Final Report Submitted to Sonoran Joint Venture (11-22-2008)

Montane Forest Birds in the Santa Catalina Mountains: Monitoring Population Trends and Reproductive Success and Examining Potential Limiting Factors for Breeding Populations

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ABSTRACT

We studied reproductive success and habitat associations of montane forest birds within 4 study sites located in high-elevation (>2,000 m) forests of the Santa Catalina Mountains, Arizona from 2004-2007. We focused our research on ground-nesting forest birds because they represent some of the most common bird species within our study system and provide high-quality data via easy access to nests during nest monitoring efforts. We also examined the effect of a recent wildfire on the montane forest bird community by determining population trends of montane forest birds following a wildfire that burned portions of our 4 study sites in 2003. The wildfire was a low- to moderate severity surface fire, so we concentrated our fire research on ground-nesting forest bird species, particularly red-faced warblers (*Cardellina rubrifrons*) and yellow-eyed juncos (*Junco phaeonotus*), because nests of these species were most likely to be affected by surface fire. We detected a total of 34 montane forest bird species during annual point-count bird surveys and red-faced warblers, cordilleran flycatchers (*Empidonax occidentalis*), yellow-eyed juncos, warbling vireos (V*ireo gilvus*), house wrens (*Troglodytes aedon*), western tanagers (*Prianga ludoviciana*), black-headed grosbeaks (*Pheucticus melanocephalus*), yellow-rumped warblers (*Dendroica coronata*), American robins (*Turdus migratorius*), and mountain chickadees (*Poecile gambeli*) were the 10 most frequently detected species. We found that yellow-eyed juncos, house wrens, black-headed grosbeaks, and mountain chickadees increased in relative abundance within our study area after the 2003 fire. A closer look at the ground-nesting bird species within our study area revealed that yellow-eyed juncos and red-faced warblers were the 2 most common ground-nesting birds and density of yellow-eyed juncos (1.2 males/ha) was twice as great as for red-faced warblers (0.6 males/ha). Compared to random sites, most red-faced warblers and yellow-eyed juncos selected nest-sites close (≤50 m) to drainage bottoms in stands of montane riparian forest characterized by more saplings and small trees (red-faced warblers), more shrubs and less canopy cover (yellow-eyed juncos), and more ferns, forbs, brush, and small woody debris (both species). Although red-faced warblers and yellow-eyed juncos nested in close association in montane riparian forest, the 2 species appear to coexist by selecting available nest-sites with different environmental features at both the macrohabitat and microhabitat scales. Compared to red-faced warblers, yellow-eyed juncos selected nest-sites at the macrohabitat scale with more ferns and logs and fewer white fir (*Abies concolor*) saplings and small trees and fewer large southwestern white pines (*Pinus strobiformis*). At the microhabitat scale, yellow-eyed juncos situated most nests adjacent to grass, whereas red-faced warblers situated nests adjacent to a

variety of plant species, but especially big-tooth maples (*Acer grandidentatum*), white firs, and Douglas-firs (*Pseudotsuga menziessi*). Both species avoided nesting in areas that were burned by a recent low-severity surface suggesting short-term negative effects of fire for breeding populations of red-faced warblers and yellow-eyed juncos. Moreover, daily nest survival declined substantially immediately following the Aspen wildfire for both yellow-eyed juncos and red-faced warblers. Montane riparian forest in the southwestern U.S. appears to provide important breeding habitats for red-faced warblers, yellow-eyed juncos, and numerous other montane forest bird species. However, little research or conservation planning has been directed toward montane riparian forest in the region, even though this forest type is limited in its areal extent (<1% of the total land mass in the Sky Island region of Arizona) and increasingly threatened by disturbances such as fire.

INTRODUCTION

High-elevation (>2,000 m) forests in the southwestern U.S. provide breeding habitats for a diverse assemblage of bird species. Two relatively common montane forest bird species, the red-faced warbler and yellow-eyed junco (*Junco phaeonotus*), are ground-nesting birds that breed in close association in the Sky Island Mountains of southeastern Arizona and active nests of both species have been observed as close as 2 m from one another (C. Kirkpatrick and C. Conway, unpublished data). Although the yellow-eyed junco is locally common (Phillips et al. 1964, Sullivan 1999), the status of the red-faced warbler is less certain (Martin and Barber 1995). Arizona Partners in Flight considers the red-faced warbler a "high priority" for conservation and ranks the species 34th out of 234 species on a list of birds of conservation concern in the state (Latta et al. 1999). We know relatively little about the factors influencing nest-site selection or nesting success for red-faced warblers or yellow-eyed juncos (but see Martin 1998, Sullivan 1999) or the mechanisms by which these 2 species partition available nest-sites. Acquiring this knowledge is important given that coexisting ground-nesting bird species can have profound ecological effects on one another (e.g., displacement from preferred nest-sites; Martin 1993, Martin and Martin 2001).

Populations of red-faced warblers, yellow-eyed juncos, and other montane forest bird species within the southwestern U.S. are vulnerable to disturbance because the area encompassed by high-elevation forests is only a fraction of the total landmass of the region. For example, high-elevation forests represent only 3% of the land area in the Sky Island region of Arizona (see results). Moreover, anecdotal observations (Bulmer 1966) and survey data from the Arizona Breeding Bird Atlas (Corman and Wise-Gervais 2005) indicate that the highest breeding densities of red-faced warblers, yellow-eyed juncos, and other montane forest bird species are concentrated in a relatively small number of steep-sided drainages within these high-elevation forests. The potential for disturbance to these important breeding areas appears to be increasing. For example, the frequency of extensive, often severe, wildfires has increased in montane forests of the southwestern U.S. (Swetnam et al. 1999) and wildfire is considered the greatest conservation concern for breeding populations of these red-faced warblers, yellow-eyed juncos, and numerous other montane forest bird species (Corman and Wise-Gervais 2005). Indeed, most of the high-elevation forests in the Santa Catalina Mountains burned during back-to-back wildfires in 2002 and 2003.

We studied the reproductive success and habitat associations of montane forest birds in 4 study sites located in high-elevation (>2,000 m) forests of the Santa Catalina Mountains, Arizona from 2004-2007. We focused our research on ground-nesting forest birds because they represent some of the most common bird species within our study system and provide high-quality data via easy access to nests during nest monitoring efforts (C. Kirkpatrick, personal observation). We also examined the effect of a recent wildfire on montane forest birds by determining population trends of montane forest birds following a wildfire that partially burned our 4 study sites in 2003. The wildfire was a low- to moderate severity surface fire, so we concentrated our fire research on ground-nesting forest bird species, particularly red-faced warblers (*Cardellina rubrifrons*) and yellow-eyed juncos (*Junco phaeonotus*), because nests of these species were most likely to be affected by surface fire. We estimated breeding densities of red-faced warblers and yellow-eyed juncos, identified environmental features associated with their nest-site selection (i.e., use vs. availability), and determined differences in nest-site selection between red-faced warblers and yellow-eyed juncos to account for mechanisms by which these species might partition available nest-sites. Finally, we examined whether recent wildfire may have affected nest-site selection and nesting success for breeding populations of red-faced warblers and yellow-eyed juncos. Taken together, these data can be used by managers to facilitate management and conservation of red-faced warblers, yellow-eyed juncos, and other montane forest birds in high-elevation forests of the southwestern U.S.

STUDY AREA

We conducted this study in high-elevation (>2,000 m) forests of the Santa Catalina Mountains, Pima County, Arizona, USA. The Santa Catalina Mountains are part of the Sky Island Mountains, a group of approximately 40 isolated mountain ranges scattered throughout the southwestern U.S. and northern Mexico. The Sky Island Mountains are part of the Sky Island Ecoregion; 1 of only 2 designated biodiversity hotspots in all of North America (Conservation International 2006). Climate in the region is arid or semi-arid but high-elevation forests in the Sky Island Mountains are cooler and wetter than surrounding deserts. Mean annual precipitation is 681 mm in the Santa Catalina Mountains (Brown 1994) with most precipitation falling during a brief summer season of localized thunderstorms (Jul-Aug) and during a longer winter season of widespread frontal storms (Nov-Mar).

We located 4 study sites in the Santa Catalina Mountains within 3 steep-sided drainages situated in a 20-km^2 area between the 2 highest summits in the range, Mount Lemmon (2,791 m) and Mount Bigelow (2,606 m). We placed study sites in upper Bear Wallow Canyon (2,422 m), lower Bear Wallow Canyon (2,367 m), Marshall Gulch (2,319 m), and Sabino Canyon (2,488 m). Study sites were 200 x 1,000 m in size (Sabino Canyon was 200 x 1,200 m) and were situated along drainage bottoms. The 34,300-ha Aspen wildfire burned most high-elevation forests in the Santa Catalina Mountains including portions of our study area in late June 2003.

Our study sites contained stands of both Madrean montane conifer forest (Forest Formation 122.3; ponderosa pine [*Pinus ponderosa*], aspen [*Populus tremuloides*] subclimax, and mixed-conifer communities) and Rocky Mountain montane riparian forest (henceforth "montane riparian forest"; Brown 1994). Common overstory trees included Douglas-fir (*Pseudotsuga menziessi*), white fir (*Abies concolor*), ponderosa pine, and southwestern white pine (*Pinus strobiformis*). Common understory trees included the above listed species as well as New Mexican locust (*Robinia neomexicana*), big-tooth maple (*Acer grandidentatum*), and Gambel oak (*Quercus gambelii*). Common shrubs included mountain snowberry (*Symphoricarpos oreophilus*), fivepetal cliffbush (*Jamesia americana*), New Mexican raspberry (*Rubus* *neomexicana*), and orange gooseberry (*Ribes pinetorum*). Grass (principally *Muhlenbergia* spp.), bracken (*Pteridium aquilinum*), and various forb species comprised the ground cover.

METHODS

Bird Surveys and Nest Monitoring: In 2002, we established a point-count bird survey route bisecting each of the 4 study sites with point-count stations located every 200 m (starting 100 m from the end of each study site) along drainage bottoms. We conducted 1 bird survey along each survey route in late May or early June from 2002-2007 to coincide with the peak breeding of red-faced warblers, yellow-eyed juncos, and other montane forest birds in southeastern Arizona (Corman and Wise-Gervais 2005). One observer (C. Kirkpatrick) conducted the majority (>90%) of bird surveys to reduce the potential for observer bias. Observers began each bird survey 15 minutes after sunrise on days without precipitation and with wind speeds <19 kph.

After arriving at each survey point, observers waited 1 minute and then began a count of all birds heard or seen during a 6-minute survey period. For each bird detected, the observer recorded the species and detection type (song, call or visual), the minute during the 6-minute survey when the bird was first detected, and the distance (m) from the survey point to the bird (measured using an infrared rangefinder whenever possible). We estimated relative abundance for most bird species but used distance data to estimate density of red-faced warblers and yellow-eyed juncos (Buckland et al. 2003). We used detection histories generated from data on when each red-faced warbler and yellow-eyed junco was first detected by song during surveys to estimate P_{sings} (i.e., the probability that a bird within the survey area sings; sensu Farnsworth et al. 2002).

We monitored nests of red-faced warblers, yellow-eyed juncos, and 3 other ground-nesting bird species (Table 1) in each of the 4 study sites every 2-3 days from sunrise until early-afternoon from late April to early July from 2004-2007. We followed standardized nest searching and monitoring protocols to reduce disturbance to adults and young at nests (Martin and Geupel 1993). We collected Universal Transverse Mercator (UTM) coordinates of nest locations using a hand-held Global Positioning System (GPS) receiver. Our study sites were large, so we made an effort to search the entire area within each site at least once per week.

Habitat Associations: We derived our protocol for sampling environmental features from the BBIRD nest monitoring program (Martin et al. 1997). Following the completion of a red-faced warbler or yellow-eyed junco nesting attempt in 2004 or 2005, we sampled environmental features at 2 spatial scales around each nest (Table 2): 1) microhabitat scale (i.e., at the nest), and 2) macrohabitat scale (i.e., within a 5- and an 11.3-m radius plot centered on the nest). We sampled environmental features in a similar manner at a total of 70 sites distributed randomly across our 4 study sites in 2004 (henceforth “random sites”). To avoid disturbing active nests, we sampled environmental features at nests after the nesting attempt was complete. We sampled environmental features at nests beginning in June and ending in early September, an average of 60 days (range 7-148 days) after most nesting attempts had been initiated. We sampled environmental features at random sites during the same time period to reduce bias in the timing of our sampling. We also imported UTM coordinates for nest-sites and random sites into ArcView GIS to measure distances (m) of nest- and random sites to the closest drainage bottom.

Effects of Recent Fire: We compared estimates of relative abundance for montane forest birds before (2003) and after (2004-2007) the 2003 wildfire using data collected during point-count bird surveys. For red-faced warblers and yellow-eyed juncos, we also estimated the percent surface area burned and the dominant burn severity class (e.g., less-severe or severe; Kirkpatrick et al. 2006) within the 11.3-m radius plot at each nest-site or random site affected by the 2003 wildfire. We mapped the extent of burn within each study site by walking along the edge of the burn while recording UTM coordinates using a GPS receiver. We imported these UTM coordinates into ArcView Geographic Information System (GIS) 3.2 software (Environmental Sciences Research Institute 1999) to calculate the percent area burned within each study site. We also compared estimates of post-fire nesting success with pre-fire estimates of nesting success collected during a pilot study in 2002 and 2003.

Areal Extent of Montane Riparian Forest: We estimated areal extent of montane riparian forest in high-elevation forests of the Santa Catalina Mountains, and within the entire Sky Island region of Arizona by first estimating the width of montane riparian forests within each of our 4 study sites. Because big-tooth maple is a signature riparian tree of montane riparian forests in southern Arizona (Szaro 1989), we estimated the width of montane riparian forest by using an infrared rangefinder to measure the distance (m) across the drainage that encompassed the extent of big-tooth maple growth at each bird survey point in each study site. In ArcView GIS, we used the average width of montane riparian forest in our study area to buffer all stream channels within Madrean montane conifer forest in the Santa Catalina Mountains and calculate the percentage of montane riparian forest within Madrean montane conifer forest in this mountain range.

To extrapolate to the entire Sky Island region of Arizona, we first used ArcView GIS to estimate the areal extent of Madrean montane conifer forest and Rocky Mountain forest subalpine conifer forest (another high-elevation forest type found in other mountain ranges in Arizona; Forest Series 121.3; Brown 1994) within the Sky Island region of Arizona, a 1,478,616-ha area delineated by The Nature Conservancy (2005). We multiplied the total area of these high-elevation forests by the estimated percentage of montane riparian forest in the Santa Catalina Mountains to calculate areal extent of montane riparian forest throughout the entire Sky Island region of Arizona.

Statistical Analysis: To examine the effect of fire on montane forest birds, we compared estimates of relative abundance before (2003) and after (2004-2007) the 2003 wildfire using a one-way repeated measures ANOVA. We included only species in these analyses for which we detected >50 birds total during surveys and we report results for species with P-values <0.05 for F statistics. Because we lacked spatial controls, inferences from our results are limited to describing trends in relative abundance after fire that may or may not be attributable to the fire itself. We also used Program DISTANCE (Thomas et al. 2006) to calculate densities of singing male red-faced warblers and yellow-eyed juncos (averaged for 2005 and 2006) and we adjusted these density estimates using an estimate of P_{sings} generated in Program CONTRAST (Rexstad and Burnham 1991). Previous authors have recommended combing analytical methods to account for various components of detection probability (i.e., P_{sings} and P_{detect}; Farnsworth et al. 2001).

For the red-faced warbler and yellow-eyed junco habitat analysis, we screened all data and eliminated most variables for which >90% of values were equal to zero before running analyses. We retained some highly correlated variables for which >90% of values were equal to zero by combining these variables into 1 (e.g., small and large ponderosa pine saplings; Appendix A). We tested the data for multivariate outliers by calculating Mahalanobis distances and applied transformations (e.g., square root +1, log10 +1, logit, rank) to variables to control outliers where necessary (Morrison et al. 1998, Meyers et al. 2006). We used exploratory factor analysis to reduce our large sets of continuous explanatory variables to smaller sets of uncorrelated factors for use in subsequent logistic regression analyses (Meyers et al. 2006). We retained factors with eigenvalues ≥1 and used a varimax rotation to facilitate interpretation of factor weights (Meyers et al. 2006).

We identified 13 factors (from 38 continuous variables) for the red-faced warbler use versus availability analysis, 10 factors (from 34 continuous variables) for the yellow-eyed junco use versus availability analysis, and 14 factors (from 45 continuous variables) for the red-faced warbler versus yellow-eyed junco nest-site analysis (Appendix A). These 3 sets of factors retained 71%, 68%, and 70% of the variability within our data sets, respectively. Results from Kaiser-Meyer-Olkin tests were >0.70 for all 3 factor analyses, indicating that our data were suitable for factor analysis (Meyers et al. 2006). For each factor, we report variables with factor weights ≥0.45 (indicating that ≥20% of the variance in the variable was accounted for in the factor), but named factors based on factor weights ≥0.55 (indicating that ≥30% of the variance in the variable was accounted for in the factor).

We ran 3 stepwise logistic regressions using SPSS PROC NOMEG (SPSS, Inc. 2007) with the binary response variable being either 1) used versus random sites for red-faced warblers, 2) used versus random sites for yellow-eyed juncos, or 3) red-faced warbler versus yellow-eyed junco nest-sites. The red-faced warbler versus yellow-eyed junco nest-site analysis allowed us to compare microhabitat-scale environmental features at nest-site (e.g., nest area concealment, closest plant to nest; Table 2) for both species that we did not record at random sites. For our explanatory variables, we used factor scores generated from factor analyses (Appendix A) and dummy variables for our nominal variable "closest plant to nest". We collapsed some highly-correlated levels (e.g., Douglas fir and white fir, fern and forb) within our nominal variable "closest plant to nest" to reduce sparse cells in the variable. In addition to these explanatory variables, we controlled for the potentially confounding influence of study site, year of data collection, nest initiation date, and lag-time in vegetation sampling (i.e., days between nest initiation and sampling) by including these variables in our multivariate analyses where appropriate.

We used a backward stepwise procedure to fit candidate models and used liberal criteria for variable inclusion ($P \leq 0.25$) and retention ($P \leq 0.30$) because of the exploratory nature of our analyses (Hosmer and Lemeshow 2000). We chose stepwise variable-selection instead of model selection based on information-theoretic methods (Burnham and Anderson 2002) because variable selection is considered a valid approach when considering are a large number of potential explanatory variables (e.g., ≥35 in our study; Hosmer and Lemeshow 2000, Stephens et al. 2005, Steidl 2007). For similar reasons, we did not include interaction terms in our models. When discussing our results, we considered odds ratios <0.66 (i.e., approx. 50% decrease) and >1.50 (i.e., approx. 50% increase) to indicate biologically significant effects.

We also conducted univariate analyses on the 5 microhabitat variables that we recorded at nests of red-faced warblers and yellow-eyed juncos (Table 2) given the importance of microhabitat-scale environment features to ground-nesting birds in Arizona (Martin 1998). We used independent samples *t*-tests for continuous variables and contingency table analyses for the nominal variable. We used a Bonferonni adjustment to keep the experiment-wise error rate at alpha <0.05 and we report results of univariate tests for which we detected differences (based on our a priori alpha level).

To evaluate red-faced warbler and yellow-eyed junco nesting success, we estimated daily nest survival and nesting success (incubation through nestling periods; Mayfield 1961, 1975) for red-faced warblers and yellow-eyed juncos using a subset of nests with known fates from 2004-2007 and compared daily nest survival for red-faced warblers and yellow-eyed juncos using a *Z*-test (Hensler and Nichols 1981). We also compared estimates of post-fire nesting success with pre-fire estimates of nesting success collected during a pilot study in 2002 and 2003.

RESULTS

Bird Surveys and Nest Monitoring: We detected a total of 34 montane forest bird species during annual point-count bird surveys and red-faced warblers, cordilleran flycatchers (*Empidonax occidentalis*), yellow-eyed juncos, warbling vireos (V*ireo gilvus*), house wrens (*Troglodytes aedon*), western tanagers (*Prianga ludoviciana*), black-headed grosbeaks (*Pheucticus melanocephalus*), yellow-rumped warblers (*Dendroica coronata*), American robins (*Turdus migratorius*), and mountain chickadees (*Poecile gambeli*) were the 10 most frequently detected species. We detected relatively few Grace's Warbler's, a species of conservation concern in the southwestern U.S. (Rich et al. 2004). This species appears to be more common at slightly lower elevations in the Santa Catalina Mountains (C. Kirkpatrick, personal observation).

We found that red-faced warblers and yellow-eyed juncos were the 2 most common ground-nesting birds within our study area based on the density of singing males detected during May/June surveys and the total number of nests located during the breeding season (Table 1). Density of yellow-eyed juncos was greater than density of red-faced warblers and we found more red-faced warbler than yellow-eyed junco nests because these nest were generally easier to find (93% located using parental behavior cues vs. 1% by flushing birds) compared to yellow-eyed junco nests (33% located using parental behavior cues vs. 53% by flushing birds).

Yellow-eyed juncos initiated nests as early as 11 April and as late as 1 July; whereas, red faced warbler initiated nests as early as 4 May and as late as 19 June. Nest depredation accounted for 92% of all nest failures; 89% for red-faced warblers and 98% for yellow-eyed juncos. Estimates of daily nest survival and nest success were 0.922 (95% CI = 0.904-0.940) and 13% for red-faced warblers and 0.936 (95% CI = 0.919-0.953) and 19% for Yellow-eyed Juncos, respectively. We were unable to detect a difference in daily nest survival between the 2 species ($Z = 1.1$, $P = 0.282$).

Habitat Associations: Most (≥85%) nest-sites of both species were located <50 m from drainage bottoms (Fig. 1). Average distance of a red-faced warbler and yellow-eyed junco nest from the closest drainage bottom was 26.2 m (SD = 23.2 m) and 21.4 m (SD = 17.3 m), respectively. All nests were situated on the ground except for 2 yellow-eyed junco nests located 10 and 6 m above the ground in white fir trees.

For red-faced warblers, the logistic regression use vs. availability analysis produced a model (Table 3) that was a statistically significant improvement over the intercept only model ($\chi^2 = 131$, df = 10, $P < 0.001$). Overall predictive success was high (85%) with a 92% correct classification rate for red-faced warbler nest-sites and a 71% correct classification rate for random sites. A total of 10 factors were statistically significant predictors of nest-site selection for red-faced warblers. Positive associations were strong (odds ratios >1.50) for 6 factors: 1) brush cover, Gambel oak saplings and small trees, and small woody debris cover; 2) fern and forb cover; 3) big-tooth maple saplings and small trees; 4) New Mexican locust saplings and small trees; 5) southwestern pine trees large; and 6) Douglas-fir and white fir saplings and small trees. Negative associations were strong (odds ratios <0.66) for 2 factors: 1) area burned and snags; and 2) white fire large trees.

For yellow-eyed juncos, the logistic regression use vs. availability analysis produced a model (Table 3) that was a statistically significant improvement over the intercept only model ($\chi^2 = 91$, df = 7, $P < 0.001$). Overall predictive success was high (82%) with a 79% correct classification rate for yellow-eyed junco nest-sites and an 84% correct classification rate for random sites. A total of 7 factors were statistically significant predictors of nest-site selection for yellow-eyed juncos. Positive associations were strong for 3 factors: 1) small woody debris cover, brush cover, and mountain snowberry shrubs; 2) forb cover, fern cover, and close to drainage bottom; and 3) log cover. Negative associations were strong for 2 factors: 1) canopy cover and white fire large trees; and 2) snags and area burned.

The logistic regression use vs. availability analysis comparing red-faced warbler and yellow-eyed junco nest-sites produced a model (Table 3) that was a statistically significant improvement over the intercept only model ($\chi^2 = 82$, df = 16, $P < 0.001$). Overall predictive success was high (82%) with an 93% correct classification rate for red-faced warbler nest-site and an 57% correct classification rate for yellow-eyed junco nest-site. A total of 8 factors and 3 variables (1 nominal and 2 nuisance) were statistically significant predictors of a yellow-eyed junco nest-site compared to a red-faced warbler nest-site. Positive associations were strong for 1 factor: fern cover and log cover. Negative associations were strong for 3 factors: 1) closest plant to nest (Douglas fir or white fir sapling or tree); 2) white fir saplings and small trees; and 3) southwestern white pine trees large.

Univariate analyses revealed that yellow-eyed junco nest-sites had greater nest area concealment from the side (56%) compared to red-faced warbler nest-sites (46%; $t = 2.91$, df = 214, $P = 0.004$). The closest plant to nests for most red-faced warbler and yellow-eyed junco nests was grass (Fig. 2). However, relative to yellow-eyed junco nests, red-faced warbler nests were situated less frequently adjacent to grass (26% vs. 55%) and more frequently adjacent to big-tooth maple (15% vs. 3%) or white fir/Douglas-fir (16% vs. 3%) saplings and trees ($\chi^2 = 29.5$, df = 6, $P < 0.001$).

Effects of Recent Fire: Yellow-eyed juncos, house wrens, black-headed grosbeaks, and mountain chickadees increased in relative abundance within our study area after the 2003 fire (Figs. 3a-d). We found that daily nest survival of red-faced warblers and yellow-eyed juncos declined precipitously following the 2003 Aspen wildfire but appeared to be returning toward pre-burn levels (at least for yellow-eyed juncos) by the end of he study (Fig. 4). Both red-faced warblers and yellow-eyed juncos avoided nest-sites in areas that burned during the 2003 wildfire (Table 3). Most (84%) nest-sites and random sites that were burned to some extent were affected by low-severity surface fires. All told, the wildfire burned 0% of the upper Bear Wallow Canyon, 10% of the lower Bear Wallow Canyon, 26% of the Sabino Canyon, and 70% of the Marshall Gulch study sites. We found that the typical burn pattern within each of the 3 burned study sites was that forests burned more extensively on slopes above drainages (perhaps because the more mesic conditions found in the drainage bottoms acted as a fire barrier; Fitzhugh et al. 1987). We considered the possibility that the spatial pattern of the wildfire may have biased nest-site selection by red-faced warblers and yellow-eyed juncos by forcing birds to select nest-sites lower in drainages in areas of unburned montane riparian forest. However, our models were similar when we re-ran analyses after removing data from the 1 extensively-burned study site (Marshall Gulch).

Areal Extent of Montane Riparian Forest: Average width of montane riparian forest within our study sites was 55.5 m (SD = 35.6 m). Of the 5,831 ha of Madrean conifer forest in the Santa Catalina Mountains, we estimated that approximately 602 ha (10%) of this forested area contained montane riparian forests. Total areal extent of Madrean conifer forest and Rocky Mountain subalpine conifer forest in the entire Sky Island region of Arizona was 43,504 ha (3%) and 1,549 ha (0.1%), respectively. Of the 45,053 ha of high-elevation forest in the entire Sky Island region, we estimated that approximately 4,641 ha of this forested area contained montane riparian forest. Overall, we estimated that montane riparian forest covered approximately 0.3% of the entire Sky Island region of Arizona.

DISCUSSION

Bird Surveys and Nest Monitoring: We detected numerous species of montane forest birds during annual point-count bird surveys within our study area and found that yellow-eyed juncos and red-faced warblers were 2 of the most common montane forest bird species and the 2 most common ground-nesting bird species breeding within high-elevation, steep-sided drainages of the Santa Catalina Mountains, Arizona, USA. Although orange-crowned warblers, Virginia's warblers, and spotted towhees also nested within our study area, these ground-nesting birds were relatively uncommon because these birds tend to breed in greater numbers at lower elevations (e.g., spotted towhee, Virginia's warblers; Corman and Wise-Gervais 2005) or at higher latitudes (e.g., orange-crowned warbler, Virginia's warbler; Sogge et al. 1998, Olson and Martin 1999). In fact, our records of nesting orange-crowned warblers represent the most southerly breeding population of this species in Arizona. Given the relative absence of other ground-nesting bird species, yellow-eyed juncos and red-faced warblers were the 2 species most-likely to interact ecologically for critical resources such as nest-sites within our study area (Martin and Martin 2001).

Red-faced warblers appeared to be the most common ground-nesting bird within our study area based on relative abundance and number of nests found. However, density of yellow-eyed juncos (1.2 males/ha) was twice as great as for red-faced warblers (0.6 males/ha). Two factors explain this discrepancy: 1) we detected fewer yellow-eyed juncos during point-count surveys because juncos were more difficult to detect aurally (e.g., P_{sings} was lower) than red-faced warblers; and 2) we found fewer yellow-eyed junco nests because junco nest were generally harder to find than red-faced warbler nests. Nevertheless, our density estimates for red-faced warblers and yellow-eyed juncos were similar to those reported previously for red-faced warblers in snow-melt drainages on the Mogollon Rim, Arizona (0.7-2.0 males/ha; Martin and Barber 1995) and for yellow-eyed juncos in southern Arizona (1.4 males/ha; Sullivan 1999). These results highlight the importance of accounting for detection probability during survey and nest monitoring efforts (Pendleton 1995, Conway and Simon 2003).

Habitat Associations: Red-faced warblers selected nest-sites at the macrohabitat scale with a greater number and diversity of saplings and small trees (e.g., Gambel oak, big-tooth maple) and more large southwestern white pines compared to random sites. Selection of nest-sites with these trees may enhance foraging opportunities because red-faced warblers in Arizona forage close to the ground in deciduous trees (Marshall 1957), big-tooth maples (Martin and Barber 1995), and medium to large southwestern white pines (Franzreb and Franzreb 1983) among other species. Similar to previous studies (Moore 1972, Martin 1998, Sullivan 1999, Short 2003), both red-faced warblers and yellow-eyed juncos selected nest-sites at the macrohabitat scale with more ground cover (especially ferns and forbs) and both species selected nest-sites with more small-woody debris compared to random sites. Yellow-eyed juncos are known to favor nest-sites with coarse woody debris that they use to conceal nests (Short 2003). In addition, yellow-eyed juncos selected nest-sites at the macrohabitat scale with more mountain snowberry shrubs and less canopy cover compared to random sites (junco territories usually contain some open areas; Sullivan 1999).

Red-faced warblers and yellow-eyed juncos selected nest-sites across the moisture gradient within our study area (i.e., from mesic drainage bottoms to xeric ridge tops). However, most nests of both species were situated close (<50 m) to drainage bottoms. Many of the environmental features that we found positively associated with nest-site selection for red-faced warblers and yellow-eyed juncos are typical of montane riparian forest located within drainage bottoms. For example, montane riparian forests support a compositionally- and structurally-diverse mix of shorter deciduous and taller coniferous trees, with the dominant aspect of this forest type being one of "shrubbery" (i.e., an increased presence and extent of saplings and shrubs [including mountain snowberry] in the understory; Whittaker and Niering 1975, Fitzhugh et al. 1987, Brown 1994). Montane riparian forests also support a rich herb layer of grasses, ferns, and forbs (Whittaker and Niering 1975, Fitzhugh et al. 1987, Szaro 1989). In contrast, adjacent mixed-conifer forest typically contains large trees with a dense canopy and extensive litter accumulation; factors that tend to restrict growth of shrubs, saplings, and forbs in the understory (Whittaker and Niering 1975, Brown 1994). Similarly, adjacent ponderosa pine forest also lacks an extensive understory of shrubs and saplings (Brown 1994).

Our results suggest that red-faced warblers and yellow-eyed juncos preferentially selected nest-sites in montane riparian forest because surrounding forest types lacked many of the proximate structural (e.g., presence of shrubs and saplings) and compositional (e.g., diversity of tree species and ground cover) cues that promote settlement and nest-site selection by breeding birds. Ultimately, food availability may drive selection of nest-sites in montane riparian forest. Indeed, montane riparian forests in the Santa Catalina Mountains have one of the highest rates of net primary productivity (1,123g/m^2 aboveground) of any forest type within this mountain range (Whittaker and Niering 1975). Conversely, nest depredation may ultimately drive selection of nest-sites by red-faced warblers and yellow-eyed juncos within our study area. We found that nest depredation was the leading cause of nest failure for both red-faced warblers and yellow-eyed juncos (pattern that has been reported for red-faced warblers and other ground-nesting bird species in the southwestern U.S.; Martin 1992, Martin and Martin 2001) and use of preferred nest-sites is associated with decreased nest depredation and increased nesting success in ground-nesting birds (Martin 1998).

Compared to red-faced warblers, yellow-eyed juncos selected nest-sites at the macrohabitat scale with more ferns and logs and fewer white fir saplings and small trees and fewer large southwestern white pines. At the microhabitat scale, yellow-eyed juncos situated most nests adjacent to grass, whereas red-faced warblers situated nests adjacent to big-tooth maples, white firs, and Douglas-firs. Previous studies have reported selection of these plant species at the microhabitat scale by yellow-eyed junco in montane forests of southeastern

Arizona (Moore 1972, Short 2003) and for red-faced warblers in snow-melt drainages on the Mogollon Rim, Arizona (Martin 1993, Martin 1998). Moreover, selection of firs by red-faced warblers and selection of big-tooth maples by other ground-nesting birds (e.g., orange-crowned warblers) at the microhabitat scale is associated with reduced nest depredation and increased nesting success in these species (Martin et al. 1998, Martin and Martin 2001). Thus, red-faced warblers and yellow-eyed juncos may reduce nest-site overlap (and increased nest depredation; Martin and Martin 2001) and coexist within our study area by selecting nest-sites with different environmental features at the macrohabitat and especially the microhabitat scales.

However, we observed several instances in which yellow-eyed juncos built nests in the exact locations of red-faced warbler nests from previous years and we observed 1 instance of a yellow-eyed junco building a nest in the exact site where a red-faced warbler had been observed building a nest several days before (C. Kirkpatrick, personal observation). In addition, yellow-eyed juncos often chase and fight with red-faced warblers early in the breeding season (Sullivan 1999; C. Kirkpatrick, personal observation). These observations suggest some degree of competition between red-faced warblers and yellow-eyed juncos for nest-sites, nearby food, or territories. If these 2 species compete for nest-sites, yellow-eyed juncos may dominate physically and behaviorally because of their larger size ($\bar{x}$ = 20 g vs. $\bar{x}$ = 10 g; Martin and Barber 1995, Sullivan 1999) and their ability to arrive on the breeding grounds, establish territories, and initiate nesting attempts earlier in the breeding season compared to red-faced warblers (11 Apr vs. 4 May). Indeed, yellow-eyed juncos placed nests slightly lower in drainages, had an average of 23% more vegetation concealing nests from the side, and exhibited a trend toward having higher nesting success than red-faced warblers (although the difference was not statistically significant).

Effects of Recent Fire: We found that 4 species of montane forest bird (black-headed grosbeak, house wren, mountain chickadee, and yellow-eyed junco) increased in relative abundance within our study area following the 2003 wildfire. Because we lacked spatial controls, inferences from our results are limited to describing trends in relative abundance for these species after fire that may or may not be attributable to the fire itself. However, previous research has shown that both house wrens (Kirkpatrick et al. 2006) and mountain chickadees (Horton 1987) increase in abundance within burned areas following fire in high-elevation forests of southern Arizona.

We found that red-faced warblers and yellow-eyed juncos avoided nest-sites in areas that burned during a predominantly low-severity surface fire in 2003. Low-severity surface fires can temporarily reduce the abundance of herbs, brush, small woody debris, logs, shrubs, and saplings (Artman et al. 2001, Short 2003), environmental features that were positively associated with nest-site selection by red-faced warblers or yellow-eyed juncos. Although red-faced warblers and yellow-eyed juncos avoided burned areas in the short term, low-severity surface fires may improve long-term habitat quality for both species by encouraging the growth of understory vegetation including grasses, forbs, ferns, shrubs and saplings (Short 2003). Indeed, yellow-eyed junco nesting success declined 77% 1 year after a low-severity surface fire in southern Arizona, but increased in the second year post-fire as preferred microhabitat of grass and ferns increased (Short 2003). Fire data are lacking for red-faced warblers, but red-faced warblers declined substantially or vanished altogether following logging on their breeding grounds (Franzreb 1977, Szaro and Balda 1979), suggesting that fires that are severe enough to remove understory and overstory vegetation are likely to have a negative effects on red-faced warblers.

Besides limiting the availability of nest-sites, the 2003 wildfire may have reduced nesting success of red-faced warblers and yellow-eyed juncos indirectly by increasing nest depredation within our study area. Indeed, we found that daily nest survival of red-faced warblers and yellow-eyed juncos declined precipitously following the 2003 Aspen wildfire, although daily nest survival appeared to be returning to pre-burn levels (at least for yellow-eyed juncos) by the end of he study (Fig. 4). Ground-nesting birds that nest in recently burned forests often place their nests in remaining undisturbed habitat (Aquilani et al. 2000) and may be more susceptible to nest depredation if predators have to search fewer potential nest locations before finding a nest (Best 1979). Thus, nests placed in unburned vegetation surrounded by large areas of burned vegetation (as in our study) may be particularly susceptible to nest depredation (Short 2003).

Areal Extent of Montane Riparian Forest: Montane riparian forest is rare within the Santa Catalina Mountains and likely makes up a very small percentage (<1%) of the land area within the entire Sky Island region of the southwestern U.S. Previous authors have commented on the rarity of montane riparian forest in the region (Fitzhugh et al. 1987) and our estimates corroborate these statements. In addition, our estimates are likely biased high because our 4 study sites were located within 3 of the largest drainages in the Santa Catalina Mountains (many of the other drainages in this mountain range were burned during the 2003 Aspen wildfire, precluding a random sample of drainages for this analysis).

MANAGEMENT IMPLICATIONS

Although red-faced warblers and yellow-eyed juncos breed across a range of elevations (approx. 1,600-2,800 m) in the southwestern forests, our results provide some of the first quantitative data (see also Martin 1998) to support observations that red-faced warblers and yellow-eyed juncos obtain high breeding densities in and select environmental features associated with high-elevation, montane riparian forests (Bulmer 1966, Martin and Barber 1995, Corman and Wise-Gervais 2005). Thus, persistence of healthy populations of red-faced warblers and yellow-eyed juncos may depend on maintaining and conserving montane riparian forest within high-elevation forests in the region. Similar spatial patterns of nest-site selection have been observed for other species of montane forest birds in the southwestern U.S. (e.g., orange-crowned warbler [*Vermivora celata*; Sogge et al. 1994]) highlighting the need to manage and conserve these important breeding areas for the benefit of multiple bird species. Additional research is needed to identify the specific environmental features associated with fitness (e.g., nesting success; Martin 1993, Morrison et al. 1998) at nest-sites of red-faced warblers and yellow-eyed juncos To this end, our results can be used during future research to inform candidate models (Stephens et al. 2005) to compare environmental features associated with successful and unsuccessful nests.

Bird communities in low-elevation riparian forests of the southwestern U.S. have been the focus of substantial research and conservation (Ohmart 1994, Skagen et al. 1998, Krueper et al. 2003). In contrast, comparatively little research and conservation planning has been directed toward bird communities in montane riparian forests of the southwestern U.S. (but see Martin 1993). This is surprising given 1) the designation of high-elevation forests of the Sky Island Ecoregion as a global hotspot of biodiversity (Conservation International 2006), 2) the presence of species of conservation concern (e.g., red-faced warblers and Grace's warbler; Latta et al. 1999, Rich et al. 2004) in these high-elevation forests, and 3) the perceived importance of montane riparian forest within high-elevation forests to wildlife (Fitzhugh et al. 1987).

Moreover, areal extent of montane riparian forest is extremely limited in the southwestern U.S., comprising <1% of the total land area within the Sky Island region of Arizona. Given the potential increase in disturbance (e.g., wildfire) to montane riparian forest, we recommend that managers seek to control negative effects of disturbance on concentrated breeding populations of red-faced warblers, yellow-eyed juncos, and other montane forest bird species by prioritizing the protection of montane riparian forest in the region.

ACKNOWLEDGMENTS

The Sonoran Joint Venture, the Arizona Bird Conservation Initiative, the U.S. Fish and Wildlife Service, T & E, Inc, and the University of Arizona provided funding. M. H. Ali, S. B. Cariss, D. Holstein-Radin, D. D. LaRoche, A. M. Purdy, E. T. Rose, D. Tracey, and A. Westling-Douglass assisted with field work, J. Taiz (U.S. Forest Service Coronado National Forest) provided logistical support, M. H. Ali helped with data processing, and M. Borgstrom (University of Arizona) assisted with statistical analyses. R. L. Peterson and the University of Arizona Steward Observatory provided field housing.

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Table 1. Average relative abundance, average density, P_{sings}, adjusted density, and total number of nests of 5 ground-nesting bird species found breeding within 4 study sites in high-elevation forests of the Santa Catalina Mountains, Arizona, USA in 2004-2005.

Species	Relative abundance[a]	Density[b] $\bar{x}$	Density[b] 95% CI	P_{sings}[c]	Adjusted Density[d]	Nests[e]
Red-faced warbler (*Cardellina rubrifrons*)	2.88	0.58	0.45-0.76	0.98	0.59	151
Yellow-eyed junco (*Junco phaeonotus*)	0.88	0.76	0.44-1.30	0.34	1.23	78
Orange-crowned warbler (*Vermivora celata*)	0.47					9
Virginia's warbler (*Vermivora virginiae*)	0.15					0[f]
Spotted towhee (*Pipilo maculatus*)	0.09					1

[a] Average relative abundance of males detected by song ≤100 m from each survey point in 2004-2005.

[b] Average density per ha of males detected by song ≤100 m from each survey point in 2004-2005.

[c] P_{sings} = probability of male singing during a 6-min point-count survey in 2004-2005.

[d] Adjusted density = Density + density X (1- P_{sings}).

[e] Total number of nests found in 2004-2005.

[f] We confirmed breeding by Virginia's warblers in our study area in 2007 (C. Kirkpatrick and C. Conway, unpublished data).

Table 2. Environmental features measured at 2 spatial scales surrounding red-faced warbler and yellow-eyed junco nests and at 1 spatial scale surrounding random sites within 4 study sites in high-elevation forest of the Santa Catalina Mountains, Arizona, USA in 2004-2005.

Variable	Explanation
Microhabitat[a]	
Closest plant to nest	Closest plant (e.g., tree stem, shrub stem, grass, forb) <30 cm from nest. "In open" indicates no plant (but may include inanimate objects such as branch or rock) <30 cm from nest.
Nest area concealment (overhead)	% of 12.5-cm radius circle centered on nest concealed by vegetation or debris from 1 m above nest
Nest area concealment (from side)	% of 12.5-cm radius semi-circle centered on nest concealed by vegetation or debris from 1 m to side of nest (average across 4 cardinal directions)
Nest concealment (overhead)	% of nest cup concealed by vegetation or debris from 1 m above nest
Nest concealment (from side)	% of nest cup concealed by vegetation or debris from 1 m to side of nest (average of 4 cardinal dir.)
Macrohabitat[b]	
Slope	Maximum slope (°)
Cover (0-0.5 m above ground)	% cover of ferns, grass, shrubs and saplings, brush, and forbs 0-0.5 m above ground
Shrub or sapling stems	# shrub or sapling (<8 cm DBH) stems for each species in 2 height (0.1, 1.4 m) classes
Macrohabitat[c]	
Area burned	% surface area burned
Burn severity[d]	Burn severity class (e.g., less severe or severe)
Canopy cover	Average % of 4 densiometer readings taken from 4 cardinal directions standing at nest or random sites
Canopy height	Average height of upper canopy (m)
Tree stems	# tree stems by species (and total) in 2 size classes (0-23, >24 cm DBH)
Snag stems	# snag stems by species (and total) in 2 size classes (0-12, >12 cm DBH)
Other	
Distance to drainage	Distance (m) to closest drainage bottom

[a] Measured at nests only.
[b] Measured within a 5-m radius of nests and random sites.
[c] Measured within an 11.3-m radius of nests and random sites.
[d] See methods and Kirkpatrick et al. (2006) for full description of Burn Severity Index.

Table 3. Final models from stepwise logistic regression analyses using data from ≥34 environmental variables (most reduced to set of ≥10 uncorrelated factors) collected at 1) 149 red-faced warbler nests, 78 yellow-eyed junco nests, and 70 random sites within 4 study sites in high-elevation forests of the Santa Catalina Mountains, Arizona, USA in 2004-2005. Variables and factors are ordered by strength of odds ratios.

		Coefficient				Odds Ratio	
Analysis	Variables[a] and factors[b] selected in final models	*b*	SE	Wald χ^2	*P*	Exp *b*	95% CI
1	Brush cover, QUEGAM[c] saplings and small trees, small woody debris cover	1.56	0.28	30.0	<0.001	4.8	2.7-8.3
	Fern cover	1.41	0.28	25.1	<0.001	4.1	2.4-7.1
	ACEGRA[c] saplings and small trees	1.27	0.29	19.0	<0.001	3.6	2.0-6.3
	ROBNEO[c] saplings and small trees	0.88	0.26	11.7	0.001	2.4	1.4-4.0
	Area burned and snags	-0.63	0.22	8.0	0.005	0.5	0.3-0.8
	PINSTR[c] large trees	0.56	0.21	6.9	0.009	1.8	1.2-2.6
	PSEMEN[c]/ABICON[c] saplings and small trees	0.56	0.21	6.8	0.009	1.8	1.2-2.6
	ABICON[c] large trees	-0.49	0.22	4.9	0.027	0.6	0.4-1.0
	Slope (absence of SYMORE[c] shrubs)	0.37	0.23	2.6	0.107	1.4	0.9 -2.2
	Log cover	-0.32	0.20	2.6	0.110	0.7	0.5-1.1
	Intercept	1.48	0.26	31.8	<0.001		
2	Small woody debris cover, brush cover, and SYMORE[c] shrubs	1.64	0.33	25.1	<0.001	5.2	2.7-10.0
	Small woody debris cover, brush cover, and SYMORE[c] shrubs	1.64	0.33	25.1	<0.001	5.2	2.7-10.0
	Forb cover, fern cover , and close to drainage bottom	1.38	0.28	24.0	<0.001	4.0	2.3-6.9
	Canopy cover and ABICON[c] large trees	-0.81	0.26	9.8	0.002	0.4	0.3-0.7
	Snags and area burned	-0.79	0.26	9.2	0.002	0.4	0.3-0.8
	Log cover	0.39	0.25	2.3	0.126	1.5	0.9-2.4
	Leaf litter cover (absence of bare ground cover and rock cover)	-0.32	0.22	2.1	0.148	0.7	0.5-1.1
	ABICON[c]/PSEMEN[c] small trees and saplings	0.29	0.23	1.6	0.211	1.3	0.8-2.0
	Intercept	0.25	0.25	1.0	0.315		
3	Closest plant to nest (PSEMEN[c]/ABICON[c])	-2.20	1.17	3.5	0.060	0.1	0.0-1.1
	Closest plant to nest (other tree species)	-1.15	0.96	1.4	0.230	0.3	0.0-2.1
	Closest plant to nest (ACEGRA[c])	-0.72	0.91	0.7	0.424	0.5	0.1-2.9
	Closest plant to nest (grass)	0.38	0.57	0.4	0.505	1.5	0.5-4.5
	Closest plant to nest (forb/fern)	-0.82	0.70	1.4	0.241	0.4	0.1-1.7
	Closest plant to nest (shrub)	-0.44	0.86	0.3	0.610	0.6	0.1-3.5
	Closest plant to nest (in open) [d]	0					
	ABICON[c] saplings and small trees	-0.62	0.23	7.2	0.007	0.5	0.3-0.8
	PINSTR[c] large trees	-0.58	0.20	8.6	0.003	0.6	0.4-0.8
	Fern cover and log cover	0.50	0.22	5.4	0.020	1.7	1.1-2.5

Table 3. cont.

PINPON[c] trees and PINSTR[c] saplings	-0.39	0.20	3.8	0.052	0.7	0.5-1.0
Snags	-0.29	0.20	2.2	0.134	0.8	0.5-1.1
Leaf litter cover (absence of bare ground cover and rock cover)	-0.28	0.19	2.1	0.146	0.8	0.5-1.1
Shrub cover	0.28	0.19	2.0	0.154	1.3	0.9-1.9
ABICON[c] large trees	-0.20	0.19	1.1	0.288	0.8	0.6-1.2
Nest initiation date	-0.08	0.02	16.6	<0.001	0.9	0.9-1.0
Lag time	-0.02	0.01	2.5	0.111	1.0	1.0-1.0
Intercept	11.01	3.09	12.7	<0.001		

[a] See Table 1 for complete list of variables.

[b] See Appendix A for complete list of factors.

[c] ABICON = white fir (*Abies concolor*), ACEGRA = big-tooth maple (*Acer grandidentatum*), PINPON = ponderosa pine (*Pinus ponderosa*), PINSTR = southwestern white pine (*Pinus strobiformis*), PSEMEN = Douglas-fir (*Pseudotsuga menziessi*), QUEGAM = Gambel oak (*Quercus gambelii*), ROBNEO = New Mexican locust (*Robinia neomexicana*), and SYMORE = mountain snowberry (*Symphoricarpos oreophilus*).

[d] Reference category.

Appendix A. Factor descriptions, Eigenvalues, and factor weights of original variables for 1) 13 factors generated for the red-faced warbler use vs. availability analysis, 2) 10 factors generated for yellow-eyed junco use vs. availability analysis, and 3) 14 factors generated for red-faced warbler vs. yellow-eyed junco nest-site analysis.

		Eigenvalue			
Analysis	Factor Description[a]	Total	% of Variance	Original variable[b]	Factor Weight
1	PSEMEN/ABICON saplings and small trees	6.1	16	PSEMEN[c] sapling stems (large)	0.86
				PSEMEN[c] sapling stems (small)	0.84
				PSEMEN[c] tree stems (small)	0.80
				ABICON[c] sapling stems (small)	0.70
				ABICON[c] sapling stems (large)	0.69
				ABICON[c] tree stems (small)	0.64
				PINSTR[c] sapling stems (small and large)[d]	0.54
	ACEGRA saplings and small trees	4.0	10	ACEGRA[c] sapling stems (small)	0.89
				ACEGRA[c] sapling stems (large)	0.88
				ACEGRA[c] tree stems (small)	0.86
				ACEGRA[c] tree stems (large)	0.54
				Canopy cover	0.46
				PINPON[c] tree stems (small)	-0.48
				PINPON[c] tree stems (large)	-0.50
	Leaf litter cover (absence of rock cover and bare ground cover)	2.5	7	Leaf litter cover	0.77
				Bare ground cover	-0.62
				Rock cover	-0.79
	Area burned and Snags	2.4	6	Area burned	0.80
				Snag stems (small)	0.75
				Snag stems (large)	0.71
	Brush cover, QUEGAM saplings and small trees, small woody debris cover	1.7	5	Brush cover	0.69
				QUEGAM[c] sapling stems (small and large) and tree stems (small)[d]	0.66

Appendix A. cont.

				Small woody debris cover	0.61
	Other shrubs and shrub cover	1.7	4	Shrub cover	0.68
				Other shrub stems (small and large)[d]	0.67
	PINSTR large trees	1.5	4	PINSTR[c] tree stems (large)	0.61
				PINSTR[c] sapling stems (small and large)[d]	0.50
				Grass cover	-0.48
	ABICON large trees	1.5	4	ABICON[c] tree stems (large)	0.78
				Canopy height	0.46
	Fern cover and forb cover	1.3	3	Fern cover	0.83
				Forb cover	0.55
	Log cover	1.2	3	Log cover	0.81
	Slope (absence of SYMORE shrubs)	1.1	3	Slope	0.77
				SYMORE[c] shrub stems (small and large)[d]	-0.55
	ROBNEO saplings and small trees	1.0	3	ROBNEO[c] sapling stems (small and large) and tree stems (small)[d]	0.82
	PSEMEN large trees	1.0	3	PSEMEN[c] tree stems (large)	0.77
2	ABICON/PSEMEN small trees and saplings	5.8	17	ABICON[c] tree stems (small)	0.83
				ABICON[c] sapling stems (large)	0.82
				ABICON[c] sapling stems (small)	0.79
				PSEMEN[c] sapling stems (small and large)[d]	0.77
				PSEMEN[c] tree stems (small)	0.77
	Leaf litter cover (absence of bare ground cover and rock cover)	3.6	11	Leaf litter cover	0.83
				Rock cover	-0.69
				Bare ground cover	-0.75
	ACEGRA saplings and small trees and shrub cover	3.1	9	ACEGRA[c] sapling stems (small and large)[d]	0.75
				ACEGRA[c] tree stems (small and large)[d]	0.67
				Shrub cover	0.66
	PINPON small trees and PINSTR saplings	2.3	7	PINPON[c] tree stems (small)	0.87
				PINSTR[c] sapling stems (small and large)[d]	0.83

Appendix A. cont.

				PINPON[c] tree stems (large)	0.54
				ROBNEO[c] sapling stems (small and large) and tree stems (small)[d]	0.49
	Snags and area burned	1.9	6	Snag stems (large)	0.83
				Snag stems (small)	0.80
				Area burned	0.75
				Other shrub stems (small and large)[d]	-0.48
	Small woody debris cover, brush cover, and SYMORE shrubs	1.6	5	Small woody debris cover	0.73
				Brush cover	0.67
				SYMORE[c] shrub stems (small and large)[d]	0.60
	Forb cover, fern cover, and close to drainage bottom	1.5	4	Forb cover	0.64
				Fern cover	0.62
				Slope	-0.48
				Distance to drainage	-0.66
	Canopy cover and ABICON large trees	1.3	4	Canopy cover	0.69
				ABICON[c] tree stems (large)	0.69
	Log cover	1.1	3	Log cover	-0.74
	PINSTR large trees	1.1	3	PINSTR[c] tree stems (large)	0.85
3	ACEGRA saplings and trees	5.8	13	ACEGRA[c] sapling stems (large)	0.81
				ACEGRA[c] tree stems (large)	0.66
	Leaf litter cover (absence of bare ground cover and rock cover)	4.5	10	Leaf litter cover	0.76
				Canopy height	0.54
				ACEGRA[c] sapling stems (small)	0.78
				ACEGRA[c] tree stems (small)	0.70
				Canopy cover	0.44
				Rock cover	-0.68
				Bare ground cover	-0.75
	PSEMEN saplings and small trees	3.0	7	PSEMEN[c] sapling stems (large)	0.83
				PSEMEN[c] sapling stems (small)	0.81

Appendix A. cont.

			PSEMEN[c] tree stems (small)	0.76
ABICON saplings and small trees	2.7	6	ABICON[c] sapling stems (large)	0.81
			ABICON[c] sapling stems (small)	0.79
			ABICON[c] tree stems (small)	0.70
PINPON trees and PINSTR saplings	2.3	5	PINPON[c] tree stems (small)	0.81
			PINSTR[c] sapling stems (small and large)[d]	0.80
			Nest area concealment (from side)	0.81
			Nest concealment (from side)	0.57
			Nest concealment (overhead)	0.54
			PINPON[c] tree stems (large)	0.70
Nest area concealment	2.2	5	Nest area concealment (overhead)	0.82
			Grass cover	0.49
Snags and area burned	1.9	4	Snag stems (large)	0.75
			Snag stems (small)	0.72
			Area burned	0.58
SYMORE shrubs	1.7	4	SYMORE[c] shrub stems (large)	0.90
			SYMORE[c] shrub stems (small)	0.88
Fern cover, log cover, and forb cover	1.5	3	Fern cover	0.70
			Log cover	0.65
			Forb cover	0.56
Shrub cover	1.4	3	Shrub cover	0.65
			Small woody debris cover	0.53
PINSTR large trees	1.3	3	PINSTR tree stems (large)	0.74
			PINSTR tree stems (small)	0.54
ABICON large trees	1.1	2	ABICON tree stems (large)	0.80
			Brush cover	0.48
			Other shrub stems (small and large)[d]	0.48
			Other ground cover	-0.49

Appendix A. cont.

Close to drainage bottom	1.1	2	QUEGAM[c] sapling stems (small and large) and tree stems (small)[d]	0.52
			Moss cover	0.46
			Distance closest drainage	-0.77
ROBNEO saplings and small trees	1.0	2	ROBNEO[c] sapling stems (small and large) and tree stems (small)[d]	0.75

[a] We named factors based on factor weights ≥0.55 indicating that ≥30% of the variance in the variable was accounted for in the factor.
[b] See Table 2 for complete list of variables.
[c] ABICON = white fir (*Abies concolor*), ACEGRA = big-tooth maple (*Acer grandidentatum*), PINPON = ponderosa pine (*Pinus ponderosa*), PINSTR = southwestern white pine (*Pinus strobiformis*), PSEMEN = Douglas-fir (*Pseudotsuga menziessi*), QUEGAM = Gambel oak (*Quercus gambelii*), ROBNEO = New Mexican locust (*Robinia neomexicana*), and SYMORE = mountain snowberry (*Symphoricarpos oreophilus*).
[d] ≥2 highly-correlated variables with ≥90% cases with zero values that were combined into 1 variable before running analyses.

Figure 1. Percentage of yellow-eyed junco and red-faced warbler nests found in 2004-2005 as a function of distance (m) from drainage bottoms within 4 study sites in high-elevation forests of the Santa Catalina Mountains, Arizona, USA.

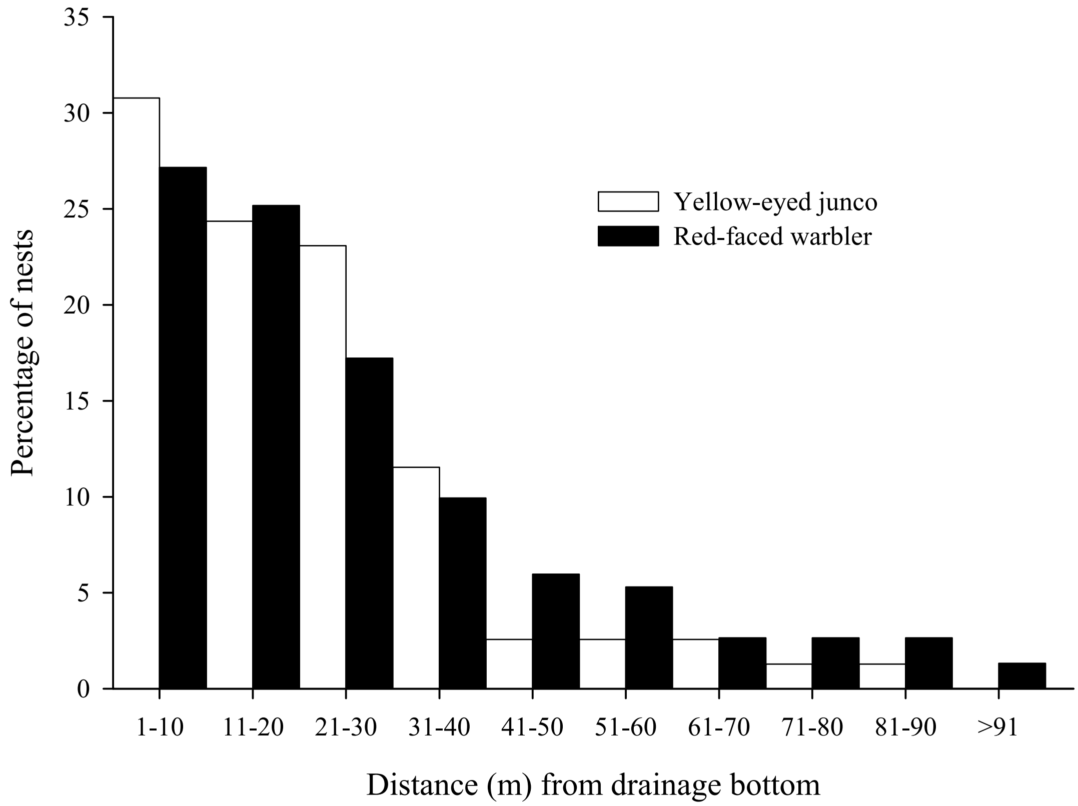
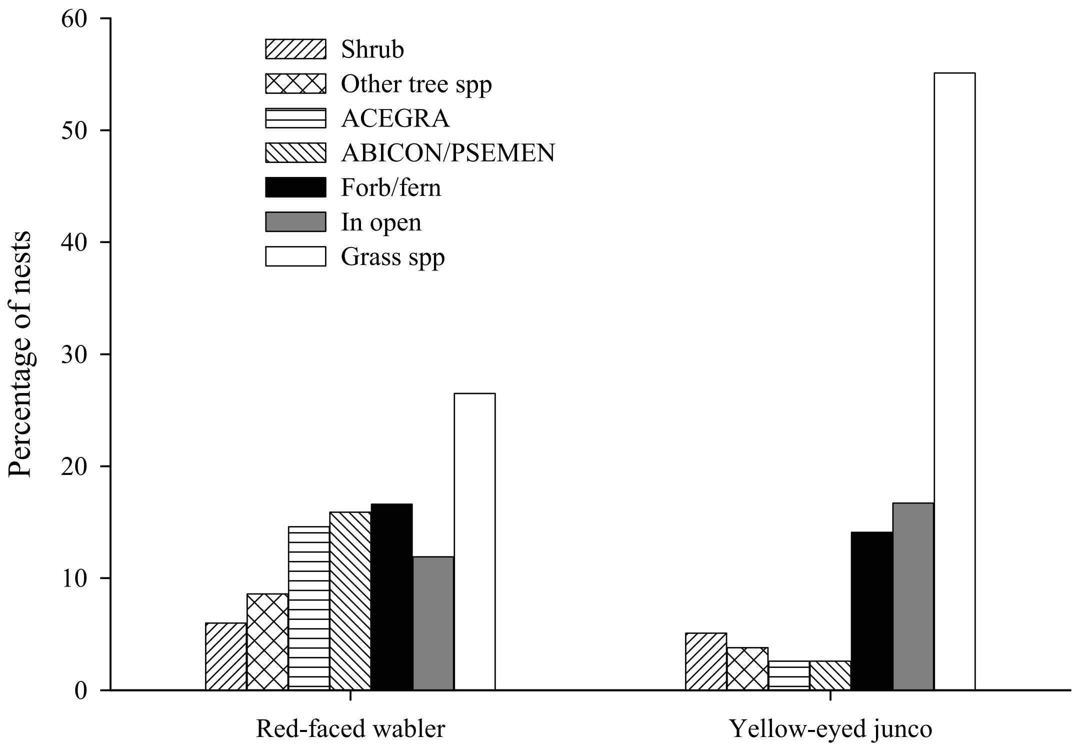
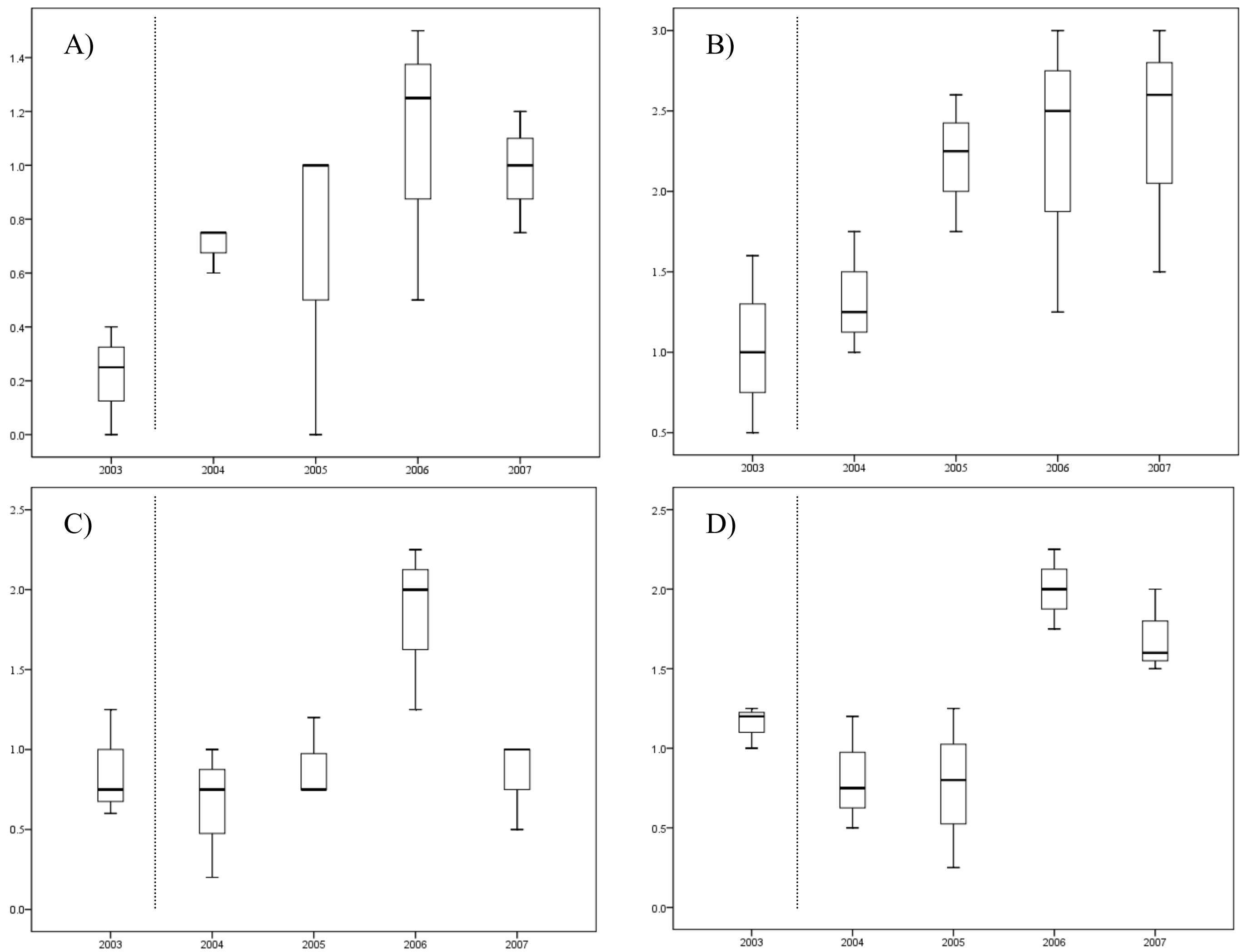


Figure 2. Percentage of red-faced warbler and yellow-eyed junco nests found in 2004-2005 that were located <30 cm from a plant or were in open within 4 study sites in high-elevation forests of the Santa Catalina Mountains, Arizona, USA.





Figures 3a-d. Trends in relative abundance (average number of birds detected per survey point) of 4 montane forest bird species, A) mountain chickadee, B) yellow-eyed junco, C) black-headed grosbeak, and D) house wren, following a wildfire that burned portions of 4 study sites in high-elevation forests of the Santa Catalina Mountains, Arizona, USA in the summer of 2003. The vertical, dotted line indicates the approximate time of the wildfire.

Figure 4. Trends in daily nest survival for yellow-eyed juncos (dashed line) and red-faced warblers (solid line) before the Aspen Wildfire (2002 and 2003 data combined) and after (2004-2007) the 2003 Aspen Wildfire in the Santa Catalina Mountains, Arizona.