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ABSTRACT

The use of a bird community index that characterizes ecosystem integrity is very attractive to conservation planners and habitat managers, particularly in the absence of any single focal species. In riparian areas of the western USA, several attempts at arriving at a community index signifying a functioning riparian bird community have been made previously, mostly resorting to expert opinions or national conservation rankings for species weights. Because extensive local and regional bird monitoring data were available for Nevada, we were able to develop three different indices that were derived empirically, rather than from expert opinion. We formally examined the use of three species weighting schemes in comparison with simple species richness, using different definitions of riparian species assemblage size, for the purpose of predicting community response to changes in vegetation structure from riparian restoration. For the three indices, species were weighted according to the following criteria: (1) the degree of riparian habitat specialization based on regional data, (2) the relative conservation ranking of landbird species, and (3) the degree to which a species is under-represented compared to the regional species pool for riparian areas. To evaluate the usefulness of these indices for habitat restoration planning and monitoring, we modeled them using habitat variables that are expected to respond to riparian restoration efforts, using data from 64 sampling sites in the Walker River Basin in Nevada and California. We found that none of the species-weighting schemes performed any better as an index for evaluating overall habitat condition than using species richness alone as a community index. Based on our findings, the use of a fairly complete list of 30–35 riparian specialists appears to be the best indicator group for predicting the response of bird communities to the restoration of riparian vegetation.

1. Introduction

Riparian areas of the semi-arid Intermountain West (USA) are responsible for a large proportion of biological diversity in this region (Knopf et al., 1988; Ohmart, 1994). Their high productivity also makes riparian areas among the most valuable lands for human uses in desert regions, which has resulted in degradation and transformation due to agriculture, water diversion, and channelization (Patten, 1998). As a result of these major impacts to western rivers, much effort and money has been devoted to the goal of restoring historical conditions of river channels and floodplains (Goodwin et al., 1997; Rood et al., 2003), often with the explicit objective of improving wildlife habitat conditions. It is therefore surprising that there has not been more standardized scientific planning and success evaluation made available for guidance in projects that have multiple wildlife objectives (Palmer, 2009).

Restoration planning and monitoring requires some method of site evaluation, and the first step in this process is selecting appropriate environmental indicators (e.g., Carignan and Villard, 2002; Caro, 2010). Despite a great deal of literature on the subject, however, the selection of such indicators is often arbitrary and the indicators themselves are rarely tested (Niemeijer and de Groot, 2008).

The development of biological criteria for site evaluation using faunal communities has become an important approach to riparian monitoring and assessment (Carignan and Villard, 2002), and many different taxa have been used (Hilty and Merenlender, 2000). In general, species assemblages have been found to make better indicators of ecosystem integrity than single species, regardless of the criteria by which these species were selected (Hutto, 1998;

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Niemeijer and de Groot, 2008). This may especially be the case if, as often occurs, there may be no singles species that can serve as an “umbrella” or other surrogate for all wildlife needs (Caro, 2010), and many species of conservation concern may be rare or absent.

Birds have often been proposed as indicators of ecosystem integrity (e.g., Croonquist and Brooks, 1991; Morrison, 1986). Birds are particularly useful for scientific planning and evaluation of riparian restoration projects because most riparian-associated species respond quickly and sensitively to habitat change (Sanders and Edge, 1998). A complete riparian bird assemblage may use riparian areas for nesting, foraging, or migration corridors, and requires a diversity of microhabitats (Saab, 1999), often missing in a landscape that has been simplified by past land uses. Also, well-established and easily replicated survey protocols can monitor a large number of bird species at once (Hutto, 1998; Ralph et al., 1995). However, any indicator set might still be enhanced by the inclusion of other taxa (Caro, 2010).

Past attempts at using bird community data for the purpose of riparian habitat evaluation included approaches using expert opinion about the habitat specializations of bird species (e.g., Rich, 2002; Wiens et al., 2008), historical comparisons of species abundances (e.g., Ammon, 2002), or habitat modeling for individual species that serve as surrogates for larger species groups (e.g., Caro, 2010; Dickson et al., 2009). More quantitative and empirically tested tools are needed (Simaika and Samways, 2009).

Community summary statistics have been criticized for potentially hiding more than they reveal (Lamb et al., 2009), and species richness, in particular, is criticized for treating all species the same (Fleishman et al., 2006). Species differ in conservation concern, in degree of habitat specialization, and in regional habitat occupancy. The objective of this paper is to test whether a bird community index could be developed that responds to habitat restoration more sensitively than species richness alone, by weighting species according to these three criteria.

This paper addresses the use of bird community indicators for conservation planning and monitoring on the Walker River in west-central Nevada, USA, which is currently the focus of watershed-wide restoration planning. Because extensive bird monitoring data were available for Nevada, we were able to develop three different indices based on both local and regional bird data, rather than from expert opinion. The usefulness of each of these indices for riparian restoration planning and monitoring was then evaluated based on how well they are expected to respond to changes in riparian woody vegetation, as modeled using variables derived from LiDAR and other vegetation mapping methods.

2. Methods

2.1. Study area

The Walker River drains the eastern slopes of the Sierra Nevada in Mono County, CA, and flows in two forks through Douglas, Lyon, and Mineral Counties, Nevada, to its terminal lake, Walker Lake (Otis Bay Ecological Consultants, 2009). The headwaters and higher elevations of the east and west forks are dominated by montane meadow and riparian vegetation such as shrub-willow (*Salix* spp.) and aspen (*Populus tremuloides*), and the lowland areas are dominated by riparian gallery forests (primarily Fremont cottonwood, *Populus fremontii*), agricultural areas, and transitional shrub communities. Much of the historic lowland floodplain has been converted for agricultural uses, but significant sections of riparian shrublands and woodlands are still present. Despite an artificial wetland management area and several reservoirs, floodplain wetlands are relatively rare in the lower elevations (Sharpe et al., 2007), although they were historically more abundant (Dilts et al., 2012).

2.2. Bird surveys

Birds were surveyed during the breeding season, over a period of five years (2006–2010). Thirteen transects were randomly placed along accessible sections of the Walker River, primarily in lowland reaches within the cottonwood zone, but with some transitional montane shrub-willow communities. The study area covered about 350 km of river distance, and the elevation range was 1210–1960 m. Each transect had ten survey points spaced at 250 m apart, as near as possible to the river edge.

Survey effort varied among years as new transects were established, with one visit to six transects in 2006, two visits to ten transects in 2007, three visits to 13 transects in 2008, two visits to 13 transects in 2009, and two visits to 12 transects in 2010.

Birds were sampled using standard 10-min point counts (Ralph et al., 1995). The surveys were conducted between May 25 and July 10, between sunrise and 10:00 a.m. in fair weather conditions. For this paper, we included only those birds detected within a 100-m-radius circle from the survey point, excluding fly-over observations, in order to correlate bird detections with local habitat features.

2.3. Bird community indices

We developed indices based on the bird community using a two-step process. We first defined the list of riparian species to be considered in the index, and then considered differential weightings of these species using three separate criteria.

2.3.1. Defining the species assemblage and effects of species inclusion

The indicator species that are expected to be most useful for habitat conservation planning are those specialized on the target habitat (Pearson, 1994). We used two alternative methods for ranking the bird species observed on the Walker River according to their degree of specialization on riparian habitats, based on (1) regional data on relative abundance in riparian versus non-riparian habitats and (2) inclusion in riparian nesting guilds. In both cases we excluded all waterbirds (e.g., shorebirds, colonial nesters, and non-passerine marsh birds) from the species list, because our survey method was not designed for them, as well as aerial foragers (e.g., raptors, swallows, swifts, nighthawks), because these could not be tied to local habitat conditions that were subject to restoration. We also excluded non-native species.

For ranking riparian specialization based on relative abundance in riparian compared with non-riparian sites, we used data from 225 transects in the Great Basin region of Nevada, within the same elevation range as the Walker River data (1200–2000 m), collected during the Great Basin Bird Observatory's ten-year Nevada Bird Count program (2002–2011). The program uses a habitat-stratified sampling plan, which categorizes transects according to their dominant habitat types. We compared the mean abundance per point-count survey for each species on the 118 transects from non-riparian habitats versus the 107 riparian- or aspen-dominated transects (aspen is most often riparian-associated in Nevada and supports a riparian bird community). We further filtered the data at the individual point level by using a GIS cover type map, and used only the 980 points from riparian transects that also had riparian habitat within 100 m, and only the 980 points from non-riparian habitats that did not. We used the ratio of the abundances in these two datasets to score the degree of riparian specialization. To select the best threshold for inclusion in the riparian species list, we then used the resulting scores to progressively remove the least specialized species from the list of species used in the indices.

The second method of selecting riparian specialists followed a more traditional guild-based approach often used in the development of bird-based indices (e.g., Bradford et al., 1998; Bryce et al., 2002). We assigned species to nesting guilds based on their known natural history (e.g., Poole, 2005), and included only those species that depend on broadleaf riparian trees or shrubs for nesting. This was intended to further restrict the list of species to those that are more dependent on the woody vegetation that is most affected by restoration, and specifically for breeding rather that just foraging or migration.

2.3.2. Weighting species

To evaluate the effects of weighting species for refining community indices, we included a "baseline" index where all species were weighted equally (*Species Richness Index*) in our community index evaluation. The other indices were developed using species weightings based on (1) degree of riparian habitat specialization, (2) relative conservation ranking of landbird species, and (3) degree to which a species is underrepresented in the Walker River basin when compared with other riparian areas in the same ecoregion.

2.3.2.1. Riparian Specialization Index (RSI). Because a species' degree of habitat specialization is expected to be particularly important for its response to habitat restoration, we created an index that weights species according to riparian specialization. We began with the same habitat specialization metric described in Section 2.3.1 for defining the species assemblage, based on the ratio of riparian to non-riparian abundances in the region, and then assigned these ratios to category rankings to achieve 10–12 species in each of the five ranks, with higher values indicating greater specialization for riparian and aspen habitats: a score of 1 was assigned to species with a mean abundance at riparian points that is the same to three times as high as their mean abundance at non-riparian points, a score of 2 was assigned to those three to seven times as abundant at riparian points, a score of 3 to those seven to 25 times as abundant. Species greater than 25 times as abundant on riparian points scored 4, and those species found exclusively at riparian points scored 5.

2.3.2.2. Partners in Flight (PIF) Index. Because species differ in degree of conservation concern, we also examined an index that weights species according to a nationally recognized conservation ranking system. PIF developed this system to rank conservation priority among all North American landbird species (Beissinger et al., 2000; Panjabi et al., 2012), and it has been suggested that the PIF scores for an entire bird assemblage may be used to rank sites for conservation planning and monitoring (Nuttle et al., 2003).

The PIF index combines scores for several different measures related to conservation status of bird species (Panjabi et al., 2012). These attributes are each ranked on a 1–5 scale with higher ranks indicating greater conservation concern. Scores are calculated at the continental level and also at the level of Bird Conservation Regions (BCR), which are based on broad biome divisions. The regional scores are based on: (1) global population size (with high scores indicating smaller population size and thus greater conservation concern), (2) global breeding distribution, (3) regional threats to breeding, (4) regional population trend (steep declines score higher than small or no declines), and (5) relative density (higher scores indicate higher density of a birds species in the BCR relative to the densest region, and thus greater regional stewardship responsibility).

We used the combined regional PIF bird conservation score, which represents the sum of the individual scores in the five categories defined in the previous paragraph, for the breeding season in the Great Basin BCR (Panjabi et al., 2012), resulting in total scores potentially varying from 5 to 25.

2.3.2.3. Representation Index (REP). Another approach to evaluating riparian bird assemblages is to compare them to those of the same habitat types in the larger region in order to determine what species are available in the regional species pool, but missing locally (Rich, 2002). If a species is underrepresented on the Walker River compared with other lowland riparian sites in the region (Great Basin portion of Nevada), we assume that the Walker River currently lacks adequate habitats for these species, even if they may have been present historically. This approach uses the regional bird community in lieu of a reference condition to evaluate the 'intactness' of the Walker River species assemblage (Lamb et al., 2009; Nielsen et al., 2007).

To characterize bird species assemblages available in Great Basin riparian systems, we used the same riparian data as used in the Riparian Specialization Index (980 points with riparian habitat from 118 transects in riparian strata). However, for the Representation Index we calculated the ratio of average detections (per point-count survey) on the 13 Walker River transects over average detections on the other 105 riparian transects in the Great Basin. Species with lower ratios were less abundant than expected on the Walker River and may indicate a need for restoring particular habitat characteristics. We assigned these ratios to ranked category scores, with higher scores indicating greater underrepresentation (to be consistent with the other indices): ratio $\leq 0.2 = 5$; ratio $0.21–0.36 = 4$; ratio $0.37–0.65 = 3$; ratio $0.66–1.0 = 2$; ratio $> 1.0 = 1$. Species that were absent on the Walker River, but present on other rivers received a representation score of 5.

2.4. Evaluation of indices

To evaluate the usefulness of community indices for habitat restoration planning and monitoring, we defined a vegetation gradient as a surrogate for a comparison of restored and un-restored sites, using habitat variables that are typically used to evaluate riparian restoration success (Ruiz-Jaen and Aide, 2005), specifically cover type, height, and structural diversity of the riparian vegetation (Table 1). We derived these variables from both a ground-truthed vegetation cover map and vegetation profile data collected remotely throughout the Walker River corridor using Light Detection and Ranging (LiDAR) remote sensing technology (Bradbury et al., 2005). The bird indices were then evaluated against this vegetation gradient using linear regression models.

2.4.1. Vegetation map

A vegetation map for the Walker River Basin was generated in 2007 by photo-interpreting polygons from 1:2000 scale National Agriculture Inventory Program (NAIP) imagery, with a minimum mapping unit of 135 m^2. At least 50% of photo-interpreted polygons were verified through field visitation. A total of 19 classes were mapped according to dominant plant community types. The map was subsequently validated with independent field data from 291, 0.1-ha sites selected using proportionally stratified random sampling, resulting in an overall classification accuracy of 80% (Otis Bay Ecological Consultants, 2009).

We then used the vegetation map to calculate the combined areal cover of riparian vegetation within the sample units, including the Riparian Shrub, Cottonwood Forest and Wet Meadow habitat types (RIPARIAN; Table 1), because these cover types are targeted by restoration efforts and are also most likely to impact landbird communities due to past losses from land uses. We excluded emergent wetland and open water.

2.4.2. LiDAR data

We used multiple discrete-return LiDAR to provide fine-grained information about vegetation structure in both the vertical and horizontal dimensions (Vierling et al., 2008). LiDAR data were acquired at flight specifications resulting in an average of <1.0-m nominal post-spacing in October 2006, along the upper and middle reaches

Table 1
Predictor variables used for modeling the performance of bird community indices on 64 bird survey sites along the Walker River. All variables are calculated for a 250-m × 250-m grid cell around each of two survey points and averaged for a site total.

Predictor variable	Description	Correlational structure		
		RIPARIAN	CVR_GT_6M	MAX_HT
Vegetation map variable				
RIPARIAN	Proportional cover of Riparian habitat			
LiDAR vegetation structure variables				
CVR_GT_6M	Percent cover of vegetation > 6 m tall	0.34		
MAX_HT	Maximum canopy height	0.25	0.68	
SD_2TO6M	SD of mid-range vegetation (2–6 m)	0.44	0.20	0.31

of the Walker River system and in February 2009, along the lower reach of the Walker River. Coverage of the acquisition along the river channel varied from 100 to over 1000 m on both sides of the channel depending on local topography. LiDAR returns were processed and classified into ground and non-ground returns using vendor proprietary software and algorithms and double-checked for accuracy using the de-spike algorithm as described in Haugerud and Harding (1999). The ground classified returns were used to derive a digital elevation model (DEM) gridded and interpolated at 1 m using a triangular irregular network (TIN). Non-ground return heights above the ground were computed by subtracting the DEM from their respective elevation within each 1-m cell grid.

We extracted raw LiDAR data classified as vegetation and centered at each bird survey point ±125 m, resulting in a 250-m × 250-m block (6.25 ha), which represents approximately twice the area of the bird-survey sampling unit (3.14 ha). This block size for vegetation map and LiDAR data was selected to provide a buffer around the 100-m-radius bird-survey unit that captures average territory sizes for most small landbirds. We calculated predictor variables using the heights above ground (i.e., canopy heights) within each block.

We calculated three measures of woody vegetation structure from the LiDAR data. The cover of vegetation > 6 m tall (CVR_GT_6M, Table 1) was calculated as the proportion of LiDAR samples (at 1-m intervals) with first returns at >6 m. This threshold was intended to differentiate between mature trees and tall shrubs, or at least the structural equivalent. The second LiDAR variable was the maximum height of vegetation within the 250-m × 250-m block (MAX_HT).

Heterogeneity in vegetation structure has often been shown to be an important predictor of bird communities (e.g., Finch, 1989; Seavy et al., 2009), consistent with fundamental niche theory (MacArthur and MacArthur, 1961). Several measures of heterogeneity were calculated from the LiDAR data, but the one we found to have the strongest predictive power for the bird community was the standard deviation of the mid-range vegetation cover (2–6 m tall). For this, the 250-m × 250-m sample unit was partitioned into 25 grid cells (50 m × 50 m each), and the mid-range vegetation cover was calculated for each, as a way to calculate various predictor variables representing heterogeneity in structure within each 250-m × 250-m block (Newton, 2012). The standard deviation was then calculated over the 25 cells (SD_2TO6M, Table 1).

2.4.3. Index calculation

We divided all 13 of the 10-point transects into five two-point sections to use as sample units, representing the approximate length of 500 m river sections that are used for watershed conservation planning in this project. This resulted in 64 two-point sample units (one pair of points had been removed because it was not in the riparian zone). A list of bird species detected was generated for every survey of the two points combined. Index scores were then assigned to each bird species in the target species list, summed for each survey visit, and averaged for all visits.

The resulting index scores for each site were used to test the bird indices against the four habitat variables using linear regression models. We used R^2 to compare the effectiveness of the habitat gradient in predicting the different bird indices.

2.4.4. Application of indices

The bird indices can be used to evaluate specific sites of management interest, but conservation planning at the watershed scale would benefit from indices that may be extrapolated to management units that are outside of avian survey plots. This requires variables that can be mapped using remote sensing, so the selected bird index must be related back to vegetation structure. To illustrate uses of the bird community indices in a spatially explicit decision-support tool for the entire Walker River, we used the best regression model for each index and evaluated it over each of 700 stream reaches (500-m stream segments) being used in restoration planning. We thus mapped the indices over the entire study area, and compared them by correlating the results for the 700 stream reaches.

3. Results

A total of 127 bird species were detected on 64 Walker River bird survey sites during the five-year survey period. Of these, 78 species were selected because they fit the basic criteria of being small, native, territorial landbirds, excluding only aerial foragers and nocturnal landbirds (Table 2). There were 56 species that had a higher mean abundance at riparian points than non-riparian points throughout the Great Basin (RSI > 0 in Table 2), with the remaining 22 species assigned an RSI = 0. All 78 species were used for some analyses. Results from the multiple regression models are reported in Table 3.

3.1. Species richness

A large proportion of variation in the Species Richness Index, with equal weights for all species, was explained by the vegetation gradient (Table 3). Varying the number of species included in the index affected the strength of association with the habitat gradient (rows in Table 3). In general, relationships became stronger as more upland-associated species were removed from the list, up to a point. Using the full list of 78 landbird species (R^2 = 0.63) was less effective than using the 56 species that were more abundant at riparian points (R^2 = 0.71). The coefficients of determination were highest at the level of 34 species, and then declined again when fewer species were included, despite the fact that these were increasingly dominated by riparian-obligates.

Using the alternative method of selecting riparian-obligate species by defining the assemblage through nesting guild resulted in 30 species in the riparian species list (Table 2). Bird species excluded using this criterion included five of the ten most common species (Spotted Towhee, Brown-headed Cowbird, Mourning Dove, Red-winged Blackbird, and California Quail; scientific names

Table 2
Values assigned as species weights for the three indices, for the 78 bird species with higher mean abundance at riparian points compared with non-riparian points, listed by degree of riparian specialization. Also listed are the number of sites at which the species was present on the Walker River, from a total of 64 bird survey sites. Asterisks indicate species that were used in the guild-based index of riparian tree and shrub nesters. RSI = Riparian Specialization Index; PIF = Partners-in-Flight Index; REP = Representation Index.

Species	# Sites	Riparian nesters	RSI	PIF	REP
Yellow-breasted Chat, *Icteria virens*	24	*	5	10	3
Black Phoebe, *Sayornis nigricans*	22		5	12	1
Blue Grosbeak, *Passerina caerulea*	25	*	5	9	1
Common Yellowthroat, *Geothlypis trichas*	5		5	8	5
Willow Flycatcher, *Empidonax traillii*	11	*	5	15	1
Indigo Bunting, *Passerina cyanea*	1	*	5	14	1
MacGillivray's, Warbler, *Geothlypis tolmiei*	5	*	5	14	5
Belted Kingfisher, *Ceryle alcyon*	3		5	15	4
Calliope Hummingbird, *Selasphorus calliope*	1	*	5	14	3
Cedar Waxwing, *Bombycilla cedrorum*	1		5	8	4
Marsh Wren, C*istothorus palustris*	1		5	11	5
Rufous Hummingbird, *Selasphorus rufus*	1		5	11	1
Yellow-headed Blackbird, *X. xanthocephalus*	10		4	13	4
Red-winged Blackbird, *Agelaius phoeniceus*	54		4	9	2
Lesser Goldfinch, *Spinus psaltria*	5	*	4	9	5
Song Sparrow, *Melospiza melodia*	48	*	4	10	1
Western Bluebird, *Sialia mexicana*	5	*	4	10	2
Yellow Warbler, *Setophaga petechia*	50	*	4	10	2
Bullock's Oriole, *Icterus bullockii*	55	*	4	13	2
American Crow, *Corvus brachyrhynchos*	1	*	4	9	5
Downy Woodpecker, *Picoides pubescens*	9	*	4	10	3
Lazuli Bunting, *Passerina amoena*	36	*	4	14	4
House Wren, *Troglodytes aedon*	27	*	4	10	3
Black-billed Magpie, *Pica hudsonia*	22	*	3	12	3
Broad-tailed Hummingbird, *Selasphorus platycercus*	3	*	3	12	4
California Quail, *Callipepla californica*	49		3	13	2
Western Kingbird, *Tyrannus verticalis*	44	*	3	9	1
Warbling Vireo, *Vireo gilvus*	18	*	3	9	4
American Kestrel, *Falco sparverius*	12	*	3	16	3
Bewick's Wren, *Thryomanes bewickii*	61	*	3	9	1
Brown-headed Cowbird, *Molothrus ater*	61		3	10	1
Savannah Sparrow, *Passerculus sandwichensis*	8		3	10	5
Black-headed Grosbeak, *Pheucticus melanocephalus*	49	*	3	10	1
Wilson's Warbler, *Cardellina pusilla*	8		3	10	2
Brewer's Blackbird, *Euphagus cyanocephalus*	37		2	13	3
American Robin, *Turdus migratorius*	47	*	2	10	2
Dusky Flycatcher, *Empidonax oberholseri*	5	*	2	13	4
Northern Flicker, *Colaptes auratus*	23	*	2	12	4
Fox Sparrow, *Passerella iliaca*	4	*	2	11	5
Canyon Wren, *Catherpes mexicanus*	3		2	11	2
Western Wood-Pewee, *Contopus sordidulus*	34	*	2	11	1
Lewis's Woodpecker, *Melanerpes lewis*	1	*	2	18	5
Bushtit, *Psaltriparus minimus*	21	*	2	13	3
Spotted Towhee, *Pipilo maculatus*	61		2	11	1
Mourning Dove, *Zenaida macroura*	60		2	11	1
House Finch, *Haemorhous mexicanus*	33		2	8	1
Rock Wren, *Salpinctes obsoletus*	16		1	16	5
Say's Phoebe, *Sayornis saya*	7		1	11	2
Green-tailed Towhee, *Pipilo chlorurus*	2		1	17	5
Hairy Woodpecker, *Picoides villosus*	6		1	10	1
Yellow-rumped Warbler, *Setophaga coronata*	4		1	9	4
Orange-crowned Warbler, *Oreothlypis celata*	3		1	9	3
Hammond's Flycatcher, *Empidonax hammondii*	1		1	11	3
Steller's Jay, *Cyanocitta stelleri*	4		1	11	5
Western Tanager, *Piranga ludoviciana*	14		1	11	2
Black-chinned Hummingbird, *Archilochus alexandri*	2	*	1	12	1
Western Meadowlark, *Sturnella neglecta*	29		0	13	4
Ash-throated Flycatcher, *Myiarchus cinerascens*	30		0	10	1
Blue-gray Gnatcatcher, *Polioptila caerulea*	42		0	9	1
Northern Mockingbird, *Mimus polyglottos*	9		0	8	1
Mountain Chickadee, *Poecile gambeli*	4		0	14	3
White-crowned Sparrow, *Zonotrichia leucophrys*	2		0	8	1
Cassin's Finch, *Haemorhous cassinii*	2		0	14	5
Gray Flycatcher, *Empidonax wrightii*	5		0	14	5
Dark-eyed Junco, *Junco hyemalis*	1		0	10	4
Loggerhead Shrike, *Lanius ludovicianus*	7		0	12	4
Lark Sparrow, *Chondestes grammacus*	20		0	14	1
Brewer's Sparrow, *Spizella breweri*	27		0	18	4
Sage Thrasher, *Oreoscoptes montanus*	4		0	17	5
Western Scrub-Jay, *Aphelocoma californica*	1		0	10	5
Chipping Sparrow, *Spizella passerina*	2		0	12	5
Black-throated Sparrow, *Amphispiza bilineata*	29		0	13	1

Table 2 (*Continued*)

Species	# Sites	Riparian nesters	RSI	PIF	REP
Mountain Bluebird, *Sialia currucoides*	3		0	13	4
Horned Lark, *Eremophila alpestris*	14		0	13	1
Pinyon Jay, *Gymnorhinus cyanocephalus*	3		0	18	1
Cassin's Vireo, *Vireo cassinii*	1		0	14	1
Black-throated Gray Warbler, *Setophaga nigrescens*	1		0	12	4
Sage Sparrow, *Artemisiospiza belli*	8		0	16	2

for all bird species are in Table 2). The fit of this regression model was similar to that of the first method of selecting riparian specialists when 34 species remained ($R^2 = 0.73$ or 0.74, respectively; Table 3).

3.2. Species weightings

3.2.1. Riparian Specialization Index (RSI)

The Riparian Specialization Index produced regression results similar to the Species Richness Index with R^2 values that were slightly lower overall (Table 3). The high correlation coefficient (0.99) between species richness and RSI explains their similar regression results. Increasing the relative weightings of the species, using RSI scores of 1–20 instead of the 1–5 used here, decreased the correlation but weakened the RSI model ($R^2 = 0.61$).

3.2.2. Partners in Flight Index (PIF)

Although total PIF scores can range from 5 to 25, the scores only varied from 8 to 18 for the Walker River landbird assemblage (Table 2). The resulting scores were strongly correlated with scores of the Species Richness Index ($r = 0.99$), and the regression results were therefore similar, but with slightly lower R^2 values for most models (Table 3).

3.2.3. Representation Index (REP)

Although scores for the REP index were also correlated highly with scores of the Species Richness Index ($R = 0.95$), the R^2 values were lower using the REP index compared to all other indices in most tests (Table 3). This index did not respond as well to the vegetation gradient.

3.3. Application of selected index

Our analyses showed that an intermediate list of 34 bird species, with equal weights, provided the index (Species Richness Index) that was best explained by the riparian vegetation gradient using a multiple linear regression model (Table 3):

$$1.761 + 3.687 \times \text{RIPARIAN} + 8.065 \times \text{CVR\_GT\_6M} + 0.065 \times \text{MAX\_HT} + 49.138 \times \text{SD\_2TO6M}$$

We then used this model to map the index for the entire length of the Walker River for which these spatially explicit variables were available, and demonstrated this application for a selected portion of the river (Fig. 1). The predicted Species Richness Index for all 700 stream reaches ranged from 3.14 to 15.44 (mean = 8.63, s.d. = 2.65). We also mapped the three other indices, but since the resulting correlations among them over 700 stream reaches were all extremely high ($r > 0.99$), we do not report them here.

However, there were still some polygons with considerable differences in ranking among the four indices. Generally, polygons that ranked higher for the Species Richness Index than for the Riparian Specialization Index were sites with tall tree cover but little understory, especially when associated with rural human disturbance (such as farms or grazing). Such sites would not have many of the characteristic riparian shrub specialists that are weighted heavily in the Riparian Specialization Index (such as Yellow Warbler, Song Sparrow, Yellow-breasted Chat, or Willow Flycatcher), even though they still score high for overall riparian cover. Conversely, polygons that ranked higher with the Riparian Specialization Index than the Species Richness Index tended to have significant riparian shrubs but no tall trees. Of course, polygons that ranked high for all indices had both trees and shrubs.

4. Discussion

A wildlife community index is extraordinarily attractive to riparian conservation and habitat restoration planners, and several attempts have been made at defining a "healthy" riparian bird community for this purpose (Wiens et al., 2008). This is especially important in the American West, where large amounts of conservation funding are spent on restoring riparian areas for improving wildlife values, often in the absence of a single species that can encapsulate the needs of other species (Lambeck, 1997). However, formal evaluations of which community indices are most useful for which purpose have been largely lacking (Heink and Kowarik, 2010).

Our study indicated that a community index that consisted simply of riparian species richness was not significantly improved by adding species weightings, whether based on riparian specialization, underrepresented species, or the logical assumption that improved riparian woodlands would lead to a community response

Table 3
Multiple linear regression results (R^2) of models including four vegetation variables (Table 1) used as predictors of index scores on four different indices (columns) at 64 bird survey sites along the Walker River, using different species lists (rows). All relationships are positive. There is no Riparian Species Index for all landbirds because non-riparian species had scores of zero (Table 2).

Species list used	Number of species	Species Richness Index	Riparian Specialization Index	Partners in Flight Index	Representation Index
All landbirds	*78*	0.63	–	0.56	0.43
Riparian specialists only					
RSI scores 1–5	*56*	0.71	0.71	0.67	0.62
RSI scores 2–5	*46*	0.70	0.71	0.69	0.66
RSI scores 3–5	*34*	0.74	0.73	0.73	0.69
Riparian nesting guild only	*30*	0.73	0.72	0.70	0.68
RSI scores 4–5	*23*	0.59	0.59	0.58	0.62
RSI scores 5 only	*12*	0.24	0.24	0.26	0.21

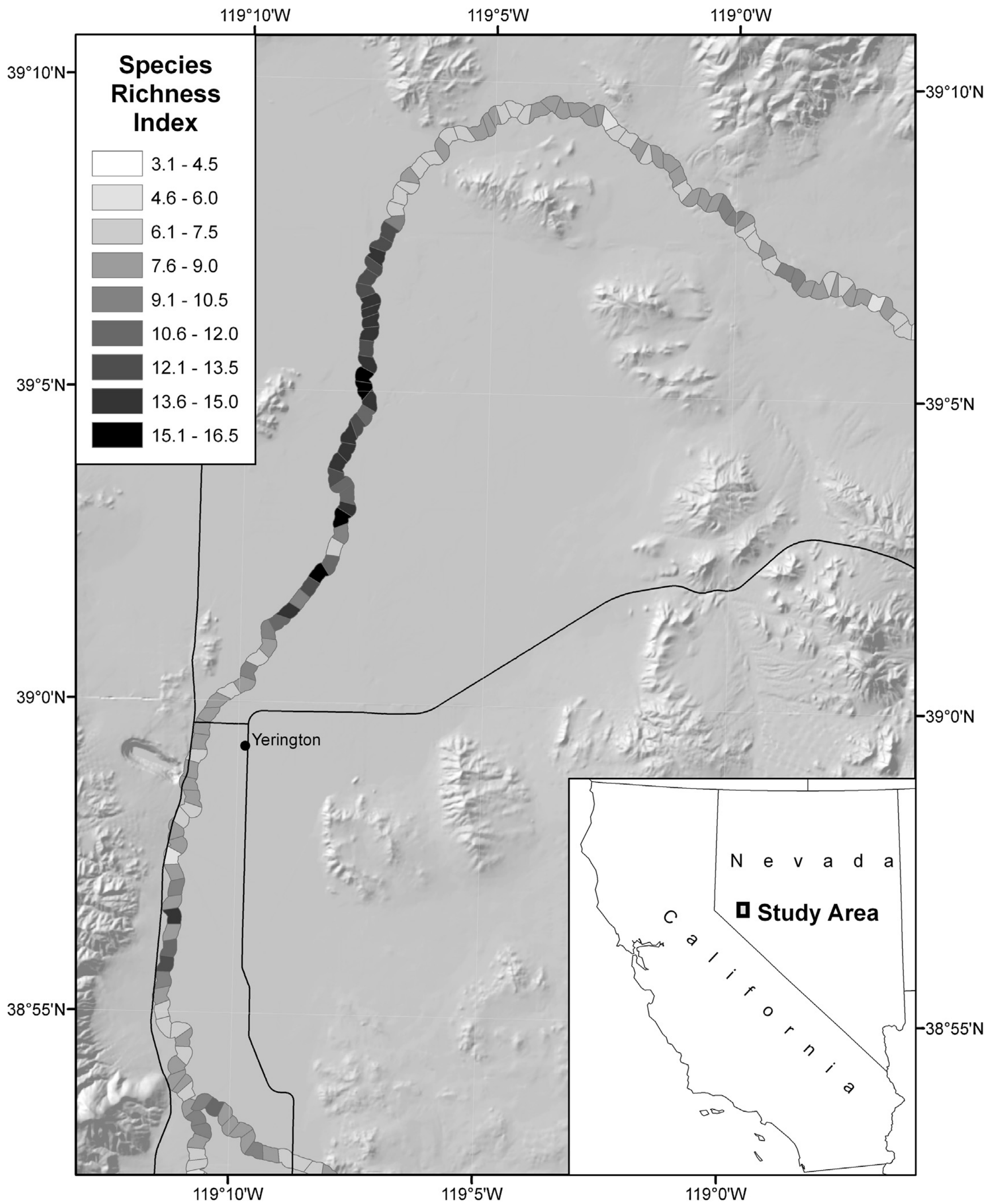

Fig. 1. Map demonstrating the evaluation of the Species Richness Index over 143 of the 700 stream reaches (500 m stream lengths) along the Walker River study area, featuring the Mason Valley. Darker colors indicate higher values of the index and thus higher predicted riparian integrity.

that favors conservation priority species (Table 3). The indices were tested using the variables predicted to be most affected by riparian restoration, such as total riparian cover and riparian vegetation height, and our models were slightly improved by reducing the species assemblage to the 30–35 strict and moderately strict riparian obligates. An index that ranked specialization based on nesting guild performed similarly in our models compared with defining riparian specialization based on regional habitat use data, even though the lists differed in inclusion of several common species.

We found that the Partners-in-Flight (PIF) Index performed no better for the purpose of predicting bird response to vegetation structure than did the unweighted Species Richness Index alone. This may be due to the fact that conservation rankings of species may not directly relate to local habitat conditions (Hilty and Merenlender, 2000; Seavy and Gardali, 2012), but more likely to threats, population sizes, and population trends at a regional level (Larsen et al., 2009). Of course, conservation status of species in an assemblage may still be useful for evaluating regional conservation effectiveness, but our results suggest that conservation rankings alone are not as useful in predicting a positive response of a bird assemblage to local habitat restoration. A Species Richness Index is generally correlated more closely with common species rather than rare species (Koch et al., 2011; Pearman and Weber, 2007), so it may still be necessary to single out high-ranking conservation species for specific conservation measures directed at them.

The Representation (REP) Index was developed by us as a species-weighting approach that follows the rationale that species are underrepresented at the Walker River (in presence or abundance compared to regional averages) because of inadequate local habitat conditions. Improving these habitat conditions in an overall riparian woodland restoration effort should, according to this rationale, increase the prevalence of underrepresented riparian species. However, the predictive model for the REP index performed the poorest in our case when using habitat variables affected by riparian woodland restoration. We largely attribute the poorer performance of this index to our observation that many of the classic riparian-associated species of the region are actually well-represented at the Walker River compared to other riparian areas in the Great Basin, for example, Willow Flycatcher, Black-headed Grosbeak, Yellow Warbler, and Song Sparrow. If this index were evaluated in a more degraded system, or if a more appropriate reference condition could be determined, it may perform much better.

5. Conclusions

Our case study of the Walker River riparian bird assemblage demonstrated that community indices involving species weightings based on conservation ranking or riparian specialization are not, by default, better correlated with potential outcomes of restoration than riparian species richness alone. We also found that the purpose of an index very much matters to its applications, and species weightings that highlight a particular aspect of a species' relevance to conservation, may not be the most useful in community assessments of riparian restoration. However, our Walker River case study is the first to rigorously compare these approaches for the development of bird community indices for the purpose of an overall bird community integrity index in light of habitat degradation and habitat restoration planning, and we encourage further exploration of current and new indices and index applications for these purposes. Evaluation with successfully restored sites versus controls would be especially desirable.

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