WESTERN BIRDS

Volume 55, Number 2, 2024

BIRD COMMUNITY RESPONSES TO RESTORATION ALONG LAS VEGAS WASH, NEVADA

JENNIFER BALLARD and ELISABETH M. AMMON, Great Basin Bird Observatory, 1755 E Plumb Lane #256A, Reno, Nevada 89502; ballard@gbbo.org, ammon@gbbo.org;

DEBORAH M. VAN DOOREMOLEN, Southern Nevada Water Authority, 100 City Parkway Ste. 700, Las Vegas, Nevada 89106; debbie.vandooremolen@snwa.com

ABSTRACT: In a 12-year study of seasonal bird use along Las Vegas Wash (Clark County, Nevada), an area undergoing intensive channel stabilization and riparian and wetland restoration, we found that total bird abundance and species richness significantly increased. In the late phase of the project, total bird abundance was greatest during the nonbreeding season and winter transition, and species richness was greatest during the fall transition. Species associated with riparian shrubs decreased, likely as a response to large-scale removal of non-native shrubs and the lag in recovery of a native shrub understory. Species associated with trees and the mid-story had a mixed response, with detections of those species previously most closely associated with non-native trees showing a negative trend, while those associated with native overstory plants showing an increasing or mixed trend. Detections of wetland and aquatic species increased significantly throughout the project. This study shows differential restoration responses of species based on their natural history, seasons of primary use of the site, and the lag time in recovery of particular vegetation elements that are used by various species assemblages.

Monitoring of the effectiveness of restoration projects routinely includes bird assessments so the ecological benefits of the effort can be measured, but most studies focus primarily on landbirds during the breeding season (e.g., Gardali et al. 2006, Golet et al. 2008, Malcom and Radke 2008, but see Kus and Beck 2003, Golet et al. 2011, Latta et al. 2012, Dybala et al. 2015). In this study, we examine multi-year seasonal responses of the whole bird community to wetland and riparian restoration along Las Vegas Wash, a tributary of the Colorado River in southern Nevada. While the wash was historically ephemeral, it has become a perennial river owing to discharge of treated wastewater, urban runoff, and shallow groundwater. As discharge increased in the 20th century, it cut the channel deeper, degrading the wash and transferring significant amounts of sediment into Lake Mead. To address this issue, the Las Vegas Wash Coordination Committee, a 28-member community stakeholder group, came together in 1998 with the Southern Nevada Water Authority as lead agency. The committee developed the Las Vegas Wash

Comprehensive Adaptive Management Plan (Las Vegas Wash Coordination Committee 2000) to guide activities to halt the channel's degradation, restore riparian and wetland habitats, improve water quality, and monitor wildlife. The Southern Nevada Water Authority implemented the plan, overseeing construction of approximately 20 grade-control structures (low dams or weirs) to impound and slow water flow to protect the channel bed from erosion, as well as the installation of more than 10 miles of rock riprap to protect the wash's banks. Activities also included removal of the dominant tamarisk (*Tamarix ramosissima*), an aggressively growing non-native tree, and revegetation with native emergent vegetation and riparian and upland trees and shrubs. Because of the length of the channel, the scale of restoration, and the central importance of maintaining water flow and quality through the wash, construction occurred throughout the study period and occasionally disrupted areas previously restored.

The Mojave Desert surrounding the wash averages 10.6 cm of rain per year (National Weather Service 2022); the volume and consistency of water flowing through the wash therefore provides mesic habitats and resources to support a wide variety of wildlife, including a rich bird community. In this study we recorded approximately 44% of the species that have been found in Nevada, including 53 of conservation priority (GBBO 2018). Here, we examine the relationships between phases of the restoration project (early to late) and seasonal use by birds dependent on riparian trees, shrubs, and wetlands through 12 years of study.

METHODS

Study Area

Las Vegas Wash is the primary drainage of the Las Vegas Valley Hydrographic Basin and is located in the southeastern portion of Las Vegas Valley in Clark County, Nevada. It extends approximately 20 km, flowing through the 1175-ha Clark County Wetlands Park and terminating in Las Vegas Bay of Lake Mead. The study area encompasses 8.7 km of the wash that is under riparian and wetland restoration (Figure 1). In 2005, the riparian areas were still dominated by the non-native tamarisk, which also formed extensive stands perched on dry terraces; the uplands were dominated by the native creosote bush (*Larrea tridentata*). By the end of 2014, cover by non-native riparian vegetation had been greatly reduced as a result of removal, weir construction, and replanting with native plants, although non-native species remained common along the wash. By 2016, tamarisk cover had declined from 36% to 4% (GBBO 2018). Cover of honey and screwbean mesquites (*Neltuma glandulosa* and *Strombocarpa pubescens,* respectively) had collectively increased from 1% to 7%, surpassing tamarisk as the most abundant trees in the study area (GBBO 2018). Upland shrub cover (e.g., saltbushes such as *Atriplex canescens* and *A. lentiformis*) had also increased, from 15% in 2005 to 22% in 2016. Goodding willow (*Salix gooddingii*), Fremont cottonwood (*Populus fremontii*), and sandbar willow (*S. exigua*) were actively planted and passively established in the project area but were still limited (each 0–3% cover, in all years; GBBO 2018). Overall, vertical vegetation structure between 2 and 6

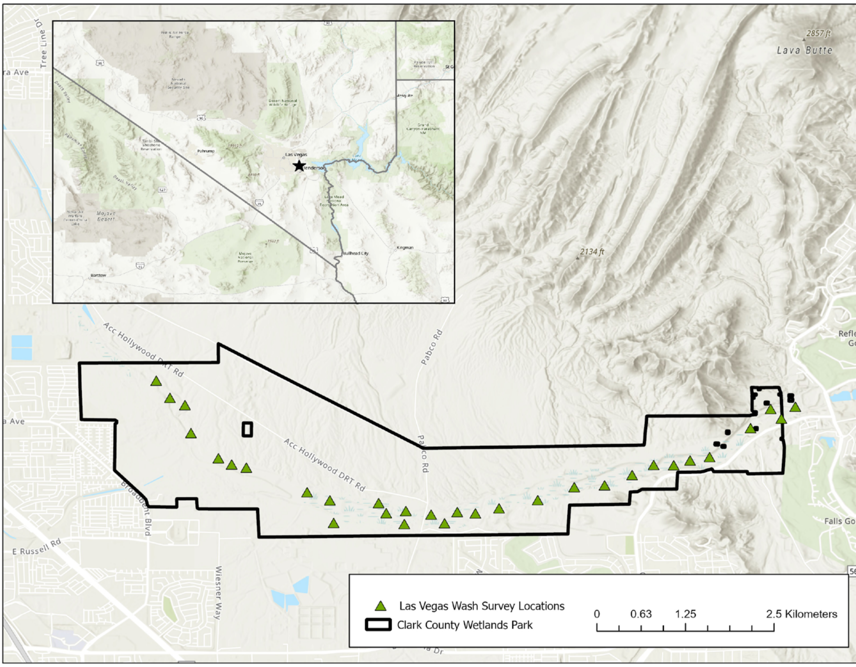

Figure 1. Riparian restoration study area (in black) along Las Vegas Wash, Clark County, Nevada. Triangles represent survey locations.

m declined over the course of the project (GBBO 2018). Emergent marsh vegetation, primarily bulrush (*Schoenoplectus* spp.), was planted in the channel, and southern cattail (*Typha domingensis*) and common reed (*Phragmites australis*) encroached from upstream sources.

Active channel stabilization and revegetation took place the length of the study area throughout the study period. By the end of the first year (2006), nine weirs had been installed and 30 ha had been revegetated. By the end of the sixth year, 12 weirs had been installed and approximately 113 ha had been revegetated. By the end of the 12th year, 19 weirs had been installed and over 200 ha had been revegetated.

Bird Surveys

Birds and vegetation of the study area were monitored from 12 February 2005 to February 2009 by the San Bernardino County Museum and by the Great Basin Bird Observatory from 15 February 2009 to 30 January 2011 and again from 1 September 2014 to 31 August 2017. We recorded all birds detected during standardized 5-minute counts (Ralph and Scott 1981) at permanently established geo-referenced survey points along the restoration area. The points were spaced at least 200 m apart and arranged on both sides of the channel. The study began with 26 survey points; 3 were added within a few months, and the total reached 31 by the end of the second year. Points were distributed along the wash in wetland, riparian, and upland habitats, in areas that had already undergone stabilization and restoration and in those that had not. Weir construction shifted the channel in some locations, requiring 8 points to be replaced. We established these replacement points as close to the original location as was safely possible, up to 50 m from their original location. Surveys at some points were occasionally omitted because of inaccessibility from construction or flooding. We surveyed these points year round, approximately every 2 weeks over a 2-day period, for 26 surveys per year. Each survey began at a randomly selected point, and the order in which we visited survey points was rotated on successive visits. To capture the period of greatest bird activity, surveys began at sunrise and continued for approximately 5 hours. From 2009 to 2017 we used electronic rangefinders to record the distance from the observer to the bird as accurately as possible.

Data Analysis

Using the statistics software Stata (StataCorp 2015), we modeled total bird detections, species richness (i.e., number of species detected), and species-specific detections by negative binomial regression for count data. For all species-specific modeling, we included observations of 11 focal species (species of conservation interest with a minimum of 900 detections) in separate negative binomial regression analyses. We apportioned these species among three guilds: birds associated with riparian shrubs—the Abert's Towhee (*Melozone aberti*), Song Sparrow (*Melospiza melodia*), and Yellow-breasted Chat (*Icteria virens*), those associated with riparian trees—the Lucy's Warbler (*Leiothlypis luciae*), Orange-crowned Warbler (*Leiothlypis celata*), Verdin (*Auriparus flaviceps*), Yellow Warbler (*Setophaga petechia*), and Yellow-rumped Warbler (*Setophaga coronata*), and those associated with wetlands—the Common Yellowthroat (*Geothlypis trichas*), Mallard (*Anas platyrhynchos*), and Red-winged Blackbird (*Agelaius phoeniceus*).

All analyses included only bird detections within a 100-m radius of a survey point. We excluded observations of birds flying overhead, even those directly above a survey point, because these birds were generally not actively using the surveyed area. This allowed us to compare bird abundances by survey point and project phase, but it precluded analyses of species with a primarily aerial lifestyle, such as swallows (family Hirundinidae), swifts (family Apodidae), and nighthawks (family Caprimulgidae).

On the basis of previous analyses (Braden et al. 2009), we defined the breeding season as the period between 15 March and 31 August, which encompasses the breeding periods of the majority of both year-round resident and migratory species. We excluded hatch-year birds from analyses of breeding-season data. The breeding season so defined also encompasses spring and early fall migration of several mid- and long-distance migrants, so, inevitably, some nonbreeding birds were included in breeding-season estimates. The nonbreeding season was defined as 1 October through 31 January to include overwintering birds but exclude nesting of most resident species. The fall transition therefore includes September, and the winter transition covers February through mid-March. Further, we divided the 12 years of the project into the early phase (2005–2008), intermediate phase (2008–2011), and late phase (2014–2017).

We modeled species richness, total bird detections, and detections of focal species per survey visit by using season and project phase as explanatory variables, and an interaction between season and phase, where appropriate, such that we compared four models: (1) season, (2) phase, (3) season + phase, and (4) season + phase + season × phase. In addition, we included a null model as a baseline reference.

We ranked models by Akaike's information criterion (AIC) and evaluated them by their weight (w_i; Burnham and Anderson 2002). Our multi-model comparisons of factors influencing total detections, species richness, and detections of focal species generally yielded strong support for a single model (weight of the top model ≥0.72 in all sets). Models for the Yellow Warbler, however, were more equivocal (w_i = 0.54 and 0.45 for the top two models), but the interpretation for each was similar. For the sake of simplicity, we thus report only the results of the best-supported model within each set.

For each of these top models, we calculated the incident-rate ratios and associated *p* values of contrasts within restoration phases and seasons (Stata version 14.2, StataCorp 2015). Because not every survey visit included all 31 points, we used the number of points per survey as an exposure variable in the analysis. An incident-rate ratio is the estimated change in species richness or overall detections for that phase or season relative to a baseline value, given that the other variables in the model remain constant. We based the models on project phase rather than time since restoration because of the complexity and differing schedules of weir construction, tamarisk removal, restoration plantings, and passive restoration.

We summarized raw counts (means and standard errors) by project phase and season, and represented these summaries in two ways. First, we plotted the total number of bird species and the number of bird detections per 40 ha, converted from the fixed radius of 100 m around each point (3.14 ha), by survey visit in order to illustrate temporal variation in species richness and abundance and to show differences among phases. Second, we estimated richness and detections by season and phase from species-specific negative binomial models. Results were considered statistically significant at $\alpha = 0.05$.

RESULTS

Total Bird Abundance

Counts varied by species, season, and phase of restoration (Table 1). The best-supported model of total bird detections included season, phase, and an interaction between the two variables (Table 2). During the early phase, there was no significant difference in detections between the breeding and nonbreeding seasons, but detections during the nonbreeding period were 22% greater than during the breeding season in the intermediate phase, and 68% greater in the late phase (Figures 2 and 3; Tables 1 and 3).

With respect to the fall transition and nonbreeding season, total detections increased significantly from the early phase to the intermediate phase. Across all seasons, detections during the late phase were significantly greater than during the early phase, but this difference was strongest for the nonbreeding and winter transition periods (2.3 and 3.4 times greater, respectively). For all

Table 1 Mean Number of Detections (± Standard Error) within 40 ha of Dominant Species on Point Counts along Las Vegas Wash, Nevada, 2005–2017, by Season and Restoration Phase[a]

	Season and project phase					
	Breeding			Fall transition		
Variable	Early	Intermediate	Late	Early	Intermediate	Late
Total birds	131.4 (4.7)	141.1 (7.1)	191.1 (9.7)	107.3 (10.9)	156.1 (25.6)	173.7 (12.7)
Species richness	34.1 (0.9)	34.0 (0.9)	45.7 (0.9)	36.2 (2.1)	43.2 (1.9)	46.3 (2.3)
Abert's Towhee	14.4 (1.0)	11.0 (1.3)	8.3 (0.6)	18.7 (3.3)	14.5 (2.3)	10.2 (1.4)
Common Yellowthroat	8.8 (0.6)	10.1 (0.8)	10.7 (0.9)	5.3 (1.4)	4.4 (1.5)	5.4 (1.3)
Lucy's Warbler	7.7 (0.9)	4.5 (0.6)	2.8 (0.4)	0.3 (0.2)	0.3 (0.3)	0.3 (0.3)
Mallard	1.0 (0.2)	3.4 (0.6)	8.6 (0.7)	1.2 (1.1)	7.4 (3.5)	10.7 (2.1)
Orange-crowned Warbler	0.4 (0.1)	0.3 (0.1)	0.5 (0.2)	4.0 (1.4)	6.6 (2.4)	7.3 (2.4)
Red-winged Blackbird	8.6 (1.1)	15.0 (1.4)	24.4 (2.0)	1.6 (0.5)	2.6 (1.3)	6.3 (2.4)
Song Sparrow	13.8 (0.8)	10.7 (0.7)	8.3 (0.5)	8.8 (1.6)	6.5 (1.5)	2.4 (0.4)
Verdin	4.7 (0.3)	5.6 (0.4)	6.7 (0.4)	4.7 (0.4)	7.1 (0.6)	7.1 (0.8)
Yellow-breasted Chat	5.8 (0.7)	4.2 (0.7)	2.4 (0.4)	0.7 (0.4)	0.9 (0.7)	0.3 (0.2)
Yellow-rumped Warbler	1.0 (0.4)	0.7 (0.3)	2.0 (0.7)	3.3 (1.5)	8.6 (7.2)	0.9 (0.7)
Yellow Warbler	2.4 (0.3)	5.0 (0.7)	2.9 (0.4)	0.4 (0.2)	1.9 (0.9)	2.3 (1.3)
	Nonbreeding			Winter transition		
	Early	Intermediate	Late	Early	Intermediate	Late
Total birds	138.3 (6.9)	172.5 (12.4)	320.7 (22.7)	113.4 (12.6)	138.5 (9.0)	382.0 (27.5)
Species richness	32.4 (0.9)	33.0 (1.2)	45.8 (0.9)	29.3 (1.4)	33.8 (1.7)	48.3 (2.1)
Abert's Towhee	12.1 (0.6)	10.1 (0.7)	8.5 (0.6)	9.8 (0.5)	12.1 (1.9)	8.4 (0.7)
Common Yellowthroat	0.0 (0.0)	0.1 (0.1)	0.4 (0.2)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)
Lucy's Warbler	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
Mallard	4.3 (1.1)	9.1 (1.4)	31.7 (4.3)	4.6 (2.6)	8.0 (1.1)	39.1 (7.3)
Orange-crowned Warbler	2.7 (0.3)	3.7 (0.5)	4.8 (0.9)	1.1 (0.2)	1.9 (0.6)	3.2 (1.0)
Red-winged Blackbird	10.9 (2.5)	4.4 (2.0)	8.2 (2.8)	1.3 (0.6)	9.4 (4.3)	10.2 (2.7)
Song Sparrow	9.8 (0.4)	6.8 (0.6)	4.2 (0.4)	12.0 (1.2)	8.5 (1.2)	7.1 (0.9)
Verdin	3.0 (0.3)	5.0 (0.4)	5.3 (0.3)	3.5 (0.8)	4.4 (0.7)	5.2 (0.5)
Yellow-breasted Chat	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Yellow-rumped Warbler	16.1 (2.4)	33.0 (5.8)	24.1 (2.9)	5.8 (2.9)	4.7 (0.7)	12.0 (1.5)
Yellow Warbler	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

[a]See Methods for definitions.

seasons but the fall transition, total detections during the late phase were also significantly greater than during the intermediate phase (Figure 3; Table 4). A large portion of this increase was driven by the creation and expansion of wetland and open-water habitats and the subsequent increases in waterbirds: during the nonbreeding season and winter transition, the proportion consisting of coots, cormorants, ducks, gallinules, and grebes increased from 16% in the intermediate phase to 57% in the late phase.

Table 2 Rankings[a] of Models Describing Detections of Birds along Las Vegas Wash, Nevada, 2005–2017

Model and variables[b]	AIC	ΔAIC	w_i
Total detections			
Season × phase	2886.83	0	1.00
Season + phase	2923.77	36.94	0.00
Season	3060.72	173.90	0.00
Phase	2953.80	66.97	0.00
Null	3087.37	200.54	0.00
Species richness			
Season × phase	1468.27	2.23	0.24
Season + phase	1466.03	0	0.72
Season	1610.48	144.44	0.00
Phase	1471.53	5.50	0.05
Null	1610.84	144.81	0.00
Abert's Towhee			
Season × phase	1782.33	5.66	0.05
Season + phase	1776.67	0	0.83
Season	1809.70	33.03	0.00
Phase	1780.51	3.84	0.12
Null	1813.26	36.60	0.00
Common Yellowthroat			
Season × phase	1173.30	0	0.98
Season + phase	1181.70	8.41	0.01
Season	1184.39	11.09	0.00
Phase	1499.73	326.43	0.00
Null	1496.23	322.93	0.00
Lucy's Warbler			
Season × phase	816.001	5.68	0.06
Season + phase	810.32	0	0.94
Season	824.68	14.36	0.00
Phase	1086.11	275.79	0.00
Null	1089.47	279.15	0.00
Mallard			
Season × phase	1735.68	5.64	0.06
Season + phase	1730.05	0	0.94
Season	1850.50	120.45	0.00
Phase	1797.02	66.98	0.00
Null	1892.78	162.74	0.00
Orange-crowned Warbler			
Season × phase	1099.09	9.25	0.01
Season + phase	1089.84	0	0.90
Season	1094.42	4.59	0.09

(continued)

Model and variables[b]	AIC	ΔAIC	w_i
Phase	1222.55	132.71	0.00
Null	1224.26	134.42	0.00
Red-winged Blackbird			
Season × phase	1941.11	0	1.00
Season + phase	1963.79	22.69	0.00
Season	1973.61	32.50	0.00
Phase	1993.64	52.53	0.00
Null	2004.56	63.45	0.00
Song Sparrow			
Season × phase	1629.74	0	0.72
Season + phase	1631.67	1.92	0.28
Season	1717.16	87.41	0.00
Phase	1701.31	71.57	0.00
Null	1760.13	130.39	0.00
Verdin			
Season × phase	1422.12	7.25	0.03
Season + phase	1414.87	0	0.97
Season	1448.73	33.86	0.00
Phase	1432.79	17.92	0.00
Null	1462.47	47.60	0.00
Yellow Warbler			
Season × phase	794.35	0.34	0.45
Season + phase	794.01	0	0.54
Season	801.76	7.75	0.01
Phase	1009.49	215.48	0.00
Null	1010.59	216.59	0.00
Yellow-breasted Chat			
Season × phase	795.72	9.97	0.01
Season + phase	785.75	0	0.97
Season	792.80	7.05	0.03
Phase	989.70	203.95	0.00
Null	990.69	204.94	0.00
Yellow-rumped Warbler			
Season × phase	1594.92	0	0.82
Season + phase	1599.07	4.15	0.10
Season	1599.78	4.86	0.07
Phase	1710.12	115.20	0.00
Null	1709.84	114.92	0.00

[a]By Akaike's information criterion and inference based on model weight w_i.
[b]Restoration phase (early, intermediate, or late) and season (breeding , fall transition, nonbreeding, or winter transition) were explanatory variables.

Species Richness

The best-supported model of species richness included the additive effect of season and project phase (Table 2). Richness predicted by this model was significantly higher in the fall transition than in any other season (Figures 4 and 5). Relative to the fall transition, predicted richness during the breeding season was 8% lower, during the nonbreeding season 11% lower, and during the winter transition 10% lower. Predicted richness also tended to be lower during the nonbreeding season than during the breeding season, though this

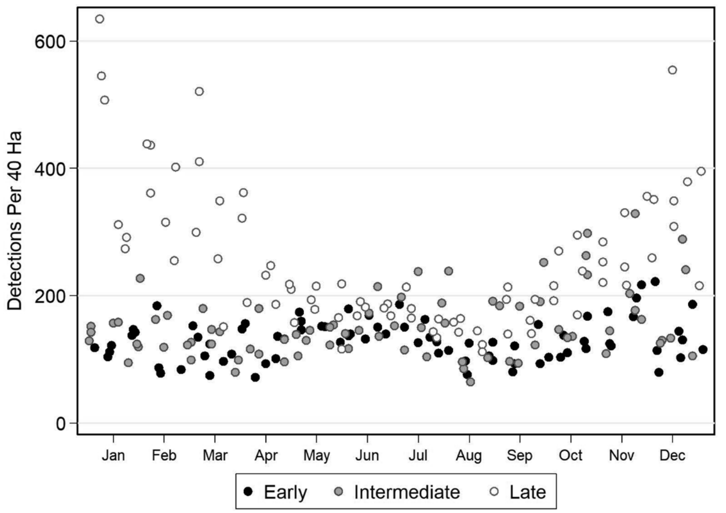

FIGURE 2. Abundance of birds (number of detections per 40 ha), by date and restoration phase, during surveys of Las Vegas Wash, Nevada, 2005–2017.

difference was not significant at α = 0.05 (Figures 4 and 5; Table 5). Predicted species richness in the late phase was significantly greater than in the early and intermediate phases; there was no difference between the early and intermediate phases (Table 6). A large portion of this effect was driven by the increase in waterfowl and other wetland species.

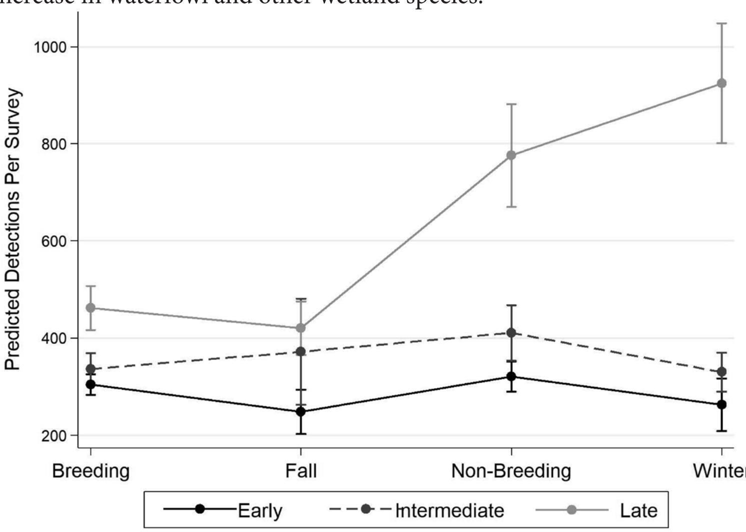

FIGURE 3. Predicted bird detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

Table 3 Incident-Rate Ratios and Probabilities Comparing Seasons (Breeding, Fall Transition, Nonbreeding, and Winter Transition) by Project Phase (Early, Intermediate, and Late) for Models Containing Interactions[a]

	Phase		
Analysis and contrast	Early	Intermediate	Late
Total birds			
Fall vs breeding	0.82 (0.042)		
Nonbreeding vs breeding		1.22 (0.020)	1.68 (<0.001)
Winter vs breeding			2.00 (<0.001)
Nonbreeding vs fall	1.29 (0.016)		1.85 (<0.001)
Winter vs nonbreeding	0.82 (0.089)	0.80 (0.020)	1.19 (0.072)
Winter vs fall			2.20 (<0.001)
Song Sparrow			
Fall vs breeding	0.64 (0.010)	0.61 (0.021)	0.29 (<0.001)
Nonbreeding vs breeding	0.71 (<0.001)	0.63 (<0.001)	0.51 (<0.001)
Winter vs breeding			
Nonbreeding vs fall			1.77 (<0.001)
Winter vs nonbreeding	1.22 (0.063)		1.66 (<0.001)
Winter vs fall			2.95 (<0.001)
Yellow-rumped Warbler			
Fall vs breeding	3.22 (0.036)	12.54 (0.004)	
Nonbreeding vs breeding	15.49 (<0.001)	47.85 (<0.001)	11.93 (<0.001)
Winter vs breeding	5.59 (0.005)	6.79 (<0.001)	5.93 (<0.001)
Nonbreeding vs fall	4.82 (<0.001)	3.81 (0.096)	27.05 (<0.001)
Winter vs nonbreeding	0.36 (0.040)	0.14 (<0.001)	0.50 (<0.001)
Winter vs fall			13.43 (<0.001)
Common Yellowthroat			
Fall vs breeding	0.61 (0.043)	0.43 (0.008)	0.50 (0.003)
Nonbreeding vs breeding	0.00 (<0.001)	0.01 (<0.001)	0.04 (<0.001)
Winter vs breeding	0.01 (<0.001)	0.02 (<0.001)	0.01 (<0.001)
Nonbreeding vs fall	0.01 (<0.001)	0.03 (<0.001)	0.08 (<0.001)
Winter vs nonbreeding			
Winter vs fall	0.02 (<0.001)	0.04 (<0.001)	0.02 (<0.001)
Red-winged Blackbird			
Fall vs breeding	0.18 (<0.001)	0.17 (<0.001)	0.26 (<0.001)
Nonbreeding vs breeding		0.30 (0.007)	0.34 (0.002)
Winter vs breeding	0.15 (<0.001)		0.42 (0.001)
Nonbreeding vs fall	6.90 (<0.001)		
Winter vs nonbreeding	0.12 (<0.001)		
Winter vs fall		3.60 (0.045)	

[a]Results shown only for $p < 0.100$.

Riparian Shrub-Associated Species

Abert's Towhee (present at study site: year round). The best-supported model explaining Abert's Towhee detections included season and project phase, with no interaction between the two variables (Table 2). Estimated detections were significantly higher in the fall transition than in the other seasons, with 28% fewer predicted detections in the nonbreeding season and winter transition, and 22% fewer detections in the breeding season (Table 5). Overall, Abert's Towhee detections decreased significantly through the study (Figure 6). Predicted abundance was significantly lower in the intermediate and late phases than in the early phase (17% and 36%,

Table 4 Incident-Rate Ratios and Probabilities Comparing Project Phases (Early, Intermediate, and Late) by Season (Breeding, Fall Transition, Nonbreeding, and Winter Transition) for Models Containing Interactions[a]

	Season			
Analysis and contrast	Breeding	Fall	Nonbreeding	Winter
Total birds				
Intermediate vs early		1.46 (0.034)	1.25 (0.010)	
Late vs early	1.45 (<0.001)	1.62 (<0.001)	2.32 (<0.001)	3.37 (<0.001)
Late vs intermediate	1.35 (<0.001)		1.86 (<0.001)	2.76 (<0.001)
Song Sparrow				
Intermediate vs early	0.77 (0.002)		0.69 (<0.001)	0.71 (0.041)
Late vs early	0.60 (<0.001)	0.27 (<0.001)	0.43 (<0.001)	0.59 (0.001)
Late vs intermediate	0.78 (0.002)	0.37 (<0.001)	0.63 (<0.001)	
Yellow-rumped Warbler				
Intermediate vs early			2.05 (0.002)	
Late vs early		0.27 (0.094)	1.50 (0.034)	
Late vs intermediate	2.93 (0.058)	0.10 (0.025)		2.55 (<0.001)
Common Yellowthroat				
Intermediate vs early				
Late vs early	1.22 (0.051)		13.12 (0.001)	
Red-winged Blackbird				
Intermediate vs early	1.74 (<0.001)		0.40 (0.069)	7.06 (0.001)
Late vs early	2.84 (<0.001)	3.98 (<0.002)		7.70 (<0.001)
Late vs intermediate	1.63 (<0.001)			

[a]Results shown only for $p < 0.100$.

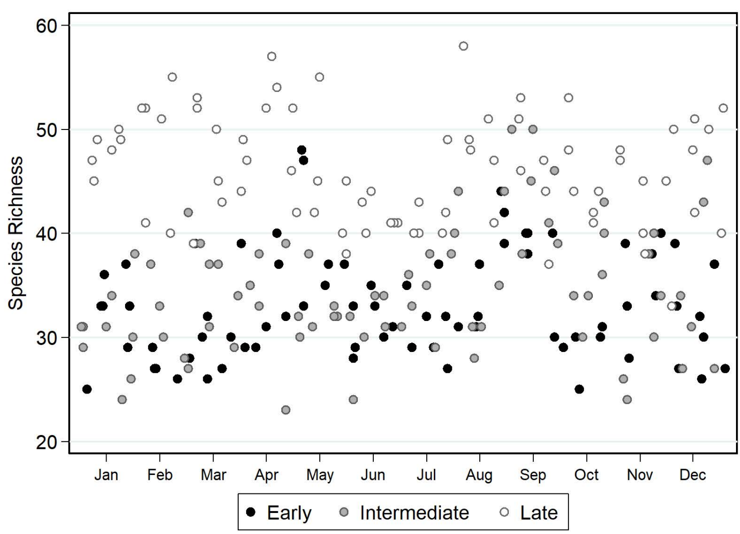

Figure 4. Species richness (number of species detected), by date and restoration phase, during surveys of Las Vegas Wash, Nevada, 2005–2017.

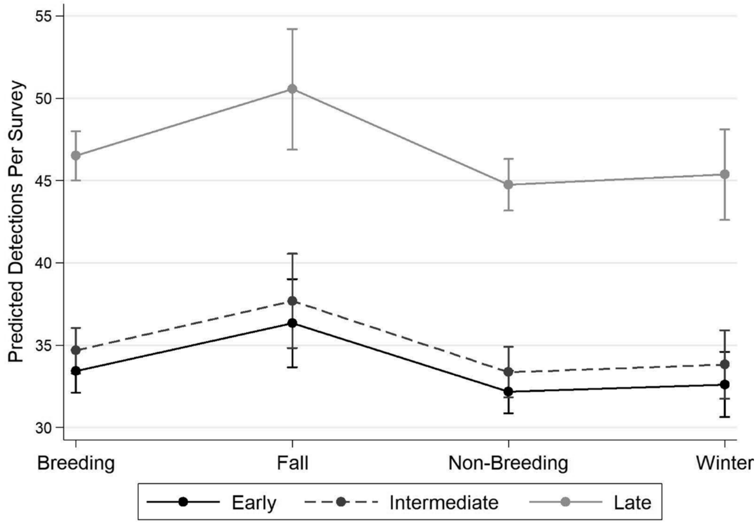

FIGURE 5. Predicted species richness per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

respectively). Detections in the late phase were also significantly lower than in the intermediate phase (Figure 6; Table 6).

Song Sparrow (present at study site: year round). The best-supported model of Song Sparrow detections included season, phase, and an interaction between these two variables (Table 2). In all seasons, detections were significantly lower during the

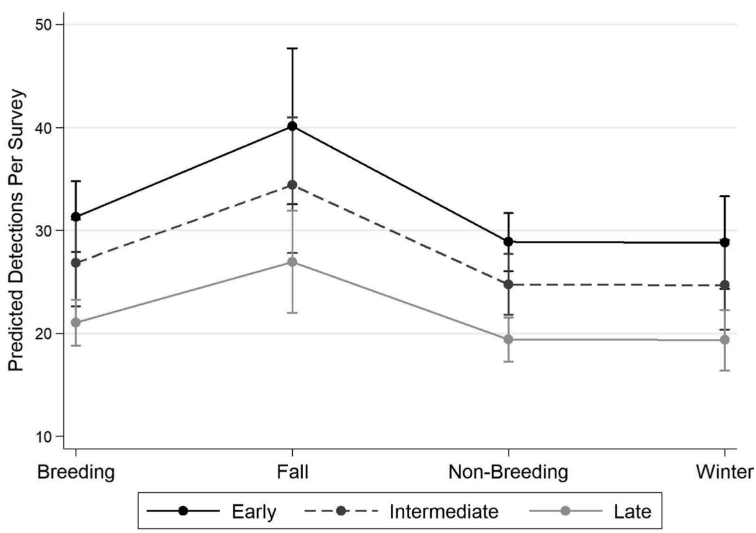

FIGURE 6. Predicted number of Abert's Towhee detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

Table 5 Contrast Results (Incident-Rate Ratios and Probabilities) for Models Lacking Interactions, Comparing Seasons (Breeding, Fall Transition, Nonbreeding, and Winter Transition) across All Project Phases[a]

Analysis and contrast	All phases (no interaction)
Species richness	
Fall vs breeding	1.09 (0.027)
Nonbreeding vs breeding	0.96 (0.061)
Nonbreeding vs fall	0.89 (0.002)
Winter vs fall	0.90 (0.016)
Abert's Towhee	
Fall vs breeding	1.28 (0.014)
Nonbreeding vs fall	0.72 (0.001)
Winter vs fall	0.72 (0.003)
Yellow-breasted Chat	
Fall vs breeding	0.16 (<0.001)
Nonbreeding vs breeding	0.00 (<0.001)
Winter vs breeding	0.00 (<0.001)
Nonbreeding vs fall	0.01 (<0.001)
Winter vs nonbreeding	0.00 (<0.001)
Winter vs fall	0.00 (<0.001)
Lucy's Warbler	
Fall vs breeding	0.07 (<0.001)
Nonbreeding vs breeding	0.00 (<0.001)
Winter vs breeding	0.01 (<0.001)
Nonbreeding vs fall	0.00 (<0.001)
Winter vs nonbreeding	1651106 (<0.001)
Winter vs fall	0.09 (0.031)
Orange-crowned Warbler	
Fall vs breeding	15.69 (<0.001)
Nonbreeding vs breeding	9.70 (<0.001)
Winter vs breeding	5.23 (<0.001)
Nonbreeding vs fall	0.62 (0.021)
Winter vs nonbreeding	0.54 (0.001)
Winter vs fall	0.33 (<0.001)
Verdin	
Nonbreeding vs breeding	0.78 (<0.001)
Winter vs breeding	0.77 (0.006)
Nonbreeding vs fall	0.70 (<0.001)
Winter vs fall	0.70 (<0.001)
Yellow Warbler	
Fall vs breeding	0.43 (0.013)
Nonbreeding vs breeding	0.00 (<0.001)
Winter vs breeding	0.00 (<0.001)
Nonbreeding vs fall	0.01 (<0.001)
Winter vs nonbreeding	0.00 (<0.001)
Winter vs fall	0.00 (<0.001)
Mallard	
Nonbreeding vs breeding	3.49 (<0.001)
Winter vs breeding	3.75 (<0.001)
Nonbreeding vs fall	2.21 (0.011)
Winter vs fall	2.38 (0.015)

[a]Results shown only for $p < 0.100$.

Table 6 Contrast Results (Incident-Rate Ratios and Probabilities) for Models Lacking Interactions, Comparing Project Phases (Early, Intermediate, and Late) across All Seasons[a]

Analysis and contrast	All seasons (no interaction)
Species richness	
Late vs intermediate	1.32 (<0.001)
Late vs early	1.33 (<0.001)
Abert's Towhee	
Intermediate vs early	0.83 (0.016)
Late vs intermediate	0.77 (0.001)
Late vs early	0.64 (<0.001)
Yellow-breasted Chat	
Late vs intermediate	0.54 (0.008)
Late vs early	0.40 (<0.001)
Lucy's Warbler	
Intermediate vs early	0.64 (0.013)
Late vs intermediate	0.61 (0.011)
Late vs early	0.39 (<0.001)
Orange-crowned Warbler	
Late vs intermediate	1.38 (0.089)
Late vs early	1.71 (0.004)
Verdin	
Intermediate vs early	1.35 (<0.001)
Late vs intermediate	1.13 (0.052)
Late vs early	1.53 (<0.001)
Yellow Warbler	
Intermediate vs early	2.22 (<0.001)
Late vs intermediate	0.70 (0.084)
Late vs early	1.57 (0.026)
Mallard	
Intermediate vs early	2.79 (<0.001)
Late vs intermediate	2.89 (<0.001)
Late vs early	8.09 (<0.001)

[a]Results shown only for $p < 0.100$.

late phase than during the early phase, by 40% (breeding season) to 73% (fall transition; Table 4). Detections during the late phase were significantly lower than during the intermediate phase for all seasons except the winter transition, and significantly lower during the intermediate phase than during the early phase for all seasons except the fall transition (Table 4). During all phases, detections were significantly lower in the fall and nonbreeding seasons than they were in the breeding season. This was particularly marked during the late phase, when fall detections of Song Sparrows were only 29% that of the breeding season, compared to approximately 60% during the early and intermediate phases. Though the rate of Song Sparrow detections in the nonbreeding season did not differ significantly from that in fall during the early and intermediate phases, during the late phase, nonbreeding detections were 77% greater than during the fall transition (Figure 7; Table 3).

Yellow-breasted Chat (present at study site: late April through late September). Yellow-breasted Chat detections varied by both season and phase, with no interaction between the two variables (Table 2). Numbers peaked during the breeding season and in the early phase of the project (Figure 8). Predicted detections were significantly lower (84%) in the fall transition than in the breeding season, and, as

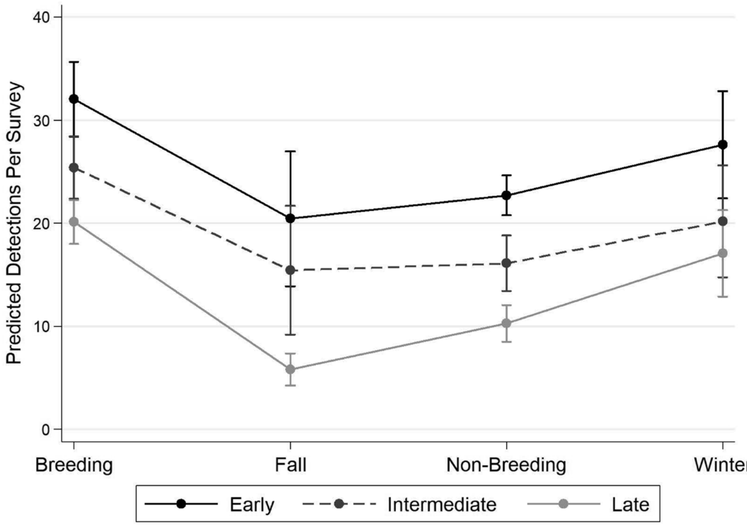

Figure 7. Number of Song Sparrow detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017, as predicted by primary model (season × phase; see Results).

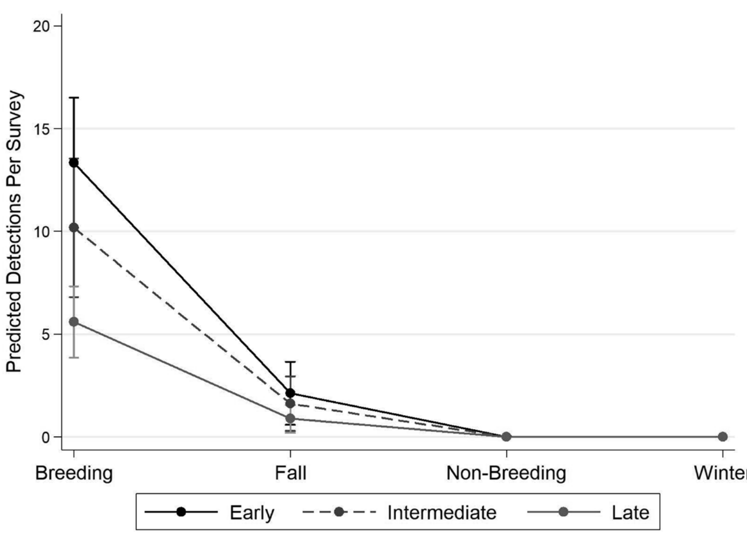

Figure 8. Predicted number of Yellow-breasted Chat detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

expected, this summer visitor was absent during the nonbreeding season and winter transition (Table 5). Yellow-breasted Chat detections were significantly fewer in the late phase than in the intermediate and early phases (46 and 60% lower, respectively; Table 6).

Riparian Tree-Associated Species

Lucy's Warbler (present at study site: late March through late August). The best-supported model of Lucy's Warbler detections included season and phase, and lacked an interaction (Table 2). Lucy's Warblers were detected almost exclusively in the breeding season, with some stragglers found during the fall and winter transitions; they were not recorded during the nonbreeding season (Figure 9; Table 5). Lucy's Warbler detections decreased by 61% from their peak in the early phase to their low in the late phase (Figure 9; Table 6).

Orange-crowned Warbler (present at study site: late July through early May). The best-supported model of Orange-crowned Warbler detections included season and phase, and lacked an interaction between the two (Table 2). Relative to their breeding season low, predicted Orange-crowned Warbler detections were more than 15 times higher in the fall transition. Orange-crowned Warblers were also found in substantial numbers in the nonbreeding season and winter transition (Figure 10, Table 5). Detections were 71% greater in the late than in the early phase (Table 6). Though there tended to be more detections in the late phase than in the intermediate phase, the difference between these two was not statistically significant (Table 6).

Verdin (present at study site: year round). The best-supported model of Verdin detections included season and phase, and lacked an interaction between the two variables (Table 2). Verdins were detected in relatively high numbers in the breeding season, with a trend toward an increase into the fall transition, though this was not significant (Figure 11; Table 5). Compared to the breeding season numbers, a significant decrease in predicted detections occurred in the nonbreeding season (22%) and winter transition (23%; Table 5). Verdin detections were at their lowest in the early phase but significantly higher during the intermediate (35%) and the late phase (53%; Table 6).

Yellow Warbler (present at study site: late March through late September). The best-supported model of Yellow Warbler detections included season and phase and lacked an interaction between the two variables (Table 2). Yellow Warblers were detected in greatest number in the breeding season, representing mostly local breeders, with significantly fewer predicted detections (57%) in the fall transition, and almost none in the nonbreeding season and winter transition (Figure 12; Table 5). Yellow Warbler detections were lowest in the early phase, higher in the late phase, and highest in the intermediate phase (Figure 12; Table 6).

Yellow-rumped Warbler (present at study site: mid-September through late April). Yellow-rumped Warbler detections were best modeled with season, phase, and an interaction between the two (Table 2). As this species is a winter visitor to southern Nevada, its abundance was lowest during the breeding season, significantly higher in the fall (in all but the late phase) and winter transitions (all phases), and highest during the nonbreeding season (all phases; Figure 13; Table 3). During the nonbreeding season, the Yellow-rumped Warbler was detected in the intermediate phase at a rate 105% higher than in the early phase, but in the late phase this difference dropped to 50% (Figure 13; Table 4).

Wetland-Associated Species

Common Yellowthroat (present at study site: mid-March through mid-November). Common Yellowthroat detections were best modeled by season, phase, and

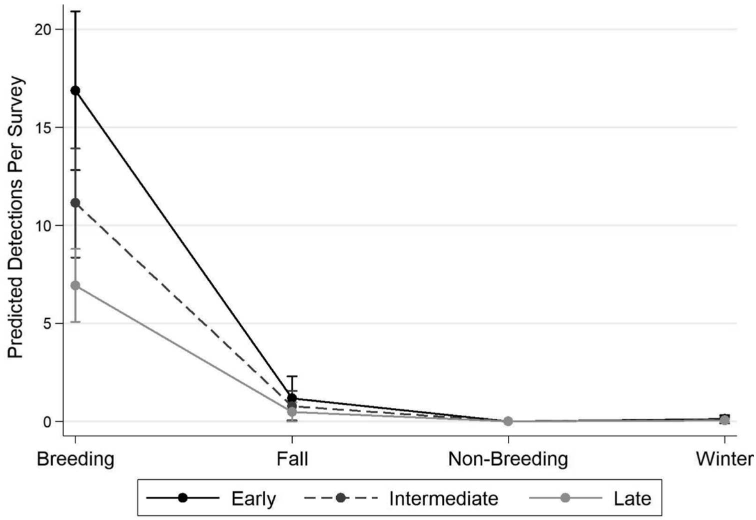

Figure 9. Predicted number of Lucy's Warbler detections per survey (± 95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

an interaction between the two (Table 2). Detections were highest in the breeding season, significantly lower in the fall transition, and few in the nonbreeding season and winter transition (Figure 14). Though the difference was not statistically significant, predicted detections during the breeding season were 22% higher in the late

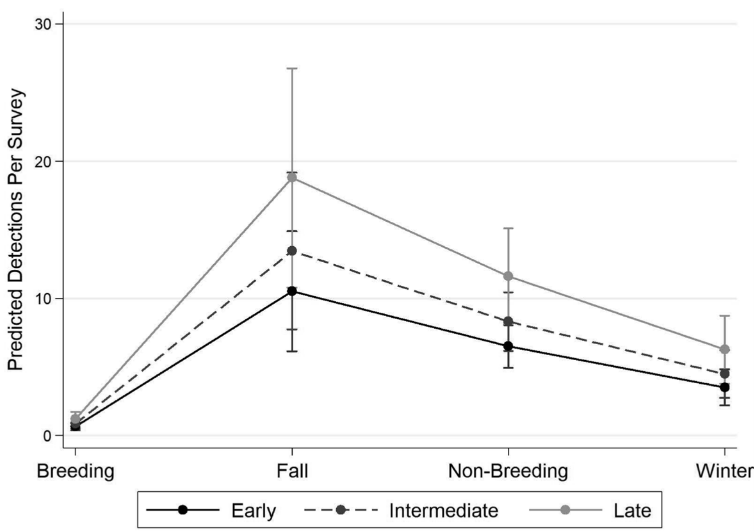

Figure 10. Predicted number of Orange-crowned Warbler detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

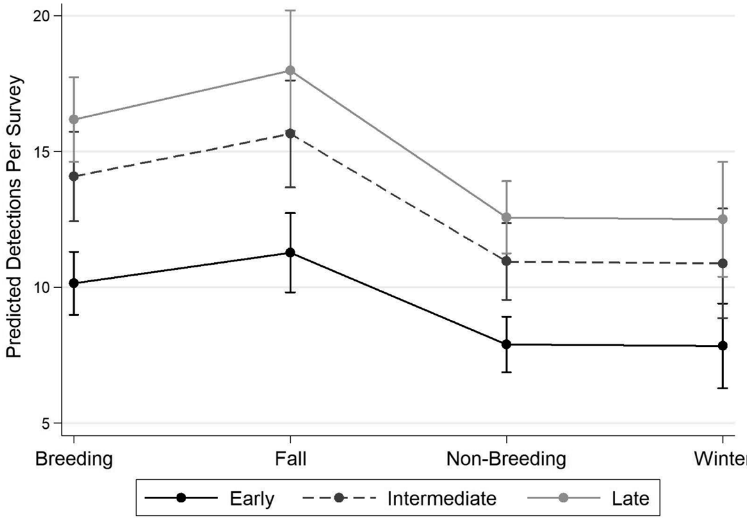

Figure 11. Predicted number of Verdin detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

phase than in the early phase ($p = 0.051$; Table 4). During the early phase, predicted detections in fall were 39% lower than in the breeding season (Figure 14, Table 3). During the late phase, this difference in fall widened to 50%. Interestingly, during the nonbreeding season, the yellowthroat became significantly more abundant in

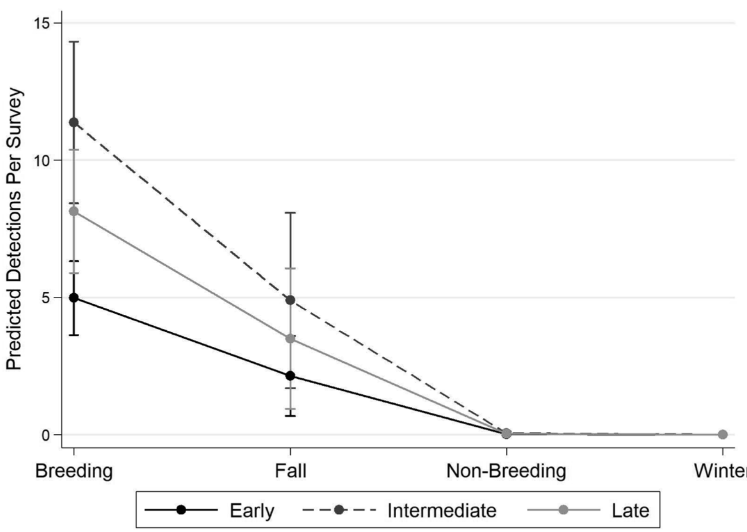

Figure 12. Number of Yellow Warbler detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017, as predicted by primary model (season + phase; see Results).

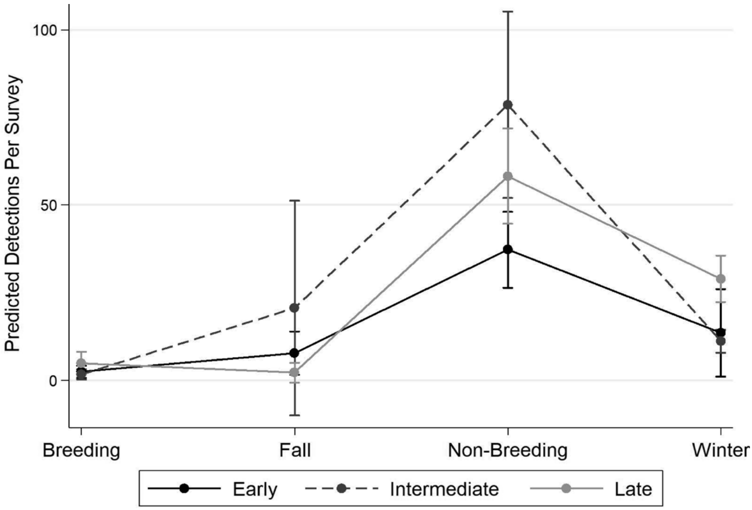

Figure 13. Predicted number of Yellow-rumped Warbler detections per survey (± 95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

the late phase: of the 37 individuals detected during the nonbreeding season, 73% were recorded in the late phase, only 5% in the early phase (Figure 14; Table 4).

Mallard (present at study site: year round). The best-supported model of Mallard detections included season and phase; there was no interaction (Table 2). The spe-

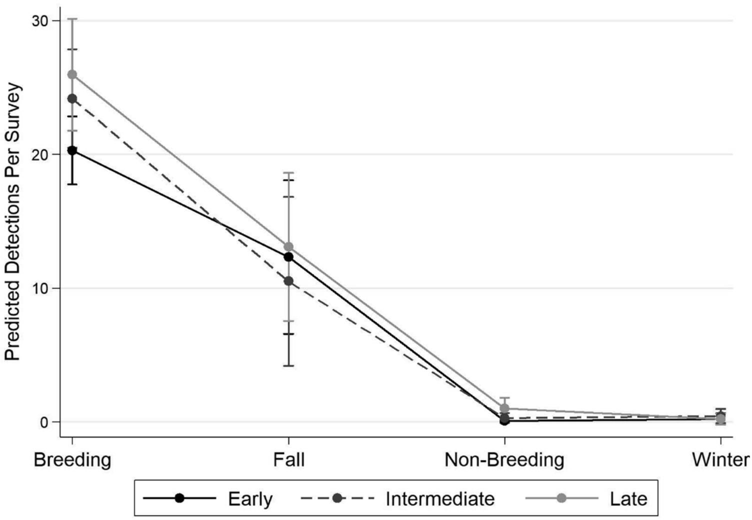

Figure 14. Predicted number of Common Yellowthroat detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

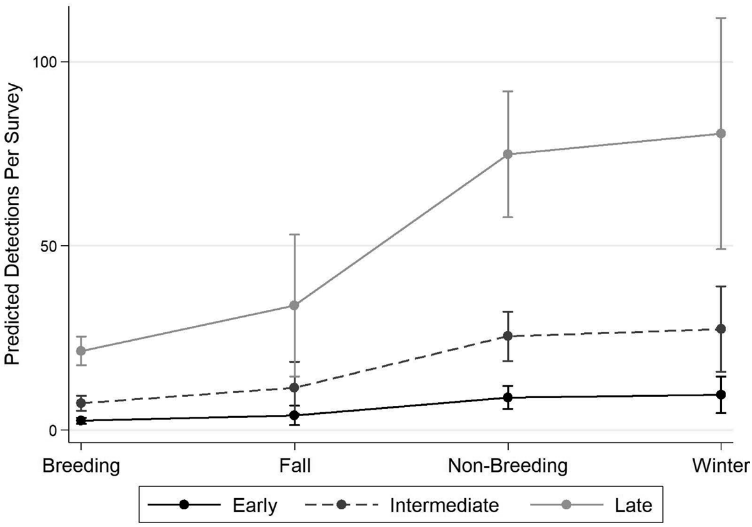

Figure 15. Predicted number of Mallard detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

cies was more abundant in the nonbreeding season and the winter transition than in the breeding season. The rate of detections increased significantly from the early to the intermediate phase and again from the intermediate phase to the late phase (Figure 15; Tables 5 and 6).

Red-winged Blackbird (present at study site: year round). The best-supported model for the Red-winged Blackbird included season, phase, and an interaction between these two variables (Table 2). In the early phase, the rate of detections in the breeding and nonbreeding seasons did not differ significantly, but later in the project, breeding numbers were significantly higher than nonbreeding numbers (Figure 16; Table 3). Overall, during the late phase, detections were significantly greater than during the early phase for all seasons except the nonbreeding period (Figure 16; Table 4).

DISCUSSION

The stabilization and restoration of Las Vegas Wash included removal of most non-native tamarisk, the creation of large wetlands as a result of the installation of weirs, and aggressive revegetation (Figure 17). Over the course of the project, tamarisk cover declined from 36% to 4%, mesquite cover increased from 1% to 7%, and upland shrub cover increased from 15% to 22%. Because of substantial channel erosion, several stands of tamarisk ended up on dry, tall terraces and could therefore not be replaced with mesic native riparian vegetation. Instead, these were replaced by upland shrubs, including saltbush.

In this 12-year study, we examined the year-round responses of the whole bird community, as well as those of select species from three habitat guilds, over three phases of the restoration project. Total bird abundance and species richness both increased significantly from the project's early phase to its late phase. Seasonally, total bird abundance was lowest during the fall transition, but species richness was highest at this time of year.

Riparian Shrub-Associated Species

All three species associated with riparian shrubs declined from the early to the late phase of the project. We attribute this decline to the disturbance associated with the building of weirs and concurrent control of tamarisk. Not only tamarisk cover but density of all vegetation at heights of 2–4 m and 4–6 m declined from 2005 to 2016 (GBBO 2018). Previous studies along Las Vegas Wash and the lower Colorado River found that bird abundances in non-native and native vegetation are similar (Shanahan et al. 2011), particularly where non-native stands grow in wet soils or near surface water (Hinojosa-Huerta 2006). Therefore, the removal of the previously dominant tamarisk likely displaced, at least temporarily, significant portions of the populations of birds associated with riparian shrubs.

Specifically, Abert's Towhee (Tweit and Finch 1994) and the Yellow-breasted Chat (Hunter et al. 1988, Thompson and Eckerle 2022) both occupy riparian woodlands and mesquite bosques, habitats that include dense shrub understories. While mesquite has become the most abundant genus of tree along the wash through plantings and natural regeneration (GBBO 2018), in most areas it has not yet formed the dense stands formerly provided by the non-native tamarisk.

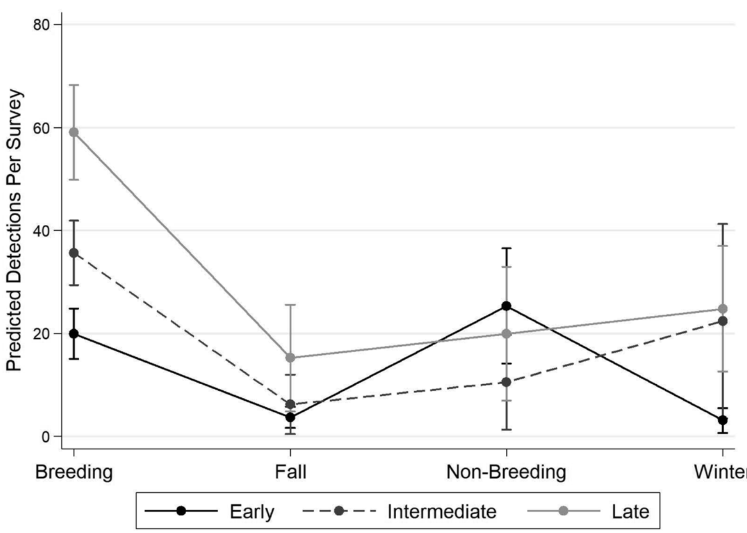

Figure 16. Predicted number of Red-winged Blackbird detections per survey (±95% confidence intervals), by season and restoration phase, at Las Vegas Wash, Nevada, 2005–2017.

Figure 17. Calico Ridge Weir impoundment at the Las Vegas Wash: (A) 2000, pre-weir construction, showing tamarisk perched on tall terrace; (B) 2005, following weir completion and initial revegetation; (C) 2017, mature.

Riparian Tree-Associated Species

The results for this group of landbirds were mixed. For instance, the mesquite-associated Verdin increased with the significant gain of mesquite, while by the end of our surveys the cavity-nesting Lucy's Warbler had not yet responded to the plantings. Given the variety of natural histories represented in this group, these results are likely related to different responses to the initial loss of overstory from tamarisk removal and construction and to the increase in native woodlands emerging from revegetation and channel restoration. Riparian woodlands reach maturity only after a long recovery period (Gardali et al. 2006) and the vegetation develops a complex physiognomy (Munro et al. 2011). Likely the bird community associated with these habitats continues to change as the trees and understory mature. Gardali et al. (2006) indicated that after 8 to 10 years restored riparian forests had matured sufficiently to provide natural cavities for small cavity-nesting species, but that prior to this period they suspected most avian use was for foraging only.

Wetland-Associated Species

Of the three wetland-associated species we modeled, the Mallard and Red-winged Blackbird increased significantly through the study, and the Common Yellowthroat appeared to do so. We attribute these increases to a quick response to the increase in the extent of open water and emergent wetland resulting from weir construction and channel restoration. These increases may also reflect a wider trend, wetlands being the only biome in North America in which numbers of birds have increased since 1970;

increases in waterfowl numbers have been particularly notable (Rosenberg et al. 2019). Breeding Common Yellowthroats are associated primarily with dense emergent wetland vegetation late in succession (Guzy and Ritchison 1999), which may explain this species' apparent increase. As native emergent wetland vegetation continues to mature, the abundance of breeding yellowthroats should continue to increase.

Although Mallards nest along the wash, we found this species primarily during the nonbreeding season, as southwestern North America provides winter habitat for multiple geographic populations (Drilling et al. 2020). Mallard abundance significantly increased over the course of the project, as the species' winter habitat requirements were met when the weirs created open water. Similarly, the increase of the Red-winged Blackbirds was likely due to the increased extent of wetlands. In both the intermediate and late phases, but not the early phase, the abundance of blackbirds was greatest during the breeding season. Red-winged Blackbirds breed in a wide variety of wetland vegetation (Yasukawa and Searcy 2019), and the recovery of marsh vegetation after construction of the weirs likely allowed the increase in breeding blackbirds observed after the early phase of the project.

CONCLUSIONS

Other studies have examined birds' responses to riparian restoration (Farley et al. 1994, Gardali et al. 2006, Munro et al. 2011), but few have examined responses of the bird community at different phases of restoration year round. Farley et al. (1994) suggested that "quality riparian habitats for birds" at a site along the Rio Grande could be established through restoration in as little as 5 years. In contrast, we found that while habitat for wetland species may be established in so short a period, the complexity and extent of a functioning mature riparian woodland that supports the full suite of associated bird species may require more time. This extended period required for recovery may be prolonged when the restoration is phased over time and over different sections of river, as is typical for many such efforts. Division of the restoration into multiple phases, rather than concentration into a single effort, delayed the full recovery of mature riparian woodlands, but it likely prevented the collapse of the local populations of some species that use tamarisk-dominated habitat when native vegetation is not available. We found that initial vegetation removal disfavored some birds, particularly those associated with riparian shrubs, as has been demonstrated in previous studies of tamarisk-dominated habitat (e.g., Fleishman et al. 2003, Hinojosa-Huerta 2006). However, removing tamarisk and growing native tree canopies, through both active restoration and passive recovery, has benefited several canopy-associated species.

ACKNOWLEDGMENTS

This study was funded by the Southern Nevada Water Authority through a grant from the Bureau of Reclamation. Thanks to all of our field surveyors and the Las Vegas Wash Coordination Committee for their support of this project. This paper was improved by the comments of reviewers Daniel Ruthrauff and Greg Golet.

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Accepted 29 August 2023
Associate editor: Daniel R. Ruthrauff