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Habitat Relations

Movements and Settlement Site Selection of Pygmy Rabbits After Experimental Translocation

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ABSTRACT We investigated the movements and selection of settlement sites of translocated pygmy rabbits (*Brachylagus idahoensis*) in southeastern Oregon from June to December 2008. We captured, radio tagged, and translocated 59 pygmy rabbits across big sagebrush (*Artemisia tridentata* ssp.) habitat with 3 categories of landscape fragmentation. We used radio telemetry to track the movements and document the fates of translocated individuals. We used Geographic Information Systems (GIS) and spatial analysis software (FRAGSTATS) to analyze the post-release movements and selection of settlement sites by pygmy rabbits. We found that pygmy rabbits settled closer to their release sites as the amount big sagebrush cover on the surrounding landscape increased. In addition, translocated pygmy rabbits settled on sites that, on average, had greater cover, greater landscape connectivity, and fewer but larger patches of big sagebrush than were present at their capture sites. Current or past presence of conspecifics also appeared to be a factor in selection of settlement sites by pygmy rabbits. Successful translocation of wild pygmy rabbits for augmenting depleted populations will require selection of release locations with continuous big sagebrush cover and a history of pygmy rabbit presence. Managers should also expect to lose a portion of translocated pygmy rabbits to homing attempts, post-release dispersal, and predation, so large numbers of individuals should be released to establish resident populations.

KEY WORDS *Brachylagus idahoensis*, dispersal, experimental translocation, Great Basin, habitat fragmentation, pygmy rabbit, radio telemetry, sagebrush.

Translocation of wildlife for the conservation and management of rare or threatened species is an established technique (Griffith et al. 1989); however, translocations are time-consuming and expensive (Rodriguez et al. 1995, Fischer and Lindenmayer 2000), and they may fail because individuals stray too far from their release sites (Linnell et al. 1997) or do not survive at the new location. Excessive movements of translocated animals can be associated with rejection of the habitat at release sites (Kenward and Hodder 1998), so selection of release sites with habitat for the target species is vital to the success of any translocation project (Wolf et al. 1996, Johnson and Swift 2000). The results from experimental translocation studies can supply essential information to the planning of re-introduction projects by providing information on habitat characteristics of settlement sites (Fisher et al. 2009) and movement behaviors of a species after their release into a novel environment (Davis 1983).

Translocation is increasingly being considered as a tool for conserving dwindling populations of pygmy rabbits (*Brachylagus idahoensis*), a species endemic to sagebrush-steppe communities of the western United States. Pygmy rabbits are a sagebrush obligate found in close association with big sagebrush (*Artemisia tridentate* spp.) growing on deep soils (Green and Flinders 1980, Katzner 1994, Gabler et al. 2001, Simons and Laundre 2004), and much of the big sagebrush habitat in the Great Basin and Intermountain West has been lost and fragmented because of land use practices by humans, altered wildfire regimes, and invasion of exotic annual grasses (Miller and Eddleman 2001, Knick et al. 2003). Population declines associated with this habitat loss (Hays 2001) have resulted in the pygmy rabbit being listed as a species of concern under the federal Endangered Species Act (ESA) throughout most of their range. A distinct population segment in Washington State is listed as endangered under

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the ESA. However, a petition to list the entire species as threatened or endangered was deemed unwarranted by the United States Fish and Wildlife Service (USFWS) in 2010 because of insufficient information about the status of the species (USFWS 2010). A captive breeding program and reintroduction effort for the threatened subgroup in Washington State has resulted in limited success (Zeoli et al. 2008), but the translocation of wild individuals into adjacent areas may be a viable option to augment declining populations elsewhere and remove individuals from areas where land management and development threatens to disturb extant populations of the species.

Our objective was to evaluate movements and habitat use of pygmy rabbits after short-distance, experimental translocations. We evaluated the responses of the translocated rabbits as a function of the amount and configuration of big sagebrush cover at both the landscape and local spatial levels. At the landscape scale, we recorded the directions and distances that radio-collared pygmy rabbits moved away from their release sites as a function of proximate habitat characteristics. We translocated wild individuals expecting that they would move away from their release sites, but predicted that the amount of big sagebrush cover and patch configuration at the release site would influence the distances they moved. At the local scale, we compared characteristics of big sagebrush surrounding the original capture sites to that of settlement areas. Previous experience with habitat conditions may influence site selection by translocated animals (Biggins et al. 1999, Selonen et al. 2007, Stamps and Swainsgood 2007), and because pygmy rabbits are habitat specialists, we predicted that individuals would settle in locations with similar habitat characteristics to those in the areas where they were captured. We also hypothesized that the presence of roads and/or little sagebrush (*Artemisia arbuscula*) communities might act as physical barriers and directly hinder the movements of individuals after translocation. Our study provides information about translocation of pygmy rabbits and describes an experimental approach to evaluating the habitat selection and post-release movements of this habitat specialist.

STUDY AREA

We conducted our study in Lake and Harney counties, Oregon, on lands administered by the Lakeview District of the Bureau of Land Management (BLM). We found 3 regions with sufficient populations of pygmy rabbits for our study: 1) The Flint Hills area northeast of Abert Lake, 2) the West Gulch area near Beatty's Butte, and 3) the Dixon waterhole area near the Oregon-Nevada border. We subdivided these 3 study regions into smaller sites based on variation in landscape characteristics. The Flint Hills region consisted of 4 study sites: Flint Hills Valley, Corn Lake Road, Hogback Road, and Nasty Flat. Elevation of the Flint Hills region was 1,500–1,700 m. We divided the West Gulch area into 3 smaller sites: West Gulch Burned, West Gulch Unburned, and Lone Grave Mountain. Elevation of the West Gulch area was 1,600–1,800 m. One site was at the Dixon waterhole area, which had an elevation of 1,700–1,800 m. Big sagebrush and yellow rabbitbrush (*Chrysothamnus viscidiflorus*) were the dominant overstory plants at all sites. Detailed information on the locations and vegetative characteristics of the study areas is available in Lawes (2009).

METHODS

Capture, Handling, and Tracking

We captured pygmy rabbits with permission of Oregon Department of Fish and Wildlife (Scientific Taking Permit #133-07) and in compliance with Oregon State University Animal Care and Use guidelines (permit # 3744). We trapped pygmy rabbits using single-door Tomahawk #201 live traps (Tomahawk Live Trap Co., Tomahawk, WI) from June to December 2008. We placed traps, without bait, in burrow openings, runways, and frequently used sites; camouflaged them with burlap, soil, and debris several hours before dawn; and checked them after sunrise. We closed traps and removed them daily to avoid incidental captures and deaths of rabbits.

We weighed (g) and attached very high frequency (VHF) radio transmitters (164 MHz and 165 MHz band, Model RI-2DM [7.1 g and 10.6 g]; Holohil Systems Ltd Carp, Ontario, Canada) to each rabbit at the capture sites. We identified sex by inspecting genitals and age class (adult or juvenile) by weight and condition of pelage. We measured to the nearest millimeter the hind foot, ear, and total body lengths of each individual. We released individuals that were pregnant, lactating, or weighed <250 g immediately and did not use them in experiments. We marked all rabbits with uniquely numbered #1005-4 monel ear tags (National Band and Tag Co., Newport, KY) as a permanent secondary marker in case of radio collar loss. We did not translocate any rabbits more than once to ensure independence in collection and analysis of data. We trapped new individuals continuously during the tracking phase and used the monel ear tags to identify individuals that were present on the capture areas after they had been recaptured and returned to their initial capture sites with their radio collars removed.

We transported rabbits to release sites inside a small (50 cm $\times$ 30 cm $\times$ 30 cm) covered pet carrier or Tomahawk trap that was covered and lined with burlap to reduce handling stress during translocation. At release sites, we placed the carrier or Tomahawk trap under the cover of sagebrush, opened the door immediately, and allowed rabbits to exit under their own free will. Because of the lack of an acclamation period, this protocol is best categorized as a hard release.

Each individual was translocated and released within a 1–2-km radius ($\bar{x} = 1.14$ km, SE $= 0.03$ km) from its capture site. We selected this range of distances because it was similar to the median natal dispersal distance of pygmy rabbits in Idaho (Estes-Zumpf and Rachlow 2009). We chose release sites such that the habitat characteristics separating the release site and capture site fell into 1 of 3 categories (see below for definitions). Random assignment of captured individuals to a category was not feasible because of logistical constraints and local habitat availability. We determined translocation distance and direction by the availability of release habitat within 1–2 km of each capture site. We did not pre-select habitat characteristics in the immediate vicinity of the release site, except that we chose locations beneath sagebrush large enough to provide shade and cover from predators. All rabbits captured on the same day were released $\geq$200 m from each other to reduce potential bias from social interactions between individuals at release sites.

We tracked rabbits with radio receivers and directional 3-prong or 2-prong antennas and handheld Global Positioning System (GPS) units (Garmin International, Inc., Olathe, KS). Immediately after release, we located individuals every 15–30 minutes until movement ceased. Tracking typically continued for several hours immediately after release, but once individuals appeared to become sedentary, we recorded locations twice per day for a minimum of 14 days, after which time we attempted to recapture rabbits to remove radio collars and return them to their original capture location. This minimum period of 14 days was part of a secondary objective to evaluate the homing ability of the species (Lawes et al. 2012). We recaptured radio-collared rabbits with live traps within the individual's documented use area or by placing traps in the openings of burrows known to be occupied by the radio-collared rabbit.

We recorded locations of rabbits by sight or located a burrow from which we heard radio signals. We made a deliberate effort to approach rabbits without causing a disturbance or flight behavior; we often approached individuals that were not occupying burrows within several meters without causing an evasive response. Occasionally, a rabbit flushed before we sighted it; in which case, we did not pursue the rabbit. We approximated the location of these individuals based on the direction and signal strength of the VHF radio collar. We then walked to the approximated location and recorded a waypoint. In addition, rabbits would occasionally remain motionless in an attempt to avoid detection by using the available sagebrush cover. If such an individual was located by radio signal strength, but remained visually undetected after a quick search, we recorded an approximate location. We estimated that our coordinates were accurate to within 10 m. At the location of each rabbit, we recorded the activity (when possible) of the individual (i.e., sitting, running, foraging), vegetative cover type (i.e., sagebrush ssp., grassland, bare soil), time, and the location (Universal Transverse Mercator [UTM] referenced by the North American datum of 1927 [NAD27]).

We captured and translocated 59 pygmy rabbits; however, we only used a subset of this total in our analyses. We excluded from our analysis of movements 2 individuals with unknown fates because of radio collar failure, 5 individuals killed by predators prior to 14 days after translocation, and 9 rabbits that returned to their original home ranges (i.e., successfully homed). An approximate diameter for a typical adult pygmy rabbit home range is 150 m (Sanchez 2007, Crawford 2008), and we considered rabbits that returned to within 150 m of their initial site of capture to have homed. One rabbit was killed by a predator on the fourteenth day after translocation, and we excluded this individual from our analysis of settlement site selection. When an individual died, we visually examined the radio collar, physical remains, and the surrounding area to determine the possible cause of mortality.

Movement Calculations

We calculated 2 measures of the distances moved by pygmy rabbits after release using ArcGIS 9.3 (ESRI; Environmental Systems Research Institute, Redlands, CA). First, we calculated the straight-line distance (m) between the UTM coordinates of a rabbit's release site and its final location. We based final locations on either the recapture site or the location where the rabbit was last known to be alive. Second, we calculated the straight-line distance between the UTM coordinates of a rabbit's release site and the telemetry location farthest from that release site. We chose these 2 measures of movement because the final locations of rabbits were occasionally closer to the release site than the farthest location and, as such, did not represent the maximum distances that some individuals moved during their search for a settlement site. Although we had multiple telemetry locations for each rabbit, we used straight-line distances rather than the summation of the distances between the telemetry locations. We used straight-line distances because we were unable to calculate a standardized measure of movement between telemetry locations of different rabbits because of incongruities in timing and number of the telemetry locations among rabbits. Because our estimates are based on straight-line measurements, we acknowledge that they underrepresent the total amount of movement made by pygmy rabbits after translocation but represent the end result of those movements. Recording of continuous movements and locations of rabbits was not possible because GPS units were not available for small animals during the study, nor were they resolute enough to provide accurate locations within 10 m.

Habitat Classification and Landscape Characteristics

We used 3 broad landscape categories in our study to compare the post-translocation movements and habitat selection of pygmy rabbits. Differences in habitat composition were physically distinct, and we visually assessed the landscape and assigned the categories while in the field based on established models of habitat suitability (Green and Flinders 1980, Gabler et al. 2001, Rachlow and Svancara 2006) and BLM survey protocols for pygmy rabbits. We later used ArcGIS 9.3 and FRAGSTATS spatial pattern analysis software (McGarigal et al. 2002) to calculate overstory cover and patch configuration from 2005 National Agricultural Imaging Program aerial photographs with 1-m resolution (Appendix A). Category identifiers assigned in the field were: 1) suitable habitat ($n = 19$), 2) suitable habitat bisected by a roadway ($n = 21$), and 3) marginal habitat ($n = 19$). The suitable habitat category was comprised of areas with relatively continuous cover, dominated by big sagebrush (i.e., a sage-steppe landscape with little habitat fragmentation). Landscapes bisected by a road were similar to those in the suitable category, with the exception that they were fragmented by a secondary (dirt or gravel) road.

Landscapes in the marginal habitat category lacked extensive big sagebrush cover and soil characteristics typically associated with occupancy by pygmy rabbits, and they were areas dominated by little sagebrush or bunch grasses. For a description of vegetative composition, traffic levels, and road dimensions at each study site, see Lawes (2009).

We used ArcGIS 9.3 to create circular areas for habitat sampling. A 100-m radius (3.14 ha) area was centered at the UTM coordinates of capture and release sites of all pygmy rabbits that survived for $\geq$14 days after translocation and did not return to their original home ranges ($n = 43$). These circular areas represented habitat within each individual's original home range and the area surrounding their release locations. Home range sizes of pygmy rabbits are highly variable and depend on the sex, season, geographic area, habitat characteristics, and estimation technique (Sanchez 2007, Crawford 2008). Our 3.14-ha circles were 2.7 times larger than the mean annual home range size of 1.2 ha (95% fixed kernel least-squares cross validation), but approximately a third as large as the maximum estimate of 10.46 ha for similar sites in southeastern Oregon (Crawford 2008). We also characterized the big sagebrush habitat on the landscape between the capture and release sites using ArcGIS. We created larger habitat sampling areas that represented the area separating the rabbits from their original home ranges after release by centering a circle at the midpoint between the capture and release sites of each rabbit. We extracted our circular sampling areas from a 1-m resolution aerial photograph raster layer and classified the vegetation based on color reflectivity. We used FRAGSTATS to quantify the spatial arrangement, extent, and connectivity of the big sagebrush cover found within these sampled areas.

Data Analysis

We used 1-way analysis of variance in Proc GLM (SAS Institute, Inc., Cary, NC) to determine if distances moved (i.e., final location) by translocated pygmy rabbits after release varied significantly ($\alpha = 0.05$) among the 3 categories of landscape described above. We considered our sites to be fixed effects and combined our data into categories for this analysis because we did not have a large enough sample size to analyze for differences among our sites. We used least-squared means tests with a Tukey–Kramer adjustment for multiple comparisons to determine significant differences among all pair-wise comparisons of the final distances moved among the 3 categories.

We investigated the dependence between distance moved from release site ($n = 43$) to settlement site (response variable) and 6 landscape metrics (explanatory variables) by multiple regression analysis. We selected the most parsimonious model explaining distances moved using Akaike's Information Criterion corrected for small sample sizes (AIC_c). We first removed from consideration any model that contained highly correlated variables (Pearson's correlation coefficient >0.75; Appendix B) to reduce the effects of multicollinearity within our candidate models. Then, we evaluated all remaining 1-variable, 2-variable, and 3-variable models, in addition to a null model for a total of 22 a priori models. This type of an experiment has not been done previously on pygmy rabbits, and we thought that all of these models were plausible without further guidance from the published literature. We considered the model with the lowest AIC_c value to be the best model, and all models within 2 ΔAIC_c values of the best model to be competitive models (Burnham and Anderson 2002). We used Proc Reg (SAS Institute, Inc.) to complete the model selection and regression analyses. We assessed the influence of any potential outliers using a Cook's distance statistic. Our linear regression analysis ($n = 43$) of movement included the 39 individuals that survived until recapture and 4 individuals that were depredated $\geq$2 weeks after release.

Differences in the big sagebrush cover and patch configuration around the original capture sites and settlement sites of pygmy rabbits were investigated by performing a multivariate analysis of variance and paired *t*-tests on the 8 landscape metrics described above. We began with a multivariate approach to test for an overall difference among capture and settlement sites and followed with paired *t*-tests of each landscape metric to explore which ones explained any statistical differences. We used a paired analysis to control for any potentially confounding spatial autocorrelation between the habitat characteristics of capture and settlement sites due simply to the geographic proximity of those sites (Lawes 2009).

RESULTS

Movements

We recorded 1,669 locations for the 59 marked pygmy rabbits during the study; 1,408 of the locations were above ground, and 261 were from rabbits in burrows. While tracking and recording above ground locations, we observed rabbits running short distances between cover (27.6% of observations), sitting or resting under shrub cover (40.5% of observations), foraging on sagebrush (2.1% of observations), and walking or scampering (4.5% of observations). We obtained 301 locations with unknown behaviors (21.4%) in which we did not visually observe rabbits and recorded an approximate location based on radio signal strength. On average, we tracked rabbits for 2.17 days (SE = 0.35) before they were located inside a burrow system for the first time.

Distances from release sites at which pygmy rabbits ($n = 43$) settled after translocation varied considerably and ranged from 2 to 2,827 m ($\bar{x} = 525$ m, SE = 80). Characteristics of habitat where rabbits were released influenced distances moved by pygmy rabbits ($F_{2, 40} = 5.28$, $P = 0.009$; Fig. 1). Rabbits which were translocated across areas with marginal habitats moved farther away from their release sites than individuals that were translocated across suitable habitat ($t_{40} = 2.59$, $P = 0.035$) or suitable habitat bisected by roads ($t_{40} = 3.15$, $P = 0.009$). Roads in suitable habitats had no significant influence on distances moved by rabbits compared with suitable habitats without roads ($t_{40} = -0.6$, $P = 0.82$). As such, the roads present in our study sites did not appear to create a barrier to their movements as rabbits readily crossed

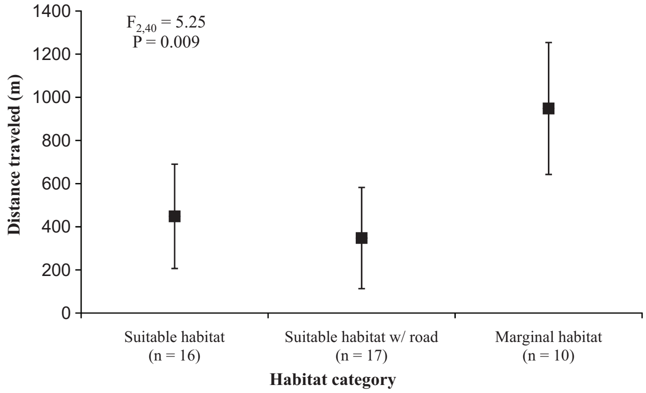

Figure 1. Mean straight-line distance traveled (m) from release to settlement sites across 3 categories of habitat by experimentally translocated pygmy rabbits in southeastern Oregon, 2008. Error bars represent 95% confidence intervals.

them. Mean distance moved between release and settlement sites was 448 m (95% CI: 207–690; $n = 16$) in suitable habitat, 348 m (95% CI: 113–582; $n = 17$) in suitable habitats with roads, and 948 m (95% CI: 643–1,254; $n = 10$) in marginal habitat.

Nearly all (40 of 43) individuals moved farther from their release sites than was suggested by the final straight-line distance to their settlement locations. The difference between farthest telemetry location and final settlement distance of individuals ranged from 2–675 m ($\bar{x} = 151$ m, SE = 27). We located 28 individuals at a distance ≥500 m from their release sites, but 10 of these individuals ultimately moved back and settled within 500 m of release sites. After release, 1 individual moved to an area >500 m away but eventually returned and settled within 6 m of its release site. The longest movement of an individual from a release site was 3,501 m, but this individual ultimately returned to settle 2,827 m away from its release site.

Distances moved from release sites by pygmy rabbits appeared to be influenced by the vegetative characteristics around those sites. Models with the percent of the landscape composed of the single largest patch of sagebrush shrub cover (largest patch index; LPI) and the percent of the landscape classified as big sagebrush shrub cover (PLAND) had the lowest AIC_c values (Table 1). One or both of these variables were included in all competitive models, and the 95% confidence intervals around their regression coefficients (βs) did not, or barely included zero (Table 2). The best model included the percent of the landscape composed of the single largest patch of sagebrush cover (LPI). This model accounted for 14% of the AIC_c weights and was 2.57 times more likely than the null model of no effect. The regression equation for this model was distance (m) = 784–18.44 (LPI). We found support for an 18.44-m decrease in the final distance from release for every 1% increase in the amount of the landscape composed of the single largest patch of

Table 1. Akaike's Information Criterion corrected for small sample size (AIC_c) selection results for multiple linear regression models of the final distances moved from release sites by pygmy rabbits after translocation as a function of big sagebrush habitat covariates in southeastern Oregon, 2008. We calculated big sagebrush habitat covariates from 1-m resolution aerial photos using ArcGIS and FRAGSTATS spatial analysis computer programs. For a complete list of evaluated models, see Lawes (2009).

Model[a]	AIC_c	ΔAIC_c[b]	w_i[c]	Model likelihood	K[d]
LPI	537.87	0.00	0.14	1.00	2
PLAND	538.38	0.53	0.11	0.77	2
PROX_AM	538.82	0.96	0.09	0.62	2
PLAND + CLUMPY	539.24	1.38	0.07	0.50	3
LPI + CLUMPY	539.36	1.50	0.06	0.47	3
LPI + AI	539.44	1.58	0.06	0.45	3
LPI + PD/100	539.51	1.65	0.06	0.44	3
Null	539.74	1.89	0.05	0.39	1
PD/100 + LPI + AI	539.90	2.04	0.05	0.36	4
PD/100 + LPI + CLUMPY	540.21	2.35	0.04	0.31	4
PLAND + PD/100	540.51	2.66	0.04	0.26	3
PD/100 + PROX_AM	540.64	2.79	0.03	0.25	3
CLUMPY + PROX_AM	540.74	2.89	0.03	0.24	3
PLAND + PD/100 + CLUMPY	540.80	2.95	0.03	0.23	4
AI + PROX_AM	541.07	3.21	0.03	0.20	3
AI	541.15	3.30	0.03	0.19	2
CLUMPY	541.78	3.93	0.02	0.14	2
PD/100	541.90	4.05	0.02	0.13	2
PD/100 + CLUMPY + PROX_AM	542.24	4.39	0.02	0.11	4
PD/100 + AI + PROX_AM	542.78	4.93	0.01	0.08	4
PD/100 + AI	543.45	5.60	0.01	0.06	3
PD/100 + CLUMPY	543.98	6.12	0.01	0.05	3

[a] Parameter definitions: LPI = percent of the landscape composed of the single largest patch of big sage, PLAND = percent of the landscape classified as big sagebrush, PROX_AM = area weighted mean number of big sage brush patches with edges within a 50-m search radius a focal big sage patch, CLUMPY = proportional deviation of the proportion of big sage adjacencies from that expected under a spatially random distribution, AI = frequency with which different pairs of big sage patches appear side-by-side within the classified habitat circles, PD/100 = number of big sage patches per hectare.
[b] Difference in AIC_c.
[c] Akaike weight.
[d] Number of parameters including the intercept.

Table 2. Model rank based on Akaike's Information Criterion corrected for small sample size (AIC_c) model selection, parameter estimates, and 95% confidence intervals for sagebrush habitat covariates (explanatory variables) that influenced distances from release sites moved by pygmy rabbits after translocation. We calculated big sagebrush habitat covariates from 1-m resolution aerial photos using ArcGIS and FRAGSTATS spatial analysis computer programs.

Parameter[a]	Model rank	Estimate	SE	Lower 95% CI	Upper 95% CI	R^2
LPI	1	−18.44	9.12	−36.85	−0.03	0.09
PLAND	2	−9.50	5.05	−19.69	0.69	0.08
Prox_AM	4	−0.03	0.02	−0.06	0.00	0.07
PLAND	5	−11.78	5.38	−22.65	−0.90	0.11
CLUMPY		1,304.71	1,110.45	−939.60	3,549.02	
LPI	6	−20.22	9.37	−39.15	−1.29	0.11
CLUMPY		929.21	1,062.88	−1,218.90	3,077.37	
LPI	7	−26.54	13.40	−53.62	0.53	0.11
AI		8.47	10.23	−12.21	29.14	
LPI	8	−20.47	9.51	−39.69	−1.24	0.15
PD/100		−1.80	2.29	−6.42	2.82	
Intercept	9	524.97	80.07	363.39	686.55	0.00

[a] Parameter definitions: LPI = percent of the landscape composed of the single largest patch of big sage, PLAND = percent of the landscape classified as big sagebrush, PROX_AM = area weighted mean number of big sage brush patches with edges within a 50-m search radius a focal big sage patch, CLUMPY = proportional deviation of the proportion of big sage adjacencies from that expected under a spatially random distribution, AI = frequency with which different pairs of big sage patches appear side-by-side within the classified habitat circles, PD/100 = number of big sage patches per hectare, intercept = null model.

sagebrush ($\hat{\beta} = -18.44$, 95% CI: −36.85 to −0.03, $R^2 = 0.09$, $P = 0.05$; Fig. 2). However, we found a lot of variability in movements of pygmy rabbits when big sagebrush comprised <30% of the landscape. The second best model included the percent of the landscape classified as big sagebrush cover (PLAND) and accounted for 11% of the total AIC_c weights. The regression equation for this model was distance (m) = 858.32–9.5 (PLAND), and we found some support for this variable as the 95% confidence interval barely included zero ($\hat{\beta} = -9.5$, 95% CI: −19.69 to 0.69, $R^2 = 0.08$, $P = 0.07$). The explanatory variables included in these 2 models were highly correlated (Pearson correlation coefficient, $r = 0.93$), which indicated that pygmy rabbits in our study settled nearer to their release sites in areas with greater sagebrush cover after experimental translocation.

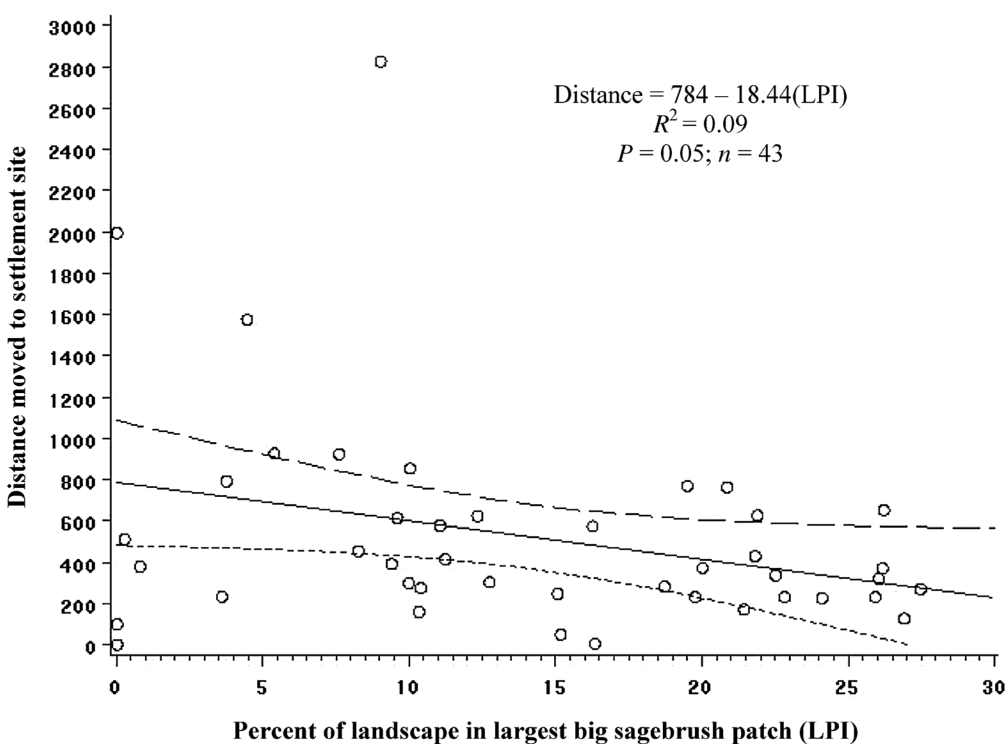

Figure 2. Straight-line distances moved (m) from release to settlement sites by pygmy rabbits as a function of the percent of the landscape composed of the largest single patch of big sagebrush (LPI). Dotted lines represent 95% confidence intervals.

Table 3. Mean difference, 95% confidence intervals, and *P*-value of the differences between landscape metrics of the capture and settlements sites of pygmy rabbits after experimental translocation in Oregon, 2008. We calculated differences as capture site values minus settlement site values.

Comparison	Lower 95% CI	Mean difference	Upper 95% CI	*P*
% Land in big sagebrush	−12.53	−6.20	0.13	0.055
Patch density/ha	22.00	52.55	83.11	0.001
Largest patch index	−17.12	−9.39	−1.67	0.018
Clumpiness index	−0.05	−0.01	0.02	0.487
Connectance index	−5.29	−3.15	−1.02	0.005
Cohesion index	−8.01	−4.33	−0.64	0.023
Aggregation index	−8.59	−4.43	−0.27	0.037
Proximity index	−280.00	−176.00	−71.96	0.001

Settlement Site Selection

We found significant differences in habitat characteristics between capture and settlement sites of pygmy rabbits. We found differences in patch configuration and amount of big sagebrush cover between the capture and settlement sites (Wilks' λ, $F_{8,\ 75} = 3.32$, $P = 0.003$). We found differences (Table 3) in patch aggregation index ($t_{41} = -2.15$, $P = 0.037$), patch cohesion index ($t_{41} = -2.37$, $P = 0.023$), patch connectance index ($t_{41} = -2.98$, $P = 0.005$), patch density/ha of big sagebrush ($t_{41} = 3.47$, $P = 0.001$), percent of the landscape composed of the single largest patch of sagebrush cover ($t_{41} = -2.46$, $P = 0.018$), and the area weighted mean proximity index ($t_{41} = -3.42$, $P = 0.001$) between capture and settlement sites (Fig. 3). Capture sites had an average of 4.4% (±2.1 SE) lesser aggregation index than did settlement sites (Fig. 3). The mean cohesion index of capture sites was 4.3 (±1.8 SE) units less than observed on settlement sites. We found 52.6 (±15.13 SE) more patches of big sagebrush per ha around capture sites, but the largest patch index was 9.4% (±3.8 SE) less than in settlement sites. The area weighted mean proximity index was 176.0 (±51.5 SE) units less around capture sites, and connectance was 3.2% (±1.1 SE) less on capture sites than on settlement sites. We also found support for a 6.2% (±3.14 SE) decrease in the amount of the landscape classified as big sagebrush on captures sites compared to settlement sites ($t_{41} = -1.98$, $P = 0.055$). Finally, we found no evidence for a difference between the 2 sites as a function of the patch clumpiness index ($t_{41} = -0.7$, $P = 0.49$).

DISCUSSION

Movements

Understanding how a species responds after release is an important first step during the planning of a reintroduction or translocation project. The translocation of pygmy rabbits out of areas affected by development projects has been proposed for other areas, but little information on the response of wild pygmy rabbits to translocations and hard releases (i.e., capture, transport, and immediate release) is available. One study has evaluated a soft release of captive-raised pygmy rabbits prior to reintroduction into the Sagebrush Flat area of central Washington (Westra 2004). Those rabbits moved only an average of 54.1 m from their release burrows, and they readily used artificial burrows and supplemental feed that was provided (Westra 2004). Unfortunately, the release of captive-raised pygmy rabbits into central Washington was not successful in establishing a viable population. However, captive-reared rabbits may respond differently to translocation after a soft release than translocation of wild individuals (Davis 1983, Bright and Morris 1994, Carbyn et al. 1994), and our study confirmed this prediction.

We examined the response of wild pygmy rabbits after translocation with a hard release. The individuals that we translocated settled an average of 525 m from their release sites, a distance that is approximately 10 times greater than that reported for the soft release of captive-bred pygmy rabbits in Idaho (Westra 2004). Our results are consistent with the findings of Bright and Morris (1994) who reported that wild dormice (*Muscardinus avellanarius*) dispersed farther from release sites after experimental translocation than did their captive-reared counterparts.

During our study, distances moved by pygmy rabbits after release differed as a function of the characteristics of the sagebrush habitat at the landscape scale, which supported our prediction. Individuals that were moved across open, fragmented sagebrush habitats (marginal habitat category) prior to release settled the farthest distance from their release sites ($\bar{x} = 0.95$ km, SE = 0.29 km). This distance was similar to that which those individuals were originally transported ($\bar{x} = 1.05$ km, SE = 0.008 km). This group also had the greatest variability of movements. We recaptured 1 individual 2.0 m from its release site in the same 5-m × 5-m big sagebrush patch where it was released, whereas another rabbit crossed large patches of bunch grass vegetation and settled 2,827 m from the release site. Individuals that we transported across suitable habitat, with and without roads, settled an average of 0.45 km (SE = 0.06 km) and 0.35 km (SE = 0.05 km) from their release sites, respectively. These distances were approximately half and a third of the distance traveled by rabbits that we released in marginal habitat. We found a negative correlation between the distances that pygmy rabbits moved away from release sites prior to settlement and the amount and spatial arrangement of big sagebrush in the surrounding landscape. This provided some support for our prediction that rabbits would settle closer to their release sites in areas with greater amounts and more contiguous big sagebrush cover.

The measures of big sagebrush cover we used were derived from aerial photographs using a GIS, which was influenced

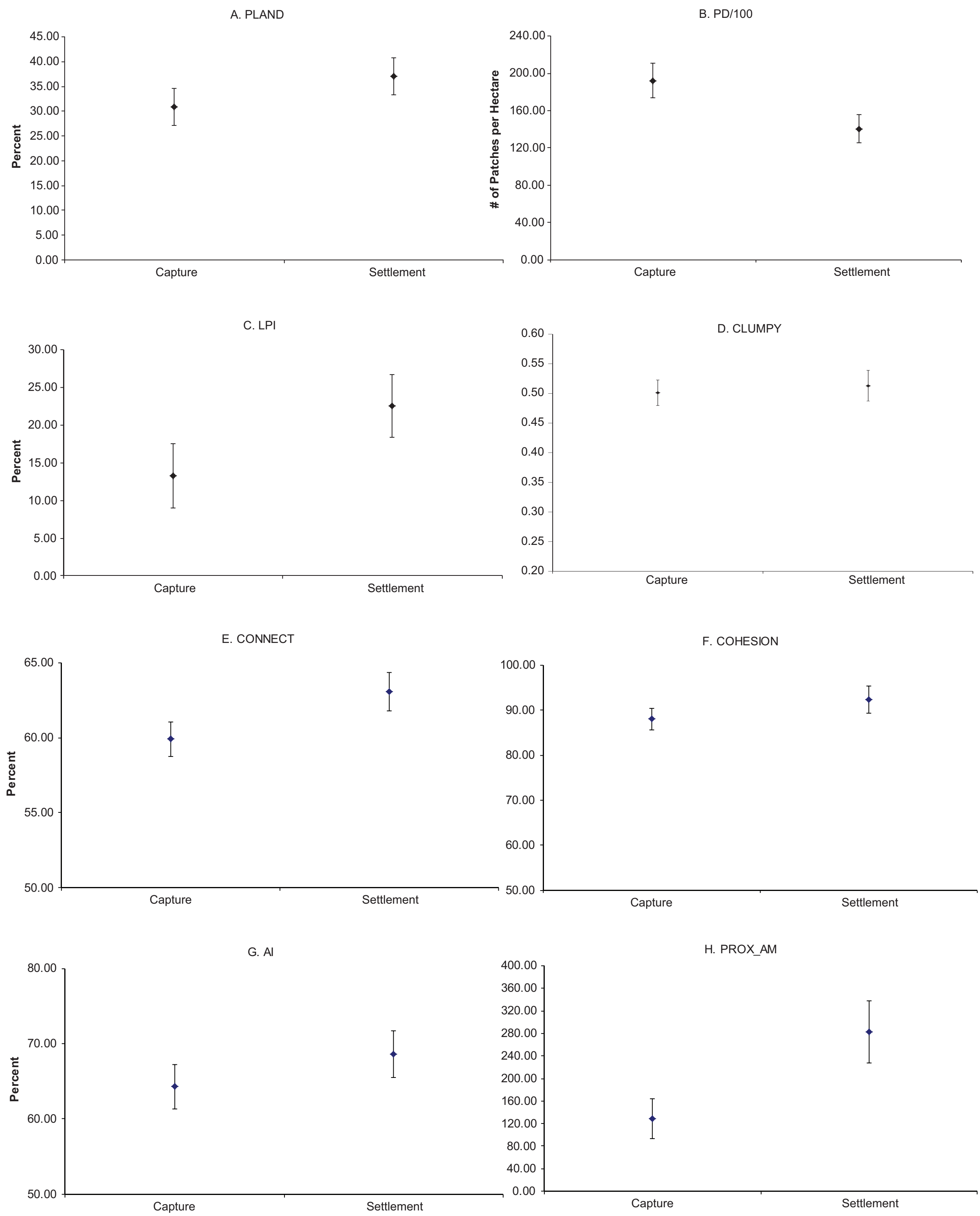

Figure 3. Mean and 95% confidence intervals for vegetative characteristics of capture and settlement sites of pygmy rabbits in southeastern Oregon, 2008 ($n = 42$). Landscape metrics include (A) Percent of the landscape classified as big sagebrush (PLAND), (B) number of big sage patches per hectare (PD/100), (C) percent of the landscape composed of the single largest patch of big sage (LPI), (D) clumpiness index (CLUMPY), (E) connectance index (CONNECT), (F) cohesion index (COHESION), (G) aggregation index (AI), and (H) proximity index (PROX_AM).

by the scale and grain size (1-m resolution) of the source photographs (Turner 1990, Wu 2004). As such, the estimates of shrub cover we report are not directly comparable to those from other investigations on selection for big sagebrush cover by pygmy rabbits, which used line-intersect methods to estimate shrub cover in the field. However, our methods and results provide a preliminary approach for assessing landscapes for suitability as release sites of pygmy rabbits using GIS and FRAGSTATS spatial analyses prior to field searches and investigations. Our methodology is not a substitute for ground searches, but use of these techniques may reduce the amount of time needed for field studies to locate suitable release sites for pygmy rabbits and other species associated with sagebrush communities.

The distances we observed pygmy rabbits travel after translocation (0.02–3.5 km) were within the range (0.02–11.9 km) reported for dispersal of juvenile pygmy rabbits from natal burrows (Estes-Zumpf and Rachlow 2009) and movements by undisturbed adult and juvenile individuals (Katzner and Parker 1998, Burak 2006, Sanchez 2007, Crawford 2008). We observed pygmy rabbits making exploratory movements away from their release sites, and 15% successfully homed back to their original capture locations from distances >1 km (Lawes et al. 2012). Unfortunately, the resolution of daily movement patterns we were able to measure was limited by our use of standard VHF radio telemetry, which was dictated by cost constraints and weight restrictions for small species. Future studies of the movements of this species will benefit by development of small and inexpensive GPS collars.

Katzner and Parker (1998) noted small patches of big sagebrush provided protective cover for dispersing pygmy rabbits. We also observed pygmy rabbits using patches of big sagebrush as temporary resting sites during movements. Although pygmy rabbits generally used a scampering gate while moving through dense sagebrush, we observed individuals using a leaping gate as they bounded over little sagebrush and bunch grasses while moving over areas with little vegetative cover. Several individuals made long distance movements away from their release sites, subsequently returned, and then ventured out again in another direction until they located a final settlement site. The results of our study suggest that relatively large areas of big sagebrush habitat may be necessary for successful translocation of wild pygmy rabbits.

Settlement Site Selection

The pygmy rabbit is a burrowing, sagebrush obligate and much of the past research on the species has concentrated on measuring and modeling their habitat selection (Weiss and Verts 1984, Gabler 1997, Gabler et al. 2000, Rachlow and Svancara 2006, Himes and Drohan 2007). Quantitative descriptions of selected habitat vary among studies depending on geographic location, time of year, and methodologies, but most indicate that pygmy rabbits select areas with the greatest cover of big sagebrush and deep soils that are conducive to burrowing.

Pygmy rabbits not only select specific habitat characteristics, but also have a high rate of juvenile dispersal (Estes-Zumpf and Rachlow 2009). Also, previous experience with habitat conditions has influenced selection of settlement sites of other species of translocated animals (Stamps and Swainsgood 2007). We assumed that the adult rabbits that we translocated had already completed their natal dispersal and had selected settlement habitat after natal dispersal. As such, we predicted that translocated pygmy rabbits would select settlement areas with similar cover of big sagebrush and patch attributes as their capture areas. Our results did not support this prediction, and they were contrary to the findings of previous studies of translocated mammals. Translocated red squirrels (*Sciurus vulgaris*) in England selected sites similar to those found at capture sites (Kenward and Hodder 1998), and this phenomena also has been described for hedgehogs (*Erinaceus europaeus*; Morris et al. 1993) and woodland caribou (*Rangifer tarandus*; Warren et al. 1996). In our study, the areas in which pygmy rabbits settled had greater cover and less fragmentation of big sagebrush (i.e., larger patches with greater levels of connectivity) than found at their capture sites. Given that pygmy rabbits select big sagebrush habitats, translocated individuals appeared to have settled in sites of higher habitat quality than was found at their original capture locations. Similarly, translocated hedgehogs settled in sites of higher habitat quality compared to their original capture sites (Doncaster et al. 2001). In our study, pygmy rabbits moved greater distances prior to settling on study sites possessing less cover of big sagebrush. Our results indicated that the species is capable of traveling relatively long distances (>3 km), and they will traverse marginal habitat and secondary roads to locate larger areas of big sagebrush cover.

In addition to vegetative characteristics, the presence of other pygmy rabbits or burrow systems appeared to be influential for selection of settlement sites in our study. All translocated pygmy rabbits settled in areas with either active or inactive burrows shortly after their release. They rarely constructed new burrows but frequently re-excavated uninhabited burrow systems. Similarly, the presence of conspecifics was influential in the selection of settlement sites of translocated water voles (*Arvicola terrestris*; Fisher et al. 2009). We released individuals in a manner that reduced any social interactions; however, individuals that we released separately in both space and time still settled within the same burrow systems. Both soil and big sagebrush cover were influential habitat features of settlement sites for pygmy rabbits, and the presence of inactive burrows on sites with previous inhabitation are a good indicator of potential release sites of translocated pygmy rabbits (Price and Rachlow 2011). Our findings emphasize the importance of ground-based site selection of release sites, in addition to GIS analysis, for successful translocation of the species.

MANAGEMENT IMPLICATIONS

Curtailing impacts that destroy, further degrade, or fragment sagebrush-steppe habitat should be of primary concern in efforts to conserve pygmy rabbit populations and their habitat. Translocations should be considered an alternative after other options to manage habitat and threats to that habitat have been exhausted. If translocations are deemed necessary to restore extant populations, the results of this study suggest that wild captured pygmy rabbits are capable of locating suitable habitat after translocations with a hard release. Further, individuals may be less likely to leave the release areas with abundant big sagebrush cover that is not greatly fragmented. Consequently, the success of pygmy rabbit translocations will likely depend on areas of continuous big sagebrush cover with deep, friable soils suitable for burrowing. In addition, release sites with recent pygmy rabbit inhabitation, uninhabited burrow systems, or existing populations will enhance success of such projects. A great deal of research and published literature has been devoted to habitat selection by pygmy rabbits, so use of that information on a regional basis will help reduce risks of failure of translocation projects. Lastly, managers should expect to lose a large portion of translocated pygmy rabbits to homing attempts, post-release dispersal, and predation. As such, the repeated release of a relatively large number of individuals may be required to successfully establish resident populations of the species through translocations.

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Appendix A. Mean and 95% confidence intervals of 8 landscape metrics calculated for each of 3 broad landscape categories used to compare the post-translocation movements and habitat selection of pygmy rabbits after experimental translocation in Oregon, 2008. We calculated landscape metrics from 1-m resolution aerial photographs using ArcGIS and FRAGSTATS spatial pattern analysis computer programs.

Landscape metric[a]	Habitat category[b]	*n*[c]	Mean	Lower 95% CL	Upper 95% CL
	Suitable	19	39.56	35.62	43.49
PLAND	Road	21	41.85	36.63	47.07
	Marginal	19	16.42	11.98	20.85
	Suitable	19	144.59	131.42	157.75
PD/100	Road	21	149.16	126.39	171.93
	Marginal	19	123.02	108.07	137.97
	Suitable	19	15.78	13.09	18.47
LPI	Road	21	17.64	14.12	21.15
	Marginal	19	3.85	1.87	5.83
	Suitable	19	0.59	0.58	0.61
CLUMPY	Road	21	0.58	0.56	0.59
	Marginal	19	0.58	0.52	0.63
	Suitable	19	2.07	1.21	2.92
CONNECT	Road	21	3.26	3.04	3.48
	Marginal	19	3.19	3.00	3.38
	Suitable	19	99.41	99.28	99.55
COHESION	Road	21	99.17	98.73	99.62
	Marginal	19	90.03	83.89	96.17
	Suitable	19	75.42	73.52	77.33
AI	Road	21	75.48	73.26	77.69
	Marginal	19	63.57	56.73	70.40
	Suitable	19	8,518.00	7,326.30	9,709.73
PROX_AM	Road	21	7,963.70	5,450.50	10,477.00
	Marginal	19	1,071.10	516.44	1,625.84

[a] Landscape metric definitions: PLAND = percent of the landscape that was classified as big sage, PD/100 = number of big sage patches per hectare, LPI = percent of the landscape composed of the single largest patch of big sage, CLUMPY = proportional deviation of the proportion of big sage adjacencies from that expected under a spatially random distribution, CONNECT = number of functional joinings between all patches of the big sage within a 100 meter distance criterion, COHESION = physical connectedness of corresponding big sage patches, AI = frequency with which different pairs of big sage patches appear side-by-side within the classified habitat circles, PROX_AM = area weighted mean number of big sage brush patches with edges within a 50 m search radius a focal big sage patch.

[b] Landscape classification of the region between capture and release sites.

[c] Number of individual landscapes classified.

Appendix B. Correlation matrix of landscape metrics used to describe the habitat of 43 pygmy rabbits experimentally translocated to assess barriers to dispersal, post-release movements, and settlement site selection in southeastern Oregon, 2008. We calculated landscape metrics from 1-m resolution aerial photographs using ArcGIS and FRAGSTATS spatial analysis programs. Top number equals the Pearson correlation coefficient between the two variables. Bottom number equals the ***P***-value under H_0: $\rho = 0$.

	PLAND	LPI	PD/100	CLUMPY	AI	PROX_AM
PLAND	1.000	0.928	−0.106	0.360	0.854	0.846
		<0.001	0.498	0.018	<0.001	<0.001
LPI	0.928	1.000	−0.270	0.217	0.730	0.866
	<0.001		0.080	0.162	<0.001	<0.001
PD/100	−0.106	−0.270	1.000	0.292	0.114	−0.254
	0.498	0.080		0.058	0.465	0.101
CLUMPY	0.360	0.217	0.292	1.000	0.787	0.109
	0.018	0.162	0.058		<0.001	0.487
AI	0.854	0.730	0.114	0.787	1.000	0.622
	<0.001	<0.001	0.465	<0.001		<0.001
PROX_AM	0.846	0.866	−0.254	0.109	0.622	1.000
	<0.001	<0.001	0.101	0.487	<0.001	

Variable descriptions: PLAND = percent of the landscape classified as big sagebrush, PD/100 = patch density per hectare, LPI = largest patch index, CLUMPY = clumpiness index, AI = aggregation index, PROX_AM = area weighted mean proximity index.