Patterns and drivers of long-term changes in breeding bird communities in a global biodiversity hotspot in Mexico

Running-title: Changes in Madrean bird communities

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Abstract

Aim: To evaluate changes in breeding bird communities and assess implications for conservation.

Location: Madrean Sky Islands and northern Sierra Madre Occidental, Mexico.

Methods: I compared observations from recent fieldwork (2009-2012) with an extensive historical dataset (1887-1954) and used modelling and multivariate techniques to assess spatiotemporal changes in species occurrence, richness, and assemblage composition, and associations with climate, land-use, and landscape factors.

Results: Breeding species richness peaked in larger ranges often in the south and east, and regional beta diversity was attributable much more to turnover (0.80) than nestedness (0.07).

Although richness increased across time, spatial assemblage heterogeneity declined due only to changes in nestedness, with temporal shifts in beta diversity equally attributable to variation in nestedness and turnover. Community change was associated with variation in climate, land-use, and landscape factors in ways that depended on species' traits. Major gains in Madrean and lowland Neotropical species from the south contrasted little change in Nearctic species, and there was some evidence lowland species expanded eastward into the higher-elevation interior, suggesting poleward and up-elevation shifts now occurring globally. Some such patterns were associated with increasing temperature and summer-fall precipitation typical of the south suggesting climate forcing. Despite regional gains in pine-dependent species linked to post-logging forest recovery, losses and turnover were greater in smaller more arid ranges due likely to climate-mediated habitat loss. High regional losses of cavity-nesting species in forest were greater in ranges subjected to past logging indicating effects of historical habitat degradation persist today.

Main conclusion: Despite ongoing forest recovery and potential for northward range expansion to offset climate-mediated losses of montane species, further assemblage homogenization seems likely. Active forest restoration that promotes large old trees, snags, and mature forest conditions combined with increasing the capacity of local communities to implement best management practices will enhance conservation.

KEYWORDS

climate change, distributional change, land-use change, Madrean Sky Islands, Mexico, pine-oak woodland, Sierra Madre Occidental.

1 | INTRODUCTION

Understanding biodiversity dynamics in an age of broad global change is important for guiding management responses to ongoing and emerging threats. Inferences on biodiversity dynamics, however, are often limited by historical data, especially in developing countries where both biodiversity and threats are typically concentrated (Sala et al., 2000; Brooks et al., 2006; Soberón & Peterson, 2009). Even where historical data are present, inferring biodiversity change is often complicated by variation in survey effort, sampling methodology, and information on historical environments (Magurran et al., 2010). These and other factors are contributing to ongoing debate regarding local trends in biodiversity across the globe (e.g., Gonzalez et al., 2016; Vellend et al., 2017). Despite limited consensus on the generality of trends, a broad range of processes have been linked to systematic changes in biodiversity parameters including climate change, habitat loss and fragmentation due to deforestation, agriculture, urbanization and other alterations in land use and landcover, invasion of exotic species, and interactions among these and other factors (Brook et al., 2008; Aronson et al., 2014; Murphy & Romanuk, 2014; Harrison et al., 2015; Newbold et al., 2015). Accordingly, studies of biodiversity dynamics from underrepresented and biodiverse regions are important for evaluating global trends and guiding conservation.

Biogeographic transition zones offer useful settings to assess the patterns and drivers of biodiversity change. These regions are characterized by high species turnover and environmental filtering along biotic and abiotic gradients, and an intermingling of marginal and more widespread species with varying evolutionary histories. Hence, changes in biodiversity parameters linked to expanding or contracting range boundaries and more complex assemblage shifts are likely to occur first and be focused in transition zones highlighting potential changes at larger scales. Mexico is a rapidly developing, mega-diverse country that spans a broad Nearctic-Neotropical transition zone (Halffter, 1987; Mittermeier et al., 1997), and faces numerous ecological threats (Mas et al. 2004; FAO, 2007; Visconti et al., 2011). Efforts to understand biodiversity dynamics in Mexico are advancing with support from various data resources including some focused on birds, but remain limited to few regions or species (Martínez-Morales et al., 2010; Peterson & Navarro-Sigüenza, 2006; Peterson et al., 2015, 2016). Although birds are only a small facet of overall biodiversity, they provide a useful focal group for assessing biodiversity change. This is because most species are conspicuous, easy to sample, and linked to specific sets of resources and conditions required for nesting, foraging, and other needs, and given relatively high availability of historical data (Temple & Wiens, 1989; Canterbury et al., 2000; Suarez & Tsutsui, 2004).

In the early 1950s, Joe Marshall Jr. (1957) described breeding bird assemblages in nine Madrean Sky Islands (MSI) and five areas in the adjacent Sierra Madre Occidental (SMO) in northwest Mexico, and MSI in adjacent Arizona. Together with earlier efforts (Mearns, 1907; Van Rossem, 1945), this work provides among the most comprehensive historical baselines on wildlife in Mexico, and opportunities to understand biodiversity change. The MSI are mountain ranges that arise from semi-arid lowlands between the SMO in northwest Mexico and Rocky Mountains in the south-western USA. This region spans the north-western portion of a broad Nearctic-Neotropical transition zone in Mexico and is where distributions of Madrean, Petran, Sonoran, Chihuahuan, Great Plains, Great Basin, and lowland Neotropical species converge (Halffter, 1987; Warshall, 1995; Escalante et al., 2004). Mountain ranges that span this cordilleran gap are termed Sky Islands because they support disjunct patches of montane vegetation separated from these massifs by lowland "seas" of desertscrub, grassland, and subtropical thornscrub (Gehlbach, 1981). Climatic flux over eons drove marked changes in the size and arrangement of these montane habitat islands, which greatly influenced diversification and distribution of the biota (Findley, 1969; Van Devender, 1977; McCormack et al., 2008). Such complexity combined with steep elevation and climatic gradients promote high biodiversity and endemism, and make this region a global conservation priority (Felger & Wilson, 1995; Marshall & Liebherr, 2000; Spector, 2002; Mittermeier et al., 2004).

To evaluate spatiotemporal changes in assemblages and factors that drove them, I assessed breeding bird communities across the MSI and adjacent SMO in Mexico through extensive fieldwork and compared observations with historical data (1887-1954). Given observed patterns and broad multifaceted signs of global change at larger scales, I focused on potential range expansion of lowland Neotropical and Madrean species with affinities to southern environments, contractions of Nearctic species with northern affinities, and shifts in lowland species linked to climate change, and the influences of land-use change and landscape factors on communities. If climate change is driving range expansion of southern species or contractions of northern species, I predicted such changes would occur first in smaller, lower-elevation and thus more arid ranges, and be associated with spatiotemporal changes in climatic attributes. If land-use change is driving assemblage shifts, I predicted such patterns would be associated with variation in forestry practices because some MSI were intensively logged in the early to mid 1900s after which logging and associated road construction largely ceased. Addressing these questions is timely given accelerating threats to montane forests and wildlife in the U.S.-Mexico borderlands and broad information gaps on biodiversity dynamics in this and other nearby regions (Sekercioglu et al., 2008; Allen et al., 2010; Flesch et al., 2010; Van Devender et al., 2013).

2 | METHODS

2.1 | Study region

The MSI are of sufficient elevation to support patches of montane woodland and forest dominated by oaks (*Quercus* spp.) that are often mixed with pines (*Pinus* spp.), and separated from the SMO by lowland vegetation (Warshall, 1995). These lowlands create the only gap in the vast highland cordillera that traverses western North America between Alaska and Central America. I considered MSI in Mexico in a region bounded by the SMO to the east, Sierra el Humo to the west, sierras Aconchi, Oposura, and Bacadéhuachi to the south, and portions of the adjacent SMO (Figure 1). Although oak woodland along ridgelines connects some ranges I considered to be discrete, ranges were defined based largely on the distribution of pine-oak woodland, which has lower levels of connectivity.

Six major montane vegetation communities dominate the region. At low elevations, oak woodland is dominated by open stands of evergreen oaks interspersed with grasslands and arid scrub that transitions to denser more diverse stands of oaks at higher elevations. At moderate elevations, oak-pine woodland transitions into pine-oak woodland at higher elevations as pines such as Apache pine (*P. engelmannii*) and Arizona pine (*P. arizonica*) achieve greater dominance. At a broad range of elevations, mountain scrub dominated by shrubby oaks, manzanita (*Arctostaphylos* spp.), and other evergreen shrubs occurs in uplands, whereas montane riparian vegetation dominated by broadleaf deciduous trees including sycamore (*Platanus wrightii*) and maple (*Acer grandidentatum*) mixed with oaks, pines, and locally by Arizona cypress (*Cupressus arizonica*), occurs along drainages. At higher elevations, pine forest is dominated by pure stands of Arizona pine and south-western white pine (*P. strobiformis*), which transitions into mixed-conifer forest dominated by pines and Douglas fir (*Pseudotsuga menziesii*) at the highest elevations.

2.2 │ Design

I assessed the occurrence, breeding status, and richness of landbirds in most MSI in Mexico, and evaluated spatiotemporal changes in communities by comparing observations with historical data. To foster comparisons, I focused on 11 ranges surveyed intensively by Marshall (1957) and two additional ranges with extensive collections from 1887-1942 (Cíbuta, San Jose; Van Rossem, 1945; Figure 1), and surveyed the same general areas within ranges where known. Although Marshall focused in pine-oak and oak-pine woodland at moderate elevations, he visited a broad range of montane vegetation communities and documented all bird species he observed. To provide a broad context for documenting spatial patterns of biodiversity and baselines for future monitoring, I also surveyed other ranges not visited historically. To sample birds, I placed transects in representative areas within each montane vegetation community. Because bird communities in larger ranges required more effort to describe, I allocated effort in proportion to range size and number of montane vegetation communities present. To maximize coverage, I visited most (96%) transects once.

2.3 │ Surveys

Marshall (1957) gathered observations of birds while travelling throughout ranges, and while surveying linear transects in pine-oak and oak-pine woodland and adjacent riparian areas often along canyon bottoms. During surveys Marshall mimicked the calls of pygmy-owls (*Glaucidium* spp.) to rouse birds and augment aural and visual detection probabilities, and recorded the number of individuals, pairs, and flocks of each species he observed during mornings and nights focusing between April and August. I used multiple complementary methods to assess occurrence, breeding status, and richness in each mountain range during the breeding season between May and July (2009-2012), and estimated the number of individuals, pairs, and flocks of each species in each range based on both incidental observations and standardized surveys. I conducted 8-min. point counts from 30 min. before to 3.5 hours after sunrise at stations spaced ~200-m apart along transects that traversed canyon bottoms, slopes, and ridges (see Flesch et al. 2016 for details). For nocturnal species, I broadcast conspecific vocalizations at night along portions of some transects and in camp where conditions allowed. Whereas Marshall collected specimens to inform classifications of breeding status, I relied on behavioural observations and classified species as possible, presumed, or confirmed breeding, or as non-breeding (NAOAC, 1990). Individuals observed in potential breeding habitat outside their known breeding range or at times when migrants were still moving through the region were considered possible breeders unless other evidence was observed.

2.4 | Analyses

To describe contemporary communities, I computed beta diversity as total multiple-site dissimilarity (β_{SOR}) and its turnover (β_{SIM}) and nestedness (β_{SNE}) components based on Sørensen distances for the entire study region and MSI (Baselga & Orme, 2012). Turnover measures species replacement or the substitution of one species for another, whereas nestedness measures nested patterns of species losses (or gains) that result in poorer assemblages being strict subsets of richer ones. I computed observed species richness in each region and range as the number of presumed or confirmed breeding landbird species. To account for undetected species, I also estimated richness based on observed abundance distributions and the jack-knife and bias-corrected Chao1 estimators (Hines et al., 1999; Chao, 1984; Gotelli & Colwell 2011). To describe spatial patterns in species richness, I fit linear models with observed and estimated richness as response variables, and latitude, longitude, elevation, distance to SMO, and island size as explanatory variables. To estimate island size, I used log-transformed areas of all montane woodland and forest and of conifer-dominated forest based on recent inventories (Velázquez et al., 2001), which I adjusted in some ranges based on observations. Because montane vegetation communities were dominant at all survey points, I included species associated with attributes of lowland vegetation.

I used multiple techniques to assess assemblage change between time periods. In assessing change, I considered all species combined, 10 species groups linked to habitat affinity (lowlands, riparian, mountain scrub, oaks, pines, cavities in mature montane forest, forest, mixed-conifer forest, generalist, urban), and five species groups linked to biogeographic affinity (lowland Neotropical, Madrean or temperate Neotropical, Nearctic, Americas, Exotic). These trait-based classifications were derived with data on habitat use and fundamental limiting resources from the literature (see Table S1) and maps of breeding ranges (Howell and Webb 1995). For richness, I fit linear mixed-effect models with time period (1950s, 2000s) as a fixed effect, survey effort as a covariate, mountain range as a random effect, and used observed richness as a response because historical abundance distributions and repeated measures were unavailable. To quantify survey effort, I considered both the number of survey days and linear transect effort in oak-pine, pine-oak, and riparian vegetation in each range and time period. Because both effort metrics were correlated ($r = 0.69$, $P<0.001$), they were fit in separate models. For community composition, I performed non-metric multidimensional scaling (NMDS) on a Sørensen distance matrix of observed occurrence data in up to six dimensions, and used stress values to select an optimal solution. To test for compositional difference, I used permutational multivariate analyses of variance (PerMANOVA) with year as a fixed effect and site as a blocking factor. To compare temporal beta diversity, I computed total dissimilarity and its turnover and nestedness components for historical and recent assemblages. To assess temporal changes in spatial beta diversity, I computed total multiple-site dissimilarity and its components for each period, 1000 dissimilarity estimates by randomly sampling ~33% of sites, and compared resulting distributions with paired t-tests. To summarize patterns of historic and recent species occurrences, I classified species that were historically present and recently detected (a), historically undetected but recently observed (b), and historically present but recently undetected (c) in each range, then calculated percent species gains ($100b/(a+b)$), losses ($100c/(a+c)$), and turnover ($100(b+c)/(a+b+c)$). For richness and assemblage comparisons, I considered data gathered by Marshall in 11 ranges we each surveyed (Figure 1). For species gains and turnover, I considered additional historical data for these ranges, and for losses two additional ranges with substantial historical baselines (Cíbuta, San Jose; Van Rossem 1945).

To assess factors that explained spatiotemporal changes in communities, I evaluated patterns in the habitat and biogeographic affinities of species contributing to observed changes in richness, occurrence, and assemblage composition to infer potential drivers of change. Second, I used blocked indicator species analysis (ISA; Dufrêne & Legendre 1997) to identify species and traits indicative of each time period. This approach compares observations among sites (blocks) and computes indicator values between 0 and 1 to quantify associations between species and time periods, with P-values based on random permutations. Such values are indicative of shifts in communities, or potentially, differences in detection probabilities. Third, I assessed correlations between NMDS axes and geographic, landscape, temporal, land-use, and climatic factors. To describe historical and recent climates, I used locally downscaled estimates of precipitation (annual, summer-fall, winter-spring) and temperature (mean annual, summer maximum, winter minimum) interpolated from weather stations (Wang et al. 2016) during 15-year periods ending the last year of fieldwork (1954, 2012). To describe land use, I used historical descriptions (White, 1948; Marshall, 1957) to classify ranges that were commercially logged and largely unlogged as a binary factor. Finally, I used multiple linear regression to assess associations between species gains, losses, and turnover, and the explanatory factors noted above including differences between historical (1900-1954) and recent (1998-2012) climates. I implemented NMDS and ISA with PC-ORD (McCune & Mefford, 2011) and estimated beta diversity with the *betapart* library in R (Baselga & Orme, 2012, R Core Team 2017).

3 │ RESULTS

3.1 │ Effort and contemporary patterns

I surveyed 26 MSI and 6 areas in the adjacent SMO (Table S2). Transects (n = 210) totalled 288.9 km in length, were between 1,150 and 2,750 m elevation, and traversed nearly all MSI supporting pines. Effort extended to within 200 m of the maximum elevation of 84% of MSI.

Regional beta diversity as indexed by total multiple-site dissimilarity (0.873) was attributable much more to turnover (0.803) than nestedness (0.070). In the MSI alone, however, contributions of nestedness nearly doubled (0.125) and turnover declined (0.705). Regionally, observed species richness totalled 165 species with 7 additional possible breeders, with 152 and 8 species observed, respectively, in the MSI (Tables S2 & S3, Appendix S1). Jack-knife-based richness estimates suggested at least 169 species likely breed in montane vegetation communities in the

MSI (95% CI=158-180). Among MSI, richness increased with increasing area of montane woodland and forest and with maximum elevation, with similar results among estimators (Table 1). There was also some evidence richness increased with increasing proximity to the SMO and along west-to-east and north-to-south gradients. Thus, on average, richness was typically greater in larger more southern ranges and those near the SMO, and lower in smaller northern and western ranges. Spatial patterns of observed richness largely tracked estimates; in the MSI jack-knife-based estimates averaged 2.5% lower than Chao1-based estimates, and averaged 19.9±1.1% (±SE) greater than that observed (Table S2).

Species associated with oaks were distributed broadly occurring as far west as the sierras Cíbuta, San Juan, and in some cases Humo. Pine-dependent species were distributed more narrowly, generally occurring as far west as the Sierra el Pinito. Species dependent on conifer forest and other high-elevation resources often occurred only in the tallest MSI, with nine such species restricted to the SMO (Table S3).

3.2 │Historical changes

Community composition varied both temporally and spatially ($P \leq 0.001$; PerMANOVA). NMDS projected the distance matrix into three-dimensional space with relatively low stress (0.132) explaining 81.4% of variation. Temporal shifts in community composition were characterized by increasing values along the first and second ordination axis, and small decreases along a third axis (Figure 2). Increases along the first axis were associated with absences of secondary-obligate cavity nesters in mature montane forest (e.g., Thick-billed Parrot, Violet-green Swallow; scientific names in Table S4, NMDS results in Table S5), and occurrences of species dependent on montane shrublands (e.g., Black-chinned Sparrow), open vegetation near cliffs (e.g., Peregrine Falcon), and some pine-dependent species (e.g., Buff-breasted Flycatcher). Increases along the second axes were associated with occurrences of montane forest- (Townsend's Solitaire) and some pine-dependent (Grace's Warbler) species, and especially lowland Neotropical and Madrean species associated with thornscrub (Elegant Quail, Sinaloa Wren) and riparian vegetation (Gray Hawk, Tufted Flycatcher). Increases along the third axis were associated with occurrences of species dependent on mixed-conifer forest and cavity nesters in forest, with decreases associated with lowland Neotropical and riparian species. Oak-woodland species were all clustered near the origin.

Blocked ISA suggested three species of secondary-obligate cavity nesters were indicative of historical communities (American Kestrel, Flammulated Owl, Pygmy Nuthatch). Indicative of recent communities were three pine-dependent species (Short-tailed Hawk, Grace's Warbler, Olive Warbler), species associated high-elevation forest (Cordilleran Flycatcher) and montane riparian vegetation (Violet-crowned Hummingbird), and Wild Turkey (Table S5).

Historical and recent climates varied but there was more evidence for changes in temperature than precipitation (Table 2). Mean annual temperature (*MAT*) increased by ≥0.9±0.1°C across time, with similar changes in mean maximum summer and minimum winter temperatures. Changes in total annual precipitation (*TAP*) depended on the historical period considered with decreases in winter-spring precipitation being of greater relative magnitude than increases during the monsoon-influenced summer-fall (Table 2). Climatic variation was associated with temporal shifts in assemblages, with spatiotemporal variation often negatively correlated with the first and third NMDS axes (Table 3). Occurrences of Neotropical and Madrean species that use lowland and riparian vegetation and absences of secondary-obligate cavity nesters in forest were associated with wetter summer-fall conditions and warmer annual and especially minimum winter temperatures (Figure 2).

Temporal variation in beta diversity averaged 0.26±0.02 among ranges with similar changes in turnover (β_{sne} = 0.15) and nestedness (β_{sim} = 0.11; *P* = 0.24, *t*-test) despite much higher levels of regional spatial turnover. Thus, on average, 15% of species were unique to the period of lower richness, with similar levels of species gains and losses in a nested pattern. Temporal variation in beta diversity did not vary geographically or with climate, land use, or landscape factors in all ranges or in those that were logged and unlogged ($P \geq 0.12$). Spatial assemblage heterogeneity declined by an estimated 11.2±0.5%, with changes attributable only to variation in nestedness ($P<0.001$) not turnover ($P=0.85$) as indicted by broadly overlapping distributions of re-sampled values of β_{SIM} (Figure 3). Additionally, relative contribution of nestedness to overall spatial assemblage heterogeneity was much higher in the subset of ranges visited historically compared to that across the broader region.

Breeding species richness increased by 8.0±3.0 species on average (14.0±5.3%) across time ($P=0.026$) after adjusting for effort as indexed by the number of survey days (Table S6 & S7). Results were similar after adjusting for effort as indexed by linear transect effort ($\beta=8.2\pm3.8$ species; $P=0.059$). On average, 1.7±0.4 more species were detected with each additional day of effort ($P<0.001$), with similar estimates for each additional km of effort ($\beta=1.3\pm0.5$ species, $P=0.021$). Overall effort was similar between periods ($P\leq0.79$). Species contributing to increased richness were associated with pines, forest, riparian vegetation, and had Madrean and lowland Neotropical affinities (Figure 4). In contrast, richness of secondary-obligate cavity nesters in forest declined markedly whereas richness of oak-depended species was nearly identical across time.

Regional gains of pine-, forest-, and riparian-dependent species and those with Madrean and lowland Neotropical affinities exceeded losses ($P \leq 0.063$; Figure 5), generally matching richness patterns. Pervasive losses and turnover of secondary-obligate cavity nesters were 15-19% higher in logged than in unlogged ranges ($P \leq 0.032$). Despite overall regional gains, there was some evidence local gains, losses, and turnover of pine-dependent species increased with decreasing area of conifer-dominated forest (P=0.046-0.087), suggesting greater dynamism in smaller ranges. Differences in *MAT* also increased (P=0.028) with decreasing area of conifer forest, suggesting increasing aridity in smaller ranges. There was some evidence that gains of lowland species increased with increasing *TAP* (P=0.072) and from west to east (P=0.080), suggesting climate-mediated range expansion into the higher-elevation interior. Losses of lowland species, however, increased with area of montane forest and woodland (P=0.015), suggesting less expansion into larger ranges. There was little evidence that gains, losses, and turnover of riparian-, oak-, forest-, and conifer forest-dependent species varied geographically or with differences in climate, land-use, or other factors (P>0.12). However, turnover of Madrean species increased with increasing mean maximum summer temperatures (P=0.041), and losses of lowland Neotropical species increased with cover of conifer forest (P=0.053). Across all MSI, species gains were highlighted by observations of 16 species not detected historically compared to losses of 8 species (Table S3 & S8).

4 | DISCUSSION

I documented complex distribution and assemblage patterns and high levels of species richness and turnover of breeding birds across the Madrean Sky Islands (MSI) and adjacent Sierra Madre Occidental (SMO) in Mexico. Observed shifts in local and regional species assemblages were associated with variation in climate, land-use, and landscape factors, but such patterns depended markedly on species' traits. Despite widespread losses of secondary-obligate cavity nesters dependent on mature montane forest, species richness increased across time due largely to gains in pine-, forest-, and riparian-dependent species and those with Madrean and lowland Neotropical affinities. In contrast, spatial assemblage heterogeneity declined with time by approximately the same magnitude as estimated increases in richness, with changes linked only to species gains and losses in a nested pattern and not to turnover. Temporal shifts in beta diversity, however, were equally attributable to changes in nestedness and turnover. Significant gains in Madrean and lowland Neotropical species with affinities to southern environments suggested northward range expansion contrasting largely stable patterns for Nearctic species, and there was some evidence lowland species expanded eastward into the higher-elevation interior. These patterns together with observed associations with climatic factors suggest poleward and up-elevation distributional shifts linked to climate change, which match recent trends elsewhere on Earth (Parmesan, 2006; Chen et al. 2011). Additionally, ongoing forest recovery following extensive logging in some ranges in the early 1900s, persistent habitat degradation linked to past logging, and higher extinction risks of small populations in more vulnerable habitat patches likely drove other observed changes (Hanski & Gaggiotti, 2004; Clarke et al., 2015; Jones et al., 2017).

4.1 │Contemporary patterns

The MSI and SMO are globally-recognized hotspots of biodiversity and endemism but very few studies have assessed faunal patterns based on recent fieldwork (Felger & Wilson, 1995; Marshall & Liebherr, 2000; González-Elizondo et al. 2012; Bezy & Cole, 2014). With regard to birds, estimates of breeding species richness in the MSI and northern SMO range from as low as 103 species, which includes only Mexican landbirds (Escalante-Pliego et al., 1993), to as high as 295 species, which includes adjacent lowland vegetation and central SMO (Felger & Wilson, 1995). At larger spatial scales, lowland and montane regions of the MSI and SMO are thought to support 478 species or approximately 45% of the Mexican avifauna (Kobelkowsky-Vidrio et al., 2014), but such estimates are often based on coarse distribution maps or models of idealized ranges often interpolated from historical data.

During extensive fieldwork across most MSI in Mexico and portions of the adjacent northern SMO, I documented 165 breeding species of landbirds and seven possible breeders in montane vegetation communities. Including 10 species that breed only at high elevations in the adjacent USA and three species observed recently in Mexico but not during the study (Table S4; Corman & Wise-Gervais, 2005), at least 185 landbird species likely breed in montane vegetation communities in this binational region. As one considers more humid areas to the south, richness increases (Escalante-Pliego et al., 1993) and includes species that may breed locally in the region considered here (Table S4). Among MSI, there was some evidence richness was greater in larger more southern ranges and those closer to the SMO due likely to increasing habitat diversity, larger population sizes that are less vulnerable extinction, and other processes that drive latitudinal diversity gradients (Hanski & Gaggiotti, 2004; Rosenzweig, 1995; Rosenzweig et al., 2012).

Complexity of faunal assemblages in the MSI region has been attributed to varied biogeographic influences, climate-mediated historical variation in island size and isolation, and broad physiographic and climatic gradients (Findley, 1969; Warshall, 1995; Coblentz & Riitters, 2004; McCormack et al., 2008). With regard to total beta diversity, regional turnover was >10-

times greater than nestedness indicating the importance of species replacement, but strength of this pattern declined over 2 fold when only MSI were considered, indicating significant assemblage discontinuity between the MSI and SMO. Such small contributions of nestedness to regional beta diversity are somewhat surprising given assemblages in ranges dominated by oaks include similar sets of widespread species some of which are subsets of richer communities in larger ranges supporting pines, which also include some widespread pine-dependent species. In this region, species substitutions typical of high turnover are due likely to replacement of ecologically similar species along a latitudinal Petran-Madrean gradient and niche differentiation to the south and east that foster additions of lowland Neotropical and Madrean species, which generally characterize biogeographic transition zones. In contrast, more limited longitudinal Sonoran-Chihuahuan transitions at lower elevations are due likely to higher levels of historical connectivity among aridlands, especially for more vagile taxa such as birds (Findley, 1969; Hubbard, 1973; Zink et al., 2001).

4.2 | Historical changes

I found evidence of marked spatiotemporal changes in breeding bird communities underscored by numerous species and populations observed for the first time in the region, and systematic apparent absences of other species and populations encountered historically. Although limitations in historical data precluded explicit adjustments for variation in detection probability, which may have biased estimates, many observed patterns were linked to common and conspicuous species that were either present or not observed by skilled observers expending similar effort in the same general areas across time. Such patterns, similar traits among species exemplifying them, and general coherency of observed associations with climate, land-use, and landscape factors with predictions and broader global trends, suggest marked community and environmental change driven by multiple processes.

I found evidence of northward range expansion by Madrean and especially lowland Neotropical species from the south. For the later group, spatiotemporal shifts in assemblages were correlated with increasing mean annual and minimum winter temperatures and summer-fall precipitation that typify more Neotropical environments to the south, which suggests climate forcing. Such patterns match observed (Johnson, 1994; Flesch, 2008; Snyder et al., 2010; Rappole et al., 2011; Flesch et al., 2015) and expected (Martínez-Morales et al., 2010) poleward range expansion by Neotropical breeding birds in northern Mexico and the adjacent USA, and species with more varied biogeographical affinities in North America that have been attributed to climate change (Hitch & Leberg, 2007; Zuckerberg et al., 2009).

In addition to poleward shifts, climate change is expected to force up-elevation shifts of montane taxa driven by altered thermal niches, climate-induced physiological stress, and interactions with climate-mediated factors such as insect outbreaks and wildfire. Such patterns have been described nearly worldwide (Lenoir et al. 2008, Allen et al., 2010, Chen et al. 2011), in one MSI in the USA (Brusca et al., 2013), and are suggested by observed expansion of lowland species into the higher-elevation interior and losses of pine-dependent species from smaller ranges in which aridity increased. In ranges I considered that supported small patches of pines for example, I observed pervasive signs of drought stress and high mortality of pines in the Sierra Cíbuta, which explains observed losses of pine-dependent species (Van Rossem, 1945). Similarly, in the Sierra San José, I observed few pines only on the highest north faces that contrasts historical descriptions of more widespread forest (Mearns, 1907), and extensive stands of mountain scrub and first records of associated bird species (Black-chinned Sparrow), suggesting climate change and wildfire drove these changes. These and other signs of drought stress and conifer mortality in south-western North America (Breshears et al. 2005; Ferguson et al., 2013) foreshadow potential for pervasive future contractions of montane taxa (Gómez-Mendoza & Arriaga, 2007; Sáenz-Romero et al., 2010; Rehfeldt et al., 2012; Monterrubio-Rico et al. 2015).

Despite broad evidence of poleward range expansion linked to climate change, examples of retreating distributions at southern range margins are more limited (Parmesan et al*.,* 2005; Lima et al. 2007). In this region, little variation in richness and occurrence of Nearctic species match these broader patterns but could develop in the future if climate impacts intensify. Observations of some Nearctic species not detected historically, however, were likely due to differences in survey coverage. Although Marshall (1957) considered MSI in Mexico too low in elevation to support many Nearctic species dependent on high-elevation forest that occur in the adjacent USA, I observed some of these species (Hermit Thrush, Virginia's Warbler, Western Tanager) breeding or likely breeding near their southern range margins for the first time. These species were probably present but undetected historically due to their rarity and restricted distributions at high elevations where past coverage was lower, which likely contributed some bias in estimates.

Regional changes in land use likely drove some observed assemblage shifts. Marshall (1957) lamented the impacts of logging on pines and wildlife in Mexico but noted ranges largely spared from logging. In the Sierra el Tigre, such logging-induced vegetation change occurred rapidly given accounts of extensive old-growth pine forest in 1941 that contrast descriptions of dense second growth in 1953, and likely eliminated habitat for Thick-billed Parrot and perhaps other species such as Eared Quetzal and Imperial Woodpecker (Sheffler, 1931; White, 1948; Marshall, 1957). Increased human activities associated with logging and road construction can augment hunting pressure on wildlife and contributed to major declines of Wild Turkey in mid 20th Century northwest Mexico (Leopold, 1949; Marshall, 1957). In contrast, I found little evidence of recent logging and little human activity in general in the MSI, old degraded logging roads, and extensive stands of often moderate-sized pines that had matured rapidly 60-90 years following disturbance (Flesch et al. 2016). In combination with better management, such changes likely contributed to observed gains in pine-, forest-, and possibly riparian-dependent species, major expansion of Wild Turkey, associated increases in species richness, and declines in spatial assemblage heterogeneity as widespread pine- and forest-dependent species expanded into newly available habitats. In contrast, high stability of oak-dependent species and the conspicuousness and often broad distributions of many species observed for the first time in the region further suggest these drivers. Although studies of Mexican endemic birds at national scales suggest little influence of land-use change on distributional dynamics (Peterson et al. 2015), this may not be representative of broader communities in our region given the rarity of endemics. Regardless, observed associations between turnover of Madrean species and mean maximum summer temperature further suggest increasing temperature is an important driver of faunal change.

Despite some auspicious trends linked to ongoing forest recovery, systematic apparent absences of species with similar traits from ranges in which they occurred historically suggest widespread extinctions. High regional losses and turnover of secondary-obligate cavity-nesters that rely on elements of mature montane forest were greatest in ranges subjected to intensive logging. Although some of these species were likely uncommon before logging and near their ecological tolerances limits, such patterns suggest changes driven by past land use. Importantly, nest cavities required by these species often occur only in large trees and snags (Lanning & Shiflett, 1983; Monterrubio-Rico & Enkerlin-Hoeflich, 2004), which are among the last legacies of old forests to recover following logging (Franklin et al., 2000) and were often rare. Limitations of these keystone resources due to past logging have been implicated in declines of these and similar bird species in coniferous forests across western North America (Brawn & Balda, 1988; Hejl, 1994; Jones et al. 2017), including endemic Thick-billed Parrott and Imperial Woodpecker in Mexico (Lammertink et al., 1996; Monterrubio-Rico et al. 2015). Such patterns are especially troublesome in the SMO where logging remains widespread, and for declining regional endemics of foremost conservation concern. Thus, whereas pines are recovering following logging in the MSI, more time, and potentially active management are needed to restore these systems.

4.3 │ Conservation Implications

Despite global threats to montane forests from logging, drought, wildfire, and other stressors linked to climate and land-use change (Allen et al., 2010; Rehfeldt et al., 2012; Meunier, et al. 2014), low human population densities, limited accessibility and recent land uses, and ongoing forest recovery have created large areas of *de facto* wilderness in many MSI. In Mexico, these patterns are noteworthy given major changes in landcover that have markedly reduced coverage of some vegetation communities and impacted wildlife and forest structure in the SMO where large-scale logging persists (Lammertink et al., 1996; Mas et al., 2004; FAO, 2007; Sarukhán et al., 2014). Such conditions together with existing and proposed federal natural protected areas offer important conservation opportunities in this region of Mexico.

In spite of some encouraging trends, evidence of shifting assemblages linked to climate and land-use change involved widespread declines of secondary-obligate cavity nesters dependent on mature montane forest. Such patterns suggest active forest restoration and enhancement that promotes development of large old trees, snags, and mature forest conditions, creation of artificial cavities by erecting nest boxes, and possibly, targeted translocation of extirpated populations will advance conservation (Snyder et al., 1994; Lindenmayer, 2017). These approaches are likely to be most effective when coupled with efforts to identify and protect areas with high potential to support mature forest conditions (e.g., protected sites with deep soils; Lindenmayer et al, 2014), and provide resources to local communities to implement best management practices. Although additional increases in species richness may temporarily offset anticipated losses of montane species due to climate change, such changes are likely to further homogenize assemblages via expansion of widespread species of lesser concern. While the ecological significance of these and other recovering forests will continue to grow as they mature, so too will economic values and renewed interest in logging. In advance of these and other threats, policy makers should develop conservation priorities based on rigorous criteria and take action.

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BIOSKETCH

Aaron D. Flesch is an ecologist interested in processes that drive the distribution and abundance of animal populations and in applying ecological theory to the conservation and management of wildlife and habitats. Dr. Flesch has worked in the south-western USA and north-western Mexico for more than 20 years, and is passionate about the ecology, biogeography, and conservation of the Sky Islands region.

DATA ACCESSIBILITY

All data are available in online supporting information and cited references.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article

Table 1 Associations between species richness of breeding birds and various landscape and geographic factors across 26 Madrean Sky Island mountain ranges in Sonora and Chihuahua, Mexico, 2009-2012. Estimates are from simple linear models.

Estimator Factor (units)	R^2	β	SE	$\|t\|$	P
Observed					
Area - montane woodland and forest (ln km^2)	0.35	4.94	1.38	3.58	0.002
Area - conifer woodland and forest (ln km^2)	0.37	5.52	1.46	3.78	<0.001
Maximum elevation (m)	0.33	0.034	0.010	3.45	0.002
Distance to Sierra Madre (10 km)	0.17	-1.03	0.47	2.22	0.037
Longitude (west to east; 10 km)	0.14	0.83	0.43	1.95	0.063
Latitude (south to north; 10 km)	0.15	-1.40	0.68	2.06	0.050
Jack-knife					
Area - montane woodland and forest (ln km^2)	0.35	5.58	1.55	3.60	0.001
Area - conifer woodland and forest (ln km^2)	0.35	5.97	1.68	3.56	0.002
Maximum elevation (m)	0.31	0.036	0.011	3.25	0.003
Distance to Sierra Madre (10 km)	0.14	-1.07	0.53	2.00	0.057
Longitude (west to east; 10 km)	0.11	0.85	0.49	1.74	0.094
Latitude (south to north; 10 km)	0.14	-1.55	0.77	2.01	0.056
Chao1					
Area of montane woodland and forest (ln km^2)	0.28	5.06	1.65	3.07	0.005
Area of conifer woodland and forest (ln km^2)	0.33	5.89	1.72	3.42	0.002
Maximum elevation (m)	0.21	0.030	0.012	2.51	0.019
Distance to Sierra Madre (10 km)	0.08	-0.802	0.559	1.43	0.164
Longitude (west to east; 10 km)	0.06	0.61	0.51	1.20	0.243
Latitude (south to north; 10 km)	0.11	-1.37	0.79	1.73	0.097

Table 2 Changes in historic and recent temperature (°C) and precipitation (mm) in 13 mountain ranges in the Madrean Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. Two different time periods were used to represent historic climates depending on the focal comparison. Test statistics and *P*-values are from paired *t*-tests comparing annual estimates in each range and time period. Climatic data are from downscaled estimates interpolated from weather stations.

	Historical 1 (1900-1954)		Historical 2 (1940-1954)		Recent (1998-2012)		Historical 1 vs. Recent		Historical 2 vs. Recent	
Factor	Mean	SE	Mean	SE	Mean	SE	*t*	*P*	*t*	*P*
Mean annual temperature	14.6	0.05	15.0	0.08	15.9	0.08	13.52	<0.001	7.48	<0.001
Mean maximum temperature - summer	30.0	0.05	30.6	0.08	31.1	0.09	10.33	<0.001	4.10	<0.001
Mean minimum temperature - winter	-0.50	0.07	-0.44	0.13	0.20	0.11	5.05	<0.001	3.73	<0.001
Precipitation - annual	526.0	5.1	480.2	7.6	502.6	8.8	2.19	0.029	1.93	0.055
Precipitation - summer and fall	378.1	3.7	344.4	5.7	389.3	8.8	1.33	0.18	4.26	<0.001
Precipitation - winter and spring	148.1	2.7	137.0	4.0	117.3	4.8	5.38	<0.001	3.16	0.002

Table 3 Pearson correlation coefficients between temporal, geographic, landscape, and climatic factors, and the three-dimensional non-metric multidimensional scaling configuration of 11 mountain ranges in species space. Estimates ≥0.40 are bolded. Factor abbreviations used on Figure 2 are in parentheses.

Factor	Axis 1	Axis 2	Axis 3
Time period (1-historical, 2-current; Time)	**0.57**	**0.58**	0.16
Longitude (Long)	-0.01	0.27	**0.53**
Latitude (Lat)	**0.62**	**-0.53**	0.12
Elevation (Elev)	**0.52**	-0.11	**0.51**
Area - woodland and forest (Area)	-0.23	**0.48**	0.24
Area - conifer woodland and forest	0.01	**0.47**	0.26
Mean annual temperature (MAT)	**-0.57**	-0.06	-0.23
Mean maximum temperature - summer	-0.26	-0.24	0.16
Mean minimum temperature – winter (T_{min})	**-0.51**	0.09	**-0.40**
Precipitation – annual (MAP)	**-0.50**	0.14	-0.34
Precipitation - summer and fall (P_s)	**-0.68**	0.04	-0.27
Precipitation - winter and spring	0.23	0.29	-0.37

Figure 1 Study area and locations of historic and recent bird surveys in the Madrean Sky Islands and adjacent Sierra Madre Occidental in Sonora and Chihuahua, Mexico. Red polygons show locations of recent survey effort in 26 mountain ranges and 6 areas in the adjacent Sierra Madre Occidental, 2009-2012. Dark arrows indicate 11 mountain ranges that were intensively surveyed in the 1950s and white arrows show two ranges with significant historical baselines from museum collections (1887-1942), which provided the basis of comparisons. Inset map shows study area with reference to state and national boundaries.

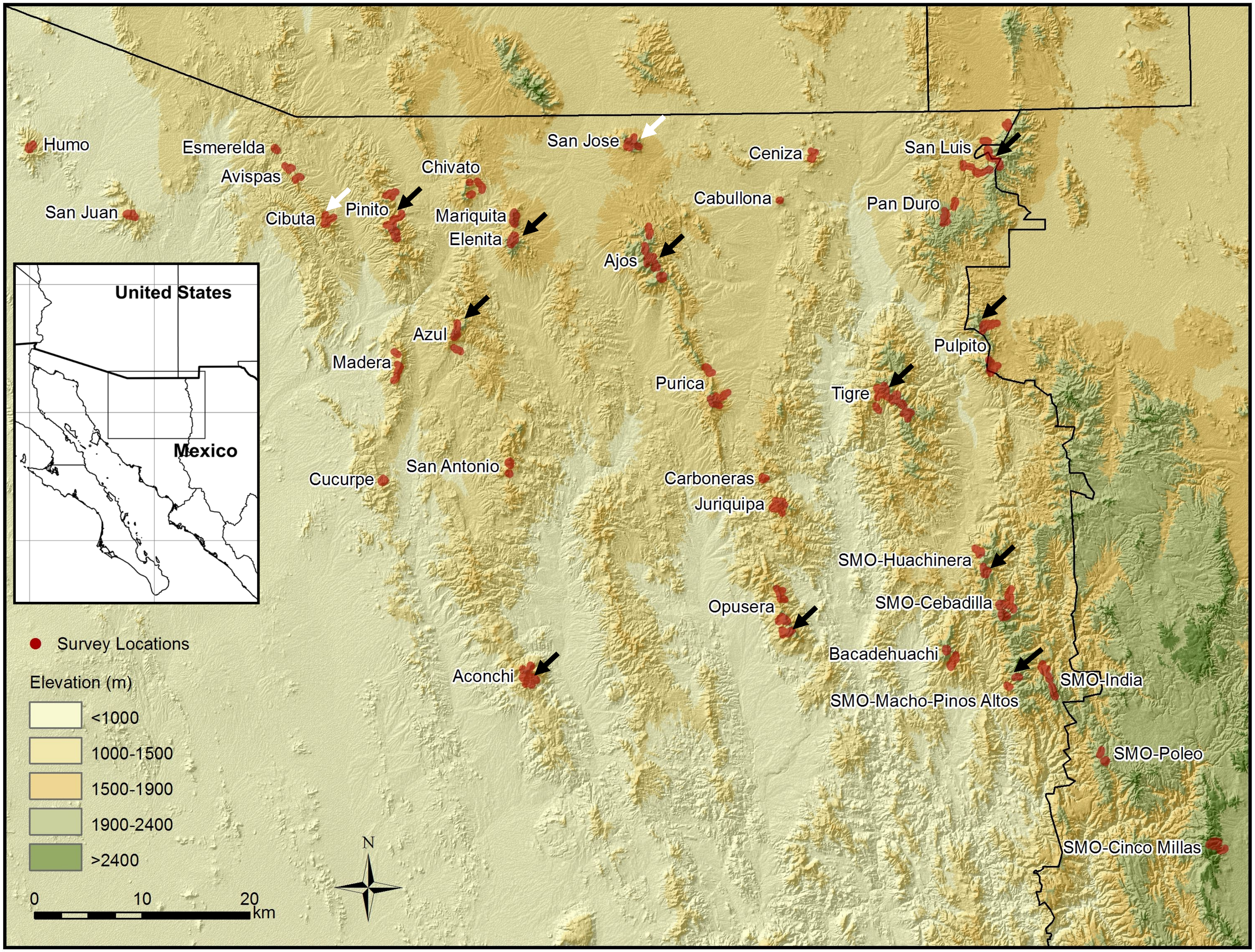
Figure 2 Three dimensional non-metric multidimensional scaling ordination of historic and recent breeding bird communities in the Madrean Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. Top panel shows spatiotemporal variation in species composition among 11 mountain ranges in the early 1950s and recently (2009-2012). Mountain ranges are: 1) Cananea, 2) Ajos, 3) San Luis, 4) Púlpito, 5) Pinito, 6) Azul, 7) Aconchi, 8) Oposura, 9) Tigre, 10) Huachinera, and 11) Pinos Altos. Bottom panel shows results for 112 species by habitat (colours; see Figure 3 legend) and biogeographic (symbols) affinity. Some representative species are labelled with mnemonic codes (see Table S1) to illustrate patterns, and 14 habitat generalists and one exotic species are omitted to highlight patterns. Vectors show correlations between ordination results and temporal, geographic, landscape, and climatic factors (Table 3), point in directions factors most rapidly change in ordination space, and have lengths scaled to the magnitude of correlation. Results are based on Sørensen distances (stress=0.132).

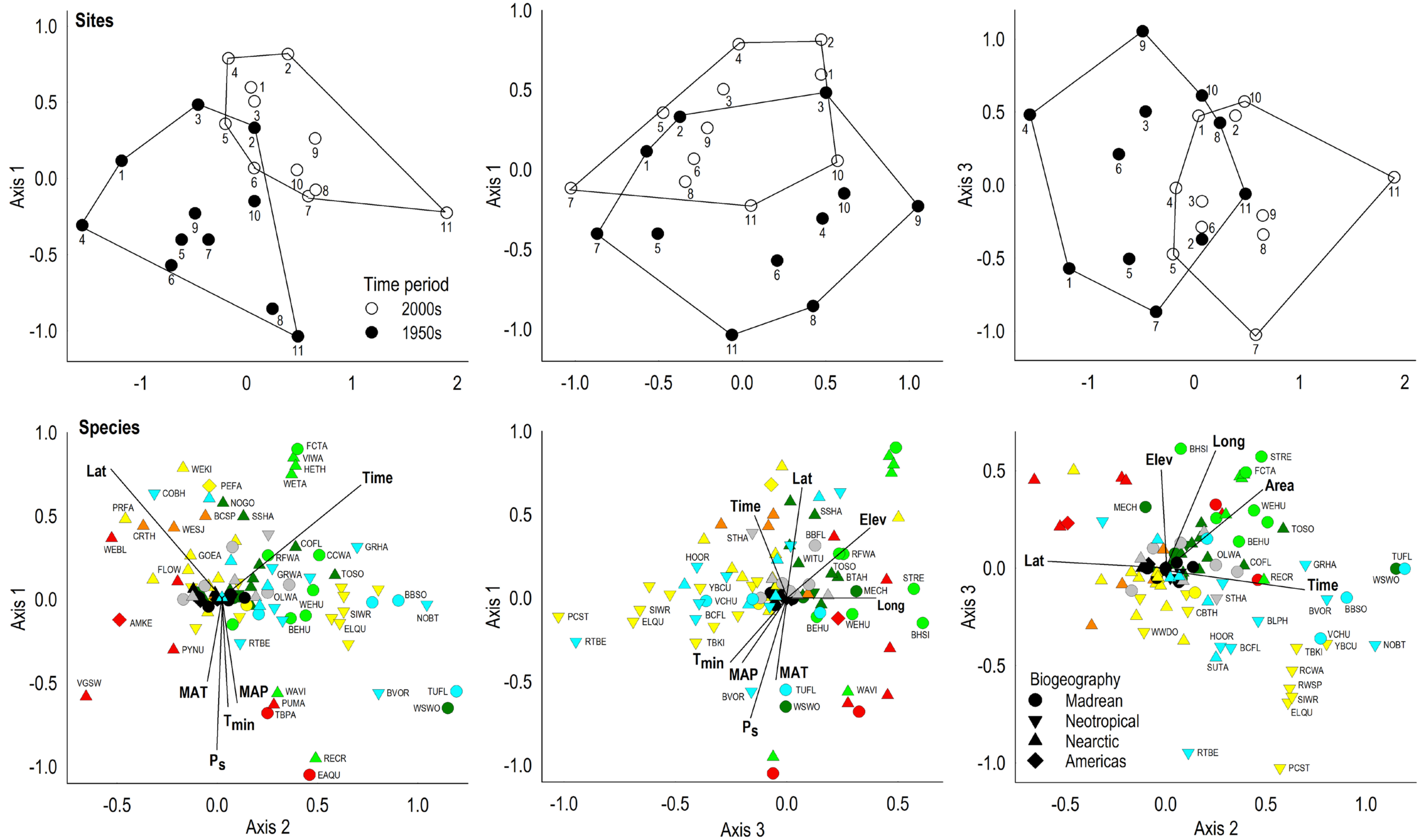
Figure 3 Spatiotemporal variation in beta diversity of breeding bird communities in 11 mountain ranges the Madrean Sky Islands and adjacent Sierra Madre Occidental of northwest

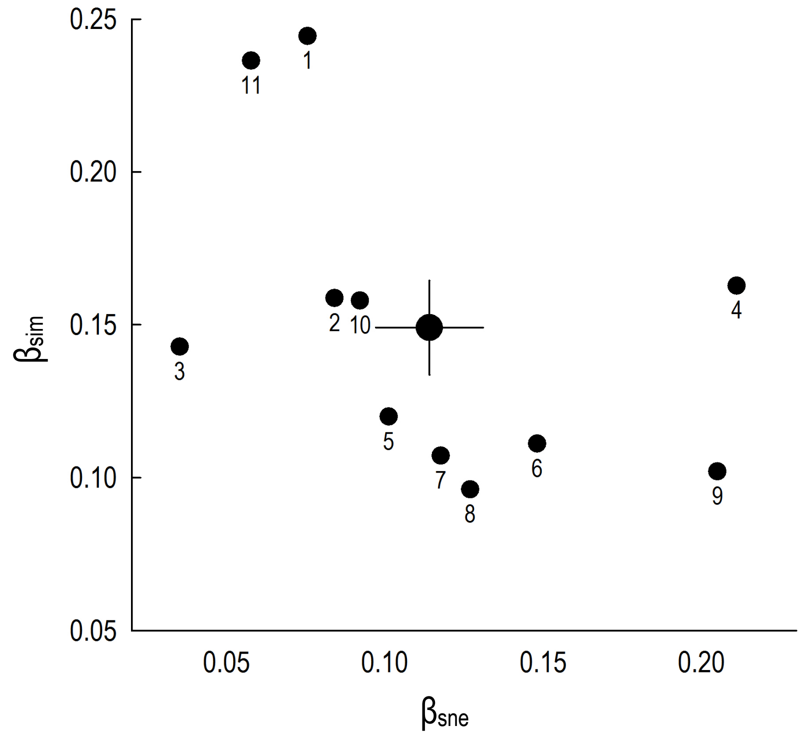
Mexico. Top panel shows temporal variation in assemblages in each range between the 1950s and recently (2009-2012; see Figure 2 for labels) and on average (large point ±1 SE) for the turnover (β_{sim}) and nestedness (β_{sne}) components of beta diversity. Bottom panel shows distribution of multiple site dissimilarity during each time period for turnover (β_{SIM}; black lines), nestedness (β_{SNE}; green lines), and total beta diversity (β_{SOR}; red line) after re-sampling values at approximately one third of sites 1000 times.

Figure 4 Richness of historical (1950s) and recent (2009-2012) breeding bird communities across 11 mountain ranges in the Madrean Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. At the regional scale (gamma; left) estimates are totals among all species. At the local scale (alpha; right) estimates are least-square means from mixed-effect models in which survey effort (no. of survey days in each range and time period) was a covariate and mountain range as a random effect. Estimates are summarized for species with various habitat (top) and biogeographic (bottom) affinities. Asterisks indicate *P*-values ≤0.05. Species associated with cavities are secondary-obligate cavity nesters in mature montane forest, and lowland species are associated with arid scrub or open vegetation associations.

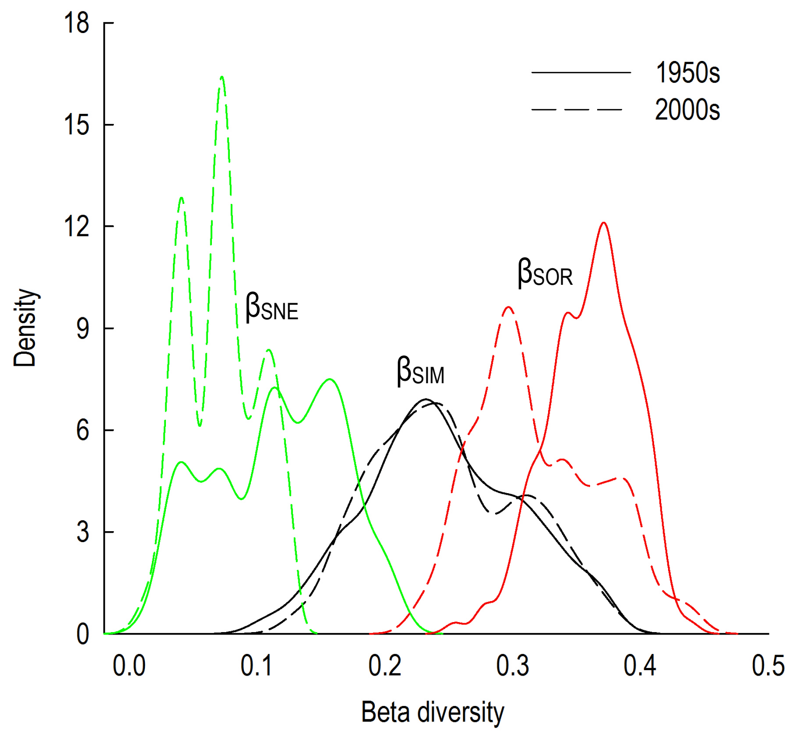
Figure 5 Percent gains, losses, and turnover of breeding birds observed historically (1887-1954) and recently (2009-2012) in 11 mountain ranges in the Madrean Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. Estimates are for species with various habitat and biogeographic affinities and all species combined, and are means among ranges surveyed in each time period. Data from two ranges where only species losses were estimated are omitted. One exotic species is excluded from the right panel.


Humo
Esmerelda
Avispas
San Juan
Cibuta
Pinito
Chivato
Mariquita
Elenita
San Jose
Ceniza
Cabullona
San Luis
Pan Duro
Ajos
United States
Mexico
Azul
Madera
Purica
Tigre
Pulpito
Cucurpe
San Antonio
Carboneras
Juriquipa
SMO-Huachinera
SMO-Cebadilla
Opusera
Bacadehuachi
SMO-India
SMO-Macho-Pinos Altos
Aconchi
SMO-Poleo
SMO-Cinco Millas
Survey Locations
Elevation (m)
<1000
1000-1500
1500-1900
1900-2400
>2400
N
0
10
20
km

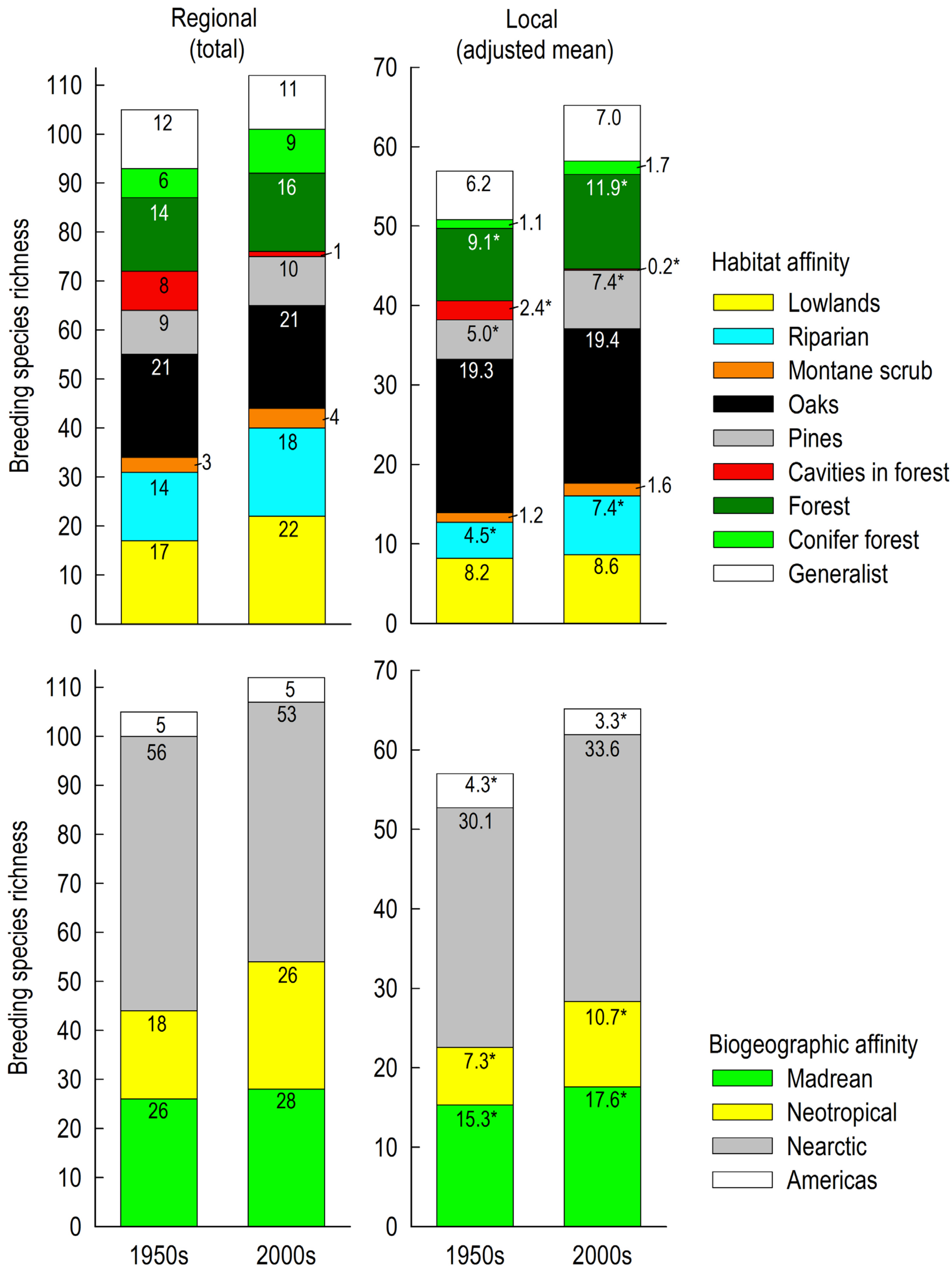

Sites
Species
Time period
2000s
1950s
Axis 1
Axis 2
Axis 3
Lat
Time
MAT
MAP
T_{min}
P_s
Elev
Long
Area
Biogeography
Madrean
Neotropical
Nearctic
Americas



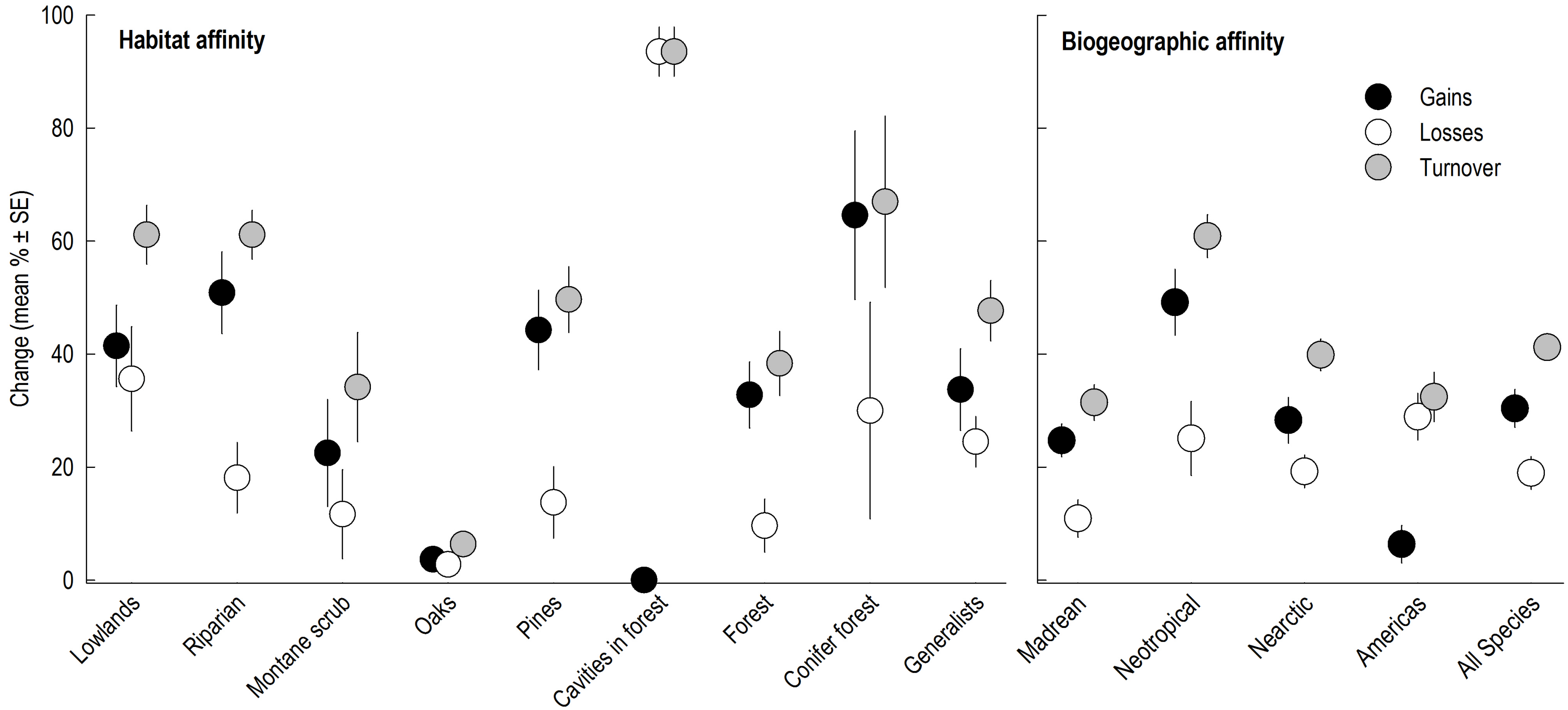
0.25
0.20
0.15
0.10
0.05
0.05
0.10
0.15
0.20
βsim
βsne
1
2
3
4
5
6
7
8
9
10
11



1950s
2000s
βSNE
βSIM
βSOR
Density
Beta diversity
0
3
6
9
12
15
18
0.0
0.1
0.2
0.3
0.4
0.5



Regional
(total)
Local
(adjusted mean)
Breeding species richness
Habitat affinity
Lowlands
Riparian
Montane scrub
Oaks
Pines
Cavities in forest
Forest
Conifer forest
Generalist
12
6
14
8
9
21
3
14
17
11
9
16
1
10
21
4
18
22
6.2
1.1
9.1*
2.4*
5.0*
19.3
1.2
4.5*
8.2
7.0
1.7
11.9*
0.2*
7.4*
19.4
1.6
7.4*
8.6
Biogeographic affinity
Madrean
Neotropical
Nearctic
Americas
5
56
18
26
5
53
26
28
4.3*
30.1
7.3*
15.3*
3.3*
33.6
10.7*
17.6*
1950s
2000s



Habitat affinity
Biogeographic affinity
Gains
Losses
Turnover
Change (mean % ± SE)
100
80
60
40
20
0
Lowlands
Riparian
Montane scrub
Oaks
Pines
Cavities in forest
Forest
Conifer forest
Generalists
Madrean
Neotropical
Nearctic
Americas
All Species

Supporting Information

Table S1: Habitat and biogeographic species groupings used to compare changes between historical and recent breeding bird communities across the Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. Details and literature sources used to classify species among the 10 primary habitat affinities are noted with colors corresponding to those depicted in Figures 2 and 4 in the main text. Species associated with desertscrub, thornscrub, openings, and cliffs were largely grouped in the lowlands category. Species associated with cavities are secondary-obligate cavity nesters in mature montane forest. Species dependent on deciduous vegetation in mixed-conifer forest (MCF) are placed in the mixed-conifer forest group. Some species classified as generalists are linked to unique resources with little similarity to other species. Species are ordered taxonomically within each of 10 primary habitat affinities. The four biogeographic groupings are based on published maps of breeding ranges (Howell and Webb 1995).

Code	Common name	Habitat affinity	Habitat details, key resources, secondary grouping	Source for habitat classifications	Biogeographic affinity
ELQU	Elegant Quail	Lowlands	Thornscrub	CLO a	Neotropical
WWDO	White-winged Dove	Lowlands	Desertscrub, thornscrub	Russell and Monson (1998)	Neotropical
YBCU	Yellow-billed Cuckoo	Lowlands	Shrubby areas in scrub and woodland	Flesch, unpubl.	Neotropical
GRRO	Greater Roadrunner	Lowlands	Open slopes	CLO b, Marshall (1957)	Neotropical
WESO	Western Screech-Owl	Lowlands	Desertscrub, open woodlands	Russell and Monson (1998), Marshall (1957)	Nearctic
ELOW	Elf Owl	Lowlands	Lowlands, and open woodlands	Russell and Monson (1998)	Neotropical
COPO	Common Poorwill	Lowlands	Openings, slopes, desertscrub	Russell and Monson (1998), Marshall (1957)	Nearctic
BBIH	Broad-billed Hummingbird	Lowlands	Lowland and riparian vegetation	Russell and Monson (1998)	Neotropical
PCST	Plain-capped Starthroat	Lowlands	Thornscrub	CLO a	Neotropical
ATFL	Ash-throated Flycatcher	Lowlands	Desertscrub, open woodlands	Russell and Monson (1998), Marshall (1957)	Nearctic
TBKI	Thick-billed Kingbird	Lowlands	Lowlands, open woodlands, riparian areas	Marshall (1957)	Neotropical
SIWR	Sinaloa Wren	Lowlands	Thornscrub, oak and riparian woodland	Russell and Monson (1998)	Neotropical
CBTH	Curve-billed Thrasher	Lowlands	Desertscrub, openings, cholla	Russell and Monson (1998), Marshall (1957)	Neotropical
RCWA	Rufous-capped Warbler	Lowlands	Thornscrub, shrubby slopes in forest or woodland	Russell and Monson (1998), Flesch, unpubl.	Neotropical
RWSP	Rufous-winged Sparrow	Lowlands	Desertscrub and thornscrub	Russell and Monson (1998)	Neotropical
GOEA	Golden Eagle	Lowlands - Cliffs	Open country, cliffs	Russell and Monson (1998)	Nearctic
PEFA	Peregrine Falcon	Lowlands - Cliffs	Open country, cliffs	Russell and Monson (1998)	Americas
PRFA	Prairie Falcon	Lowlands - Cliffs	Open country, cliffs	Russell and Monson (1998)	Nearctic
ROWR	Rock Wren	Lowlands - Cliffs	Openings, rocky areas	Russell and Monson (1998)	Nearctic
CANW	Canyon Wren	Lowlands - Cliffs	Openings, rocky canyons	Russell and Monson (1998)	Nearctic
CONI	Common Nighthawk	Lowlands - Openings	Openings, flat country, sometimes highlands	Russell and Monson (1998), Marshall (1957)	Nearctic
WEKI	Western Kingbird	Lowlands - Openings	Open woodlands	CLO b	Nearctic
CANT	Canyon Towhee	Lowlands - Openings	Openings in woodland, desertscrub	Marshall (1957)	Nearctic
CHSP	Chipping Sparrow	Lowlands - Openings	Openings in woodland	Marshall (1957)	Nearctic
COHA	Cooper's Hawk	Riparian	Riparian	Marshall (1957)	Nearctic

COBH	Common Black-Hawk	Riparian	Surface water	Marshall (1957)	Neotropical
GRHA	Gray Hawk	Riparian	Mesquite	Russell and Monson (1998)	Neotropical
VCHU	Violet-crowned Hummingbird	Riparian	Riparian woodland	Russell and Monson (1998)	Madrean
BTHH	Blue-throated Hummingbird	Riparian	Riparian woodland	Russell and Monson (1998)	Madrean
BCHU	Black-chinned Hummingbird	Riparian	Riparian woodland, foothills slopes	Marshall (1957)	Nearctic
NOBT	Northern Beardless-Tyrannulet	Riparian	Riparian trees, lowlands	Russell and Monson (1998)	Neotropical
TUFL	Tufted Flycatcher	Riparian	Riparian areas in forest	Flesch, unpubl.	Madrean
WEWP	Western Wood-Pewee	Riparian	Riparian, oak, and pine-oak woodland	Flesch et al. (2016), Marshall (1957)	Nearctic
BLPH	Black Phoebe	Riparian	Riparian, surface water	Russell and Monson (1998)	Neotropical
BCFL	Brown-crested Flycatcher	Riparian	Riparian woodlands with large trees	Russell and Monson (1998), Marshall (1957)	Neotropical
SBFL	Sulphur-bellied Flycatcher	Riparian	Riparian woodlands with large trees	Russell and Monson (1998), Marshall (1957)	Neotropical
RTBE	Rose-throated Becard	Riparian	Tall riparian trees	Russell and Monson (1998)	Neotropical
BBSO	Brown-backed Solitaire	Riparian	Canyons and slopes, riparian and conifer forest	CLO a, Flesch, unpubl.	Neotropical
SUTA	Summer Tanager	Riparian	Riparian vegetation, deciduous trees	Russell and Monson (1998)	Nearctic
BVOR	Black-vented Oriole	Riparian	Riparian, palms, woodland and forest	CLO a, Russell and Monson (1998)	Neotropical
HOOR	Hooded Oriole	Riparian	Riparian, palms	CLO b, Russell and Monson (1998)	Neotropical
LEGO	Lesser Goldfinch	Riparian	Riparian, openings	Russell and Monson (1998)	Nearctic
WESJ	Woodhouse’s Scrub-Jay	Mountain scrub	Mountain scrub, oak scrub	CLO b, Flesch et al. (2016)	Nearctic
CRTH	Crissal Thrasher	Mountain scrub	Mountain scrub, oak scrub	Russell and Monson (1998), Flesch, unpubl.	Nearctic
SPTO	Spotted Towhee	Mountain scrub	Mountain scrub, shrubs in forest and woodland	Flesch et al. (2016), Marshall (1957)	Nearctic
BCSP	Black-chinned Sparrow	Mountain scrub	Mountain scrub, oak scrub	CLO b	Nearctic
MONQ	Montezuma Quail	Oaks	Oaks	Flesch et al. (2016)	Madrean
RTHA	Red-tailed Hawk	Oaks	Open country, cliffs	Russell and Monson (1998)	Nearctic
BTPI	Band-tailed Pigeon	Oaks	Mast, upland forest and woodlands	Marshall (1957), CLO b	Americas
WHSO	Whiskered Screech-Owl	Oaks	Dense oak, and pine-oak woodland	Russell and Monson (1998), Marshall (1957)	Madrean
NOPO	Northern Pygmy-Owl	Oaks	Oak and pine-oal woodland	Marshall (1957)	Nearctic
ELTR	Elegant Trogon	Oaks	Oak woodland and riparian trees	Flesch et al. (2016), Marshall (1957)	Madrean
ACWO	Acorn Woodpecker	Oaks	Oaks and riparian trees	Flesch et al. (2016), Marshall (1957)	Americas
ARWO	Arizona Woodpecker	Oaks	Oaks and pine-oak woodland	Flesch et al. (2016), Marshall (1957)	Madrean
DCFL	Dusky-capped Flycatcher	Oaks	Oak, pine-oak, and riparian woodland	Flesch et al. (2016), Marshall (1957)	Neotropical
CAKI	Cassin's Kingbird	Oaks	Woodlands with openings	Russell and Monson (1998), Marshall (1957)	Nearctic
HUVI	Hutton's Vireo	Oaks	Oaks, dense-short tree layer	Flesch et al. (2016), Marshall (1957)	Nearctic
MEJA	Mexican Jay	Oaks	Oak and pine-oak woodland	Russell and Monson (1998), Marshall (1957)	Madrean
BRTI	Bridled Titmouse	Oaks	Oak and pine-oak woodland	Marshall (1957)	Madrean

BUSH	Bushtit	Oaks	Oak and pine-oak woodland	Marshall (1957)	Nearctic
BEWR	Bewick's Wren	Oaks	Oak woodland, mountain scrub	Flesch et al. (2016), Marshall (1957)	Nearctic
PARE	Painted Redstart	Oaks	Oak-Pine, pine-oak, and riparian woodland	Flesch et al. (2016), Marshall (1957)	Madrean
RCSP	Rufous-crowned Sparrow	Oaks	Grassy or shrubby slopes in woodland and forest	Flesch et al. (2016), Marshall (1957)	Nearctic
HETA	Hepatic Tanager	Oaks	Oak and pine-oak woodland	Flesch et al. (2016), Marshall (1957)	Madrean
BHGR	Black-headed Grosbeak	Oaks	Generalist, oak and pine-oak, riparian vegetation	Flesch et al. (2016), Marshall (1957)	Nearctic
SCOR	Scott's Oriole	Oaks	Oak and pine-oak woodland, slopes, generalist	CLO b, Russell and Monson (1998)	Neotropical
STHA	Short-tailed Hawk	Pines	Forest	Snyder et al (2010)	Neotropical
HAWO	Hairy Woodpecker	Pines	Pine and mixed-conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
BBFL	Buff-breasted Flycatcher	Pines	Openings in pine and riparian forest	Flesch et al. (2016), Marshall (1957)	Madrean
PLVI	Plumbeous Vireo	Pines	Pine-oak woodland, conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
STJA	Steller's Jay	Pines	Pines, conifer forest	CLO b, Flesch et al. (2016)	Nearctic
EABL	Eastern Bluebird	Pines	Pine forest, pine-oak and oak woodland	CLO b, Marshall (1957)	Madrean
TOSO	Townsend's Solitaire	Pines	Pines, mixed-conifer forest	CLO b, Flesch et al. (2016)	Nearctic
OLWA	Olive Warbler	Pines	Tall pines, mixed-conifer forest	Flesch et al. (2016), Marshall (1957)	Madrean
GRWA	Grace's Warbler	Pines	Pines in forest and pine-oak woodland	Flesch et al. (2016), Marshall (1957)	Madrean
YEJU	Yellow-eyed Junco	Pines	Pine forest, tall pine-oak woodland	Flesch et al. (2016), Marshall (1957)	Madrean
AMKE	American Kestrel	Cavities	Forest openings, large snags	Marshall (1957)	Americas
TBPA	Thick-billed Parrot	Cavities	Cavities in mature coniferous forest	Flesch et al. (2016), Monterrubio-Rico et al. (2004)	Madrean
FLOW	Flammulated Owl	Cavities	Cavities in mature coniferous forest	CLO b, Marshall (1957)	Nearctic
EAQU	Eared Quetzal	Cavities	Cavities in mature coniferous forest	González-Rojas et al. (2008), Marshall (1957)	Madrean
PUMA	Purple Martin	Cavities	Forest openings, large snags	CLO b, Marshall (1957)	Nearctic
VGSW	Violet-green Swallow	Cavities	Forest openings, large snags	CLO b, Marshall (1957)	Nearctic
PYNU	Pygmy Nuthatch	Cavities	Cavities in mature coniferous forest, pines	Marshall (1957)	Nearctic
WEBL	Western Bluebird	Cavities	Forest and forest openings	CLO b, Marshall (1957)	Nearctic
WITU	Wild Turkey	Forest	Forest	Marshall (1957)	Nearctic
SSHA	Sharp-shinned Hawk	Forest	Mixed-conifer forest	Marshall (1957)	Nearctic
NOGO	Northern Goshawk	Forest	Mature forest, tall trees	Marshall (1957)	Nearctic
ZTHA	Zone-tailed Hawk	Forest	Any woods	Russell and Monson (1998)	Neotropical
SPOW	Spotted Owl	Forest	Forest conifers and tall oaks	Russell and Monson (1998), Marshall (1957)	Nearctic
MAHU	Magnificent Hummingbird	Forest	Forest, pine-oak woodland, riparian areas	Russell and Monson (1998), Marshall (1957)	Madrean
BTAH	Broad-tailed Hummingbird	Forest	Conifer forest, deciduous growth herein	Marshall (1957)	Nearctic
NOFL	Northern Flicker	Forest	Mixed-conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
WSWO	White-striped Woodcreeper	Forest	Pine-oak woodland, riparian areas in forest	Russell and Monson (1998), Flesch, unpubl.	Madrean

GRPE	Greater Pewee	Forest	Conifer forest	Flesch et al. (2016)	Madrean
COFL	Cordilleran Flycatcher	Forest	Conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
MECH	Mexican Chickadee	Forest	Forest, pine-oak woodland	Marshall (1957)	Madrean
WBNU	White-breasted Nuthatch	Forest	Forest, and tall woodland	Marshall (1957)	Nearctic
BRCR	Brown Creeper	Forest	Forest, pine-oak woodlands	Marshall (1957)	Nearctic
HOWR	House Wren	Forest	Forest, mixed-conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
AMRO	American Robin	Forest	Tall trees, openings, surface water	Marshall (1957)	Nearctic
WEHU	White-eared Hummingbird	Mixed-conifer forest	Flowering forbs, wet areas in conifer forest	Marshall (1957)	Madrean
BEHU	Berylline Hummingbird	Mixed-conifer forest	Pine-oak woodland	CLO a	Madrean
HETH	Hermit Thrush	Mixed-conifer forest	Dense short firs	CLO b	Nearctic
CCWA	Crescent-chested Warbler	Mixed-conifer forest	Forest, humid oak woodland	CLO a, Flesch et al. (2016)	Madrean
VIWA	Virginia's Warbler	Mixed-conifer forest	Deciduous shrubs in conifer forest	CLO b, Marshall (1957)	Nearctic
WETA	Western Tanager	Mixed-conifer forest	Mixed-conifer forest, forest conifers	CLO b, Marshall (1957)	Nearctic
FCTA	Flame-colored Tanager	Mixed-conifer forest	Mixed-conifer forest, deciduous trees	CLO a, Flesch, unpubl.	Madrean
RECR	Red Crossbill	Mixed-conifer forest	Conifer cones	CLO b, Marshall (1957)	Nearctic
BHSI	Black-headed Siskin	Mixed-conifer forest	Pine-oak woodland, riparian, openings	Marshall (1957)	Madrean
WAVI	Warbling Vireo	Deciduous in MCF	Deciduous trees in conifer forest, riparian	CLO b	Nearctic
RFWA	Red-faced Warbler	Deciduous in MCF	Deciduous vegetation in conifer forest	Flesch et al. (2016), Marshall (1957)	Madrean
STRE	Slate-throated Redstart	Deciduous in MCF	Deciduous vegetation and herbs conifer forest	CLO a, Flesch et al. (2016)	Madrean
TUVU	Turkey Vulture	Generalist	Cliffs	Marshall (1957), pers. obs.	Americas
MODO	Mourning Dove	Generalist	Openings	CLO b, Marshall (1957)	Nearctic
GHOW	Great Horned Owl	Generalist	Open country, cliffs	Russell and Monson (1998), Marshall (1957)	Americas
MWPW	Mexican Whip-poor-will	Generalist	Woodlands, forest, canyons with leaf litter	Flesch, unpubl., Marshall (1957)	Madrean
WTSW	White-throated Swift	Generalist	Open air often near cliffs	Flesch, unpubl.	Nearctic
ANHU	Anna's Hummingbird	Generalist	Scrub, oak woodlands, ranches, riparian	CLO b	Nearctic
CORA	Common Raven	Generalist	Cliffs, ridges	CLO b, Marshall (1957)	Nearctic
JUTI	Juniper Titmouse	Generalist	Oaks woodland with juniper or pinyon	Marshall (1957)	Nearctic
BGGN	Blue-gray Gnatcatcher	Generalist	Oak and oak-pine woodland, mountain scrub	Flesch et al. (2016), Marshall (1957)	Nearctic
NOPA	Northern Parula	Generalist	Habitat unknown in region, forest?	CLO b	Nearctic
BTYW	Black-throated Gray Warbler	Generalist	Oak and pine-oak woodland, mixed-conifer forest	Flesch et al. (2016), Marshall (1957)	Nearctic
RUSP	Rusty Sparrow	Generalist	Shrubby areas in woodland, forest, brushy slopes	Marshall (1957)	Madrean
BHCO	Brown-headed Cowbird	Generalist	Riparian and open areas	CLO b, Russell and Monson (1998)	Nearctic
HOFI	House Finch	Generalist	Riparian, lowlands, moved widely	CLO b, Russell and Monson (1998)	Nearctic
EUCD	Eurasian Collared-Dove	Urban	Ranches and towns	CLO b	Exotic

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Table S2: Survey effort and species richness of breeding birds in 26 Madrean Sky Islands and 6 areas in the adjacent Sierra Madre Occidental of Sonora and Chihuahua, Mexico, 2009-2012. Elevations are from digital elevation models and rounded to the nearest 5 meters. Total observed richness includes species presumed (Pres.) and confirmed (Conf.) breeding, but not possible (Poss.) breeders; 1's are singletons and 2's are doubletons noting number of species detected exactly one or two times. Estimated richness includes an upper bound (UB) of a 95% confidence interval for jackknife-based estimates (N). Chao1 estimates were bias-corrected. Thirteen ranges surveyed historically that are the focus of comparisons are noted with a †. Mountain ranges are listed from west to east.

	Effort					Observed Richness and Breeding Status						Estimated Richness			
Region												Jackknife			
Range (max. elevation)	Transects	Length (km)	Month/Day	Year	Elevations	Poss.	Pres.	Conf.	Total	1s	2s	*N*	SE	UB	Chao1
Sky Islands	181	249.7	5/1-7/20	2009-'12	1,155-2,600	8	81	71	152	14	14	169	5.8	180.4	158.1
Humo (1,640)	3	3.4	5/19-22	2010	1,180-1,535	1	32	2	34	12	1	46	4.7	55.2	67.0
San Juan (1,630)	4	6.6	5/15-18	2012	1,260-1,610	0	57	2	59	13	5	72	5.1	82.0	72.0
Esmeralda (1,620)	2	2.4	7/19-20	2012	1,300-1,540	0	33	4	37	11	3	50	5.7	61.6	50.8
Avispas-Cíbuta (2,070) †	8	9.6	5/9-7/19[1]	2009,'10	1,170-2,060	0	70	8	78	15	11	94	5.5	104.8	86.8
Pinito (2,230) †	12	19.5	5/3-8	2012	1,400-2,180	4	53	8	61	12	7	71	4.5	79.8	69.3
Madera (2,030)	4	5.5	6/17-22	2009	1,290-2,020	0	49	7	56	10	8	66	4.5	74.8	61.0
Chivato (2,190)	4	6.8	7/5-9	2010	1,440-1,785	0	55	11	66	12	6	79	5.1	89.0	75.4
Azul (2,450) †	8	9.1	5/29-6/2	2010	1,320-2,435	1	57	11	68	11	8	81	5.1	91.0	74.1
Cucurpe (1,720)	3	3.4	7/15-18	2010	1,155-1,520	0	39	1	40	6	8	46	3.5	52.9	41.7
Mariquita (2,480)	7	9.8	6/24-29	2009	2,070-2,480	2	51	2	53	9	6	62	4.2	70.2	58.1
Elenita (2,460) †	6	6.7	5/4-15[2]	2009,'11	1,875-2,455	2	51	2	53	10	5	64	4.5	72.8	60.5
San Antonio (2,200)	3	3.6	5/1-4	2011	1,435-1,955	1	43	0	43	11	5	55	4.9	64.6	52.2
San José (2,530) †	5	5.8	7/5-10	2010	1,675-2,360	0	35	4	39	9	10	48	4.2	56.2	42.3
Ajos (2,630) †	12	16.1	6/09-17	2010	1,700-2,600	0	50	12	62	11	4	73	4.7	82.2	73.0
Aconchi (2,190) †	12	17.9	5/30-7/9[3]	2012	1,285-2,170	2	72	14	86	16	6	103	6.1	114.9	103.1
Púrica (2,460)	9	13.2	5/9-24[4]	2010,'12	1,370-2,450	1	80	3	83	18	12	100	5.8	111.5	94.8
Cabullona (1,880)	1	0.7	6/2-3	2012	1,720-1,855	0	30	0	30	7	4	37	3.7	44.3	34.2
Ceniza (1,820)	2	2.2	5/30-6/1	2012	1,440-1,600	0	41	2	43	6	11	49	3.5	55.9	44.3
Carboneras (1,920)	2	3.1	7/6-7	2012	1,640-1,920	1	35	2	37	11	5	48	4.7	57.2	46.2
Juriquipa (2,180)	9	12.3	5/1-22[5]	2010,'12	1,525-2,165	3	49	4	53	8	7	61	4.0	68.8	56.5
Oposura (2,320) †	14	20.0	7/7-12[6]	2009,'12	1,505-2,240	1	64	12	76	13	9	89	5.1	99.0	83.8
Tigre (2,440) †	15	22.1	5/19-7/1[7]	2009,'10	1,280-2,385	0	67	20	87	13	2	98	4.9	107.6	113.0
Pan Duro (2,300)	6	7.6	5/18-24	2011	1,680-2,150	2	58	0	58	15	8	73	5.5	83.8	69.7

San Luis (2,520) †	13	18.0	5/12-7/6[8]	2011,'12	1,425-2,310	4	77	3	80	11	10	91	4.7	100.2	85.0
Púlpito (2,460) †	11	15.0	6/8-12	2012	1,580-2,390	2	64	18	82	18	9	100	6.0	111.8	97.3
Bacadéhuachi (2,400)	6	9.3	6/26-29	2012	1,420-2,320	0	74	10	84	14	15	98	5.3	108.4	89.7
Sierra Madre Occidental	29	48.9	6/12-30	2012	1,400-2,750	3	82	35	117	28	12	135	6.0	146.8	146.1
Huachinera (2,420) †	6	9.4	6/12-14	2012	1,565-2,302	0	53	8	61	10	5	72	4.7	81.2	68.5
Cebadilla (2,640)	9	15.4	6/14-17	2012	1,400-2,620	3	69	20	89	14	5	105	5.5	115.8	104.2
Macho-Pinos Altos (2,360)†	2	3.3	6/29-30	2012	1,465-2,202	0	60	6	66	21	7	84	6.0	95.8	92.3
La India (2,560)	6	10.0	6/17-19	2012	1,595-2,480	0	57	13	70	16	6	88	6.4	100.5	87.1
El Poleo (2,340)	2	3.4	6/19-20	2012	2,180-2,320	0	34	8	42	8	9	51	4.2	59.2	44.8
Cinco Millas (2,800)	4	7.4	6/20-23	2012	2,310-2,750	0	43	5	48	12	2	71	8.9	88.4	70.0

[1]5/30-31/09, 6/10-11/09, 7/18-19/09, 5/7-9/10, 6/7-9/10, [2]5/12-15/09, 5/4-6/11, [3]5/30-6/4, 7/8-9/12, [4]5/9-15/10, 5/20-24/12, [5]5/1-6/10, 5/20-22/12, [6]7/7-12/09, 7/8-11/12
[7]5/19-20/09, 6/23-7/1/10, [8]5/12-18/11, 6/1-6/11,
7/5-6/12

Table S3: Distribution and status of breeding birds in the Sky Islands and adjacent Sierra Madre Occidental of Sonora and Chihuahua, Mexico, May-July, 2009-2012. Status is noted as confirmed (C), presumed (P), and possibly breeding (?), non-breeding (O), or presumed breeding only during scouting in 2004-2008 (#). Only landbird species at least possibly breeding are included. Species associated with lowland vegetation communities, cliffs, or other factors not linked to montane vegetation communities are noted by an asterisk (*). Species observed for the first time in the Mexican Sky Islands are noted with a cross (†). Mountain ranges are listed from west to east. Scientific names in Table S4.

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Scaled Quail*	P																								P							
Elegant Quail*															P						P											
Gambel's Quail*		P													P	P		P						P								
Montezuma Quail		P	P	C	P	P	P	P	#	P	P	P	P	#	P	P	P		P	P	P	P	P	P	C	P		P	P	P		
Wild Turkey						P	P	P			P	P		P	P	P			P	P	C	C	P	P	P	P	P	P		P		C
Turkey Vulture*	O	P	P	O	P	O	O	O	O	O	O	O	O	O	P	P	O	O	P	O	P	O	O	P	P	P	P	P	P	P	P	O
Sharp-shinned Hawk					?						P			P		P				?		C		P	?							
Cooper's Hawk				P	C	P	C	C		P	P			P	P	P				P	C	C	P	C	P	P	#					P
Northern Goshawk					P						C			C									P		C	P		P				
Common Black-Hawk				#																					P							
Gray Hawk				P	P		P	#				P		P		P													P			
Short-tailed Hawk				P	P	C					P			P	P				P		P	P	P	P	P			P				
Swainson's Hawk*							P																		P						O	
Zone-tailed Hawk		P		P	#	P		P		P	P	P		P	P					P	P	P	P	P	C			P				
Red-tailed Hawk	P	C	P	P	P	P	P	P	P	P	P	P	P	P	C	P		P		C	P	P	P	C	P	P	P	P	P	P		
Golden Eagle*				P	#	P	P	C		P		P	P	#		P			P	P				P								
American Kestrel			P																													
Peregrine Falcon																								P	P			P				
Band-tailed Pigeon				P	O	P	P	P	P	P	P		P	P	P	P			P	P	P	P	P	P	P	P	P	P		P	P	P
Eurasian Collared-Dove*															P	P																
White-winged Dove*	P	P	P	P	P	P		#	P			P	P		P	P	P	P	P		P			O	P	P		P				
Mourning Dove	P	P		P	P	P	P	#						#	P	P	P	P	P			P	P	P	P	P		P		P		P
Inca Dove*									P																			P	P			
Common Ground-Dove*				P	#		P		#							P							P		P	P			P			
White-tipped Dove*														#								P										
Thick-billed Parrot																														P		C

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Yellow-billed Cuckoo*							P	#	P						P							P						P	P			
Greater Roadrunner	P	P		P	P	P	P	P	P	P	P	P			P	P				P			P	P	P			P				
Flammulated Owl																										P				P	P	
Western Screech-Owl	#	#		#		P												P				P	P		P	P						
Whiskered Screech-Owl		P		P	P	P	P	P	P			P	P	P	P	P				P	P	P	P	P	P	P	P	P	P	P		
Great Horned Owl						P	P	P							P	P		P						P				P				
Northern Pygmy-Owl				P	P	P	P	P	P	P	P	P	P	P	P	P				P	P	P	P	P	P		P					
Elf Owl		P		P	P		P	P						P	P	P		P				P		P				P				
Spotted Owl				P	P	P		P	P	P	P	P		P	C					P	P	P		P			P	P		P		
Northern Saw-whet Owl†																								?								
Lesser Nighthawk*		P													P																	
Common Nighthawk					#		#																	P	P			P		P		
Common Poorwill		P	P	P	P	P		#			P		P		P	P		P		P				P	P							
Buff-collared Nightjar	P	P		P		P			P								P									P			P			
Mexican Whip-poor-will	P			P	P	C	P	P		P	P		P	P	P	P				P	P	P	P	P	P	P	P	P	P	P	P	
White-throated Swift*		P		P	P	P		P	P	P	P	P	P	P	P	P	P	O		P		P	P	P		P	P	P				
Broad-billed Hummingbird	#	P	P	P	P	P	P	P	P			P		#	P	P	P	P	P	P	P	P		P	P	P	P	P	P			
White-eared Hummingbird											P										P	P					#	P	P			P
Berylline Hummingbird†																					P							P		P		P
Violet-crowned Hummingbird								P						#	P						P	P				P			P			
Blue-throated Hummingbird															P						P	P	P		P		P	P		P		
Magnificent Hummingbird										P				P	P	P				?	P	P		P	P	P	P	P		C		
Plain-capped Starthroat*															P																	
Lucifer Hummingbird*																		P														
Black-chinned Hummingbird												O		P				P							P							
Anna's Hummingbird	P	P		P			P	P		P			P		P	P				P				P								
Costa's Hummingbird*			P															P														
Broad-tailed Hummingbird					P						P	O		P		P		O		?	P	C	P	P	C		P	P	P	P	P	P
Elegant Trogon				P	P	C	P	P	P	P	P	P	P	P	P	P			P	P	P	P		P	P	P	P	P	P	P	P	P
Mountain Trogon																												P		P	P	P

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Eared Quetzal																												P				P
Acorn Woodpecker	?		P	P	P	P	P	P		P	P	P	P	P	P	P		P	P	P	C	P	P	P	P	P	P	C	P	P	C	P
Gila Woodpecker*		P							#						P		P	P			#	P				P						
Ladder-backed Woodpecker	P	P	P	P	#	P	P	P	P			P	P		P	P	P	P			P	P			P	P						
Hairy Woodpecker								P		P	P			P		P					P			P		P	P	P	C	C	P	P
Arizona Woodpecker	P	P	P	C	C	P	P	C	P	P	P	P	P	P	P	P			P	P	P	P	P	C	P	P	P	P	P	C		
Northern Flicker	P			P	C	P	P	P	P	P	P			P	P	P				P	P	C	P	P	C	P	P	C	P	P	P	P
Gilded Flicker*	P	P		C											O																	
White-striped Woodcreeper†																										P		P	P	P		
Northern Beardless-Tyrannulet*				P	#		P								P						#	P							P			
Tufted Flycatcher															?													C	P	P	C	P
Greater Pewee					P			P		P	P			C	C	P				P	P	C	P	P	P	C	C	C	C	C	C	P
Western Wood-Pewee		P	P	P	P		C	P		P	P	O		C	C	P	O			P	C	P	P	P	P	P	P	P	P	C	P	P
Pine Flycatcher																												P			P	
Cordilleran Flycatcher					?	P		P		P	P			P	?	P					P	C	P	P	P	P	P	P	P	P	C	P
Buff-breasted Flycatcher					?						P			P								C	P	P	P	P		P	P	P	P	
Black Phoebe			P	P	P			P	#					#									P						P	P		
Say's Phoebe*				P			P			P								P							C							
Vermilion Flycatcher*		P		P			C									P		P			P	P				P			P			
Dusky-capped Flycatcher	P	P	P	P	C	C	P	P	P	P	P	P	P	P	P	P			C	P	P	P	P	P	C	P	P	C	P	P	P	P
Ash-throated Flycatcher	P	P	C	P	P	P	P	P	C			P	P	P	P	P	P	C		P	P	P		P	C	P	P	P		P		
Brown-crested Flycatcher	P	P		P	P		P	P	P						P	P			P		P	P				P		P	C	P		
Sulphur-bellied Flycatcher				P	#		P	P						P	P	P					P	P		P		P	P	P	P	P		
Cassin's Kingbird	P	P	P	C	P	P	P	P		P	P	P	P	P	C	P	P		P	P	P	P	P	P	P	P	P		P	P	P	P
Thick-billed Kingbird				C											P	P					P	P				P			C			
Western Kingbird*		P		P	#		#											P							P							
Rose-throated Becard				C											P																	
Loggerhead Shrike*						P	#									P																
Bell's Vireo*	P	P	#															P														
Gray Vireo																								?								

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Plumbeous Vireo					P			P		P	P	O		C	P	P				P	P	C	O	P	P	P	P	P	P	C	P	P
Hutton's Vireo	P	P	P	C	P	P	C	C	P	P	P	P	P	P	C	P			P	P	P	C	P	P	C	P	P	C		C	P	P
Warbling Vireo†		O			O						O	O			O	O				O		O	O	O		P		P		P	P	P
Yellow-green Vireo*†																										P						
Steller's Jay				P	C	P		P		P	P	?	P	P		P				P	P	P	P	P	P	P	P	C		P	P	P
Woodhouse's Scrub-Jay							P						C						P			P		P	P							
Mexican Jay	P	P	P	P	C	P	P	P	P	P	P	P	P	P	P	P			P	P	P	P	P	P	C	P	P	C		C		
Common Raven	P	P	P	P	P	P	P	P		P	P	P	P	P	P	P	P	P	C	P	P	P	P	P	P	P	P	P	P	P	P	P
Violet-green Swallow											O	O											?	O								
Barn Swallow*				P						P							P								P				C			
Mexican Chickadee																						C	P	P	C	P	P	C		P	C	P
Bridled Titmouse	P	P	C	P	C	P	C	C	P	P	P	P	P	P	C	P			P	P	C	C	P	P	P	P	C	C	P	P		
Verdin*		P		P													P	P														
Bushtit	P	P	P	P	P	C	P	P	P	P	P	P	P	P	C	P			P	P	P	P	P	P	C	P	P	P	P	P	P	P
Red-breasted Nuthatch																																P
White-breasted Nuthatch			P	P	P	P	P	C		C	P	P		P	P	P			P	P	P	P	P	P	P	P	P	C	P	P	P	P
Pygmy Nuthatch																												P			P	P
Brown Creeper				P	P	P		C		P	P			C	P	P				P	P	P	P	P	P	P	P	P		P	P	P
Cactus Wren*		P		P			P	P	P			P			P	P	P	P			P					P	P					
Rock Wren*	P	P	P	P	P	P	P		P				P		P	P		P	P		C	P	P	P	P		P	P				
Canyon Wren*		P	P	P	P	P		P	P	P	P	P	P	C	C	P	P	P	P	P	P	P	P	P	P	P	P	P		P		
Sinaloa Wren*												P			P	P					P											
Bewick's Wren	C	P	C	P	P	P	P	P	P	P	P	P	C	P	C	C	P	P	P	P	C	P	P	P	C	P	P	P		P		P
House Wren										P	P	O		P						O			?	P		C	C	P	P	C	P	C
Blue-gray Gnatcatcher		P		P	P	P	P	P		P	P	P	P	P		P	P		P	P	P	C	P	P	P	P	P	P	P	P		P
Black-tailed Gnatcatcher*									P																							
Black-capped Gnatcatcher*		P	P												P							P										
Eastern Bluebird					P		C	C			P					P				C	C	P				C		P		P	P	
Western Bluebird																							P	P	P							
Townsend's Solitaire†					?					P	?									O		C			P		P	P	P	P	P	P

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Brown-backed Solitaire†															P							P				C	P	P	P	P		
Orange-billed Nightingale-Thrush																												P				
Russet Nightingale-Thrush																																P
Hermit Thrush†					O						O	O		C	O	O				O			O	O								
American Robin				P	P		P	P		P	P			C	P	P				P	P	P	P	P	C	P	P	C	P	C	C	C
Northern Mockingbird*	P	P	#	P			P	P	P				C		P	P	P	P	P	P		P		P	P	P	P		P			
Curve-billed Thrasher*	#	P				P	C	P	P			P			P		P	P			P	P				P			P			
Crissal Thrasher	#	P			P												P	P					P	P	P							
Phainopepla*	P	P		P			P	?								P										O		O				
Olive Warbler					P			P			P			C	P	P			?		P	P	P	P	P	C	P	C	P	P	C	P
Crescent-chested Warbler†														P							C					C	P	C		P		P
Lucy's Warbler*	#	P	#	P			P					P			C	P		P								P						
Virginia's Warbler†					O					P				P																		
Hooded Warbler																												?				
Northern Parula																												?				
Yellow-rumped Warbler†					O					?	O					O		O		O		O	O	O				P				
Grace's Warbler					P			C		P	C			P	P	P				P	P	C	P	P	P	P	C	P	P	C	P	P
Black-throated Gray Warbler				P	P		C	P		P	P	O		P		P				P	?	P	P	P	C							
Fan-tailed Warbler																										P		P				
Rufous-capped Warbler				#		P		#				P			C						P	P				P		P				
Red-faced Warbler														C								C	P	P	P	C	C	P	P	C	P	P
Painted Redstart			#	P	C	P	P	C		P	P	P		C	C	P			P	C	C	C	P	P	C	C	P	C	C	C	C	C
Slate-throated Redstart†																										P	C	P		P	P	P
Yellow-breasted Chat*																								O				P	P			
Spotted Towhee		P		P	P	P	P	C		C	P	P	P	P		C	P		P	P	C	P	P	P	C	C	P	C	P	P	P	P
Rusty Sparrow															P				P	P	C	P				P		P	P			
Rufous-crowned Sparrow	C	P	C	C	P	C	C	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	C	P	P		
Canyon Towhee	#	P	P	P	P	P	P	P	P			P	P		P	P	P	P	P		P	P		P	P				P			
Rufous-winged Sparrow*															P			P				P										

Common Name	Humo	San Juan	Esmeralda	Avispas-Cíbuta	Pinito	Madera	Chivato	Azul	Cucurpe	Mariquita	Elenita	San Antonio	San José	Ajos	Aconchi	Púrica	Cabullona	Ceniza	Carboneras	Juriquipa	Oposura	Tigre	Pan Duro	San Luis	Púlpito	Bacadéhuachi	SMO-Huachinera	SMO-Cebadilla	SMO-Pinos Altos	SMO-India	SMO-Poleo	SMO-Cinco Millas
Botteri's Sparrow*																				P												
Chipping Sparrow†					O											O								?	?					P	P	P
Black-chinned Sparrow†													P											P	P							
Lark Sparrow*							P									O								P	P							
Five-striped Sparrow	P	P	#	#				#	P						P						P	P	P			P			P			
Black-throated Sparrow*		P		P				#										C							C		P					
Yellow-eyed Junco					P			P		P	P			P		C						C	P	P	C	P	C	C	P	P	P	P
Hepatic Tanager		P	P	P	P	P	C	P	P	P	P	P	P	P	P	P	P		P	C	P	C	P	P	P	C	C	C	P	P	P	P
Summer Tanager			P	P			P	P						#	P	P					P	P		P		P		P		P		
Western Tanager†		O			O			P		?	O	O		C	O	P		O	O	O	O		O	?	O		O		O			
Flame-colored Tanager†														P														P				
Northern Cardinal*		P		P											P	P	P	P								P						
Pyrrhuloxia*		P																P														
Black-headed Grosbeak	P	C	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	C	P	P	C	P	P	P	P
Blue Grosbeak*			P	P		P	P	P	P				P	O	P	P		P	P		P	P		P	P	P	P	P	P	P		
Indigo Bunting																P												?				
Varied Bunting*	P	P	P	P		P		P	P						P	P		P	P		P	P				P	P		P			
Bronzed Cowbird*				P			P								P	P					P	P							P			
Brown-headed Cowbird	P	P		P	P	P	C	P	P	P					P	P	P	P		P	P	P	P	P	P	P	P		P	P		
Black-vented Oriole															P														P			
Hooded Oriole			P	P	P		P	P	#			P			P		P	P			P	C	O	P								
Scott's Oriole	P	P	P	P	P	C	P	P	P	P	P	P	P	P	C	P	P	P	P	P	P	P	P	P	P	P	P	P	P			
House Finch*	P	P	P	P	P	P	P	P	P	P		P	C	P		P	P	P		P	P		P	P	P	P	P			P		
Red Crossbill																?						O										
Pine Siskin					O						?					O							O	O								
Black-headed Siskin																												P				
Lesser Goldfinch	P	P	P	P	P		P	#		P				#	P					P	P	P		P	P	P		P	P	P		

Appendix S1: Details on important observations of birds in the study region including location, date, behavior, habitat, and elevation.

Eight species classified as possible breeders in the Sky Islands: **Northern Saw-whet Owl**, San Luis, 3 June 2011, at 1,780 m; **Tufted Flycatcher**, Aconchi, 3 June 2012, calling at 1,800 m; **Gray Vireo**, San Luis, 14 May 2011, singing at 1,810 m; **Violet-green Swallow**, Pan Duro, 22 May 2011, calling at 2,060 m; **Yellow-rumped Warbler** (Audubon's Warbler), Mariquita, 27 June 2009, singing at 2,440 m; **Chipping Sparrow**, San Luis, 17 May 2011, 1,780 m, and Púlpito, 11 June 2012, 1,740 m; **Pine Siskin**, Elenita, 6 May 2011, pair courting at 2,340 m; **Red Crossbill** (Púrica, 24 May 2012, at 2,400 m).

Three species classified as possible breeders in the Sierra Madre: **Northern Parula**, Cebadilla, 15 June 2012, singing in riparian forest at 1,470 m; **Hooded Warbler**, Cebadilla, 16 June 2012, singing in riparian forest at 1,890 m; **Indigo Bunting**, Cebadilla, 15 June 2012, 2 in riparian vegetation at 1,420-1,470 m.

Three species that had been detected only once in the Sky Islands region in potential breeding habitat during the breeding season: **Tufted Flycatcher**, Aconchi, 3 June 2012, in riparian woodland at 1,800 m; **Gray Vireo**, San Luis, 14 May 2011, singing in mountain scrub at 1,810 m; **Pine Siskin**, Elenita, 6 May 2011, singing male courting female in meadow in pine forest at 2,290 m.

Species documented for the first time in the Sky Islands of Mexico that have strong Madrean affinities: **Berylline Hummingbird**, Oposura, 11 July 2009, one in pine-oak woodland at 2,010 m; **White-striped Woodcreeper**, Bacadéhuachi, 27-29 June 2012, 10 calling or paired in oak, oak-pine, and pine-oak woodland at 1,600-1,810 m; **Yellow-green Vireo**, Bacadéhuachi, 29 June 2012, singing in oak-riparian woodland at 1,620 m; **Slate-throated Redstart**, Bacadéhuachi, 28 June 2012, pair in pine-oak woodland at 2,100 m, **Brown-backed Solitaire**, Aconchi, 4 June 2012, 1-2 singing in pine-oak woodland at 1,920 m, Bacadéhuachi, 29 June 2012, 4 singing and nest with 3 young in pine-oak and riparian woodland in canyon at 1,620-1,820, first nest for Sonora, Tigre, 26-29 June 2010, 3 singing in pine-oak woodland in canyon at 1,880-1,970 m; **Crescent-chested Warbler**, Oposura, 7 July 2009, singing male with female building nest in oak woodland at 1,980 m, Bacadéhuachi, 28 June 2012, 5 singing, paired, or carrying food in pine-oak woodland at 2,090-2,160 m, Ajos,15 June 2010, pair in riparian and pine-oak woodland at 2,160 m; **Flame-colored Tanager**, Ajos, 14-17 June 2010, singing male and pair in riparian forest and mixed-conifer forest or pine-oak woodland at 2,010-2,160 m).

Species documented for the first time in the Sky Islands of Mexico that have strong Nearctic affinities: **Black-chinned Sparrow**, San Luis, 13 May 2011, 1 singing in mountain scrub at 1,420 m, 6 July 2012, 4 singing in mountain scrub at 1,700-1,820 m, San José, 7 July 2010, 1 in mountain scrub at 1,800 m, Púlpito, 10 June 2012, 1 singing in mountain scrub at 1,800 m; **Virginia's Warbler**, Ajos, 14 June 2010, 1 singing in pine-oak woodland associated with dense deciduous brush at 2,080 m, Mariquita, 29 June 2009, one in riparian woodland adjacent to dense deciduous brush of New Mexican locust at 2,100 m; **Hermit Thrush**, Ajos, 14-17 June 2010, 10 individuals or pairs singing, paired, and carrying food in mixed-conifer forest and riparian areas at 2,120-2,370 m; **Townsend Solitaire**, Tigre, 26-28 June 2010, 9 territories including nest with young in pine forest and pine-oak woodland at 2,190-2,400 m, first nest for Sonora, Mariquita, 27 June 2009, 1 singing in pine-oak woodland at 2,130, Púlpito, 12 June 2012, 1 calling in pine-oak woodland at 2,310; **Yellow-rumped Warbler** (Audubon's Warbler), Mariquita, 27 June 2009, 1-2 singing in tall pine forest at 2,440 m); **Western Tanager**, Ajos, 14-17 June 2010, 10 territories indicted by singing, paired, and carrying food in mixed-conifer forest and pine-oak woodland at 2,100-2,450 m, other observations that suggest breeding include Sierra Azul, 31 May-1 June 2010, 5 males singing in pine forest or adjacent pine-oak woodland including 3 that sang for >1 hour and were present on the same territories later in the day at 2,100-2,390 m, Sierra Púrica, 24-25 May 2012, 5 males including 1 paired and singing in pine forest and pine-oak woodland at 2,080-2,260 m, Sierra San Luis, 4 June 2012, pair in pine-oak woodland in the at 1,970, and Mariquita, 26 June 2009, male calling in pine-aspen forest at 2,380; **Warbling Vireo**, Bacadéhuachi, 25-26 June 2012, one singing in montane riparian woodland and adjacent pine-oak woodland at 1,810 and 2,260 m; **Northern Saw-whet Owl**, San Luis, 3 June 2011, 1 in canyon forest of pine and cypress at 1,780 m, first record in potential breeding habitat and second record for Sonora.

Species that had not been documented or that had been observed few times in areas I surveyed in the Sierra Madre Occidental: **Mountain Trogon**, Cebadilla, 16-17 June 2012, 3 singing in pine-oak woodland and pine and mixed-conifer forest at 2,250-2,550 m, Cerro de la India, 19 June 2012, 9 singing in pine-oak woodland and riparian areas at 2,110-2,470 m, El Poleo, Chihuahua, 20 June 2012, 8 pine-oak woodland and pine forest at 2,170-2,320 m, Cinco Millas, Chihuahua, 21-23 June 2012, 15 singing in pine-oak woodland and pine and mixed-conifer forest at 2,300-2,760 m; **Eared Quetzal**, Cebadilla, 15 June 2012, 1 calling in montane riparian forest and pine-oak woodland on the north face at 1650 m, only the fifth record in potential breeding habitat in Sonora and first since 1995; **Thick-billed Parrot**, Cerro de la India, 19 June 2012, 4-5 individuals over pine-oak woodland at 2,070 m, fifth record in Sonora since 1954; **Tufted Flycatcher**, Cebadilla, 15 June 2012, constructing nest in tall montane riparian forest at 1,570 m, northernmost record in Sonora; **Slate-throated Redstart**, Huachinera, 14 June 2012, pair feeding 2 fledglings in pine forest at 2,210 m, first breeding record for Sonora.

Table S4: Common and scientific names of bird species. Ten species that breed only at higher elevations in Sky Islands in the adjacent USA but not in Mexico are noted with a dagger (†). Three species observed recently in this study region in Mexico but not during the study are noted with a double dagger (‡). Four species with more Neotropical affinities that may breed locally at the southern end of the region I considered but that were not detected are indicated by an asterisk (*)

Common Name	Scientific Name
Scaled Quail	*Callipepla squamata*
Elegant Quail	*Callipepla douglasii*
Gambel's Quail	*Callipepla gambelii*
Montezuma Quail	*Cyrtonyx montezumae*
Wild Turkey	*Meleagris gallopavo*
Turkey Vulture	*Cathartes aura*
Sharp-shinned Hawk	*Accipiter striatus*
Cooper's Hawk	*Accipiter cooperii*
Northern Goshawk	*Accipiter gentilis*
Common Black-Hawk	*Buteogallus anthracinus*
Gray Hawk	*Buteo nitidus*
Short-tailed Hawk	*Buteo brachyurus*
Swainson's Hawk	*Buteo swainsoni*
Zone-tailed Hawk	*Buteo albonotatus*
Red-tailed Hawk	*Buteo jamaicensis*
Golden Eagle	*Aquila chrysaetos*
American Kestrel	*Falco sparverius*
Peregrine Falcon	*Falco peregrinus*
Prairie Falcon‡	*Falco mexicanus*
Band-tailed Pigeon	*Patagioenas fasciata*
Eurasian Collared-Dove	*Streptopelia decaocto*
White-winged Dove	*Zenaida asiatica*
Mourning Dove	*Zenaida macroura*
Inca Dove	*Columbina inca*
Common Ground-Dove	*Columbina passerina*
White-tipped Dove	*Leptotila verreauxi*
Thick-billed Parrot	*Rhynchopsitta pachyrhyncha*
Yellow-billed Cuckoo	*Coccyzus americanus*
Greater Roadrunner	*Geococcyx californianus*
Flammulated Owl	*Psiloscops flammeolus*
Western Screech-Owl	*Megascops kennicottii*
Whiskered Screech-Owl	*Megascops trichopsis*
Great Horned Owl	*Bubo virginianus*
Northern Pygmy-Owl	*Glaucidium gnoma*
Elf Owl	*Micrathene whitneyi*
Spotted Owl	*Strix occidentalis*
Northern Saw-whet Owl	*Aegolius acadicus*
Lesser Nighthawk	*Chordeiles acutipennis*
Common Nighthawk	*Chordeiles minor*
Common Poorwill	*Phalaenoptilus nuttallii*
Buff-collared Nightjar	*Caprimulgus ridgwayi*
Mexican Whip-poor-will	*Caprimulgus arizonae*
White-throated Swift	*Aeronautes saxatalis*
Broad-billed Hummingbird	*Cynanthus latirostris*

White-eared Hummingbird	*Hylocharis leucotis*
Berylline Hummingbird	*Amazilia beryllina*
Violet-crowned Hummingbird	*Amazilia violiceps*
Blue-throated Hummingbird	*Lampornis clemenciae*
Magnificent Hummingbird	*Eugenes fulgens*
Plain-capped Starthroat	*Heliomaster constantii*
Lucifer Hummingbird	*Calothorax lucifer*
Black-chinned Hummingbird	*Archilochus alexandri*
Anna's Hummingbird	*Calypte anna*
Costa's Hummingbird	*Calypte costae*
Broad-tailed Hummingbird	*Selasphorus platycercus*
Elegant Trogon	*Trogon elegans*
Mountain Trogon	*Trogon mexicanus*
Eared Quetzal	*Euptilotis neoxenus*
Acorn Woodpecker	*Melanerpes formicivorus*
Gila Woodpecker	*Melanerpes uropygialis*
Ladder-backed Woodpecker	*Picoides scalaris*
Hairy Woodpecker	*Picoides villosus*
Arizona Woodpecker	*Picoides arizonae*
Northern Flicker	*Colaptes auratus*
Gilded Flicker	*Colaptes chrysoides*
White-striped Woodcreeper	*Lepidocolaptes leucogaster*
Northern Beardless-Tyrannulet	*Camptostoma imberbe*
Tufted Flycatcher	*Mitrephanes phaeocercus*
Greater Pewee	*Contopus pertinax*
Western Wood-Pewee	*Contopus sordidulus*
Gray Flycatcher†	*Empidonax wrightii*
Pine Flycatcher	*Empidonax affinis*
Cordilleran Flycatcher	*Empidonax occidentalis*
Buff-breasted Flycatcher	*Empidonax fulvifrons*
Black Phoebe	*Sayornis nigricans*
Say's Phoebe	*Sayornis saya*
Vermilion Flycatcher	*Pyrocephalus rubinus*
Dusky-capped Flycatcher	*Myiarchus tuberculifer*
Ash-throated Flycatcher	*Myiarchus cinerascens*
Brown-crested Flycatcher	*Myiarchus tyrannulus*
Sulphur-bellied Flycatcher	*Myiodynastes luteiventris*
Cassin's Kingbird	*Tyrannus vociferans*
Thick-billed Kingbird	*Tyrannus crassirostris*
Western Kingbird	*Tyrannus verticalis*
Gray-collared Becard*	*Pachyramphus major*
Rose-throated Becard	*Pachyramphus aglaiae*
Loggerhead Shrike	*Lanius ludovicianus*
Bell's Vireo	*Vireo bellii*
Gray Vireo	*Vireo vicinior*
Plumbeous Vireo	*Vireo plumbeus*
Hutton's Vireo	*Vireo huttoni*
Warbling Vireo	*Vireo gilvus*
Yellow-green Vireo	*Vireo flavoviridis*
Steller's Jay	*Cyanocitta stelleri*

Woodhouse's Scrub-Jay	*Aphelocoma woodhouseii*
Mexican Jay	*Aphelocoma wollweberi*
Common Raven	*Corvus corax*
Purple Martin‡	*Progne subis*
Violet-green Swallow	*Tachycineta thalassina*
Barn Swallow	*Hirundo rustica*
Mountain Chickadee†	*Poecile gambeli*
Mexican Chickadee	*Poecile sclateri*
Bridled Titmouse	*Baeolophus wollweberi*
Juniper Titmouse†	*Baeolophus ridgwayi*
Verdin	*Auriparus flaviceps*
Bushtit	*Psaltriparus minimus*
Red-breasted Nuthatch	*Sitta canadensis*
White-breasted Nuthatch	*Sitta carolinensis*
Pygmy Nuthatch	*Sitta pygmaea*
Brown Creeper	*Certhia americana*
Cactus Wren	*Campylorhynchus brunneicapillus*
Rock Wren	*Salpinctes obsoletus*
Canyon Wren	*Catherpes mexicanus*
Sinaloa Wren	*Thryothorus sinaloa*
Bewick's Wren	*Thryomanes bewickii*
House Wren	*Troglodytes aedon*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Black-tailed Gnatcatcher	*Polioptila melanura*
Black-capped Gnatcatcher	*Polioptila nigriceps*
American Dipper†	*Cinclus mexicanus*
Golden-crowned Kinglet†	*Regulus satrapa*
Ruby-crowned Kinglet†	*Regulus calendula*
Eastern Bluebird	*Sialia sialis*
Western Bluebird	*Sialia mexicana*
Townsend's Solitaire	*Myadestes townsendi*
Brown-backed Solitaire	*Myadestes occidentalis*
Orange-billed Nightingale-Thrush	*Catharus aurantiirostris*
Russet Nightingale-Thrush	*Catharus occidentalis*
Hermit Thrush	*Catharus guttatus*
American Robin	*Turdus migratorius*
Aztec Thrush*	*Ridgwayia pinicola*
Northern Mockingbird	*Mimus polyglottos*
Curve-billed Thrasher	*Toxostoma curvirostre*
Crissal Thrasher	*Toxostoma crissale*
Phainopepla	*Phainopepla nitens*
Gray Silky-flycatcher*	*Ptilogonys cinereus*
Olive Warbler	*Peucedramus taeniatus*
Crescent-chested Warbler	*Oreothlypis superciliosa*
Orange-crowned Warbler†	*Oreothlypis celata*
Lucy's Warbler	*Oreothlypis luciae*
Virginia's Warbler	*Oreothlypis virginiae*
MacGillivray's Warbler†	*Geothlypis tolmiei*
Hooded Warbler	*Setophaga citrina*
Northern Parula	*Setophaga americana*

Yellow-rumped Warbler	*Setophaga coronata auduboni*
Grace's Warbler	*Setophaga graciae*
Black-throated Gray Warbler	*Setophaga nigrescens*
Fan-tailed Warbler	*Basileuterus lachrymosus*
Rufous-capped Warbler	*Basileuterus rufifrons*
Red-faced Warbler	*Cardellina rubrifrons*
Painted Redstart	*Myioborus pictus*
Slate-throated Redstart	*Myioborus miniatus*
Yellow-breasted Chat	*Icteria virens*
Spotted Towhee	*Pipilo maculatus*
Rusty Sparrow	*Aimophila rufescens*
Rufous-crowned Sparrow	*Aimophila ruficeps*
Canyon Towhee	*Melozone fusca*
Rufous-winged Sparrow	*Peucaea carpalis*
Botteri's Sparrow	*Peucaea botterii*
Striped Sparrow‡	*Oriturus superciliosus*
Chipping Sparrow	*Spizella passerina*
Black-chinned Sparrow	*Spizella atrogularis*
Lark Sparrow	*Chondestes grammacus*
Five-striped Sparrow	*Amphispiza quinquestriata*
Black-throated Sparrow	*Amphispiza bilineata*
Yellow-eyed Junco	*Junco phaeonotus*
Hepatic Tanager	*Piranga flava*
Summer Tanager	*Piranga rubra*
Western Tanager	*Piranga ludoviciana*
Flame-colored Tanager	*Piranga bidentata*
Northern Cardinal	*Cardinalis cardinalis*
Pyrrhuloxia	*Cardinalis sinuatus*
Black-headed Grosbeak	*Pheucticus melanocephalus*
Blue Grosbeak	*Passerina caerulea*
Lazuli Bunting†	*Passerina amoena*
Indigo Bunting	*Passerina cyanea*
Varied Bunting	*Passerina versicolor*
Bronzed Cowbird	*Molothrus aeneus*
Brown-headed Cowbird	*Molothrus ater*
Black-vented Oriole	*Icterus wagleri*
Hooded Oriole	*Icterus cucullatus*
Scott's Oriole	*Icterus parisorum*
Elegant Euphonia*	*Euphonia elegantissima*
House Finch	*Carpodacus mexicanus*
Red Crossbill	*Loxia curvirostra*
Pine Siskin	*Spinus pinus*
Black-headed Siskin	*Spinus notatus*
Lesser Goldfinch	*Spinus psaltria*
Evening Grosbeak†	*Coccothraustes vespertinus*

Table S5: Results of non-metric multidimensional scaling and blocked indicator species analysis of historical and recent breeding bird communities in 11 mountain ranges in the early 1950s and from 2009-2012 in the Sky Islands and adjacent Sierra Madre Occidental of northwest Mexico. Pearson correlation coefficients (*r*) are correlations between ordination axes and species occurrence data. Habitat and biogeographical affinities note groupings used to interpret results with colors corresponding to habitat groups depicted in Figures 2 and 4 in the main text. Group of max. association notes the time period (1-historic, 2-recent) most associated with occurrence of each species and the associated *P*-value from blocked indicator species analyses. Species are ordered taxonomically within each of 10 habitat affinity groups.

Code	Common name	Axis 1	Axis 2	Axis 3	r_1	r_2	r_3	Habitat affinity	Biogeographic affinity	Group of max. association	Indicator value (%)	*P*
ELQU	Elegant Quail	-0.10	0.62	-0.68	-0.06	0.28	-0.41	Lowlands	Neotropical	2	18	0.50
WWDO	White-winged Dove	-0.17	-0.11	-0.33	-0.35	-0.15	-0.63	Lowlands	Neotropical	1	44	0.38
YBCU	Yellow-billed Cuckoo	0.06	0.80	-0.39	0.06	0.54	-0.35	Lowlands	Neotropical	2	21	0.63
GRRO	Greater Roadrunner	0.07	-0.13	-0.15	0.18	-0.22	-0.36	Lowlands	Neotropical	1	35	1.00
WESO	Western Screech-Owl	0.18	-0.15	-0.25	0.22	-0.13	-0.29	Lowlands	Nearctic	1	24	0.69
ELOW	Elf Owl	0.10	0.10	-0.13	0.21	0.15	-0.26	Lowlands	Neotropical	2	31	1.00
COPO	Common Poorwill	0.12	-0.32	-0.06	0.30	-0.55	-0.15	Lowlands	Nearctic	1	50	0.24
BBIH	Broad-billed Hummingbird	-0.03	0.15	-0.13	-0.10	0.31	-0.36	Lowlands	Neotropical	2	53	0.38
PCST	Plain-capped Starthroat	-0.12	0.59	-1.03	-0.05	0.18	-0.43	Lowlands	Neotropical	2	9	1.00
ATFL	Ash-throated Flycatcher	0.00	-0.03	-0.09	0.02	-0.08	-0.37	Lowlands	Nearctic	2	41	1.00
TBKI	Thick-billed Kingbird	-0.27	0.65	-0.41	-0.34	0.57	-0.48	Lowlands	Neotropical	2	27	0.50
SIWR	Sinaloa Wren	-0.10	0.62	-0.68	-0.06	0.28	-0.41	Lowlands	Neotropical	2	18	0.50
CBTH	Curve-billed Thrasher	-0.10	0.11	-0.22	-0.23	0.17	-0.46	Lowlands	Neotropical	1	39	0.69
RCWA	Rufous-capped Warbler	0.02	0.63	-0.53	0.02	0.36	-0.40	Lowlands	Neotropical	2	27	0.25
RWSP	Rufous-winged Sparrow	0.07	0.62	-0.62	0.05	0.28	-0.37	Lowlands	Neotropical	2	18	0.51
GOEA	Golden Eagle	0.26	-0.13	-0.05	0.33	-0.12	-0.06	Lowlands, Cliffs	Nearctic	2	14	1.00
PEFA	Peregrine Falcon	0.65	-0.05	-0.07	0.42	-0.02	-0.04	Lowlands, Cliffs	Americas	2	18	0.51
PRFA	Prairie Falcon	0.48	-0.46	0.50	0.22	-0.14	0.21	Lowlands, Cliffs	Nearctic	1	9	1.00
ROWR	Rock Wren	0.13	0.00	-0.20	0.24	0.01	-0.35	Lowlands, Cliffs	Nearctic	2	48	0.23
CANW	Canyon Wren	0.08	-0.04	-0.02	0.43	-0.16	-0.12	Lowlands, Cliffs	Nearctic	2	50	1.00
CONI	Common Nighthawk	0.07	-0.04	-0.05	0.10	-0.04	-0.06	Lowlands, Openings	Nearctic	1	34	0.38
WEKI	Western Kingbird	0.79	-0.17	-0.02	0.36	-0.05	-0.01	Lowlands, Openings	Nearctic	2	9	1.00
CANT	Canyon Towhee	-0.08	-0.05	-0.08	-0.40	-0.17	-0.39	Lowlands, Openings	Nearctic	1	64	0.25
CHSP	Chipping Sparrow	0.33	0.08	-0.37	0.15	0.02	-0.16	Lowlands, Openings	Nearctic	1	9	1.00
COHA	Cooper's Hawk	0.23	0.07	-0.04	0.63	0.13	-0.11	Riparian	Nearctic	2	57	0.24
COBH	Common Black-Hawk	0.64	-0.31	0.24	0.42	-0.14	0.15	Riparian	Neotropical	2	5	1.00

GRHA	Gray Hawk	0.32	0.70	0.02	0.26	0.39	0.01	Riparian	Neotropical	2	27	0.25
VCHU	Violet-crowned Hummingbird	-0.02	0.77	-0.36	-0.02	0.60	-0.38	Riparian	Madrean	2	46	0.07
BTHH	Blue-throated Hummingbird	-0.09	0.21	0.15	-0.17	0.27	0.26	Riparian	Madrean	2	23	1.00
BCHU	Black-chinned Hummingbird	0.60	-0.04	0.15	0.59	-0.03	0.13	Riparian	Nearctic	2	9	1.00
NOBT	Northern Beardless-Tyrannulet	-0.03	1.05	-0.39	-0.02	0.59	-0.30	Riparian	Neotropical	2	27	0.26
TUFL	Tufted Flycatcher	-0.63	1.19	0.00	-0.41	0.54	0.00	Riparian	Madrean	2	5	1.00
WEWP	Western Wood-Pewee	0.01	0.02	-0.05	0.10	0.15	-0.44	Riparian	Nearctic	2	55	1.00
BLPH	Black Phoebe	0.13	0.46	-0.27	0.13	0.31	-0.25	Riparian	Neotropical	2	21	0.63
BCFL	Brown-crested Flycatcher	-0.12	0.33	-0.41	-0.24	0.42	-0.72	Riparian	Neotropical	2	35	0.62
SBFL	Sulphur-bellied Flycatcher	-0.05	0.28	-0.08	-0.15	0.59	-0.22	Riparian	Neotropical	2	40	1.00
RTBE	Rose-throated Becard	-0.26	0.11	-0.95	-0.17	0.05	-0.57	Riparian	Neotropical	2	5	1.00
BBSO	Brown-backed Solitaire	-0.01	0.90	-0.15	-0.01	0.61	-0.14	Riparian	Neotropical	2	36	0.13
SUTA	Summer Tanager	0.08	0.25	-0.46	0.11	0.24	-0.60	Riparian	Nearctic	2	34	0.38
BVOR	Black-vented Oriole	-0.56	0.80	-0.15	-0.54	0.54	-0.14	Riparian	Neotropical	2	9	1.00
HOOR	Hooded Oriole	0.19	0.27	-0.40	0.27	0.27	-0.53	Riparian	Neotropical	2	47	0.13
LEGO	Lesser Goldfinch	-0.04	0.21	-0.17	-0.11	0.40	-0.44	Riparian	Nearctic	2	32	1.00
WESJ	Woodhouse’s Scrub-Jay	0.43	-0.22	-0.08	0.48	-0.17	-0.09	Mountain scrub	Nearctic	2	17	1.00
CRTH	Crissal Thrasher	0.44	-0.37	-0.29	0.43	-0.25	-0.27	Mountain scrub	Nearctic	2	21	0.64
SPTO	Spotted Towhee	0.03	-0.01	0.09	0.17	-0.05	0.57	Mountain scrub	Nearctic	2	46	1.00
BCSP	Black-chinned Sparrow	0.65	-0.05	-0.07	0.42	-0.02	-0.04	Mountain scrub	Nearctic	2	18	0.51
MONQ	Montezuma Quail	-0.04	-0.04	-0.05	-0.29	-0.20	-0.32	Oaks	Madrean	1	59	0.50
RTHA	Red-tailed Hawk	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Nearctic	2	50	1.00
BTPI	Band-tailed Pigeon	-0.01	-0.08	0.02	-0.04	-0.38	0.13	Oaks	Americas	1	59	0.50
WHSO	Whiskered Screech-Owl	0.03	0.07	-0.07	0.16	0.24	-0.35	Oaks	Madrean	2	50	1.00
NOPO	Northern Pygmy-Owl	0.01	-0.09	0.00	0.10	-0.59	-0.02	Oaks	Nearctic	1	55	1.00
ELTR	Elegant Trogon	0.01	0.14	0.00	0.06	0.62	0.03	Oaks	Madrean	2	59	0.50
ACWO	Acorn Woodpecker	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Americas	2	50	1.00
ARWO	Arizona Woodpecker	-0.01	0.06	0.03	-0.05	0.37	0.24	Oaks	Madrean	2	55	1.00
DCFL	Dusky-capped Flycatcher	0.01	0.07	-0.02	0.14	0.48	-0.20	Oaks	Neotropical	2	55	1.00
CAKI	Cassin's Kingbird	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Nearctic	2	50	1.00
HUVI	Hutton's Vireo	0.06	-0.12	0.00	0.41	-0.54	0.00	Oaks	Nearctic	2	46	1.00
MEJA	Mexican Jay	0.01	-0.09	0.00	0.10	-0.59	-0.02	Oaks	Madrean	1	55	1.00
BRTI	Bridled Titmouse	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Madrean	2	50	1.00
BUSH	Bushtit	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Nearctic	2	50	1.00

BEWR	Bewick's Wren	0.01	-0.09	0.00	0.10	-0.59	-0.02	Oaks	Nearctic	1	55	1.00
PARE	Painted Redstart	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Madrean	2	50	1.00
RCSP	Rufous-crowned Sparrow	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Nearctic	2	50	1.00
HETA	Hepatic Tanager	0.00	0.00	0.00	0.00	0.00	0.00	Oaks	Madrean	2	50	1.00
BHGR	Black-headed Grosbeak	0.04	-0.01	-0.02	0.39	-0.08	-0.18	Oaks	Nearctic	2	55	1.00
SCOR	Scott's Oriole	0.01	0.02	-0.05	0.10	0.15	-0.44	Oaks	Neotropical	2	55	1.00
STHA	Short-tailed Hawk	0.39	0.25	-0.15	0.61	0.27	-0.22	Pines	Neotropical	2	73	0.01
HAWO	Hairy Woodpecker	0.02	0.19	0.19	0.04	0.33	0.43	Pines	Nearctic	2	36	1.00
BBFL	Buff-breasted Flycatcher	0.31	0.08	0.13	0.65	0.11	0.25	Pines	Madrean	2	44	0.38
PLVI	Plumbeous Vireo	0.11	0.09	-0.07	0.50	0.26	-0.27	Pines	Nearctic	2	68	0.13
STJA	Steller's Jay	0.02	-0.12	0.05	0.11	-0.56	0.30	Pines	Nearctic	1	59	0.51
EABL	Eastern Bluebird	-0.03	-0.17	-0.12	-0.06	-0.24	-0.22	Pines	Madrean	1	30	1.00
TOSO	Townsend's Solitaire	0.15	0.59	0.20	0.16	0.45	0.21	Pines	Nearctic	2	32	0.24
OLWA	Olive Warbler	0.04	0.25	0.01	0.15	0.66	0.05	Pines	Madrean	2	73	0.07
GRWA	Grace's Warbler	0.09	0.36	-0.02	0.27	0.75	-0.06	Pines	Madrean	2	82	0.02
YEJU	Yellow-eyed Junco	0.08	-0.06	0.10	0.35	-0.19	0.41	Pines	Madrean	2	41	1.00
AMKE	American Kestrel	-0.12	-0.49	0.23	-0.17	-0.48	0.30	Cavities	Americas	1	64	0.02
TBPA	Thick-billed Parrot	-0.68	0.27	0.32	-0.56	0.15	0.25	Cavities	Madrean	1	27	0.25
FLOW	Flammulated Owl	0.11	-0.20	0.45	0.11	-0.13	0.41	Cavities	Nearctic	1	36	0.12
EAQU	Eared Quetzal	-1.04	0.49	-0.06	-0.47	0.15	-0.03	Cavities	Madrean	1	9	1.00
PUMA	Purple Martin	-0.59	0.28	0.27	-0.39	0.13	0.17	Cavities	Nearctic	1	18	0.51
VGSW	Violet-green Swallow	-0.58	-0.66	0.45	-0.38	-0.30	0.28	Cavities	Nearctic	1	18	0.50
PYNU	Pygmy Nuthatch	-0.30	-0.22	0.46	-0.34	-0.17	0.48	Cavities	Nearctic	1	46	0.06
WEBL	Western Bluebird	0.37	-0.53	0.21	0.36	-0.35	0.19	Cavities	Nearctic	2	9	1.00
WITU	Wild Turkey	0.21	0.21	0.05	0.52	0.36	0.12	Forest	Nearctic	2	64	0.06
SSHA	Sharp-shinned Hawk	0.50	0.13	0.13	0.63	0.11	0.15	Forest	Nearctic	2	27	0.51
NOGO	Northern Goshawk	0.58	0.03	0.02	0.65	0.02	0.02	Forest	Nearctic	2	32	0.26
ZTHA	Zone-tailed Hawk	0.03	0.10	0.12	0.09	0.20	0.31	Forest	Neotropical	2	44	0.69
SPOW	Spotted Owl	0.06	0.06	-0.06	0.19	0.15	-0.18	Forest	Nearctic	2	50	0.51
MAHU	Magnificent Hummingbird	0.00	0.05	0.07	0.01	0.10	0.21	Forest	Madrean	1	41	1.00
BTAH	Broad-tailed Hummingbird	0.13	0.18	0.23	0.34	0.34	0.58	Forest	Nearctic	2	57	0.22
NOFL	Northern Flicker	0.01	0.08	0.07	0.09	0.35	0.44	Forest	Nearctic	2	59	0.49
WSWO	White-striped Woodcreeper	-0.63	1.19	0.00	-0.41	0.54	0.00	Forest	Madrean	2	5	1.00
GRPE	Greater Pewee	0.01	0.08	-0.06	0.04	0.29	-0.27	Forest	Madrean	2	64	0.25

COFL	Cordilleran Flycatcher	0.31	0.39	0.01	0.59	0.51	0.02	Forest	Nearctic	2	91	0.00
MECH	Mexican Chickadee	0.04	-0.10	0.31	0.07	-0.12	0.50	Forest	Madrean	1	27	1.00
WBNU	White-breasted Nuthatch	0.01	0.08	-0.02	0.04	0.38	-0.15	Forest	Nearctic	2	59	0.51
BRCR	Brown Creeper	0.01	-0.09	0.00	0.10	-0.59	-0.02	Forest	Nearctic	1	55	1.00
HOWR	House Wren	-0.04	0.17	0.15	-0.08	0.24	0.30	Forest	Nearctic	1	31	1.00
AMRO	American Robin	0.07	0.17	-0.01	0.33	0.51	-0.04	Forest	Nearctic	2	68	0.12
WEHU	White-eared Hummingbird	-0.10	0.44	0.29	-0.14	0.43	0.39	Mixed-conifer forest	Madrean	2	22	1.00
BEHU	Berylline Hummingbird	-0.11	0.37	0.14	-0.07	0.17	0.08	Mixed-conifer forest	Madrean	2	5	1.00
HETH	Hermit Thrush	0.82	0.39	0.47	0.37	0.12	0.20	Mixed-conifer forest	Nearctic	2	9	1.00
CCWA	Crescent-chested Warbler	0.27	0.51	0.23	0.22	0.29	0.18	Mixed-conifer forest	Madrean	2	27	0.25
WETA	Western Tanager	0.82	0.39	0.47	0.37	0.12	0.20	Mixed-conifer forest	Nearctic	2	9	1.00
FCTA	Flame-colored Tanager	0.82	0.39	0.47	0.37	0.12	0.20	Mixed-conifer forest	Madrean	2	9	1.00
RECR	Red Crossbill	-1.04	0.49	-0.06	-0.47	0.15	-0.03	Mixed-conifer forest	Nearctic	1	9	1.00
BHSI	Black-headed Siskin	-0.15	0.08	0.61	-0.07	0.02	0.26	Mixed-conifer forest	Madrean	1	9	1.00
WAVI	Warbling Vireo	-0.59	0.28	0.27	-0.39	0.13	0.17	Deciduous in MCF	Nearctic	1	18	0.51
VIWA	Virginia's Warbler	0.82	0.39	0.47	0.37	0.12	0.20	Deciduous in MCF	Nearctic	2	9	1.00
RFWA	Red-faced Warbler	0.26	0.25	0.25	0.50	0.33	0.45	Deciduous in MCF	Madrean	2	36	0.49
STRE	Slate-throated Redstart	0.05	0.48	0.57	0.03	0.15	0.24	Deciduous in MCF	Madrean	2	9	1.00
TUVU	Turkey Vulture	0.00	0.00	0.00	0.00	0.00	0.00	Generalist	Americas	2	50	1.00
MODO	Mourning Dove	0.07	-0.19	-0.15	0.16	-0.29	-0.31	Generalist	Nearctic	1	39	0.69
GHOW	Great Horned Owl	-0.08	-0.19	-0.12	-0.16	-0.24	-0.20	Generalist	Americas	1	48	0.22
MWPW	Mexican Whip-poor-will	0.00	0.00	0.00	0.00	0.00	0.00	Generalist	Madrean	2	50	1.00
WTSW	White-throated Swift	0.11	-0.16	0.03	0.38	-0.36	0.09	Generalist	Nearctic	2	36	1.00
ANHU	Anna's Hummingbird	0.15	0.25	-0.48	0.12	0.14	-0.36	Generalist	Nearctic	2	27	0.26
CORA	Common Raven	0.03	0.03	-0.01	0.26	0.22	-0.09	Generalist	Nearctic	2	55	1.00
JUTI	Juniper Titmouse	0.48	-0.46	0.50	0.22	-0.14	0.21	Generalist	Nearctic	1	9	1.00
BGGN	Blue-gray Gnatcatcher	0.17	0.24	0.12	0.51	0.50	0.35	Generalist	Nearctic	2	68	0.07
NOPA	Northern Parula	0.33	0.08	-0.37	0.15	0.02	-0.16	Generalist	Nearctic	1	9	1.00
BTYW	Black-throated Gray Warbler	0.36	-0.12	-0.10	0.74	-0.17	-0.19	Generalist	Nearctic	2	46	0.24
RUSP	Rusty Sparrow	-0.33	0.53	-0.18	-0.51	0.57	-0.26	Generalist	Madrean	2	18	1.00
BHCO	Brown-headed Cowbird	0.02	0.18	-0.30	0.04	0.33	-0.77	Generalist	Nearctic	2	56	0.28
HOFI	House Finch	0.21	-0.06	-0.09	0.44	-0.08	-0.17	Generalist	Nearctic	2	41	0.52
EUCD	Eurasian Collared-Dove	-0.12	0.59	-1.03	-0.05	0.18	-0.43	Urban	Exotic	2	9	1.00

Table S6: Observed breeding species richness as described by Marshall (1957) and found during the study (2009-2012) in 9 Sky Islands and 2 areas of the adjacent Sierra Madre Occidental in Sonora and Chihuahua, Mexico. Effort notes the number of total survey days in each range in each time period. Historical transect lengths (km) note spatial survey effort and were based on Table 3 in Marshall (1957). Contemporary transect lengths consider only stations in areas dominated by oak-pine, pine-oak, and riparian vegetation, which are the communities in which Marshall focused his standardized surveys. To compare richness, observations of the following species were omitted: 1) species classified as possible breeders, 2) species associated exclusively with lowland vegetation communities, 3) species detected only within the Huchita Hueca portion of the Sierra Púlpito, which was not surveyed historically, and 4) species detected only within the Mariquita portion of the Sierra Cananea, which was not surveyed historically.

	1950s			2000s			Differences		
Range	Effort	Length	Richness	Effort	Length	Richness	Effort	Length	Richness
Cananea	5	5.5	45	12	4.4	55	7	-1.1	10
Ajos	18	17.7	77	9	10.8	63	-9	-6.9	-14
San Luis	10	2.3	70	13	7.2	76	3	4.9	6
Púlpito	3	1.1	43	4	0.4	68	1	-0.7	25
Pinito	5	3.5	50	6	5.2	63	1	1.7	13
Azul	3	2.7	45	5	2.8	63	2	0.1	18
Aconchi	5	5.3	56	8	3.8	73	3	-1.5	17
Opusera	4	4.5	52	10	6.2	69	6	1.7	17
Tigre	5	3.2	49	9	12.6	78	4	9.4	29
SMO-Huachinera	14	7.1	71	3	5.6	57	-11	-1.5	-14
SMO-Pinos Altos	3	3.4	64	2	2.2	55	-1	-1.2	-9

Table S7: Distribution of breeding bird species detected by Marshall (1957) in the early 1950s (M), during the present study between 2009 and 2012 (F), and during both time periods (M-F) in 9 Sky Islands and 2 areas in the adjacent Sierra Madre Occidental (SMO) in Sonora and Chihuahua, Mexico. To compare richness, I omitted observations of species classified as possible breeders, species associated exclusively with lowland vegetation communities, and species detected only within the Huchita Hueca portion of the Sierra Púlpito, and Mariquita portion of the Sierra Cananea, which were not considered historically.

Common Name	Cananea	Ajos	San Luis	Púlpito	Pinito	Azul	Aconchi	Opusera	Tigre	SMO-Huachinera	SMO-Pinos Altos	Difference
Elegant Quail							F	F				2
Montezuma Quail	M-F	M	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	M-F	-2
Wild Turkey	F	M-F	M-F	F		F	F	M-F	F	M-F		5
Turkey Vulture	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Sharp-shinned Hawk	F	M-F	M-F						F			2
Cooper's Hawk	F	M-F	M-F	F	F	F	M-F	F	M-F	M		4
Northern Goshawk	F	M-F		F	F							3
Common Black-Hawk			M	F								0
Gray Hawk		F			F						F	3
Short-tailed Hawk	F	F	F	F	F		F	F	F			8
Zone-tailed Hawk	F	F	M-F	F		M-F	F	M-F	M-F	M	M	2
Red-tailed Hawk	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Golden Eagle	F	M	M-F		M	F						0
American Kestrel		M	M	M		M	M		M	M		-7
Peregrine Falcon			F	F								2
Prairie Falcon			M									-1
Band-tailed Pigeon	M-F	M-F	M-F	M-F	M	M-F	M-F	M-F	M-F	M-F	M	-2
Eurasian Collared-Dove							F					1
White-winged Dove	M	M		F	M-F	M	M-F	M-F			M	-3
Mourning Dove	M	M	M-F	M-F	M-F		F		F	M	M	-2
Thick-billed Parrot								M		M	M	-3
Yellow-billed Cuckoo		M					F		F		F	2
Greater Roadrunner	M-F	M	M-F	F	F	M-F	M-F			M	M	-1
Flammulated Owl		M	M						M	M		-4
Western Screech-Owl		M	M	F	M		M		F			-2
Whiskered Screech-Owl	M	M-F	M-F	F	M-F	M-F	M-F	F	M-F	M-F	M-F	1
Great Horned Owl		M	M-F	M	M	F	M-F	M		M		-4
Northern Pygmy-Owl	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	-1
Elf Owl		M-F	M-F		M-F	F	F		F	M	M	1
Spotted Owl	F	M-F	M-F		M-F	M-F	M-F	M-F	F	M-F		2
Common Nighthawk		M	M-F	F			M			M	M	-3
Common Poorwill	M-F	M	M-F	M-F	M-F		M-F		M	M		-3
Mexican Whip-poor-will	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
White-throated Swift	M-F	M-F	M-F	M	F	M-F	M-F		M-F	M-F		0
Broad-billed Hummingbird		M	F	F	M-F	M-F	M-F	M-F	M-F	F	F	3
White-eared Hummingbird	F							M-F	M-F	M	F	1
Berylline Hummingbird								F		M		0

Violet-crowned Hummingbird						F	F	F	F		F	5
Blue-throated Hummingbird			M	F			F	M-F	M-F	M-F	M	0
Magnificent Hummingbird		M-F	M-F	M-F			M-F	M-F	M-F	M-F	M	-1
Plain-capped Starthroat							F					1
Black-chinned Hummingbird		M-F	M	F								0
Anna's Hummingbird			F			F	F					3
Broad-tailed Hummingbird	F	F	M-F	F	F	M		M-F	M-F	M-F	F	4
Elegant Trogon	F	M-F	M-F	F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	2
Eared Quetzal											M	-1
Acorn Woodpecker	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Hairy Woodpecker	F	M-F	M-F	M		F		M-F		M-F	M-F	1
Arizona Woodpecker	F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	1
Northern Flicker	F	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	M-F	M-F	2
White-striped Woodcreeper											M-F	0
Northern Beardless-Tyrannulet							F		F		F	3
Tufted Flycatcher											M-F	0
Greater Pewee	M-F	M-F	F	M-F	F	M-F	M-F	M-F	F	M-F	M-F	3
Western Wood-Pewee	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	1
Cordilleran Flycatcher	F	F	F	F	F	F		F	F	F	F	10
Buff-breasted Flycatcher	F	M-F	M-F	M-F	F				F	M	F	3
Black Phoebe		M			F	F					F	2
Dusky-capped Flycatcher	M-F	M-F	M-F	F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	1
Ash-throated Flycatcher	M	M-F	M-F	F	M-F	M-F	M-F	M-F	M-F	F	M	0
Brown-crested Flycatcher		M			M-F	F	M-F	F	F		M-F	2
Sulphur-bellied Flycatcher		M-F	M-F		M	F	M-F	M-F	F	M-F	M-F	1
Cassin's Kingbird	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Thick-billed Kingbird							M-F	F	F		M-F	2
Western Kingbird				F								1
Rose-throated Becard							M-F					0
Plumbeous Vireo	M-F	M-F	M-F	M-F	F	F	M-F	F	F	M-F	M-F	4
Hutton's Vireo	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F		0
Warbling Vireo										M	M	-2
Steller's Jay	M-F	M-F	M-F	M-F	M-F	M-F	M	M-F	M-F	M-F	M	-2
Woodhouse’s Scrub-Jay	M		M-F	F					F			1
Mexican Jay	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	-1
Common Raven	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	M-F	M-F	M-F	1
Purple Martin										M	M	-2
Violet-green Swallow				M				M				-2
Mexican Chickadee			M-F	M-F					M-F	M-F	M	-1
Bridled Titmouse	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Juniper Titmouse			M									-1
Bushtit	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
White-breasted Nuthatch	F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	2
Pygmy Nuthatch			M			M			M	M	M	-5
Brown Creeper	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	-1
Rock Wren	M		F	F	F		M-F	F	M-F	F		4

Canyon Wren	M-F	M-F	M-F	F	M-F	M-F	M-F	M-F	M-F	M-F		1
Sinaloa Wren							F	F				2
Bewick's Wren	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	-1
House Wren	M-F	M-F	F			M		M		M-F	M-F	-1
Blue-gray Gnatcatcher	F	M-F	M-F	F	F	F		F	M-F	M-F	M-F	5
Eastern Bluebird	F	M		M	M-F	M-F	M	F	F	M		-1
Western Bluebird			M-F	M-F								0
Townsend's Solitaire				F					F	M-F	F	3
Brown-backed Solitaire							F		F	F	F	4
Hermit Thrush		F										1
American Robin	M-F	M-F	M-F	F	F	M-F	F	M-F	F	M-F	M-F	4
Curve-billed Thrasher	M	M	M		M	F	M-F	F	M-F		M-F	-2
Crissal Thrasher	M		F	F	F							2
Olive Warbler	F	M-F	F	F	M-F	F	F	M-F	M-F	M-F	M-F	5
Crescent-chested Warbler		F						F		F		3
Virginia's Warbler		F										1
Northern Parula		M										-1
Grace's Warbler	F	M-F	F	F	F	F	F	M-F	F	M-F	M-F	7
Black-throated Gray Warbler	M-F	M-F	M-F	F	M-F	F			F			3
Rufous-capped Warbler							F	F	F			3
Red-faced Warbler		M-F	M-F	F					M-F	M-F	F	2
Painted Redstart	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Slate-throated Redstart										F		1
Spotted Towhee	M-F	M-F	M-F	M-F	M-F	M-F		M-F	M-F	M-F	M-F	0
Rusty Sparrow							M-F	M-F	F	M	M-F	0
Rufous-crowned Sparrow	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Canyon Towhee	M	M	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M	M-F	-3
Rufous-winged Sparrow							F		F			2
Chipping Sparrow		M										-1
Black-chinned Sparrow			F	F								2
Yellow-eyed Junco	M-F	M-F	M-F	M-F	M-F	M-F			M-F	M-F	M-F	0
Hepatic Tanager	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	0
Summer Tanager		M	F			F	M-F	F	F			3
Western Tanager		F										1
Flame-colored Tanager		F										1
Black-headed Grosbeak	M-F	M-F	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	M-F	1
Brown-headed Cowbird	M	M	F	F	M-F	F	M-F	F	F	F	M-F	4
Black-vented Oriole							F	M			M-F	0
Hooded Oriole		M	F		F	F	F	F	F			5
Scott's Oriole	M-F	M-F	M-F	M-F	M-F	M-F	M-F	M-F	F	M-F	M-F	1
House Finch	M	M-F	F	F	F	F	M	F	M	F		3
Red Crossbill											M	-1
Black-headed Siskin										M		-1
Lesser Goldfinch		M	M-F	F	M-F		M-F	M-F	F	M	M-F	0

Reference: Marshall, J.T., Jr. 1957. Birds of pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna 32:1-125.

Table S8: Description and significance of notable records of breeding birds in the Sky Islands and adjacent Sierra Madre Occidental in Sonora and Chihuahua, Mexico, 2009-2012. Significance was evaluated on the basis of noted sources.

Species	Notable Findings	Sources
Wild Turkey	First confirmed breeding records (2) in Mexican Sky Islands; 13 new Sky Island populations found	1, 3, 6
Sharp-shinned Hawk	Second nest for Sonora; 3 new Sky Island populations documented; reconfirmed in Ajos and San Luis where populations known	1, 3, 6, 7
Northern Goshawk	First nests for Mexican Sky Islands (3); previous records from Ajos, Oposura, and Huachinera; new populations found in Pinito, Elenita, Pan Duro, Púlpito, Bacadéhuachi, Cebadilla.	1, 3
Short-tailed Hawk	First nest for Sonora and northwest Mexico; new populations found in 9 Sky Islands and at Cebadilla, reconfirmed in Ajos, Cananea, Oposura where found in 2006-'08	3, 6, 7, 8
Golden Eagle	Second nest for Mexican Sky Islands and Sonora	1, 3
Thick-billed Parrot	First record in Sonora since 1995 (la India) and only fifth since 1954. Not in Tigre, Oposura, Huachinera, El Macho, or Cebadilla where documented previously	1, 2, 3, 9, 10
Flammulated Owl	Second and third records for Sonora since 1954 (Bacadéhuachi, la India); not found at 3 localities (Ajos, Tigre, San Luis) where documented previously	1, 3, 10
Spotted Owl	Second nest and confirmed breeding record for Sonora; new populations found in Madera, Cucurpe, Mariquita, Juriquipa, San Antonio, Tigre, India, and confirmed in 10 other known localities.	1, 3, 7, 10
Northern Saw-whet Owl	First possible breeding record for Sonora in San Luis	1, 3
Berylline Hummingbird	First record in Mexican Sky Islands	1, 3
Broad-tailed Hummingbird	First and second nests and confirmed breeding records in Sonora (Tigre and Púlpito); new potential breeding populations in Elenita, San Luis, Pan Duro, Pinito, Púrica	1, 3, 6
Mountain Trogon	First records in northern Sierra Madre of Sonora; ~190 km range extension. Not in Sky Islands	1, 2, 3
Eared Quetzal	Fifth record in breeding habitat in Sonora and first since 1996 (Cebadilla). Not in Sky Islands	1, 2, 3, 7
Acorn Woodpecker	Westernmost record in Sonora in Humo; not found in San Juan where there are records outside breeding season	3, 4, 6
Hairy Woodpecker	New populations found in Azul, Mariquita, Elenita, Púrica, Bacadéhuachi. Confirmed in Ajos, San Luis, Huachinera where known. First records in Oposura since 1887.	1, 3, 6
White-striped Woodcreeper	First Sky Island and north-westernmost record in Bacadéhuachi.	1, 3, 4, 7

Tufted Flycatcher	Westernmost record in Aconchi; northernmost nesting sites in Sonora at Cebadilla >180 km north of known locations. Not found in Oposura where observed in 1887	1, 3
Pine Flycatcher	Northernmost population in Sonora found in Cebadilla	1, 3
Cordilleran Flycatcher	Second nest for Sonora found in Tigre; new populations found in 11 Sky Islands and reconfirmed in Ajos and Huachinera.	1, 3, 6
Buff-breasted Flycatcher	Second nest or confirmed breeding record for Sonora; new populations found in Pinito, Elenita, Tigre, Pan Duro, Bacadéhuachi and reconfirmed in Ajos, Púlpito, and San Luis where known.	1, 3
Gray Vireo	First possible breeding record for Sonora (San Luis); found singing in nearby Chihuahua in 2005	3, 5
Plumbeous Vireo	Westernmost breeding sites in Mexican Sky Islands found in Pinito, Azul. New populations in Pinito, Azul, Oposura, Tigre, Juriquipa, Pan Duro; reconfirmed in Ajos, Aconchi, Púlpito, Cananea.	1, 3, 6
Warbling Vireo	First likely nesting record in Mexican Sky Islands in Bacadéhuachi	1, 3
Yellow-green Vireo	First likely breeding record for Mexican Sky Islands in Bacadéhuachi	1, 3
Violet-green Swallow	First possible breeding record for Sonora in Pan Duro; not found in Púlpito, Oposura, San Luis where present in past	1, 3
Mexican Chickadee	Second, third, and fourth confirmed breeding records for Sonora	1, 3
Pygmy Nuthatch	Second record in study region since 1954 (in Cebadilla) with 2010 record from Bacadéhuachi. Not found in Azul, Cananea, Tigre, San José , San Luis, or Huachinera where present in 1890s or 1950s	1, 3, 6, 9, 11
Eastern Bluebird	New populations in Chivato, Juriquipa, Carbonera, Oposura.	1, 3, 6
Townsend's Solitaire	First nest for Sonora and Mexican Sky Islands	1, 3
Brown-backed Solitaire	First nest for Sonora and Mexican Sky Islands; northernmost breeding sites found >180 km north of known localities	1, 3
Orange-billed Nightingale-Thrush	Northernmost population in Sonora found in Cebadilla >300 km north of known potential breeding localities in Sonora	1, 3
Hermit Thrush	Only breeding locality in Mexican Sky Islands in Ajos; second breeding record for mainland Mexico	1, 3, 5, 6
Olive Warbler	New populations found in the Aconchi, Azul, Elenita, Púrica, Pan Duro	1, 3
Crescent-chested Warbler	First records in Mexican Sky Islands in Ajos, Oposura, Bacadéhuachi >180 km north of known breeding localities in Sonora; Second, third, and fourth confirmed breeding records for Sonora	1, 3
Virginia's Warbler	First records in Mexican Sky Islands of probable breeders (in Ajos and Mariquita)	1, 3, 6
Hooded Warbler	Fourth record for Sonora and third in possible breeding habitat during breeding season (in Cebadilla)	1, 3

Northern Parula	Second record in possible breeding habitat in the breeding season (in Cebadilla); first since 1950s	1, 3
Yellow-rumped Warbler	First possible breeding records in Mexican Sky Islands in Mariquita and in Sonora in Cebadilla	1, 3
Grace's Warbler	Ten new Sky Island breeding populations found; not found in Cíbuta or San José where reported before 1945; reconfirmed in Ajos, Oposura, Púlpito, Huachinera, and to southeast	1, 3, 6, 9
Black-throated Gray Warbler	Nine new Sky Island breeding populations found; populations confirmed again in Ajos, Cananea, Púlpito, and San Luis	1, 3
Red-faced Warbler	Three new breeding populations found in Pan Duro, Púlpito, Bacadéhuachi; confirmed again in Ajos, Tigre, San Luis, Huachinera; 9 total confirmed breeding records including first nest for Sonora	1, 3, 6
Slate-throated Redstart	First confirmed breeding record for Sonora; first Sky Island record in Bacadéhuachi; found >180 km north of known localities in Sonora	1, 3
Rusty Sparrow	First confirmed breeding record in Mexican Sky Islands in Oposura	1, 3
Black-chinned Sparrow	First records in potential breeding habitat during the breeding season in Sonora in San Luis, San José , Púlpito	1, 3
Yellow-eyed Junco	Not found in San José or Aconchi where once present; found in all other 7 localities where Marshall observed in 1950s; new populations found in Pan Duro, Púrica, Bacadéhuachi	1, 3, 6
Western Tanager	Third confirmed breeding record in mainland Mexico and second in Mexican Sky Islands; behavior suggests potential breeding in Azul and Púrica	1, 3, 5
Flame-colored Tanager	First records in Mexican Sky Islands (Ajos) and potential breeding localities in northern Sonora	1, 3
Black-vented Oriole	New population found in Aconchi; not found in Oposura where observed in past	1, 3
Pine Siskin	Second possible breeding record in Mexican Sky Islands in Elenita	1, 3, 6

Sources: [1]Marshall 1957, [2]Lammertink 1996, [3]Russell and Monson 1998, [4]Flesch and Hahn 2005, [5]Gomez de Silva 2005, [6]Flesch 2008a, [7]Flesch 2008b, [8]Snyder et al. 2010, [9]Van Rossem 1945, [10]Cirett Galán and Rogero Diaz 1993, [11]S. Jacobs, *pers. comm.*

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