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Source: The Southwestern Naturalist, 58(2):150-162. 2013.
Published By: Southwestern Association of Naturalists
DOI: http://dx.doi.org/10.1894/0038-4909-58.2.150
URL: http://www.bioone.org/doi/full/10.1894/0038-4909-58.2.150

PROJECTING AVIAN RESPONSES TO LANDSCAPE MANAGEMENT ALONG THE MIDDLE RIO GRANDE, NEW MEXICO

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Abstract—Most lowland rivers in the southwestern United States have been impounded, diverted, or dewatered. Lack of flooding due to river impoundments on the Middle Rio Grande has contributed to the spread of exotic vegetation such as Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix*) associated with fuel loads of dense understory. Management has largely focused on thinning of understory vegetation to remove nonnative species and reduce fire risk, but it is unclear how these actions impact avian populations. Using distance-sampling methods, we quantified densities of five groups of birds (birds nesting in canopy, midstory, and understory; water-obligates; and spring migrants) across 12 types of vegetation spanning managed and nonmanaged stands. We used a space-for-time substitution model to estimate changes in abundance of birds from scenarios that applied four possible options for management at the landscape scale. One option, mechanical clearing of cottonwood understory, had severe detrimental impacts for abundances of the three nesting guilds and spring migrants when applied across the study area. A hand-thinning method to remove most exotics but retain native shrubs and the ground layer also negatively impacted birds nesting in understory but had positive or no effect on the other four groups of birds. Over the short term (5–10 years), not clearing would increase the proportion of native and nonnative understory and generally increase abundances of birds. With application of "no management" over a longer period (50–75 years), we assumed transition of most cottonwood (*Populus deltoides* var. *wislizeii*) stands to shrublands of Russian olive and projected that canopy-nesting birds would decrease but other groups would increase. A scenario of wetland restoration that converted 25% of open habitat to wetland increased abundances of understory-nesting birds slightly and water-obligate birds substantially. Our projections of changes in avian populations will help managers evaluate biological impacts of management being considered for the Middle Rio Grande.

Resumen—La mayoría de los ríos de tierra baja del suroeste de los Estados Unidos ha sido embalsada, desviada, o deshidratada. La falta de inundaciones debido a embalses de la parte media del río Bravo ha contribuido a la propagación de vegetación exótica como el olivo ruso (*Elaeagnus angustifolia*) y el cedro salado (*Tamarix*), asociada con cargas de combustible del sotobosque denso. El manejo se ha enfocado en disminuir la vegetación del sotobosque para remover las especies no nativas y reducir los riesgos de incendios, pero no es claro el impacto que estas acciones tienen sobre las poblaciones aviarias. Por medio de métodos de muestreo a distancia, cuantificamos las abundancias de cinco grupos de aves (pájaros que anidan en el dosel, el estrato medio y el sotobosque; obligados al agua; y especies migratorias primaverales) en 12 tipos de vegetación en parcelas manejadas y no manejadas. Utilizamos un modelo de sustitución de espacio por tiempo para estimar los cambios de abundancia de aves en escenarios que aplicaron cuatro posibles opciones para manejo a escala de paisaje. Una opción, la limpieza mecánica de álamos del sotobosque, tuvo impactos negativos severos sobre la abundancia de los tres grupos de aves según su anidación y las especies migratorias primaverales cuando se aplicó a toda el área de estudio. El método de limpieza manual para remover la mayoría de las especies exóticas y mantener los arbustos nativos y el sotobosque también impactó negativamente a las aves anidando en el sotobosque pero tuvo un impacto positivo o neutro en los otros cuatro grupos de aves. A corto plazo (5–10 años), no limpiar incrementaría la proporción del sotobosque nativo y no nativo y en general incrementaría la abundancia de aves. Con la aplicación de "no-manejo" a largo plazo (50–75 años), asumimos la transición de la mayoría de las parcelas de álamos (*Populus deltoides* var. *wislizeii*) a matorrales de olivos rusos y proyectamos que las aves que anidan en el dosel disminuirán pero las aves de los otros grupos se incrementarán. Un escenario de restauración de humedales que convirtió 25% del hábitat abierto a humedales incrementó la abundancia de las aves anidando en el sotobosque en poca medida pero incrementó sustancialmente la abundancia de las aves ligadas a agua. Nuestras proyecciones sobre los cambios en las poblaciones de aves ayudarán a evaluar los impactos biológicos del manejo siendo considerado para la parte medio del río Bravo.

Most lowland rivers in the southwestern United States have been impounded, diverted, or dewatered, resulting in changes to the magnitude, timing, and frequency of flood regimes (Poff et al., 1997; Stromberg, 2001). These factors contributed to changes in vegetation along many regulated rivers, including the spread of nonnative trees and shrubs such as saltcedar (*Tamarix*) and Russian olive (*Elaeagnus* angustifolia; Howe and Knopf, 1991; Molles, 1998; Stromberg, 2001; Shafroth et al., 2005). Reduced flooding limits scour and contributes to increased fuel loads of the understory and increased frequency of fires on some rivers (Molles et al., 1998). Given the large area of southwestern riparian corridors covered by saltcedar and Russian olive, removal of exotic vegetation has been a primary goal of restoration and management (Zavaleta et al., 2001; Fleishman et al., 2003; Shafroth et al., 2005). However, restoration of riparian habitat by removal of exotics without replacing them with high-quality native species may reduce habitat value for some avian species (Zavaleta et al., 2001; Fleishman et al., 2003; Sogge et al., 2008; van Riper et al., 2008). There have been extensive efforts to manage or restore floodplains, often to improve habitat, although few projects evaluated effects on wildlife populations (Shafroth et al., 2005; Palmer et al., 2005; Shah et al., 2007). Given potential impacts of removing exotic species, the expected response of key populations of wildlife to a range of options for management should be assessed prior to application of these options across a large spatial scale.

The floodplain of the Middle Rio Grande in central New Mexico contains one of the largest stands of cottonwood-willow (*Populus-Salix*) in the southwestern United States (Howe and Knopf, 1991; Kelly et al., 2000). However, due to extensive efforts to modify the channel and control the river during the last century, the active channel is constrained between levees to ca. 15% of its historic size (Molles et al., 1998; Scurlock, 1998). Flooding is controlled by upstream reservoirs and structures stabilizing banks to protect adjacent agriculture and urban areas, and flows have been diverted for irrigation (Smith et al., 2009). In part due to extensive alteration of the hydrograph, floristic composition of the floodplain has transitioned from predominantly native species of plants to predominantly nonnative species, including Russian olive (Howe and Knopf, 1991; Molles et al., 1998). Extensive wildfires have occurred in the past decade, with dense understories of mostly exotic species of trees and shrubs and coarse woody debris providing fuel loads (Molles et al., 1998; Smith et al., 2009). Such fires present hazards for neighboring landowners, particularly in dense, urban areas.

Concerns about fire risk and public preference for native vegetation have led to various proposed options for management for the Middle Rio Grande (Shah et al., 2007; Bateman et al., 2008). In 2004, >800 ha within Albuquerque, New Mexico, were treated to remove nonnative understory, much of which was mechanically cleared (United States Army Corps of Engineers, http://www.spa.usace.army.mil/fonsi/FEAfire.pdf). A hand-thinning method was applied in certain locations to reduce fire risk but retain native understory. Other reaches on the Rio Grande have remained essentially unmanaged and contain dense understory with high fuel loads. Substantial federal funding also has been allocated to wetland restoration within the floodplain mainly for recreation enhancement. The question remains, however, how the variety of options for management might affect wildlife populations.

Birds serve as an important means to evaluate impact of management because birds respond strongly to changes in composition and structure of vegetation in southwestern riparian systems (Mills et al., 1991; Farley et al., 1994; Walker, 2008; Brand et al., 2010) and more so than other vertebrate taxa on the Middle Rio Grande (Bateman et al., 2008). In dryland regions, total densities of birds strongly correlate with volume of vegetation, regardless of the composition of native or nonnative species (Mills et al., 1991; Fleishman et al., 2003). Floristics within structural types also influence abundance of birds for certain avian guilds (Fleishman et al., 2003; Walker, 2008). Previous work in southwestern riparian systems also highlights the different responses of species and groups of birds to changes in vegetation based on nesting location, water dependence, and migratory status (Cody, 1985; Hinojosa-Huerta et al., 2006; Bateman et al., 2008; Brand et al., 2011).

Projection of ecological impacts of alternative scenarios can aid decision-making by providing a means to assess possible future conditions (Peterson et al., 2003). Objectives of our study were to assess effects of alternative scenarios for management related to removal of vegetation for reduction of fuels, control of invasive species, and restoration of wetlands on five groups of birds (three nesting guilds, breeding water-obligate birds, and spring migrants) that we expected to respond strongly to management on the Middle Rio Grande. We first estimated avian densities for the five groups of birds as a function of 12 types of native, nonnative, thinned, and restored vegetation. We then projected expected responses in avian abundance to alternative scenarios of management, reflecting a range of options for managing vegetation that could be applied across the Middle Rio Grande. Our goal was to provide information useful for evaluating alternatives for management prior to their application at a large spatial scale.

Materials and Methods—We studied 10 reaches on a 128-km segment of the Middle Rio Grande between Bernalillo and La Joya Wildlife Area, New Mexico (Fig. 1). These included lands managed by the Middle Rio Grande Conservancy District, the United States Army Corps of Engineers, and the New Mexico Department of Game and Fish. Riparian vegetation was dominated by floodplain forest (known as bosque) with Rio Grande cottonwood (*Populus deltoides* var. *wislizeni*) as the dominant overstory. Due to hydrologic alterations, little recruitment of cottonwoods has occurred in the last 50 years, and existing stands are aging (Howe and Knopf, 1991; Molles et al., 1998). While understory in the historic bosque was thought to be sparse (Campbell and Dick-Peddie, 1964), the understory of unmanaged stands of cottonwood often is now densely covered by exotics, particularly Russian olive and saltcedar. Native shrubs, such as coyote willow (*Salix exigua*) and New Mexico olive (*Forestiera neomexicana*), occur in smaller patches. The bosque on both sides of the river was bordered by a mixture of agricultural fields, desert scrub, suburban areas, and urban areas.

We classified current vegetation using Geographic-Information-System vegetational coverages in vector format developed by the United States Army Corps of Engineers from recent (2002 and 2005) aerial photography followed by ground-truthing. Based on composition and structure, this classification yielded >150 types of vegetation spanning the historic floodplain. We collapsed categories based on lack of effect of secondary dominants on avian densities. This process yielded 12 types of vegetation in six classes of structure (Table 1). The classification was consistent with that of prior studies (V. C. Hink and R. D. Ohmart, in litt.). Five of the 12 types had an overstory of cottonwood >12-m high. Of the five types, two had a sparse understory (<25% cover). The first had understory mechanically cleared by Franklin machines that ground all shrub and herbaceous vegetation and soil substrate. The second was naturally sparse or selectively thinned of most nonnative shrubs and understory trees but maintained minor components of Russian olive, coyote willow, New Mexico olive, saltcedar, white mulberry (*Morus alba*), and the herbaceous ground layer. The remaining three types of tall cottonwood had a dense

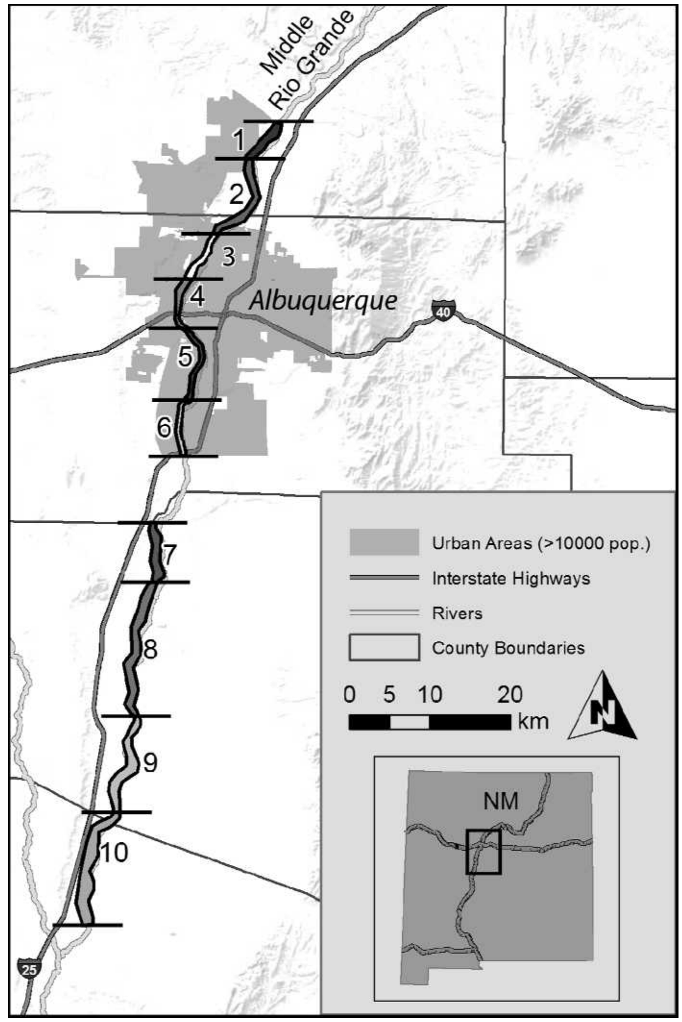

Fig. 1—Map of the Middle Rio Grande showing 10 reaches and location of the metropolitan area of Albuquerque between Bernalillo and La Joya Wildlife Area, New Mexico. Urban reaches 1 and 3–6 were in the areas of Rio Rancho and Albuquerque, while rural reaches 2 and 7–10 included areas of Corrales and Middle Rio Grande Conservancy District south of Albuquerque. The Isleta Pueblo between reaches 6 and 7 was not sampled.

understory (>25% cover) but differed in composition (coyote willow, New Mexico olive, or Russian olive). We also included one type of vegetation with a mixed canopy of cottonwoods of intermediate age and height (6–12 m high) and Russian olive. Of the remaining six types of vegetation, four were shrub stands (Russian olive, saltcedar, coyote willow, and New Mexico olive), all with dense vegetation >1.5 but <4.6 m. The two final classes (i.e., open terrestrial and marsh) had herbaceous or shrub vegetation <1.5 m high.

We defined reaches by anthropogenic features such as bridges that corresponded with areas of active management (Fig. 1) and considered four options for management applied at the scale of a river reach (Table 2). The first option (MO1: mechanical clearing) incorporated intensive mechanical clearing of all native and nonnative understory to reduce fire risk in mature stands of cottonwood. The second option (MO2:

Table 1—Description for 12 types of vegetation sampled on the Middle Rio Grande in New Mexico with number of sampled transects for each.

Type	Structure	Composition	Number of transects
C2-cleared[a]	Cottonwood-cleared	Cottonwood with mechanically cleared understory	4 (6)
C2-sparse	Cottonwood-sparse	Cottonwood with naturally sparse or hand-thinned to mimic naturally sparse understory	5
C/CW1	Cottonwood-dense	Cottonwood with dense understory of coyote willow	2
C/NMO1	Cottonwood-dense	Cottonwood with dense understory of New Mexico olive	3
C/RO1[a]	Cottonwood-dense	Cottonwood with dense understory of Russian olive	7 (5)
C/RO3	Cottonwood-dense	Intermediate-sized cottonwood and Russian-olive with understory of coyote-willow	2
RO5	Shrub	Russian-olive-dominated vegetation >1.5 m tall	5
SC5	Shrub	Saltcedar-dominated vegetation >1.5 m tall	3
CW5	Shrub	Coyote-willow-dominated vegetation >1.5 m tall	3
NMO5	Shrub	New-Mexico-olive-dominated vegetation >1.5 m tall	1
OP6	Open	Terrestrial open area with sparse vegetation <1.5 m tall	5
MH6	Marsh	Marsh vegetation or water <1.5 m tall	2

[a] Two C/RO1 transects were mechanically cleared in Fall 2004 and became C2-cleared thereafter; the number of transects after clearing is shown in parentheses.

selective hand-thinning) applied selective hand-thinning of nonnative understory but retention of native understory within stands of cottonwood to reduce fire risk but maintain some native vegetation. The third option (MO3: no clearing) involved no clearing over a relatively short term (5–10 years), with dense understory allowed to remain or expected to reestablish within this period (Queheillalt and Morrison, 2006). The fourth option (MO4: cottonwood senescence) represents projected vegetational conditions in 50–75 years assuming natural successional processes in the absence of active management and no change in hydrologic processes or other conditions. We based our assumptions for MO4 on the current age of stands of cottonwood, extremely low levels of recruitment, and proportions of vegetational types on existing maps. Based on literature, we assumed senescence of 90% of older stands of cottonwood (>12 m high) and 50% of younger stands of cottonwood (6–12 m high) given current distributions of age (most stands >50 years old) and an expected lifespan of 100 years (Howe and Knopf, 1991; Molles et al., 1998; Table 2). Assuming current hydrologic conditions will persist (e.g., no overbank-flooding and inadequate depth to groundwater), we applied minimal large-scale recruitment and replacement of cottonwoods with later successional species of shrub according to current proportions in different river reaches (Howe and Knopf, 1991; Molles et al., 1998) and based on life-history and regeneration traits of species (e.g., Stromberg et al. 2010). However, we projected some recruitment and, thus, persistence of stands of cottonwood as well as other woody riparian pioneers (coyote willow, and saltcedar), based on current proportions of the younger age class near the river margin (Table 2). We assumed that wetland habitat could be restored in floodplains classified as open habitat at a conversion rate of 25% (considered reasonable by a local expert, O. Hummel, United States Army Corps of Engineers, pers. comm.) and that this option could be applied across any scenario of the vegetational management.

We developed eight hypothetical scenarios by applying one or more options for management across reaches. We limited our vegetational projections to the extent of tall-canopied cottonwood, marsh, and open habitats within the flood-control levees encompassing 27.4 km^2. In the first four scenarios, we applied each of the options for management across all reaches. We also considered three additional scenarios wherein two of the three short-term options were applied to rural versus urban reaches. For example, with Scenario 5, mechanical clearing of understory was applied to the most urbanized reaches with greatest risk of fire in municipal areas (reaches 1 and 3–6), whereas less intensive hand-thinning was applied to the rural reaches to balance the needs of reduction of fire risk with maintenance of some native understory (Table 3). The option of wetland-restoration (converting 25% of open habitat to marsh) can be applied to any of the scenarios; for illustration, we present the results for restoration of wetlands associated with Scenario 7. All scenarios considered only short-term conditions (5–10 years) except for Scenario 4, in which we assumed changes would occur in 50–75 years (e.g., senescence of older stands of cottonwood and failure of recruitment leading to loss of cottonwood). For each scenario, we estimated the total area of each vegetational type according to rules for transition for each management option applied by reach (Tables 2 and 3).

We used distance-sampling (Buckland et al., 2001) to estimate density of birds from data collected on 42 transects in 12 vegetational types within the historic floodplain. Transects were >1 km apart and, thus, considered independent from the standpoint of avian territories. To sample a given vegetational type, lengths of transects varied from 440–920 m (732 $\pm$ 88 m; mean $\pm$ *SD*). For 18 of 42 transects, sampling was conducted on only one side, so the sampling fraction was one half. We collected data on birds from 1 March–31 May in 2005 and 2006 for spring migration and 1 June–31 August 2004–2006 for the breeding season and data for the marsh in both seasons of 2007. Each transect was visited three times per month with $\geq$5 days between surveys for a total of nine visits per season in a given year. Observers recorded all birds seen or heard while walking the length of each transect within 4 h of sunrise. Birds flying above the vegetation were not counted. Four experienced observers spent $\geq$3 weeks training in the field prior to data collection and were able to identify birds by sight and sound; >80% of all data was collected by one author (TF). Training

TABLE 2—Assumed transitions of vegetation from current types of vegetation for four options for management applied to the Middle Rio Grande in New Mexico.

	Option			
Current type	1	2	3	4
C2-cleared	No change	C2-sparse	C/RO1 or C/NMO1[ab]	10% to C/RO1 or C/NMO1[a];10% (20% [c]) to SC5, CW5, or C/RO3[d]; 80% (70%[c]) to RO5 or NMO5[d]
C2-sparse	No change	No change	C/RO1 or C/NMO1[ab]	10% to C/RO1 or C/NMO1[a]; 10% (20%[c]) to SC5, CW5, or C/RO3[d]; 80% (70%[c]) to RO5 or NMO5[d]
C/CW1	No change	No change	No change	10% to C/RO1 or C/NMO1[a]; 10% (20%[c]) to SC5, CW5, or C/RO3[d]; 80% (70%[c]) to RO5 or NMO5[d]
C/NMO1	No change	No change	No change	10% to C/NMO1; 10% (20% [c]) to SC5, CW5, or C/RO3[d]; 80% (70%[c]) to NMO5[d]
C/RO1	C2-cleared	C2-sparse	No change	10% to C/RO1; 10% (20%[c]) to SC5, CW5, or C/RO3[d]; 80% (70%[c]) to RO5 [d]
C/RO3	C2-cleared	C2-sparse	No change	50% to C/RO1; 10% (20%[c]) to SC5, CW5, or C/RO3[d]; 40% (30%[c]) to RO5 [d]

[a] Following current reach-specific proportions of these types of cover.

[b] Assumed that hydric pioneer species (coyote willow, CW) would not be able to recolonize under cottonwood, so most recolonization by shrubs would be by later successional species, Russian olive (RO) and New Mexico olive (NMO). Based on proportions, nearly all of these stands would convert to C/RO1.

[c] Larger percentage eroded, resulting in recruitment on more fluvially dynamic Middle Rio Grande Conservancy District reaches (Isleta to Bernardo).

[d] Assumed secondary colonization or long-term persistence of hydric pioneer species (CW or saltcedar, SC) unlikely under existing canopy. Rather, expect later successional species (RO, NMO) to dominate. Based on existing proportions, we assumed that these stands would overwhelmingly convert to RO5.

involved using laser rangefinders to improve estimation of distance. For each bird encountered, observers recorded the lateral distance of birds from the transect line within the distance classes of <5 m, 5–15 m, 16–30 m, 31–45 m, and 46–60 m. Each vegetational type was sampled on 2–7 transects, except one (New Mexico olive) covering only a small area, where only one transect was used (Table 1); sampling effort was approximately in proportion to total area covered by each vegetational type. We used the level of survey effort (based on number of transects, visits, line length, and sampling fraction) to adjust estimates of density using a multiplier in the analysis (Buckland et al., 2001).

We classified species according to ecological characteristics that affect response of birds to structural differences in riparian vegetation (Brand et al., 2010) and that we expected would be sensitive to management on the Rio Grande. We classified groups of birds based on our data and regional information included in The Birds of North America Online (Cornell Laboratory of Ornithology, Ithaca, New York; http://bna.birds.cornell.edu/bna/). We categorized breeding birds by average nesting-height as understory nesters (0–2 m), midstory nesters (>2–4 m), and canopy nesters (>4 m). To capture the potential influence of expected changes in restoration of wetlands, we considered water-obligate birds to include those that swim,

TABLE 3—Hypothetical scenarios for management based on options[a] applied to urban and rural reaches (locations shown in Fig. 1) on the Middle Rio Grande in New Mexico.

Scenario	Urban reaches (1, 3–6)	Rural reaches (2, 7–10)
Current condition	MO1: mechanical clearing	MO3: no clearing (reaches 7–10), MO2: selective hand-thinning (reach 2)
S1	MO1: mechanical clearing	MO1: mechanical clearing
S2	MO2: selective hand-thinning	MO2: selective hand-thinning
S3	MO3: no clearing	MO3: no clearing
S4	MO4: cottonwood senescence	MO4: cottonwood senescence
S5	MO1: mechanical clearing	MO2: selective hand-thinning
S6	MO1: mechanical clearing	MO3: no clearing
S7	MO2: selective hand-thinning	MO3: no clearing
S7W	MO2: selective hand-thinning, wetland restoration[b]	MO3: no clearing, wetland restoration[b]

[a] MO = Management options and include: MO1 = application of mechanical clearing of understory in stands of cottonwood; MO2 = application of selective hand-thinning of understory in stands of cottonwood; MO3 = no clearing that allows dense native and nonnative understory to return or remain short term (5–10 years); and MO4 = application of "no management" over the long term (50–75 years) assumes most mature stands of cottonwood would senesce and be replaced by stands of shrub.

[b] Includes conversion of 25% of open habitats to wetland.

wade, and frequent the shore as well as songbirds dependent on surface water in the Southwest. Spring migrants detected during the spring season included species that only migrate through the Middle Rio Grande and those that migrate and breed during the summer months; we excluded resident species from this category.

We estimated probabilities of detection for each group of birds within each vegetational type using the distribution of distances from transect line to individual birds in program Distance 5.0 (Thomas et al., 2010). To improve estimation of detection-functions, we screened and truncated data at farthest distances from the transect line to meet the shape criterion (Buckland et al., 2001; Thomas et al., 2010). We developed a set of candidate detection-functions for each combination of avian group and vegetational type. We considered candidate detection-functions that included uniform-cosine models with no covariate, as well as half normal-cosine and half normal-simple polynomial models with and without covariates (Buckland et al., 2001). We considered two factor covariates: observer and detection-rank. To develop detection-rank for each species, we classified each species according to ease of detection (high versus medium-low) based on sight and sound. The best detection-function for each species in each vegetational type was selected using Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). We used detection probabilities combined with mean counts of grouped species to estimate average density across years and the standard error of density for each vegetational type (Buckland et al., 2001). We considered differences in densities among vegetational types to be meaningful if they had nonoverlapping 95% confidence intervals.

We used avian density by vegetational type from the historic floodplain, applied to vegetation-area-projections by scenario, as the basis for projecting changes in abundance of avian groups using space-for-time substitution. Estimates of density of birds by vegetational type were multiplied by the projected area of each vegetational type, and these values were summed across all reaches. Changes in vegetation were assumed; thus, the estimates of standard error of projections of avian abundance stemmed from errors in avian density only using the equation

$$S\hat{E}(\hat{N}) = \sqrt{A^2 \cdot V\hat{a}r(\hat{D})},$$

where $\hat{N}$ is estimated abundance of birds, $\hat{D}$ is estimated density, $V\hat{a}r(\hat{D})$ is estimated variance of density, and A is a vegetational area. The standard error of estimated abundance does not contain a covariance because avian densities for vegetational types were independent. We considered differences in abundances among scenarios to be meaningful if they had nonoverlapping 95% confidence intervals.

Table 4—For each avian group, the five most common species detected on 42 transects on the Middle Rio Grande in New Mexico during 2004–2006 for breeding birds and 2005–2006 for spring migrants; data for marsh were collected in 2007.

Avian group and species	Number of detections
Canopy-nesting	
Lesser goldfinch (*Carduelis psaltria*)	1,895
White-breasted nuthatch (*Sitta carolinensis*)	1,573
House finch (*Carpodacus mexicanus*)	1,558
Bushtit (*Psaltriparus minimus*)	1,533
Downy woodpecker (*Picoides pubescens*)	1,180
Midstory-nesting	
Black-chinned hummingbird (*Archilochus alexandri*)	17,459
Blue grosbeak (*Passerina caerulea*)	4,356
Mourning dove (*Zenaida macroura*)	3,405
Bewick's wren (*Thryomanes bewickii*)	3,235
Black-headed grosbeak (*Pheucticus melanocephalus*)	2,547
Understory-nesting	
Spotted towhee (*Pipilo maculatus*)	7,204
Yellow-breasted chat (*Icteria virens*)	2,408
Red-winged blackbird (*Agelaius phoeniceus*)	1,612
Common yellowthroat (*Geothlypis trichas*)	1,443
Chipping sparrow (*Spizella passerina*)	847
Water-obligate	
Common yellowthroat (*Geothlypis trichas*)	1,443
Mallard (*Anas platyrhynchos*)	290
Wood duck (*Aix sponsa*)	246
American coot (*Fulica americana*)	223
Blue-winged teal (*Anas discors*)	116
Spring migrant	
Black-chinned hummingbird (*Archilochus alexandri*)	3,449
White-crowned sparrow (*Zonotrichia leucophrys*)	1,071
Black-headed grosbeak (*Pheucticus melanocephalus*)	874
Yellow-rumped warbler (*Dendroica coronata*)	823
Cedar waxwing (*Bombycilla cedrorum*)	695

Results—We recorded 65,388 detections of 91 species of birds on the Middle Rio Grande during the breeding season. Of these, we classified 31, 19, and 35 species as canopy, midstory, and understory nesters, respectively, as well as 22 species as water-obligate. During the spring migration, we recorded 14,020 detections of 115 species migrating through the study area. The five most abundant species per group are shown in Table 4.

Densities of avian groups varied substantially among stands of cottonwood depending on structure and composition of the understory (Fig. 2). Among the tall-cottonwood types, canopy-nesting birds had highest densities in dense understory of either New Mexico olive or Russian olive, intermediate densities in dense understory of coyote willow or sparse natural understory, and significantly lower density in stands of cottonwood with mechanically cleared understory. Midstory-nesting birds and spring migrants showed similar patterns to the canopy-nesting birds. Understory-nesting birds had highest densities in cottonwood with understory of New Mexico olive; confidence intervals slightly overlapped those with understory of Russian olive or coyote willow. Mechanically cleared stands maintained an average of 27 understory-nesting birds/km^2, substantially lower than all

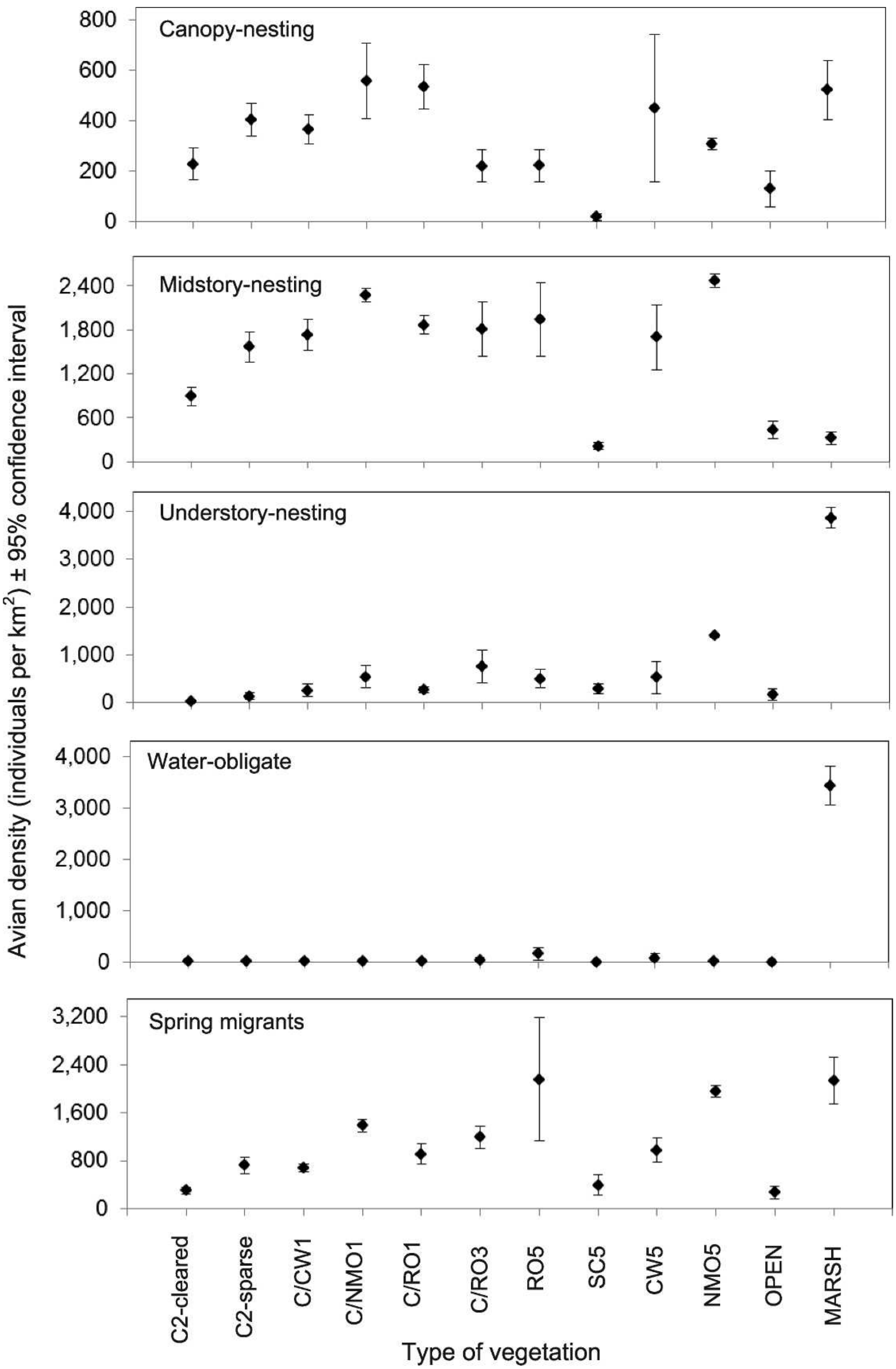

FIG. 2—Avian densities for five avian groups in 12 types of vegetation (codes defined in Table 1).

Table 5—Areas (in hectares) for 12 types of vegetation (described in Table 1) under current conditions and projected areas for the 12 types under eight scenarios (described in Table 2) for restoration of the Middle Rio Grande in New Mexico.

Type of vegetation	Current condition	Scenario							
		S1	S2	S3	S4	S5	S6	S7	S7W
C2-cleared	652.6	1763.7	0.0	0.0	0.0	746.2	746.2	0.0	0.0
C2-sparse	513.2	513.2	2,276.9	0.0	0.0	1,530.7	11.0	757.2	757.2
C/CW1	47.8	47.8	47.8	47.8	0.0	47.8	47.8	47.8	47.8
C/NMO1	60.3	60.3	60.3	204.4	21.2	60.3	88.2	88.2	88.2
C/RO1	550.5	0.0	0.0	1,572.1	441.6	0.0	963.0	963.0	963.0
C/RO3	560.7	0.0	0.0	560.7	188.7	0.0	528.9	528.9	528.9
RO5	0.0	0.0	0.0	0.0	1,387.5	0.0	0.0	0.0	0.0
SC5	0.0	0.0	0.0	0.0	96.6	0.0	0.0	0.0	0.0
CW5	0.0	0.0	0.0	0.0	98.4	0.0	0.0	0.0	0.0
NMO5	0.0	0.0	0.0	0.0	151.0	0.0	0.0	0.0	0.0
OP6	317.9	317.9	317.9	317.9	317.9	317.9	317.9	317.9	238.4
MH6	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	119.3

other tall-cottonwood vegetation that ranged from 132 birds/km^2 in cottonwood with sparse understory to 755 birds/km^2 in cottonwood with an understory of New Mexico olive (Fig. 2).

Avian densities varied across shrub and open stands, but patterns varied by group. Stands of saltcedar had low densities of all groups of birds (Fig. 2), while stands of Russian olive had relatively higher densities of all groups. Stands of coyote willow maintained highest density of canopy-nesting birds among stands of shrub, but confidence intervals overlapped with other types of shrub. Stands of New Mexico olives had high densities of midstory-nesting birds, understory-nesting birds, and spring migrants. Densities of all groups except midstory nesters were high in marsh habitat (Fig. 2).

Based on current distributions of vegetation, the study area was comprised of the following: 24% tall-cottonwood with mechanically cleared understory; 19% tall-cottonwood with sparse understory; 20% tall-cottonwood with understory of Russian olive; 20% short (younger) canopy of cottonwood and Russian olive; 12% open habitat; and smaller percentages of tall cottonwood with understory of coyote willow or New Mexico olive and stands of shrub (Table 5). Scenarios that increased the area of mechanically cleared understory within stands of cottonwood decreased abundances of birds when compared with current conditions (Fig. 3). For example, application of Scenario 1 decreased coverage of cottonwood with understory of Russian olive and increased the mechanically cleared stands to 64% of the study area. This scenario produced declines for all five groups of birds, with 59% decline for understory-nesting birds and 41% decline for spring migrants when compared with current conditions. Application of Scenario 2 decreased the area of mechanical clearing and increased the proportion of the study area in the naturally sparse or hand-thinned understory to 83%. This scenario reduced the decline in understory-nesting birds to 39% when compared with current conditions and resulted in a 16% increase for canopy-nesting birds. Scenario 5 provided a compromise between Scenarios 1 and 2 but still significantly reduced abundances of birds that were midstory nesters, understory nesters, and spring migrants when compared with current conditions (Fig. 3).

Scenarios that increased (or retained) dense understory vegetation generally increased abundances of birds when compared with current conditions (Fig. 3). Scenario 3, which resulted in a higher proportion of cottonwood with understory of Russian olive, increased abundances of all avian groups except for water-obligates. A hybrid scenario (Scenario 6) that applied the mechanical clearing to only the most urbanized areas had minimal changes in vegetational areas and no significant change in avian abundances. However, hybrid Scenario 7, that allowed some regrowth and applied hand-thinning to the urbanized reaches, generally increased abundances for all groups of birds, including significant increases for canopy nesters, midstory nesters, and spring migrants. With application of no management over the long term (MO4) to all reaches (Scenario 4), 63% of stands of cottonwood transitioned to shrub (51% of the area to Russian olive). In relation to current conditions, canopy-nesting birds declined but other groups were projected to increase significantly, based on assumed changes in vegetation. In comparison with current conditions, we projected significant increases for all nesting guilds in the scenario with restoration of wetlands (S7W; Fig. 3). A comparison of Scenario 7 with and without restoration of wetlands shows significant increases in understory-nesting birds and water-obligate birds given the restoration at assumed levels.

Discussion—Native vegetation has been replaced by exotics along many southwestern rivers with altered hydrologic conditions (Howe and Knopf, 1991; Poff et al., 1997). On the Middle Rio Grande, regulation of flow

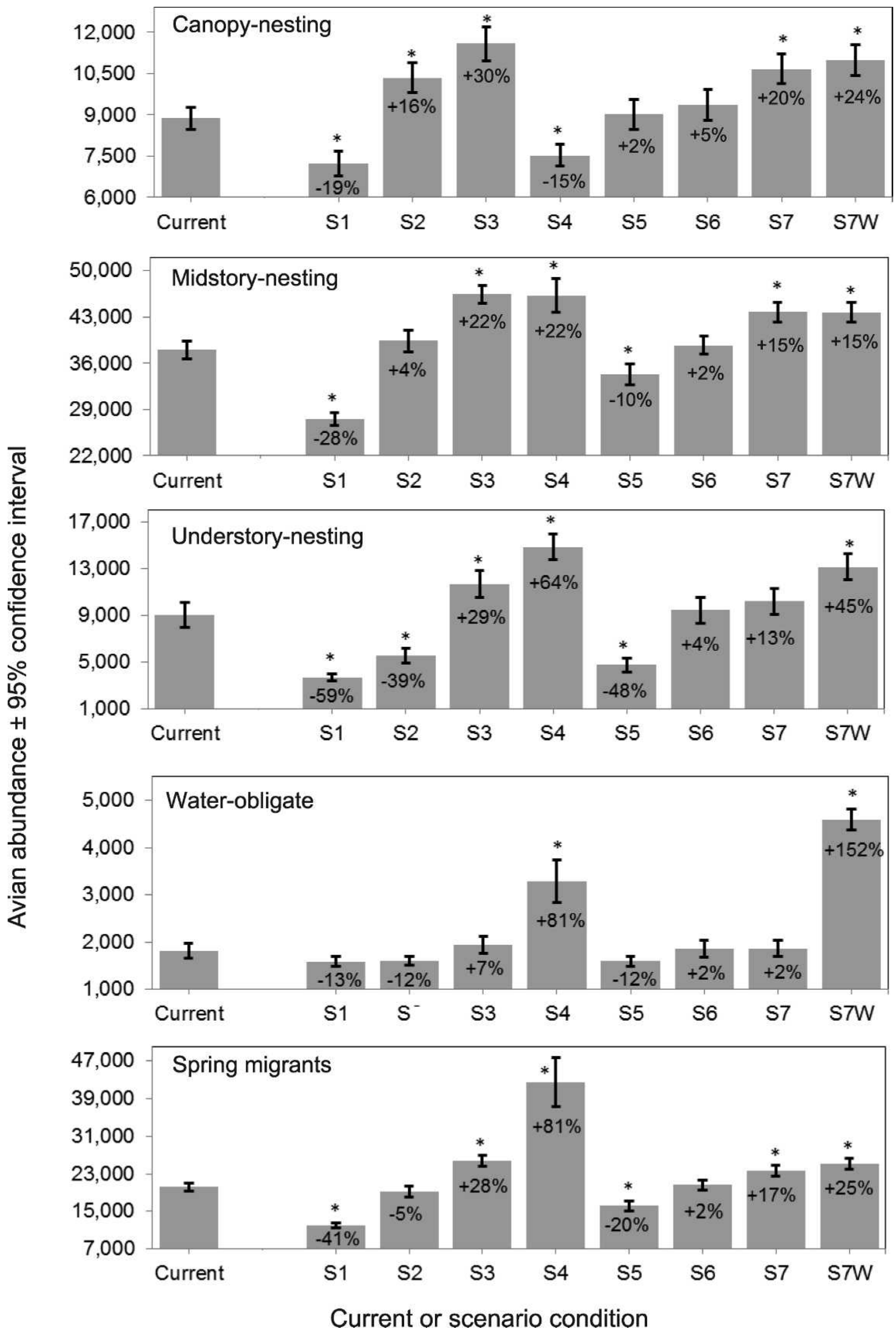

FIG. 3—Projected abundances of birds by avian group for current conditions and scenarios of restoration applied to the Middle Rio Grande in New Mexico. Projected percentage of change in abundance of birds from current conditions to each scenario is shown on bars. S1 = Scenario 1, S7W = Scenario 7 with restoration of wetland. An asterisk indicates significant differences between scenario and current conditions based on nonoverlapping 95% confidence intervals.

has eliminated large floods needed for recruitment of cottonwoods, and later-successional exotics such as Russian olive thrive in the wider range of moisture, light, and soil conditions (Howe and Knopf, 1991; Shafroth et al., 1995; Katz and Shafroth, 2003). Despite discussions about hydrologic restoration (e.g., Howe and Knopf, 1991; Molles et al., 1998), recent restoration projects have focused largely on clearing vegetation to remove exotics and reduce fire risk (Shah et al., 2007; Bateman et al., 2008). Our results indicate that such management is detrimental to densities of some but not all of the avian groups we considered.

Riparian vegetation on the Middle Rio Grande is important for avian diversity, with at least 277 species of birds using the area to breed, migrate, or overwinter (V. C. Hink and R. D. Ohmart, in litt.). Densities of birds of the Middle Rio Grande are influenced by structure and composition of the riparian forests. The findings that stands of cottonwood maintained higher densities across avian groups if they had dense (versus sparse) understories supports previous studies that have documented strong, positive relationships between volume of vegetation and abundances of birds (Mills et al., 1991; Fleishman et al., 2003). Cottonwoods with mechanically cleared understory had the lowest avian densities for all nesting guilds and for spring migrants, because simplification of the structure of vegetation affects not only bird guilds that require understory as nesting substrate but also those that primarily use understory vegetation to forage. Lower avian densities in these stands probably reflect low availability of resources such as prey, nesting sites, or roosting sites (Mills et al., 1991). The comparatively greater avian densities in stands of cottonwood with sparse understory (versus mechanically cleared) likely is due to greater opportunities for foraging and nesting provided by retention of some understory vegetation and an herbaceous ground layer.

We also found that densities of birds were influenced by species composition of vegetation, a finding similar to other studies in southwestern riparian systems (Fleishman et al., 2003; Walker, 2008). Understory-nesting birds historically may have depended on early-successional or pioneer species of plants (Farley et al., 1994), but many of these birds now occur in cottonwoods with dense, later-successional understory. Dense stands of cottonwood with an understory of pioneer coyote willow generally had lower avian densities than those with later-successional understories of New Mexico olive and Russian olive that have increased with terrestrialization of the Middle Rio Grande floodplain due to inadequate flooding (Molles et al., 1998). In a study on the Gila River in New Mexico where Russian olive was a minor component of the understory within stands of cottonwood, certain nesting birds of the understory and midstory, such as yellow-breasted chats and mourning doves, placed their nests preferentially in Russian olive, perhaps due to increased protective cover for nest sites (Stoleson and Finch, 2001). Overall, we found cottonwoods with nonnative understory (Russian olive) had intermediate avian densities in comparison with the understory of two native shrubs (New Mexico olive and coyote willow). Thus, similar to results of Fleishman et al. (2003), our findings support the hypothesis that birds cue on structure and composition of vegetation regardless of whether the vegetation species is native or exotic.

Composition of plants also affected avian densities within dense stands of shrub. New Mexico olive maintained highest densities of understory-nesting birds when compared with other woody vegetation, likely due to its denseness. Stands of New Mexico olive and Russian olive had high densities of midstory-nesting birds; other studies also documented the importance of Russian olive for shrub-nesting birds (Knopf and Olsen, 1984; Stoleson and Finch, 2001). The two types of olive also supported high densities of spring migrants. While large-scale biogeographical considerations influence whether migrants use the Rio Grande (Skagen et al., 2005), food availability provides one of the most important cues for habitat selection within the riparian corridor (Moore et al., 1995). Both Russian olive and New Mexico olive produce large crops of edible berries, some of which last through the year and are eaten by birds including cedar waxwings and black-headed grosbeaks during spring (T. Fetz, in litt.). Insectivorous species also occurred in high numbers in these types of vegetation (T. Fetz, in litt.), and some, such as the yellow-rumped warbler, likely shift their diet to frugivory when in migration (Kelly et al., 2000; T. Fetz, in litt.)

In contrast with stands of other shrubs, we found very low densities for all groups of birds in saltcedar. This finding contrasts with another study on the Rio Grande (Walker, 2008) and may result from differences in structure of stands, context of the landscape, or the greater distance of our stands of saltcedar from the river channel. Stands of Russian olive had higher-than-expected density of water-obligate birds, possibly due to proximity of these stands to the river channel, which may increase the prey base. While not possible with our study design, future studies should incorporate effects of riparian-upland gradients on avian communities.

Projection of avian responses to alternative scenarios of management on the Middle Rio Grande provides a means to assess possible future conditions prior to their application across a large spatial scale (Peterson et al., 2003). Clearing of understory on the Middle Rio Grande has been justified on the basis of removal of exotics and reduction of fire risk. Our results indicate that the effect of these two goals on the avian community will depend on the method and intensity of clearing. Overall, we found that mechanical clearing of understory to meet goals for reduction of fire risk and plans to maintain such conditions in perpetuity would have a substantial negative affect on avian populations. In contrast, selective hand-thinning of most exotics (but not natives) in the understory also reduced fuel loads, but only negatively impacted habitat for understory birds and improved habitat for birds that nest in the canopy. No clearing over the short term with subsequent increases in dense understory, particularly in the Albuquerque reaches, may increase fire risk but had a substantial positive affect on all nesting guilds and on spring migrants. Scenarios that reduced fuel loads by mechanical clearing or selective thinning only near urbanized zones (e.g., Albuquerque), but left dense understories undisturbed in outlying reaches, had either a net positive effect or no impact in comparison with current conditions for all avian groups. This exemplifies an approach that could be used to balance the need to reduce fire risk near municipal areas while also attempting to maintain populations of birds. When considered separately from reduction of fire risk, removal of exotic Russian olive would not necessarily be detrimental for birds depending on what vegetation replaced it. In particular, given the high avian densities observed in New Mexico olive, this plant could be incorporated in future restoration efforts that focus on replacing exotics.

The long-term scenario (S4) we considered revealed how avian communities may change in response to natural successional processes on the flow-regulated Middle Rio Grande. Without changes to the flood regime, and given the current age structure of cottonwoods, we projected that most of the stands of cottonwood in the Middle Rio Grande floodplain would transition to shrubs, primarily Russian olives (Howe and Knopf, 1991; Molles et al., 1998). Canopy-nesting birds declined in this scenario by 15%, given reduction in stands of cottonwood, though not as much as we expected. While canopy-nesting birds occur in relatively high numbers in Russian olive, this vegetation likely does not provide adequate nesting substrate for specific guilds including birds that nest very high in the canopy, primary and secondary cavity nesters, and raptors that require large horizontal branches as found in mature cottonwood trees (Hunter et al., 1987; Stoleson and Finch, 2001; Sogge et al., 2008); species in these groups probably would decline substantially under this scenario. Migrants did well under this long-term scenario and would perhaps benefit from berries of Russian olives as a food source during migration. However, Farley et al. (1994) found that a matrix of vegetational types was important for maintaining diversity of migrant birds on the Middle Rio Grande; thus, it is unclear whether decreased proximity to other types of vegetation in large, monotypic stands of Russian olive would maintain high-quality habitat for migrants. Further study would be warranted because the Rio Grande appears to perform as a funnel during migration and may influence widespread geographical areas (Yong and Finch, 1997).

Though once common in the Middle Rio Grande valley, most marshlands within the riparian corridor have been drained (Scurlock, 1998). Some wetlands have already been restored, and there are proposals to create or restore additional wetlands within the floodplain (O. Hummel, pers. comm.). Our results indicate that wetlands of similar characteristics to those we studied, which were relatively large, have the potential for substantial benefits to water-dependent species of birds, as well as spring migrants and understory-nesting species. Wetlands generally harbor high densities of water-dependent birds (Cody, 1985), and these high densities extend to restored or created wetlands (Hotaling et al., 2002; Lynn et al., 2006). The spatial distribution of wetlands, including aspects of size and relative isolation, is important in determining use by birds (Brown and Dinsmore, 1986), and future studies should incorporate analysis of these effects.

While our study projects changes in avian abundance under scenarios of restoration, it does not provide full indication of quality of habitat. Projections of density may overestimate quality of habitat if birds have low demographic success (Bock and Jones, 2004). While information regarding nest success of shrub-nesting birds is scarce in the Southwest (Sogge et al., 2008; Brand et al., 2010), Stoleson and Finch (2001) found no difference in nest success for three shrub-nesting species between Russian olive and native shrubs, though they did find higher rates of parasitism for willow flycatchers (*Empidonax traillii*) in Russian olive. Further work is needed to document nesting success for birds in stands of Russian olive, given projected increases in this type of vegetation. In addition, future experimental studies applied within a framework of adaptive management could help establish cause and effect between mechanical clearing of forest understory and decline of particular avian groups.

We thank the United States Army Corps of Engineers, Middle Rio Grande Bosque Initiative Group through the United States Fish and Wildlife Service, and the United States Bureau of Reclamation for funding the collection of field data. Analysis and writing portions were supported by SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) under the Science and Technology Program of the National Science Foundation (Agreement No. EAR-9876800), the United States Environmental Protection Agency "Integrated Modeling and Ecological Valuation" EPA STAR grant Program #2003-STAR-G2, the Science Impact Laboratory for Policy and Economics based at the University of New Mexico, and the United States Geological Survey in collaboration with the United States Department of Agriculture-Agricultural Research Service. We also thank the governmental agencies and private individuals that provided access to the study area and the field staff that collected data. J. Grandy, C. S. Crawford, J. Thatcher, and O. Hummel provided comments and insights pertaining to study design. We are grateful to G. D. Schnell, P. K. Kennedy, S. P. Jones, J. Demers, and two anonymous reviewers for their helpful comments that improved this manuscript. We are also grateful to S. A. Rosenfeld and K. Ramirez for translating the abstract.

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Submitted 7 January 2010. Accepted 23 March 2013.
Associate Editor was Gary D. Schnell.