Mazama Pocket Gopher Occupancy Modeling

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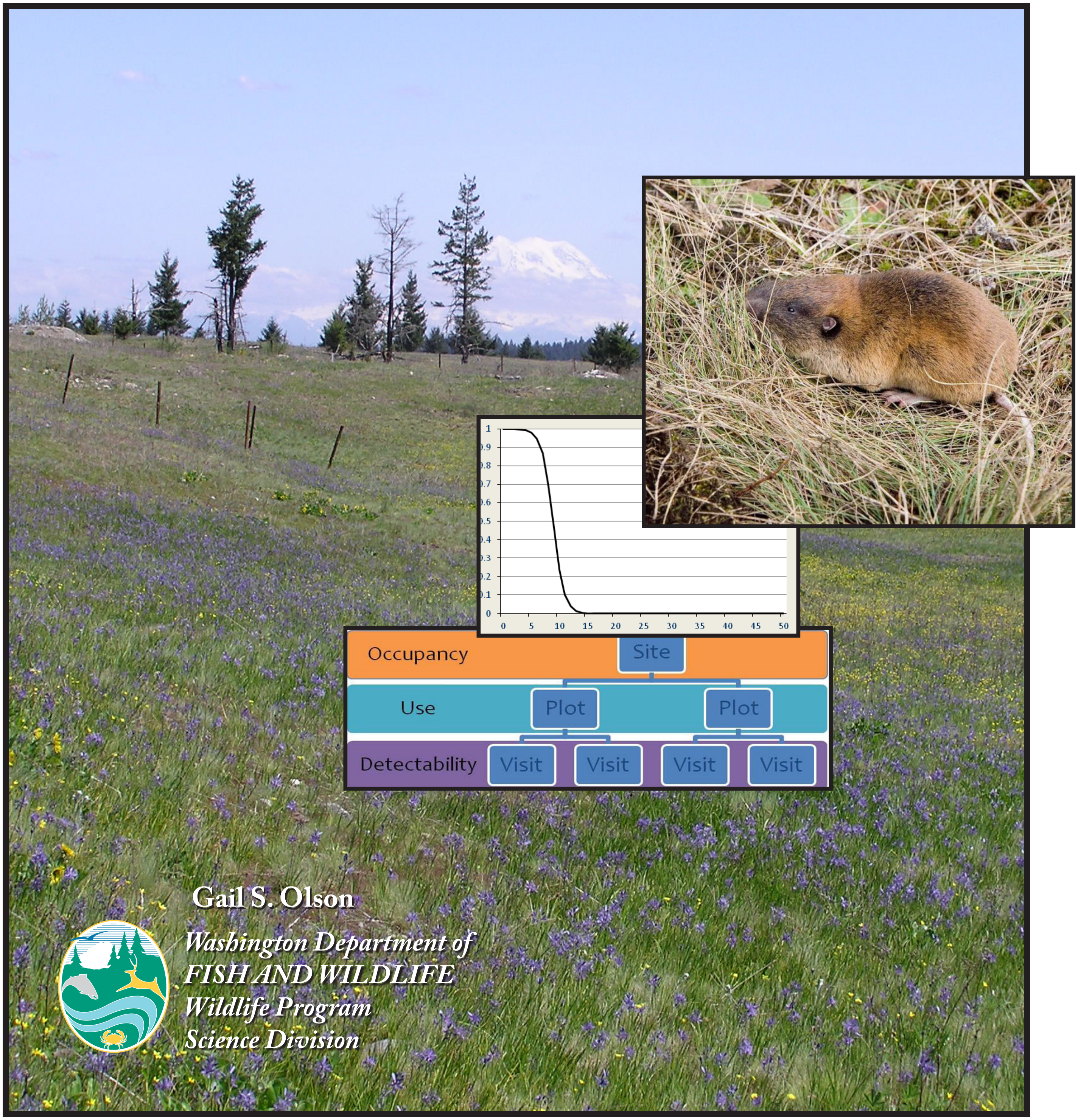

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Washington Dept. of Fish and Wildlife
Thurston County, Washington
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ABSTRACT

PART I: Occupancy Modeling for the Mazama Pocket Gopher

This study used state-of-the-art methods to model site occupancy, within-site use, and detection probabilities of Mazama pocket gophers in Thurston and Pierce Counties. Data on pocket gopher presence (using mounds as indicators of presence) and a suite of habitat variables were collected from surveys of 41 sites in Spring 2008, and repeated on 40 sites in Fall 2008. Most sites (n=33) were on public lands including 24 sites on Joint Base Lewis McChord. Sites with low levels of Scots broom cover, shorter average vegetation, and soils containing fewer rock fragments (especially those 5.0-10.cm in size) tended to have higher occupancy probabilities. Within occupied sites, plot use was higher when broom density was low, fall vegetation was taller and the soil was of a sandy-loam type. Detection probabilities were most strongly influenced by time of year, with surveys in September and October having 6 times greater detectability than Mar-May, and about double that of November surveys.

PART II: The Use of Mound Surveys to Index Pocket Gopher Abundance

This study investigated the relationship between pocket gopher mounds and abundance at two sites in Thurston County: the Olympia Airport and Wolf Haven International. Replicate square plots that were 25m on each side were established at each site in Spring and Fall 2008. All pocket gopher mounds located in each plot were mapped and subsequently live-trapped to determine their association with individual gophers. Overall, there was a positive relationship between the number of mounds and number of gophers, but the Airport had about 3 times more mounds per gopher than did Wolf Haven in both seasons. Both sites had about the same number of mounds per gophers across seasons within sites. An evaluation of the general utility of mound surveys as an index to pocket gopher abundance (including results from this study and those from other published studies) concluded that establishing a site-specific relationship between the two metrics is necessary. This is likely practical only on the most important sites for which the effort required to simultaneously estimate abundance and conduct mound counts is worthwhile. Otherwise, mound surveys should be restricted to use in establishing pocket gopher presence.

BACKGROUND

The Mazama pocket gopher (*Thomomys mazama*) was listed by the State of Washington, USA, as a threatened species in 2007 and has been a Federal Candidate for listing since 2003. Despite the reputation of pocket gophers as pests in much of the United States, and their apparent abundance in other parts of their range (northern California and Oregon), Mazama pocket gophers face significant threats to their survival in Washington State (Stinson 2005).
This species, once distributed throughout the Puget Sound lowland prairies and ranging to the Olympic Peninsula, is now apparently restricted in Washington to a few sites in Clallam, Mason, Thurston and Pierce counties (Stinson 2005). This study focused on the populations that occur in Pierce and Thurston counties.

Most of the known populations of pocket gophers in these counties were within the Joint Base Lewis McChord (JBLM) military base, and thus were subject to military training activities including ground troop exercises, artillery fire, and heavy vehicle operations. The importance of military training in support of current national defense policies make it likely that these activities will continue, and in fact they are proposed to increase as part of the Grow the Army Initiative. Thus further impacts on pocket gopher populations within JBLM are possible. Similarly, populations outside JBLM boundaries face threats from private land development. To reduce the impacts of these activities on the broader pocket gopher population, the Army Compatible Use Buffer Program (ACUB) funded this research study to address some key components for a broader program designed to identify and enhance populations outside JBLM boundaries.

This study had two distinct goals, which are addressed in separate parts of this report:

1. Develop a habitat based model of Mazama pocket gopher occupancy (Part I)
2. Investigate the utility of using mound surveys as an index of pocket gopher abundance. (Part II)

PART I: Occupancy Modeling for the Mazama Pocket Gopher

Most recent research on Mazama pocket gophers was conducted with the objective of limiting populations because they were considered agricultural pests (cf. Witmer and Engeman 2007), and there was little interest in determining conditions that are favorable for Mazama pocket gophers. Therefore, there are few studies that have looked at habitat associations of pocket gophers, and none using modern analytical methods. Mazama pocket gophers are primarily associated with open grassland habitats in western Washington (Stinson 2005). Although it is commonly assumed that they prefer light-textured, well-drained soils (Stinson 2005), no studies of soil associations have been conducted. Steinberg and Heller (1997) found a negative association between pocket gopher presence and the percentage of 1-2” diameter rocks in the soil. Several authors have reported on Mazama pocket gopher diets (Scheffer 1931, Dalquest 1948, Burton and Black 1978, Witmer et al. 1996), but each study listed a variety of plants that generally indicated that diets reflected availability of food resources. Hansen and Beck (1968) found no differences in vegetation composition between sites occupied by northern pocket gophers (*T. talpoides)* and adjacent unoccupied sites. Steinberg (1995) noted that pocket gophers appeared to avoid areas with dense growth of Scots broom (*Cytisus scoparius*) and areas where moles are abundant, but neither of these associations has been formally documented.

This study is the first to investigate the associations of these factors (and others) with Mazama pocket gopher site occupancy in western Washington.

The objectives of the occupancy study were to: 1) identify important habitat factors affecting site occupancy; 2) develop a habitat-based model that could be used to evaluate sites based on site occupancy probabilities; and 3) identify and model factors affecting detectability and within-site use by pocket gophers. To meet these objectives I used an occupancy modeling approach developed by MacKenzie at el. (2002), and since extended by others (cf. MacKenzie et al. 2006, Nichols et al. 2008). These methods use a multinomial likelihood based modeling approach that estimates occupancy probabilities while simultaneously accounting for imperfect and variable detectability.

METHODS

Overall approach

Data for occupancy modeling were collected following a typical design for a single species, single season analysis (MacKenzie et al 2006). This required a set of study sites to estimate occupancy probabilities, and repeated independent surveys within sites to estimate detection probabilities. The total effort expended was constrained by project budget, but the study design emphasis was to maximize the number of sites surveyed yet survey each site adequately to detect pocket gopher presence. Because some sites were large (up to 236ha), it was not possible to completely survey entire sites. Therefore, we surveyed subsamples (plots) within sites, and used these plots as the repeated surveys required to estimate detection probabilities (MacKenzie et al. 2006).

Another feature of the study design was the timing of surveys. Since presence of fresh pocket gopher mounds was used to indicate gopher presence, we attempted to conduct surveys when mounding activity was the greatest and avoid periods when it was low or inconsistent. Based on literature reviews and personal observations, we felt that mounding activity would be greatest during the spring (Mar-May) and fall (Sep-Nov). We also had to consider the time period over which we could assume closure for occupancy status. The main factor that we felt might affect a change in occupancy status was dispersal, which for pocket gophers occurs in summer-fall. Therefore, the two survey periods were considered to be separate seasons in the initial study design.

Site selection

A list of potential sites was developed from multiple sources: 1) historic pocket gopher location database (Washington Department of Fish and Wildlife databases Heritage and WSDM), 2) Ft. Lewis Pocket Gopher Management Plan (Draft date October 2006), 3) pocket gopher workshop proceedings (Site Table), 4) Legacy site characterization implementation plan (draft date January 17, 2007), and 5) Integrated Training Area Management Range and Training Land Assessment (RTLA) pocket gopher survey records (JBLM sites only). Each of these documents or databases contained a different (but sometimes overlapping) list of potential pocket gopher sites, some (but not all) of which were currently occupied. I aggregated those lists into a single list of potential sites. Of the original sources of potential sites, only the Heritage, WSDM, and

RTLA databases contained specific location information, so various means were used to determine the locations of other sites. These included site descriptions, aerial photos, Google searches on the internet and conversations with people that proposed some of the potential locations. County tax parcel maps were used to determine site boundaries and ownership information except for JBLM sites. For Thurston County, additional parcel information was available (such as size and land use) but few other details were available for Pierce County sites in general. Parcel information was not available for JBLM sites in either county, so site boundaries were based on RTLA site designations, which were either training areas or firing ranges, or portions of these. Potential sites were restricted to Thurston and Pierce counties.

I visited each site on the potential site list (except JBLM sites) during winter 2007-8. At that time of year pocket gopher presence was ambiguous (because mounding activity is low during winter), so these visits were simply intended to confirm the locations of the sites, and assess whether they could be considered for further study. This assessment was based on the current land use status of the site, and whether the site was accessible (especially in the case of privately owned sites). Sites that could not be located, were obviously no longer suitable for pocket gophers (due to land development), or were inaccessible, were dropped from the list.

During the spring study season (Mar-May 2008), surveys were conducted on all public lands (not including JBLM) on the potential site list (n=10). Landowners were contacted for permission to survey all private sites on the list (approximately 15) but we were only granted access to 7. Access was granted to 24 sites on JBLM that were randomly selected from approximately 50 total sites located on the base. This resulted in a total of 41 sites surveyed, 40 of which were also surveyed during the fall season (Sep-Nov 2008).

Survey methods

For all sites, a GIS and aerial photos were used to delineate the boundaries of areas generally suitable for pocket gophers (undeveloped non-forested lands not in an annual flood plain) and to measure site size. For sites > 2 ha, the survey area was gridded into 25m X 25m square plots ($625m^{2)}$, and up to 10% of the plots within the area (up to a maximum of 30 plots) were randomly selected for surveys. UTM coordinates of the selected plots were downloaded to a GPS data logger (Trimble GeoExplorer XT 2005 Series) and used to locate the plots in the field. The size of the sample plots was chosen for several reasons. It was large enough to encompass the home range of multiple pocket gophers (on order of $100m^2$, Wittmer et al. 1996), yet small enough to be searched thoroughly to detect mounds and measure habitat variables. Plots adjacent to occupied plots might also be likely to be occupied, but not highly so, as clusters of pocket gophers may occupy an area smaller than $625m^2$ (see Part II of this report).

During surveys, flagging was placed to mark the plot corners and the following characteristics were recorded: presence of pocket gopher mounds; presence of mole mounds; overall vegetation height (minimum, maximum and average); scotch broom height (average only); percent cover of grasses, forbs, scotch broom, shrubs, bare ground, and moss; slope (steep, shallow, flat, or mounded prairie); aspect (cardinal direction, if slope was not flat or mounded prairie); disturbance type (categories included vehicle use, mowing, grazing, pedestrian use, and other); and presence of trees. In addition we attempted to estimate the relative amount of rock fragments present in the substrate by estimating the percentage of soil fines (including rock fragments <2.5 cm), gravel (rock fragments 2.5-5.0 cm), coarse gravel (5.0-10.0 cm), and cobble (>10.0 cm) found in any visible bare ground. All measurements were based on ocular estimates except height, which was measured using a meter stick, but height measurements (to the nearest cm) were based on representative plants as selected by observers. Thus all measures were subject to observer bias although an effort was made to ensure consistency among different observers. Observers usually worked in pairs and estimated measures by consensus.

Pocket gopher mound presence was recorded in multiple categories to reflect different levels of certainty as to whether mounds were created by pocket gophers. "None" indicated the certain absence of pocket gopher mounds within the plot, "fresh" indicated certain presence of pocket gopher mounds, "probable" indicated that mounds were present and more likely to be pocket gopher mounds, and "unknown" indicated that mounds were present but that it was uncertain whether they were made by pocket gophers. Subsequent analyses were conducted using only fresh mounds to indicate presence, coded as a "1" , and all other categories were coded as absent ("0"). Mole mound presence was recorded in 3 categories: "yes", indicated present with certainty, "no" indicated absent with certainty, and "maybe" indicated mounds were present that could have been made by moles but determination was uncertain.

Some additional variables for data analysis were generated from map data. Distance to nearest occupied site was measured as the minimum distance to the closest known occupied site as determined by the WDFW's historical pocket gopher location data base. Soil types for each plot were recorded by overlaying plot locations on USDA NRCS soil maps for Thurston and Pierce Counties. If soil type boundaries bisected a plot, plots were assigned to the type that covered the majority of the plot area. Altogether, 14 different soil types occurred in our survey plots (Table 1). Because site selection was not based on soil types, the number of plots in each soil type did not reflect the county-wide occurrence of these types. However, the plots surveyed within sites were sampled in the same proportion as the area covered by each soil type within the site, with the requirement that there be at least two plots of each type (i.e, a stratified random sample with soil types as strata). To facilitate analyses, soil types were pooled into 4 categories: 1) sandy loams without gravel (SL); 2) gravelly loams not clay or silt (GL); 3) silt and clay loams (SC); 4) Spanaway-Nisqually complex (SN) which occurred only on mounded prairie and represent a combination of soils within categories SL and GL (Table 1). These categories reflected both the sample sizes of plots within each soil type (Table 1), and our hypotheses regarding soil types that were most likely used by pocket gophers.

All variables used in occupancy modeling are listed in Table 2, including acronyms used in results tables.

Multiple approaches were used to model occupancy, with each set of analyses using the same data but sometimes different subsets or organization. All approaches were single species methods described in MacKenzie et al. (2006), or extensions of those methods. In general these models all simultaneously estimate the probability of site occupancy and per-visit detection probabilities, and allow for variables to be included to explain variation in these parameters. First, spring and fall survey data were analyzed separately using the single season model approach, then they were combined into one single season model with all visits combined and treated as though they occurred in the same season, except for the assignment of per-visit variable values. The single season model assumed there were no changes in occupancy status (closure) during the survey period. For the separate season analyses this was thought to be a reasonable assumption; however, for the combined analysis the closure assumption could be invalid if sites had a change in occupancy status during the summer. This assumption was tested by also analyzing the combined season data using a multiple season model that allowed for changes in site occupancy status between spring and fall.

Finally, a multi-scale model approach was used to examine the factors affecting the probability of use at the plot level within occupied sites. This analysis was intended to better refine the factors influencing pocket gopher distribution within sites, taking advantage of habitat data collected at the plot level.

In all analyses, an exploratory model development approach was used (Burnham and Anderson 2002). In this type of modeling, I did not have a clear set of *a priori* hypotheses, but rather, a list of variables that were thought to influence occupancy and/or detection probabilities. This "data dredging" approach allowed the inclusion of *post hoc* models based on previous model results, in the interest of finding the best overall models for the data. The drawback of this approach is the potential to over-fit models and make Type I errors (conclude relationships exist when they do not).

Program Mark (White and Burnham 1999) was used for all occupancy analyses. I used a hierarchical approach to model development. First, detection probabilities were modeled as a function of appropriate variables with occupancy probabilities set as constant. These models were ranked based on Akaike's Information Criterion, corrected for small sample sizes (AIC_c: Burnham and Anderson 2002), and the best model (or set of models, if there were >1 model with $\Delta AIC_c<2.0$) were used to model occupancy probabilities. The occupancy probabilities were then modeled as a function of prospective habitat variables, and also ranked based on AIC_c. As a final step, multiple variables from the best models were combined in a single model if those variables were not highly correlated (i.e., $\rho < 0.75$).

Modeling Details

Single season analyses

The single season model assumed that there were no changes in occupancy status during the survey period. In this study, plots within sites were treated as separate visits, thus detection probabilities represented the probability of detecting pocket gopher presence within a single sample plot if the site was occupied. Presence of gophers detected on any plot sampled was considered sufficient to establish site occupancy.

The parameters to be estimated in the single season model were ψ, the probability of site occupancy, and p_i, the plot-specific detection probabilities. Site occupancy was modeled with site-level habitat variables, and detection probabilities were modeled with both plot- and site-level variables.

Spring and fall data were first analyzed separately, using season-specific variables as appropriate. For detection probabilities, all visits were assumed to have constant probability (within season) except as modeled by the variables. Plot-level individual variables were used to examine the potential effects of vegetation height (mean and maximum), and scotch broom height or percent cover on detection probabilities. Means of those same factors were also computed at the site level and used to model both occupancy and detection probabilities. Additional site-level variables used in detection probability models were size of site (area in ha) and month the site was surveyed.

Except for month of survey, these same variables were used to model site occupancy probability along with means of %grass cover, %forb cover, %shrub cover, %soil fines, %gravel, %coarse gravel, and the percent of plots with trees, of moles, and of any type of disturbance. I also included the distance to nearest known occupied site as a variable.

The data from both seasons were then combined into one single season analysis, with the same set of variables used in this analysis. Under the assumption that occupancy status does not change, but could be associated with either the fall or spring variables, each set of season-specific variables were examined as factors in the joint models.

Multiple season analysis

The combined spring and fall data were also used in a multiple season model analysis to investigate whether there was evidence that occupancy status changed between spring and fall, and to see what factors might be associated with those changes if so. The parameters modeled were: ψ = initial occupancy probability (spring), ε = the site extinction probability between seasons, and γ = the site colonization probability between seasons. Variables were applied to first detection probabilities, and then to initial occupancy probability as described above, followed by the same set of variables on extinction and colonization probabilities. To test the closure assumption, models with either ε or γ, or both, fixed at zero were included in the model set.

Multi-scale analysis

The multi-scale analysis was based on an approach described by Nichols et al. (2008) for multiple survey methods, but as they point out, multiple surveys (repetitions) of the same type can also be used. This was a single season approach, therefore a single occupancy probability (ψ) was estimated, along with sets of detection probabilities (p_t^s) for each visit. Additionally, plot use probabilities were estimated (θ_t), which were the probabilities the animals were present on plot *t* given that the site was occupied. Models of the latter can include plot-level variables. To apply this model to the data collected in this study, it was necessary to treat spring and fall visits to individual plots as replicate surveys. This required the assumption that site occupancy status did not change between spring and fall, which was tested by the multi-season modeling analysis. The dataset used for the multi-scale analysis also differed slightly than the previous analyses, as it required the exact same set of plots to be used from both spring and fall surveys. Thus some plots that did not match exactly, and data from one site, were excluded from this analysis.

I modeled site occupancy and detection probabilities using the same factors as in previous analyses, except that plot-level variables were used to model variation in use probabilities. However, soil composition variables were not used as candidate variables for plot use because those measures were not recorded when there was no visible bare ground. Instead, I included indicator variables for soil type categories (as defined above).

Estimates of occupancy parameters for the most important continuous factors were plotted by variable over the range they were measured in this study, using model averaged regression coefficients. For this exercise, the variables in the model that were not being plotted were set to their mean values. For site occupancy, the means and ranges were computed over all sites, and for plot use, the means and ranges were computed based on occupied sites only.

RESULTS

Occupancy modeling

Single season analyses

Results from the separate single season analyses of detectability indicated that size of site most affected detection probabilities (a positive effect) in the spring, but by far the most important factor in the fall surveys was the month of survey (Table 3). In the latter analysis, November had a lower detection probability (0.21, 95% CI 0.16-0.26) which was less than half that of September (0.59, 0.52-0.65) or October (0.55, 0.45-0.65). Detection probabilities in the spring were much lower (0.09, 0.03-0.10) than in any of the fall months.

For occupancy probabilities, average percent broom cover was an important factor in both the spring and fall models (Table 3), and it was a negative effect in both analyses (Figures 1,2). They also both contained an affect for substrate composition, but for spring, coarse gravel (5-10 cm) was more important (a negative effect, Figure 1) whereas for fall it was the average percent of soil fines (a positive effect, Figure 2). These variables were somewhat negatively correlated with each other ($\rho = -0.35$, $p = 0.03$), but models containing other substrate variables that were more highly correlated with each other did not rank as highly. For instance, both spring percent soil fines ($\rho = 0.64$, $p < 0.0001$) and percent cobble ($\rho = -0.40$, $p = 0.01$) were more highly correlated with fall percent soil fines, but models in the spring analysis containing these variables did not rank as highly as the model with percent gravel. Such results could indicate a seasonal difference in the effect of substrate composition on either occupancy probability or mounding activity or a difference in capability of estimating substrate composition between the two seasons.

When all data were combined into a joint single season analysis there were few changes in the results from the separate analyses, despite the potential for more power to detect associations. For detection probabilities, the model with the factors identified in the season analyses were still the best, with the exception that mean vegetation height was no longer a significant factor once the occupancy variables were included in the model. Spring broom cover (-) and fall percent soil fines (+) were the factors most associated with occupancy probabilities, but confidence intervals on regression coefficients of both factors overlapped zero, indicating lack of precision in the effects.

Multi-season analysis

When data were analyzed to allow changes in occupancy status to occur between seasons, the model in which both colonization and extinction probabilities were set to 0, with the same variables for occupancy and detectability as selected in the single season analysis, was the best overall model (Table 4). This indicated that there were not significant changes in occupancy status of sites within the year.

Multi-scale analysis

Because it was apparent that fall and spring detectability differed greatly, these probabilities were modeled separately in the multi-scale analysis, but otherwise detection probabilities were constrained to be constant across plots except for the inclusion of covariates.

As in the site scale analyses, detection probabilities varied by survey month. The best model was one in which spring months (Mar-May) were all the same, but fall months differed. September surveys had the highest detection probabilities, but the standard error of the coefficient estimate was so large that the 95% confidence intervals were completely unrealistic. These suspect estimates led me to model detectability only by season; this had no effect on the occupancy and plot use parameter estimates.

The same factors that had previously been found to be important for modeling occupancy probabilities (percent soil fines and percent Scot's broom cover) were likewise the most important factors associated with occupancy probabilities in the multi-scale approach (Table 5), even after the plot level version of those same variables were included for plot use probabilities. Mean fall vegetation height also was associated with site occupancy, but that effect was not always in the best models (Table 5, Figure 3).

After trying multiple combinations of plot level variables, the best model for use probabilities was one that included percent shrub cover (-), fall mean vegetation height (+), Scot's broom density (-), and an indicator variable for the Sandy Loam soil category (+) (Table 5, Figure 5). There were 3 other models with $\Delta AIC_c < 3.0$, all of which had the same variables as the best model, but in addition included either the fall mean vegetation height variable (-) on occupancy probabilities or the SN-complex soil type variable (+) on plot use, or both effects (Table 5). Because of the interest in relating pocket gopher presence to specific soil types, I estimated these effects separately in a model with no other variables (except for detection probabilities). In this analysis, plot use probability was, as expected, highest for the Sandy Loam category (Figure 5). There was a significant difference between the Sandy Loam and Gravelly Loam categories, with the latter having 1/3 less probability of use. Plot use of the Spanaway-Nisqually Complex category was intermediate between these two categories, apparently reflecting the mixed nature of the soil type. The Silt or Clay Loam category (which had a very small sample size, see Table 2) had the lowest point estimate but a very broad CI that overlapped all of the other estimates.

Evaluation of model

As a final step towards evaluating whether an occupancy model developed in this analysis might be useful for assessing whether sites are suitable for pocket gophers, I compared the estimated occupancy probability from the multi-scale occupancy model for each site to its apparent occupancy status based on fall survey data. While this is a relatively weak form of model evaluation (comparing the output of a model to the data that was used to develop it; Rykiel 1996, Johnson 2001), the results were interesting (Figure 6). Only 4 sites (out of 40) were classified as having high occupancy probabilities when no fresh mounds were found in the fall. Two of these sites were on JBLM: Range 74N and Training Area 4-5. The other sites were West Rocky WA and the Caverness property, both sites that are currently being restored by ACUB cooperators. Only one site with estimated occupancy probability <0.50 was found to be occupied: Rocky Prairie NAP (0.47).

DISCUSSION

Analyzing the same basic set of data using multiple approaches was beneficial for elucidating relationships that might have otherwise been misinterpreted or gone undetected. Factors with strong effects on occupancy parameters appeared in the highest ranked models for all analyses, but other factors were important in some analyses and not in others. These may be indicative of more subtle relationships, or effects that were not consistent through time or space.

The positive association of percent soil fines with site occupancy might be expected because of the presumed greater ease of digging in soil lacking rock fragments. This is especially important for this fossorial species, which spends little time above ground and uses tunnels as regular pathways to gather food resources. Although several studies of other pocket gopher species have described preferred soil conditions (cf. Davis et al. 1938, Miller 1964, Hoffman and Choate 2008), few have examined the effects of rock fragments. Steinberg and Heller (1997) looked at the relationship between Mazama pocket gopher presence and rock composition and found a negative association between percentage of “medium” rocks (2.5-5.0cm) and pocket gopher presence at the site level, but no relationship with soil fines, small rocks (1.2-2.5cm) or large rocks (>5.0cm). Hansen and Beck (1968) found northern pocket gophers preferred sites with less than 25% rock >0.6cm and “low” amounts of rock >2.5cm. Both of these studies used soil pits to estimate rock composition, and presumably this is a more accurate measure than the ocular estimates used in my study, but they did not examine plot level associations and this may be a more appropriate scale at which to look at these effects. The differences in rock sizes measured and the methodology used to assess them could explain the differences in size categories found important in each analysis, but all studies found a negative association with intermediate sized rocks. These may be the ones most difficult for pocket gophers to cope with when digging tunnels. Smaller rocks might be easily handled, whereas larger rocks could be just avoided by digging around them. Clearly this relationship should be looked at more closely before using rock size and composition to predict Mazama pocket gopher site occupancy and plot use, particularly if different means of assessment are used.

This study was the first to investigate the association of pocket gophers with specific soil types in Washington. Although the assignment of soil types to plots was done at a scale well below that for which accuracy may be expected, it still seemed to result in strong relationships between soil categories and plot use. These results seemed to be consistent with the soil composition results found at the site occupancy scale as the best soil type (SandyLoam) has fewer rock fragments than the Gravelly Loam or Spanaway-Nisqually complex types. The relationship between soil texture categories and pocket gophers seems somewhat ambiguous. Studies of other pocket gophers (Davis et al. 1938, Miller 1964, Hoffman and Choate 2008) have reported that sandy loam soils are more favorable for pocket gophers than silty or clay loams, and the results of this study seemed to support that. However, the small sample size of plots with these soil types precluded statistically significant results. The large confidence interval associated with plot use probability for the Silt or Clay Loam category may also be due to pooling these soil textures into a single group. Sullivan et al. (1987) found that clay loams seemed to be less associated with pocket gopher use, but that otherwise soil texture was not a factor, and Kjar et al. (1984) found that silt content had no apparent affect on pocket gopher distribution. Thus silt loams may be more often used by pocket gophers than are clay loams.

The interpretation of associations between pocket gophers and any vegetation characteristics is confounded by the potential for pocket gophers to modify the plant community around them, both by consumption and by their digging activities. There are a number of papers published that have investigated the effects of gophers on plants, but virtually none that have looked at the effects of vegetation characteristics on pocket gophers. Scot's broom has been presumed to negatively affect pocket gophers, but with little scientific evidence. Surveys conducted in areas with tall, dense stands of Scot's broom often were unsuccessful in finding pocket gopher mounds, but it was not known whether that is due to greater difficulty in detecting mounds or actual lack of use. Despite this lack of evidence, invasion by Scot's broom of prairie grasslands in the south Puget Sound has been cited as a possible reason for decline in pocket gopher abundance (Stinson 2005). On the other hand, Witmer et al. (1996, p. 94) described a site in Thurston county dominated by Scot's broom as "good quality pocket gopher habitat". This assessment was supported by their finding of Scot's broom clippings in pocket gopher food caches at two study sites, including the one dominated by broom.

My study of occupancy seems to contradict Witmer et al (1996) and lends support to the presumption that Scot's broom is detrimental to pocket gophers. I found no evidence that Scot's broom affected mound detectability, but did find Scot's broom to be negatively associated with both site occupancy and plot use. Site occupancy seemed more influenced by mean percent cover, whereas plot use seemed more affected by the combination of percent cover and average height of broom. This could indicate a general avoidance of heavily overgrown sites by pocket gophers, but within sites that are occupied, pocket gophers may be avoiding the tall (and therefore older and well established) thick patches of broom but not the areas where broom is newly sprouted, whether it is thickly covered or not.

The negative association of pocket gopher plot use and shrub cover is also one that may be difficult to interpret because it could be due to either avoidance of shrubs by gophers, or the ability of pocket gophers to prevent shrubs from becoming established. Pocket gophers are well-known in most of the U.S. as agricultural pests that cause much damage to seedlings at tree nurseries (Witmer and Engeman 2007), and they likely play a similar role in natural settings. Without knowing which came first, it isn't possible to determine whether the shrubs influence the gophers or vice versa, and it may be that both situations occur. It is also not possible to clearly establish whether shrubs affect occupancy at the site level, because sites heavily covered with shrubs were not included in the candidate site list. An experimental approach is required to determine the cause-and-effect relationship between shrubs and pocket gophers.

Perhaps the most puzzling relationships with vegetation characteristics were those between pocket gophers and average fall vegetation height. Vegetation associations in general may be the most difficult to interpret because vegetation serves as both direct components of pocket gopher habitat (food, cover) and as an indirect indicator of soil characteristics such as fertility and depth. At the site level, the negative relationship between occupancy and vegetation height may indicate avoidance of thick, established stands of non-native grasses such as tall oatgrass that would be difficult for pocket gophers to negotiate when moving about above ground (as they are thought to do during dispersal, especially) or depositing soil above ground from their tunnels. At the plot level, taller vegetation may indicate deeper soils (known to be associated with pocket gophers—Davis et al. 1938) and greater food availability. However, the ability of gophers to affect their habitat may cause them to move on once they have depleted the vegetation in an area, thereby maintaining a positive association with taller vegetation. Again, these are questions that must be addressed experimentally to determine cause and effect.

More conspicuous, in some ways, was the apparent lack of relationship between gopher occupancy and the other variables measured, such as percent grass or forb cover, and presence of trees. This should not be taken as evidence that these factors are not important, but that they were not very good explanatory variables in this study. Percent grass and forb cover were very coarsely assessed in our surveys, and they represent very broad categories of vegetation. There may be plants within these categories that are preferred or avoided by pocket gophers, but previous studies have not shown any consistent relationships. It would take a much more intensive survey of plant species across a number of sites to discern such relationships, and this was beyond the scope of our study.

Although forested sites were not surveyed in this study, most of the open grasslands that were included in the study had scattered trees within the surveyed area, and it was thought that presence of trees at the plot level might affect pocket gopher use, but this was not apparently the case. Although trees might have affected some of the other variables (vegetation and broom cover and height, for instance), they also may provide roosts for avian predators and their root systems may make burrowing more difficult. Yet there is no indication that these affected pocket gopher use of plots with trees.

Also interesting is the lack of any apparent relationship between pocket gophers and moles. Steinberg (1995) noted that pocket gophers distribution on Fort Lewis Army Military Reservation in Pierce Co., WA was apparently negatively associated with moles, and some have speculated that there might be a negative relationship because of their presumed competition for space. But the lack of dietary overlap (moles are carnivores), the naturally low density of moles, and their more nomadic lifestyle likely reduce this possibility. Others have postulated that presence of moles may be positively related to pocket gopher presence because both species may be associated with the same soil characteristics. Although this may be true, this study does not support either hypothesis.

The proximity of sites to nearest known occupied sites also did not appear to be important in our analyses, probably because of inaccuracies in these measures. Since this study was completed, surveys for pocket gopher presence have been conducted on additional private lands in Thurston County because of requirements for land development permits. These surveys have found evidence of pocket gophers in areas where they had not previously been documented. The distances we used in our analyses did not include these newly detected sites, nor other potentially occupied sites on private lands that have not been surveyed. Until a more comprehensive survey is conducted throughout the region, it is unlikely this measure will be accurate enough to be useful in analyses, even though it is undoubtedly an important factor in site occupancy probability.

A more comprehensive survey of potential pocket gopher sites should also address a vital question about the applicability of the occupancy model developed in this study. One of the most important aspects of any research study is defining the realm of inference to which the results may be applied. In sample survey-based research (as opposed to experiments) the realm of inference is established by drawing a sample from the population of interest, and thus results from the study should only be extrapolated to that population. Sometimes, it is not practical to draw a survey sample from the entire population of interest and the sample is drawn from some subset of that population. Usually it is assumed that the sample is still representative of the population of interest, but in a rigorous scientific sense, the results should only be assumed to be applied to the subset. This review of sampling principles is relevant to this study of Mazama pocket gopher occupancy for several reasons. First, the population of sites from which the survey sample was drawn was certainly incomplete, and may not have been representative of the larger population of sites to which we would like to extrapolate the results. At the time this study was conducted, it represented the best compilation of potential sites available. Secondly, the set of surveyed sites inadequately represented privately owned properties. The assumption was made that privately owned sites that were not available for surveys would have similar characteristics to publicly owned sites; this assumption remains untested, but an effort should be made to survey privately owned sites to verify whether it is reasonable. Finally, this study made the *a priori* assumption that pocket gophers would not be found on sites that were forested or heavily overgrown with shrubs, and it also did not include sites that were recently clearcut. Therefore, the results should only be applied to sites that are non-forested, undeveloped, and primarily grassland. They also should be applied only within the general geographic boundaries (portions of Thurston and Pierce Counties) of the study sites. Whether results apply to other areas, or other types of sites, should be investigated with additional surveys.

Detectability

The use of an occupancy modeling approach that accounted for imperfect detectability was especially important in this study. Although none of the plot-level variables were found to be associated with detection probabilities, the time of year during which surveys were conducted was found to be very important. Although they are active throughout the year, pocket gophers are known to show seasonal variation in mounding activity. Several authors (cf. Miller and Bond 1960, Romanach et al. 2005) have reported little to no mounding activity for *T. bottae* in California during dry summer months, with greatest production occurring during rainy winters. Klaas et al. (2000) found less than 1 mound produced per day from mid-September to late March for *Geomys bursarius* in NW Iowa, as compared to >4 mounds/day in summer months. The timing of surveys in this study was chosen because it was thought that spring and fall were periods of greater burrowing activity and therefore detectability of pocket gophers was presumed to be highest in those months. Whereas this was certainly true in the fall, spring was not a good time to conduct surveys, at least not in Mar-May 2008. In fact, per plot detectability in the spring was about a sixth what it was in the fall, meaning that surveys conducted only in the spring would have a much lower chance of detecting site occupancy.

Other factors may have also influenced detectability. Size of sites was a factor in the spring single-season analysis, but not in the fall. The positive relationship between site size and detectability was probably more important in the spring because of the much lower average per plot detection probabilities. With an average per-plot detection probability of about 0.09, the greater number of plots sampled in the larger sites may have been more likely to detect site occupancy. This is despite the fact that percentage of site surveyed actually declined for the largest sites due to the upper limit we placed on sample size. Conversely, the smaller sites may have been less likely to have been occupied in the spring than in the fall, although this hypothesis was not supported by the multi-season analysis.

Multi-scale modeling

Although the data in this study were collected in a manner most appropriate for the single season modeling approach, it was possible to use more complex model structures to gain additional insight into pocket gopher habitat use. This was especially true for the multi-scale approach. In this study, and in many others, the definition of sites was somewhat arbitrary. They also ranged widely in size and only about half were selected at random. Therefore, the more interesting questions may not have been about the factors affecting site occupancy, but what might have affected the distribution of pocket gophers within sites. In this study, it was possible to randomly select plots within sites to survey and collect data at a scale that may have more appropriate to the relatively sedentary pocket gopher.

The results from the multi-scale modeling appeared to be consistent with the site scale modeling methods, and the relationships found between plot use and variables seemed sensible. However, the validity of the assumption that occupancy status did not vary between visits widely separated in time can certainly be questioned. This is especially true if site occupancy increased because of dispersal of juvenile pocket gophers. However, results from the multi-season modeling seemed to indicate that this was not the case. What may be more important is whether plot use is consistent among visits (i.e., between seasons), an assumption that seems even more likely to be violated by dispersal. Although plots were large enough to encompass multiple home ranges (estimated as on the order of $100m^2$, Witmer et al. 1996), plots were only 25m across which is well within the range of pocket gopher movements (Howard and Childs 1959, Daly and Patton 1990). However, it is also possible that dispersers traveled mostly to already used plots, in which case there would be no violation of closure between plot visits. The validity of these assumptions and the possible affect on conclusions from this study, could be (and should be) tested with further study, in which sampling is specifically conducted for the multi-scale analysis. This would require conducting >1 visits to plots within a much shorter interval so that plot use closure is assured.

In this study, the multi-scale modeling approach was effective in detecting relationships that were not evident in the site scale analyses, possibly because of the greater sample size associated with plots than sites. There were more factors associated with plot use in the best models and the relationships between plot use and variables were more precise. Therefore, there may be more success with predicting where pocket gophers may be found within sites, than in estimating site occupancy probabilities themselves.

Management Implications

Detectability

A critical finding of this study was the seasonal, and even monthly, differences in detectability of pocket gopher occupancy. Although this study was conducted at times when we thought pocket gopher activity would be high, detectability was about 6 times higher in the September and October than in the spring. Pocket gophers are active throughout the year and it may be possible to find pocket gopher mounds at any time of year, therefore establishment of presence may be possible at any time. But to determine absence of pocket gophers with any degree of certainty, fall surveys are necessary.

Habitat associations

This study identified some important factors associated with Mazama pocket gopher site occupancy and within-site use. These were: soil composition (%soil fines and soil type), Scot's broom cover or density, woody shrub cover, and fall vegetation height. The soil-related factors important to pocket gophers obviously cannot be manipulated by management. These characteristics likely define the sites, or areas within sites, where management would be most useful for enhancing sites for pocket gophers. Soil types may be considered as a first indicator of whether sites might be occupied (or occupiable) by gophers, but the broad scale of resolution of USDA soil maps means that a site-specific soil survey may be needed to determine the areas within sites that contains soils that are appropriate for gophers.

The other factors may be manipulated by management, especially Scot's broom and woody shrub removal/reduction. Any land management that is intended for enhancing pocket gophers should include this strategy. Based on the occupancy analyses conducted in this study, a reasonable target should be to reduce both Scot's broom cover and woody shrub cover to <10%. This does not mean pocket gophers may not be found on sites with greater broom or shrub cover, but their probability of occupancy and/or use is much higher below this target (Figures 1-4). Another factor related to both occupancy and within-site use that might be manipulated by management is vegetation height, but the strategy for this is not clear. The best conclusion that might be drawn at this time is that sites should average <40cm fall vegetation height, but that there should be a mixture of vegetation heights within sites. However, the means to accomplish this is unclear without further study. Would manipulation of any vegetation (through mowing, burning, or herbicide treatments, for instance) be sufficient, or must this target be accomplished through establishment and/or maintenance of plants that naturally have these characteristics? If the relationship between plot use and vegetation height is actually due to soil depth, neither of these management strategies may be helpful. Therefore, at this time it is not recommended that management strategies include vegetation height as a goal, at least not for pocket gophers in particular.

Management Implications for ACUB prairies

One objective of this study was to build a model that could be used to evaluate sites for their probability of site occupancy, and this study was tentatively successful in meeting this objective. There was high concurrence of model estimates with apparent occupancy of sites used in the analysis, but this is to be expected. The validity of this model (and true utility) will only come from further testing with data from new sites, where both occupancy status and variable measures are assessed. However, among the sites surveyed in this study were nearly all ACUB prairies: Scatter Creek Wildlife Area (North and South units), West Rocky Wildlife Area, Rocky Prairie NAP, Mima Mounds Natural Area, Glacial Heritage Preserve, and Tenalquot Preserve (only Wolf Haven International was not included). Four of these sites (both Scatter Creek units, Rocky Prairie, and Tenalquot) were occupied by pocket gophers at the time of this study, and only Rocky Prairie had an occupancy probability lower than any of the unoccupied sites. West Rocky had the highest occupancy probability of any unoccupied ACUB prairie and it is somewhat fortuitous that it was chosen as a recipient site for pocket gopher translocations. Otherwise, the occupied prairies all had occupancy probability estimates very near 1.0 and the unoccupied sites (Glacial Heritage and Mima Mounds) had occupancy probabilities of 0.0. The Caverness property, a non-ACUB site managed by The Nature Conservancy (an ACUB partner) is also an unoccupied site with a high (1.0) probability of occupancy according to the model. However, this site had few plots where soil substrate composition was visible, and so the values for this variable may be based on a small proportion of the site. Still, it appears at least portions of this site may have promise for future pocket gopher translocations, if this strategy is deemed to be feasible for establishment of new populations.

Looking more closely at the variable data from Glacial Heritage and Mima Mounds,, it appeared that the main cause of their near-zero occupancy estimates was that both sites had low percent soil fines (<35%). This is not a factor that can be changed with management, leaving it debatable whether or not these sites would be suitable for translocations. However, within-site variability should be taken into account before making a final assessment. For instance, there may be areas within Glacial Heritage with greater percent soil fines that are large enough to support pocket gophers.

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Table 1. Soil types and number of plots surveyed in each type for Spring and Fall 2008 Mazama pocket gopher mound surveys. Soil Category is the group each type was assigned to for data analysis, based on soil texture and presence of gravel: SL = Sandy Loam, GL = Gravelly Loam, SC = Silt or Clay loam, SN = Spanaway-Nisqually complex (see text for further information).

Soil Type	Soil Category	Spring	Fall
		No. plots	No. plots
Alderwood	GL	7	8
Cagey	SL	2	1
Everett	GL	14	13
Galvin	SC	0	1
Godfrey	SC	5	12
Indianola	SL	23	14
Melbourne	SC	0	6
Nisqually	SL	123	123
Norma	SC	11	13
Semiahmoo	SC	0	1
Spana	GL	1	1
Spanaway	GL	552	613
Spanaway-Nisqually	SN	131	139
Sultan	SC	3	3
Totals	GL	574	634
	SL	148	138
	SN	131	139
	SC	19	36
	ALL	872	947

Table 2. Variables measured for occupancy modeling analyses. Acronyms are used in subsequent results tables. Season-specific variable names were designated by adding the prefix "SP" (for spring) or "FA" (for fall) to the acronym.

Acronym	Type	Description	Measured Units	Scale
GRASSCOV	Continuous	Percent cover of grasses	Percent	Plot
FORBCOV	Continuous	Percent cover of forbs	Percent	Plot
BROOMCOV	Continuous	Percent cover of Scots broom	Percent	Plot
SHRUBCOV	Continuous	Percent cover of woody shrubs (not broom)	Percent	Plot
BAREGRCOV	Continuous	Percent cover of bare ground	Percent	Plot
MOSSCOV	Continuous	Percent cover of moss, lichens	Percent	Plot
VEGHTMAX	Continuous	Maximum vegetation height (not incl. shrubs or broom)	cm	Plot
VEGHTMIN	Continuous	Minimum vegetation height	cm	Plot
VEGHTAVE	Continuous	Average vegetation height	cm	Plot
BROOMHT	Continuous	Average Scots broom height	cm	Plot
BROOMDEN	Continuous	BROOMHT × BROOMCOV/100		Plot
TREES	Category	Presence of trees > 2m (yes=1 or no=0)		Plot
MOLES	Category	Mole mounds (yes=1 or no=0)		Plot
DISTURB	Category	Any type (yes=1 or no=0)		Plot
PERSOIL	Continuous	Percent of visible bare ground with soil fragments < 2.5cm	Percent	Plot
PERGRAVEL	Continuous	Percent of visible bare ground with soil fragments 2.5-5.0 cm	Percent	Plot
PERCOARSE	Continuous	Percent of visible bare ground with soil fragments 5.0-10.0 cm	Percent	Plot
PERCOBBLE	Continuous	Percent of visible bare ground with soil fragments > 10.0 cm	Percent	Plot
SITESIZE	Continuous	Size of site	ha	Site
OCCDIST	Continuous	Distance between site and nearest known occupied site	km	Site
SEASON	Category	Spring or Fall		Site
MONTH	Category	Month of year		Site
SOILTYPE	Category	USDA soil type from NRCS soil maps (see Table 1 for categories)		Plot

Table 3. Model selection results from Fall and Spring single season occupancy analyses of Mazama pocket gophers. Only models within the 95% Confidence Set (Cummulative sum of w_i = 0.95) are shown. Acronyms for variables are given in Table 2.

A. Spring

Model[a]	AIC_c	ΔAIC_c	Akaike weight (w_i)	Cumm. w_i	No. parameters
ψ BROOM COV + PERCOARSE , p SITESIZE	271.8	0.0	0.61	0.61	5
ψ BROOM COV + PERCOARSE , p	275.1	3.4	0.11	0.72	4
ψ PERCOARSE , p BROOM COV	276.5	4.7	0.06	0.78	4
ψ BROOM COV , p	277.3	5.5	0.04	0.82	3
ψ PERGRAVEL , p BROOM COV	277.5	5.7	0.03	0.85	4
ψ BROOM COV + PERCOARSE, p BROOM COV	277.7	5.9	0.03	0.88	5
ψ SHRUBCOV , p BROOM COV	278.5	6.7	0.02	0.91	4
ψ , p BROOM COV	279.5	7.7	0.01	0.92	3
ψ BROOM COV , p BROOM COV	279.6	7.8	0.01	0.93	4
ψ BROOM COV + PERCOARSE , p MONTH	279.7	7.9	0.01	0.94	6
ψ PERSOIL , p BROOM COV	280.2	8.4	0.01	0.95	4

[a] ψ = occupancy probability and p = detection probability

B. Fall

Model	AIC_c	ΔAIC_c	Akaike weight (w_i)	Cumm. w_i	No. parameters
ψ BROOM COV + PERSOIL, p MONTH	657.9	0.0	0.46	0.45	6
ψ BROOM COV + PERSOIL, p MONTH +VEGHTAVE	659.7	1.8	0.18	0.64	7
ψ BROOM COV + PERSOIL, p MONTH + SITESIZE	659.7	1.8	0.18	0.82	7
ψ BROOM COV + PERSOIL +PERCOARSE , p MONTH	660.8	2.9	0.10	0.93	7
ψ BROOM COV + PERSOIL, p MONTH + VEGHTAVE + SITESIZE	661.8	3.9	0.06	0.99	8

Table 4. Model comparison results from multi-season occupancy modeling for spring and fall for Mazama pocket gopher site survey data collected in Thurston and Pierce Counties, Washington, in 2008. Models with other variable combinations were not competitive (ΔAIC_c > 19). Variable acronyms are listed in Table 2.

Model[a]	AIC_c	ΔAIC_c	Model wt (w_i)	Cumm. w_i	No. parms
ψ(SPBROOMCOV+FAPERSOIL), ε(0), γ(0), p(MONTH,.)	918.0	0.0	0.48	0.48	9
ψ (SPBROOMCOV+FAPERSOIL), ε (0), γ (0), p(MONTH+SITESIZE,.)	919.8	1.8	0.20	0.67	10
ψ (SPBROOMCOV+FAPERSOIL), ε(0), γ, p(MONTH,.)	920.6	2.6	0.13	0.80	10
ψ (SPBROOMCOV+FAPERSOIL), ε (.), γ (0), p(MONTH,.)	920.6	2.6	0.13	0.93	10
ψ (SPBROOMCOV+FAPERSOIL), ε (0), γ (SITESIZE), p(MONTH,.)	923.3	5.3	0.03	0.97	11

[a] ψ = occupancy probability, ε = extinction probability, γ = colonization probability.
(0) indicates the parameter was fixed to a value of 0.0.

Table 5. Model selection results from multi-scale occupancy analyses of Mazama pocket gopher site survey data from Thurston and Pierce Counties, 2008. Only models in the 95% Confidence Set are shown. In all models detection probabilities are a function of season (spring or fall). Variable acronyms are described in Table 1 and Table 2.

Model						
Occupancy parameters	Use parameters	AIC_c	ΔAIC_c	Akaike wt (w_i)	Cumm w_i	No. parms
FAPERSOIL, SPBROOMCOV	SPBROOMDEN, FASHRUBCOV, FAVEGHTAVE, SL	869.05	0.00	0.39	0.39	11
FAPERSOIL, SPBROOMCOV, FAVEGHTAVE	SPBROOMDEN, FASHRUBCOV, FAVEGHTAVE, SL	869.76	0.71	0.28	0.67	12
FAPERSOIL, SPBROOMCOV	SPBROOMDEN, FASHRUBCOV, FAVEGHTAVE, SL, NS	870.58	1.53	0.18	0.85	10
FAPERSOIL, SPBROOMCOV, FAVEGHTAVE	SPBROOMDEN, FASHRUBCOV, FAVEGHTAVE, SL, NS	871.57	2.52	0.11	0.97	11

Table 6. Model averaged estimates of regression coefficients from multi-scale occupancy models for Mazama pocket gopher survey data from 2008. Variable acronyms are given in Table 1 and Table 2.

Parameter type	Variable	Estimate	SE	95% CI
Occupancy	Intercept	-9.73	8.39	-26.18 - 6.72
	FAPERSOIL	0.32	0.28	-0.23 - 0.89
	SPBROOMCOV	-1.02	1.10	-3.19 - 1.14
	FAVEGHTAVE	-0.10	0.14	-0.36 - 0.17
Plot use	Intercept	-1.84	0.47	-2.75 -0.92
	SPBROOMDEN	-0.30	0.11	-0.52 - -0.09
	FASHRUBCOV	-0.16	0.06	-0.27 - -0.05
	FAVEGHTAVE	0.09	0.02	0.04 - 0.14
	SL	3.68	1.88	0.00 - 7.37
	NS	0.31	0.47	-0.61 - 1.22

Table 7. Plot use probability estimates (and 95% CI) by soil type categories from multi-scale occupancy modeling of Mazama pocket gophers from 2008 surveys. Plot use estimates are within occupied sites from a model with no other variables modeling plot use or site occupancy, with detection functions modeled by season.

Soil Type	Plot use probability	95% CI
Gravelly Loam	0.40	0.33 – 0.48
Sandy Loam	0.61	0.50 – 0.72
S-N Complex	0.52	0.39 – 0.66
Silt/Clay Loam	0.22	0.03 – 0.72

Figure 1. Site occupancy probabilities plotted as a function of the variables in the best single season occupancy models for Mazama pocket gophers in Spring 2008. Regression coefficients are from model-averaged estimates and applied over the range of measured values, with non-plotted variables set to their mean values.

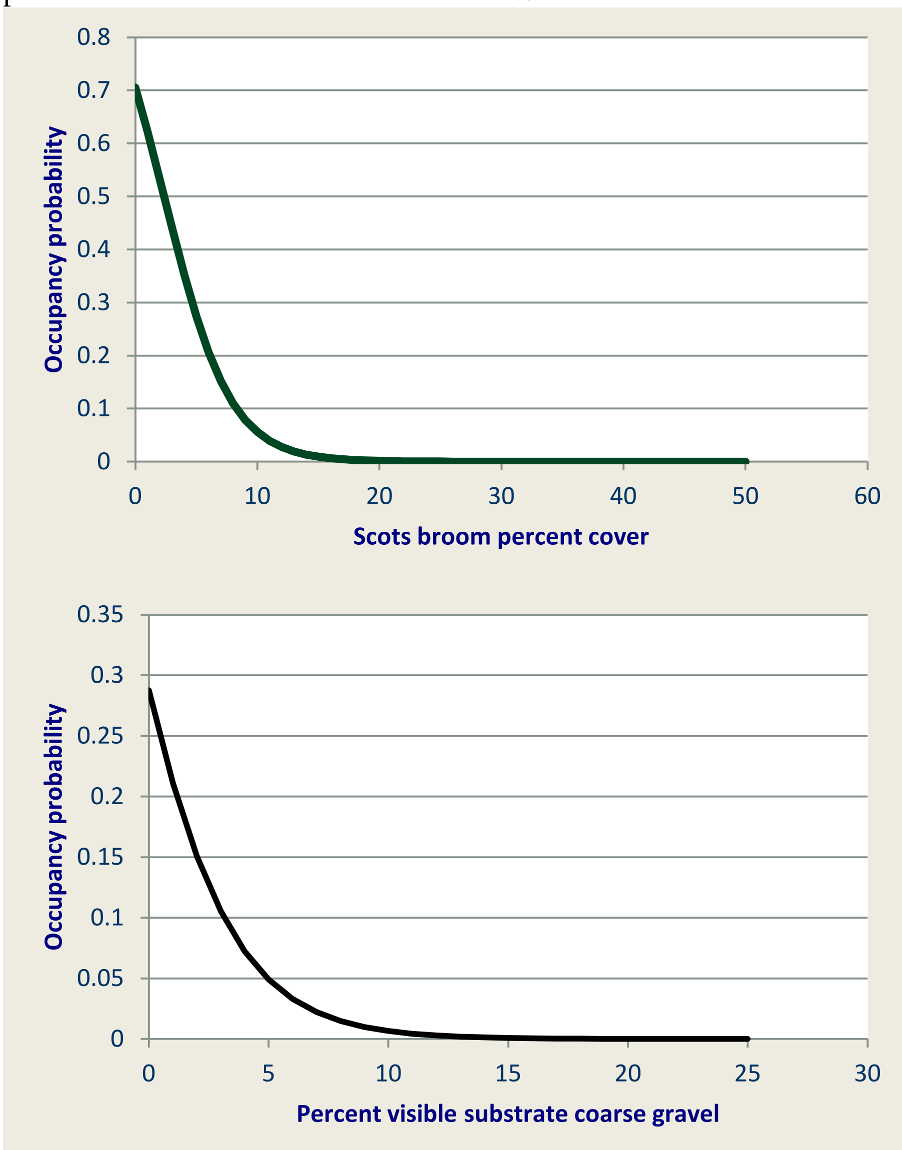


Figure 2. Site occupancy probabilities plotted as a function of the variables in the best single season occupancy models for Mazama pocket gophers in Fall 2008. Regression coefficients are from model-averaged estimates and applied over the range of measured values, with non-plotted variables set to their mean values.

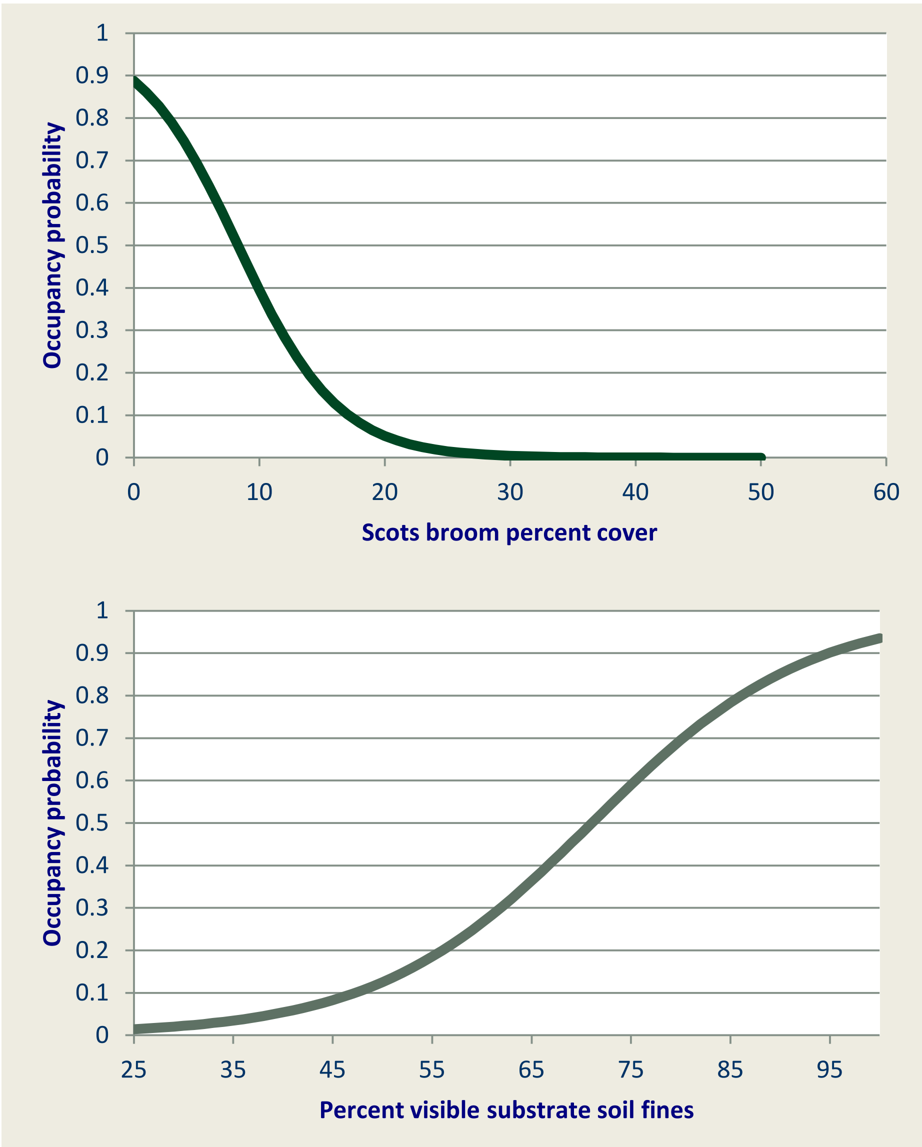
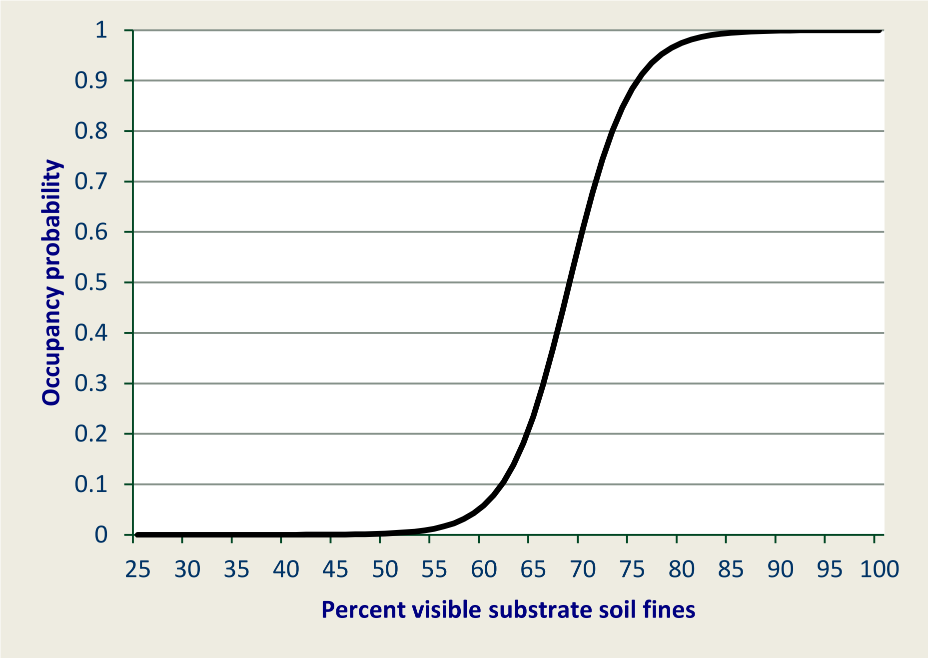
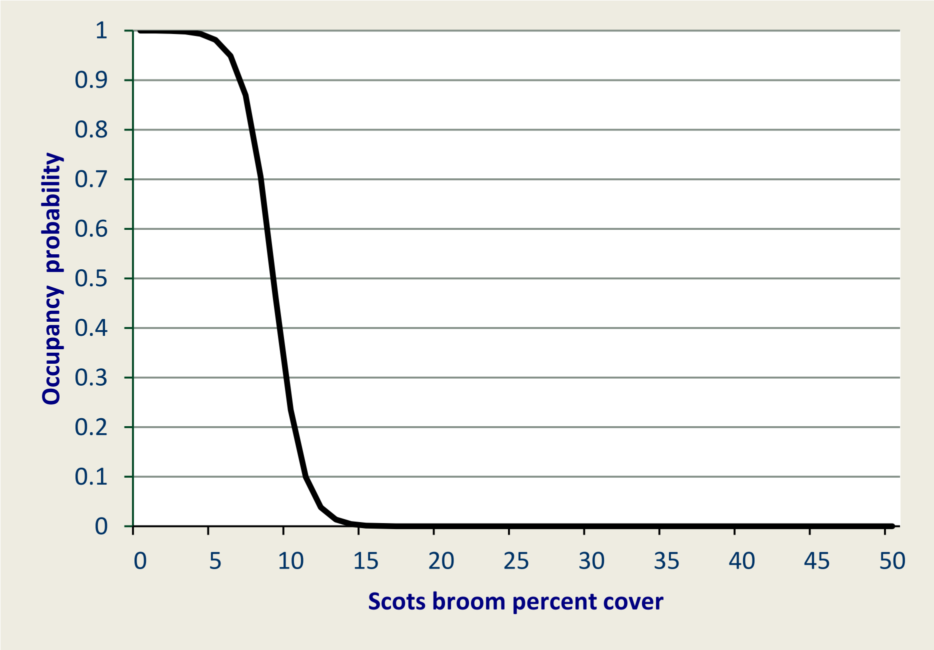


Figure 3. Site occupancy probabilities plotted as a function of the variables in the best multi-scale models for Mazama pocket gophers in 2008. Regression coefficients are from model-averaged estimates and applied over the range of measured values, with non-plotted variables set to their mean values.





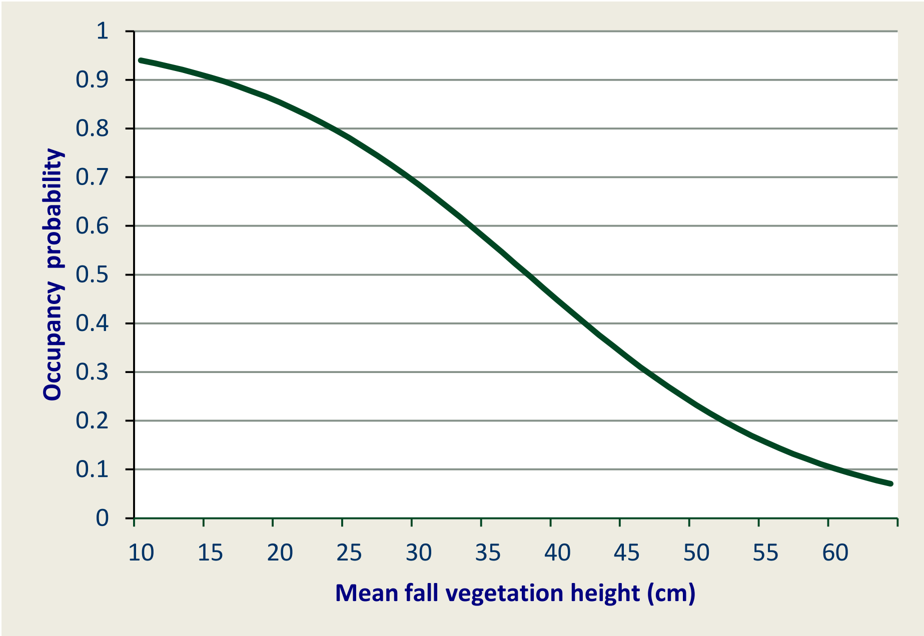
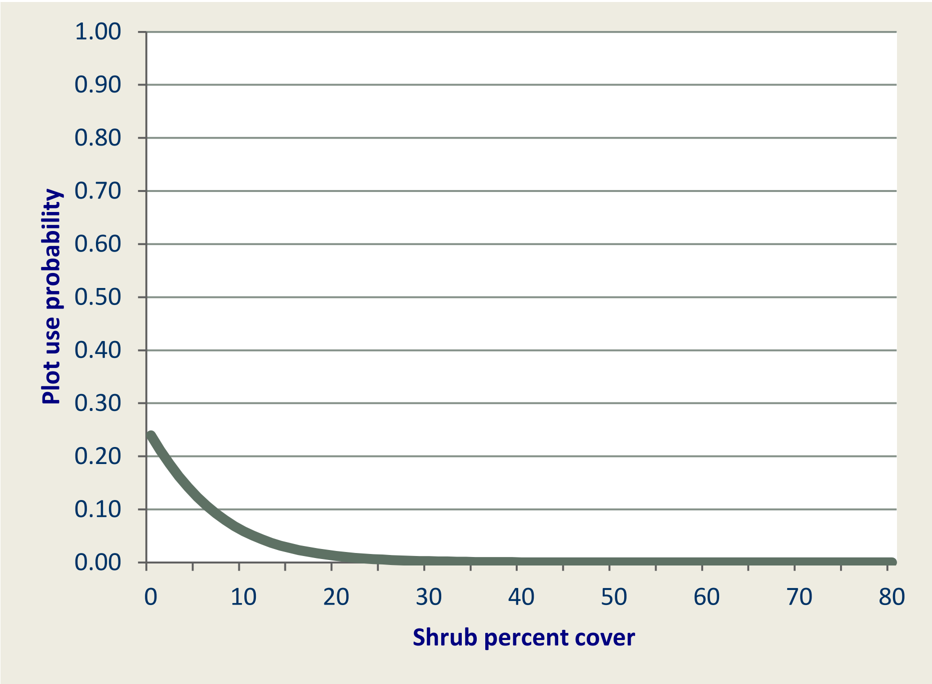
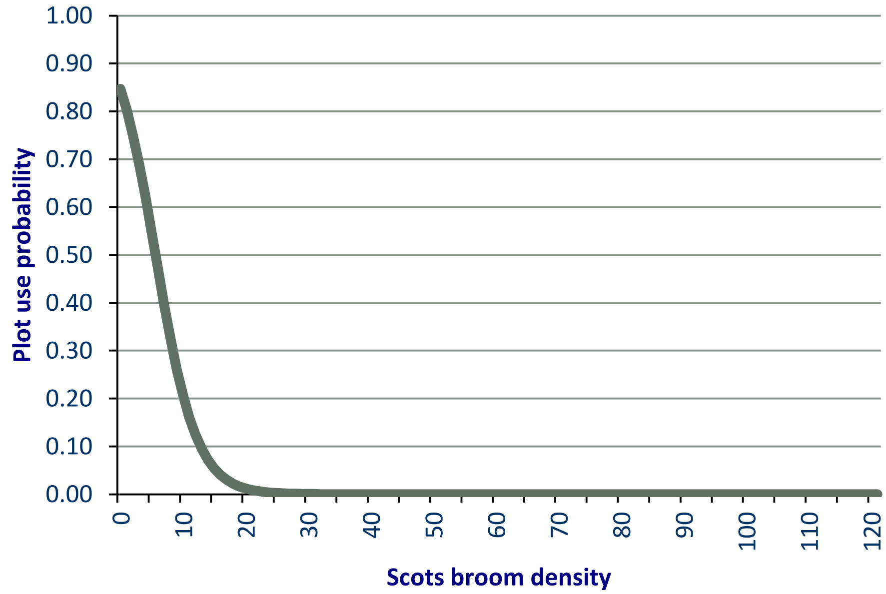

Occupancy probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 15 20 25 30 35 40 45 50 55 60
Mean fall vegetation height (cm)

Figure 4. Plot use probabilities plotted as a function of the variables in the best multi-scale models for site occupancy of Mazama pocket gophers in 2008. Regression coefficients are from model-averaged estimates and applied over the range of measured values, with non-plotted variables set to their mean values.





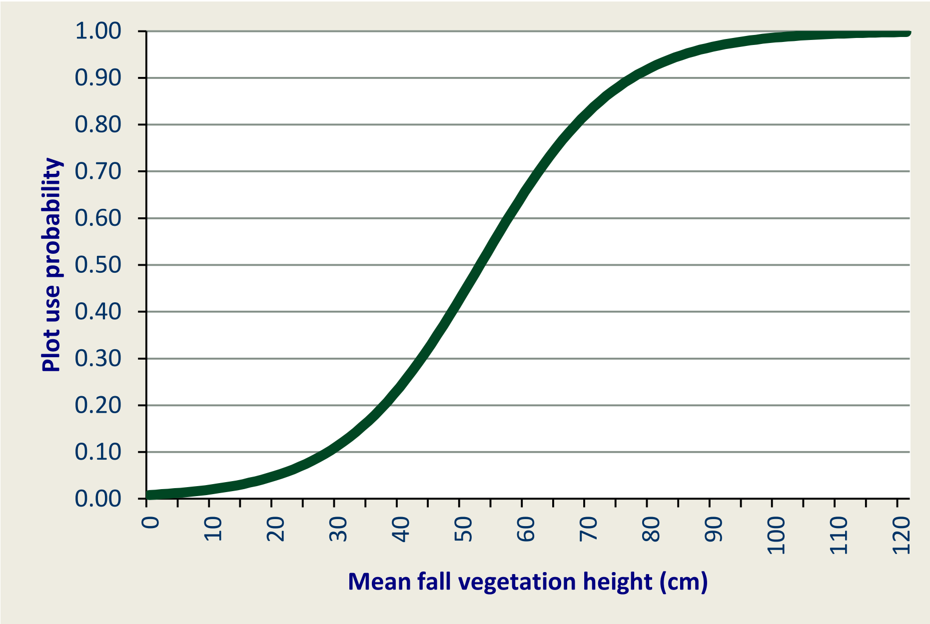


Figure 5. Plot use probabilities (and 95% confidence intervals) by soil type category from multi-scale modeling of Mazama pocket gophers in 2008. Estimates are from a model with no other variables on plot use or site occupancy, with detection functions modeled by season.

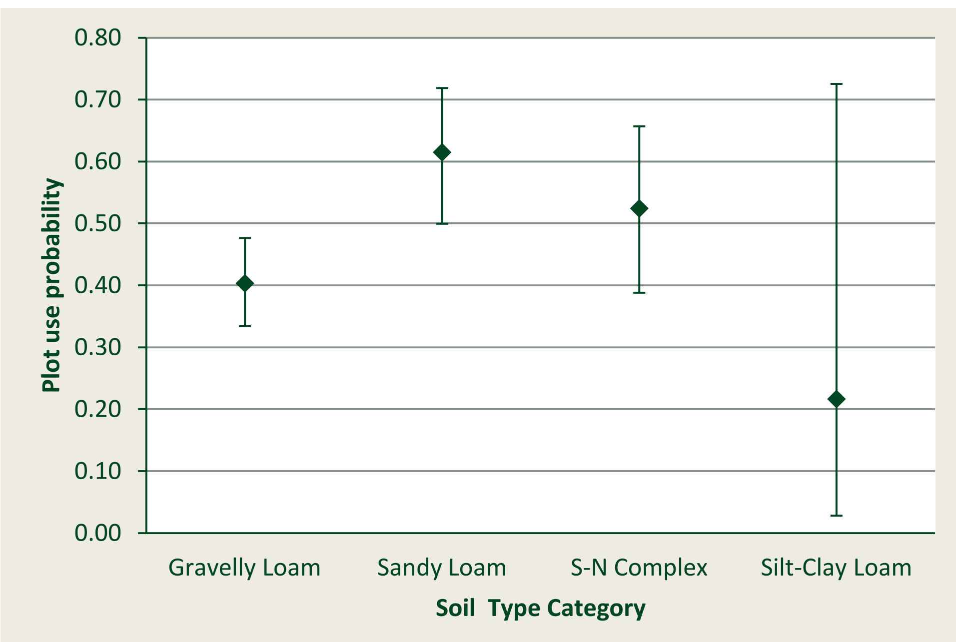
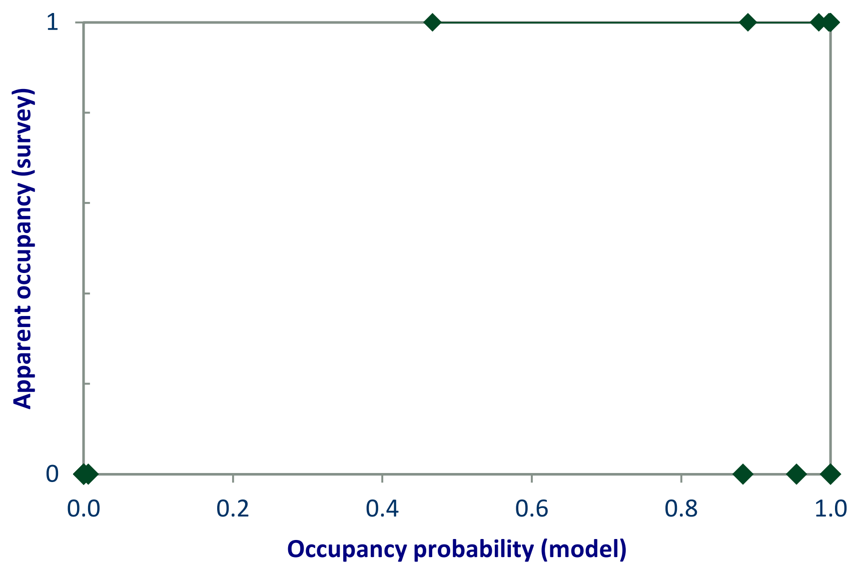


Figure 6. Comparison of occupancy probability estimates from the best multi-scale occupancy model for sites in the analysis (n=40), with occupancy status in Fall 2008 (0 = unoccupied and 1 = occupied). Points in the lower left and upper right are a close match between model prediction and reality, points located elsewhere indicate mismatches.



PART II: The Use of Mound Surveys to Index Pocket Gopher Abundance

BACKGROUND

Pocket gophers are subterranean animals that rarely venture above ground. Consequently, determination of pocket gopher presence is nearly always based on the detection of the dirt mounds pocket gophers create from the construction and maintenance of their burrows. However, there is often an interest in estimating pocket gopher abundance and the methodology for doing so remains uncertain. Live trapping of pocket gophers is a highly labor intensive effort that may also be damaging to existing vegetation. This often makes capturing gophers impractical to apply on even a modest scale. Several previous studies have found that the number of mounds can be related to numbers of pocket gophers (Richens 1965, Reid et al. 1966, Scrivner and Smith 1981, Smallwood and Erickson 1995), so beyond the use of mound presence to indicate gopher presence, there has been much interest in using mound surveys to index pocket gopher abundance. However, there are a several factors that make the relationship between dirt mounds and pocket gophers ambiguous:

1. Moles also produce dirt mounds when digging tunnels, and the characteristics of mounds constructed by moles and those constructed by pocket gophers can overlap, leading to misidentification of species present. These errors can increase as mounds "age" over time as weathering may obscure the diagnostic characteristics of mounds. Likewise, soil type and topography may make it more difficult to distinguish mound origin.

2. Pocket gopher burrowing activity varies throughout the year, and at times they may produce no mounds. Gophers may dispose of waste dirt in old tunnel systems, thus having no need to transport dirt to the surface. Therefore, pocket gophers may be present but they may be missed because there are no mounds. Even when mounds are present, there may be variation in the number of mounds produced seasonally. Thus the number of mounds may not consistently reflect the number of pocket gophers present within a year.

3. Pocket gopher burrowing activity may vary with soil type and quality of vegetation. Rockier soils may restrict digging activity, which may in turn lead to fewer mounds. Pocket gophers are known to have smaller home ranges in areas with higher vegetation quality (Reichman et al. 1982, Romanach et al. 2005), which would result in less tunneling activity. Therefore, the number of mounds per pocket gopher may vary between sites, although neither Andersen (1987) or Sparks and Andersen (1988) were able to detect an effect of resource level on excavation or mound building rates.

4. Burrowing activity may vary by other factors as well, including age and gender (Bandoli 1981, Romanach et al. 2005), further obscuring the relationship between number of mounds and number of individuals.

5. Pocket gophers are known to be asocial and, outside of the breeding season, adults do not share burrow systems. This has led some to assume that clusters of mounds in close proximity are associated with a single pocket gopher, and that counts of mound clusters may accurately reflect numbers of individual animals (Smallwood and Erickson 1995, McAllister and Schmidt 2005). This method relies on at least an approximate estimate of home range size, as well as the presumption of exclusive use of an area.

To test some of these assumptions, this study was designed to investigate the relationship between pocket gopher mounds and individual gophers. Specific objectives were to:

1. Compare total number of mounds, mounds per gopher, and area associated with mounds and gophers between study areas, among plots within study areas, and between seasons.

2. Determine whether an index based on number of mounds and/or mound area could be used to approximate numbers of pocket gophers.

METHODS

Study areas

Two areas were chosen for this study, the Olympia Airport, and Wolf Haven International. These areas were selected because they were not included in the occupancy modeling surveys, they had limited access to the general public, and they represented two very different sets of circumstances. The Olympia Airport supports a very large, long-persisting population of pocket gophers and is completely within the Nisqually soil type (a deep sandy loam apparently ideal for pocket gophers). Vegetation on the Airport is generally a mix of non-native grasses and forbs, and the area is mowed twice a year. The area of the study was located well away from flight operations and rarely sees any human use. Wolf Haven International has a small, recently established population (via translocation) of pocket gophers, and is mounded prairie (Mima mounds) with very rocky, shallow soils (officially designated as Spanaway-Nisqually complex). Vegetation at Wolf Haven is a mixture of native and non-native prairie plants with recent active management by The Nature Conservancy to enhance the native species. Both sites are also occupied by moles and hawks and coyotes are known to be found in both areas. Although the study areas are approximately 10 kilometers apart, the pocket gophers at Wolf Haven were likely mostly descendents from translocated individuals, the majority of which were trapped from areas within 1km of the Airport.

Mound mapping

Within each study area, we established square plots, 25m on a side, by staking corners and marking them with cotton twine. We also used the twine to mark 5m squares within each plot, forming a grid of 16 blocks. On the first day of mapping, we walked through each block and marked on graph paper the exact location of every fresh pocket gopher mound found. Hand-drawn maps were used instead of GPS locations because we needed to distinguish mound locations more accurately than could be obtained from even highly accurate (<1m) GPS equipment. We could also draw the approximate shape of the mounds which helped us to track them. We used a 3m long fiberglass pole marked at 0.10m intervals to facilitate accuracy. All mounds larger than a human fist (approximately 10cm in diameter) were mapped, and mounds were numbered sequentially within the study plot. All mounds were mapped and given separate numbers, even if they overlapped.

Mound maps were updated periodically (at less than 1 week intervals) until trapping commenced (at least 1 week from when mounds were first mapped). Mound maps were always updated immediately before trapping. Fresh mounds were mapped and assigned numbers, thus documenting temporal changes in mounds present.

Animal trapping

Trapping was conducted during both day and night in the spring, and during daytime hours only in the fall. We used metal box live traps with 3 solid sides and a bottom of wire mesh constructed specifically for use with pocket gophers. Within each plot, individual fresh mounds or mound clusters were selected haphazardly for trapping; generally the freshest mounds in the plot were selected first but eventually all mounds or clusters within a plot were trapped.

Pocket gopher tunnels were located by probing the edges of mounds with a metal rod; if no tunnel was found even after exploratory digging, then the next nearest mound was tried. Occasionally, tunnels were found between mounds simply by the pressure of walking on the surface – these were trapped only if closely associated with a fresh mound and were therefore assigned to that mound location. When a tunnel was found, we dug down to find a horizontal tunnel, and cleared an area large enough to place the traps within it with the trap flush with the tunnel bottom. Often, the tunnel would branch into at least 2 directions before a trap could be placed, in which case we cleared an additional area and set more than one trap so that an open trap faced all directions of the tunnel. In this process, adjacent mounds were sometimes destroyed, but these mounds were then known to be associated with the same burrow system as the selected mound. Traps were baited with a small chunk of carrot, then covered with sheet of black plastic weighted with dirt removed from the hole so that no daylight was visible underneath.

Traps were checked between 2 and 18 hours later, depending on the time they were set. When checked, the condition of the trap was noted as having a capture, empty and open, empty but closed, or plugged. Plugged traps were those packed partially or completely with dirt and rocks by gophers, often without tripping the trap. Except for captures, traps were re-set and replaced in the same locations for the next trapping session. Trapping continued until all mounds within a plot were trapped.

All animals captured in this study were pocket gophers. Captured gophers were scanned with a PIT tag reader to verify if they had been previously marked. If not, they were injected with a new PIT tag. Captured gophers were weighed to the nearest gram, and we recorded PIT tag number, weight, trap location, general body condition, and apparent sex and age (juvenile or adult) of the gophers. During spring trapping, age was readily apparent based on body mass, as was sex of adults based on genetalia (descended testes in males, swollen mammaries in females). But for juveniles in both seasons, and sometimes for adults in the fall, sex was difficult to determine with confidence. We used categories for sex of “probable male” and “probably female" to reflect this uncertainty, and also used the category "unknown" when sex could just not be determined. Although Mazama pocket gophers are slightly dimorphic in size, there is so much overlap that this is not a definitive characteristic of sex. However, in some cases very large animals (>115g) could be safely assumed to be male.

Data analyses

Mound maps were entered into a GIS by digitizing them onto grids spatially referenced to plot corner points GPS'd in the field. Mounds were assigned to individual pocket gophers based on capture locations. Mounds within the same cluster as mounds with captures, or otherwise known to be within the same burrow system, were also assigned to individuals. Several mounds could not be assigned. A rough estimate of the area associated with each individual was computed based on the minimum convex polygon constructed by connecting the outer mound locations assigned to it. From these data we computed mounds per plot, mounds per individual, and area used per individual and compared these between study areas and seasons using F tests. Finally, I used linear regression to compare the number of mounds per plot with the number of animals per plot to facilitate comparisons of results with other studies.

RESULTS

We set up 8 plots for mound mapping in the spring, and 15 in the fall. In the spring, it was difficult to find areas with fresh pocket gopher mounds at both the Airport and Wolfhaven, even in areas known to be occupied the previous fall. Therefore, the 4 plots located at the Airport were not adjacent to each other, and centered over the areas where activity was first seen (Figure 1). At Wolfhaven, the 4 plots were adjoining (Figure 2), but no activity was seen on 3 of the plots until May. In the fall, most of the area at the Airport had fresh burrows so 9 plots were laid out that overlapped the area of 3 of the spring plots (Figure 1). At Wolfhaven, 2 plots were added adjacent to the 4 used in the spring, as this area was consistently used by pocket gophers (Figure 2).

In both seasons, there were more mounds per plot and per individual at the Airport than at Wolfhaven (Table 1, Figures 1,2). Even with the biased placement of plots in the spring, there were more mounds per plot recorded in the fall than in spring at the Airport, but at Wolfhaven, there were approximately the same number of mounds per plot (Table 1). Mounds per individual were about the same between seasons within both study areas.

Table 1. Summary statistics for the number of mounds per 625m^2 plot (A) and number of mounds per individual (B) by study site and season, for Mazama pocket gophers in Thurston Co., WA, in 2008.

A. Mounds per plot

	Olympia Airport				Wolf Haven			
Season	n	Mean	SE	Range	n	Mean	SE	Range
Spring	4	41.2	8.8	22-59	4	16.5	11.0	2-49
Fall	9	66.1	15.4	8-139	6	14.9	6.1	2-44

B. Mounds per individual

	Olympia Airport				Wolf Haven			
Season	n	Mean	SE	Range	n	Mean	SE	Range
Spring	11	15.4	4.5	2-56	7	6.3	3.2	1-25
Fall	28	17.2	3.3	1-70	18	4.4	0.7	1-13

The regression of the number of animals per plot with the number of mounds per plot, treating each plot as an independent replicate. This was probably not appropriate due to repeated measures of plot locations in some cases, but consistent with the treatment of plot data from other studies. Linear regression models treating animals as the dependent variable were highly significant ($p<0.0001$) when centered through the origin, whether or not the mound counts were transformed (see Reid et al. 1966, Table 2).

Table 2. Results from linear regression analyses with number of animals per plot as the dependent variable and number of mounds per plot as the explanatory variable, fit through the origin (no intercept). Plots were treated as independent replicates. P-values for F tests of models were each <0.0001.

Model	R^2	Slope estimate	CV(mean)
mounds	0.72	0.08	60%
log(mounds)	0.90	1.46	37%
sqrt(mounds)*log(mounds+1)	0.80	0.68	51%

The area per individual proved to be difficult to measure. In some cases there was only one mound associated with an individual, which was assigned an area of $0.2m^2$, or approximately the size of an average mound. Other times there were only 2 mounds, thus the "area" estimate was simply 0.2 times the distance between the mounds. Finally, there were several cases where the animal appeared to be on the edge of the study plots so that the area it used was greater than the area within the plots. The data from these individuals (when identifiable) were dropped from the area analyses.

Once again there were large differences in the area associated with individuals among study sites but not among seasons (Table 3), tracking the same pattern of the number of mounds per individual. None of the pocket gophers at Wolf Haven were thought to have ranged outside of the study grids, but 9 of the gophers at the Airport did (6 in fall and 3 in spring).

Table 3. Summary statistics for area[a] per individual (in m^2) by study site and season, for Mazama pocket gophers in Thurston Co., WA, in 2008.

	Olympia Airport				Wolf Haven			
Season	n	Mean	SE	Range	n	Mean	SE	Range
Spring	7	27.0	12.6	0.7-87.3	6	5.2	4.1	0.2-25.7
Fall	21	29.8	8.4	0.2-169.1	18	2.9	1.0	0.2-15.9

[a]Reported areas likely under-estimate home ranges because of sampling biases, and thus should not be considered home range estimates.

DISCUSSION

This limited study identified some important points about the relationship between pocket gophers and mounding activity that have implications for the use of mound surveys for pocket gopher presence and abundance. First, the difficulty of finding fresh mounds in the early spring months (March and April) in areas known to have gophers calls into question the validity of conducting mound surveys at that time of year, even if only used to establish presence. Number of mounds per plot also varied between seasons at the airport, indicating that there are at least some seasonal differences in mounding activity. However, some of this may be attributed to seasonal increases in number of animals present (see below). Seasonal differences in mounding activity were also supported by the occupancy modeling study results, and numerous other studies of pocket gophers have noted the same. However, none of those studies were of *T. mazama*, and the reasons for those differences varied. In the only known previous study to map pocket gopher mounds in detail similar to our study, Klaas et al (2000) found variation in *G.*

bursarius mound production in Iowa both within and among years (n=2), with daily rates varying from 0.50 – 10.29 (for intervals ≤ 10 days) in 6400m^2 grids. In general, mounding activity was greatest in June-July, with the lowest rates in April and August-September (they did not collect data during October- March). Romanach et al. (2005) found increased activity of *T. bottae* to be associated with increased soil moisture after a dry spell, and with increased vegetation growth associated with prolonged moisture. Miller and Bond (1960) felt that increased mounding by *T. bottae* coincided with the spring reproductive period, and with dispersal of young in the fall.

Second, all of the metrics examined (mounds per plot and individual, and area per individual) differed between the two study areas, indicating that survey methods based on either number or area associated with mounds should not be used to make comparisons among different areas without adjusting for site differences. These differences were large, ranging from 3 to 5 fold differences. Unfortunately, the reasons for the differences between the two study areas cannot be determined from this limited study. Possibilities include: soil characteristics, vegetation quality, disturbance, and population history. Some of these have been shown to affect burrow size characteristics (Romanach et al. 2005), so it is logical that they might affect mounding rates.

Ignoring site and season affects, an overall statistically significant positive relationship between mounds and animals was found when compared at the plot level. Although this analysis was similar to that of previous studies (Richens 1965, Reid et al. 1966), the treatment of plots as independent replicates was probably inappropriate. In all of these studies, plots were located close together, measured repeatedly (or nearly so) through time, and selected non-randomly. While there appears to be an overall positive relationship between number of mounds and number of pocket gophers, it may not be consistent across sites or time (Gibbs 2000, this study). Previous studies have either recommended pilot studies in the area of application to establish the form of the relationship (calibration), or that mound surveys be used when comparisons are to be made among paired replicates in a treatment/control experiment. However, since the relationship between mounds and number of gophers appears to vary spatially, temporally, and demographically, the work required to calibrate the mound index may be as much work as direct enumeration.

A variation on mound surveys based on area associated with mounds also appears problematic. In this method, only fresh mounds that are at least a pre-determined distance apart are counted and assumed to be created by different individuals (Smallwood and Erickson 1996, McAllister and Schmidt 2005). So far no study has been conducted that has evaluated this method relative to actual numbers of individuals, perhaps for the reasons that made determination of area in this study so difficult. There is also the added difficulty of determining the distance criterion, presumably based on the home range of individuals. But pocket gopher home ranges are also variable (cf. Reichman et al. 1982, Cameron et al. 1988, Witmer et al. 1996) and most methods of estimation are themselves proxies for actual home ranges. Pocket gophers are somewhat unique in that excavation of their burrows allows exact measurement of home ranges. But excavation is very labor intensive and destructive so most home range estimates are from radio-telemetry or repeated live-trapping (cf. Howard and Childs 1959, Witmer et al. 1996). No study has verified that these are good approximations of actual home ranges, but Figure 1 from Cameron et al. 1988 indicates that radio-telemetry locations may under-estimate true home ranges. Further, a study by Reichman et al. (1982) on burrow spacing and geometry in *T. bottae* found that independent burrows were approximately 4m apart, yet burrow size (home range) varied from 11-75m^2. Thus mounds created by different individuals could be as close a 4m from each other, yet multiple mounds from the same individual could be >25m apart.

The scope of this study was too limited to investigate the actual area of use per individual, and thus the estimates in Table 2 should not be considered as home ranges. Even these might be underestimates of use areas because pocket gophers are constantly refilling old tunnels and building new ones (Reichman et al. 1982). They also are temporally dynamic, so that pocket gophers may either expand their home ranges or shift them seasonally (Klaas et al. 2000) and/or annually (Hobbs and Mooney 1991).

EVALUATION OF MOUND SURVEYS AS INDICES TO ABUNDANCE

Because of the persistent interest in using mound surveys to index pocket gopher abundance, and the intermittent publication of papers claiming that they are useful for this purpose, it is worth elaborating on the properties of good indices, evaluating whether mound surveys have these properties, and specifying the circumstances under which mound surveys might be useful.

Several authors have written about the good properties of an index in a wildlife context (cf., Conroy 1996, Anderson 2001, Conn et al. 2004, Engemann 2005). In the specific case of mound surveys as an index to abundance, the following apply:

1. The index should match the target population estimate spatially, temporally, and demographically. Thus the area and time frame of the mound counts should match that for which abundance estimates are desired, and the demographic composition of the population should be that estimated by the mound count. For instance, if mounds are made only by adults at the time of survey, then the projected population is of adults only.

2. The relationship between the actual population and the mound count should either be consistent over all of the conditions to which it will be applied, or the factors that affect this relationship should be identified and their influence measured.

3. The variability of the abundance estimate should be estimated and within the range of precision desired. In the case of mound surveys and pocket gopher abundance, this estimate is the accumulation of four components: 1) the sampling variance associated with the mound counts including any variability associated with detectability; 2) the degree of reliability in the relationship between the mound count and actual abundance; 3) the variation associated with the factors affecting the relationship between mounds and abundance; and 4) the variability associated with the model used to associate mound counts and pocket gopher abundance (model selection error).

In applications of mound surveys, the first criterion is usually met. Counts may be conducted either across entire sites or within sample plots extrapolated to larger sites. Timing of counts within years has also been addressed in general (Richens 1965, Reid et al. 1966) but would certainly need to be adjusted by species and location. The main recommendation seems to be to conduct mound surveys during the post-reproductive phase, yet even those counts may be affected if the reproductive season is variable.

The second criterion usually is not met. Although Gibbs (2000) was able to identify both temporal and spatial differences in the mound-abundance relationship, he did not attribute these differences to specific effects that could be modeled and used in future surveys. In fact, none of the studies that compared mound numbers to abundance determined whether the relationships they found were reliable beyond the scope of the original study. Thus, most researchers recommend that these relationships be investigated for each application of mound counts. However, this may be as impractical as estimating actual abundance.

The third criterion has never been applied in studies using mound surveys. While Reid et al. (1966) estimated the variance associated with use of sample plots and Richens (1965) reported the residual variance from regression models between counts and abundance estimates, no one has estimated prediction intervals, even under the assumption that no other factors affect the relationship. Since no one has developed a model including explanatory factors, there is little basis from which to calculate the affects of those variance components on the precision of abundance. Both model error and model selection error (see Burnham and Anderson 2002) could possibly be estimated for data from three studies (Reid et al. 1966, Scrivner and Smith 1981, and Richens 1965), but the development of different functional relationships (linear, log-linear, polynomial) in each case indicate that numerous models should be tested.

In summary, the utility of mound surveys to estimate abundance seems to be limited to situations where the effort needed to establish the relationship between the two is worthwhile. For instance, if long-term monitoring is desired for specific sites, then it might be useful to establish a two-stage sampling scheme wherein the entire site is surveyed for mounds and a smaller portion of it is trapped to calibrate the mound-animal relationship. After some number of years it may be also possible to suspend the sub-sampling if a consistent relationship is found.

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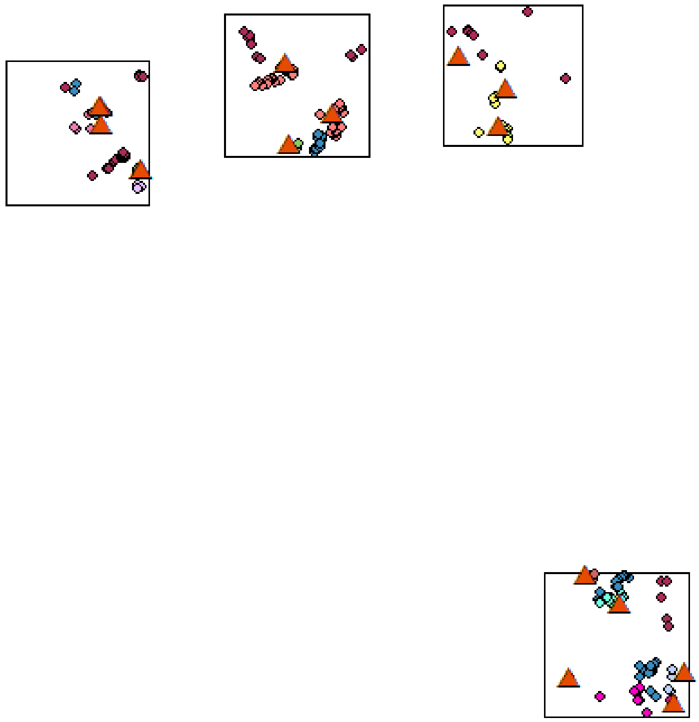
Figure 1. Maps of mounds and captures of Mazama pocket gophers during 2008 at the Olympia Airport. Mounds are small diamonds with like colors associated with the same burrow system. Large orange triangles are capture locations of individual pocket gophers. Plots are 625m[2] (25m on each side). The top map is from Spring and the bottom map is from Fall.



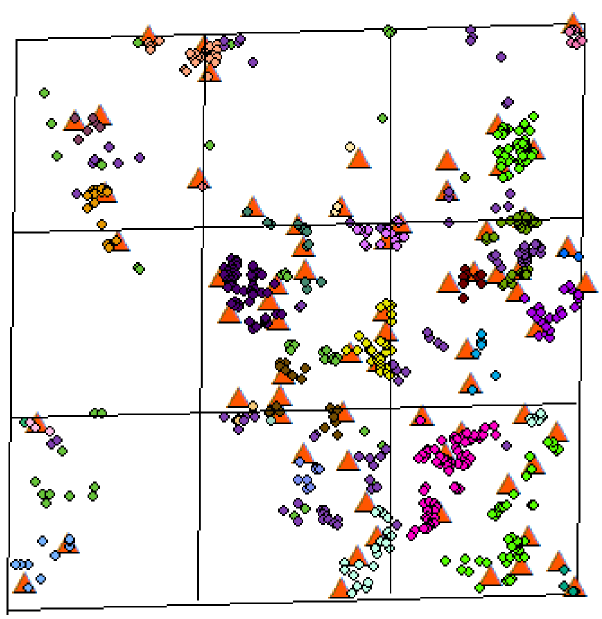


Figure 2. Maps of mounds and captures of Mazama pocket gophers during 2008 at Wolf Haven Internation. Mounds are small diamonds with like colors associated with the same burrow system. Large orange triangles are capture locations of individual pocket gophers. Plots are $625m^2$ (25m on each side). The top map is from Spring and the bottom map is from Fall.