Articles

Habitat Selection by the Endangered New Mexico Meadow Jumping Mouse on an Irrigated Floodplain

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Abstract

The New Mexico meadow jumping mouse *Zapus hudsonius luteus* is endemic to the American Southwest. It has undergone severe declines in distribution over the past century and it has been listed as endangered under the Endangered Species Act. The goal of this study was to determine current status and habitat selection by the New Mexico meadow jumping mouse at three spatial scales (landscape, macrohabitat, microhabitat) on a managed high-order floodplain. We hypothesized that the New Mexico meadow jumping mouse is a habitat specialist that might rely on specific habitat components at multiple spatial scales. The study occurred at Bosque del Apache National Wildlife Refuge, New Mexico. In comparison with the status of the species 2 decades ago, the New Mexico meadow jumping mouse was rare, with only 29 individuals captured. Trapping results and radiotelemetry of 20 individuals revealed that the current population existed along 2.7 km of a single irrigation canal. At the landscape scale, the distribution of the New Mexico meadow jumping mouse was determined by selection of canals, water, foxtail barley *Hordeum jubatum* herbaceous temporarily flooded association, and narrowleaf willow *Salix exigua* mesic graminoids shrubland association. At the macrohabitat scale, jumping mice selected canals and *Hordeum jubatum* herbaceous temporarily flooded association. At the microhabitat scale, jumping mice selected areas that were near water and contained moist soils, dense herbaceous canopy cover, dogbane *Apocynum cannabinum,* foxtail barley, and common threesquare *Schoenoplectus pungens*; jumping mice avoided habitats represented by eight plant species, including mule-fat *Baccharis salicifolia,* kochia *Bassia scoparia,* and saltcedar *Tamarix ramosissima*. Jumping mice only occurred where there is an overlap of the required habitats at all three scales and this may be a key limiting factor for the New Mexico meadow jumping mice at Bosque del Apache National Wildlife Refuge. Habitats used by jumping mice during maternal nesting and hibernation contained more woody plants and woody debris than at other times of their life cycle. Information gained from this study can help land managers protect and create habitat conditions required by the New Mexico meadow jumping mouse.

Keywords: endangered species; irrigation; multiple-scale habitat selection; New Mexico meadow jumping mouse; Rio Grande; wildlife refuge; *Zapus hudsonius luteus*

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Introduction

In the American Southwest, riparian habitats are vital to a large proportion of vertebrate species (Hubbard 1977; Ohmart and Anderson 1982), but they also have been highly modified through the creation of dams, channelization, improper grazing practices, conversion of floodplains for agriculture, and urbanization (Johnson et al. 1977; Howe and Knopf 1991; Krueper 1993).

Figure 1. A radiocollared New Mexico meadow jumping mouse *Zapus hudsonius luteus* perched in vegetation while foraging at Bosque del Apache National Wildlife Refuge, New Mexico, during a study of habitat selection conducted 2009–2010.

Because riparian areas are subject to such high levels of disturbance and are essential to many species of wildlife, conservation efforts tend to focus on these areas (Knopf et al. 1988) and many protected wildlife areas are established within riparian corridors. Many of these tracts are National Wildlife Refuges and state Waterfowl Management Areas that were originally created to preserve habitat for migratory game birds. Most wildlife management decisions on these protected areas are currently focused on game species, which tend to be vagile habitat generalists. Consequently, the hopes are that the needs of nongame species are provided by efforts geared toward game management (Thompson et al. 2000). In this approach, the habitat needs of every species in the landscape may not be met, especially for species that rely on a specific suite of habitat conditions (Simberloff 1998; Roberge and Angelstam 2004). If researchers are able to discover the needs of specialist species that are not being met, those needs can be incorporated into land-management plans.

The New Mexico meadow jumping mouse *Zapus hudsonius luteus* (Figure 1) is a distinctive, monophyletic subspecies that occurs in portions of New Mexico, Arizona, and southern Colorado (Hafner et al. 1981; Frey 2012a; Malaney et al. 2012) and it has been listed as endangered under the U.S. Endangered Species Act (ESA 1973, as amended; USFWS 2014). In the eastern United States where humidity is higher, *Zapus hudsonius* is often regarded as a habitat generalist (Quimby 1951; Whitaker 1963). The New Mexico meadow jumping mouse, however, is considered a habitat specialist exclusively dependent upon riparian areas (Morrison 1990, 1992; Frey and Malaney 2009). Human impacts to these specialized habitats have led to widespread population declines in recent decades (Frey and Malaney 2009; USFWS LRT 2014). For instance, the species historically occurred throughout the Middle Rio Grande Valley in New Mexico (Hafner et al. 1981). However, its modern distribution along this river is greatly reduced and fragmented. As of the late 1980s, it was only confirmed to persist in four disjunct areas along the river (Morrison 1988). The two northern populations occurred on relatively undeveloped areas of Native American tribal lands (i.e., Ohkay Owingeh Pueblo [= San Juan Pueblo], Isleta Pueblo), while the two southern populations, which occur in a progressively more arid environment, included a state wildlife area (Casa Colorada) and a National Wildlife Refuge (Bosque del Apache; Morrison 1988). Recent surveys failed to confirm persistence of the population at Casa Colorada Wildlife Area (Frey 2012b). Bosque del Apache National Wildlife Refuge (BANWR) contains the southernmost known population of the New Mexico meadow jumping mouse along the Rio Grande, and it represents the largest publicly held tract of potentially suitable habitat for the species in the Middle Rio Grande Valley.

Habitat selection studies test the null hypothesis that animals are using habitats in direct proportion to their availability (Manly et al. 1993). Johnson (1980) developed a system of four scales of habitat selection that have become the standard in habitat selection studies: first-order (physical or geographical range; herein, landscape scale); second-order (home range of an individual or group; herein, macrohabitat scale); third-order (use of habitat within the home range; herein, microhabitat scale); and fourth-order (food items from within the chosen feeding site). Few studies investigate habitat selection across multiple scales (Thomas and Taylor 2006). However, failure to examine habitat selection at multiple scales might be short-sighted, because a species might select different aspects of habitat at different scales and it can allow discovery of habitat factors that might be limiting a population.

There are few published studies concerning habitat relations of the New Mexico meadow jumping mouse. Prior studies in montane areas found that the New Mexico meadow jumping mouse was associated with natural riparian habitats on low-order streams containing saturated soils and tall, dense herbaceous vegetation of sedges, grasses, and forbs (Morrison 1990; Frey and Malaney 2009). However, habitat relationships of the New Mexico meadow jumping mouse on managed floodplains associated with low-elevation higher order rivers are less well-understood, with published studies mainly limited to reporting occurrence in different major habitat types (Morrison 1990; Zwank et al. 1997). No studies have evaluated habitat selection by the New Mexico meadow jumping mouse. Consequently, the main goal of this study was to determine habitat selection by the New Mexico meadow jumping mouse at BANWR, which is an area primarily managed for game species on a floodplain of a high order river. Our specific objectives were to 1) determine the current status of the New Mexico meadow jumping mouse on BANWR in order to evaluate how it is fairing within this landscape that is intensively managed for game species; 2) determine habitat selection by the New Mexico meadow jumping mouse at three scales (landscape, macrohabitat, and microhabitat) in order to determine what habitat features might limit the population; and 3) report aspects of the species' life history, including nest locations and seasonal shifts in behavior, that have not been described previously.

Study Site

We conducted our study at BANWR, Socorro County, New Mexico, from May 2009 to May 2011. Bosque del Apache National Wildlife Refuge was created in 1939 to preserve habitat for wintering migratory birds and is centered upon the floodplain of the Rio Grande at the northern edge of the Chihuahuan Desert. It encompasses >23,000 ha, including an historical floodplain of >3,600 ha. Currently, the river is confined to a narrow active floodplain by dikes along its west side and abrupt uplands along its east side. The remainder of the historical floodplain to the west of the dikes is actively managed and was the location of our study. This area is intensively managed through irrigation and other techniques to promote a variety of riparian habitats and wildlife food crops. Management units are partitioned by dikes, roads, and irrigation waterways. Nearly all of the uplands represent natural Chihuahuan Desert and are not intensively managed.

The irrigation system included canals and ditches (which deliver water) and drains (which return water to the river). Typically, canals and drains are earthen and hold water perennially. The banks of canals may be dominated by wetland plants near water's edge, which transitions to grasses and forbs on drier soils at higher elevation. Because roads parallel most canals, the width of the vegetation gradient between canals and roads is typically narrow (8–10 m). Banks of canals are mowed regularly during summer to control invasive plant species and during autumn to provide wildlife viewing opportunities. Drains are regularly excavated, resulting in deep, steep-sided channels that have little shoreline vegetation.

Some management units, referred to as managed wetlands or moist soil units, are managed to produce food for wintering waterfowl and typically contain smartweed *Polygonum* spp., common threesquare *Schoenoplectus pungens,* spikerushes *Eleocharis* spp., and other obligate or facultative wetland plants. These units are occasionally flooded and mowed to prevent growth of cocklebur *Xanthium* spp. and they are tilled approximately every 5 y to break up the impermeable soil hardpan to maintain soil productivity. Riparian forests of Rio Grande cottonwood *Populus deltoides wislizeni* or invasive exotic saltcedar *Tamarix ramosissima* exist along the Rio Grande and in units nearest to the active floodplain. Nonirrigated management units within the historical floodplain are dominated by semiriparian habitat containing screwbean mesquite *Prosopis glandulosa,* alkali sacaton *Sporobolus airoides,* and other native grasses. Crops such as corn and alfalfa are produced to provide supplemental food to waterfowl and other species.

Methods

Our methods consisted of four elements. First, we used trapping surveys to determine the status of the New Mexico meadow jumping mouse (study animals are hereafter referred to as jumping mice) on BANWR and to obtain animals for radiotelemetry. Second, we used radiotelemetry to determine locations used by jumping mice. During radiotelemetry we collected microhabitat data at telemetry and random locations. Third, we analyzed habitat data associated with telemetry locations to evaluate habitat selection by jumping mice at three spatial scales (landscape, macrohabitat, microhabitat). The habitat data consisted of mapped habitat associations for analyses at the landscape and macrohabitat scales, and field data collected at telemetry and random points for the microhabitat scale. Fourth, for comparative purposes, we described habitat conditions at nests and capture locations. We accomplished this by using

mapped habitat classes at nest sites and by collecting field data on plots at capture locations and nests following standard methods used in other studies of the New Mexico meadow jumping mouse.

Trapping surveys

Surveys primarily focused on habitats judged to be most suitable for jumping mice, but as time permitted we also trapped historically occupied locations and other habitat types. Surveys occurred during the warm season when jumping mice were not hibernating and included three periods in 2009 (21–28 May, 22 June–1 July, 30 July–17 August) and five periods in 2010 (13–29 May, 11 June–8 July, 20–27 July, 23 August–30 September, and 1–25 October). Overall sampling effort was 20,521 trap-nights in 26 management units (locations and results are in Frey and Wright [2012] and Wright [2012]). We also surveyed during the hibernation period using 7,540 trap-nights in an attempt to document any arousal from hibernation, but we did not catch any jumping mice during those attempts (methods and results are in Frey and Wright [2012] and Wright [2012]). Each survey period during the warm season was scheduled to begin 3 d prior to the start of approximately 21-d telemetry sessions. We used Sherman live traps (model LFATDG; H.B. Sherman, Tallahassee, FL) baited with commercial three-way horse sweet feed (i.e., a mixture of grains and molasses). Sherman traps are commonly used in studies of *Zapus* and are effective at capturing *Zapus* without injury or trap failure and with a relatively high incidence of recapture (Morrison 1988; Ruggles et al. 2003; Trainor et al. 2007; Frey and Malaney 2009; Schorr et al. 2009). Typically, we set traps in transects of 40 traps spaced 1 m apart. We usually set traps adjacent to water in areas with dense herbaceous vegetation (Morrison 1988; Frey and Malaney 2009). We attempted to determine the presence of jumping mice in all units where the species was previously known to occur by trapping or visually assessing habitat suitability. If no water existed in the management unit, we placed traps in the vegetation within the management unit that appeared to be most suitable for jumping mice. We set traps in late afternoon and checked them the following morning.

We transferred captured jumping mice to a zippered mesh handling bag and examined them for age, sex, reproductive condition, overall physical condition, and presence of ectoparasites (none were found). We obtained body mass by weighing the animal in the bag with a hanging spring scale. We took tissue samples by snipping an approximately 1-mm sliver from the edge of the external ear pinna with sharp scissors and storing it in ethanol. We uniquely marked jumping mice by inserting a passive integrated transponder tag subcutaneously between the shoulder blades or by applying a numbered fingerling fish metal tag (model 1005-1; National Band and Tag, Newport, KY) to the ear pinna. We only applied the ear tags to jumping mice if we encountered difficulties with them retaining passive integrated transponder tags.

We captured small mammals in accord with a New Mexico scientific collecting permit (2868) issued to J.K. Frey. All capture and handling techniques were approved by the New Mexico State University Institutional Animal Care and Use committee. Activities on BANWR were allowed under permit 22520-2009-01BIO.

Radiotelemetry

We fitted jumping mice with 0.80-g radiocollars (BD-2C; Holohil Systems Ltd., ON, Canada). We placed two approximately 0.75-cm-diameter pieces of clear plastic tubing over the collar wire to prevent irritation to the animals' neck. We attached the collar without use of anesthesia (Ruggles et al. 2003; R. Schorr, Colorado Natural Heritage Program, personal communication); total handling time to attach a collar to a jumping mouse was approximately 2 min and normally did not appear to cause the jumping mouse undue stress. Although an equal number of males and females would have allowed us to compare space-use patterns between sexes (Trainor et al. 2007), low capture rates led us to collar any animal of appropriate size. We applied radiocollars only to jumping mice with body mass >15 grams (g), which insured that the collar weighed $\leq 5.3\%$ of body mass. In most prior studies of other subspecies of the meadow jumping mouse, transmitters comprised 4–6% of the mass of the studied animal, with no significant changes in behavior or survival (Schorr 2001; Bain and Shenk 2002). The minimum body mass that we employed was less than in studies of other subspecies of the meadow jumping mouse (females 25 g, males 27 g [Ruggles et al. 2003]; both sexes 18g [Ryon 2001; Schorr 2001; Bain and Shenk 2002; Trainor et al. 2007]) because we used smaller transmitters (0.8 g versus 1.0 g) and New Mexico meadow jumping mice at BANWR are typically smaller than other subspecies of the meadow jumping mouse.

We immediately released jumping mice fitted with radiocollars at the site of capture. Initially, we tracked radiocollared jumping mice nightly from dusk until dawn during the 21-d nominal life of the collar battery (or until radio signal weakened or collar was recovered). As the study progressed and low capture rates necessitated additional survey effort, we tracked jumping mice from dusk until after midnight (approx. 2000–0300 hours, and from midnight until dawn (approx. 0000–0600 hours), alternate days (Schorr 2001). We determined locations of radiocollared jumping mice using TRX-10S receivers (Wildlife Materials, Murphysboro, IL) attached to RA-7 antennas (Telonics Inc., Mesa, AZ). In order to avoid disturbing the jumping mice or their habitat, we approached only as close as 3 m, whereupon location was determined using a handheld global positioning system, direction to the jumping mouse was determined with a compass, and distance to the jumping mouse was estimated. Homing to this distance did not disturb jumping mice, yet still allowed for visual observation (Trainor et al. 2007; Wright and Frey 2014). In addition, we attempted to find nest locations during the day at least once weekly. Meadow jumping mice routinely abandon used nests and occupy day nests for no more than 1–3 wk (Ryon 2001). Once a nest was abandoned (i.e., no day use was observed for >2 consecutive d), we

investigated it and recorded dimensions, nest material, and associated microhabitat data. After the tracking period, we attempted to recapture jumping mice to remove the collars (Douglass 1989) by saturating areas known to be used for day nesting and foraging with traps. Once the small size of the population was known, we released some females without applying radiocollars.

Home range. We input locational data into Arc Map 9.3 (Environmental Systems Research Institute, Inc., Redlands, CA) for home range analyses. All telemetry locations were assumed temporally independent and invalid points (e.g., location inconsistencies due to poor satellite reception) were removed from consideration (White and Garrott 1990). We calculated minimum convex polygons for each radiocollared jumping mouse using the Home Range Tools extension and validated them using Hawth's Analysis Tools (Beyer 2004). Minimum convex polygons are a commonly used summary of home range because of their simplicity and ease of comparison between studies (White and Garrott 1990; Bias and Morrison 1999). We included home ranges calculated from small locational sample sizes because they contributed to the area of the suitable habitat estimate used in habitat selection analyses. However, we do caution that for mice with few telemetry points the estimated home range area likely had not reached an asymptotic maximum, which began to stabilize at >20 locations (Figure S1). Telemetry locations are illustrated in Figure S2.

Microhabitat data collection. We classified radiotelemetry locations post hoc as "active" if the jumping mouse was not at a day, maternal, or hibernation nest (i.e., it was moving and/or foraging). Nest sites were determined by visual observation of the nest or by lack of movement by the jumping mouse during daylight resting periods. For the analysis of habitat selection at the microhabitat scale, we collected data, including spatial-structural variables and plant species, at active locations and at random locations associated with a subset of the active locations. Random locations were determined by a random azimuth and distance up to 300 m from a telemetry point; 300 m represented a typical maximum distance travelled between consecutive telemetry locations; 2.7% of all consecutive movements were >300 m. To avoid disturbing jumping mice, we estimated microhabitat variables from a distance of approximately 3 m. We collected measurements of the height of the dominant vegetation excluding woody trees >2 cm in diameter at breast height or >2 m tall. Additionally, we recorded a visual estimation of percent herbaceous cover, estimated distance to nearest standing water, and recorded soil moisture with a probe (Lincoln Irrigation, Lincoln, NE) inserted approximately 4 cm into the ground. Our estimates of percent herbaceous cover and vegetation height were similar to actual measurements ($t(19) = 0.52$, $P = 0.606$; $t(19) = 0.70$, $P = 0.487$; respectively). We recorded presence of dominant and codominant plant species within approximately 1 m of the jumping mouse. We used the U.S. Department of Agriculture Natural Resources Conservation Service PLANTS database for plant species names (USDA NRCS 2014).

Analyses of habitat selection

We defined our scales of habitat selection according to Johnson (1980). For the landscape and macrohabitat scales, we used geographic information system (GIS; ArcMap 9.3) to map jumping mouse locations and determined information on use and availability of habitats on a high-resolution (0.8-m resolution) vegetation map of BANWR, which was organized according to the National Vegetation Classification Standard and was the finest resolution vegetation map available (USFWS HAPET 2006). We used the classification level of National Vegetation Classification Standard vegetation association, but we reclassified portions of the map to more accurately depict actual habitat conditions near canals, roads, and the edges of dense forest canopies. For the microhabitat scale, we analyzed field-collected data at telemetry locations and random locations.

First-order (landscape-scale) habitat selection. We evaluated landscape-scale habitat selection to provide scope to the finer scale analyses within the study area (Lesmeister et al. 2007). To define the area occupied by jumping mice on BANWR, we used GIS to create a buffer around all telemetry locations. The buffer was defined as 95% of the maximum straight-line distance traveled by any jumping mouse between two consecutive time-independent radio locations (i.e., = 192 m; Figure S3). We interpreted the resulting areas to represent the distribution of jumping mice on BANWR. We inferred habitats that were disproportionately selected by jumping mice at the landscape scale by comparing the proportion of each vegetation association available within these areas to the proportion of active locations within each vegetation association. If the observed availability of a habitat type plus its standard error was less than the observed use minus its standard error, the habitat type was determined to be selected (Johnson 1980).

Second-order (macrohabitat) selection. We evaluated macrohabitat selection by examining use of available vegetation associations within the collective home ranges (i.e., a polygon that described the outer perimeter of the overlapped minimum convex polygons of each individual) of each subpopulation of jumping mice. A subpopulation was defined as an interconnected group of jumping mice separated from other subpopulations by >744 m, which was the observed maximum distance traveled between two successive points of all radiocollared jumping mice (Figure S3). We identified two subpopulations, hereafter referred to as North and South. To create a collective home range for each subpopulation, we combined each home-range minimum convex polygon from within the subpopulation using GIS and then overlaid the resulting polygon onto the map of National Vegetation Classification Standard vegetation associations. We calculated the areas of each vegetation association within the collective home ranges of each subpopulation. These habitat types were considered available to each jumping mouse within the respective subpopulation.

To analyze habitat selection at the macrohabitat scale, we employed methods developed by Neu et al. (1974) and further refined by Byers et al. (1984). This method is regarded as conservative and has less risk of Type I error than many other types of analyses of habitat selection (Bingham and Brennan 2004). However, it is considered insensitive to individual variation because observations of individuals are pooled (i.e., unit-sum constraint; McClean et al. 1998). To address this criticism we analyzed each subpopulation independently in order to be certain that all habitats were available to each animal. Following procedures of Liu et al. (2005), we tested two null hypotheses: 1) habitat use by jumping mice was not different from proportional habitat availability, considering all habitats simultaneously; and 2) individual habitat types were not used in different proportion to their availability. These hypotheses allowed us to discover habitat selection if it existed and, if so, to subsequently identify which habitats were being selected and avoided. To evaluate the first null hypothesis, we conducted a chi-square (χ^2) analysis on all available habitat types to assess whether collective habitat use within each subpopulation varied significantly from expected values based on the associated *Z*-score. If habitat selection or avoidance was indicated, we proceeded to the second hypothesis. To evaluate the second null hypothesis, we constructed Bonferroni-corrected confidence intervals for each habitat type to maintain an experiment-wise error rate of $\alpha = 0.05$. If the upper interval boundary was below the availability proportion, habitat avoidance was indicated. Conversely, if the lower interval boundary was above the availability proportion, habitat selection was indicated. The null hypothesis was not rejected if the confidence interval contained the available proportion of habitat.

Third-order (microhabitat) selection. We examined microhabitat variables at 480 active locations and 272 random locations under the use–availability design as defined by Keating and Cherry (2004). We followed a modification of statistical methods described by Avila-Flores et al. (2010) used for a case-control study. We were able to employ this method with our use–availability study design because when use of some habitats by a species is rare (as was the case in our study) case-control and use–availability designs are approximately equivalent (Keating and Cherry 2004). This method is based on the development of statistical models using multiple logistic regression that compare variables collected at used locations versus random locations. There were two types of variables: spatial-structural variables (continuous data) were based on prior knowledge of microhabitat used by the New Mexico meadow jumping mouse and included distance to water, soil moisture, vegetation height, and vegetation cover; the other type of variables was dominant plant species at locations (binary data; $N = 50$). All data were nonnormal. Prior to creation of models we used descriptive univariate tests to reduce the variable field to increase model fit: Wilcoxon rank-sum test for continuous data; Pearson's chi-square analysis for plant data; and Fischer's exact test for binary data with small sample sizes. All spatial-structural variables were retained. For plant species, we used a conservative $\alpha = 0.01$, which eliminated all but 11 species for model building. None of the final pool of 15 variables was highly correlated (i.e., correlation coefficient ≥ 0.7).

We developed models of microhabitat selection using multiple logistic regression in SAS 9.2 (SAS Institute, Inc., Cary, NC). We developed 5 kinds of models: global spatial-structural, best spatial-structural subset, global plant species, best plant species subset, and global. Global models illustrate the maximum explanatory power of each type of data represented (Avila-Flores et al. 2010). To determine the best subsets models for each group of variables (i.e., spatial-structural and plant species), we used backward elimination and evaluated Mallow's Cp scores (Procedure REG). Mallow's Cp scores are robust to overfitting and the lowest Mallow's Cp score indicated the model that contained the suite of habitat variables that best predicted selection by jumping mice. To compare models, we used Akaike's Information Criterion for small sample sizes (AIC_c; Procedure GENMOD), which is a measure of the relative quality of a model. We considered the model with the lowest AIC_c score as the best model for predicting habitat use by the New Mexico meadow jumping mouse, but also considered any models with AIC_c scores within 2.0 of the lowest AIC.

After determining the overall best model, we evaluated the influence of specific variables on the model. We examined the beta values for each variable in the model, which allowed us to determine which variables were most likely to be observed at jumping mouse locations. In addition, we calculated Wald chi-square statistic for each variable to evaluate its significance in the model.

Descriptions of habitat at nests and capture locations

We described general characteristics of locations for active sites, day nests, and maternity nests based on National Vegetation Classification Standard cover classes. The cover classes present on the study area included forest, woodland, shrubland, dwarf shrubland, herbaceous, nonvascular plant, sparse vegetation, and nonvegetated. In addition, in order to provide comparative data with other studies of habitat used by the New Mexico meadow jumping mouse and to describe habitat at nest locations, we measured habitat variables on 4-m-radius plots following the methods of Frey and Malaney (2009), with plots centered on capture locations, day nests, maternal nests, and hibernation nests. Variables included percent ground cover, canopy cover (using a spherical densiometer), distance to water, soil moisture, litter depth, two measures of stubble height, vertical cover (using a Robel pole), and number of woody stems and trees identified to species. Stubble height, litter depth, and woody stems were collected on only two of four perpendicular transects. Slope and aspect were not recorded because BANWR has little topographic relief.

Results

Current status of jumping mice at BANWR

The capture rate for jumping mice was low (0.21/100 trap-nights) with only 29 individuals captured (43 total captures) despite an intensive survey effort of >20,500 trap-nights. The capture rate has declined compared with past studies (i.e., 1.57/100 trap-nights in 1987 and 0.56/100 trap-nights in 1991–1992; Frey and Wright 2012; Wright 2012). During previous studies, the New Mexico meadow jumping mouse was captured in 14 of 33 (42%) management units on BANWR that were surveyed (Text S1). We sampled 26 units but captured jumping mice in only 5 units (19%), although survey efforts in some units may not have been large enough to confirm absence (Text S1). In addition, we determined that many units did not have suitable habitat for jumping mice based on visual assessment of habitat (Text S1). During radiotelemetry, we documented jumping mice using 10 management units, but all were closely associated with a 2.7-km reach of one irrigation canal (i.e., Riverside Canal).

Radiotelemetry

We fitted 20 jumping mice with radiocollars and tracked them. We tracked one jumping mouse during both the first and second tracking period in 2010. The mean number of observations per animal per tracking session was 48.6 (range = 6–90). Of 992 total telemetry locations, 552 were unique. Duplicated telemetry locations were due to extreme site fidelity by individual jumping mice (i.e., at both day nests and feeding sites) and long-term use of maternal nests by females. The mean home range size was 1.37 ha (range = 0.02–4.15 ha). There was a trend toward males having larger home ranges than females ($t(18) = 1.43$, $P = 0.08$; males: $n = 11$, $\bar{x} = 1.77$ ha, variance = 2.19, range = 0.08–4.15 ha; females: $n = 9$, $\bar{x} = 0.88$ ha, variance = 1.49, range = 0.02–3.59 ha). Known sources of mortality for three radiocollared jumping mice included predation by kingsnake *Lampropeltis splendida,* great-horned owl *Bubo virginianus,* and an unidentified mammalian mesocarnivore. Three of the 17 remaining radiocollared jumping mice lost their collars prior to the end of the 21-d telemetry period. Of six radiocollared jumping mice that we recaptured, all but one either maintained or increased body mass.

Habitat selection

First-order (landscape-scale) habitat selection. Jumping mice at BANWR used four vegetation associations (*Salix exigua* mesic graminoids shrubland association, canal bank, water, and *Hordeum jubatum* herbaceous temporarily flooded association) at the landscape scale in greater proportion than their availability (Table 1). The *Hordeum jubatum* herbaceous temporarily flooded association and canal bank were the most strongly selected. Managed wetlands, road and roadside ditches, and *Tamarix ramosissima* monotypic alien shrubland association were used less frequently than expected based on availability.

Second-order (macrohabitat) selection. Jumping mice selected vegetation associations significantly different than expected based on availability at the macrohabitat scale (North subpopulation: $\chi^2 = 388$, $P < 0.001$; South subpopulation: $\chi^2 = 365$, $P < 0.001$; Tables S1, S2, S3). The North subpopulation used canal banks more frequently than expected and managed wetlands less frequently than expected (Table 2). Nine available vegetation associations were not used by the North subpopulation, many of which contained a woody components or consisted of sparse, recently disturbed vegetation. All other available vegetation associations were used in proportion to their availability. The South subpopulation used the *Hordeum jubatum* herbaceous temporarily flooded association in greater proportion than expected (Table 2). Four available vegetation associations were not used by the South subpopulation, including three with a strong woody components and one that was sparse and recently disturbed. All other available vegetation associations were used in proportion to their availability.

Third-order (microhabitat) selection. Based on percent of locations with a plant species dominant or codominant, jumping mice were closely associated with just eight wetland species, including foxtail barley *Hordeum jubatum* (22.4%), dogbane *Apocynum cannabinum* (20.7%), narrowleaf willow *Salix exigua* (19.8%), annual rabbitsfoot grass *Polypogon monspeliensis* (9.1%), common threesquare (8.1%), smartweed *Polygonum* spp. (6.0%), Baltic rush *Juncus arcticus* (5.3%), and mule-fat *Baccharis salicifolia* (5.0%); 45 other plant species occurred at <5% of locations. Descriptive statistics indicated that used locations tended to be closer to water, to have higher soil moisture and shorter vegetation, and to have greater herbaceous cover as compared with random locations (Table S4). In addition, used locations tended to be associated with common threesquare, narrowleaf willow, dogbane, foxtail barley, and Japanese brome *Bromus japonicus,* but tended to not be associated with Rio Grande cottonwood, plains bristlegrass *Setaria vulpiseta,* alkali sacaton, saltgrass *Distichlis spicata,* mule-fat, spikerush *Eleocharis* spp., and two exotic invasive species—kochia *Bassia scoparia* and saltcedar (Table S4).

The best subsets modeling did not eliminate any spatial-structural variables (Table S5) and eliminated only one plant species from the global plant species model (Table S6). The spatial-structural model performed better than either the global plant species or best subsets plant species models (Table S7). However, we selected the full global model as the overall best performing model. The global model had the lowest AIC_c score ($AIC_c = 443.3$ compared with $AIC_c = 506.1$ for the spatial-structural model). However, the global model had a large number of variables (i.e., 15) and relatively low predictive power ($R^2 = 0.409$), though it had better predictive power than the next best model (i.e., $R^2 = 0.309$ for spatial structural model; Table S7).

In evaluating individual variables in the global model, the beta statistic indicated that common threesquare was the microhabitat variable most likely to be observed in association with jumping mice (Table 3). Foxtail barley and dogbane also had strong positive relationships with

Table 1. Percent of available (SE = 1.81) and used (SE = 1.61) vegetation associations at the landscape scale within the distribution (i.e., within a 192-m buffer around all telemetry locations) of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Excluded are 10 vegetation associations that each consisted of <0.25% of the total area and that had no use by jumping mice. Vegetation associations are classified according to the National Vegetation Classification System (USFWS HAPET 2006).

Vegetation association	Percent of available	Percent of use
Riparian–wetland communities		
Herbaceous riparian–wetland vegetation—temporarily flooded		
Distichlis spicata herbaceous association	1.96	3.06
Hordeum jubatum herbaceous temporarily flooded association	0.46	12.73
Wetland managed temporarily flooded herbaceous association (= managed wetland)	63.96	52.97
Shrub riparian–wetland vegetation		
Lowland interior southwest riparian shrubland—temporarily flooded		
Baccharis salicifolia mesic forb–graminoid shrubland association	1.10	0.00
Lowland western riparian–wetland shrubland—temporarily flooded		
Salix exigua mesic forbs shrubland association	0.35	0.00
Salix exigua mesic graminoid shrubland association	2.08	5.77
Salix exigua barren shrubland association	0.43	0.00
Lowland exotic riparian–wetland shrubland—temporarily flooded		
Tamarix ramosissima–Distichlis spicata alien shrubland association	0.13	1.19
Tamarix ramosissima monotypic alien shrubland association	4.69	0.00
Tamarix ramosissima mixed alien shrubland association	0.90	0.00
Forest and woodland riparian–wetland vegetation		
Lowland interior southwest riparian–wetland forests and woodlands—temporarily flooded		
Populus deltoides spp. *wislizeni–Distichlis spicata* woodland association	3.32	0.34
Populus deltoides ssp. *wislizeni* mixed woodland association	0.93	0.00
Populus deltoides ssp. *wislizeni* planted forest association	0.40	0.00
Populus deltoides spp. *wislizeni–Salix exigua* woodland association	1.49	0.00
Populus deltoides spp. *wislizeni–Salix gooddingii* woodland association	1.25	0.00
Tamarix ramosissima–Populus deltoides ssp. *wislizeni* sparse	0.36	0.00
Salix exigua–Baccharis salicifolia shrubland association	1.01	0.00
Upland vegetation		
Grassland vegetation		
Chihuahuan lowland–swale desert grassland		
Sporobolus airoides mixed association	0.21	1.02
Shrubland vegetation		
Chihuahuan mesquite desert scrub		
Prosopis glandulosa–Atriplex canescens shrubland association	0.75	0.00
Land use descriptors		
Nonagricultural disturbed areas	0.00	0.00
Planted–cultivated	1.27	0.00
Abiotics		
Water	0.94	3.90
Unconsolidated materials sparse vegetation	0.00	0.00
Road and roadside ditch[a]	6.99	0.34
Canal bank[a]	3.46	18.68
Down woody vegetation	0.28	0.00

[a] Reclassified to reflect conditions during the period of study.

jumping mice ($P \leqq 0.0001$; Table 3). Distance to water was negatively associated with jumping mice, and was the most strongly significant spatial-structural variable ($P < 0.0001$; Table 3), meaning that jumping mice were found near water. Some variables exhibited little influence in the global model, yet were highly influential in their respective subglobal model. Notably, in the plant species model, the presence of saltcedar was the

Table 2. Proportion of available and observed use of vegetation associations at the macrohabitat scale within two subpopulations of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Vegetation association	Proportion of availability	Proportion of observations	CI on proportion of observations	Habitat selection
North subpopulation				
Managed wetland	0.696	0.552	0.431 – 0.673	less frequent
Canal bank	0.061	0.332	0.185 – 0.480	more frequent
Water	0.029	0.067	−0.107 – 0.242	in proportion
Sporobolus airoides mix	0.02	0.022	−0.156 – 0.201	in proportion
Distichlis spicata herbaceous vegetation	0.011	0.015	−0.164 – 0.194	in proportion
Populus deltoides–Distichlis spicata woodland	0.064	0.007	−0.172 – 0.187	in proportion
Salix exigua mesic graminoid shrubland	0.007	0.004	−0.176 – 0.184	in proportion
Down woody vegetation	0.007	0.000	0.000	not selected
Nonagricultural disturbed areas	0.016	0.000	0.000	not selected
Populus deltoides–Salix exigua woodland	0.000	0.000	0.000	not selected
Prosopis glandulosa–Atriplex canescens shrubland	0.057	0.000	0.000	not selected
Road and road ditch	0.017	0.000	0.000	not selected
Salix exigua–Baccharis salicifolia shrubland	0.000	0.000	0.000	not selected
Tamarix ramosissima monotype	0.007	0.000	0.000	not selected
Tamarix ramosissima–Populus deltoides	0.002	0.000	0.000	not selected
Unconsolidated material sparse vegetation	0.006	0.000	0.000	not selected
South subpopulation				
Managed wetland	0.478	0.524	0.411 – 0.637	in proportion
Hordeum jubatum herbaceous vegetation	0.041	0.236	0.0925 – 0.380	more frequent
Salix exigua mixed grass shrubland	0.173	0.097	−0.059 – 0.253	in proportion
Canal bank	0.024	0.052	−0.108 – 0.212	in proportion
Distichlis spicata herbaceous vegetation	0.049	0.045	−0.115 – 0.206	in proportion
Tamarix ramosissima–Distichlis spicata shrubland	0.013	0.023	−0.140 – 0.185	in proportion
Water	0.046	0.016	−0.147 – 0.179	in proportion
Road and road ditch	0.087	0.003	−0.161 – 0.167	in proportion
Unconsolidated material sparse vegetation	0.000	0.003	−0.161 – 0.167	in proportion
Nonagricultural disturbed area	0.004	0.000	0.000	not selected
Populus deltoides woodland	0.081	0.000	0.000	not selected
Salix exigua–Baccharis salicifolia shrubland	0.000	0.000	0.000	not selected
Salix exigua mesic forb shrubland	0.003	0.000	0.000	not selected

strongest negative predictor of jumping mice ($\beta = -0.3166$, Wald $\chi^2 = 24.53$, $P < 0.0001$).

Life history observations

Nest sites. We tracked 20 jumping mice to 34 different day nests. Day nests were usually (58%) in the herbaceous cover class, but also were found in areas classified as shrubland, sparse vegetation, and woodland cover classes (Table 4). Similar to active and capture locations, day nests were on moist soil, near water, and in tall herbaceous vegetation with little woody canopy cover (Table 5). We were able to visually observe 14 day nests, all of which were above ground and most commonly in dense stands of saltgrass, but occasionally among other grass species. Observed nests were constructed of grasses and other plant fibers woven into a hollow ball approximately 10 cm in outside diameter. Maternity nests usually were in woody cover classes and located in areas devoid of dense green vegetation, and under fallen sticks and limbs of willow, cottonwood, and screwbean mesquite (Tables 4 and 5). Unlike day nest locations, these nests were below ground and usually were well-shaded by the canopies of trees and shrubs. The only jumping mouse that we tracked into hibernation hibernated along the east-facing slope along the east side of a road bank within the wooded shoreline of a managed wetland. The hibernaculum was below ground and beneath woody debris. Dominant plants at the hibernation site were saltgrass, mule-fat, kochia, and cottonwood. Microhabitat features are in Table 5.

Seasonal variation in habitat use. All captures of jumping mice in our study occurred between 19 May and 25 October (26 October was the last date that we recorded jumping mouse activity above ground). Following emergence from hibernation, jumping mice used both managed wetlands and canal banks. However, during the summer jumping mice almost

Table 3. Estimated beta, standard error (SE), Wald chi-square 95% confidence intervals, Wald chi-square statistics, and corresponding *P*-values for variables in the global model of microhabitat selection by the meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Variable	Beta	SE	Wald 95% CI	Wald χ^2 statistic	*P*
Vegetation height	−0.003	0.001	−0.004–(−0.001)	8.2	0.004
Herbaceous cover	0.002	0.001	0.001–0.004	9.4	0.002
Distance to water	−0.010	0.001	-0.012–(-0.008)	108.2	<0.0001
Soil moisture	0.018	0.007	0.004–0.033	6.0	0.014
Dogbane *Apocynum cannabinum*	0.209	0.054	0.103–0.316	14.8	0.0001
Common threesquare *Schoenoplectus pungens*	0.470	0.111	0.252–0.688	17.8	<0.0001
Rio Grande cottonwood *Populus deltoides wislizeni*	−0.130	−0.130	−0.252–(−0.007)	4.3	0.038
Spike rush *Eleocharis* spp.	−0.051	−0.051	−0.190–0.088	0.5	0.471
Foxtail barley *Hordeum jubatum*	0.221	0.221	0.125–0.318	20.2	<0.0001
Saltgrass *Distichlis spicata*	−0.064	−0.064	−0.177–0.050	1.2	0.271
Saltcedar *Tamarix ramosissima*	−0.001	−0.001	−0.132–0.130	0.0	0.988
Kochia *Bassia scoparia*	−0.107	−0.107	−0.252–0.038	2.1	0.148
Mule-fat *Baccharis salicifolia*	0.164	0.164	0.051–0.277	8.1	0.004
Alkali sacaton *Sporobolus airoides*	−0.134	−0.134	−0.278–0.009	3.4	0.067
Plains bristlegrass *Setaria vulpiseta*	−0.142	0.125	−0.387–0.102	1.3	0.254

exclusively used canal banks and other habitats associated with flowing water or temporarily flooded habitats. Capture rates for jumping mice declined over the summer in both years, despite substantially greater survey effort during those periods (Figure S4). In late July and August we observed a shift in habitat use by adult females (Table S8). All radiocollared females abandoned their usual habitat and moved to nests in woody riparian areas where they remained for an approximately month-long period of inactivity, during which time they presumably reared their young. Nesting commenced on or about 27 July 2010 and ended on or about 25 August 2010.

Discussion

There has been a precipitous decline in the distribution and abundance of jumping mice at BANWR over the past 2 decades (Morrison 1988; Najera 1994; Zwank et al. 1997). Based on our visual assessment of habitat throughout BANWR and based on results of our trapping and radiotelemetry, the population of jumping mice on BANWR during this study was exceptionally small and restricted to portions of a 2.7-km reach of one irrigation canal. This decline is likely due to a reduction in area of habitat required by jumping mice. We found that habitats used by jumping mice on this managed floodplain were similar to habitats used on low-order montane streams and were characterized by tall, dense herbaceous vegetation on saturated soils in proximity to flowing water (Frey and Malaney 2009). Further, we found that the New Mexico meadow jumping mouse is a habitat specialist at all three spatial scales that we investigated: jumping mice selected habitats disproportionate to their availability at the landscape and macrohabitat scales, and selected specific microhabitat components nested within those broader scales (Figure 2). Active jumping mice consistently selected riparian vegetation associations that experienced temporary flooding and consisted of specific early seral-stage herbaceous vegetation. This extreme habitat specialization likely represents a key limiting factor for the New Mexico meadow jumping mouse.

Table 4. Percent of total observations of active locations, day nests, and maternal nests in different National Vegetation Classification Standard (NVCS) cover classes for the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

NVCS cover class[a]	Active locations (*N* = 580)	Day nests (*N* = 38)	Maternal nests (*N* = 6)
Forest	0.0	0.0	50.0
Woodland	12.4	10.5	16.7
Shrubland	6.4	15.8	16.7
Herbaceous	63.1	57.9	16.7
Sparse vegetation	14.8	15.8	0.0
Nonvegetated	3.3	0.0	0.0

[a] Two additional cover classes—nonvascular plant and shrubland dwarf—also existed within the study area but contained no jumping mouse radiotelemetry locations.

Table 5. Microhabitat characteristics for locations of captures, day nests, maternal nests, and a hibernation nest of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

	Capture location (N = 43)			Day nest (N = 14)			Maternal nest (N = 4)			Hibernation nest (N = 1)
	$\bar{x}$	Range	SD	$\bar{x}$	Range	SD	$\bar{x}$	Range	SD	
Soil moisture	9.5	6.0–10.0	1.1	8.9	3.0–10.0	2.3	9.0	8.0–10.0	1.2	7.0
Distance to water (m)	20.8	0.0–100.0	26.7	35.0	1.0–70.0	25.9	16.5	5.0–50.0	22.3	5.0
% Canopy cover	10.6	0.0–67.8	17.6	11.4	0.0–54.3	17.0	55.2	28.3–79.3	20.9	61.0
Woody stems (per m^2)	1.8	0.0–8.9	2.0	0.4	0.0–3.1	0.7	5.5	0.0–4.8	3.5	4.7
Vertical stubble height (cm)	63.0	0.0–203.2	35.8	51.6	13.2–88.9	21.3	103.9	0.0–203.2	84.3	61.0
Laid over stubble height (cm)	54.6	0.0–203.2	37.3	51.8	0.0–88.9	22.6	101.9	0.0–203.2	86.1	54.6
Vertical cover (cm)	46.2	4.1–93.8	20.6	41.1	13.2–66.8	14.5	34.0	3.6–82.0	30.5	37.1
Depth of litter (cm)	0.5	0.0–5.1	0.8	0.8	0.0–5.1	1.0	3.6	0.0–3.8	3.6	5.3
Ground-cover class (1–6)										
Rush	1.1	1.0–6.0	1.7	0.0	0.0–6.0	1.5	0.8	0.0–0.0	0.0	0.0
Forb	2.4	1.0–6.0	1.7	1.7	0.0–6.0	1.7	1.5	0.0–5.0	1.8	2.7
Grass	2.2	1.0–6.0	1.7	3.2	0.0–6.0	2.0	0.8	0.0–5.0	1.5	2.4
Litter	0.8	1.0–6.0	1.3	1.2	0.0–5.0	1.3	2.6	0.0–5.0	1.5	2.7
Bare ground	0.7	1.0–6.0	1.3	0.4	0.0–4.0	0.9	1.0	0.0–6.0	1.7	0.1
Water	0.2	1.0–6.0	1.4	0.1	0.0–1.0	2.3	0.0	0.0–0.0	1.9	0.0

Habitat selection

First-order (landscape-scale) habitat selection. At the landscape scale, which represents the distribution of jumping mice at BANWR, jumping mice selected areas that were representative of riparian shoreline vegetation. Besides canal banks and water, the only vegetation associations selected were dominated by foxtail barley or narrowleaf willow, which are both wetland species. Jumping mice selected the *Hordeum jubatum* herbaceous temporarily flooded association. There are 4.6 ha of this association mapped on BANWR, of which 1.1 ha occurred within the distributional area (i.e., 192-m buffer) occupied by jumping mice. However, this association is likely underrepresented on the vegetation association map

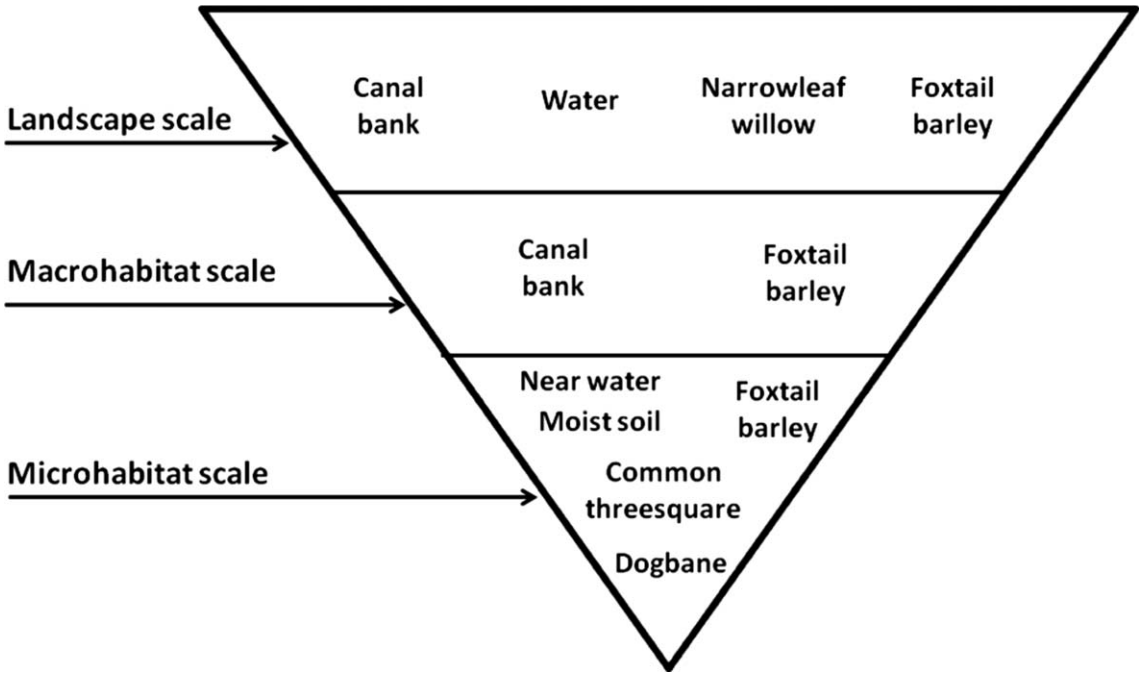

Figure 2. The nested hierarchy of habitat components selected by the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at three spatial scales at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. The landscape scale pertains to the distribution of jumping mice at Bosque del Apache National Wildlife Refuge (i.e., 192-m buffer around all telemetry locations), the macrohabitat scale pertains to features within the collective home ranges of all jumping mice, and the microhabitat scale pertains to features within 1 m of an active jumping mouse location.

because managed wetlands are capable of producing this association yet are mapped as "managed wetlands." The *Hordeum jubatum* herbaceous temporarily flooded association is found within emergent herbaceous wetlands that are temporarily flooded during spring (USFWS HAPET 2006). The association is composed almost entirely of graminoids with ground cover near 100%. It is dominated by foxtail barley but it may contain other riparian grasses that tolerate saline conditions such as saltgrass; shrubs are typically sparse or absent. The association grades to a saltgrass-dominated habitat on more saline soils, whereas it grades to Baltic rush on more frequently flooded areas, or to cattails and reeds *Phragmites* spp. on semipermanently flooded areas. It is therefore typically found on margins of managed wetlands at BANWR.

Jumping mice also selected the *Salix exigua* mesic graminoids shrubland association at the landscape scale. Over 150 ha of *Salix exigua* mesic graminoid shrubland occur at BANWR, of which nearly 7.6 ha occurred within the distributional area occupied by jumping mice. This association is common in the floodplain of the Rio Grande and it is described as temporarily flooded, occurring along pond margins and among temporarily flooded forest stands with alluvial soils (USFWS HAPET 2006). We almost never found jumping mice in association with stands of older, woody willows, which was the most common expression of this plant association at BANWR (personal observation). Rather, jumping mice were associated with regenerating (<3 y old) sapling narrowleaf willows that had lush understories of diverse herbaceous plants. Often, these areas were in a transitional edge habitat along the shores of canals and bordering temporarily inundated areas within managed wetlands. This suggests that stands of immature willows with a canopy sparse enough to allow sunlight to penetrate and promote a mesic herbaceous understory are important to jumping mice.

Second-order (macrohabitat) selection. The habitat components selected by jumping mice at the macrohabitat scale (i.e., in areas they were known to occur) represented a subset of the habitat components selected at the landscape scale. Each subpopulation exhibited significant macrohabitat selection for only one habitat component: the North subpopulation selected canal banks and the South subpopulation selected the *Hordeum jubatum* herbaceous temporarily flooded association. This probably was because each subpopulation selected the best developed herbaceous wetland habitat that was accessible. Both subpopulations used canal banks. The cumulative minimum convex polygon of the North subpopulation was for the most part linear along the Riverside Canal. The portion of this canal bank that jumping mice used most frequently contained a gentler slope and more moist soil than other reaches of the canal; also, the herbaceous vegetation was taller and more diverse than in unused habitats along the canal (personal observation). This corroborates conclusions by Morrison (1990) that manmade canals can provide important habitat for jumping mice.

In addition to canal banks, the South subpopulation also used a small area of herbaceous riparian habitat in association with semipermanent flowing water formed via irrigation flooding and a leak in an irrigation gate. This area was approximately 100 m long and 10 m wide, and was bordered on one side by a dense stand of narrowleaf willows and on the other side by woodland containing cottonwood, narrowleaf willow, and mule-fat. The rivulet contained tall herbaceous wetland vegetation dominated by foxtail barley. The winding nature of the rivulet created more shoreline habitat per linear meter than canals or drains of comparable length (personal observation).

Most habitat studies focus entirely on what habitats are selected. However, habitats that are available, yet routinely avoided, are equally as important in understanding habitat relations of a species. We found that drier vegetation associations were available to mice but were avoided completely. For instance, the *Prosopis glandulosa–Atriplex canescens* shrubland association occupied 5.7% of the North subpopulation's cumulative home range but was completely avoided by jumping mice, which suggests that this association is of little benefit to the New Mexico meadow jumping mouse.

Third-order (microhabitat) selection. The third-order habitat selection analyses defined microhabitat features selected by jumping mice from within the vegetation associations that were selected at the landscape and macrohabitat scale. Our analyses clearly illustrate significant selection for nearness to water, high soil moisture, and presence of specific obligate (common threesquare) and facultative (dogbane, foxtail barley) wetland plants. These microhabitat features are similar to those used by montane populations of the New Mexico meadow jumping mouse. In montane areas, however, the New Mexico meadow jumping mouse uses different plant associations. For instance, montane populations are often found in association with sedges of the genus *Carex* (Frey and Malaney 2009), whereas in our study they were often found near sedges of the genus *Schoenoplectus* (e.g., common threesquare), rushes, and dogbane. This difference can possibly be attributed to the lack of *Carex* spp. at our study location. The plants important to jumping mice provide food (foxtail barley, common threesquare) or provide important structure and cover (dogbane), which may reduce predation risk or buffer intraspecific interactions with other small mammals (Wright and Frey 2014).

Jumping mice were closely associated with tall, dense herbaceous vegetation and stands of young narrowleaf willows that contained a dense herbaceous understory. These habitat features are mainly the result of management actions that result in moist soil, temporary flooding, and infrequent yet regular disturbance (J. Vradenburg, BANWR, personal communication). That these microhabitats often coincided with canals may not be as much a function of surface water as it is of the habitats created by the water regime near the canal, as suggested by Cranford (1983). As evidenced by the presence of jumping mice in some managed wetlands, the specific suite of plants required to support jumping mice for at least a portion of the warm season can be produced in areas other than along canals, although all had moist soil. Periodic inundation, soil moisture, micro-

topography, and other ecological factors probably all contribute to the presence of microhabitats selected by the New Mexico meadow jumping mouse.

Important features for jumping mice at BANWR

Canals. Bosque del Apache National Wildlife Refuge has >50 km of canals, drains, and ditches that contain water either permanently or during a portion of the time when the New Mexico meadow jumping mouse is not hibernating. Because jumping mice selected canals, and yet had a restricted distribution on BANWR, we conclude that the limiting habitat feature is shoreline vegetation and not the canals themselves. We believe that the restricted distribution of jumping mice along these waterways is primarily a function of the influence of bank structure on shoreline vegetation, as well as management (e.g., mowing). Irrigation ditches lined with cement inhibit plant growth, and canals and drains with very steep banks produce only a narrow moist-soil zone that often is completely devoid of riparian plants. Well-developed riparian vegetation only occurred along canal reaches with gently sloped banks near water level that provide a broad moist-soil area. Such channels were limited in distribution during our study, yet existed in some places where jumping mice did not. Typically, these places were dominated by monotypic stands of mature woody narrowleaf willows and did not contain herbaceous shoreline vegetation.

Because the Middle Rio Grande is controlled by several dams and confined to within dikes, manmade canals serve a heightened importance to the New Mexico meadow jumping mouse. Hydrology and vegetation of the historical floodplain of the river has been greatly altered, such that it is now unlikely to provide suitable habitat for the New Mexico meadow jumping mouse in many areas. During our study, jumping mice were found along canals during the entire warm season. Similarly, many records of the New Mexico meadow jumping mouse from other sites on high-order rivers were from irrigation waterways (J.K. Frey, unpublished data). Canals may mimic the anabranching planform of historical unmodified river valleys that were created mainly through the activity of the American beaver *Castor canadensis* (Polvi and Wohl 2013).

Habitats associated with irrigation systems at BANWR have changed. When past studies of the New Mexico meadow jumping mouse were conducted in the late 1980s and early 1990s, it took water nearly 23 d to pass completely through BANWR from north to south via irrigation canals and drains; this slow passage was due to blockages in the irrigation system caused by beavers and dense vegetation (J. Vradenburg, personal communication). At that time jumping mice were more widely distributed along canals within BANWR than today. For instance, Morrison (1988) captured all of her jumping mice at BANWR along manmade waterways. However, since the early 1990s, water conveyance systems at BANWR have been modified to improve efficiency and water now travels directly through BANWR via canals and drains in as little as 12–18 h. One way the efficiency of water delivery has been improved is by dredging canals and drains. For instance, most of the jumping mice caught by Morrison (1988) were from riparian vegetation growing on level banks near water's edge along the Socorro Canal. However, the Socorro Canal since has been regularly cleaned and excavated and the banks have been cut steeper. Steep-banked canals have a nearly vertical bank of bare soil at the edge of the water, and hence provide little to no opportunity for development of riparian vegetation. During our study we did not observe suitable habitat for jumping mice anywhere on the Socorro Canal.

In addition to changes in the bank structure of irrigation waterways, there also has been a change in vegetation management along these waterways that has resulted in a reduction in dense herbaceous wetland vegetation. Over the past 2 decades, the usual management has been to frequently mow one side of the irrigation framework while the opposite side has been allowed to grow continuously (J. Vradenburg, personal communication). This management has produced an irrigation system dominated by two types of vegetation, neither of which is particularly desirable for the New Mexico meadow jumping mouse: 1) short (<30 cm tall) vegetation dominated by graminoids, or 2) decadent monotypic stands of narrowleaf willow.

Based on our data and observations, irrigation waterways with both appropriate bank structure and tall herbaceous riparian vegetation only existed along portions of an approximately 2.7-km reach of the Riverside Canal, which is where jumping mice persisted. Canals likely serve as both occupied habitat and dispersal corridors that allow jumping mice to reach other pockets of suitable habitat within managed wetland units. It is likely that the changes in bank structure and loss of herbaceous vegetation along canals has contributed to the reduced distribution and fragmented nature of the current population of jumping mice at BANWR.

Managed wetlands. Managed wetlands might be important to the New Mexico meadow jumping mouse at BANWR. Although managed wetlands were not selected by jumping mice more than expected, they were used in proportion to their availability at the macrohabitat scale. Managed wetlands represent a majority of the habitat available within the managed floodplain of BANWR and they are the focus of ongoing management plans. Management efforts of these units are strongly geared toward providing a large biomass of important food plants for waterfowl, such as rushes *Juncus* spp., sedges *Schoenoplectus* spp., and smartweed *Polygonum* spp.

We believe that managed wetlands with appropriate species composition are especially important to jumping mice in spring. During spring, Najera (1994) mainly captured jumping mice in wetland impoundments (Zwank et al. 1997). We also captured jumping mice in managed wetlands mainly during spring, but as late as 28 August. Common threesquare and spikerush were most prevalent in some managed wetland units, and we observed jumping mice eating the seeds of these plants (Wright and Frey 2014). Common threesquare and spikerush are among the first plants to emerge in spring at BANWR, and hence jumping mice might rely on these

plants as an important food source after emerging from hibernation (Wright and Frey 2014). Common threesquare produces the most seeds in late spring, although yields can continue into autumn (USDA NRCS 2014). As the growing season progressed, we observed that jumping mice transitioned from foraging on seeds of threesquare and spikerush to seeds of certain grasses (Wright and Frey 2014). Although we suspect that threesquare and spikerush are particularly important to jumping mice in spring, and these plants are most prevalent in wetland units, we do not believe that large monotypic stands of these plants would be particularly useful for jumping mice. The situations where we observed jumping mice using these plants were diverse, with these plants growing among other species such as dogbane that provided structure and cover (Wright and Frey 2014).

From the early 1990s until recently, managed wetlands on BANWR were laser-leveled. This reduces microtopographic relief, which decreases habitat heterogeneity and plant diversity (Van Dyke 2008). Variable microtopography within wetland units can provide dry retreats during high-water events and promote vegetation heterogeneity that might provide a more diverse selection of food plants and more complex cover stratum for jumping mice (personal observation). For instance, in one management unit, the only area extensively used by jumping mice was a several-hundred-square-meter section that had more topographical relief and a wider variety of plants than the rest of the unit. During a controlled flood event to reduce cockleburs within the management unit, jumping mice were observed to seek above-ground hummocks within the unit until water levels receded.

Management Implications

The conservation umbrella of management primarily focused on game species at BANWR has failed to provide enough of the specialized habitat components required by the New Mexico meadow jumping mouse. Consequently, this endemic habitat specialist has declined in distribution and abundance on BANWR. Multiple-scale habitat selection analyses revealed the importance of irrigation canals and other specific habitat features for jumping mice. Irrigation canals may serve as a proxy for anabranching channels that would have once been important to jumping mice and other early successional riparian species within the Middle Rio Grande Valley (Polvi and Wohl 2013). The population of New Mexico meadow jumping mice at BANWR is isolated and contains few individuals, and is therefore at a relatively high risk of extinction (Mills 2007). Because jumping mice have limited dispersal capabilities, we recommend that the population be provided an opportunity to expand in distribution and abundance by increasing the amount of suitable habitat in proximity to currently occupied sites. Gaps in suitable habitat larger than the 95% movement distance of jumping mice (i.e., 192 m) may hinder population expansion. Management that promotes foxtail barley and early seral stage narrowleaf willow habitats in proximity to flowing water could help expand distribution of jumping mice. We recommend that diverse herbaceous wetland vegetation be promoted along canals and drains and within adjacent managed wetlands. Along canals and drains, this might be accomplished, in part, by insuring 1) that canals have flat shorelines with relatively wide moist soil zone, 2) adequate water for growth of riparian plants, and 3) that short alternating sections of shoreline vegetation are periodically mowed to suppress woody vegetation and promote tall, diverse, herbaceous vegetation. In management units, diverse herbaceous wetland plant communities might be promoted by increasing topography, removing decadent woodlands, and creating perennial streams.

Supplemental Material

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Table S1. Number of telemetry locations and percent of total telemetry locations within each vegetation association available to the North subpopulation of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Abbreviations of vegetation associations are in Supplemental Table S3.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S1 (10 KB XLSX).

Table S2. Number of telemetry locations and percent of total telemetry locations within each vegetation association available to the South subpopulation of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Abbreviations of vegetation associations are in Supplemental Table S3.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S2 (9KB XLSX).

Table S3. Chi-square goodness-of-fit test (χ^2) for selection of vegetation associations at the macrohabitat scale by two subpopulations of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. The critical values ($\alpha = 0.05$) for the upper-tail one-sided test are 24.996 ($df = 15$) for the North subpopulation and 21.026 ($df = 12$) for the South subpopulation; significant selection is indicated with an asterisk (*). AB = Abbreviation of variable name.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S3 (11 KB XLSX).

Table S4. Descriptive statistics for the spatial-structural and significant ($\alpha = 0.01$) plant microhabitat variables at 480 telemetry locations of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* and 272 random locations at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. AB = Abbreviation of variable name.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S4 (13 KB XLSX).

Table S5. Model selection for the best spatial-structural model for microhabitat selection by the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Variable abbreviations are defined in Supplemental Table S4. Mallow's Cp scores and R^2 values represent model appropriateness and power, respectively.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S5 (9 KB XLSX).

Table S6. Model selection for the best plant species model for microhabitat selection by the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Variable abbreviations are defined in Supplemental Table S4. Mallow's Cp scores and associated R^2 values represent model appropriateness and power, respectively.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S6 (8 KB XLSX).

Table S7. Comparison of model performance for the global, plant species, spatial-structural, and best subset hypotheses for microhabitat selection by the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010. Statistics include number of model components (K), deviance, coefficient of determination (R^2), and Akaike's Information Criterion for small sample sizes (AIC_c). Abbreviations of variables are defined in Supplemental Table S4.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S7 (9 KB XLSX).

Table S8. Percent of monthly active telemetry locations for male (M) and female (F) New Mexico meadow jumping mice *Zapus hudsonius luteus* in National Vegetation Classification Standard (NVCS) cover classes at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S8 (9 KB XLSX).

Figure S1. Relationship between the 100% minimum convex polygon home-range size and the number of telemetry points obtained for the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S9 (2138 KB DOCX).

Figure S2. Representative photographs and aerial images of telemetry locations of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, 2009–2010. In the aerial images, each mouse is represented by a different color dot.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S9 (2138 KB DOCX).

Figure S3. Distances between two successive telemetry locations for male (black bars) and female (white bars) of the New Mexico meadow jumping mouse *Zapus hudsonius luteus* at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S9 (2138 KB DOCX).

Figure S4. Relative abundance (captures/100 trap-nights) of New Mexico meadow jumping mice *Zapus hudsonius luteus* and survey effort (trap-nights [TN] in boxes) during monthly survey sessions at Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S9 (2138 KB DOCX).

Text S1. Comparison of locations of occurrence of the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) during three studies on Bosque del Apache National Wildlife Refuge, New Mexico, 2009–2010.

Found at DOI: http://dx.doi.org/10.3996/062014-JFWM-044.S10 (11 KB XLSX).

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