Restoring habitat for riparian birds in the lower Colorado River watershed: An example from the Las Vegas Wash, Nevada

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ABSTRACT

The success of riparian restoration projects in the arid southwestern U.S. is often measured in terms of vegetation characteristics such as growth, cover, and structure. Among low-elevation riverine environments within the Colorado River watershed, restoration is typically conducted to improve degraded habitats for birds of conservation concern by replacing the exotic tamarisk (*Tamarix ramosissima*) with native cottonwoods (*Populus* spp.) and willows (*Salix* spp.). The working assumption for many restoration practitioners is that replacing exotic plants with native plants will improve habitat quality and will, therefore, benefit birds. Based on data collected at exotic and restored (i.e., native) sites along the Las Vegas Wash, Nevada, not all birds benefit from restoration. Broad measures of community benefit, including benefits to birds of conservation concern and riparian obligate/dependent birds, were not detected. There were, however, some species-specific benefits. Some environmental variables that were associated with exotic and native sites were significant in explaining the composition of the bird community. For example, the richness of forbs and grass-like plants (a proxy of soil moisture), invertebrate mass, and percent shade (a proxy for canopy characteristics) were important. Considering our results and depending on restoration goals, tamarisk replacement projects may not inherently provide benefits to birds.

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1. Introduction

Concerns with riparian restoration include whether restored environments result in net wildlife benefits and how these benefits are derived. Considering the example of birds in lowland riparian environments of the southwestern U.S., it is important that projects result in measurable benefits to wildlife because of the high cost of restoration (Zavaleta, 2000). Benefits from restoration, however, are unclear (Sogge et al., 2008) and without rigorous monitoring they may never be detected. Although many studies document that native vegetation may be more valuable than in-situ exotic vegetation (Anderson and Ohmart, 1977; Brand et al., 2008; Hunter et al., 1988; see Sogge et al., 2008), few restoration projects assess results of the replacement of exotic plants. To improve the practice of riparian restoration it is imperative that wildlife responses (positive and negative) are analyzed at these sites.

Controversy surrounds the value of riparian restoration for bird communities (Sogge et al., 2008) in association with tamarisk

(*Tamarix ramosissima*) control. Recently, Shafroth et al. (2005) have asked whether the environment that occurs following tamarisk control and revegetation is any better for wildlife than the original tamarisk habitat. The impact of tamarisk on avian communities is especially unclear when it seems that even a small percentage (20–40% cover) of native trees and shrubs within the tamarisk landscape can have a large positive influence on avian species diversity and abundance (van Riper et al., 2008). Bird use of tamarisk depends upon stand structure (Brown and Trosset, 1989), flowering phenology (McGrath et al., 2008), and stopover ecology (Paxton et al., 2008). Walker (2006) proposes that more studies are needed at a variety of tamarisk vegetation types and Walker (2006) also suggests that bird use of tamarisk is highly variable and that presently little information exists to explain why.

Hinojosa-Huerta et al. (2008) found that different factors play a role when comparing the value for birds of exotic versus native vegetation in riparian areas, including vegetation biomass, structural habitat diversity, and presence of surface water. Some variables such as proximity to water, attractiveness to pollinating insects, and understory plant characteristics are mentioned in Sogge et al. (2008) and might not be expected to necessarily have greater values in revegetated sites. Overall, it appears that the

response of avian assemblages to various riparian environments is dependent upon multiple factors at different spatial and temporal levels.

A major effort to restore and enhance ecological services in the Las Vegas Wash in Nevada has been underway since 2000. Because the channel is important to water resource infrastructure (i.e., flood conveyance, wastewater conveyance, etc.), the Southern Nevada Water Authority (SNWA) has been implementing enhancements on behalf of the 30-member Las Vegas Wash Coordination Committee stakeholder program (Las Vegas Wash Coordination Committee, 2010) to counteract past degradation. The Las Vegas Wash serves as the major surface water outlet for the Las Vegas Valley where population growth and increased water usage over the past five decades have dramatically increased water flow. Mean annual flows in the Las Vegas Wash doubled between 1990 and 2005. These increased daily flows, together with storm flows, caused erosion that led to an incised channel and disappearance of wetlands (Las Vegas Wash Coordination Committee, 2010). Stabilization of the channel bed has been taking place through constructed weirs, in conjunction with bank protection and revegetation. Revegetation with native plant species included structural dominants Fremont cottonwood (*Populus fremontii*) and willow (*Salix* spp.). In many cases vegetated sites were placed in areas where the terrain surface had been lowered and concrete or rock rubble structures had been placed in the channel to stabilize the riverine environment. The effect was to mimic a naturally functioning floodplain which provided the opportunity for occasional flooding. Historically the Las Vegas Wash was an intermittent stream that contained little mesic riparian woody vegetation (see Malmberg, 1965; Stave, 2001) and therefore the aim of "restoration" in this case is not directed to a pre-existing condition but rather toward what might be expected in a perennial stream in the region (Kloeppel et al., 2006).

The purpose of this study was to evaluate the success of recently completed restoration efforts (3–7 yr old) at the Las Vegas Wash by comparing breeding season bird assemblages found at non-manipulated exotic sites and at sites that were restored (manipulated) to more natural conditions (native sites). In particular we wanted to determine if restored riparian sites had higher diversity and abundance of birds, and identify differences at the community and species levels. We characterized environmental variables to help clarify expected differences in avian communities and we evaluated the consequences of restoration from a conservation perspective.

2. Materials and methods

2.1. Study area

Research took place along the Las Vegas Wash just east of Las Vegas, Nevada below 600 m a.s.l. (Fig. 1). The Las Vegas Wash is a perennial river consisting mostly of highly treated wastewater with lesser amounts of urban runoff and shallow groundwater. The general management goal for wildlife in the Las Vegas Wash is to enhance biodiversity services by providing best attainable conditions (Stoddard et al., 2006).

2.2. Study sites

We selected 10 sites to study in 2008 among 31 existing sites that were monitored for birds by Braden et al. (2009). Sites were selected to coincide with terrestrial invertebrate sampling sites. Of the 10 sites, half were exotic vegetation sites and half were native vegetation sites (Fig. 1; E = exotic, N = native). Exotic sites were dominated by tamarisk and common reed (*Phragmites australis*; invasive haplotype) whereas native sites were dominated by mixed
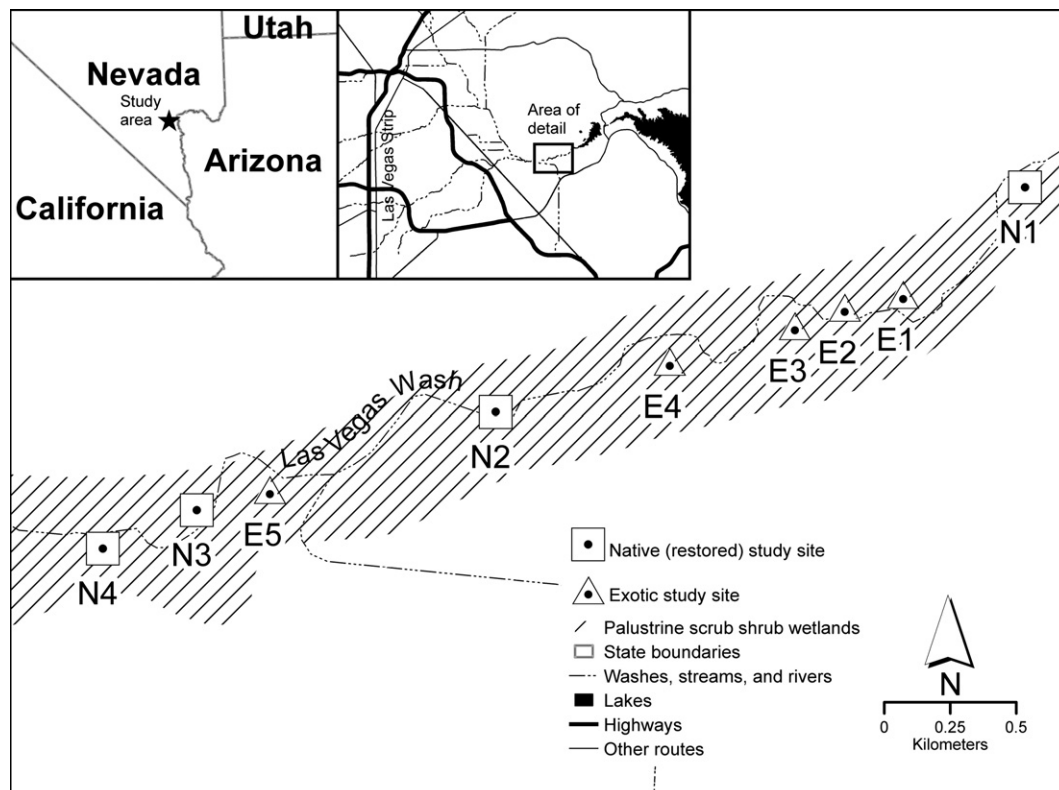

Fig. 1. Sites studied in 2008 for birds and environmental variables along Las Vegas Wash, NV USA. The Las Vegas Wash flows from left to right in the figure.

stands of Goodding's willow (*Salix gooddingii*), Fremont cotton-wood, and mesquite (*Prosopis* spp.). We selected for sites that were similar in mean vegetation cover and mean distance to water. Because sites were not entirely vegetated, we also selected sites similar in proportion of bare ground cover. As a proportion of total vegetation cover, we allowed up to 12% exotic cover in a native site and 12% native cover in an exotic site. However, total exotic cover in a native site and total native cover in an exotic site did not exceed 10%. Native sites were revegetated between 2001 and 2005 with densities >250 plants ha^{-1} and by 2008 they exhibited relatively mature stand characteristics. We delineated 1-ha areas (50–200 m each side depending upon site geography) to use as sampling units for collection of invertebrate metrics and most environmental variables. Site size was based on recommendations by Ralph et al. (1993) for bird studies (see Section 2.3). All sites were within the active floodplain and each site had perennial river water as an edge component.

2.3. Avian point counts

Birds were counted from sunrise to 10:00 am using standard five-minute point counts at stations (Ralph and Scott, 1981; Ralph et al., 1995) established at each of the 10 study sites (Braden et al., 2009). Birds that were seen or heard were counted within 50-m radius circular plots and we eliminated flyovers from the data set (surveyed area = 0.8 ha). Two counts were conducted at each site in the early (April), middle (June), and late (August/September) parts of the bird breeding season in 2008. Bird data collection timing coincided with periods of data collection for arthropods and environmental variables. Bird data were pooled across similar sites or seasons, as appropriate (see data analysis section).

2.4. Sticky-trap arthropods

Within each 1-ha study site, we used yellow single-sided sticky traps (The Tanglefoot® Company; 25.4 cm by 7.6 cm = 193 cm^2 surface area) to sample invertebrates at 5 equally spaced stations along a diagonal transect. Traps were folded, with the sticky side facing out, at the top of a 1-m long plastic pipe so that the vertical trap surface area was exposed in all directions. We set traps for 23 ± 2 h at each site during April, June, and September 2008. Collected traps were immediately placed in ziplock bags containing a small amount of Histo-Clear™ II (National Diagnostics), a citrus oil solvent that aided recovery of invertebrates from the sticky trap (e.g., Miller et al., 1993). In the laboratory, traps were again soaked in Histo-Clear™ in an enamel pan and invertebrates removed under 10 times magnification, identified to order, and placed in vials containing 70% propanol for later weighing. Samples were dried at 105 °C for 48 h, and weighed to determine dry mass.

2.5. Environmental variables

Vegetation canopy characteristics were measured at each study site in October 2008 (Braden et al., 2009). From the center of each bird counting station, a course was set for 3 directions (60°, 180° and 300°) and traveled for 20 m. A 20-m transect was then continued on from that point and at every 2 m, canopy height was measured. Mean canopy height and coefficient of variation (CV) of canopy height were calculated from these data. The CV provided a measure of heterogeneity in canopy height (structure). We used geographic information system (GIS) software to delineate the area of vegetation and other land cover types (e.g., bare ground and water) from 15-cm ortho-rectified aerial imagery collected in July 2008. Distance from the center of the site to the river channel was measured using GIS.

Soil moisture (percent saturation relative to field capacity; Kelway soil moisture tester Model HB-2) was measured at 3 representative locations in each study site. Theoretically soil moisture is a significant parameter because moist soils and seeps are recognized as important to some invertebrates for obtaining moisture and salts (Murphy and Wilcox, 1986) and to many riparian birds (Hinojosa-Huerta et al., 2008). Wind speed (km h^{-1}) and light were measured in the sites (3 different locations). Light measurements were compared to light levels in open areas and then used to calculate percent shade. Measurements were taken during each sampling season (April, June, and September).

Estimates of insect habitat quality were measured using floral (nectar) counts along with cumulative estimates of herbaceous/graminoid richness. During the collection of environmental variables, the numbers of flowers or inflorescences considered nectar sources were estimated. Although not a direct measure of nectar, Holl (1995) reports a linear relationship between nectar amount and number of inflorescences, and suggests little information gain from sugar quantification. Sampling took place within 10 4-m diameter circles at disjunct locations every 15–20 min during a survey. To estimate herbaceous richness at each site, a running-count of forb and graminoid richness was conducted, which resulted in a mean total number of cumulative taxa (pseudo-species in some cases) found in all circles for each season.

2.6. Data analysis

Landscape site type (native vs. exotic) and season effects (early, middle, and late breeding) on bird metrics (richness and abundance) were assessed using factorial ANOVA (type, season, and type*season) followed with Tukey's test(s) if significance ($p \leq 0.05$) was revealed. We evaluated community differences by assessing the following metrics: presence of riparian obligates/dependents (Rich, 2002); and birds that were considered to have a special status by the Nevada Wildlife Action Plan (NWAP; species of either stewardship or conservation priority). NWAP groupings were included in the data analyses so that differences between native and exotic site types were addressed from a broad conservation perspective. We calculated Morisita indices of similarity (Krebs, 1999) between native and exotic sites using pooled bird count data and data grouped by riparian obligate/dependent and NWAP conservation status. We performed z-tests to compare the proportional differences of riparian obligates/dependents and NWAP conservation species between site types.

ANOVA was used to test for differences in environmental variables between landscape types. Data were normalized, if needed, with arcsin-squareroot transformations for percent data and ln ($X + 1$) for numeric data. Although there were 5 samples in each of the site types (exotic vs. native), they were not strict replicates and thus inferences from these data may be weaker than those achieved with a true experimental approach (e.g., Block et al., 2001). In large part, this reflects the difficulty of achieving true experimental rigor at the scale of a hectare. This scale, however, is important because it is characteristic of many exotic vegetation control/restoration projects. Small-scale experiments (e.g., 10 m^2) at which many restoration ecology studies take place may allow for strict replication but may be poor at predicting actual restoration effects (Osenberg et al., 2006).

Constrained ordination techniques (CANOCO 4.5, Plant Research International, The Netherlands) were used to examine gradients in bird assemblages (species and abundance) and to identify environmental variables most closely associated with bird species distributions in the ordination. GIS and canopy height data were omitted from this analysis because data were not collected to coincide with every sampling occasion. Initial analyses of data

using detrended correspondence analysis (DCA) revealed that the data set had a relatively short gradient length (less than 3), suggesting that analysis using unimodal models was inappropriate. Therefore redundancy analysis (RDA) was used to explore relationships between assemblages (square-root transformed, infrequent species contributing ≤ 1 deleted) and environmental variables (ter Braak and Verdonschot, 1995). Environmental variables were normalized, if needed, with arcsin-squareroot transformations for percent data and ln $(X + 1)$ for numeric data. If environmental variables were highly correlated ($r \geq 0.6$) only a single variable was selected for use in RDA to avoid problems with multicollinearity. Partial RDA was used to eliminate the effect of season from the ordination. Forward selection of environmental variables and Monte Carlo permutations were used to determine whether variables exerted a significant ($p \leq 0.05$) effect on bird distributions.

3. Results

3.1. Environmental variables

Some environmental variables differed significantly ($p \leq 0.05$) between landscape types with values higher at native sites for heterogeneity in canopy height (CV), proportion of landscape that was water, soil moisture, riparian rank, forb and graminoid richness, and sticky-trap invertebrate richness (Table 1). Percent shade was significantly higher at exotic sites (Table 1). Some of the variables that were obtained on a single occasion (and therefore could not be used in ordination analysis) were highly correlated with mean values of variables collected throughout the season. For example, shade was negatively correlated with canopy height CV ($r = -0.7005$, $p = 0.02$), and positively correlated with proportion of the landscape that was vegetated ($r = 0.7093$, $p = 0.02$) and mean canopy height ($r = 0.8073$, $p = 0.005$); while forb and graminoid richness was correlated with the proportion of landscape that was water ($r = 0.6874$, $p = 0.03$). None of the interaction terms between season and landscape type were significant. With the exception of wind speed ($r = 0.3743$, $p = 0.042$), invertebrate mass was not significantly correlated with any environmental variable. Sticky-trap invertebrate richness and abundance, however, were correlated with forb and graminoid richness (richness, $r = 0.4516$, $p = 0.01$; abundance $r = 0.4103$, $p = 0.02$), soil moisture (abundance, $r = 0.4132$, $p = 0.02$), and nectar (abundance, $r = 0.5039$, $p = 0.0045$).

3.2. Birds

A total of 469 birds from 46 species were detected from exotic (total detections = 213, total richness = 33) and native (total detections = 256, total richness = 35) sites (Table 2). Avian species did not differ between landscape types in richness (exotic, $\bar{\chi} = 8.1 \pm 0.8$; native, $\bar{\chi} = 8.5 + 0.8$; $p = 0.74$) or abundance (exotic, $\bar{\chi} = 14.7 \pm 1.6$; native, $\bar{\chi} = 17.1 + 2.3$; $p = 0.3017$). Total detections during the early and late parts of the breeding season were not as numerous as the middle part of the season (early = 136, middle = 221, late = 112). Interaction terms between season and landscape type were not significant. No significant differences ($p \leq 0.05$) were detected between landscape types in richness or abundance for riparian obligate/dependent species or NWAP species. Morisita indices showed that bird abundance between exotic and native sites was highly similar for all species (0.78), NWAP species (0.96), and riparian obligate/dependent species (0.81). The proportion of NWAP species abundance at each of the site types was not different (exotic, $n = 83$, proportion = 0.39; native, $n = 83$, proportion = 0.32; $z = 1.38$, $p = 0.17$). Even though there were more

Table 1
Mean environmental characteristics of exotic and restored (native) sites ($\pm$standard error) studied along Las Vegas Wash, Nevada USA.

Environmental variable	Landscape site type		
	n	Exotic	Native
Mean canopy height (m)	10	3.64 ± 0.41^a	2.51 ± 0.56^a
Maximum canopy height (m)	10	7.62 ± 0.68^a	8.64 ± 1.27^a
Minimum canopy height (m)	10	0.80 ± 0.51^a	0.00 ± 0.00^a
Coefficient of variation of canopy height	10	54.57 ± 8.94^a	132.08 ± 22.74^b
Distance to river channel (m)	10	37.27 ± 8.46^a	40.64 ± 7.00^a
Proportion of landscape that was vegetated	10	0.82 ± 0.02^a	0.61 ± 0.09^a
Proportion of landscape that was bare ground	10	0.12 ± 0.006^a	0.26 ± 0.12^a
Proportion of landscape that was water	10	0.04 ± 0.02^a	0.10 ± 0.04^b
Proportion of landscape that was inaccessible	10	0.01 ± 0.006^a	0.03 ± 0.02^a
Soil moisture (%)	30	14.5 ± 4.1^a	42.4 ± 8.9^b
Riparian rank	30	5.1 ± 0.2^a	6.1 ± 0.1^b
Shade (%)	30	59.1 ± 4.8^a	39.8 ± 5.9^b
Wind speed (km h^{-1})	30	1.04 ± 0.31^a	2.21 ± 0.58^a
Nectar (florets m^{-2})	30	166 ± 71^a	191 ± 113^a
Forb and graminoid richness	30	1.2 ± 0.2^a	5.0 ± 0.6^b
Sticky-trap invertebrate richness	30	4.9 ± 0.3^a	6.3 ± 0.3^b
Sticky-trap invertebrate abundance (sampling occasion^{-1})	30	73.2 ± 15.3^a	96.1 ± 15.1^a
Sticky-trap invertebrate biomass (mg)	30	0.0681 ± 0.0184^a	0.0954 ± 0.0225^a

Rows with the same superscript letter indicate that no significant differences were found between landscape types for the given environmental variable, while those with different letters indicate that a significant difference ($P \leq 0.05$) was detected.

total detections at native sites, there was a greater proportion of riparian/dependents at exotic sites (exotic, $n = 131$, proportion = 0.62; native, $n = 124$, proportion = 0.48; $z = 2.73$, $p = 0.006$). Of the five most abundant bird species (Abert's towhee [*Pipilo aberti*], brown-headed cowbird [*Molothrus ater*], common yellowthroat [*Geothlypis trichas*], marsh wren [*Cistothorus palustris*], and song sparrow [*Melospiza melodia*]) none differed significantly ($p \geq 0.12$) in abundance between landscape types.

Initial environmental variables in the multivariate model included: forb and graminoid richness; nectar amount; percent shade; wind speed; and sticky-trap invertebrate richness, abundance and mass. Other variables were omitted because of highly significant correlations with selected variables (e.g., see Section 3.1). RDA indicated that forb and graminoid richness (correlated with soil moisture), sticky-trap invertebrate mass, and percent shade (correlated with canopy characteristics) were significant in describing the distribution of the bird community (Figs. 2 and 3). Results of the RDA for bird assemblages had eigenvalues of 0.098, 0.080, and 0.037 for the first three axes and explained 22.9% of the species data variation and 100% of the species–environment relationship. Forb and graminoid richness was correlated with Axis I, invertebrate mass associated with Axis II, while percent shade was mostly correlated with Axis III (Table 3).

There was separation in the RDA diagram by landscape type with native vegetation sites mostly in the positive portion of Axis I and exotic vegetation sites in the negative portion of Axis I (Fig. 2). One site (E-5) tended to associate with native vegetation sites in the

Table 2
Bird species detected during surveys conducted in 2008 at Las Vegas Wash, NV USA that were listed by the Nevada Wildlife Action Plan (NWAP) as conservation or steward species, and by Rich (2002) as riparian dependents or obligates.

Common name	Scientific name	Number Detected	NWAP status	Riparian dependency
Abert's towhee	*Pipilo aberti*	46	Conservation	Obligate
Bewick's wren	*Thryomanes bewickii*	20		Dependent
Black Phoebe	*Sayornis nigricans*	6	Steward	
Black-chinned hummingbird	*Archilochus alexandri*	3		Dependent
Black-tailed gnatcatcher	*Polioptila melanura*	14	Steward	
Blue grosbeak	*Guiraca caerulea*	8	Steward	Obligate
Common yellowthroat	*Geothlypis trichas*	42		Obligate
Costa's hummingbird	*Calypte costae*	2	Conservation	
Crissal thrasher	*Toxostoma crissale*	2	Conservation	
Great-tailed grackle	*Quiscalus mexicanus*	11	Steward	
Lazuli bunting	*Passerina amoena*	1		Dependent
Least bittern	*Ixobrychus exilis*	1	Conservation	
Lesser goldfinch	*Carduelis psaltria*	6		Dependent
Lucy's warbler	*Vermivora luciae*	26	Conservation	Dependent
Song sparrow	*Melospiza melodia*	47		Obligate
Southwestern willow flycatcher[a]	*Empidonax traillii extimus*	1	Conservation	Obligate
Spotted sandpiper	*Actitis macularius*	1	Steward	
Verdin	*Auriparus flaviceps*	25	Conservation	
Western wood-pewee	*Contopus sordidulus*	1		Dependent
Wilson's warbler	*Wilsonia pusilla*	2		Obligate
Yellow warbler	*Dendroica petechia*	29		Obligate
Yellow-breasted chat	*Icteria virens*	24	Steward	Obligate

[a] Federally endangered species detected beyond the 50-m radius plot.

diagram; this exotic vegetation site contained a band of native sandbar willow within it. Forb and graminoid richness increased along Axis I and was also significantly higher at native vegetation sites (Table 1). Birds found at the extremes of Axis I included the marsh wren and yellow warbler (*Dendroica petechia*) at the positive end, and in the negative portion of the axis, Bewick's wren (*Thryomanes bewickii*). It appeared that there were differences in abundance of these particular bird species between the landscape types. Bewick's wren and yellow warbler were evenly distributed at sites within the given landscape and differed in abundance significantly between landscape types (Bewick's wren, native sites, $\bar{\chi} = 0.2 \pm 0.2$, exotic sites, $\bar{\chi} = 3.8 \pm 0.8$, $p < 0.002$; yellow warbler, native sites, $\bar{\chi} = 5.4 \pm 1.8$, exotic sites, $\bar{\chi} = 0.4 \pm 0.4$, $p \leq 0.002$). The marsh wren, however, was only found at two of the native vegetation sites (N-1 and N-2) and these sites were responsible for 77% of the detections. It is likely that the variance associated with this bird led to the non-significance (native sites, $\bar{\chi} = 6.0 \pm 4.0$, exotic sites, $\bar{\chi} = 1.4 \pm 0.8$, $p = 0.12$) in abundance between landscape types. The sites N-1 and N-2 appeared to be somewhat separated in ordination space from the other native vegetation sites and it was noted that both of these sites had strong components of emergent vegetation like cattails (*Typha domingensis*). Invertebrate mass was associated with Axis II and bird abundance was correlated with invertebrate mass ($r = 0.5568$, $p = 0.0014$) (Fig. 4).

Percent shade was most associated with Axis III (Fig. 3). Sites in the positive portion of Axis III were almost all exotic vegetation sites. The single exception was the native vegetation site (N-2) which was a densely vegetated island site.

4. Discussion

4.1. Overall bird community

Broad measurements of the bird community (similarity indices, richness, and abundance) did not discern any differences between native and exotic sites. The presence of migratory species during
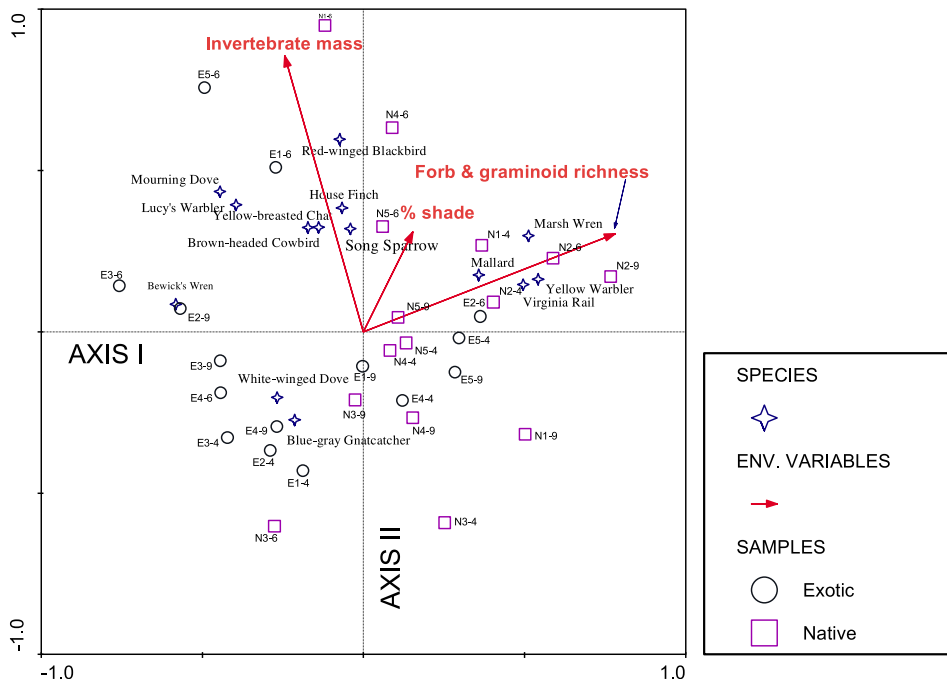

Fig. 2. Redundancy analysis for Axes I and II showing the distribution of the bird community and study sites in ordination space as they relate to environmental variable trajectories. Data are from sites studied in 2008 along the Las Vegas Wash, NV USA. In the plot, only species with a fit above 10% are shown.
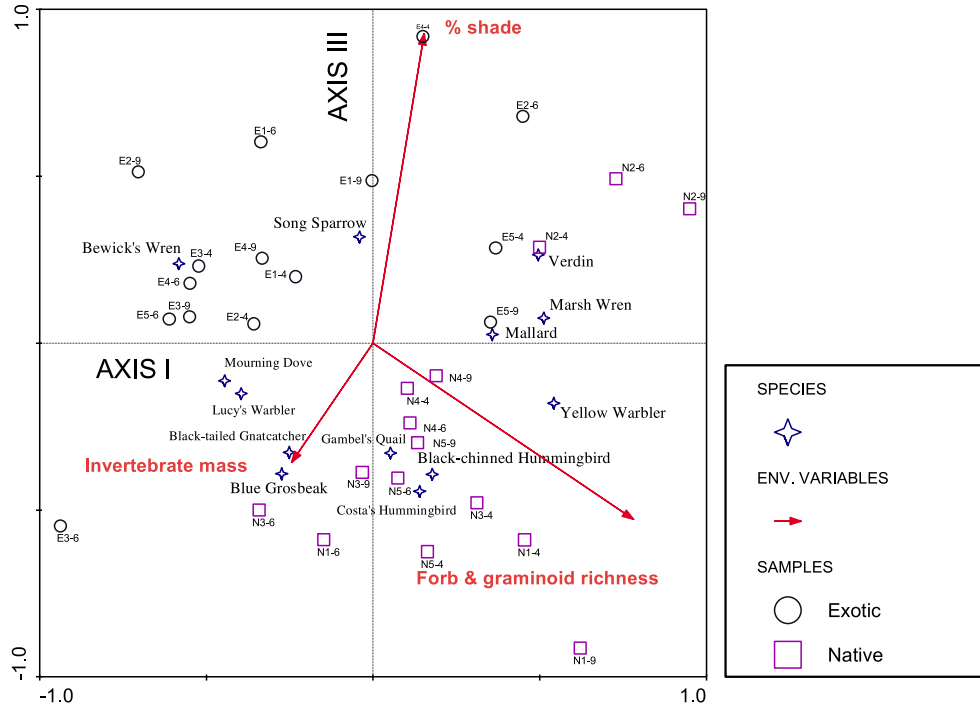
Fig. 3. Redundancy analysis for Axes I and III showing the distribution of the bird community and study sites in ordination space as they relate to environmental variable trajectories. Data are from sites studied in 2008 along the Las Vegas Wash, NV USA. In the plot, only species with a fit above 10% are shown.

the early part of the breeding season does not appear to confound these results since we did not detect a migratory pulse. Species of conservation concern were equally represented in both site types, suggesting that restoration did not broadly improve conditions for these birds. The detection of an individual southwestern willow flycatcher (*Empidonax traillii extimus*) at a native site (N5; detected beyond the 50-m sampling plot from May 28 to June 30) provides minimal positive evidence of some conservation benefit. Riparian birds made up a greater proportion of the community at exotic sites even though Morisita indices showed that riparian bird composition was very similar between site types. Overall, restoration did not appear to grossly improve community attributes from either general or conservation perspectives.

4.2. Species-specific differences between exotic and native sites

We detected species-specific differences but only a few bird species appeared to be strongly associated with one or the other landscape. For example, Bewick's wren was mostly found at exotic vegetation sites, suggesting that restoration did not successfully increase abundance of this species. Rosenberg et al. (1991) found that, among other shrubby habitats, Bewick's wren nest in tamarisk with an overstory of cottonwoods and Taylor (2003) found these

areas to harbor the greatest abundance of wrens. Because none of our native sites were structurally dominated by cottonwoods, together these findings suggest that in the absence of a cottonwood overstory, Bewick's wrens are more abundant in tamarisk dominated sites than native dominated sites.

Yellow warbler results show a related but somewhat different trend in that they were more abundant at native vegetation sites. This trend showed that restoration was successful for this species. In contrast, Heath (2008) states that yellow warblers are predominately found in tamarisk along the lower Colorado River. Birds, however, may have been forced into tamarisk habitat because of the decline of native vegetation on the river (Heath, 2008). Besides the yellow warbler's probable affinity for native vegetation types, this association may also be related to the higher amount of backwater habitat found therein. Yard et al. (2004) found that the diet of

Table 3
Weighted correlation matrix showing relationship between species axes and significant environmental variables from data collected along the Las Vegas Wash, NV USA.

Environmental variable	Axes		
	1	2	3
Forb and graminoid richness	**0.6107**	0.2199	−0.3505
Invertebrate mass	−0.1977	**0.6384**	−0.2450
Percent shade	0.1200	0.2239	**0.6160**

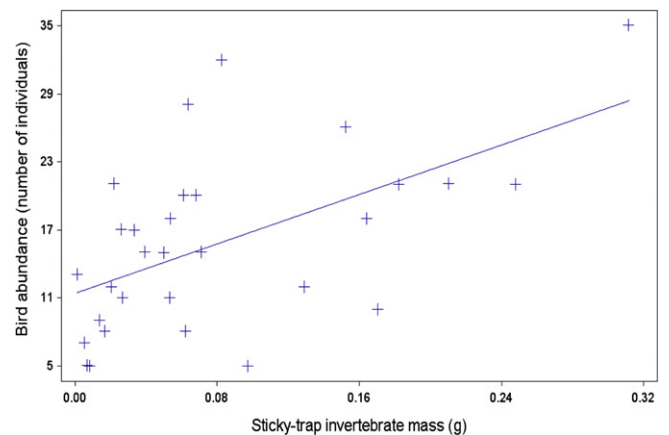Highest correlations associated with a given variable are shown in bold.

Fig. 4. Relationship between sticky-trap invertebrate mass and bird abundance ($r = 0.5568$, $p = 0.001$) at exotic and native (restored) study sites along the Las Vegas Wash, NV USA.

yellow warblers in canyon areas of the Colorado River differed from other insectivorous birds in utilizing large amounts of aquatic midges. These midges may be more abundant in habitat that contains standing water. There were significantly higher amounts of standing water at native vegetation sites along the Las Vegas Wash.

Detecting a bird within an environment provides only limited information and few studies have examined how breeding in different riparian environments actually affects bird survivorship and productivity (e.g., Sogge et al., 2008). In the present study, neither landscape type provided large, old trees and this may explain the near absence of certain species such as 'timber drillers' (woodpeckers) and habitat specialists such as summer tanager (*Piranga rubra*) which are associated with cottonwood-dominated riparian areas in other systems (Ellis, 1995).

4.3. Importance of site-specific environmental variables

The association of environmental variables with bird assemblages seemed complex, with forb and graminoid richness (which was highly correlated to soil moisture and proportion of landscape that was water), invertebrate mass, and percent shade (which was highly correlated with canopy characteristics) all playing small parts in structuring communities. Forb and graminoid richness and percent shade differed significantly between landscape types while invertebrate mass did not. Our results did not completely fit with any of the hypotheses posited by Durst et al. (2008) that could potentially explain this. For example, Durst et al. (2008) hypothesized that a "tourist" effect (immigrating invertebrates from adjacent habitats) could cause exotic and native sites to be equally diverse and exotic sites could potentially contain more biomass. Our limited study was unable to confirm a "tourist" effect, however, the close proximity of our sites and the adjacency of highly productive invertebrate source-habitats (streamside habitats) provide some evidence that this effect may have been important. Other sticky-trap invertebrate metrics (richness and abundance), however, were correlated with other environmental variables such as forb and graminoid richness, soil moisture, and nectar.

Some environmental variables appear to be more important to birds than others. Williams (1993), for example, pointed to the important trophic linkages between flowering plants, arthropod populations, and bird communities. Our study and others (e.g., Walker, 2006) suggest that some bird habitat use may be less dependent upon the presence of particular woody vegetation then on understory characteristics like forb and graminoid richness (and its correlates; e.g., soil moisture and proportion of landscape that was water). If increased soil moisture and increased backwater habitats were constructed in environments dominated by tamarisk a bird community similar to that found in native vegetation might be achieved.

Our finding that the composition of bird communities is affected by increased site wetness may be responsible for some of the confounding patterns observed in avian communities when different river systems are observed. Hunter et al. (1988) observed declines in certain birds on the Colorado River that were coincident with the proliferation of tamarisk, while these bird communities were stable in other tamarisk dominated riparian systems in different geographical areas. It was suggested that differences in climate could differentially affect birds within the same exotic vegetation landscape, but in different river basins. Our limited study suggests that there could also be differences in forb and graminoid richness or invertebrate biomass between exotic vegetation landscapes that could also result in changes in bird communities. Walker (2006) proposes a similar scenario and postulates that variation in floristics associated with tamarisk-

dominated vegetation might be useful in explaining avian use of tamarisk. Part of this derives from the observation that where tamarisk vegetation is similar in structure to native vegetation, these habitats generally support similar avian richness and density (Walker, 2006). Fleishman et al. (2003) have also found that species richness of native birds along the Muddy River in Nevada was best predicted by total vegetation volume and that bird species richness was not negatively affected by invasive non-native plants (including tamarisk). Perhaps the tendency for research that focuses on the dominant landscape feature (woody riparian vegetation) may have resulted in omitting other environmental aspects that are also important in driving bird assemblage makeup.

Understory components (forb and graminoid richness) and invertebrate characteristics (found in the first two axes of the multivariate analysis) were most important in describing bird distributions. Forb and graminoid richness, in turn, was correlated with the proportion of the landscape that contained water (backwater environments). Bird presence in riparian environments, according to our model, will change according to variables such as the proportion of water in the landscape and understory characteristics. These variables might be more affected by a site's placement in the environment than by the dominant woody vegetation. The importance of connecting riparian floodplains with the riverine environment has been recognized as vital in riparian restoration (e.g., Cabezas et al., 2008); and in the study by Hinojosa-Huerta et al. (2008) the presence of surface water was a significant predictor of avian richness and abundance, regardless of vegetation type. Further, Sogge et al. (2008) used standing water as a principle variable for defining suitable southwestern willow flycatcher habitat. It may not take a large amount of this sort of connective habitat to increase the potential value of riparian habitat to birds. There were limited amounts of this sort of backwater habitat with the highest mean proportion of water (10%) found at native landscape types. Increasing percentages of this habitat were, however, positively associated with other aspects of the environment that seemed to explain portions of the distribution of birds.

4.4. Implications for riparian restoration

Unlike recent (see van Riper et al., 2008) and historical (see Anderson and Ohmart, 1977) findings, we did not observe reduced overall abundances at our exotic sites when compared to our native sites. But like van Riper et al. (2008) finding that bird communities will respond positively from limited interventions (i.e., adding ~20–40% native vegetation), our study seems to suggest that other limited interventions (e.g., increases in site wetness) may produce an important response. Increasing site wetness may even be a more cost effective way to improve some bird communities, at least in mesic environments. We recognize that even native riparian areas have a wide range of characteristics that may impact bird communities in different ways (e.g., the marsh wren in this study). Nest substrate and vertical vegetation structure are among the important habitat qualities that impact bird communities (Brand et al., 2010; Brown and Trosset, 1989) and these qualities likely affected our results and other restoration responses observed across the globe (e.g., see Munro et al., 2011). Vegetation structure has been implicated as a primary driver of some positive bird community responses (e.g., bird species richness; see Cueto and de Casenave, 1999). It could be that there is a large array of qualities within native landscapes and that tamarisk environments might be found to exist along this gradient. The often perched, non-mesic environments within which tamarisk is often dominant should not be expected to provide the same level of bird use that would exist in areas that are dynamically interacting with a riverine floodplain. This pertains to both exotic and native vegetation.

Avian species richness/abundance did not differ between native and exotic sites suggesting that restoration did not clearly show improvements in broad measures of the bird community. Further, differences were not detected in metrics associated with birds of conservation concern, for which many restoration projects are purposely implemented. We recognize that meaningful community differences may have gone undetected because our study design may not have transcended scalar thresholds where responses may be detected. We further recognize that potential scale-dependent effects are important to consider when assessing the successful-ness of complex real-world situations. We did detect, however, species-specific differences between the two landscape types with each type harboring important species from the community. The presence of both landscape types likely had a net environmental benefit on the bird community because of the structural, floristic, and hydrologic additions of native site components. As we have stated, potential scale-dependent effects may also be influencing our results. When considering the effect of spatial scale on habitat use by riparian birds, Saab (1999) concluded that landscape patterns were of primary importance and patch-scale patterns were of secondary importance. It is at least reasonable to conclude that birds at our study sites were influenced by multiple spatial scales. Overall, our small scale study demonstrated that restoration was successful from a species-specific perspective but that community metrics were unchanged suggesting that both land-scape types are important in maintaining gamma diversity of birds.

Acknowledgments

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