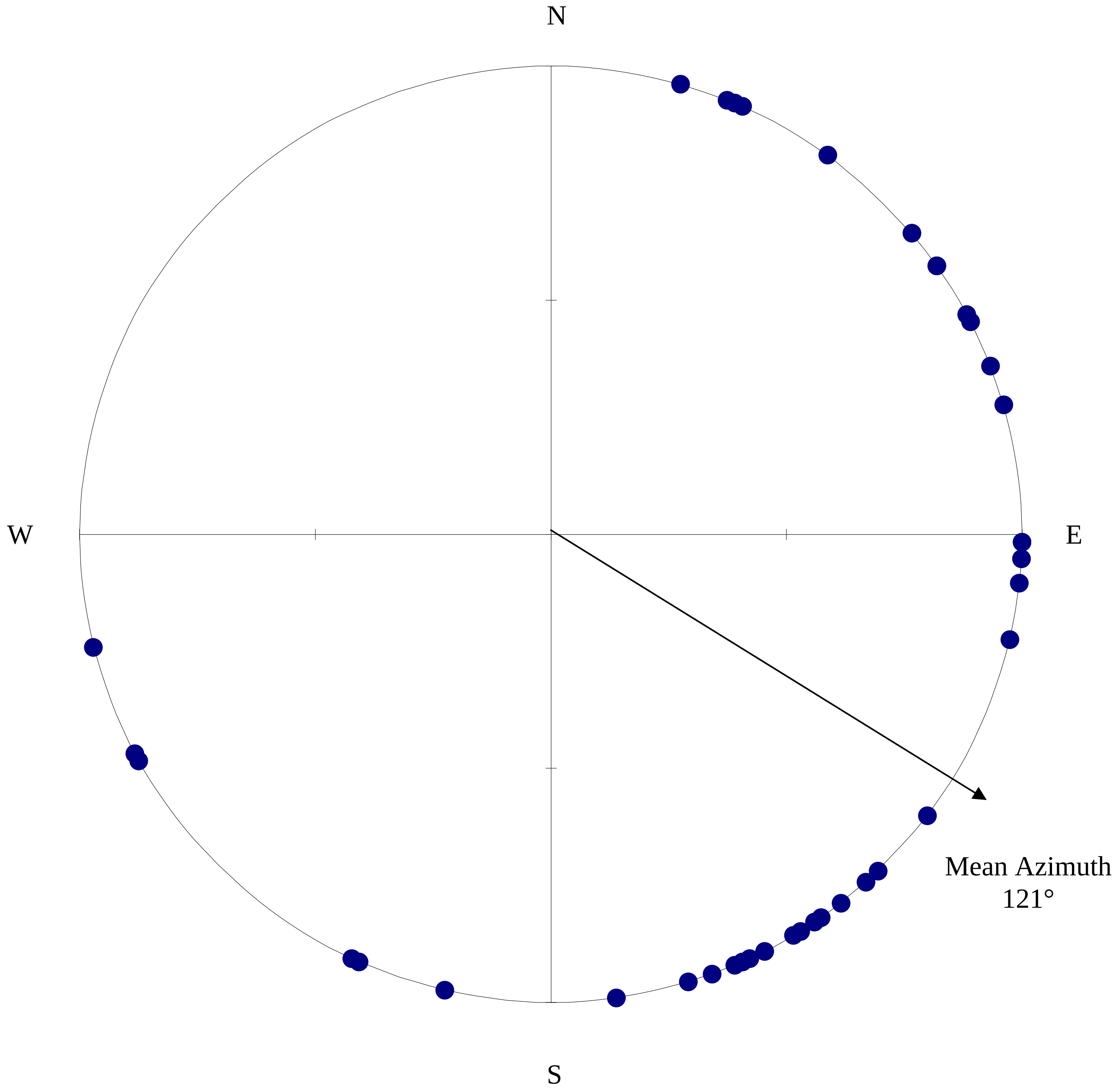
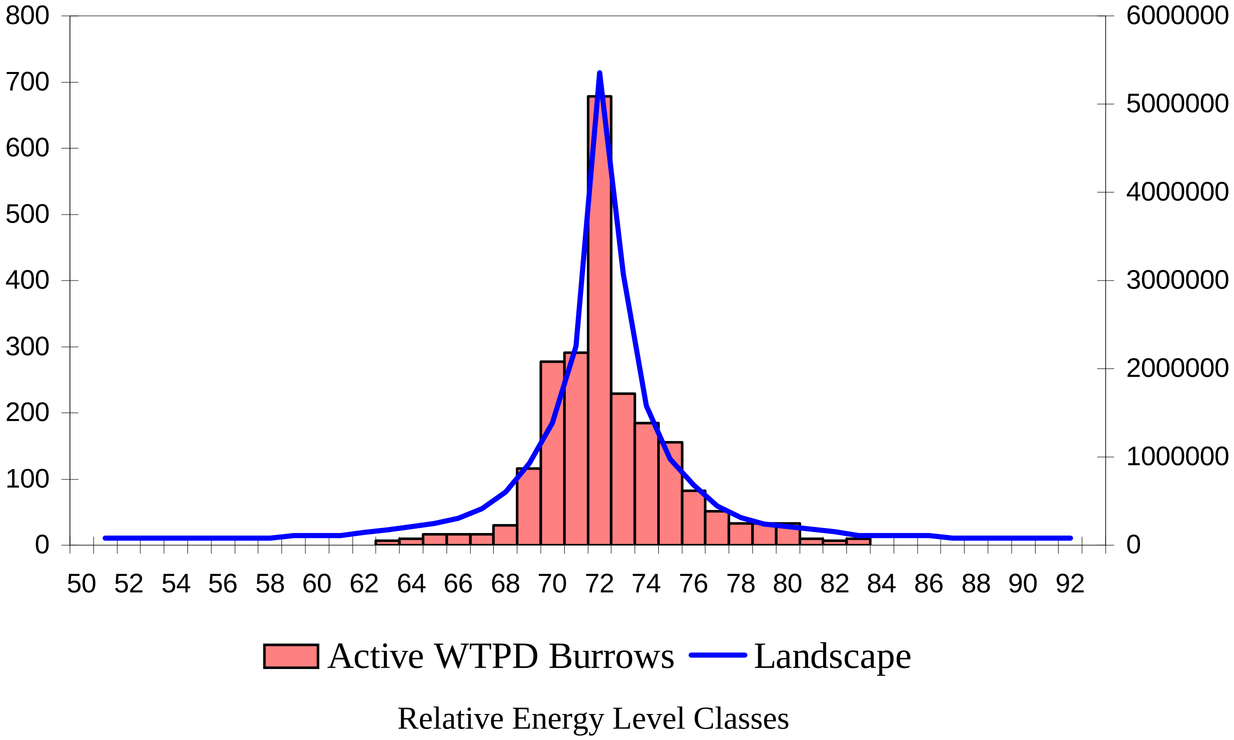


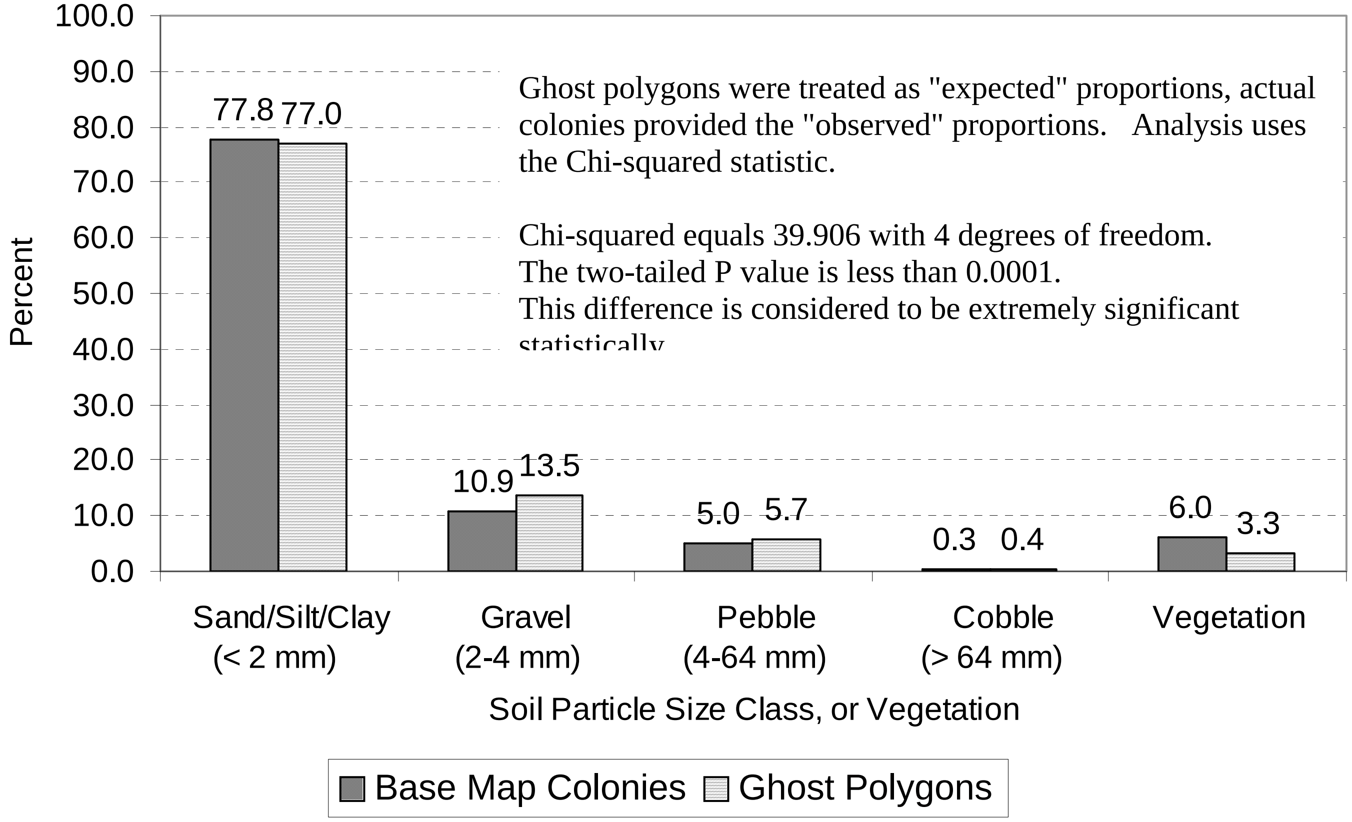
FIGURE 14

Frequency Distribution of the Accumulated Solar Heating (Energy Level)
of the PFO Landscape and of Active Prairie Dog Burrows.

10 m^2 DEM Cell Counts

Landscape: n = 21,750,172
Active Burrows: n = 1386





Ghost polygons were treated as "expected" proportions, actual colonies provided the "observed" proportions. Analysis uses the Chi-squared statistic.

Chi-squared equals 39.906 with 4 degrees of freedom.
The two-tailed P value is less than 0.0001.
This difference is considered to be extremely significant statistically