LANDSCAPE ECOLOGY OF RODENTS IN A NO-TILL AGRICULTURE SYSTEM

By

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The members of the Committee appointed to examine the thesis of JASON L. CAPELLI find it satisfactory and recommend that it be accepted.

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Chair

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LANDSCAPE ECOLOGY OF RODENTS IN A NO-TILL AGRICULTURE SYSTEM

Abstract

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No-tillage agriculture provides year-round ground cover and food for rodents and potentially may increase rodent numbers on farms by allowing colonization of these agricultural habitats. Consequently, rodents may periodically cause crop damage, particularly during high phases of population cycles. I investigated the landscape ecology of rodent species, primarily deer mice (*Peromyscus maniculatus*) in a no-tillage agriculture system in the Palouse Prairie region of Washington from 2003 through 2004. I established 600 trapping sites on the 200-acre Palouse Conservation Field Station (PCFS) to evaluate seasonal dynamics of populations and environmental factors influencing rodent distribution. Capture probabilities were calculated, using indicator kriging, and mapped over the study area using ArcGIS. I then used classification and regression tree (CART) and stepwise logistic regression analyses to evaluate and model the ecological factors that predict rodent distribution in this no-tillage landscape. Permanent non-agricultural grass cover type, and elevation were the most influential landscape variables predicting rodent capture probabilities and
distribution over the farm. Grass cover generally had a positive impact on rodent capture rates, while elevation had mixed relationships. It is apparent that although a no-tillage cropping system leaves year-round cover, allowing colonization of some agricultural habitats, rodents still tend to occur in higher abundance in permanent non-agricultural grass areas.
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The Palouse Prairie region, located in southeast Washington and northwest Idaho, is known as one of the most productive dryland wheat areas in the world (Young 2004). Other major crops grown on the Palouse include barley, peas, and lentils (Young 2004). Due to rolling topography, soil types, and seasonal precipitation patterns, the Palouse also is one of the most erosion-prone areas in the United States (Batie 1983, Young 2004). These conditions make no-tillage farming an excellent farming practice for the Palouse and an important step toward sustainable agricultural systems. No-tillage agriculture, by definition, is planting into previous crop residue, thereby maintaining surface cover and residue. No-tillage farming provides many ecological and practical advantages over conventional tillage farming including reduced soil erosion (Young 2004), decreased carbon emission (Jackson and Schlesinger 2004, West and Post 2002), and more stable yields (Fenster and Wicks 1977). However, continuous no-tillage is not widely practiced on the Palouse due, in part, to heavy surface residues and steep slopes that impede seeding operations and complicate fertilizer and pest management.

No-tillage agriculture may have large affects on the landscape ecology of wildlife species occurring in agricultural landscapes. No-tillage provides higher quality wildlife habitat than typically found on conventional tillage farms by providing better and more consistent cover for ground-nesting birds (Lokemoen and Beiser 1997; Martin and Forsyth 2003; Uri et al. 1999), protection for small
mammals from predation (Uri et al. 1999), and it may allow them to establish permanent burrow systems in agricultural fields (Sterner et al. 2003). Research on small mammal ecology on the Palouse has largely been restricted to nature reserves (Scarlett 1997; Lindberg 1971; Dunlap 1988; Francik 1979; Wright 1971). The positive response of rodents, especially voles (Microtus spp.), to increased grass cover is well documented (Birney et al. 1976; Edge et al. 1995), however, the effect of year-round agricultural cover on rodent distribution on farms is relatively unstudied. Witmer and VerCauteren (2001) provide a review of the role that voles play in no-tillage agriculture systems. In no-tillage corn rodent damage was found to be localized (Clark and Young 1986; Hygnstrom et al. 1996) and investigators concluded that large-scale rodent control programs would be rarely warranted.

Rodent ecology has been studied extensively with population dynamics, specifically population cycles, being perhaps the most widely studied ecological phenomenon of rodents (Krebs 1974; Wolff and Edge 2003). Rodents exhibit large-scale population cycles in many temperate areas of the world (Boonstra et al. 1998). Johnson (1986) found that voles showed inter-year and multi-year cycles in agricultural areas of the Palouse. Factors producing rodent cycling are still not positively explained, however, most researchers conclude that it is caused by direct and delayed density dependence (Saitoh et al. 1999; Stenseth et al. 1996). Self-regulation may cause density dependence to appear through social effects (Stenseth et al. 1996), delayed maturation (Saitoh et al. 1997), kin
selection (Charnov and Finerty 1980), or disease (Wolff and Edge 2003). However, predation likely plays a large part in most phases of population fluctuations (Boonstra, et al. 1998; Korpimäki and Norrdahl 1991; Korpimäki and Krebs 1996; Korpimäki et al. 2002) as well.

Rodents can cause severe crop damage in agricultural settings (Guy and Cox 2002; Hulme 1996; Johnson 1986). Preliminary observations suggest that montane voles (*Microtus montanus*) and deer mice (*Peromyscus maniculatus*) have the potential to cause significant crop damage on the Palouse during periods of high density (Witmer, unpubl. data). Apple orchards also suffer losses from voles eating roots of trees or girdling younger trees (Askham 1988; Tobin and Richmond 1993). Controlling a prolific rodent species is often impossible and rarely economically beneficial, and rodents may even provide benefits by acting as a natural insect and weed control agent (Clark and Young 1986). Rodent management is typically performed using rodenticide, baits, mowing, or burning on relatively small scales. Therefore, better understanding of the ecological and environmental factors influencing rodent occurrence and distribution in no-tillage agricultural landscapes can help determine when and where management might be needed and effectively applied.

Edge habitat frequently has a positive influence on wildlife activity and population numbers for many species. Rodents, especially deer mice, are considered generalist species (McDonald and St. Clair 2004) and might be
expected to favor edge habitats because of greater cover, structural diversity, productivity, or other factors. The effect of edge habitat on rodents has been investigated (Bock et al. 2002; Harris 1941), but rodents do not always have positive associations with edge and transition habitats (Bock et al. 2002) and may demonstrate a negative relationship, depending on landscape features.
Landscape ecology of rodents in a no-till agricultural system

INTRODUCTION

No-tillage farming provides several advantages over conventional tillage operations. Among these advantages are decreased soil erosion (Papendick and Miller 1977), increased efficiency of moisture usage (Phillips et al. 1980), and improved timing of planting and harvesting (Phillips et al. 1980). However, conservation tillage farming systems may also promote higher rodent populations in agricultural fields due to year-round ground cover, food, and less soil disturbance (Witmer and VerCauteren 2001). This situation may increase crop damage due to higher rodent densities, potentially hindering the widespread adoption of no-tillage agriculture. The ecology of rodents in agricultural-dominated landscapes has been investigated in several habitats including no-tillage corn (Clark and Young 1986; Hygnstrom et al. 1996), natural areas (Randall and Johnson 1979; Scarlett 1997) and other types of agricultural areas (Harris 1941; Marinelli and Neal 1995). However, specific ecological and environmental factors influencing seasonal dynamics and rodent spatial distribution in no-tillage crops in a farm setting are not well known.

We investigated the landscape ecology of rodents in a no-tillage agricultural system in the Palouse Prairie region of southeast Washington. The objectives of this study were to: 1) investigate the distribution of rodents within
continuous no-tillage agricultural fields and adjacent non-agricultural areas, and 2) examine the relationships between landscape and environmental variables potentially effecting rodent distribution and rodent capture success.

**METHODS**

**Study Area.**—The Palouse Prairie region is a highly productive agricultural landscape located in southeast Washington and northwest Idaho (Papendick and Miller 1977; Young 2004). In the annual cropping area under dry-land (>450 mm yr\(^{-1}\)) agricultural production, crops are composed primarily of wheat, barley, peas and lentils. Research was centered at and around the Palouse Conservation Field Station (PCFS) located about 1.5 miles North of Pullman, Washington. The PCFS is a 81.75-ha farm operated by the United States Department of Agriculture (USDA) and in cooperation with Washington State University. The primary focus is research and demonstration of no-tillage agriculture and alternative cropping systems. Due to the large number of individual cropping experiments being conducted, the PCFS is a relatively small and fragmented agricultural system compared to typical working farms of the Palouse, which average about 1,200 acres.

**Sampling Technique.**—All research was conducted using animal care guidelines of the American Society of Mammalogists (1998) and was performed under protocols approved by the animal care committee of Washington State University. All rodent trapping was performed using Sherman live traps. Six-
hundred trap locations were randomly selected over the study area using a random number generator. Trap locations were posted in ArcGIS 8.3 (ESRI, Inc. 2004) and transferred to a Navman 3450 GPS (±5 m) containing a Compaq Ipaq 3955 personal digital assistant (PDA) so points could be located in the field. For ease of sampling, the study area was divided into seven units containing approximately equal numbers of sampling locations. The sections were generally trapped in a random sequence generated using a random number generator. Traps were marked with a 3-inch colored flag and set near dusk, checked soon after dawn the following morning, and were closed during the day. Traps were baited using rolled oats (Farris 1971; Scarlett 1997) and non-absorbing cotton balls were provided for thermal protection during the cold nights in winter (Farris 1971; Scarlett 1997). Data collected with each rodent capture included species, sex, body weight, and evidence of reproductive activity. Rodent body weights were obtained using Pesola 100-gram spring scales. Residual cover type was recorded at all trap locations. Residual cover types consisted of wheat stubble, barley stubble, non-agricultural grasslands, pea residue, corn, and buckwheat/alfalfa (Table 1). Growing crop cover was also recorded to investigate different combinations of residual and growing cover. Growing covers included winter and spring wheat, winter and spring peas, spring barley, and alfalfa (Table 1). All 600 trap locations were sampled during fall (October 3-10) 2003 for a single night, while 580-585 locations were sampled in winter (February 16-March 7) 2004, spring (April 19-May 3) 2004, and summer (September 2-11) 2004 for three nights for a total of 5,838 trap-nights.
Rodent distribution.—We used a geostatistical method, indicator kriging, to create estimates of capture probabilities by season for the entire PCFS (Deutsch and Journel, 1998). The theoretical basis and implementation procedures for indicator kriging can be found in Isaaks and Srivastava (1989). We applied indicator kriging to binary (0 or 1, i.e., no capture or capture) coded data. Kriging, like other interpolation methods (e.g., nearest neighbor, inverse distance, polygonal), provides estimates for unsampled locations by creating linear weighted average values using neighboring sample values. The kriging weights applied to the neighboring sample values are derived from modeled variograms. A variogram is an empirical and quantitative description of the spatial variability inherent in the sample values for a direction and as a function of distance (Rossi et al. 1992). The variogram differentiates kriging from other interpolation methods in that close samples and samples oriented in directions of stronger spatial similarity are weighted more than samples that are farther away or oriented in directions of weaker spatial similarity. Indicator kriging estimates are interpreted directly as the probability that a location belongs to a class coded with a 1 (i.e., a capture). This mapping process yielded an interpolated map of rodent capture probability based solely upon known values, either at least one capture or no captures over three nights, at the trap locations. These geospatial maps of rodent capture probability, at a 2-m scale, generated by indicator kriging (Figure 1) were then used as a baseline to compare the performance of
predictive models derived from landscape and ecological variables associated with rodent capture success.

*Landscape analysis.*—We used eight calculated environmental variables to explore potential relationships with seasonal rodent distribution patterns on the farm landscape (Table 1). A 2-m digital elevation model (DEM) of the PCFS was created in ArcGIS 8.3, using the inverse distance weighted method, from a series of 27,000 GPS locations and elevations accurate to ±6 cm. Elevation, slope, aspect, potential yearly soil radiation (PYSR), and soil moisture index (SMI) were the landscape variables calculated from the DEM for analysis. Slope and aspect were calculated from the DEM using the surface analysis tool in ArcGIS 8.3. Aspect was converted for improved interpretation using a TRASP transformation (Roberts and Cooper, 1989) calculated as:

\[
1-\cos\left(\frac{\pi}{180}(\text{aspect}-30)\right)/2
\]

Soil moisture index was calculated from slope and specific catchment area as:

\[
\text{Soil moisture Index} = \ln\left(\frac{\text{specific catchment area}}{\tan(\text{slope})}\right)
\]

Specific catchment area is a catchment area draining across a unit width of contour (Wilson and Gallant, 2000) and is calculated from flow accumulation and flow direction. At each trap location, PYSR was also calculated using equations presented by Campbell and Norman (1998), modified to account for variations in slope and aspect. Distance-to-nearest-edge and meters of edge occurring within a 20-m radius of the trap site (m of edge) were calculated using the locations of field edges, determined from the crop cover raster, and trap locations.
We evaluated the influence of eight environmental variables (Table 1) on capture success using stepwise logistic regression (SLR) and classification and regression tree (CART) analysis. We performed SLR using SAS v.9.1 (SAS 2004). The binary response was either no captures over three nights (0) or at least one capture over three nights (1). This binary classification of captures was used to avoid the bias of animal recaptures and variable weather conditions during different trapping sessions over the farm. For logistic regression, the relative effect of the variables on the response within the best-fit model was analyzed using the odds ratio (Hosmer and Lemeshow 1985) which determines the effect of the response from a one unit change of a predictor variable. We used Spearman's correlation matrix (Zar 1984) to investigate the correlation of variables and determine which variables to exclude from the logistic analyses to avoid collinearity. When two variables had correlations > 0.60, we used only one of the variables in logistic models.

We also evaluated the effects of environmental variables on rodent capture success by developing predictive models using CART techniques (Salford Systems 2004). CART is a mathematical technique suited for the modeling of large data sets that are complex, correlated, and may contain missing values, however, it is not as widely known or used in ecological research compared to other traditional statistical procedures (De’Ath and Fabricius 2000; Rejwan et al. 1999). CART is a data mining technique that creates a decision tree (or classification tree) by using binary splitting rules. Data are divided
sequentially and increasingly into homogeneous groups using predictor variables and CART provides measures of predictive success describing the degree of segregation achieved at each sequential split. CART displays the proportion of observations classified into discrete nodes of the tree for each branch of a binary split (Breiman et al. 1984) which allows the relationship between the response and classification variables to be evaluated both quantitatively and visually (De’Ath and Fabricius 2000). We used a classification tree with a Gini splitting rule and default model selection parameters within CART (Salford Systems 2004). Where PYSR was a variable used by CART to build classification trees, a second tree was built with PYSR excluded, but surrogate values for other variables included, because terminal nodes using PYSR could not be mapped in ArcGIS 8.3 because it was only a point estimate and we could not generate complete coverage over the entire farm.

CART models were evaluated using misclassification rates and prediction success and optimal predictive models were selected using a 10-fold V-validation to avoid over-fitting the data set (De’Ath and Fabricius 2000; Salford Systems 2004). Additionally, CART allows variable importance to be ranked based upon the relative influence of each variable used in the decision tree. We evaluated the accuracy of the predicted capture probabilities modeled in CART by comparing them against the baseline capture probabilities calculated for the entire farm using indicator kriging. Kriging results were used as the capture probabilities against which we evaluated the CART models because it is a direct
We evaluated the performance of the CART models by calculating the absolute difference between capture probabilities generated from CART models and the baseline probabilities generated by indicator kriging for each 2m cell in the study area.

RESULTS

Rodent species captured.—Species diversity of captured rodents was low throughout the PCFS with deer mice (Peromyscus maniculatus) accounting for 98.5% of 2,042 captures. Other species captured included 26 (1.3%) montane voles (Microtus montanus), three (0.15%) shrews (Sorex spp.), and one western jumping mouse (Zapus princeps). Mean capture success was 16.2% during the fall, 53.5% in winter, 40.2% in spring, and 18.1% in summer (Table 2). Through all seasons, 46% of all vole captures occurred in non-agricultural grasslands.

Rodent distribution.—Kriging procedures created distribution maps of capture probabilities for each season over the entire farm (Fig. 1). Capture probabilities varied by season over most of the farm, however, several areas of the farm consistently demonstrated high or low capture probabilities (Fig. 2). All areas of consistently high capture probability were in areas of the PCFS with abundant non-agricultural grass areas, while all areas of consistently low capture probability were located predominantly in agricultural fields with little or no non-agricultural cover or in a small portion of the PCFS where trees are the dominant
cover. Capture probability was high over the majority of the farm during the winter (Fig. 1).

**Landscape analysis.**—Grass cover demonstrated a positive relationship with capture success in the fall, spring, and summer, and a negative relationship with trap success in the winter (Table 3). The two main cover types on the PCFS were wheat stubble (16.96 ha in fall/winter and 28.33 ha in spring/summer) and non-agricultural areas (22.05 ha). Pea residue had a negative relationship with capture success during the winter (Table 3). Elevation had a slightly negative relationship with capture success during the summer (Table 3).

Meters of edge habitat occurring within a 20 m radius of trap sites showed a slightly negative relationship with capture success in the winter (Table 3). Slope, aspect, PYSR, soil moisture index, and distance to nearest edge had no significant association with capture success in logistic regression models predicting capture success.

Like the stepwise logistic regression models, CART identified grass cover as having a strong positive influence on capture success during the fall (Fig. 3), spring (Fig. 5), and summer (Fig. 6) trapping seasons (Table 4). Elevation was identified as an influential splitting variable during all four trapping seasons by CART (Table 4), however, the relationship between elevation and capture success varied by season. Variable importance scores showed that grass cover
and elevation generally played significant predictive roles in all models (Table 4). PYSR was an influential splitter variable included in models in the spring trapping season (Fig. 5). Soil moisture index was used by CART to split data during the winter (Fig. 4) and spring seasons (Table 4) and demonstrated varying relationships with capture success.

CART models demonstrated that weather variables including maximum and minimum daily temperatures, precipitation, and snowfall, had a large effect on models predicting capture success. Daily maximum temperature had a positive relationship with capture success during the fall and winter. Daily minimum temperature had a negative impact on trap success in the spring. Summer capture success was not significantly influenced by any weather variables as weather fluctuations were minimal.

During the four trapping seasons, 82.9% of fall, 24.1% of winter, 45.2% of spring, and 61.9% of summer capture probabilities modeled by CART were within 30% of the capture probabilities generated by indicator kriging indicating good overall performance of the CART models during the fall and summer trapping seasons (Table 5).

**DISCUSSION**

Rodent distribution.—Rodent capture success varied widely between seasons and followed a yearly cycle with a peak in the winter, declining to a
yearly low in the fall. There were two areas of consistently high capture success on the PCFS (Fig. 2). These areas are both covered in permanent non-agricultural grasslands and are on relatively high elevation areas of the PCFS. Areas of consistently low capture success include two ridge-top agricultural fields and the tree-covered portion of the farm. These results indicate that while no-tillage cropping leaves large amounts of structural cover on the soil surface, rodents still occur in consistently higher densities in permanent grasslands. However, seasonal variation in trap success also could be due to seasonal variation of food supplies. High winter capture success may be influenced by low food levels in the environment, increasing attraction to baited traps. Additionally, rodents may use traps as potential shelter. High food availability in agricultural fields might also explain the low capture probabilities observed in fall and summer because those trapping sessions occurred relatively soon after harvest (0.5 - 3 months) when food supplies (i.e., waste grain, insects) were likely abundant.

_Landscape analysis._—We used both stepwise logistic regression and CART analyses to determine relationships between landscape topography and environmental variables and rodent capture success. Both classification methods determined that permanent non-agricultural grass areas and elevation were the two most influential variables predicting rodent captures. However, the CART predictive models had varying success in accurately matching the probabilities obtained through the indicator kriging procedure (Table 5). CART
attempts to split data into homogeneous groups and when a response is relatively uniform, as in the winter, CART cannot perform as well. The winter trapping season during this study had high capture rates over the majority of the PCFS, which in turn hampered the ability of CART to split the response into homogeneous groups of success and failures.

Prior to this study, montane voles were responsible for noticeable damage in portions of fields planted in winter peas on the PCFS (Witmer, unpubl. data). However, during this project the vole population appeared to collapse and the few captures of voles favored non-agricultural grass areas, which are commonly used by voles (Edge et al. 1995; Marinelli and Neal 1995; Hansson 1977; Merkens et al. 1991; Randall 1978; Randall and Johnson 1979). During this study, voles did not occur in winter pea fields, nor cause noticeable crop damage. The exclusion of deer mice by voles from grasslands has been documented on several occasions (Grant 1971; Redfield et al. 1977), however, vole densities were apparently too low for interspecific exclusion to occur during this study. Many areas of winter peas had low capture probabilities and logistic regression analyses suggested a negative relationship between pea residue and capture probabilities. However, winter peas may be damaged by rodents on certain sites within fields in some years (Huggins pers. comm.). Vole populations were low on the farm during this study, possibly reducing the potential for noticeable crop damage in winter pea fields. Additionally, winter pea stands
were marginal due to low precipitation during the fall growing season possibly reducing the ability of fields to sustain high vole numbers.

Several ecological properties of wheat fields, including relatively low density of ground cover, greater soil compaction, or higher levels of soil disturbance compared to non-agricultural areas may explain the relatively low capture rates of rodents within fields using a no-tillage cropping system. The non-agricultural grass areas had mixed positive and negative effects on capture probabilities, indicating that landscape context or other unmeasured factors influenced rodent occurrence in grasslands. Four distinct non-agricultural areas occur on the PCFS including three grass-covered areas of 1.25, 0.93, and 0.8 ha and one slope of 1 ha covered with black locust (*Robinia pseudoacacia*) and fir (*Abies grandis* and *Pseudotsuga menziesii*) trees with a grass understory. The three grass areas on the PCFS without trees had substantially different capture patterns for deer mice, while the tree-covered slope with an understory of grass had low capture success. Two grass areas consistently had high capture success while the other grass area exhibited more variable, often lower trap success. This single field was responsible for the overall negative relationship between non-agricultural grasslands and capture probability in the winter season using SLR. However, the specific environmental factors causing the differences in capture success among grass areas were not readily apparent. Elevation was a strong predictor of rodent occurrence in our analyses, however, the relationship
between elevation and capture success varied, indicating that unmeasured landscape features may have strong influences.

Relationships delineated between temperature and capture success may be explained if the higher energetic costs of thermoregulation associated with lower air temperatures limits rodent activity on the surface during colder (or wetter) nights (Speakman 2000) thereby reducing trap success within a season. We attempted to avoid capture bias caused by daily variation in weather by defining trap success as the probability of at least one capture during a three day period. However, investigators should be aware that differing weather, particularly temperatures, may influence rodent capture success and potentially affect estimates of density and abundance.

We recognize that some ecological and environmental variables that were not measured in this study may have a significant influence on rodent capture success. Soil characteristics (density, type, depth), cover density, cover height, predator densities, foraging risk and exposure to predators, and density of permanent burrow systems are potentially important ecological variables that were not investigated. Inclusion of such variables in future landscape analyses may significantly improve results and increase predictive success of the models. Our research indicates that rodents occur in higher densities in non-agricultural areas compared to cultivated areas in a no-tillage agricultural landscape. Although rodent populations persisted year-round in no-tillage agricultural fields,
capture probabilities were consistently lower in crop fields compared to non-agricultural grass areas.

We recommend that land managers and farmers attempting to control rodent populations should focus rodent control techniques on non-agricultural areas such as ditches, untilled areas, and field edges during the late fall and winter months as our analysis indicates strong positive relationships between rodent capture probabilities and non-agricultural grasslands. However, the site-specific pattern of crop damage on this farm, coupled with our observations of limited capture success in most no-tillage agricultural crops, argues against large-scale rodent control in no-tillage settings at low to moderate rodent densities. Broad-scale control measures are likely to be expensive and of limited value when rodent density is relatively low in agricultural fields as indicated in this study. Rodent populations should be monitored closely so that managers know when the vole population cycle is entering a rapid growth phase (Witmer and VerCauteren 2001). Additional research needs to be performed to examine the effects of voles on winter pea crops during peak times of the population cycles that rodents periodically exhibit in the Palouse and other farming regions.
Table 1. Environmental variables used to predict rodent capture success in a no-tillage agriculture environment at the Palouse Conservation Field Station.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover*</td>
<td>Wheat stubble, Barley Stubble, Non-agricultural grass, pea residue, Winter/Spring wheat, Winter/Spring peas, Spring barley, Corn, Buckwheat/Alfalfa</td>
</tr>
<tr>
<td>Elevation*</td>
<td>736.6-791.34 m</td>
</tr>
<tr>
<td>Slope*</td>
<td>0.467-22.38 degrees</td>
</tr>
<tr>
<td>Aspect* (transformed)</td>
<td>0-1</td>
</tr>
<tr>
<td>PYSR†</td>
<td>4867.83-9424.45 Mj/m²</td>
</tr>
<tr>
<td>Soil moisture index*</td>
<td>0.51-18</td>
</tr>
<tr>
<td>Distance to edge*</td>
<td>0.71-128.55 m</td>
</tr>
<tr>
<td>m of edge*</td>
<td>0-494 m</td>
</tr>
<tr>
<td>Weather</td>
<td>Maximum temperature, Minimum temperature, precipitation, snowfall</td>
</tr>
</tbody>
</table>

* Variables for which raster coverages were created and used in the CART node mapping at a 2-m scale.

† Potential Yearly Soil Radiation (PYSR)
Table 2. Mean rodent capture success for fall, winter, spring, and summer of 2003-2004 on the Palouse Conservation Field Station, Pullman, Washington. Capture success is calculated as number of captures/number of traps.

<table>
<thead>
<tr>
<th></th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(October 3-10)</td>
<td>(Feb. 16-March 7)</td>
<td>(April 19-May 3)</td>
<td>(September 2-11)</td>
</tr>
<tr>
<td>Day one</td>
<td>0.16</td>
<td>0.43</td>
<td>0.32</td>
<td>0.19</td>
</tr>
<tr>
<td>Day two</td>
<td>—</td>
<td>0.47</td>
<td>0.38</td>
<td>0.21</td>
</tr>
<tr>
<td>Day three</td>
<td>—</td>
<td>0.53</td>
<td>0.41</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Table 3. Results of a stepwise logistic regression analysis for fall 2003, winter 2003-2004, spring 2004, and summer 2004 predicting capture probability of rodents on the Palouse Conservation Field Station, Pullman, WA.

<table>
<thead>
<tr>
<th>Season</th>
<th>Variable</th>
<th>p-value</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Grass cover</td>
<td>&lt;0.001</td>
<td>4.347</td>
</tr>
<tr>
<td>Winter</td>
<td>Grass cover</td>
<td>0.0069</td>
<td>0.504</td>
</tr>
<tr>
<td></td>
<td>Pea residue</td>
<td>&lt;0.001</td>
<td>0.320</td>
</tr>
<tr>
<td></td>
<td>m of edge</td>
<td>0.0131</td>
<td>0.997</td>
</tr>
<tr>
<td>Spring</td>
<td>Wheat stubble/</td>
<td>0.0011</td>
<td>2.734</td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grass cover</td>
<td>&lt;0.001</td>
<td>2.103</td>
</tr>
<tr>
<td>Summer</td>
<td>Grass cover</td>
<td>&lt;0.001</td>
<td>3.216</td>
</tr>
<tr>
<td></td>
<td>Barley stubble</td>
<td>0.0170</td>
<td>0.403</td>
</tr>
<tr>
<td></td>
<td>Elevation</td>
<td>&lt;0.001</td>
<td>0.950</td>
</tr>
</tbody>
</table>
Table 4. Results from CART modeling of rodent capture probabilities on the Palouse Conservation Field Station. The variable with the most impact on the CART model was set at 100 and the subsequent variables were scaled from 100 to 0 based upon the influence each variable had on the decision tree.

<table>
<thead>
<tr>
<th>Season</th>
<th>Variable</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>elevation</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Grass cover</td>
<td>95.07</td>
</tr>
<tr>
<td>Winter</td>
<td>SMI**</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>elevation</td>
<td>71.8</td>
</tr>
<tr>
<td>Spring</td>
<td>PYSR*</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>elevation</td>
<td>92.80</td>
</tr>
<tr>
<td></td>
<td>Slope</td>
<td>86.42</td>
</tr>
<tr>
<td></td>
<td>SMI**</td>
<td>79.45</td>
</tr>
<tr>
<td></td>
<td>Grass cover</td>
<td>22.32</td>
</tr>
<tr>
<td></td>
<td>Wheat stubble/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td>44.07</td>
</tr>
<tr>
<td>Summer</td>
<td>elevation</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Grass cover</td>
<td>98.82</td>
</tr>
<tr>
<td></td>
<td>Slope</td>
<td>85.72</td>
</tr>
</tbody>
</table>

* PYSR = Potential Yearly Soil Radiation

** SMI = Soil Moisture Index
Table 5. The evaluation of the CART models predicting rodent capture probabilities on the Palouse Conservation Field Station. The models were evaluated by calculating the absolute difference between the capture probabilities generated from CART models and the baseline probabilities generated by indicator kriging for each 2m cell in the study area. The % Diff column is the range class of difference between the CART predicted capture probabilities and the kriging probabilities. The % Data is the percent of 2m CART cells which fall into the respective range class and % Cum is the cumulative percent of the CART cells which have fallen into that percentage class or less.

<table>
<thead>
<tr>
<th>% Diff</th>
<th>% Data</th>
<th>% Cum</th>
<th>% Diff</th>
<th>% Data</th>
<th>% Cum</th>
<th>% Diff</th>
<th>% Data</th>
<th>% Cum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>0.2433</td>
<td></td>
<td>0-5</td>
<td>0.0372</td>
<td></td>
<td>0-5</td>
<td>0.0806</td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>0.1833</td>
<td>0.4266</td>
<td>5-10</td>
<td>0.0355</td>
<td>0.0726</td>
<td>5-10</td>
<td>0.0798</td>
<td>0.1604</td>
</tr>
<tr>
<td>10-15</td>
<td>0.1288</td>
<td>0.5555</td>
<td>10-15</td>
<td>0.0453</td>
<td>0.1179</td>
<td>10-15</td>
<td>0.0814</td>
<td>0.2418</td>
</tr>
<tr>
<td>15-20</td>
<td>0.1050</td>
<td>0.6604</td>
<td>15-20</td>
<td>0.0387</td>
<td>0.1566</td>
<td>15-20</td>
<td>0.0779</td>
<td>0.3197</td>
</tr>
<tr>
<td>20-25</td>
<td>0.0907</td>
<td>0.7512</td>
<td>20-25</td>
<td>0.0681</td>
<td>0.2248</td>
<td>20-25</td>
<td>0.0681</td>
<td>0.3878</td>
</tr>
<tr>
<td>25-30</td>
<td>0.0782</td>
<td>0.8293</td>
<td>25-30</td>
<td>0.0166</td>
<td>0.2413</td>
<td>25-30</td>
<td>0.0638</td>
<td>0.4516</td>
</tr>
</tbody>
</table>
Figure 1. Rodent capture probabilities for Oct. 3-10, 2003, Feb.16-Mar. 7, 2004, Apr. 19-May 3, 2004, and September 2-11, 2004 on the Palouse Conservation Field Station in eastern Washington using indicator kriging. The gray scale depict 20% capture probability intervals with black representing 0-19.99% capture probability progressing to the lightest grey representing 80-100% capture probability. The fall kriging is based on one night of trapping, while the other seasons are based on three nights of trapping with a successful trap being defined as at least one capture in three nights.
Figure 2. Average rodent capture probabilities for fall 2003, winter 2004, spring 2004, and summer 2004 on the Palouse Conservation Field Station in eastern Washington using indicator kriging. The gray scale depicts 20% capture probability intervals with black representing 0-19.99% capture probability progressing to the white representing and average capture probability of 80-100% over all trapping seasons.
Figure 3. Fall 2003 CART classification tree predicting rodent trapping success on the Palouse Conservation Field Station, Pullman, WA. Each node is labeled with a trap probability and the number of cases in the node. Relationships are determined by using the node probabilities.

Grass cover
N=600
FALSE
0.11
n=464
TRUE
Elevation
0.33
n=136
<= 749.5m
0.06
n=37
> 749.5m
0.43
n=99

Model Predictive Success: 45.75%
Figure 4. The winter 2004 CART classification tree predicting rodent trapping success on the Palouse Conservation Field Station, Pullman, WA. Each node is labeled with the number of cases in the node and the probability of the data points in that node being a capture. Relationships between variables and capture success are assessed by using the node probabilities.

Model Predictive Success: 65.385%
Figure 5. Spring 2004 CART classification tree predicting rodent trapping success on the Palouse Conservation Field Station, Pullman, WA. Each node is labeled with the number of cases in the node and the probability of the data points in that node being a capture. Relationships between variables and capture success are assessed by using the node probabilities.

* WS/WW = Wheat stubble residue cover and winter wheat growing cover

Model Predictive Success: 75.284%
Figure 6. Summer 2004 CART classification tree predicting rodent trapping success on the Palouse Conservation Field Station, Pullman, WA. Each node is labeled with the number of cases in the node and the probability of the data points in that node being a capture. Relationships between variables and capture success are assessed by using the node probabilities.

Model Trap Success: 60.894%
Literature cited


APPENDIX A
Food habits of deer mice (*Peromyscus maniculatus*) and montane voles (*Microtus montanus*)

INTRODUCTION

We investigated the ecological factors related to seasonal dynamics of rodent populations and their spatial distribution in an experimental no-tillage farm landscape at the Palouse Conservation Field Station (PCFS) in Pullman, Washington, during 2003-04. Coupled with this investigation, we documented food habits of deer mice (*Peromyscus maniculatus*) and montane voles (*Microtus montanus*), in selected agricultural and grassland habitats on the PCFS. The objective of this portion of the study was to determine the relationship between stomach contents and the species, habitat type, and trap season for rodents captured on a farm with experimental cropping systems and conservation tillage.

METHODS

Rodents were generally captured using museum special snap traps at varying locations throughout the PCFS in 5m grids. Because rodent captures were primarily comprised of deer mice, additional grids or linear transects were set in permanent grass areas to gather a sufficient sample of montane voles. Trapping occurred in wheat, barley, peas, corn, and non-agricultural grass areas.

Captured rodents were placed on ice in the field and then frozen to reduce post-mortem digestion. Stomachs were removed and the stomach contents were
analyzed at the Washington State University Habitat Analysis Lab. Stomach contents were extracted and treated with bleach to rinse stomach enzymes from the samples. Eight microscope slides of each sample were made and individual components of the stomach contents were identified and recorded at 25 random locations on each slide as the percent of total stomach contents using a dot grid system.

**CART.**—Classification and regression tree (CART) analysis was performed to determine the difference of mean stomach contents and habitat variables in predicting diet differences between deer mice and voles. The response variable, voles or deer mice, was categorical so a classification tree was used with the default settings, including a gini splitting algorithm and a 10 V-fold validation process to select optimal predictive models (De’Ath and Fabricius 2000; Salford Systems 2004). Variable importance, the relative influence of a variable on the decision tree, was provided by the CART procedure. The four most influential stomach content variables that separated deer mice from montane voles in CART analyses then were used in subsequent statistical comparisons of rodent diets by habitat and season.

**GLM.**—In addition to CART analyses, a series of general linear models (GLM) were performed using Minitab v.14 (Minitab 2004). The GLM procedures were used to evaluate the relationships between species, trap season, cover type, and stomach contents. Four categories of stomach contents, non-
agricultural grass (grass), roots, insects, and cereal crop seeds, were shown to be important in CART models and therefore were selected for more detailed analysis in the GLM procedures.

RESULTS

CART.—CART identified the occurrence of roots, grasses, insects, and cereal crop seeds in stomach contents as the primary splitting variables which best separated the two species (Fig. 7). Overall model prediction success was 92.0% of deer mice and 87.7% of voles being correctly classified in the model. Grass and root stomach contents had a positive relationship with voles. The percent cereal crop seed in stomachs displayed a positive relationship with correctly identifying deer mice.

GLM.—Several significant relationships were delineated using the GLM procedure. The mean stomach contents of insects, cereal crop seeds, non-agricultural grass, and roots all demonstrated significant differences between voles and deer mice (Table 6). There was a significant difference between the percent stomach content of cereal crop seeds and trap season (p=0.006). Cover type also showed significant effects on the mean percent stomach contents of cereal crop seeds, grass, and roots (Table 6).

DISCUSSION
Stomach contents of deer mice and montane voles were analyzed using CART and GLM procedures. Deer mice utilize an omnivorous foraging strategy, while montane voles are granivores, which provides an explanation for many of the relationships observed in the stomach contents for rodents captured in this no-tillage agricultural landscape. Trap season had an effect on the mean percent content of cereal crop seeds in rodent stomachs. This is logical as the trapping seasons occurred post harvest (September) and post planting (April). The cover type in which individuals were captured had a significant association with resulting stomach contents for three of the four analyzed food contents. This result indicates that rodents are foraging on nearby available food resources and are not necessarily traveling long distances to adjacent crop fields to forage.

CART models demonstrated positive relationships between voles and percent root composition and grass, while deer mice showed a positive relationship between cereal crop seed. These results indicate that deer mice may cause crop damage in agricultural fields planted in cereal crops when populations are at high levels. Voles also have the potential to cause damage to crops, however, our data did not show large amounts of cereal products in the stomach contents of voles. Low capture success of both rodent species in pea fields hindered detailed analysis of the impact of rodents on pea crops, specifically winter peas.

The results of this diet analysis are in general agreement with conventional views on differences in diets of voles and deer mice. However, the low numbers
of voles in agricultural fields, which necessitated trapping voles in non-agricultural grasslands, may have predisposed the data to show a positive relationship between voles and mean percent grass stomach content. Additionally, the methodology in which the stomach contents were analyzed has been questioned due to differing rates of digestion between food products. However, the data shows strong significant relationships which are supported by the ecology of the these two rodent species.
Table 6. General linear models (GLM) showing the relationships between deer mice (*Peromyscus maniculatus*) and montane voles (*Microtus montanus*) and four dominant stomach contents compared by season, and cover type at the Palouse Conservation Field Station (PCFS), Pullman, Washington.

<table>
<thead>
<tr>
<th>Stomach Content</th>
<th>Species</th>
<th>Trap Season</th>
<th>Cover Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insect</td>
<td>&lt;0.001</td>
<td>Not Significant</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Cereal crop seed</td>
<td>&lt; 0.001</td>
<td>0.006</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>N-ag Grass</td>
<td>&lt; 0.001</td>
<td>Not Significant</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Roots</td>
<td>&lt; 0.001</td>
<td>Not Significant</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Figure 7. Classification and regression tree analysis of rodent stomach contents using species as the response from specimens caught at the Palouse Conservation Field Station (PCFS), Pullman, Washington.

![Classification and regression tree analysis diagram]
Figure 8. 95% confidence intervals of mean stomach contents of four diet components from two species of rodents caught on the Palouse Conservation Field Station (PCFS), Pullman, Washington.
Figure 9. 95% confidence intervals of four primary stomach contents of deer mice (*Peromyscus maniculatus*) captures on the Palouse Conservation Field Station (PCFS), Pullman, Washington.
Figure 10. 95% confidence intervals of four primary stomach contents of montane voles (*Microtus montanus*) captures on the Palouse Conservation Field Station (PCFS), Pullman, Washington.
Figure 11. 95% confidence intervals of mean stomach contents of deer mice (*Peromyscus maniculatus*) by habitat type on the Palouse Conservation Field Station (PCFS), Pullman, Washington.
Figure 12. 95% confidence intervals of mean stomach contents of montane voles (*Microtus montanus*) by habitat type on the Palouse Conservation Field Station (PCFS), Pullman, Washington.

95% Confidence Interval of Mean Stomach Content by Cover Type for Montane Voles
Comparison of rodent populations between the Palouse Conservation Field Stations and the Palouse

INTRODUCTION

The landscape ecology of rodents on the Palouse was investigated during 2003-04 at the Palouse Conservation Field Station (PCFS), Pullman, Washington. Rodent live-trapping was performed at various non-agricultural areas around the Palouse to compare capture rates and species composition of the rodent population at the PCFS with other rodent populations in adjacent areas around the Palouse.

METHODS

Sherman live traps were set in 5m grids in four types of non-agricultural areas around the Palouse, including grasslands, ditches, riparian areas, and eyebrows (areas too steep for cultivation within an agricultural field). Three separate sites of each type of non-agricultural area, selected based upon landowner access, were trapped during June and July 2004 for three consecutive nights. At every successful capture, the species, sex, and weight was recorded. Capture success and species composition were compared to the grassland areas of the summer trapping period presented in the main paper. Chi-squared analyses were performed to analyze the differences between on and off-farm capture success, and species composition.
RESULTS

Our data suggests that the PCFS has larger populations of rodents than other nearby non-agricultural areas of the Palouse. Capture success was significantly (p<0.001) higher on the PCFS (Fig. 1) than other sampled areas of the Palouse. Deer mice make up a significantly (p<0.001) higher proportion of captures on the PCFS (Fig. 13). Deer mice (*Peromyscus maniculatus*) constituted 93.20% of the captures on the PCFS and only 84.12% of the captures on non-agricultural areas off the PCFS.

DISCUSSION

Relatively higher capture success at the PCFS suggests a higher density of rodents, however, the reasons for the differences in capture success are not readily apparent. Possible explanations include occurrence of no-tillage on the PCFS, temporal differences between sampling, and unknown predator densities. Species composition was different between several non-agricultural areas and the grasslands on the PCFS, however, species composition between grasslands on the PCFS and grasslands off the PCFS did not significantly differ (p=0.106) indicating that the no-tillage farming may not have significant effects on the species composition of rodents. Generalization of these results should be done cautiously, due to differences in trapping protocol between the PCFS and the other trapping sites, the temporal differences between trappings, and the habitat differences between other sites.
Figure 13. Mean capture rate of rodent species during the summer of 2004. The Palouse Conservation Field Station (PCFS) is compared to other non-agricultural areas of the Palouse.
Figure 14. The mean capture rates of two rodent species, deer mice (*Peromyscus maniculatus*) and montane voles (*Microtus montanus*), were trapped throughout the Palouse and on the Palouse Conservation Field Station (PCFS), Pullman, Washington during the summer of 2004.