Annual Report 2016

Bird and butterfly community response to large-scale invasive plant removal and native plant restoration in desert riparian habitat along the Rio Grande/Bravo, Big Bend National Park, Texas

Rio Grande/Bravo

Queen butterfly (*Danaus gilippus*)

Summer Tanager (*Piranga rubra*)

Authors

Heather Mackey
Graduate Student
California State University of Los Angeles
5151 State University Dr.
Los Angeles, CA 90032-8201

Julie Coffey
Graduate Student
California State University of Los Angeles
5151 State University Dr.
Los Angeles, CA 90032-8201

Eric M. Wood
Assistant Professor
Department of Biological Sciences
California State University of Los Angeles
5151 State University Dr.
Los Angeles, CA 90032-8201

Lars Pomara
Research Ecologist
Eastern Forest Environmental Threat Assessment Center
US Forest Service Southern Research Station
200 W.T. Weaver Blvd
Asheville, NC 28804
Phone: (512)-501-0260

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Project Summary

This report communicates preliminary findings from the first season of a two-year study, established in 2016, to assess how National Park Service efforts to remove giant cane (*Arundo donax*) from the riparian corridor of the Rio Grande/Bravo in Big Bend National Park influences terrestrial vertebrate and invertebrate wildlife. The Rio Grande/Bravo is one of the largest and most important riverine systems in the desert southwest. Because it transports large volumes of water through arid, water-limited regions, it is subjected to intense human uses (e.g. conversion of floodplain for agriculture or urban uses and water withdrawals for irrigation). Human-driven alterations have created conditions along the riparian corridor conducive to the colonization and establishment of invasive plant species. Giant cane, the dominant invasive plant along the main stream channel within the floodplain of the Rio Grande/Bravo, has altered the structure and functioning of the riparian habitat, and has been the target for a major invasive plant species removal project along the Rio Grande/Bravo within Big Bend National Park, Texas.

The two objectives of our study were: **(1)** to evaluate the impact of restoration efforts on breeding bird and butterfly communities and the vegetation that constitutes their habitat; and **(2**) to quantify habitat characteristics for the Yellow-billed Cuckoo (*Coccyzus americanus*) in relation to restoration activities as well as broader riparian vegetation structure and composition. The western sub-population of the Yellow-billed Cuckoo is listed as threatened under the US Endangered Species Act, warranting a special focus on this species. Preliminary data collected in the first field season of this two-year study suggest that herbaceous vegetation cover and abundance and species richness of both butterfly and bird communities positively responded to giant cane removal treatments, whereas cover of giant cane was greatly reduced. The Yellow-billed Cuckoo appeared unaffected by the cane removal treatments. We documented Yellow-billed Cuckoo habitat occupancy in virtually all survey areas in the floodplain with significant tree cover, and occupancy was most strongly associated with the presence of mature honey mesquite (*Prosopis glandulosa*) trees.

Taken together, results from the first year of our multi-year effort suggest that the removal of giant cane positively affects early-successional components of riparian biodiversity, and hints at the recovery of later-successional woody vegetation, which is a strong component of habitat for breeding birds. Subsequent years of monitoring will continue to document the response by vegetation, butterflies, and birds to restoration activities. Significant additions to analyses after the second field season will explore species compositional changes in bird and butterfly communities in more detail. Additional landscape-scale covariates will be explored in Yellow-billed Cuckoo occupancy models, and models will be potentially used to assess habitat suitability throughout the river floodplain. While treatment areas extend into some within-canyon river reaches, our study sites were restricted to floodplain reaches outside canyons, and findings are limited to these areas.

The Rio Grande/Bravo with giant cane (*Arundo donax*) visible along its bank

Background

Non-native, invasive plant species are a leading factor contributing to losses in global biodiversity (Gurevitch and Padilla 2004, Pimentel et al. 2005). The spread of invasive plant species has increased worldwide, and once established, non-native plants have the potential to outcompete or displace native vegetation and negatively affect ecosystem functioning (Pimentel et al. 2005, Lambert et al. 2010). Nearly all terrestrial ecosystems are prone to invasion by non-native plant species (Zavaleta et al. 2001). However, systems that experience frequent disturbances are particularly vulnerable (Lambert et al. 2010).

Riparian ecosystems are a disturbance-dependent system that have been inundated with invasive plant species worldwide (Bateman and Paxton 2010, Lambert et al. 2010). For example, in the desert southwest of the US, early successional, non-native plant species, such as salt cedar (*Tamarix ramosissima*, hereafter *Tamarix*) and giant cane (*Arundo donax*, hereafter *Arundo*) have colonized large stretches of riparian habitat (Lambert et al. 2010). Desert riparian habitat covers only 1% of the terrestrial land cover in the southwest, yet this habitat supports a disproportionate amount of the region's flora and fauna (Soykan et al. 2012), including migratory and breeding birds (Sogge et al. 2008, van Riper III et al. 2008), arthropods (Durst et al. 2008), mammals and reptiles (Bateman and Ostoja 2012), and numerous plant and animal species of concern (US Fish and Wildlife Service 2014). Studies on the effects of invasive plant species on desert riparian biodiversity, particularly with a focus on *Arundo,* have found decreases in the maintenance of riparian habitat for native species (Lambert et al. 2010). However, in some instances, particularly with a focus on *Tamarix,* studies have found positive correlations with invasive plants and native biodiversity (Durst et al. 2008, Sogge et al. 2008, Bateman and Ostoja 2012), highlighting complexities associated with managing invasive plants in riparian habitat.

The Rio Grande/Rio Bravo constitutes one of the most important desert riparian systems in the US southwest, in terms of economic, cultural, and biological value. The river system, like others in the region, is infested with invasive plant species, including *Tamarix* and *Arundo*. One of the most biologically important sections of the Rio Grande/Rio Bravo is a 118-mile stretch within the boundaries of Big Bend National Park (BIBE). To maintain the biological diversity of the river system within BIBE, the National Park Service, in collaboration with the World Wildlife Fund and the Mexican government, is undertaking a major restoration effort to remove *Arundo* and *Tamarix* along the BIBE corridor, using a combination of burn and herbicide treatments (for *Arundo*) and a biocontrol (saltcedar leaf beetle, *Diorhabda sublineata*), for *Tamarix*. This is part of a binational effort to promote "desired future conditions" along this historically, culturally, and recreationally significant international waterway (CEC 2014).

Broad expectations are that restoration efforts in BIBE will result in regenerating native plant communities in treatment areas, leading to a more diverse structure and mix of species, and that native riparian wildlife will show similar patterns of change resulting in higher diversity and abundances, following the removal of *Tamarix* and *Arundo*. It is essential to document the ecological impacts of restoration efforts in order to evaluate project effectiveness. One way to measure the success of the restoration work in BIBE is to monitor the response of vegetation, and bird and butterfly communities, all of which are useful indicators of riparian health (Nelson and Andersen 1994, Gardali et al. 2006).

Methods

From May through July, 2016, we carried out the first field season of this study. The study is funded for a second year, and the second field season will begin in late May 2017.

Sampling Design

We established a systematic sampling design to monitor breeding bird and butterfly communities throughout the Rio Grande/Bravo in BIBE (Fig. 1). To initially place sampling locations, we used a high-resolution (1-m^2) National Agricultural Imagery Program image, taken during the summer of 2015, in a GIS (ArcMap) to digitize all riparian habitat (e.g., bosques and vegetation clearly within the floodplain) along the 118-mile stretch of the Rio Grande/Rio Bravo, outside of canyon reaches. We also relied upon an NPS-provided spatial layer depicting cane stands. We then drew a rectangular polygon covering the entirety of the riparian habitat polygons, and created a regular, 300-m^2 square grid across this rectangle. All line intersections of the grid that fell within the areas of riparian habitat on the US side of the river were identified as candidate locations for sampling points for birds and butterflies (hereafter, sample points or sample transects, Fig. 1). We used the minimum 300-m spacing as this is a standard distance to minimize the potential for double counting individual birds during breeding bird point count surveys (Ralph et al. 1995). Within contiguous sections of riparian habitat, we established walking routes, consisting of seven to ten sample points, moving some candidate points to ensure sampling of treatment areas (but adhering to the minimum separation distance). Our sampling design resulted in 163 points, arranged among 20 walking routes; 10 along the western reach of the BIBE section of the river, and 10 along the eastern reach, Mariscal Canyon being the boundary between western and eastern reaches (Fig. 1, Appendix A1-A15). Most significant riparian vegetation blocks on the US side of the river were saturated with sample points using this approach, with the important exception of a large section immediately west of Mariscal Canyon that was excluded due to remoteness (Fig. 1). All sample points were geolocated with a GPS in the field, and the resulting locations were intersected in a GIS with an NPS-provided spatial layer indicating cane treatment areas and years treated.

Bird Surveys

We used standardized, five-minute point count surveys to characterize the breeding bird community at each sample point (Ralph et al. 1995, Fig. 2). We visited each site three times, with each visit occurring one to two weeks apart, between May 19th and June 24th, 2016. We began point counts ten minutes after sunrise and ended within four hours. We varied the starting point of our walking routes with each visit to control for temporal variation in bird detectability and rotated observers among route visits to minimize observer bias. All counts were conducted by graduate students, Julie Coffey and Heather Mackey, who were trained in auditory and visual identification of birds found along the Rio Grande/Bravo by Pomara and Wood. For each bird detection during a point count, we estimated the approximate distance, and detection method (visual, call or song). We used the following distance categories for each detection: 0-10 m, 10-20 m, 20-30 m, 30-40 m, 40-50 m, with categories for >50-m and birds that were detected as flying over the habitat. We did not conduct surveys during high winds or rain.

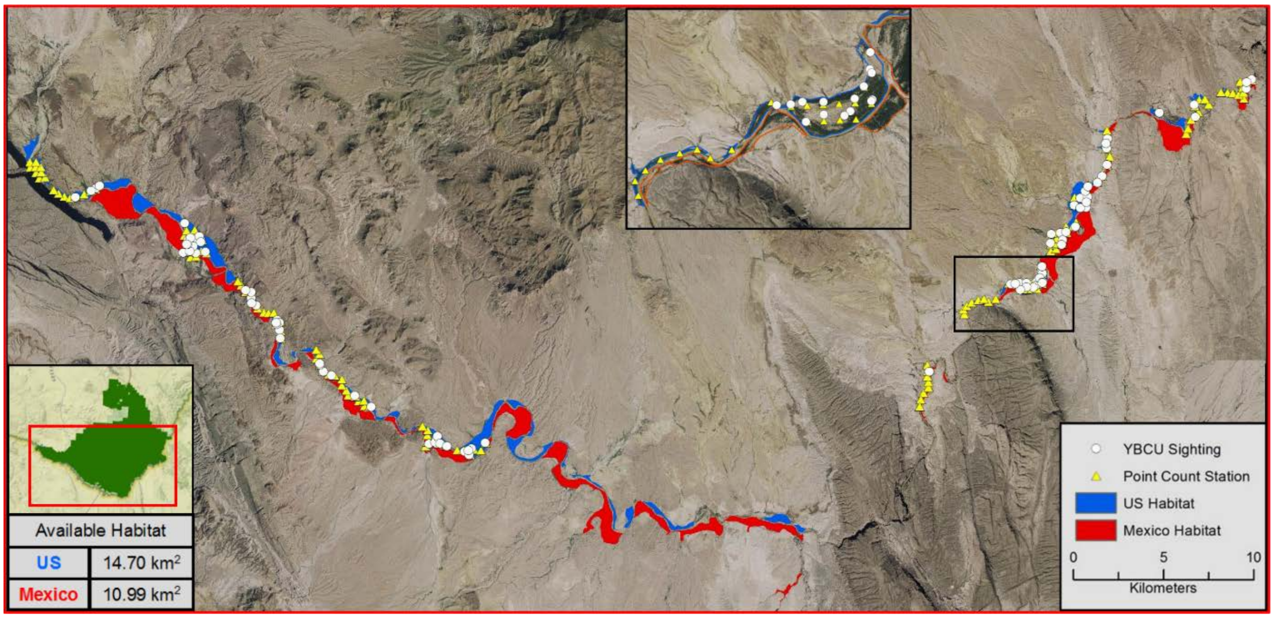

Figure 1*. Map the Rio Grande/Rio Bravo of BIBE and Mexican Sister Protected Areas, Maderas del Carmen, Ocampo and Santa Elena, depicting 163 bird and butterfly point count stations (yellow triangles) at treated and untreated sites, Yellow-billed Cuckoo sightings (white circles), and the available riparian habitat on both the US and Mexico sides of the floodplain (blue and red polygons, respectively). Inset at top provides detail of sampling.*

Yellow-billed Cuckoo surveys

A target species of our bird surveys was the Yellow-billed Cuckoo (*Coccyzus americanus*). The Yellow-billed Cuckoo is separated into two sub-populations, the 'western' and 'eastern' (US Fish and Wildlife Service 2014). The western sub-population was listed as threatened in 2014 due to losses in its preferred breeding habitat, riparian gallery forest (US Fish and Wildlife Service 2014). The USFWS-recognized geographic boundary between the western and eastern sub-populations bisects BIBE, occurring at Mariscal Canyon along the Rio Bravo/Rio Grande (US Fish and Wildlife Service 2014). Given uncertainty surrounding the precise location of this boundary (or possibly hybrid zone), management of Yellow-billed Cuckoo habitat throughout BIBE is likely warranted, as is further study of the taxonomic identity of Yellow-billed Cuckoos breeding in BIBE.

To increase detection rates for Yellow-billed Cuckoos, we used a call playback protocol at each sample point (Halterman et al. 2015). Following a passive point count, we broadcasted recordings of Yellow-billed Cuckoo calls for a one-minute period. We then listened for a minute, before repeating the process for an additional two minutes. Evidence suggests the western sub-population utilizes sonically unique vocalizations compared with the eastern subpopulation (US Fish and Wildlife Service 2014). Therefore, we designed our playback surveys to account for potential differences in responses from individuals belonging to western or eastern subpopulations. At sample points east of Mariscal Canyon, we played eastern calls for the first minute of our survey, followed by western calls for the second minute. We did the reverse for sample points west of Mariscal Canyon. We obtained western and eastern Yellow-billed Cuckoos recordings from the bird-vocalizations sharing website, xeno-canto (http://www.xeno-canto.org/). Each recording consisted of contact and territorial calls ("kowlp call" and "coo coo" call, respectively) and were broadcasted using a smartphone and handheld speaker. If we detected a Yellow-billed Cuckoo during a passive point count, we recorded its distance following our standard protocol for bird point counts. Following a detection during a passive point count, we then proceeded to perform the call playback protocol. If we detected a Yellow-billed Cuckoo during the call playback, we stopped the survey and recorded the distance to, and the location of, the individual.

Butterfly surveys

We established 100-m butterfly transects at each sample point, with the midpoint of the transect either centered on the bird point count location (n = 44), or the sample point as a start or end point for the transect (n = 119) (Fig. 2). We established straight-line transects through walkable habitat following protocols designed to monitor the federally endangered Karner Blue Butterfly (*Lycaeides melissa samuelis*, Brown and Boyce 1998). Our starting point was dependent on our ability to walk through dense vegetation and survey butterflies. On seven occasions, the bird point count was located in nearly impenetrable vegetation (i.e. mesquite forest) making it extremely difficult to maneuver. In these seven cases, we repositioned transects along the edge of the dense vegetation. Since many of our points were adjacent to the Rio Grande/Rio Bravo, we generally positioned transects parallel to the river and flagged the start, center and end points. We used compasses to ensure our walking routes were consistently followed, as any deviation from transects would influence distance estimation for butterflies (see below).

We visited butterfly transects three times between May 19th and June 24th and started surveys between 8:15 am and 1:35 pm, with an average start time of 11 am. To survey butterflies, we walked transects slowly in a straight line, identifying all butterflies detected within a search area that was approximately 10 x 100 m (Fig. 2). Butterfly detections typically occurred in two ways: (1) a butterfly sitting on a plant surface, or (2) a butterfly flying within our survey area. When we detected a butterfly on a plant surface, we noted the distance, perpendicularly, from the butterfly, or plant if the butterfly was repeatedly changing locations, to a transect, and we identified the plant that was being 'used'. When we detected a butterfly flying within our survey area, we marked the distance that the butterfly was first detected, perpendicularly, to a transect. We used the following distance categories for each detection: 0-0.5 m, 0.5-1 m, 1-1.5 m, 1.5-2.25 m, 2.25-3 m, 3-4 m, and 4-5 m, and >5-m (Brown and Boyce 1998). We surveyed each transect for a minimum of five minutes. If we were not able to identify a butterfly from the location of a transect, we would maneuver from the transect to a better viewing position to identify the species before resuming the transect survey. We would not record any new individuals during this time.

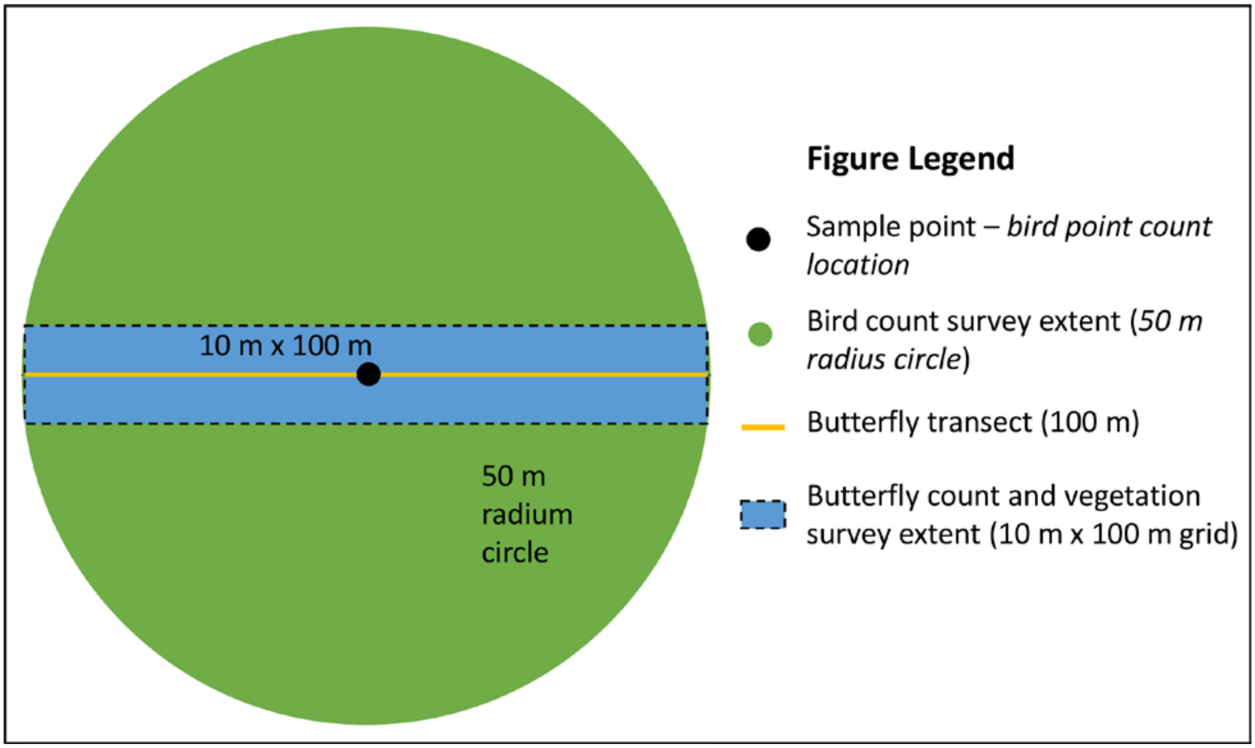

***Figure 2**. Sampling design schematic for 163 sample points, including the bird point count location, the extent of the 50-m radius bird survey circle, the 100-m butterfly transect, and the 10 m x 100 m butterfly and vegetation survey extent.*

Vegetation surveys

We quantified vegetation cover, at both the bird and butterfly survey extents (Fig. 2), between June 26th and July 7th. Our bird vegetation survey area extended to 100 m in year one. In year two, we will modify our vegetation surveys that are associated with bird surveys, to extend to 50 m from the count station. We will make this modification because vegetation changes abruptly over short distances throughout our survey area (e.g. riverbank habitats interspersed with bosque), and the 50-m extent will minimize variability in bird and vegetation communities of differing habitat types, within a sampling location. For bird-count vegetation surveys, we used a relevé method to estimate percent cover at the ground, shrub (<4 m), and canopy (>4 m) level within the 100-m radius circle at each sample point (Wood et al. 2011). Broad vegetation categories included tree (>4 m in height), shrub (<4 m in height), dead shrub, grass, herbaceous, *Arundo,* water, duff, and bare ground. Estimates of tree (>4 m) or shrub (<4 m) percent cover included mesquite, *Tamarix*, and willow (*Chilopsis* spp., and *Salix* spp.). We identified any species that covered 5% or more of the plot, and we estimated the percent cover of the individual species.

For butterfly-transect vegetation surveys, we estimated percent cover of the same variables as the bird-count vegetation surveys, but within a 10 x 100-m rectangle centered on the butterfly transect (Fig. 2). In addition to percent cover, we noted the presence of flowering plant species. Dead *Arundo* that was on the ground was included in the "duff" category. All standing *Arundo*, both alive and dead, was included in the *Arundo* percent cover estimate and we noted the condition (dead, burned, regrowth). From our vegetation surveys, we identified five habitat groupings, which are the basis for our analyses described below.

Table 1. *Habitat categories, sample sizes, and descriptions for each category for bird and butterfly sampling locations. The sample sizes differ between bird and butterfly surveys because we categorized habitat at two spatial extents: (a) 100-m radius circles surrounding bird count stations for bird habitat categories, and (b) 10 m x 100 m rectangle surrounding butterfly transects (Fig. 2). See Figures 2A-14A of the Appendix for mapped location of sampling locations and habitat categorizations.*

Categories	***n* Bird**	***n* Butterfly**	**Description**
Riverbank	20	24	Habitat within 150 m of river's edge
Treatment	35	35	Sites that received at least one burn/herbicide treatment
Floodplain	57	84	Floodplain sites inland from river's edge (> 150 m)
Bosque	45	14	Honey mesquite dominated gallery forest
Upland*	6	6	Outside of the floodplain - upland desert vegetation

*Sites excluded from analysis because they were deemed not relevant to research objectives

Analytical methods

For our first objective, we evaluated the impact of the binational restoration effort on the Rio Grande/Rio Bravo bird and butterfly community, by performing the following three analyses: **(1)** we quantified differences in vegetation cover, and bird and butterfly richness and abundance among the habitat categories detailed in Table 1. We calculated total richness and abundance during each visit, and averaged the total values among the three visits. To evaluate the degree of difference in vegetation cover and bird and butterfly richness and abundance among habitat categories, we used a one-way analysis of variance (ANOVA). Prior to analysis, we checked assumptions for ANOVA tests, which revealed all assumptions were satisfied. Following significant ANOVAs, we performed a multiple-comparisons routine, using a Tukey-Kramer's test. Because we made 15 comparisons during the multiple comparisons routine, we used a Bonferroni adjusted *p*-value of 0.003 to assess significance (=0.05/15 = 0.003). **(2)** As a preliminary evaluation of habitat associations, we assessed the correlation, using Spearman's *rho*, between bird and butterfly richness and abundance and habitat characteristics (i.e., vegetation cover variables). **(3)** As a follow-up to the correlation analysis, we wanted to understand how bird and butterfly communities and vegetation responded following restoration. To examine this, preliminarily, we quantified the mean richness and abundance of birds and butterflies and cover of habitat characteristics in sampling locations (both points and transects) that had been subjected to burning and herbicide treatments over the course of the past eight years. Twenty of our sample locations were distributed among Solis, Rooney's Place, Casa de Piedra, and San Vicente, all of which were burned in 2016 (0 years); eight of our sample locations were distributed along the western border of Boquillas Canyon and the Border Crossing area and were last burned in 2012 (4 years); and seven of our sample locations were located at Gravel Pit, which was burned in 2008 (8 years). This allowed an understanding for how the riparian systems may be responding, over time, to treatments.

For our second objective, we determined whether restoration efforts affected habitat use of the Yellow-billed Cuckoo by performing two analyses: **(4)** we divided sample points into two groups based on Yellow-billed Cuckoo naïve occupancy (i.e. presence or absence) and used Welch's two sample *t*-test to evaluate the degree of difference in habitat characteristics between groups. **(5)** We then evaluated Yellow-billed Cuckoo sample-point occupancy in a formal habitat occupancy analysis. We fitted single-season, single-species occupancy models by relating Yellow-billed Cuckoo habitat occupancy as a function of habitat characteristics, and selected top models in an information-theoretic framework. For analyses #s 1-3, we used the graphical and statistical program, *R* (R Core Team 2013), and, outside of analyses #1 and #5, we considered *p*-values < 0.05 to be significant. For analysis # 4, we used the PRESENCE statistical software (MacKenzie et al. 2006).

Results

OBJECTIVE 1: EVALUATING THE IMPACT OF THE RESTORATION EFFORT ON THE BIRD AND BUTTERFLY COMMUNITY

Analysis 1 – Response by bird and butterfly communities and vegetation to treatments

Patterns of vegetation cover were distinct among habitat groupings (Tables 2 and 3). We found that mesquite tree cover was higher, unsurprisingly, in bosque habitats at both the bird and butterfly survey extents (Tables 2 and 3). *Tamarix* shrubs and herbaceous cover were similar among habitat categories. *Arundo* was significantly higher in sites burned in 2016, which most likely characterized regeneration following burn treatments. *Arundo* cover was significantly lower in sites that had were burned in either 2012 or 2008, which is suggestive that burning, plus the likely application of herbicide treatments does, indeed, result in lower cover of *Arundo* (Tables 2 and 3).

In comparing bird and butterfly communities among habitat groupings, we found that both bird richness and abundance were highest in bosque, riverbank, and sites burned in 2012 or 2008, and lowest in sites burned in 2016 and floodplain (Tables 2 and 3). In contrast, we found that butterfly richness and abundance were greatest in sites burned in 2012 or 2008, with riverbank habitats also hosting a high diversity and abundance of butterflies. On the other hand, sites burned in 2016, floodplain, and bosque all supported the lowest richness and abundance of butterflies (Tables 2 and 3).

Analysis 2 – Relationships among bird and butterfly communities and vegetation

When examining relationships among bird and butterfly richness with habitat characteristics, we found that bird richness and abundance were negatively correlated with cover of *Arundo*, but were not correlated with other habitat characteristics (Table 4). Butterfly richness and abundance were not correlated with cover of *Arundo*, mesquite, or *Tamarix*, but were positively correlated with herbaceous cover (Table 4).

Table 4. *Spearman's correlation coefficient (rho) for richness and abundance of birds and butterflies with four habitat characteristics. Values in bold indicate a significant correlation ($p < 0.05$).*

	Arundo	Mesquite > 4m	Herbaceous	*Tamarix* < 4m
Bird richness	**-0.20**	**0.23**	0.14	0.01
Bird abundance	**-0.15**	0.15	0.12	-0.06
Butterfly richness	0.03	**-0.23**	**0.23**	0.03
Butterfly abundance	0.04	**-0.30**	**0.19**	0.00

Analysis 3 – Response, over time, of bird and butterfly communities and vegetation to restoration

We found that, over time, there was an apparent trend in the increase in bird and butterfly richness and abundance, *Tamarix,* and the herbaceous layer following the most recent burn treatment. The magnitude of increase was greatest for butterfly abundance, and, to a lesser extent, herbaceous cover. Cover of *Arundo* was greatly reduced over time, and the mesquite tree canopy appeared unchanged (Tables 2 and 3, Fig. 3 and Fig.4).

Table 2. *Average values, plus 95% confidence intervals in parentheses, for bird richness and abundance, honey mesquite trees (Mesquite > 4m), Tamarix shrubs (Tamarix < 4m), herbaceous vegetation (grass and forb species), and Arundo donax, at 157 sample points, grouped among five habitat categories that are described in Table 1. For this analysis, we further grouped treated sites into two categories: those that were treated (burned and/or herbicide) greater than, or equal to, four years prior to surveys (2012 and 2008), and those treated in 2016. The purpose for this additional grouping was to explore temporal trends in the response by bird communities and select vegetation metrics following treatment. Letters that differ, following average values within a row, indicate a significant difference among habitat categories for a particular bird or vegetation metric based on a one-way analysis of variance (ANOVA), followed by a Tukey-Kramer multiple comparisons routine for significant ANOVAs. We assessed significance at the Bonferroni adjusted p-value of 0.003 (=0.05/15 comparisons).*

	Riverbank		**Burned ≥ 4 years ago**		**Burned in 2016**		**Floodplain**		**Bosque**	
Bird richness	5.89^{AB}	(4.78, 7.01)	6.09^{AB}	(4.78, 7.40)	4.88^{A}	(3.98, 5.77)	5.52^{AB}	(5.01, 6.03)	7.02^{B}	(6.45, 7.60)
Bird abundance	11.53^{AB}	(8.65, 14.40)	11^{AB}	(8.29, 13.71)	7.67^{A}	(6.02, 9.31)	8.61^{A}	(7.56, 9.65)	12.05^{B}	(10.66, 13.43)
Mesquite > 4m	9.37^{AB}	(0.24, 18.50)	0.91^{A}	(0, 2.69)	3.54^{A}	(0.51, 6.58)	8.02^{A}	(5.05, 10.99)	20^{B}	(13.96, 26.04)
Tamarix < 4m	7	(0.25, 13.75)	7.19	(2.34, 12.034)	2.29	(0.96, 3.63)	6.07	(4.24, 7.90)	4.03	(1.96, 6.09)
Herbaceous	2	(1.04, 2.96)	5.82	(2.66, 8.98)	3.25	(0.96, 5.54)	2.95	(1.63, 4.27)	2.68	(1.39, 3.97)
Arundo donax	8.89^{A}	(4.68, 13.11)	$2.1A^{AB}$	(0.00, 4.20)	20.92^{C}	(14.96, 26.88)	4.64^{AB}	(2.94, 6.35)	1.93^{B}	(0.79, 3.07)

Table 3. *Average values, plus 95% confidence intervals in parentheses, for butterfly richness and abundance, honey mesquite trees (Mesquite > 4m), Tamarix shrubs (Tamarix < 4m), herbaceous vegetation (grass and forb species), and Arundo donax, at 157 sample points, grouped among five habitat categories that are described in Table 1. For this analysis, we further grouped treated sites into two categories: those that were treated (burned and/or herbicide) greater than, or equal to, four years prior to surveys (2012 and 2008), and those treated in 2016. The purpose for this additional grouping was to explore temporal trends in the response by butterfly communities and select vegetation metrics following treatment. Letters that differ, following average values within a row, indicate a significant difference among habitat categories for a particular butterfly or vegetation metric based on a one-way analysis of variance (ANOVA), followed by a Tukey-Kramer multiple comparisons routine for significant ANOVAs. We assessed significance at the Bonferroni adjusted p-value of 0.003 (=0.05/15 comparisons).*

	Riverbank		**Burned ≥ 4 years ago**		**Burned in 2016**		**Floodplain**		**Bosque**	
Butterfly richness	4.45^{AB}	(3.55, 5.36)	5.75^{BC}	(4.17, 7.33)	3.09^{A}	(2.24, 3.93)	2.46^{A}	(2.09, 2.83)	3.07^{A}	(1.88, 4.26)
Butterfly abundance	10.77^{AB}	(6.31, 15.23)	17.58^{BC}	(9.76, 25.41)	7.13^{A}	(4.12, 10.14)	4.73^{A}	(3.79, 5.68)	5.29^{A}	(2.67, 7.90)
Mesquite > 4m	0^{A}	(0, 0)	0.42^{A}	(0, 1.23)	0^{A}	(0, 0)	2.45^{A}	(0.57, 4.32)	28.50^{B}	(11.58, 45.42)
Tamarix < 4m	7.19	(0.26, 14.12)	0.60	(0, 1.45)	1.57	(0.57, 2.57)	5.36	(3.63, 7.09)	2.10	(0, 4.36)
Herbaceous	2.51	(1.24, 3.78)	12.93	(6.19, 19.66)	6.05	(0, 12.94)	3.92	(1.57, 6.27)	4.73	(1.39, 8.07)
Arundo donax	1.74^{A}	(0.67, 2.81)	1.43^{A}	(0, 3.87)	24.70^{B}	(13.87, 35.52)	1.06^{A}	(0.39, 1.73)	0^{A}	(0, 0)

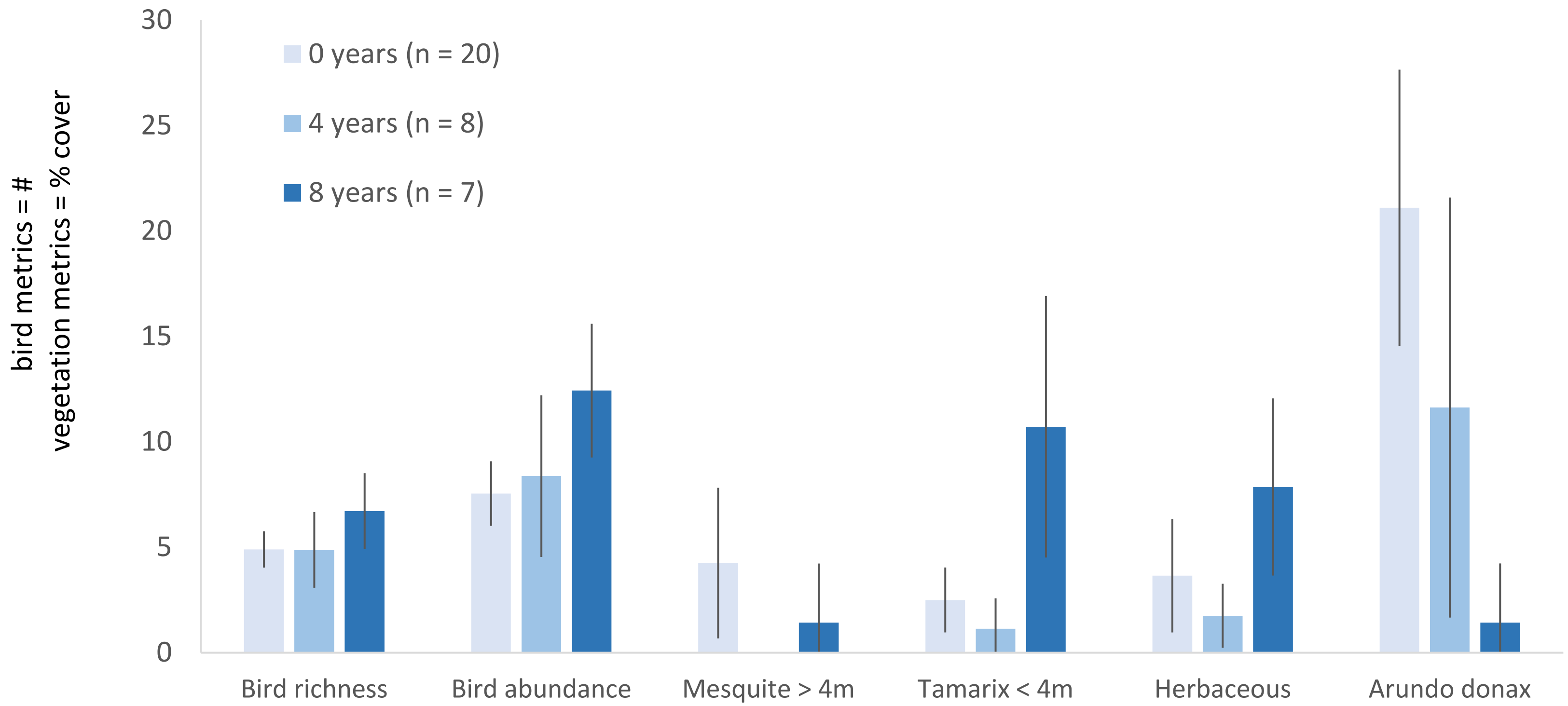

Figure 3. *Mean value, and 95% confidence interval, for bird richness and abundance, and four vegetation characteristics at 35 sampling points that were located in sites that had been exposed to burn treatments. We created the three groupings to characterize the response of bird and vegetation to the most recent burn event. Twenty of our sample points were distributed among Solis, Rooney's Place, Casa de Piedra, and San Vicente, all of which were burned in 2016 (0 years); eight of our sample points were distributed along the western border of Boquillas Canyon and the Border Crossing area and were last burned in 2012 (4 years); and seven of our sample points were located at Gravel Pit, which was burned in 2008 (8 years).*

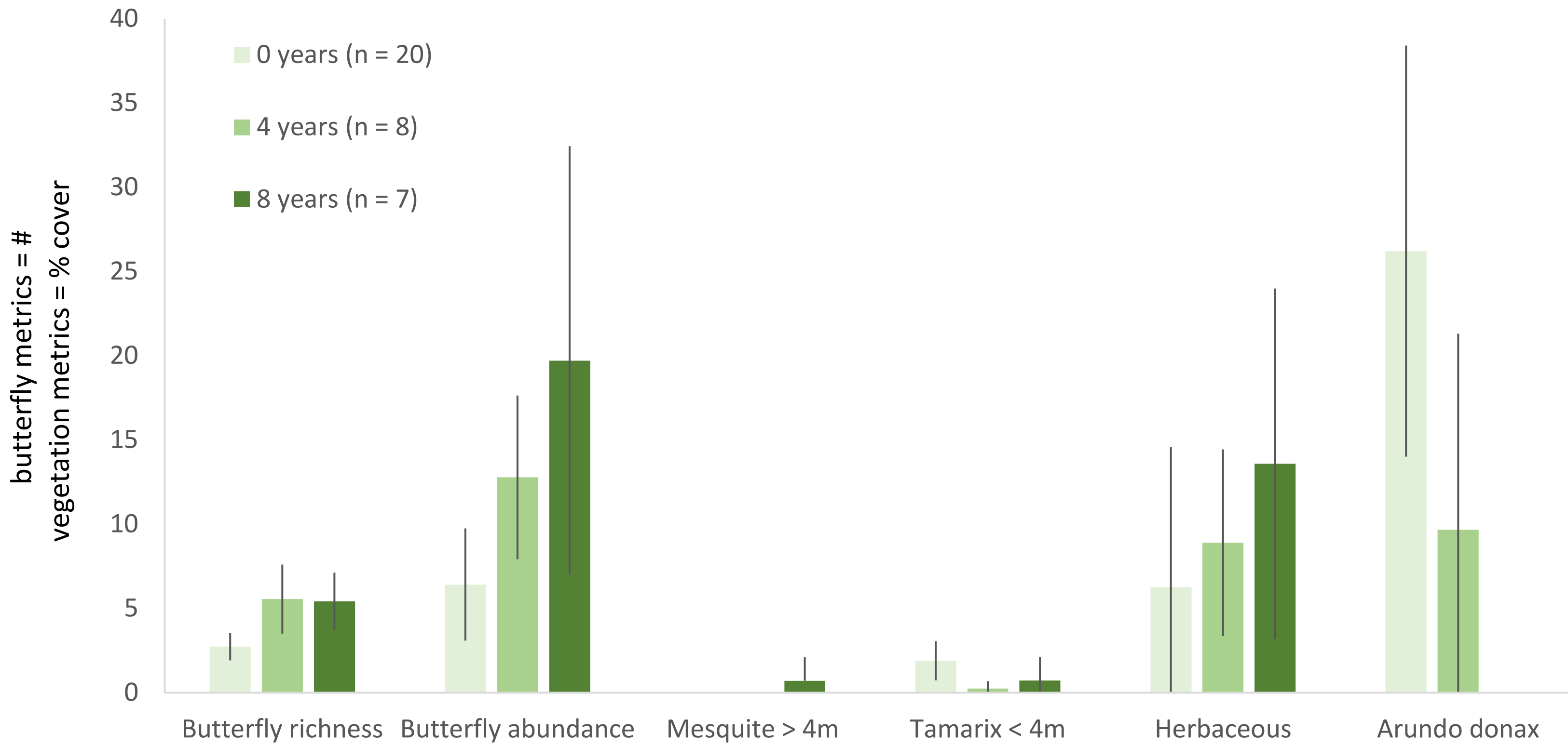

Figure 4. *Mean value, and 95% confidence interval, for butterfly richness and abundance, and four vegetation characteristics at 35 sampling transects that were located in sites that had been exposed to burn treatments. We created the three groupings to characterize the response of butterfly and vegetation to the most recent burn event. Twenty of our sample points were distributed among Solis, Rooney's Place, Casa de Piedra, and San Vicente, all of which were burned in 2016 (0 years); eight of our sample points were distributed along the western border of Boquillas Canyon and the Border Crossing area and were last burned in 2012 (4 years); and seven of our sample points were located at Gravel Pit, which was burned in 2008 (8 years).*

OBJECTIVE 2: HABITAT RELATIONSHIPS OF THE YELLOW-BILLED CUCKOO

Analysis 4 – Differences in habitat characteristics among occupied and unoccupied Yellow-billed Cuckoo locations

Yellow-billed Cuckoo naïve occupancy was 36% among all sample points. Sample points that were occupied by Yellow-billed Cuckoos had 53% higher mesquite cover than unoccupied sample points. We found there was no significant difference between *Arundo* or *Tamarix* percent cover at sample points that were occupied by Yellow-billed Cuckoos compared with unoccupied sample points.

Analysis 5 – Yellow-billed Cuckoo habitat-occupancy relationships

Based on a preliminary single-season, single-species occupancy analysis, we found that our detection probability was 0.18 (95% CI, 0.11, 0.29), and our estimate of sample-point occupancy was 0.73 (0.33, 0.94). The estimate of sample-point occupancy was 51% greater than the naïve occupancy, highlighting the need to account for detection probability with Yellow-billed Cuckoo surveys. Our top (lowest-AIC) model strongly supported the expectation that Yellow-billed Cuckoos occupy sites with high mesquite tree cover, with nearly 80% of model deviance accounted for with this variable (Table 5). All other habitat variables had low support (ΔAIC > 2.0) for predicting Yellow-billed Cuckoo occupancy (Table 5).

Table 5. *Results of a single-season, single-species occupancy analysis modeling Yellow-billed Cuckoo sample-point occupancy as a function of four habitat characteristics: % cover of mesquite trees (> 4 m), Tamarix shrubs (< 4 m), herbaceous plants, and Arundo donax. We also explored occupancy patterns in relation to restoration efforts ("treatment", i.e., treated or untreated). The table displays the ΔAIC (values < 2 indicate strong model support), AIC weights, the number of parameters in each model (K), and the direction of the relationship between the coefficient and Yellow-billed Cuckoo occupancy.*

Model	ΔAIC	AIC weight	*K*	Coefficient direction
ψ(Mesquite, > 4 m),*p*(.)	0	0.79	3	+
ψ(*Tamarix,* < 4 m),*p*(.)	3.81	0.12	3	+
ψ(Treatment),*p*(.)	6.26	0.03	3	-
ψ(.),*p*(.)	6.35	0.03	2	
ψ(Herbaceous),*p*(.)	7.81	0.01	3	+
ψ(*Arundo*),*p*(.)	8.35	0.01	3	-

Our occupancy analysis revealed that the following locations had the highest probability of hosting Yellow-billed Cuckoos: Gravel Pit, La Clocha, San Vicente, Casa de Piedra, (east side of Mariscal Canyon), and Johnson's Ranch, Black Dike, Buenos Aires, Cottonwood, and Boat Launch (west side of Mariscal Canyon) (Fig. 5).

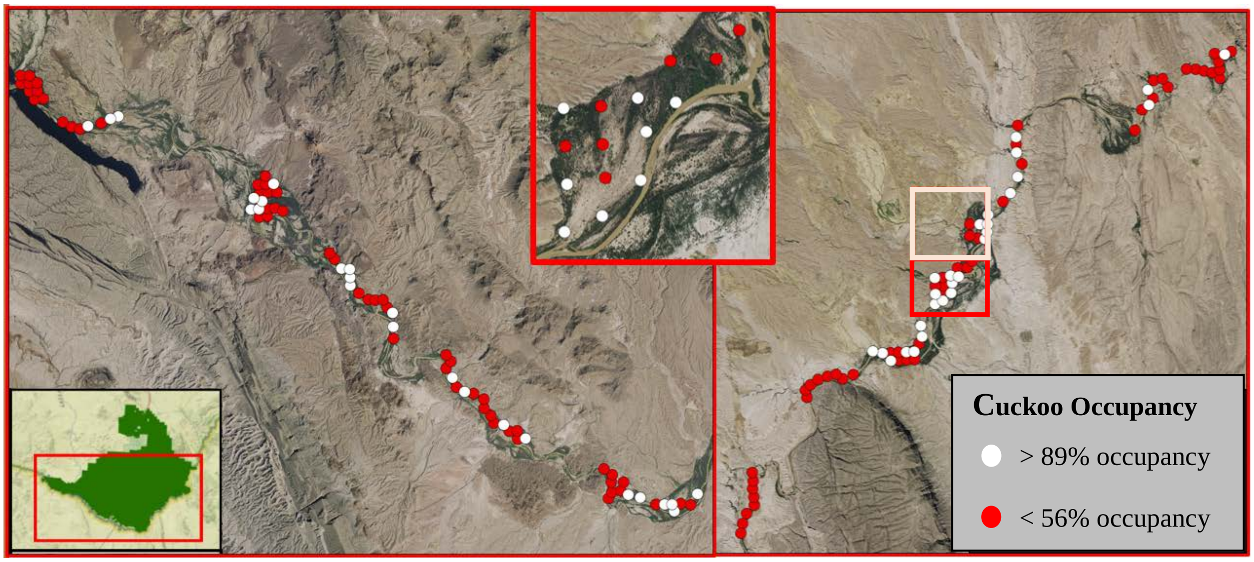

Figure 5. *Map of Yellow-billed Cuckoo predicted site occupancy calculated from a single-season, single-species intercept-only, occupancy model [ψ(.), p(.)]. Inset at top provides detail of San Vincente.*

Discussion

Our field efforts in 2016, designed to assess the effects of the removal of *Arundo* on terrestrial biodiversity, show, preliminarily, that components of early successional riparian biodiversity, namely butterfly abundance and species richness, responded positively following burn and herbicide treatments. Further, our work detailed the substantial decrease in *Arundo* cover, and increase in herbaceous cover in sites that had been treated in 2012 or 2008. In addition to butterflies, we found initial support for the expectation that breeding bird communities respond positively at least four years following the most recent controlled burn. On the basis of first-season data, Yellow-billed Cuckoos appeared to be unaffected by the restoration activities, but our occupancy analysis did reveal important habitat associations, in particular a close association with mature mesquite within large bosques, which we believe are likely to constitute breeding habitat locations.

Our first-season work initially indicates that the continued removal of *Arundo* is likely to enhance valued aspects of riparian ecosystem functioning (e.g., wildlife habitat provisioning, pollination). Further, our findings for the Yellow-billed Cuckoo describe habitat occupancy conditions which, as we continue to improve models with the addition of landscape-scale habitat characterizations, we expect to be useful for mapping and management of the species' preferred breeding habitat. Perhaps equally important, our detections of Yellow-billed Cuckoos virtually throughout mesquite bosque habitat in the river floodplain, and consistently through the breeding season, represent the most complete documentation of the full spatial extent of their presence in BBNP to date.

It is well understood that following controlled burns, herbaceous plants and insects are among the first to recolonize sites (Swengel 2001). Our initial findings regarding the response of herbaceous plants and butterflies following the removal of *Arundo* follows a standard progression of succession, which is in line with other studies documenting the linear response of early successional biodiversity following the removal of invasive plant species (Flory and Clay 2009). An interesting initial finding from our first season has been that following the initial controlled burns, which are intended to reduce *Arundo* cover, we did not find an immediate positive response by herbaceous vegetation and butterfly communities. Rather, we found a large increase in regenerating *Arundo*, and it was not until treatments had been applied for four years or more before vegetation and butterfly communities positively responded. We also found this trend to be true in bird communities, which may be due to the lag before establishment of woody vegetation. These results suggest that control of *Arundo*, and the subsequent establishment of a more diverse riparian biological community, likely require multi-year treatment efforts, allowing for favorable conditions for succession of vegetation and colonization by wildlife. Our study was not intended to document the response by later-successional plants to cane removal efforts. However, additional years of monitoring may reveal the response by terrestrial wildlife following colonization of the floodplain by mature, woody vegetation. Nevertheless, the response by early successional plants and butterflies was a strong indicator for the success of the cane removal efforts for promoting 'desired future conditions' along the Big Bend reach of the Rio Grande/Bravo (CEC 2014).

Our finding that recently treated areas (i.e. burned in 2016) had lower richness and abundance of birds than other habitat groupings are likely explained by lower shrub and tree cover at sites that were recently treated. It is well known that riparian birds are strongly affected by vegetation structure (Sogge et al. 2008), and the lack of mature-statured vegetation in recently burned sites likely resulted in less breeding bird activity. Our study coincided with the initial controlled burn at 20 out of 35 restored sites. Therefore, our surveys were unlikely to document a strong positive response by birds that may utilize woody vegetation along the river's edge (e.g. Common Yellowthroat, *Geothlypis trichas*). A hope of park biologists and restoration planners is that stands of willow (e.g. *Gooding's Willow, Salix gooddingii*) and Fremont cottonwood (*Populus fremontii*) will recover following *Arundo* removal. Willow and Fremont Cottonwood stands are positively associated with a diverse breeding bird assemblage (Brand et al. 2008). However, it will likely require many years before trees and shrubs in treated zones reach sizes of any significance to positively impact the breeding bird community. Therefore, multiple years of surveying will likely be necessary to document the response by mature woody vegetation and bird communities following treatment efforts.

We did not document statistical correlations among *Tamarix* and bird and butterfly richness and abundance (except, see Fig. 4 for an apparent visual correlation), which was in contrast with other studies in similar systems. *Tamarix* grows quickly and is used by a wide variety of riparian wildlife in southwest riverine systems (Sogge et al. 2008, Bateman and Ostoja 2012).

However, in our system, *Tamarix* now rarely approaches tree size due to the presence of saltcedar leaf beetle, which has proven an effective biocontrol limiting *Tamarix* growth in the region. This could explain the lack of correlation between *Tamarix* and the breeding bird community. We did, however, make observations of butterflies nectaring on flowering, short-statured *Tamarix* shrubs scattered throughout the study area. While these casual observations seem to positively associate butterflies with this invasive plant, it appears that other habitat characteristics, particularly herbaceous plant cover, are more likely to positively influence butterfly richness and abundance.

Our first-season results suggest that the *Arundo* removal efforts have had a limited impact on Yellow-billed Cuckoos, likely because the treatments typically occurred on small strips of habitat, immediately adjacent to the river's edge. Yellow-billed Cuckoos have relatively large home ranges compared with other riparian associated birds (e.g. Common Yellowthroat), likely extending far beyond the spatial extent of the treatments. We frequently detected Yellow-billed Cuckoos in dense stands of mesquite, often in large bosques. Yellow-billed Cuckoos typically use mature stands of cottonwood or willow for nesting and foraging throughout the desert southwest (Greco 2013, US Fish and Wildlife Service 2014). The Rio Grande/Bravo in BIBE contains very little mature cottonwood outside of the two main campgrounds, Rio Grande Village and Cottonwood campground, both of which are utilized by breeding Yellow-billed Cuckoos (Flippo and Flippo 2015). However, on the remote reaches of the river within BIBE, where our study was conducted, mesquite is the primary species that forms riparian gallery forests, occurring in large, mono-dominant stands ('bosques'). Although the association of Yellow-billed Cuckoos with riparian gallery forest is expected based on past research in the southwest (Greco 2013, US Fish and Wildlife Service 2014), this result is important because the mono-dominant mesquite stands with which it is associated in BIBE are distinctive, structurally and floristically, from cottonwood and willow gallery forest (Wiggins 2005).

We found no relationship between *Tamarix* percent cover and cuckoo detections. In BIBE, since the recent spread of saltcedar leaf beetle and decimation of the *Tamarix* population, *Tamarix* are generally shrub-sized and sparsely distributed throughout the floodplain. We therefore consider it unlikely that it directly influences Yellow-billed Cuckoo habitat occupancy. Other studies have found that *Tamarix*, when it occurs in high abundance, lowers habitat suitability for Yellow-billed Cuckoos (US Fish and Wildlife Service 2014). Our initial findings indicate this habitat feature does not exert a strong influence on Yellow-billed Cuckoo occupancy in BIBE, at least since the recent and dramatic decline of *Tamarix* in BIBE.

Continuing Project Directions

Major accomplishments in year one have included designing the study; establishing field sites; collecting the first field season's data including repeat breeding bird surveys, butterfly surveys, and vegetation measurements at 163 sites; summarizing findings from those data in initial statistical comparisons; and advancing both graduate students significantly towards completion of their master's theses. In year two, we will complete a second field season, then undertake full statistical analyses of the two-year data set and begin work toward publication of results in peer-reviewed journal articles. Further, the two graduate students will finish their degrees during the summer of 2018. In addition to repeating the basic survey design in year two, we will expand our set of survey sites to include under-sampled *Arundo* habitats – focusing on the western reaches of the Rio Grande/Bravo in BIBE (i.e. west of Mariscal Canyon) – as a comparison-habitat to treated sites, which all occur east of Mariscal Canyon; we will modify our bird vegetation survey extent from 100 m to 50 m to better capture habitat characteristics of 'unified' habitat types (e.g. riverbank, floodplain, bosque); the potential incorporation of additional data collection, such as a wider sampling of large arthropods to quantify the effect restoration efforts have on a broader suite of riparian wildlife. Additional analytical components will also be undertaken to address project goals. For community-level analyses, this is likely to include occupancy models for a subset of the most common breeding bird species in our data, and multivariate species composition analyses for birds and butterflies to more fully characterize differences in species occupancy and abundances in the different habitat types and treatment categories. For Yellow-billed Cuckoo analyses, this is likely to include landscape-level modeling of habitat occupancy, which will incorporate several remote-sensing based variables representing large-scale vegetation conditions in the river floodplain (e.g., mesquite bosque size and configuration, image texture analysis to quantify mesquite bosque structural variability). We plan then use the resulting models to quantify cuckoo habitat suitability on both US and Mexico sides of the floodplain.

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Supplementary Material

Figures 1A-14A. Maps of point and transect locations throughout the US floodplain of the Rio Grande/Bravo within Big Bend National Park.

Table A1. X and Y coordinates of 163 sample points used for bird point count locations. Points are projected in the GCS_WGS_1984 Geographic Coordinate System.

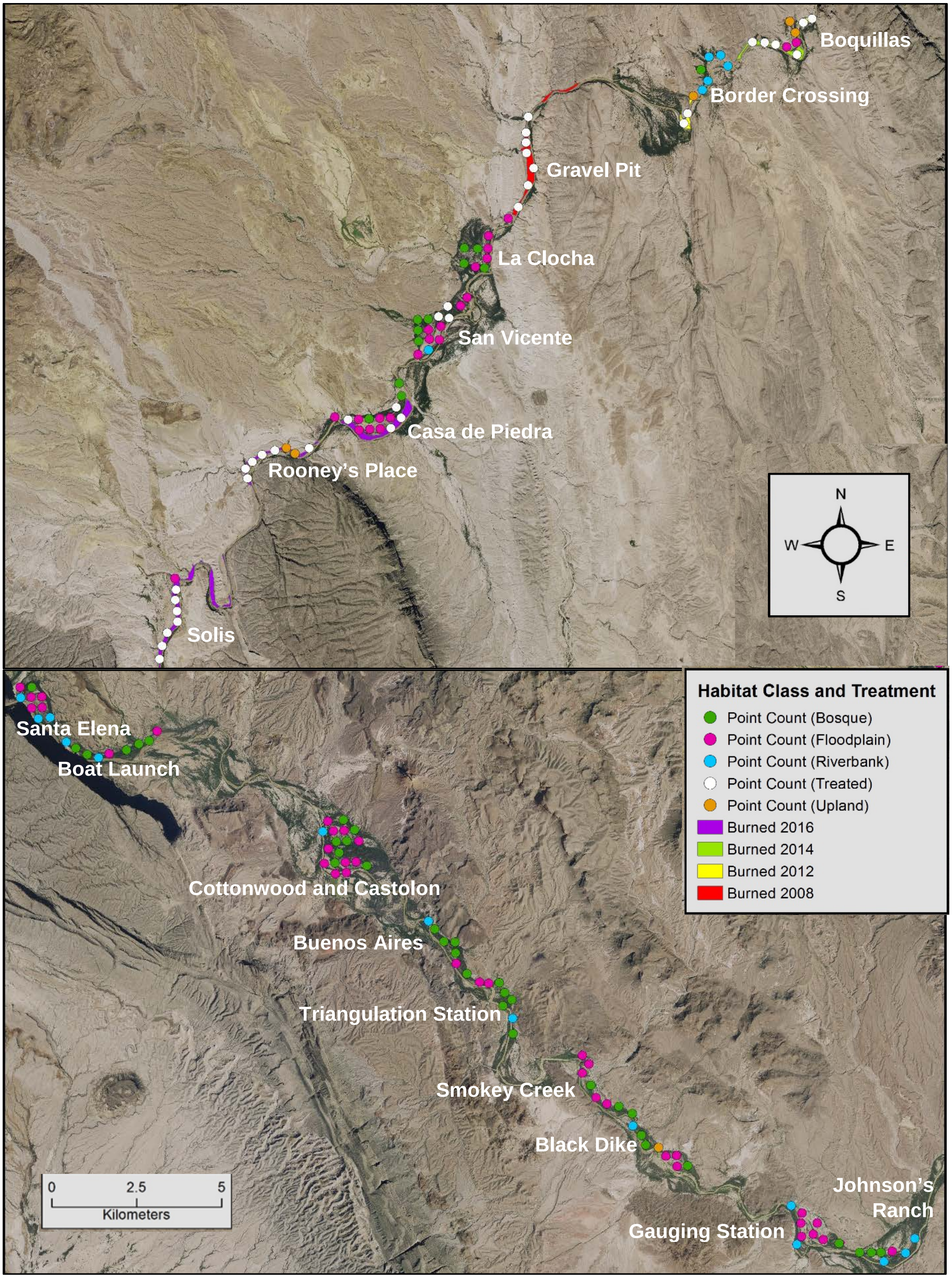

Figure 1A: *Survey locations, east (top) and west (bottom) of Mariscal Canyon. 'Point count' habitat color designations refer to both bird point count locations (circles, Figures 1A-14A) and butterfly transects (lines, Figures 2A – 14A)*

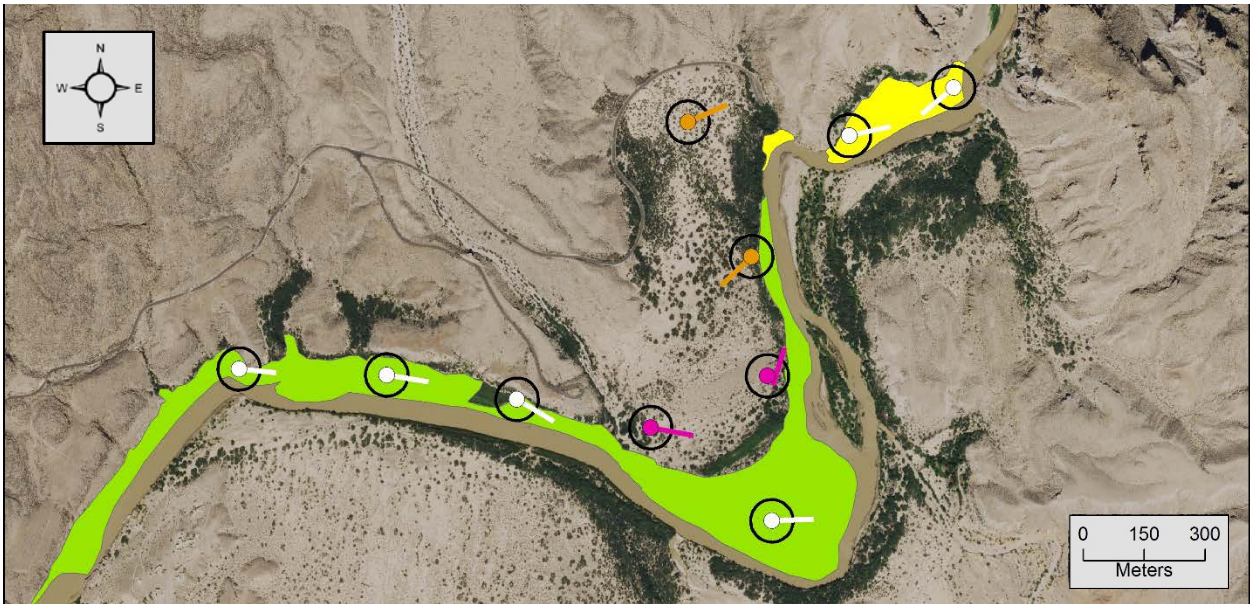

Figure 2A: *Boquillas (BO) - bird point count stations (circles) and butterfly transects (lines), 1-10 beginning on the right.*

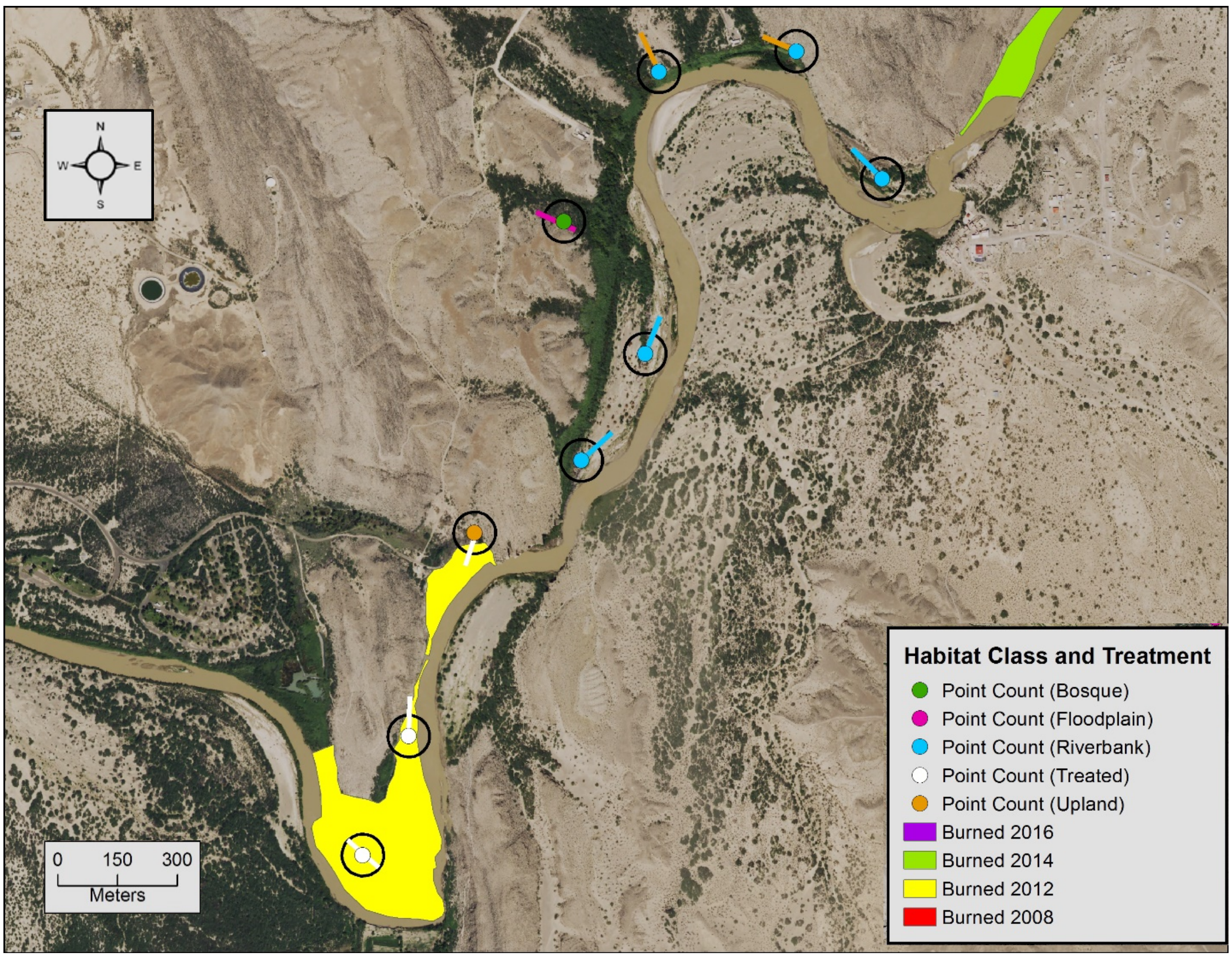

Figure 3A: *Border Crossing (BC) - bird point count stations (circles) and butterfly transects (lines), 1-10, beginning on the right. The legend, with habitat and treatment colors, valid for Figs. 2A-14A.*

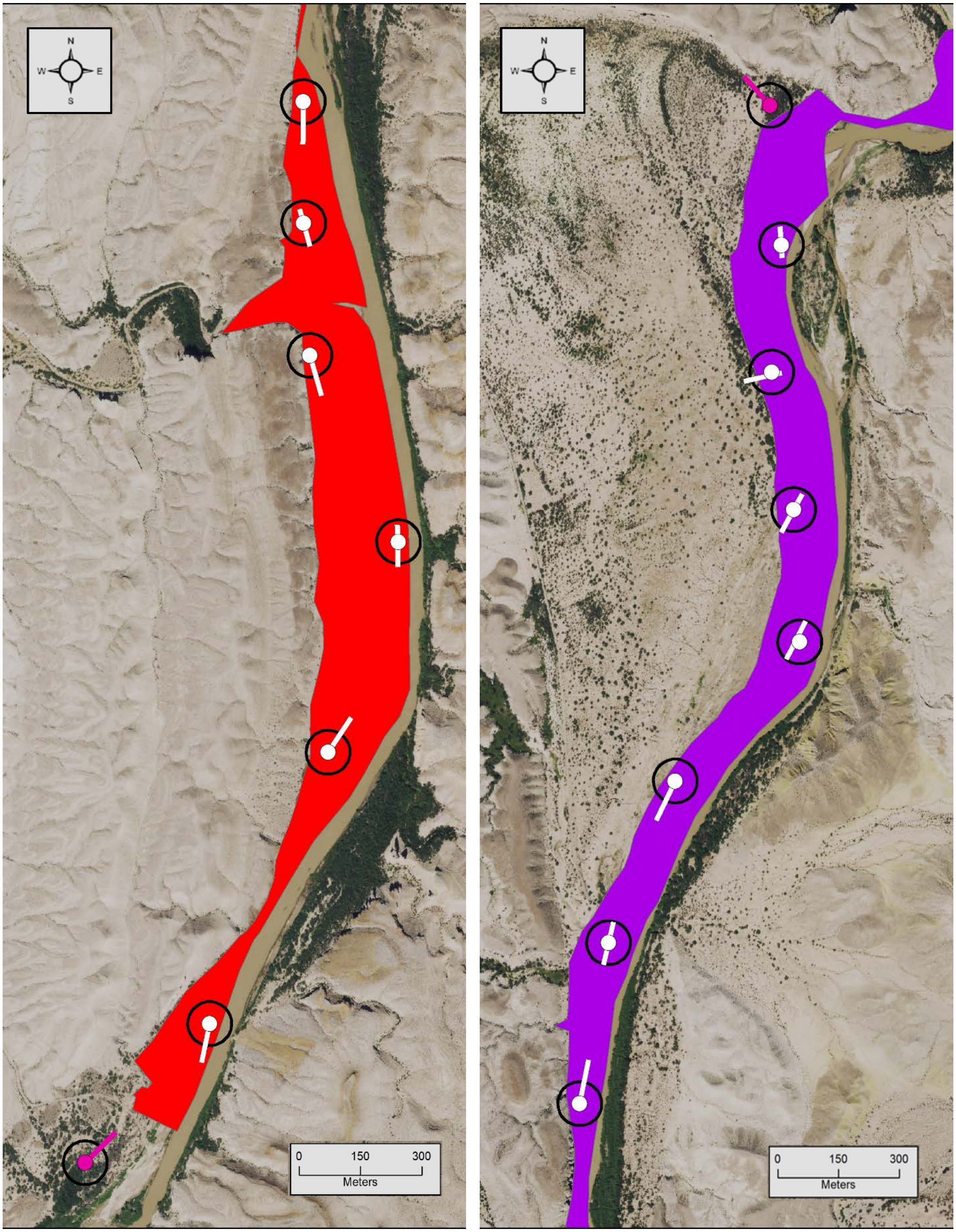

Figure 4A: *Gravel Pit (GP) (left) - bird point count stations (circles) and butterfly transects (lines), 1-8, from bottom to top. Solis (SO) (right) - bird point count stations (circles) and butterfly transects (lines), 1-8, from bottom to top.*

Figure 5A: *La Clocha (LC) - bird point count stations (circles) and butterfly transects (lines), 1-8.*

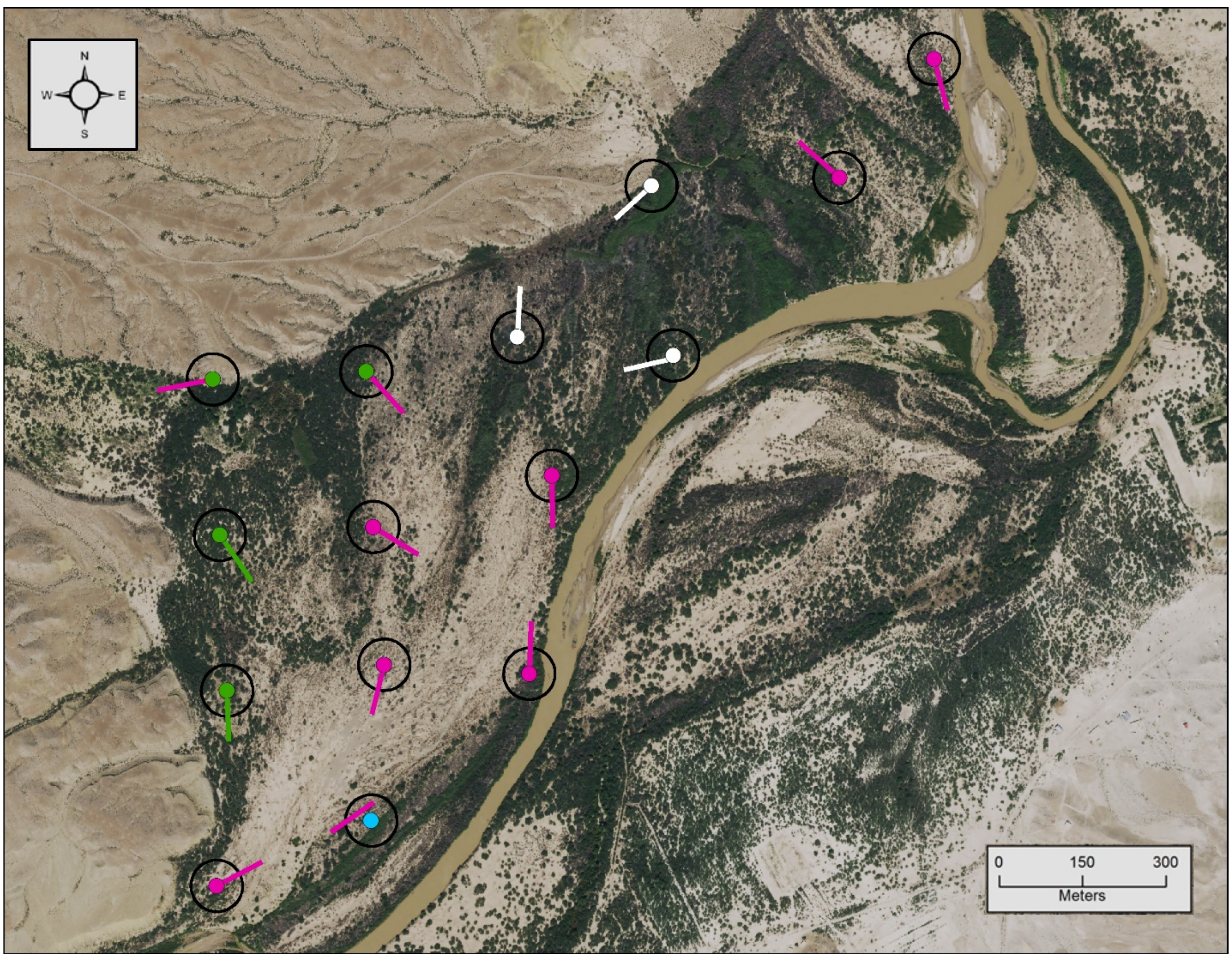

Figure 6A: *San Vicente (SV) - bird point count stations (circles) and butterfly transects (lines), 1-14.*

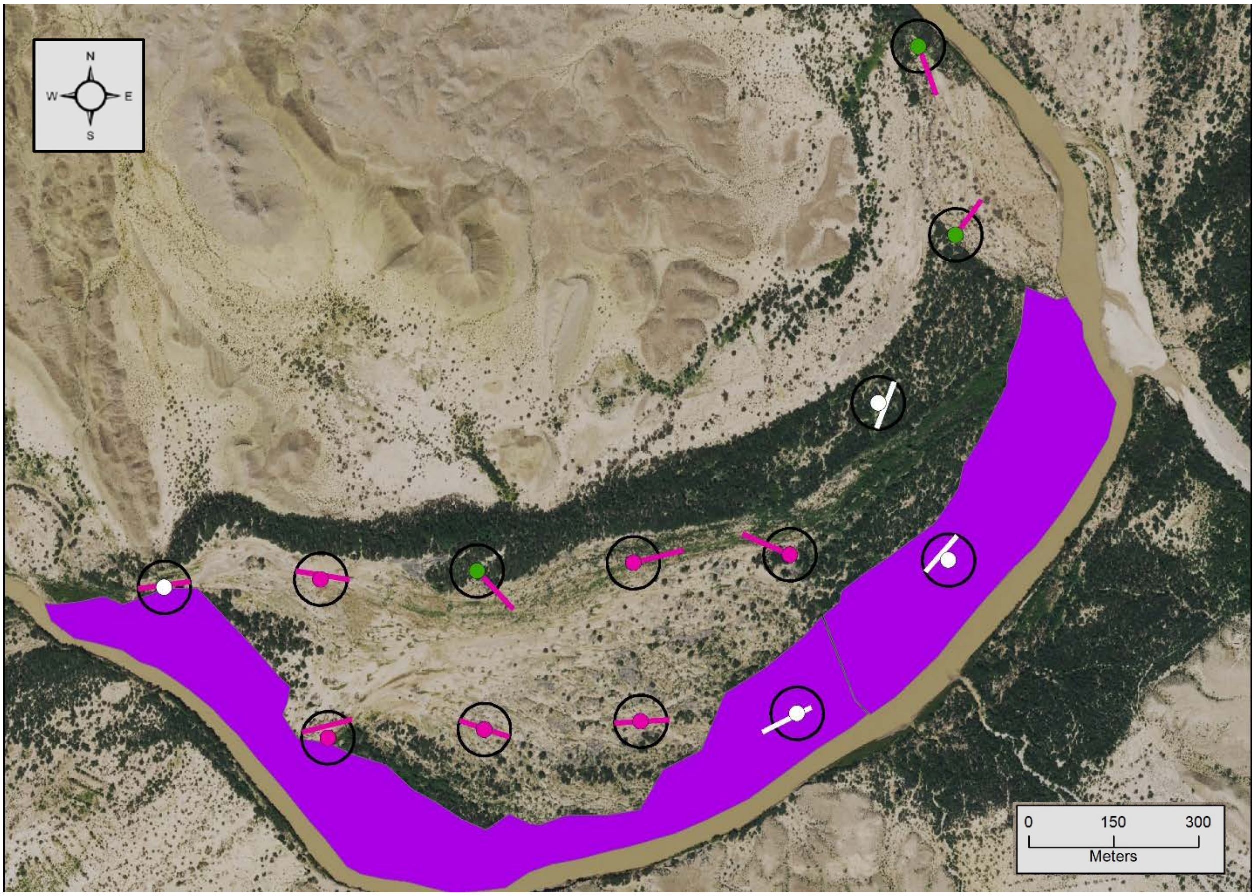

Figure 7A: *Casa de Piedra (CP) - bird point count stations (circles) and butterfly transects (lines), 1-13.*

Figure 8A*: Rooney's Place (RP) - bird point count stations (circles) and butterfly transects (lines), 1-8 from right to left.*

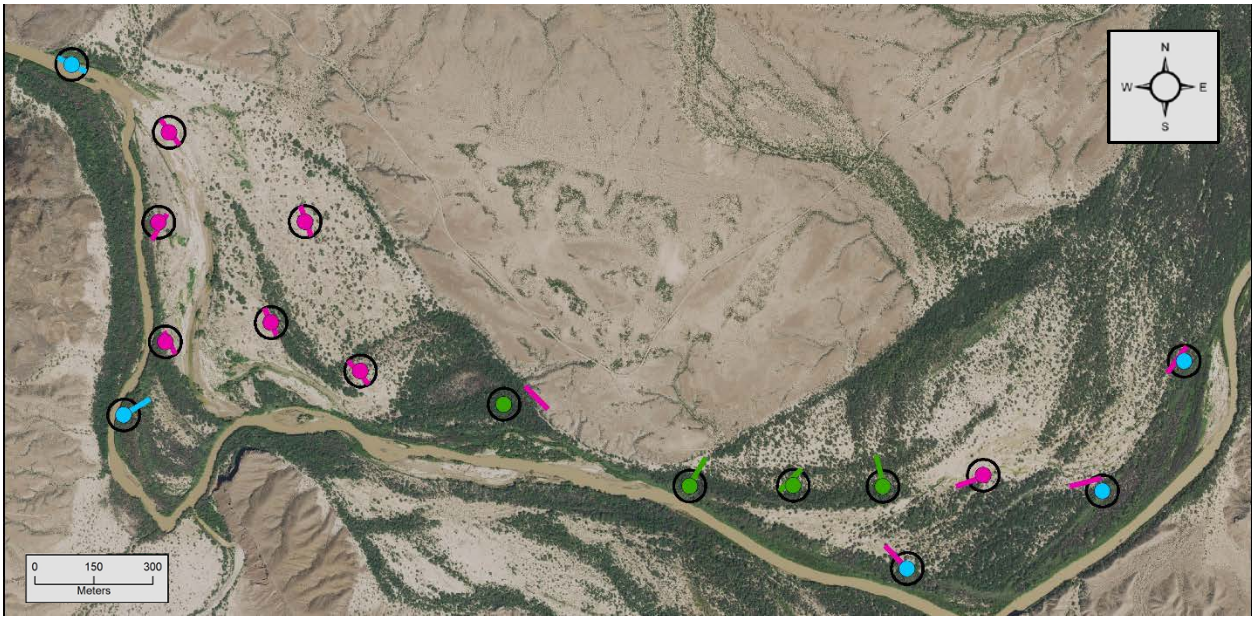

Figure 9A: *Gauging Station (GS), right (1-8) and Johnson's Ranch, right (1-8), bird point count stations (circles) and butterfly transects (lines).*

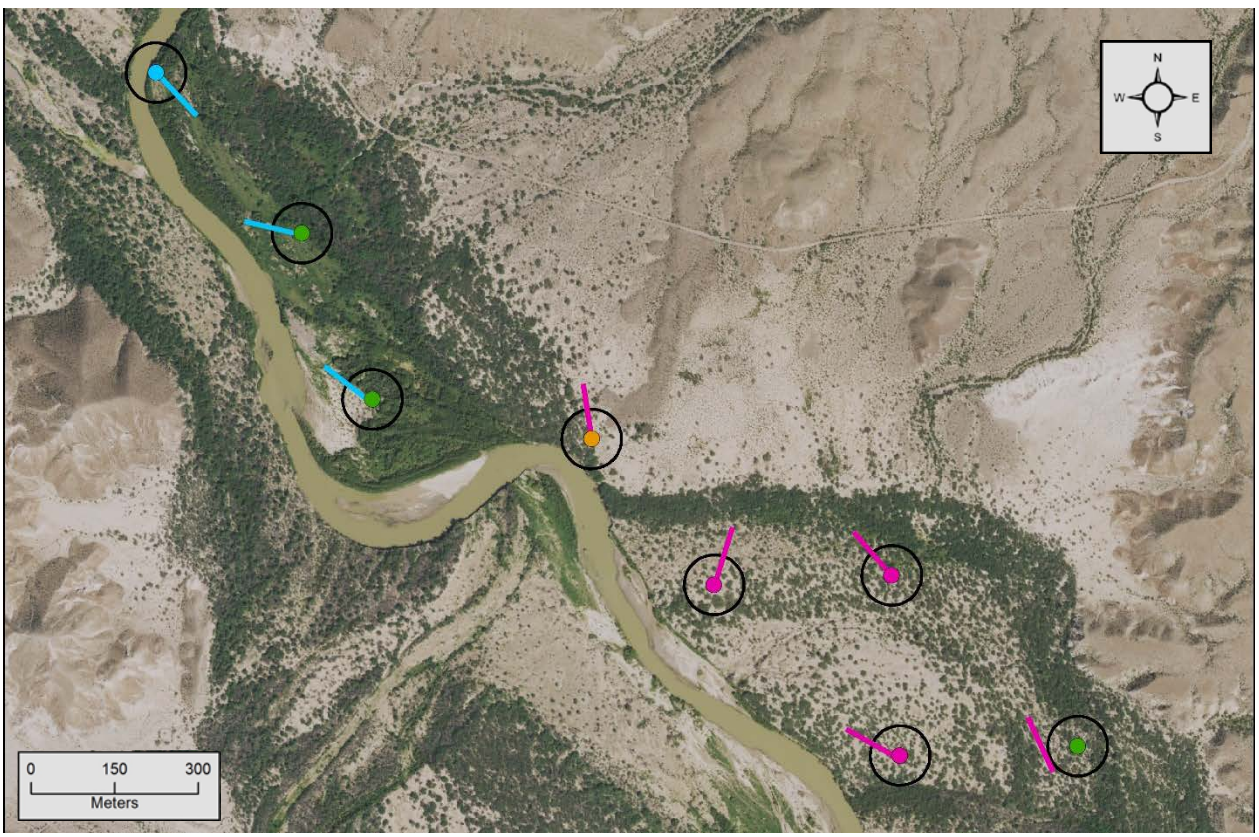

Figure 10A: *Black Dike (BD) - bird point count stations (circles) and butterfly transects (lines), 1-8.*

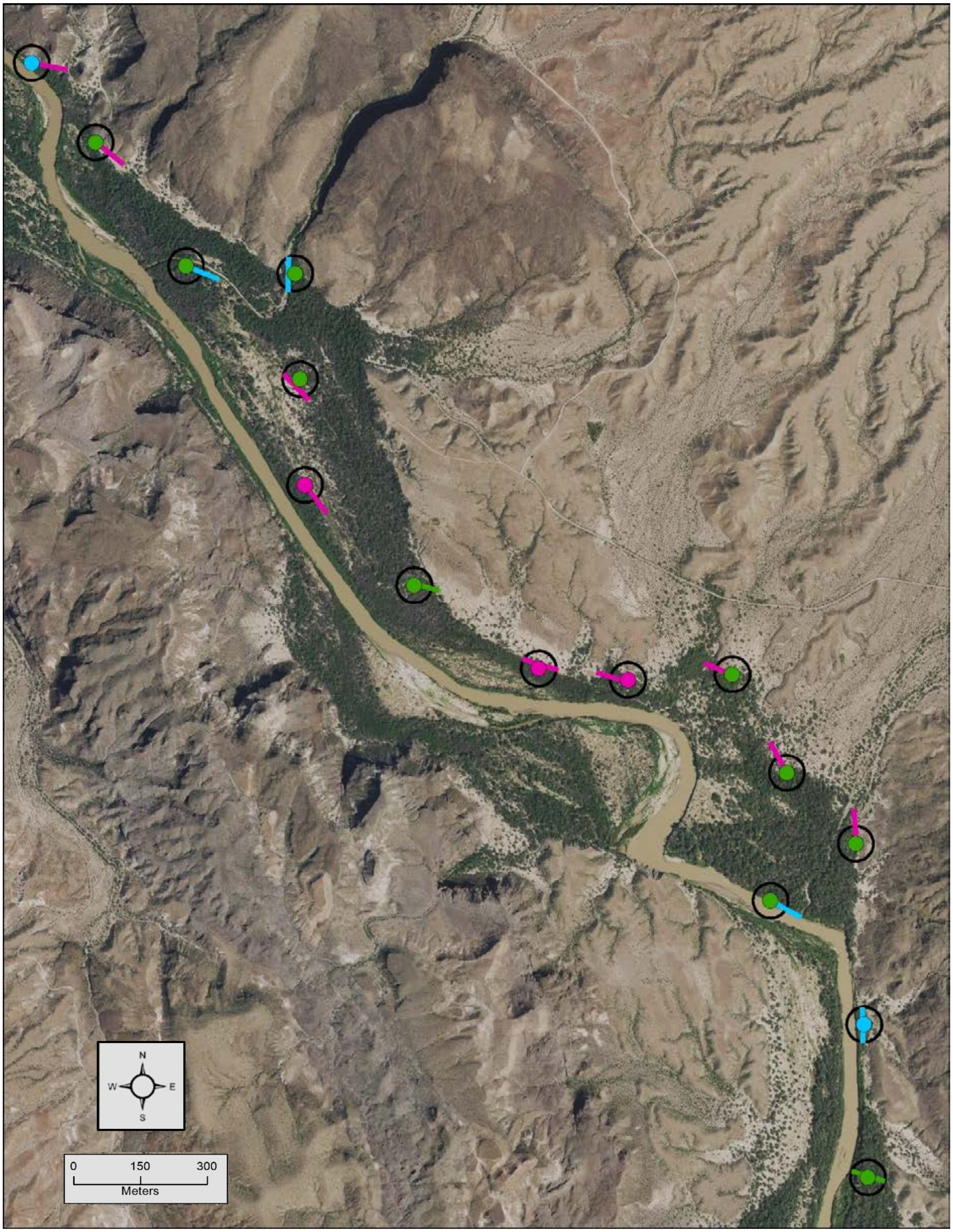

Figure 11A: *Buenos Aires (BA), right (1-7) and Triangulation Station left (1-8) - bird point count stations (circles) and butterfly transects (lines).*

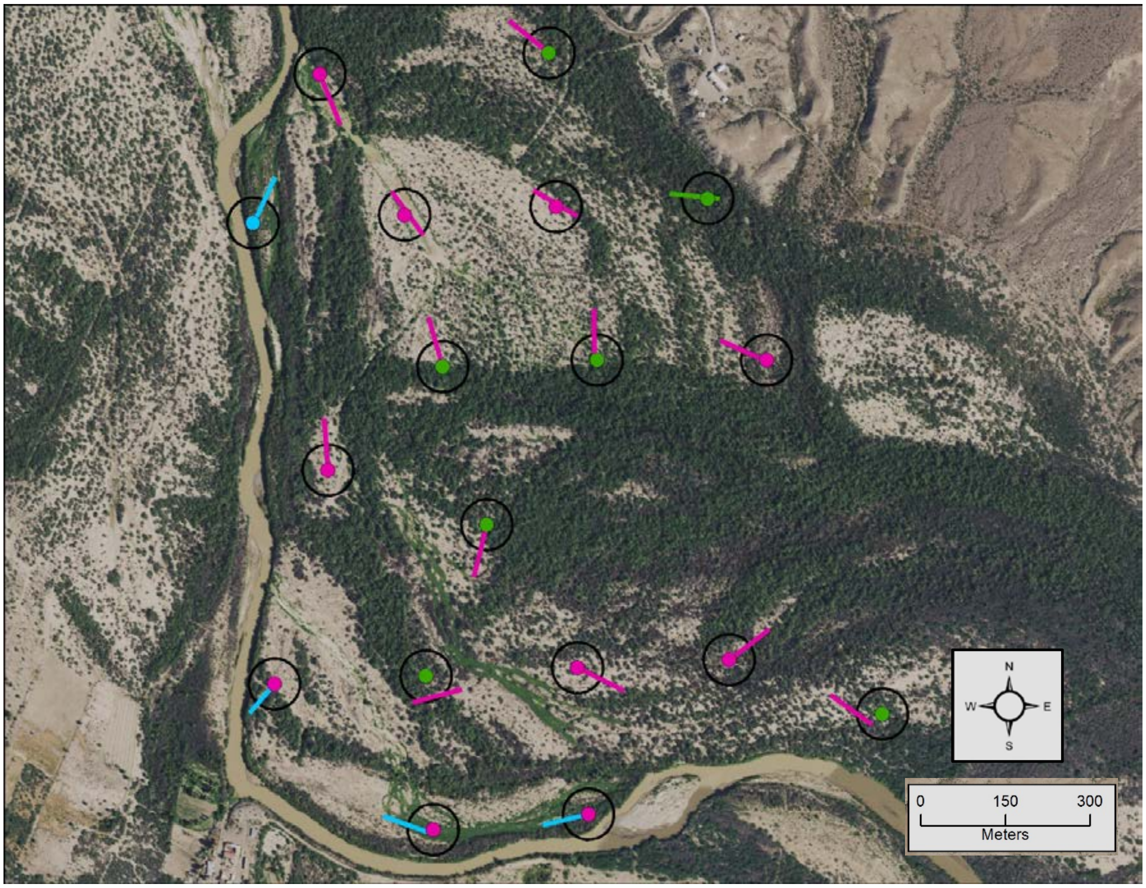

Figure 12A: *Cottonwood (CW) top (1-9) and Castolon (CA), bottom (1-9), bird point count stations (circles) and butterfly transects (lines).*

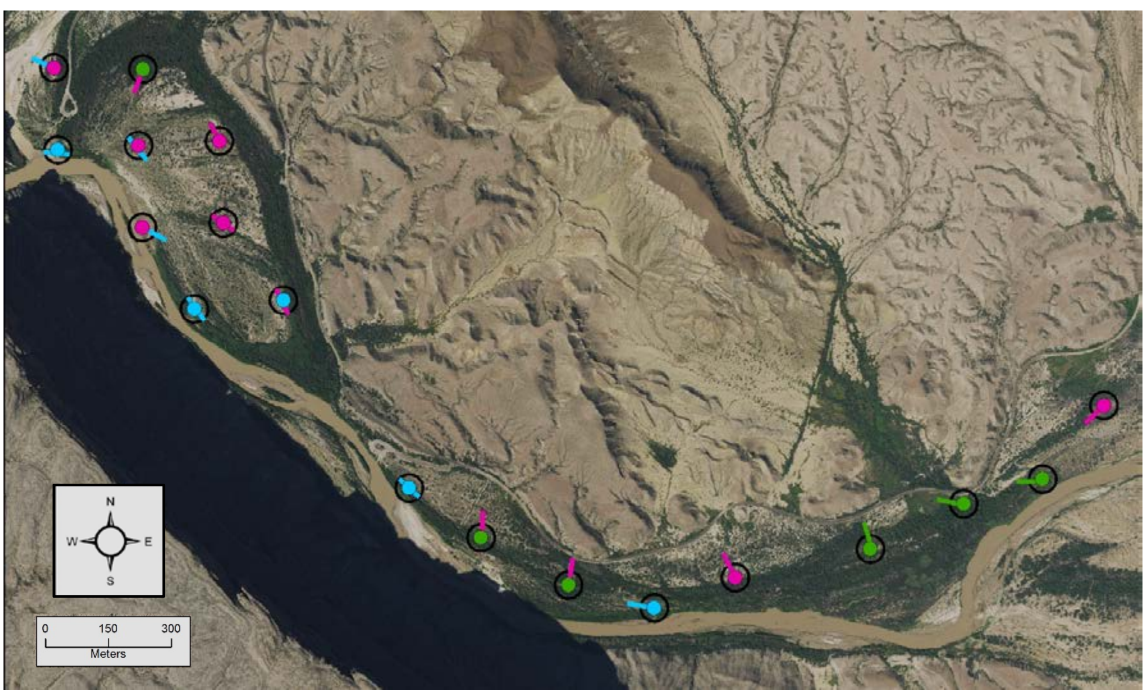

Figure 13A: *Santa Elena (SE) left (1-9) and Boat Launch right (1-9), bird point count stations (circles) and butterfly transects (lines).*

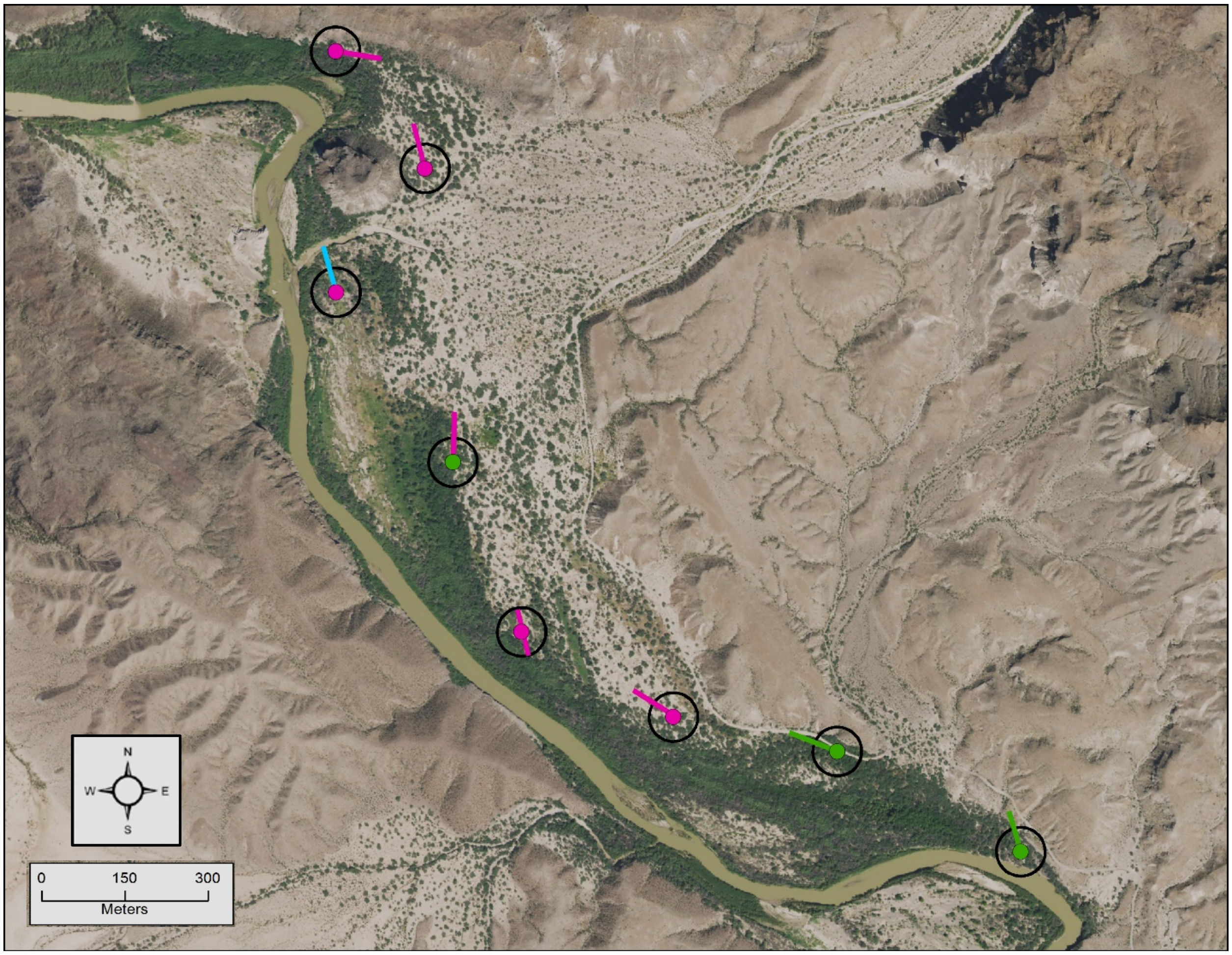

Figure 14A: *Smokey Creek (SC), bird point count stations (circles) and butterfly transects (lines), 1-8, from right to left.*