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Effects of climate change upon birds in the Mojave and Sonoran Deserts

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Effects of climate change upon birds in the Mojave and Sonoran Deserts

By

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B.A., Biology, Thiel College, 1983
M.B.A., Global Management, University of Phoenix, 2004

THESIS

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Biology

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Albuquerque, New Mexico

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DEDICATION

In memory of my oldest son, Deva Singh Khalsa, who left his body on December 1st, 2007 at the young age of 23.

Deva's inquisitive exploration and joy of being in the outdoors continues to bring a sense of loving warmth to my heart. His smile, laughter, playfulness, and loving support are deeply missed.

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And finally to my son, Simran Singh Khalsa, and my daughter-in-law, Guruparkash Kaur Khalsa, your love is the greatest gift of all.

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ABSTRACT

Climate change has increasingly become an area of concern in relation to ecological communities. In this study, climatic signals were investigated to determine whether bird diversity indices in the Breeding Conservation Region (BCR) of the Mojave and Sonoran Deserts were related (1) to the oceanic/atmospheric systems El Nino Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and/or the Atlantic Multidecadal Oscillation (AMO); (2) to regional moisture influences determined by the Palmer Drought Severity Index (PDSI); and (3) to local precipitation and temperature. Specifically, an examination was conducted to determine the relationship between climatic variables for thirteen bird species, total abundance (individuals), and species richness observed over a 40 year period from1970 to 2009 on 14 different Breeding Bird Survey (BBS) routes. Data were analyzed using the Open Source version of the S language called R. Multi-panel scatterplots, Pearson correlation coefficients, and variance inflation factors (VIF) were used to identify collinearity (correlation between covariates). An Information Theoretic (IT) approach was applied to compare a set of 12 climatic models. Generalized linear mixed modeling (GLMM) was applied to analyze multiple observations per route. The results indicated that birds are individualistically responding to climatic signals at different probability intensities at the 95% confidence level: a weak signal (between a probability of 0.001-0.05), and a strong signal (less than a probability of 0.001). Four important IT results utilizing Akaike’s Information Criteria (AIC) included each bird species diversity index responding (1) differently to each of the twelve AIC climatic models; (2) differently to covariates or explanatory climatic influences [Multivariate ENSO Index (MEI), AMO, Precipitation, Temperature, and PDSI] established within the models, in a positive or negative manner; (3) differently in relation to the significance intensities [Probability (Pr) values] to covariates or explanatory climatic variables within the models; and (4) differently to climatic influences present during the spring and summer months.

Key words: desert birds; climatic signal; fundamental niche; IT Evidence Ratios; species abundance; species pool; range; arid environments.

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CHAPTER 1

Introduction

Today, in the 21st century, humanity is witnessing, first hand, the influences of the ever changing climate regime. Quantitative documentation of a growing number of range shifts of both plant and animal communities (Brown and Ernest 2002; Brown et al. 1997; Parmesan et al. 2005, and Simmons et al. 2004) has continued to increase as ecologists search for both evidence and mechanisms that propel these changing biogeographical distribution trends.

With warmer temperatures and less precipitation predicted for many areas of the world (IPCC 2007), it becomes increasingly clear that geographical shifts in ecological communities will be driven by the impending climate change, perhaps in similar ways as in the past paleoecological climatic shifts. Researchers have determined that temporal and spatial dynamics are affected by abiotic factors (Ernest et al. 2000), and in deserts these fluctuations are highly variable (Dean 2004).

In arid environments, birds are highly sensitive to climatic influences and good indicators of environmental change (Moller et al. 2006). Birds are highly mobile, thus able to move to new nesting and foraging areas, therefore one might expect that birds are efficient at adapting to climatic impacts. Nevertheless, not all bird species are highly mobile or able to adapt effectively to diverse nesting habitats of food resources, so it seems reasonable to expect that some fluctuations will occur in bird populations, due to changes in nutrient rich food resources and species niche requirements. As a result, exchanges between local community and regional species pools occur (Ernest et al. 2008).

Due to the highly variable environmental fluctuations in deserts, that occurs temporally and spatially, one would think that birds should be ideal for studying the effects of climate change. Temperatures are high and often extreme, and water is very scarce – a limiting factor for desert ecological communities (Odum 1959, Dean 2004, Ernest et al. 2000, Brown and Ernest 2002, and Pianka 1967). In turn, the quantity and quality of food resources and their temporal and spatial availability is highly unpredictable. To cope, desert birds have a variety of behavioral and physiological strategies that enable them to survive the stressful challenges that they face (Dean, 2004; Odum 1959, and Wolf, 2000).

Birds have a high body temperature of approximately 40^{o} Centigrade (C), which is an evolutionary feature that enhances their speed and endurance, yet when their body temperature increases more than 46^{o} C, proteins are denatured, risking lethal overheating (Gill 2007). So how can they survive the heat of the desert? Physiological and behavioral adaptations enable birds to maintain homeostasis and to conserve internal water (Gill 2007; Dean 2004; Wolf 2000; and Maclean 1996), such as allowing their body temperatures to rise, via hyperthermia, so that they do not take on as much heat from the surrounding environment. They also utilize evaporative cooling, cutaneous heat loss, panting, and feather and posture adjustments in an effort to reduce heat intake under high temperature regimes (Gill 2007). During midday hours when temperatures are higher, birds often reduce their activity, enabling them to reduce evaporative water loss (Wolf 2000), and to maintain a more favorable metabolic body temperature. Additionally, birds are also able to metabolize water from food to assist with their internal water economy, which can be especially advantageous in a desert ecosystem where water is a limiting factor (Gill 2007).

A number of studies have found that local or regional climatic fluctuations can alter the reproductive capacity of birds. For instance, annual rainfall fluctuations in the Galapagos Archipelago appear to affect the population dynamics of bird species. In years following dry seasons, there appear to be reduced numbers of birds, and in years following wet seasons, the populations of bird species appears to increase (Grant and Boag 1980). In arid zones of Ecuador, Lloyd (1960) found that birds produced smaller clutches during climatically poor years and larger clutches in good years. And in South Africa, Maclean (1976) suggested that the threshold of breeding birds to rainfall might be higher in that region, because precipitation is often uncertain. Also in Africa, studies have shown that Palearctic migrants appear to have a dependence upon rainfall, due to the number of seeds, insects, and small mammals that result from precipitation (e.g. Lloyd et al. 2001 and Dean 2004).

A number of studies have additionally shown that the timing of reproductive activity seems to be driven by endogenous clocks and local factors that occur around the availability of nutritious food sources required for raising young birds (Carey 2009). Small and colleagues (2007) found that the Rufous-winged Sparrow, *Aimophila carpalis*, actively maintained reproductive capacity, via photoperiod stimulation, from March through early September. But they also reported that although testicular development was maintained for seven months it did not mean that the male *A. carpalis* always bred. The researchers determined that breeding did not occur until luteinizing hormone increased in males, which appeared to be stimulated by rainfall. Other researchers (Deviche et al.

2006; and Strand et al. 2007) determined that the breeding in *A. carpalis* occurred during the monsoon season in Arizona. In southern California, researchers significantly determined that the clutch size of the California Gnatcatcher, *Polioptila californica,* was influenced by immediate rainfall versus annual rainfall. The size of the clutch additionally appeared to be constrained by a reduced abundance of food resources (Patten and Rotenberry 1999). In arid regions of Africa, nomadic birds are known to time their breeding with rainfall (Maclean 1976). Additionally, in Australia, Zebra finches, *Taeniopygia guttata,* were found to breed after rainfall when grass seeds were abundant (Zaan 1996). In the United Kingdom, Charmantier and colleagues (2008) determined that the Great Tit, *Parus major,* behaviorally adapted breeding periods to changing environmental conditions as they temporally tracked their key food source over almost five decades. And in four different elevational transects in the Sierra Nevada Mountains of California, Tingley and colleagues (2009) determined that 48 bird species tracked a temperature and/or precipitation niche over a period of nearly one-hundred years. Additionally, researchers have demonstrated a relationship between oceanic-atmospheric systems such as ENSO and the AMO with reproduction in birds (Balis et al. 2012 and Chase et al. 2005). Ultimately, environmental conditions vary temporally and spatially, hence the actual timing of reproduction may also fluctuate (Hahn et al 2008) in accordance with year-to-year environmental influences such as rainfall, temperature, or available food resources (Mock 1998). These external cues are processed by the neuroendocrine system of birds, which ultimately regulate reproductive activity (Ball 1993).

In the southwestern United States, the close proximity of the Mojave and Sonoran Deserts to the Pacific Ocean gives rise to the general influence of one or more of the earth's oceanic/atmospheric systems: ENSO, an interannual climatic variable having a cycle of 2-7 years (NOAA, 2009), and the PDO, a decadal climatic variable with a cycle of between 30-50 years (USGS, 2004), and the AMO, a multidecadal cycle of 20-40 years (NOAA 2011a). The ENSO and the PDO climatic influences are known to partly modulate climate in the Northern Pacific Ocean (Asmerom et al., 2010), and the AMO is known to have teleconnection patterns with ENSO (Enfield et al. 2001), hence it is expected that a climatic signal can be detected in the long-term BBS data, which is administered by the US Geological Service (USGS)/Patuxent Wildlife Research Center (PWRC).

In this study, it was predicted that populations of breeding birds in the Mojave and Sonoran Deserts will fluctuate, due to a climatic signal correlated 1) regionally with oceanic atmospheric systems: ENSO, the PDO, the AMO, and 2) regionally with moisture influences determined by the PDSI, and 3) locally with temperature and precipitation. Furthermore, the abundance of breeding birds in each of the deserts was expected to vary, because each desert has different temperature and precipitation regimes: the Mojave Desert's temperatures tend to have large daily fluctuations and precipitation generally occurs during the winter season, while the more southerly Sonoran Desert temperatures have less daily fluctuations, and precipitation patterns are biseasonal, occurring in both the winter and spring (Mares 1999). Additionally, both deserts are generally affected, spatially and temporally, by the North American Monsoon that occurs July to September (Grantz et al. 2007).

The underlying biological question addressed in this paper was whether one can relate bird diversity indices to environmental conditions. Species richness, total individuals, and thirteen bird species were examined.

CHAPTER 2

Methods

Bird Data

Bird abundance data for the North American BBS survey are collected yearly by a qualified observer who documents the presence and numbers of each bird species. The annual counts occur in June along an established 39.4 km (24.5 mile) roadside route where birds are observed or heard within a 0.4 km (0.25 mile) radius at stop intervals along each 0.8 km (0.5 mile) sequence. Although variations between years and observers are likely to have occurred, the long-term data provides information that can be utilized for observing trends or relative abundances of birds in different regions (PWRC 2010).

The North American BBS data for the Mojave and Sonoran Deserts was acquired from the USGS/PWRC (2010). The data set spans a period of 43 years, 1968-2010. In an effort to reduce the amount of noise and/or variations between BBS routes, at least fourteen years of BBS observations were established as parameters for selection of a route for analysis, resulting in a total of 33 routes located within the Breeding Conservation Region (BCR, #33) established by the PWRC for the Mojave and Sonoran Deserts (Table 1), of which 17 routes lie within the physiographic region of the Mojave Desert (Stratum #83), and eight routes lie within the physiographic region of the Sonoran Desert (Stratum #82). For this study routes that fell within the Mojave Desert Ecosystem Program (MDEP) established boundary (MDEP 2010), Figure 1, were also included, of which one route lies within the physiographic region of the South California Grasslands (Stratum #90), and the other seven routes lie within the physiographic region of the Great Basin Desert (Stratum #80).

Bird species (Table 2) were selected if they had a high frequency of observations across most of the routes. Two exceptions to this established parameter were the inclusion of the Red-tailed Hawk and the Burrowing Owl, which were selected in order to include predator feeding groups. Also selected for analysis were the total abundance of individual birds and the total species richness observed on a route for each year.

Study Site

The locations of the BBS routes (Figure 1) used for this study lie between 32.8^{o} to 37.3^{o} North (N) latitude, and -113.6^{o} to -118.1^{o} West (W) longitude (Table 1). Eleven routes were spaced across the Mojave Desert region, the smallest of the North American warm deserts, which consists of approximately 130,600 square kilometers (sq km). Only a small number of routes, three, were located within the north-western portion of the Sonoran Desert, a warmer and wetter desert consisting of approximately 320,000 sq km (WWF 2012), with only 46,000 sq km lying within the US. A typical basin and range physiography occurs in both deserts, with several north-south mountain ranges occurring in the Mojave, and isolated mountain ranges occurring in the Sonoran. The resulting soil in the Mojave and Sonoran Deserts contain a high percentage of sand and coarse fragments and are classified primarily as aridisols (Mares 1999). The soils are typically deficient in organic material and tend to be calcareous, with a caliche hardpan, and have high salt deposit content, especially in basin areas (McGinnies 1976).

Desert vegetation characteristically has a spaced distribution with large bare sections between individual plants (Odum 1959). This type of vegetation spacing is also characteristic of the Mojave and Sonoran Desert in which certain plants characterize the landscape of each region. Some plants such as Creosote Bush, *Larrea tridentata,* are

Table 1: Mojave and Sonoran Desert BCR. Route numbers: Arizona = 60.., California = 14.., and Nevada = 55... Stratums: Sonoran Desert = 82, Mojave Desert = 83, Great Basin Desert = 80, and South California Grasslands = 90. Analyzed Routes = *

Route	Stratum	Name	Longitude	Latitude
6012	83	Oatman	-114.483	34.986
6013	82	Wikiup	-113.919	34.727
6056	82	Riviera	-114.582	35.123
6063	83	Alamo Res	-113.598	34.232
6064	83	Skull Valley	-114.662	35.866
*14029	80	Ubehebe	-117.574	36.713
14030	80	Haiwee Res	-117.886	36.156
14031	80	Wildrose	-117.214	36.538
*14036	83	Goldstone	-116.916	35.302
14037	83	Valley Wells	-115.703	35.474
*14041	83	Barstow	-117.005	34.624
14056	80	Darwin	-117.672	36.318
14058	80	Eureka Valley	-117.761	37.227
*14059	83	Inyokern	-117.800	35.608
14060	83	Lenwood	-117.147	34.851
14062	83	Ivanpah	-115.429	35.541
14064	83	Tewpas	-116.193	35.804
14085	83	Lucerne Valley	-116.946	34.458
*14088	82	Cottonwood	-115.802	33.674
*14089	82	Niland	-115.485	33.22
14092	82	Alamo River	-115.435	32.847
14093	82	Imperial Dam	-114.473	32.882
*14109	83	Cima	-115.412	35.174
*14112	90	Pear Blossom	-117.941	34.521
*14116	80	Long Pine	-118.099	36.507
*14131	83	Joshua Tree	-116.163	34.014
*14139	80	Greenwater Valley	-116.500	36.051
*14150	82	Brawley	-115.536	32.942
14907	82	Cholla Guard	-115.927	33.925
55029	83	Beatty	-116.762	36.907
*55031	83	Valley of Fire	-114.761	36.501
*55032	83	Jean Lake	-115.209	35.72
55906	83	Ash Meadows	-116.343	36.491

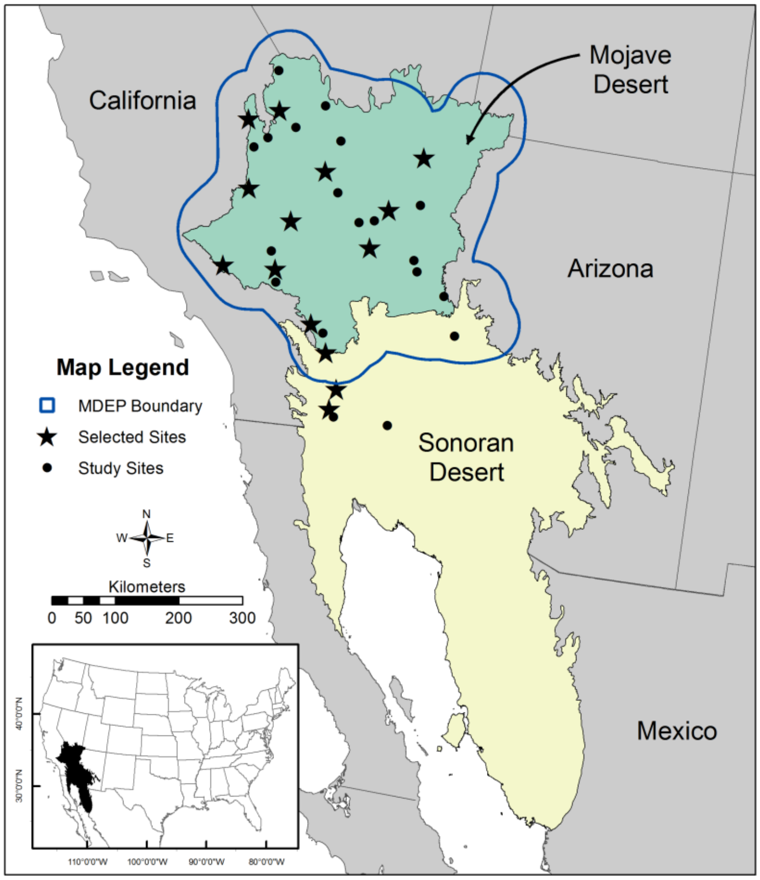
located in both deserts, yet each region has a characteristic vegetation make-up. The Mojave Desert is typically referred to as a transitional desert zone lying between the cold Great Basin Desert to the north, and the warm Sonoran Desert to the south. Characteristic plants dominating the Mojave Desert include *L. tridentata* and Bur Sage, *Franseria dumosa*, which make-up approximately 70 percent of the vegetation cover located across

Table 2: Bird Species

Bird Category	**Abbreviation**	**Habitat Type**	**Foraging Type**
Ash-throated Flycatcher, *Myiarchus cinerascens*	ATF	Open Woodland	Insectivorous
Burrowing Owl, *Athene cunicularia*	BO	Dry, open areas	Insectivorous (Generalist)
Black-throated Sparrow, *Amphispiza bilineata*	BTS	Scrub	Granivorous
Cactus Wren, *Campylorhyncus brunneicapillus*	CW	Thorn-scrub	Insectivorous
Gambel's Quail, *Callipepla gambelli*	GQ	Scrub	Granivorous
House Finch, *Carpodacus mexicanus*	HF	deserts/variety of habitats	Granivorous
Horned Lark, *Eremophila alpestris*	HL	Grassland	Granivorous
Loggerhead Shrike, *Lanius ludovicianus*	LS	Open Woodland	Insectivorous
Mourning Dove, *Zenaida macroura*	MD	Open Woodland	Granivorous
Northern Mockingbird, *Mimus polyglottos*	NM	Open ground	Omnivorous
Red-tailed Hawk, *Buteo jamaicensis*	RT	Open Woodland	Carnivorous
Verdin, *Auriparus flaviceps*	V	Scrub	Insectivorous
Western Kingbird, *Tyrannus verticalis*	WK	Grassland	Insectivorous
Total Individuals	Indiv	NA	NA
Species Richness	SpR	NA	NA

the deserts, primarily, open landscape. The Joshua Tree, *Yucca brevifolia,* found in higher elevations, typically is considered an indicator species of the Mojave Desert. In the lower elevations, halophytic, or salt loving plants, are typically found on saline soils. In the Sonoran Desert, *L .tridentata* and White Bur Sage, *Ambrosia dumosa* dominate the landscape, which make-up approximately 80-90 percent of the vegetation cover in some areas of the desert. Succulent plants are located in both deserts, but the Sonoran typically has a more prevalent population of these species, especially the well-known Saguaro, *Carnegiea gigantea.* Although halophytic plants are located in both deserts, the Sonoran Desert additionally has a prevalence of trees growing along the banks of dry washes. The

Figure 1. BCR study site locations.



Sonoran Desert also has a reputation of being one of the most ecologically complex desert biomes in the world (Mares 1999).

Climatic Variables

A number of climatic variables are known to influence the southwestern region of the US. These parameters include: temperature, precipitation, drought, and oceanic-atmospheric cycles, such as ENSO, the PDO, and the AMO.

The influence of temperature and precipitation play a role on the vitality and breeding success of birds. A number of studies have shown that varying environmental temperatures affect the daily activity, breeding success, and survival of birds (Gill 2007, Wolf 2000). Additionally, precipitation appears to also have an influence on the breeding, fledging, and survival success of birds (Augustine 2010, Carey 2009, Chase et al. 2005a, Deviche et al. 2006, Dunning, Jr. and Brown 1982, Grant and Boag 1980, Heffelfinger et al. 2009, Lloyd 1960, Maclean 1976, Patten and Rotenberry 1999, Petit et al. 1985, and Rotenberry and Wiens 1991, Small et al. 2007, Strand et al. 2007, and Tingley et al. 2009).

Precipitation and temperature data for the start points (latitude and longitude) of each BBS route were obtained from the PRISM Climate Mapping Program. The data were derived from a parameter-elevation regression on independent slopes model (PRISM): an analytical tool that uses point data, a digital elevation model, and other pertinent spatial data sets to formulate the available climatic data, which includes historical precipitation values. The PRISM model is able to analyze variations in topographical variations (PRISM, 2010), which made this tool valuable for analyzing precipitation fluctuations in the warm southwestern deserts of the U.S.

ENSO, an oceanic-atmospheric system originating in the Pacific Ocean, is known to influence global and continental climatic variability (NOAA 2011b), and has additionally been shown to have effects, such as El Nino influenced precipitation, on the regional biota of the southwestern US deserts (Bowers 2005, Brown and Ernest 2002, Meserve et al. 2003, Scanlon et al. 2006, and Scanlon et al. 2005). In this study the MEI is utilized to examine ENSO effects (NOAA 2011d). The MEI is based upon sea-level pressure, zonal, meridional components of surface wind, sea surface temperature, surface air temperature, and the cloudiness fraction of the sky over the tropical Pacific region (NOAA 2011b).

The PDO, originating in the North Pacific Ocean, predominately influences climate in the northern Pacific, but is known to have secondary signatures in the tropical region (Landscheidt 2001). When the Northern Hemisphere jet stream dips south, moist atmospheric conditions from the North Pacific are carried into the southwest region of the US (Guido 2008). The PDO index (Mantua 2011) is calculated from extended reconstruction of sea-surface temperatures (SST), based in the North Pacific Ocean (NOAA, 2011c).

The AMO, another globally known oceanic-atmospheric system, originating in the Atlantic Ocean, is also known to influence climate across the continental US, including the western region of the US. Additionally, the AMO has been reported to have an accentuating effect upon the ENSO (Enfield et al. 2001). The AMO index is calculated from Kaplan Sea Surface Temperatures (SST), which is based upon North Atlantic temperatures (NOAA 2011a).

The PDSI is a well-known regional continental climatological tool utilized to assess the scope, severity, and frequency of drought conditions, which can be utilized to indicate the availability of water moisture that may influence conditions for various biotas in specified regions (NOAA 2012). The PDSI indicates the current drought conditions based on previous months, inclusive of potential evapotranspiration; potential water recharge to soil; and potential runoff (Hu and Willson 2000). In this study the PDSI for the California South-east desert basins and the Arizona extreme north-west region (NOAA 2012) were utilized. It was expected that bird abundance would fluctuate on a local scale in the southwestern deserts, due to the regional influence of drought (PDSI) upon primary productivity, which ultimately affects the availability of food sources for desert birds (Dean 2004).

Statistical Analysis

Data were analyzed using the Open Source version of the S language called R (R Development Core Team 2008). Before starting the statistical analysis, data exploration was carried out following the protocol described in Zuur et al. (2009b and Zuur et al. 2009c) to detect outliers, collinearity or correlations that would inflate p-values, and to determine relationships between response and explanatory variables in an effort to reduce the possibility of making erroneous ecological conclusions.

When analyzing long-term field data one often encounters the problem that geographical sampling locations vary over time due to limitations and changes in funding and resources, changes in research questions and stakeholder’s interest, alterations in landscape characteristics, and/or improvements in sampling technology. Multi-panel scatterplots were used to visualize any changes over time in the geographical sampling locations between bird species/indices and covariates (Zuur et al. 2009a and Zuur et al. 2007). If necessarily (and possible) the data were truncated to ensure that a data set for analysis was obtained in which sampling effort was approximately equal over time.

All variables were inspected for outliers using Cleveland dotplots (Zuur et at. 2007 and 2009c), which provided more detailed information than boxplots (Zuur et al. 2009b). Collinearity (correlation between covariates) is a serious problem when trying to understand which covariates are driving species richness or bird abundances as it increases standard errors and therefore *p*-values (Zuur et al. 2007; Zuur et al. 2009b). Multi-panel scatterplots; Pearson correlation coefficients, which were used to measure the strength of the relationship between bird indices and covariates (Zuur et at. 2007); and VIF's [assess which variables are highly related (Montgomery and Peck 1992)] were used to identify collinearity. A threshold of three was utilized when examining VIF's as suggested by Zuur and colleagues (2009b), because high or moderate collinearity can be problematic in relation to ecological data. A lower threshold places a more stringent approach on the analysis. Collinear variables were dropped from the analysis. To visualize relationships between species richness and covariates multi-panel scatterplots were created.

Boxplots were utilized to examine the relationships between the different desert regions. Maximum and minimum temperature, precipitation, the PDSI, and the ocean-atmospheric indices (MEI, PDO, and AMO) were investigated.

An Information Theoretic (IT) approach using AIC for measuring the goodness-of-fit of the models and their complexity was applied to compare a set of models ranked according to their AIC, with the lowest AIC being the best model (Burnham and

Anderson 2002), see Table 3 for a list of models and their justification. The AIC is founded on a solid statistical principal, maximum likelihood, which provides a method for determining which model, among a set of models, is the most parsimonious (Burnham and Anderson 2002). Because there are multiple observations per route, GLMM was applied (Zuur et al. 2009 and Bolker et al. 2009). This model included observed level random effects (OLRE), with routes being the random effect. Each data set (each bird index along with all the covariates or dependent variables) was analyzed separately; analyzing all the data sets together would have made the confidence interval extremely large, resulting in very large standard deviations and unacceptable data for statistical analysis. Data was analyzed using the lmer function in the lme4 package in R (R Development Core Team 2008). The first model is specified below, with other models following a similar structure.

$Richness_{ij} \sim Poisson\ (u_{ij})$

$\text{Log}\ (u_{ij}) = \alpha + \beta_1 \text{ x } \text{MEI}_{ij} + \beta_2 \text{ x } \text{AMO}_{ij} + \beta_3 \text{ x } \text{Precip}_{ij} + \beta_{4\,+} \text{ TempDif}_{ij} + \text{PDSI}_{ij} + a_i$

$a_i \sim N(0, \sigma^2_{route})$

$Richness_{ij}$ is the richness in year j for route i and a Poisson distribution, a discrete probability distribution dealing with the pertinent ecological qualitative data, utilizing the log-link, ensures that fitted values are always positive (Zuur et al. 2007). Alpha (α) represents the constant ($\hat{\alpha} = \bar{y} - \hat{\beta}\ x\ \bar{x}$), Beta ($\beta$) represents the slope, and the random intercept a_i allows for correlation between observations from the same route. The random intercept at the end of the model, assumes the random intercept to be normally distributed with a mean of zero and variance (σ^2). Due to the sparse sampling scheme of routes more advanced temporal or spatial correlation structures were not considered.

A model validation was applied on the selected models. Models were checked over for dispersion and plot residuals versus each covariate in the model, and each covariate not in the model. Residuals were also checked for temporal and spatial correlation (Zuur et al.2007).

Model development was based on underlying biological phenomena related to climatic variables discussed in the previous section. The scope, severity, and frequency of drought conditions can be utilized to indicate the availability of water moisture that may influence conditions for various biotas in specified regions (NOAA 2012).

All environmental cofactors selected had a one-year lag built into the models, and each event (year) was treated independently over specific intervals. It was assumed that the breeding success of birds was dependent upon environmental parameters prevalent during a breeding year and would be reflected in the following year’s BBS. Clutch size has been found to vary from year-to-year, depending upon climatic factors (Lloyd 1060; Patten and Rottenberry 1999), and the number of fledglings that survive appears to be correlated with climatic factors, such as rainfall (Grant and Boag 1980). Additionally, it was assumed that each bird species would breed in relation to different environmental cues: nesting and raising fledging’s during May/June may be influenced by oceanic/atmospheric teleconnections, cool season net primary productivity (NPP), or winter precipitation (October-March), temperature (May/June), and/or PDSI (May/June) parameters [Models 1, 2, 3, and 4 (Table 3)]; other breeding birds nesting or raising fledging’s in May/June may be influenced by atmospheric-oceanic teleconnections, spring precipitation (April-May), by temperature (May-June), and/or PDSI (May-June) parameters [Models 5, 6, 7, and 8 (Table 3)]; and finally some bird species may breed during the late summer months (July/August), and may be influenced by oceanic/atmospheric teleconnections; summer precipitation (July-August), influencing late summer NPP; temperature (July-August), and/or PDSI (July-August) parameters (Models 9, 10, 11, and 12 (Table 3)]. Furthermore, all models were a function of route.

Table 3: Models and their justification. Observed Level Random Effects = OLRE.

Model	Model description	Model justification
M1	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagWinter + TempDifLagMayJun + Route + OLRE	Cool season NPP (availability of food for winter, breeding, and fledging birds in spring)
M2	Species/Index ~ PrecipLagWinter + TempDifLagMayJun + Route + OLRE	
M3	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagWinter + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	
M4	Species/Index ~ PrecipLagWinter + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	
M5	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagAprMay + TempDifLagMayJun + Route + OLRE	Spring NPP (availability of food sources for breeding and fledging birds in spring)
M6	Species/Index ~ PrecipLagAprMay + TempDifLagMayJun + Route + OLRE	
M7	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagAprMay + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	
M8	Species/Index ~ PrecipLagAprMay + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	
M9	Species/Index ~ MEILagJulAug + AMOLagJulAug + PrecipLagJul-Sept + TempDifLagJulAug + Route + OLRE	Warm season NPP (availability of food sources for breeding and fledging birds in summer)
M10	Species/Index ~ PrecipLagJul-Sept + TempDifLagJulAug + Route + OLRE	
M11	Species/Index ~ MEILagJulAug + AMOLagJulAug + PrecipLagJul-Sept + TempDifLagJulAug + PDSILagJulAug + Route + OLRE	
M12	Species/Index ~ PrecipLagJul-Sept + TempDifLagJulAug + PDSILagJulAug + Route + OLRE	

CHAPTER 3

Results

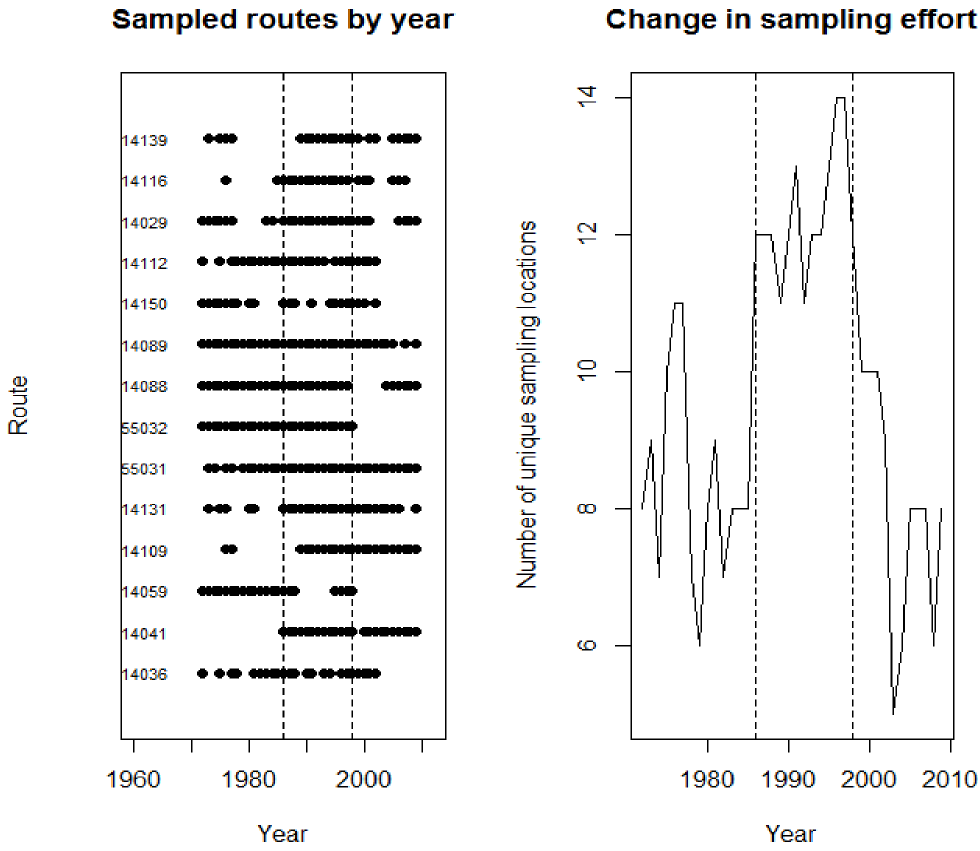
Sampling effort

Although the BBS was established to monitor the status and trends of bird populations, the data obtained for this study had several inherent problems in relation to sampling effort. Out of a total of 57 BBS routes located in the BCR for the Mojave and Sonoran Deserts, only 14 routes were sampled at least 21 years or more and only three routes were sampled over thirty years between 1968 – 2010 (PWRC 2012). This inconsistency creates difficultly when analyzing for long-term abundance trends. Sampling effort in the first few years was limited compared to later years, increasing during the 1990's, and declining during the 2000's (Figure 2).

To study the effect of the difference in sampling effort the number of sampled routes was defined as a new covariate. This covariate (sample effort) was not collinear with any of the other covariates. Additionally, covariates were plotted versus sampling effort to look visually for patterns, and no patterns were detected. This means that the number of sampled routes was not related to any of the covariates, nor to species richness or other species/indexes, which means that one can be reasonably confident that the changes in sampling effort had minimum effect on the results.

In this paper, data from 1970 to 2009 were utilized, a period of 40 years. Around 1990 there were slightly larger numbers of sampled routes (Figure 2). Removing some routes to obtain similar sampling effort over all years was rather difficult and subjective. To deal with this issue, three approaches were followed: analyze the 14 most frequently sampled routes (Table 4), analyze 15 routes drawn at random, and analyze 33 routes originally selected from the BBS data for analysis. Whatever analysis was used, the ecological interpretations for all three data sets were similar and/or identical for all species or indices utilized. Therefore only results for 14 routes were presented.

Figure 2. Sampling Effort. Left: Sampling effort over time. A dot means that a route was sampled in a particular year. Right panel: number of sampled routes per year.



Data Exploration

Cleveland dotplots (not shown) showed that there were no observations with a considerably larger or smaller richness value. Precipitation was highly skewed, indicating a need to transform the data to stabilize the variance, so a square root transformation was applied (Zuur et al. 2007; Zuur et al. 2009c).

Table 4. Fourteen analyzed routes.

Route	Stratum	Name	Longitude	Latitude	No. Yrs	Habitat Type
14029	80	Ubehebe	-117.574	36.713	24	Sparse Cover Scrub habitat
14036	83	Goldstone	-116.916	35.302	24	Sparse-scrub habitat (mixed woody scrub)
14041	83	Barstow	-117.005	34.624	22	Joshua Tree Creosote Bush
14059	83	Inyokern	-117.800	35.608	23	Shrub-steppe habitat
14088	82	Cottonwood	-115.802	33.674	27	Riparian Habitat
14089	82	Niland	-115.485	33.22	35	Desert Oasis; Desert & Sagebrush Scrub; and Riparian
14109	83	Cima	-115.412	35.174	29	Joshua Tree Habitat, and Creosote Bush.
14112	90	Pear Blossom	-117.941	34.521	34	Riparian Habitat
14116	80	Long Pine	-118.099	36.507	38	Sparse-scrub habitat
14131	83	Joshua Tree	-116.163	34.014	22	Joshua Tree Habitat
14139	80	Greenwater Valley	-116.500	36.051	27	Sparse creosote bush & assorted succulents
14150	82	Brawley	-115.536	32.942	29	Riparian habitat
55031	83	Valley of Fire	-114.761	36.501	20	Burrow bush, and brittlebush
55032	83	Jean Lake	-115.209	35.72	22	Creosote Bush

Boxplots indicated that minimum temperature differed between the Mojave and Sonoran Deserts. Out of 14 routes analyzed in this study, only three routes (Table 1) were located in the Sonoran Desert, therefore the difference between desert regions was not analyzed, due to a lack of appropriate data in the Sonoran Desert. The use of temperature difference (TempDif) between maximum and minimum temperature implicitly includes a desert effect in the models.

Additionally, boxplots indicated a very strong route effect, and species richness was utilized to depict this random effect (Figure 3). A multi-panel graph for each species, depicting the yearly fluctuations for each of the 14 routes, was utilized to acquire a visual interpretation of route effects (Figure 4).

Figure 3. Route Effect: Species Richness.

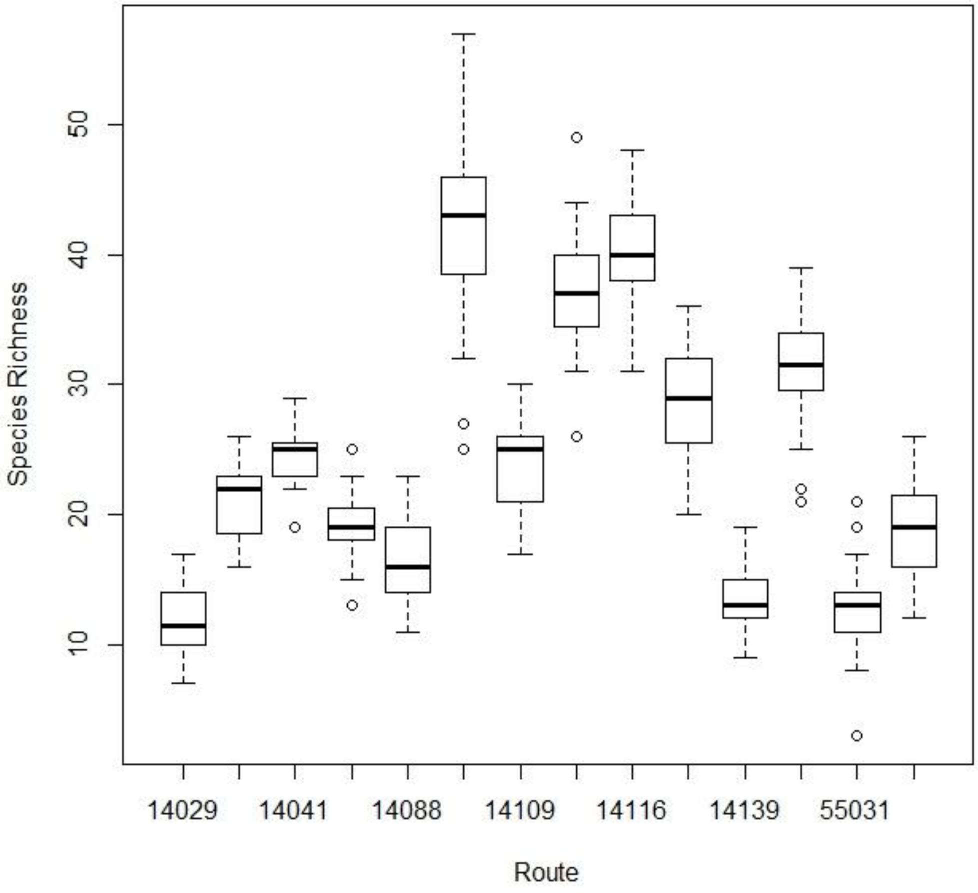
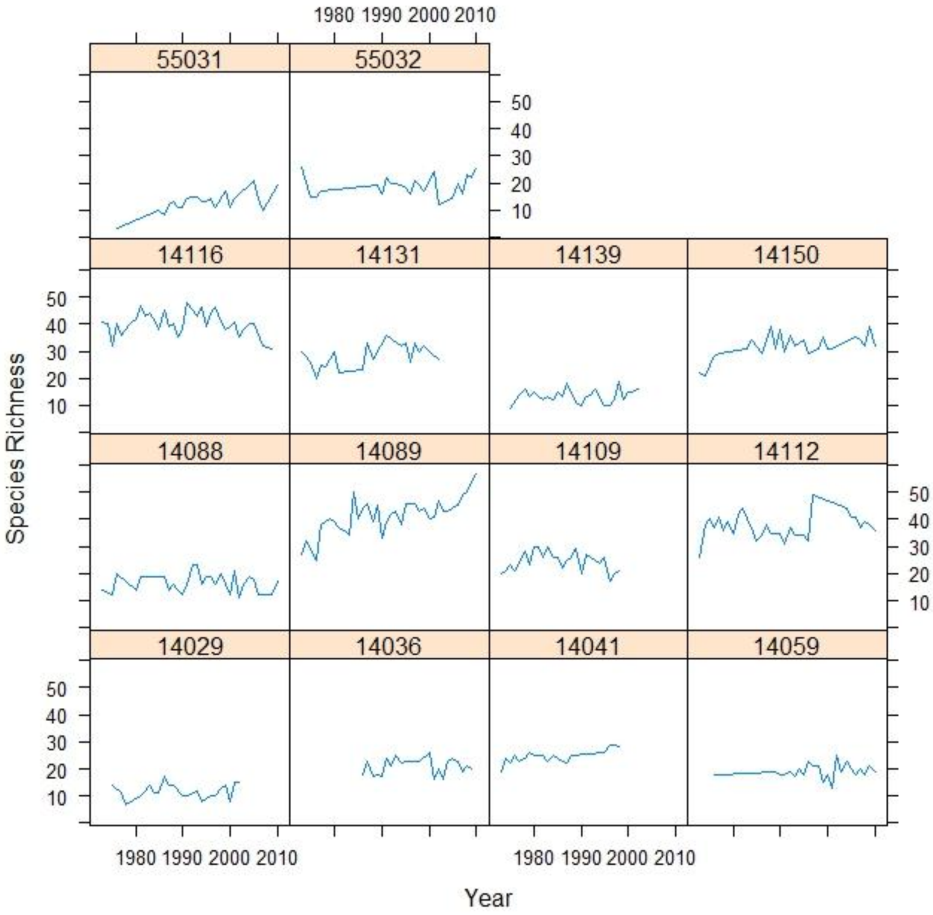


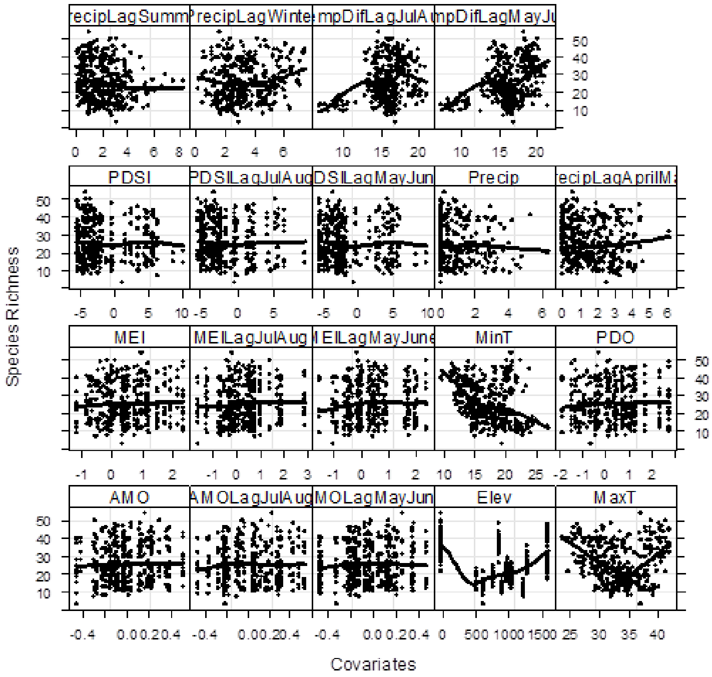
Figure 4. Yearly abundance on 14 routes: Species Richness.



Pearson correlation coefficients indicated collinearity between several covariates: MEI and PDO (Pearson correlation: 0.6), Year and AMO (Pearson correlation: 0.7), elevation and maximum temperature (Pearson correlation: -0.9), and also between maximum temperature and minimum temperature (Pearson correlation: 0.8). The PDO was dropped from the set of covariates, due to border line collinearity with the MEI. ENSO has a well-known effect in the southwestern region of the United States; hence MEI was retained as a covariate. The AMO index has been increasing since 1990, and as of 1995 the AMO index became positive (Enfield et al. 2001), therefore it was understandable that it would be collinear with increasing years; hence it was left as a covariate. Elevation was dropped from the set of covariates and maximum and minimum temperatures were converted into an index: difference between maximum and minimum temperature.

To show an example of a scatterplot, species richness versus each covariate was given in Figure 5. This type of plot was utilized to provide a visual interpretation of the covariates in relation to species richness and the other species/indices analyzed in this study.

Figure 5. Scatterplot of species richness versus each covariate. X-axis labels: Precipitation - millimeters; PDSI – negative numbers are wet soil moisture conditions and positive numbers are dry soil moisture conditions; MEI, AMO, and PDO – negative numbers are La Nina conditions and positive numbers are El Nino conditions; Temperature, ^{o}C; Elevation – meters.



Species Richness

Results of the IT approach are presented in Table 5 for Species Richness. The Akaike weights (*ω*) indicated that if sampling was repeated a large number of times then in 53% of the cases model 3 would be the best model, 19.3% of the times model 1, and 13.5% of the times model 5. When utilizing the Evidence Ratio (ER) Model 3 was found to be 2.75 times more likely to be the best model than Model 1 (ER) = 0.530/0.193), and 3.93 times more likely to be the best model than Model 5 [(ER = 0.530/0.135), Table 14]. Because the ER value was greater than two in both cases, Model 3 was determined to be the single best model; therefore, Model 3 will only be discussed.

Table 5. Species Richness Results of IT approach. The following represent the data in the table: The preferred model has the lowest Akaike Information Criteria (AIC); Degrees of freedom (*df*); ΔAIC is relative to the best model; and Akaike weight (*ω*).

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	288.8	2.022	0.193
2	5	293.26	6.484	0.021
3	8	286.78	0.000	0.530
4	6	292.86	6.087	0.025
5	7	289.52	2.742	0.135
6	5	297.42	10.639	0.003
7	8	290.87	4.098	0.068
8	6	299.39	12.615	0.001
9	7	293.64	6.864	0.017
10	5	301.88	15.106	0.000
11	8	295.56	8.789	0.007
12	6	303.74	16.966	0.000

Model 3 – Species Richness

Model 3 (Table 6) included the following climatic variables: MEILagMayJune, AMOLagMayJune, PrecipLagOctober-March (square root transformed), TempDifLagMayJune (difference between maximum and minimum temperature), and PDSILagMayJune. Results indicated that the MEILagMayJune, AMOLagMayJune, and PrecipLagOct-Mar had a weak signal [between a probability of 0.001-0.05 (Table 6)], and were different from a mean of zero at the 95% confidence level and their effect on species richness was positive. The effect of the PDSILagMayJune upon Species Richness was negative, which had a weak signal, [between a probability of 0.001-0.05 (Table 6)], at the 95% confidence level. For the random effect of routes, the estimated variance was 0.18338, and the estimated standard deviation was 0.42823.

Table 6. Fixed Effects for Species Richness – Model 3

Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.306318	0.231953	14.2540	<2e-16
MEILagMayJune	0.028233	0.013210	2.1370	0.0326
AMOLagMayJune	0.095827	0.047709	2.0090	0.0446
PrecipLagWinter	0.021659	0.009492	2.2820	0.0225
TempDifLagMayJune	-0.017882	0.012419	-1.4400	0.1499
PDSILagMayJune	-0.007345	0.003668	-2.0030	0.0452

In Model 3 none of the covariates (dependent or response variables), had a significance worth noting in the ecological realm, although it was important to recognize that the combination of the five mentioned covariates appeared to have had a noteworthy influence on species richness at the 14 BBS routes sampled. Overall, the data suggests that the rank of Model 3 as the single best model would remain the same if a series of independent samples of identical size were conducted again on the same desert routes. All covariates were weakly significant at the 95% critical level, except for the temperature lag, which did not have any significance in relation to its negative influence on abundance within Model 3 (Table 6 and Table 13).

Loggerhead Shrike

Results of the IT approach are presented in Table 7 for Loggerhead Shrike. The Akaike weights indicate that if sampling was repeated a large number of times then in 97% of the cases model 11 would be the single best model. Model 11 was 80.8 times more likely to be the best model than either Model 7 or 12 (ER = 0.970/0.012 in relation to both models). Model 11 is further discussed.

Table 7. Loggerhead Shrike Results of IT approach. The following represent the data in the table: The preferred model has the lowest Akaike Information Criteria (AIC); Degrees of freedom (*df*); ΔAIC is relative to the best model; and Akaike weight (*ω*).

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	771.274	15.658	0.000
2	5	778.702	23.087	0.000
3	8	766.450	10.834	0.004
4	6	773.572	17.956	0.000
5	7	769.600	13.984	0.001
6	5	780.117	24.502	0.000
7	8	764.440	8.824	0.012
8	6	773.063	17.447	0.000
9	7	774.704	19.088	0.000
10	5	780.038	24.422	0.000
11	8	0.000	0.000	0.970
12	6	764.372	8.756	0.012

Model 11 – Loggerhead Shrike

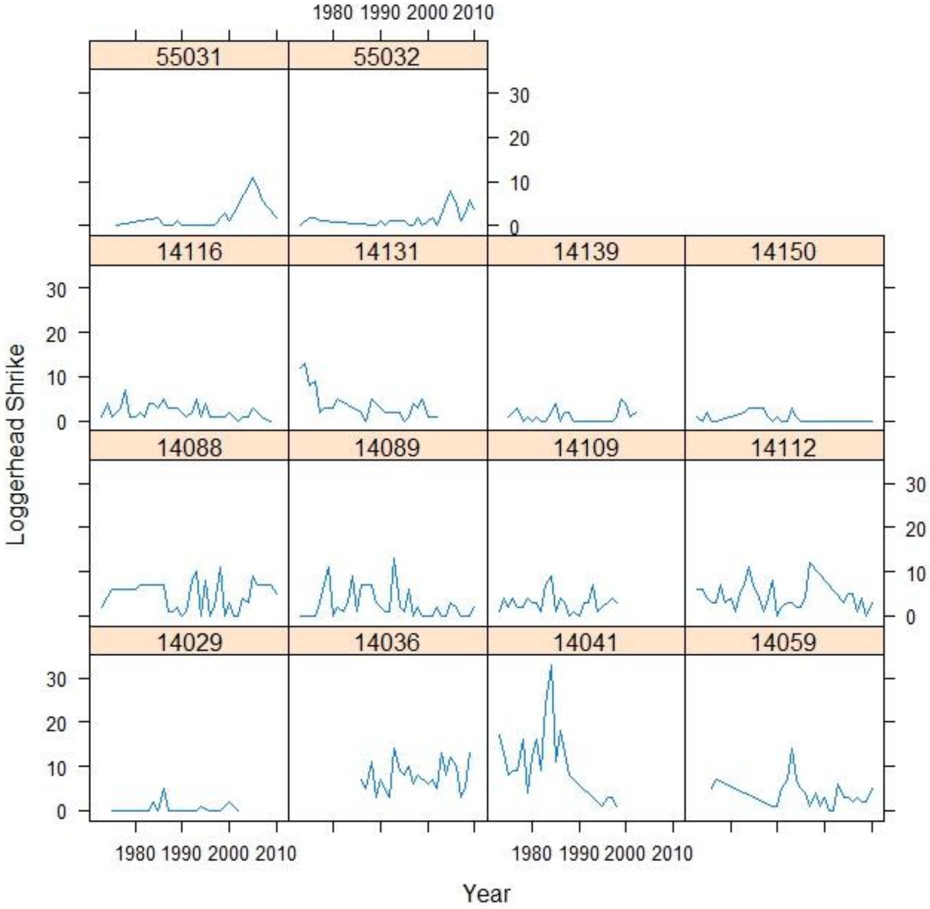
Model 11 (Table 8) was the best AIC model selected and included the following climatic variables: MEILagJulyAugust, AMOLagJulyAugust, PrecipLagJuly-September, TempDifLagJulyAugust, and PDSILagJulyAugust. Results indicated that the MEILagJulyAugust, PrecipLagJuly-September and the AMOLagJulyAugust have a weak signal [between a probability of 0.001-0.05 (Table 8)], and are different from a mean of zero at the 95% confidence level and their effect on Loggerhead Shrikes was positive. The effect of the PDSILagJulyAugust was positive and had a strong signal [less than a probability of 0.001 (Table 8)], at the 95% confidence level. For the random effect of routes, the estimated variance was 0.62697, and the estimated standard deviation was 0.79181.

Table 8. Fixed Effects for Loggerhead Shrike – Model 11.

Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.24892	0.83265	-0.299	0.76498
MEILagJulAug	0.10345	0.05144	2.011	0.04433
AMOLagJulAug	-0.65822	0.20956	-3.141	0.00168
PrecipLagSummer	0.10536	0.0427	2.468	0.0136
TempDifLagJulAug	0.05108	0.05011	1.019	0.30804
PDSILagJulAug	0.07298	0.01543	4.731	2.23E-06

In Model 11, all the covariates in combination appeared to play a very important role in the selection of this best model selected by the AIC process during the late summer months in the Mojave and Sonoran Deserts. Of special note was the positive influence of the strong signal for the PDSI (Table 8), which seems to indicate the extreme importance of the prevailing moisture conditions within the Loggerhead Shrike's insectivorous open woodland territory of the different BBS routes during the late summer months. Although the MEILagJulyAugust and PrecipLagJuly-September explanatory variables had a weak signal (between a probability of 0.001-0.05), not really noteworthy in the ecological realm, the AMOLagJulyAugust covariate did appear to have an important negative significance effect upon the Loggerhead Shrike abundance. This of course appeared to be offset by the strong and positive influence of moisture conditions upon abundance within the habitat of the Loggerhead Shrike as indicated by the PDSI values utilized within Model 11. Abundance on each of the 14 routes for the Loggerhead Shrike, over the 40 years investigated, varied (Figure 6).

Figure 6. Yearly abundance on 14 routes: Loggerhead Shrike



Black-throated Sparrow

Results of the IT approach are presented in Table 9 for the Black-throated Sparrow. The Akaike weights indicate that if sampling was repeated a large number of times then in 25.7% of the cases model 5 would be the best model, 20.5% of the times model 9, and 16.7% of the times model 6. Model 5 was 1.25 times more likely to be the best model than Model 9 (ER = 0.257/0.205), and 1.5 times more likely to be the best model than Model 6 (ER = 0.257/0.167). Comparison of the ER values indicated that each model was equally as likely to have an influence on abundance, since the ER value was less than two in both cases (Table 14). These three models are further discussed.

Table 9. Black-throated Sparrow: Results of IT approach. The following represent the data in the table: The preferred model has the lowest Akaike Information Criteria (AIC); Degrees of freedom (*df*); ΔAIC is relative to the best model; and Akaike weight (ω).

Model	***df***	**AIC**	**ΔAIC**	***Ω***
1	7	1151.09	2.881	0.061
2	5	1153.537	5.325	0.018
3	8	1152.708	4.497	0.027
4	6	1155.403	7.191	0.007
5	7	1148.212	0.000	0.257
6	5	1149.073	0.862	0.167
7	8	1150.200	1.988	0.095
8	6	1150.890	2.678	0.067
9	7	1148.671	0.459	0.205
10	5	1158.039	9.827	0.002
11	8	1150.270	2.058	0.092
12	6	1159.881	11.669	0.001

All three models (5, 9, and 6), were equally as likely, and appear to have a prominent seasonal influence upon Black-throated Sparrows. Both Model 5 and Model 6 fall into the second category of models, which were based around climatic influences that occurred during the spring months. In both cases, TempDifLagMayJune had a strong negative signal [less than 0.001 (Tables 10 and 12)], on the abundance of birds during the spring. Additionally, results for Model 5 indicated a weak, positive signal (between a probability of 0.001-0.05), for the MEILagMayJune (Table 10), and Model 6 indicated that the PrecipLagAprilMay had a weak, negative influence (between a probability of 0.001-0.05), on the abundance of Black-throated Sparrows (Table 12). Both weak signals were hardly noticeable in relation to ecological dynamics. Model 5 had an estimated variance of 4.13092, and an estimated standard deviation of 2.03247 for the random effects of routes, while Model 6 had an estimated variance of 4.001100, and an estimated standard deviation of 2.00029 for the random effects of routes.

Model 9, on the other hand, had a strong, positive signal [less than a probability of 0.001 (Table 11)], from ENSO affects, MEILagJulyAugust, and a weak, negative signal, [between a probability of 0.001-0.05 (Table 11)] resulting from PrecipLagSummer at the 95% confidence level. The estimated variance was 2.25997 and the estimated standard deviation was 4.001100 for random effect of routes. Abundance on each of the 14 routes for the Black-throated Sparrow, over the 40 years investigated, varied (Figure 7).

Table 10. Fixed Effects for Black-throated Sparrow – Model 5.

Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	4.87970	0.93393	5.225	1.74E-07
MEILagMayJune	0.10030	0.04660	2.152	0.031359
AMOLagMayJune	-0.18999	0.17561	-1.082	0.279322
PrecipLagAprilMay	-0.06493	0.03767	-1.723	0.084826
TempDifLagMayJune	-0.15102	0.04541	-3.325	0.00088

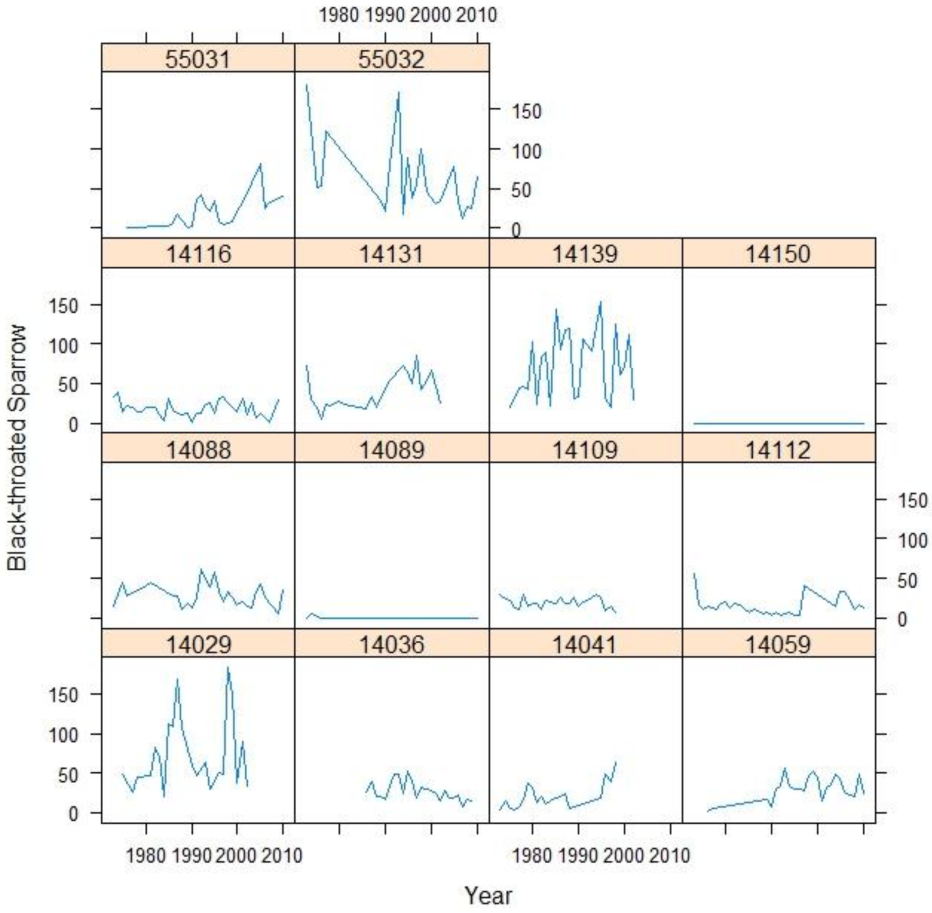
Table 11. Fixed Effects for Black-throated Sparrow – Model 9.

Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.70491	0.91812	2.946	0.003218
MEILagJulAug	0.14474	0.03923	3.690	0.000224
AMOLagJulAug	-0.09423	0.15760	-0.598	0.549883
PrecipLagSummer	-0.09610	0.03260	-2.948	0.003204
TempDifLagJulAug	-0.01063	0.04323	-0.246	0.805752

Table 12. Fixed Effects for Black-throated Sparrow – Model 6.

Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	5.45562	0.89286	6.110	9.94E-10
PrecipLagAprilMay	-0.08255	0.03682	-2.242	0.025
TempDifLagMayJune	-0.18216	0.04313	-4.224	2.40E-05

Figure 7. Yearly abundance on 14 routes: Black-throated Sparrow



Additional Species/Indices

Results of the IT approach for the other 12 species/indices are presented in Appendix A and B, and summarized in Table 13 and Table 14. Pearson residuals (Zuur et al. 2009) were plotted versus year, and for the following four species, Loggerhead Shrike, Northern Mockingbird, Red-tailed Hawk, and Western Kingbird, there were some small residual patterns, which were most likely due to one or two routes containing a cyclic pattern, leaving scope for further model improvements.

Table 13 and Appendix A provides a visual overview of the AIC models for each species/index that resulted from the IT results, and the resulting ER's are displayed in Table 14. The Fixed Effects for each species explanatory variables and the strength of their signals can be found in Appendix B. For five species/indices the ER's indicated that the first model was the single best model for the following: Borrowing Owl, Species Richness (results reported above), Individuals, Cactus Wren, and Loggerhead Shrike (results reported above). This means that the resulting ER was higher than "2" when comparing the best model with the second and third best models. The Burrowing Owl's abundance appears to be influenced by a combination of the covariates or explanatory variables within Model 1, with ENSO, the MEILagMayJune, having a positive weak signal (between a probability of 0.001-0.05). For Individuals, Model 9 was the single best model, with ENSO, the MEILagJulyAugust, appearing to have a positive strong signal, (less than a probability of 0.001) upon the total abundance of individuals. The Cactus Wren's abundance appears to be influenced by a positive strong signal (less than a probability of 0.001) by the PDSILagJulyAugust. A weak, positive signal (between a probability of 0.001-0.05), by the MEILagJulyAugust was hardly notable in the ecological realm at a 95 percent confidence interval.

For another five species/indices, the ER's indicated that the first two models were equally as likely to be selected when utilizing the IT approach and ER's: Red-tailed Hawk, Gambel's Quail, House Finch, Verdin, and Western Kingbird (Appendix A). The Fixed Effects for each species explanatory variables and the strength of their signals can be found in Appendix B. Upon examining model 1 and 5 (Table 13) for the Red-tailed Hawk it appeared that the covariates or explanatory variables affecting the abundance of this species occurred during the spring. The only covariate or explanatory variable that differed between the two models was precipitation, which seems to indicate that PrecipLagWinter (Model 1) and PrecipLagAprilMay (Model 5) were equally as likely to affect the abundance of this hawk, since the ER's were less than two (Table 13), although neither had a weak or a strong signal that was detected. For the Gambel's Quail, Model 2 and Model 1 (Table 13), it is noteworthy to recognize that these two models indicate that the spring season covariates in each model were equally as likely (Table 14) to contribute to their abundance. Additionally, PrecipLagWinter resulted in a weak, positive signal (between a probability of 0.001-0.05), as detected in both Model 2 and Model 1, although barely detectable in the ecological realm. The Verdin, like the Red-tailed Hawk had an equally likely IT result for Model 5 and Model 1 as indicated by ER's of less than two (Table 14). This suggests that the abundance of the Verdin, like the Red-tailed Hawk, can be equally influenced by either PrecipLagWinter or PrecipLagAprilMay, since they are the only two covariates that differed between the models that occurred during the spring (Table 13). It is important to note that in both Model 5 and Model 1, although precipitation occurred during a different season, the explanatory variable had neither a weak nor a strong signal. Additionally, for the Verdin, Model 5 and Model 1 (Table 13) indicated that there is a notable strong, positive influence, less than a probability of 0.001, resulting from the explanatory variable AMOLagMayJune. For the Western Kingbird, both Model 10 and Model 12 (Table 13) had an equally likely chance of influencing the abundance of this species during the late summer months. The only covariate that differed between Model 10 was the presence or absence of the influence of moisture conditions, the PDSI (Table 13). Additionally, both models indicated that there was a negative weak signal (between a probability of 0.001-0.05), from the influence of TempDifLagJulyAugust upon the Western Kingbird's abundance.

Five remaining species resulted in ER ratios that were less than 2.0 when examining the top three models for a particular species/index, indicating that each of them were just as likely to influence a particular birds abundance (Table 14, Appendix A, and Appendix B). These five birds included the Ash-throated Flycatcher, Horned Lark, Mourning Dove, Black-throated Sparrow, and Northern Mockingbird. For the Ash-throated Flycatcher, the covariates were different between precipitation (PrecipLagWinter, PrecipLagAprilMay, and PrecipLagJulyAugust), and also by the different temperatures that occurred in the Mojave and Sonoran Deserts during the spring and summer months (TempDifLagMayJune and TempDifLagJulyAugust). This may indicate that the sally hovering, insectivorous Ash-throated Flycatcher is able to meet its nesting and fledging foraging necessities both during the spring and late summer, under varying environmental influences, when conditions are good.

For the Horned Lark, it appeared that moisture conditions may have had an influence on abundance just as much as without moisture conditions, and winter precipitation may have had an effect on abundance just as much as spring precipitation (Table 13). The oceanic/atmospheric influence of ENSO had a positive weak signal (between a probability of 0.001-0.05), within each of the three models as indicated by the MEI results (Table 13).

Mourning Doves are prolific breeders that may raise up to six broods in a season. The resulting AIC models (Models 3, 7, and 11) were all equally as likely to affect the abundance of this ground foraging, granivorous species (Table 14). The models incorporated varying moisture conditions (PDSILagMayJune and PDSILagJulyAugust), and varying precipitation (PrecipLagWinter, PrecipLagAprilMay, and PrecipLagJuly-September) between seasons. Additionally, the oceanic/atmospheric influences based on the AMO varied between the spring (Models 3 and 7) with a negative strong signal (less than a probability of 0.001), and the late summer (Model 11) with a negative weak signal (between a probability of 0.001-0.05), effect upon abundance. In all three models the PDSI lags in both the spring and late summer season had a negative weak signal (between a probability of 0.001-0.05), influence upon Mourning Doves. This seems to indicate that the Mourning Dove’s abundance may be equally as likely to be influenced by the various combinations of covariates for these three models (3, 7, and 11) in all the seasons analyzed in this study.

For the Northern Mockingbird, models (3, 7, and 9) were equally as likely (Table 14). Both models 3 and 7 occurred during the spring and differ only in seasonal precipitation (PrecipLagWinter and PrecipLagAprilMay, respectively). Additionally, Model 3 and Model 7 had a positive strong signal influenced by the MEILagMayJune, and a negative strong signal influenced by the PDSI upon the abundance of Northern Mockingbirds. Both strong signals had less than a probability of 0.001. Model 9 differed from the Model 3 and Model 7, since this model dealt with late summer parameters. Additionally, the PDSI was not one of the covariates in Model 9, which indicated that moisture conditions did not appear to influence the abundance of Northern Mockingbirds during the late summer months (Table 13). Interestingly, the Northern Mockingbird is a ground foraging omnivorous species, which may have different food preferences during the spring and summer months that affect this species abundance.

Table 13. Comparison of IT results for alternative climatic models for each bird species/index, and significant variables within each model. At a 95% confidence level the following symbols represent the significance of variables within each model: (1) strong signal, is less than a probability of 0.001; (2) a weak signal (between a probability of 0.001-0.05) ; no significance (ɸ); and negative effect on the abundance (-). Other abbreviations: Observed Level Random Effect (OLRE), Temperature (Temp), Precipitation (Precip). Color coding: Red = Best Model, Blue= first 2 models just as likely, and Green = all 3 models just as likely.

Model	Model description	Best AIC Model	2nd Best	3rd Best
M1	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagWinter + TempDifLagMayJun + Route + OLRE	**BO** (MEI, 2) **RT** (AMO, 2)	**GQ** (Precip, 2) **HL** (MEI, 2) **V** (AMO, 1)	
M2	Species/Index ~ PrecipLagWinter + TempDifLagMayJun + Route + OLRE	**ATF** (ɸ) **GQ** (Precip, 2) **HF** (ɸ)		
M3	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagWinter + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	**SpR** (MEI, 2; AMO, 2; Precip, 2; PDSI, 2, -) **HL** (MEI, 2) **MD** (AMO, 1, - ; PDSI, 2, -)	**NM** (MEI, 1; PDSI, 1, -)	
M4	Species/Index ~ PrecipLagWinter + TempDifLagMayJun + PDSILagMayJun + Route + OLRE			

M5	Spcies/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagAprMay + TempDifLagMayJun + Route + OLRE	**BTS** (MEI, 2; Temp, 1, -) **V** (AMO, 1)	**RT** (AMO, 2)	**HL** (MEI, 2)
M6	Species/Index ~ PrecipLagAprMay + TempDifLagMayJun + Route + OLRE		**HF** ($^{\phi}$)	**ATF**$^{\phi}$ **BTS** (Precip, 2, -; Temp, 1, -)
M7	Species/Index ~ MEILagMayJun + AMOLagMayJun + PrecipLagAprMay + TempDifLagMayJun + PDSILagMayJun + Route + OLRE	**NM** (MEI, 1; PDSI, 1, -)	**MD** (AMO, 1, -; PDSI, 2, -)	
M8	Spcies/Index ~ PrecipLagAprMay + TempDifLagMayJun + PDSILagMayJun + Route + OLRE			
M9	Species/Index ~ MEILagJulAug + AMOLagJulAug + PrecipLagJul-Sept + TempDifLagJulAug + Route + OLRE	**Indiv** (MEI, 1)	**BTS** (MEI,1; Precip, 2, -)	**NM** (MEI, 1)
M10	Species/Index ~ PrecipLagJul-Sept + TempDifLagJulAug + Route + OLRE	**WK** (Temp, 2, -)	**ATF**$^{\phi}$	
M11	Species/Index ~ MEILagJulAug + AMOLagJulAug + PrecipLagJul-Sept + TempDifLagJulAug + PDSILagJulAug + Route + OLRE	**CW** (MEI, 2; PDSI, 1) **LS** (MEI, 2; AMO, 2, -; Precip, 2; PDSI, 1)		**MD** (MEI, 1; AMO, 2, -; PDSI, 2, -)
M12	Species/Index ~ PrecipLagJul-Sept + TempDifLagJulAug + PDSILagJulAug + Route + OLRE		**WK** (Temp, 2, -)	

Table 14. Summary of Evidence Ratios

Summary of Evidence Ratios	**ER**	**ER Interpretation**
Species/Index with best AIC Model		
Borrowing Owl	2.17	Model 1: 2.17 times more likely than Model 3
	2.72	Model 1: 2.72 times more likely than Model 5
Species Richness	2.75	Model 3: 2.75 times more likely than Model 1
	3.93	Model 3: 3.93 times more likely than Model 5
Individuals	2.42	Model 9: 2.42 times more likely than Model 3
	2.71	Model 9: 2.71 times more likely than Model 11
Cactus Wren	2.56	Model 11: 2.56 times more likely than Model 7
	3.61	Model 11: 3.61 times more likely than Model 8
Loggerhead Shrike	80.83	Model 11: 80.83 times more likely than Model 12
	80.83	Model 11: 80.83 times more likely than Model 7
First two models (Equally as likely)		
Red-tailed Hawk	1.07	Model 1: 1.07 times more likely than Model 5
	2.23	Model 1: 2.23 times more likely than Model 7
Gambel's Quail	1.10	Model 2: 1.1 times more likely than Model 1
	2.73	Model 2: 2.73 times more likely than Model 4
House Finch	1.08	Model 2: 1.08 times more likely than Model 6
	2.29	Model 2: 2.29 times more likely than Model 8
Verdin	1.73	Model 5: 1.73 times more likely than Model 1
	2.21	Model 5: 2.21 times more likely than Model 7
Western Kingbird	1.74	Model 10: 1.74 times more likely than Model 12
	12.64	Model 10: 12.64 times more likely than Model 11
All three models (Equally as likely)		
Ash-throated Flycatcher	1.05	Model 2: 1.05 times more likely than Model 10
	1.38	Model 2: 1.38 times more likely than Model 6
Black-throated Sparrow	1.25	Model 5: 1.25 times more likely than Model 9
	1.50	Model 5: 1.5 times more likely than Model 6
Horned Lark	1.12	Model 3: 1.12 times more likely than Model 1
	1.54	Model 3: 1.54 times more likely than Model 5
Mourning Dove	1.06	Model 3: 1.06 times more likely than Model 7
	1.91	Model 3: 1.91 times more likely than Model 11
Northern Mockingbird	1.25	Model 7: 1.25 times more likely than Model 3
	1.62	Model 7: 1.62 times more likely than Model 9

CHAPTER 4

Discussion

Although there are not any statistical models that represent ecological reality exactly (Burnham and Anderson 2004), the AIC models selected *a priori* for this study were based on sound ecological knowledge of birds, and are the best approximations of relationships in the Mojave and Sonoran Deserts given the available data. Kullback-Leibler divergence or information gain is a way of comparing two probability distributions: true and arbitrary. This Kullback-Leibler divergence or information gain is known to minimize information loss, or noise, when approximating reality, which Akaike incorporated into the AIC model when he designed it, therefore the AIC minimizes information loss or noise (Burnham and Anderson 2004). The AIC additionally rewards goodness of fit, and penalizes for addition of parameters. In this regard, the AIC penalty discourages overfitting, because the goodness of fit is improved when parameters are added to the model (Burnham and Anderson 2002).

In the present study, the AIC models indicate that a variety of abiotic variables are influencing each bird species population differently, not only from year to year, but also at each different route. In 1959, Odom noted that intrinsic influences such as temperature and rainfall play a major role in limiting population growth, and that food resources appear to be related to these irregular environmental factors. Balis and colleagues (2012) found that Gentoo Penguin populations at the Falkland Islands were observed to nest in relation to the Southern Oscillation Index, which may have been related to the availability of the penguin’s particular food sources. As a result, a year lag was established for their analysis. Additionally, in the Chihuahuan Desert, rodent populations were found to be correlated with at least a one year growing season lag, which correlated with the amount of stems associated with precipitation from the previous year (Ernest et al. 2000). In the present study conducted in the Mojave and Sonoran Deserts, year lags were also built into the models, based on the assumption that limiting food sources from year-to-year would influence population dynamics. Additionally, multipanel bird abundances visually indicated fluctuating populations from year to year, over a 40 year period (Figure 4, 6, and 7). The importance of the present study is that the abiotic factors, as indicated by the AIC results, appear to influence each bird species differently. Therefore, it appears imperative that when investigating climatic effects upon ecological systems that researchers are keenly aware that each species of bird, or possibly other types of organisms, due to different physiological and behavioral tolerances, are likely to respond to intrinsic factors uniquely.

The weather systems that are carried across the Mojave and Sonoran Deserts often originate from either ENSO or the AMO, or teleconnections that occur between the two oceanic-atmospheric systems (Enfield et al. 2001). As these two systems are carried by jet streams and associated wind currents across the basin and range topography, and mountain ranges located in the Mojave and Sonoran Deserts (Mares 1999), distribution of weather patterns tend to vary temporally and spatially (Archer and Predick 2008).

In this study, a data exploration of explanatory variables in relation to routes indicated a strong route effect, which provided substantial evidence of the variable explanatory variables (ENSO; AMO; Precipitation; Temperature Difference between maximum and minimum temperature; and the PDSI) that exist spatially and temporally in the deserts studied (Figure 4,6, and 7). Additionally, different responses to these spatial and temporal abiotic patterns were evident amongst bird species as noted by the AIC results (Table 13).

Results of this long-term study (40 years) indicate that there is indeed a climatic signal detected in the BBS bird abundances in relation to explanatory variables examined in the BCR of the Mojave and Sonoran Deserts. This study suggests that each bird species/index is responding to the signals differently, and with various intensities. There is not one bird species that is responding with the same signal strength, ranging from a weak signal (between a probability of 0.001-0.05), to a strong signal (less than a probability of 0.001) at the 95% critical level. Four important IT results utilizing AIC include bird species diversity indices responding (1) differently to each of the twelve AIC climatic models; (2) differently to covariates or explanatory climatic influences (MEI, AMO, Precipitation, Temperature, and PDSI) established within the models, in a positive or negative manner; (3) differently in relation to the significance intensities (Pr-values) to covariates or explanatory climatic variables within the models; and (4) differently to climatic influences present during the spring and summer months (Table 13).

The individualistic responses of bird diversity indices to different climatic variables incorporated into the models of the present study are supportive of previous research findings that also indicate that individual bird species respond independently to environmental factors (Gleason 1926, Taper et al. 1995, and Tingley et al. 2009). In a resurvey of birds, over a span of nearly one-hundred years, in the Sierra Nevada Mountains of California, Tingley and colleagues (2009) indicated that bird species were responding to changing temperature and precipitation patterns in individualistic manners.

Some bird species tracked both temperature and precipitation while other bird species appeared to track just temperature, or just precipitation.

In the present study, in the Mojave and Sonoran Deserts, the AIC models developed, *a priori,* did not investigate explanatory climatic variables separately. Instead, it was assumed that a set of intrinsic parameters (Table 13) influence the abundance of birds. For instance, out of the twelve models developed, only one set of intrinsic parameters resulted in the single best model selected, via the AIC, for Species Richness. In this model, it wasn't just one or two climatic variables that affected Species Richness from year to year; instead, it was the combination of variables in Model 3: ENSO, the AMO, Precipitation, Temperature, and the PDSI (Table 13). In this particular model a year's lag in winter precipitation from October-March played a role in the abundance of birds, although the other variables occurring with a year's lag in May and June also played a role in the abundance of species richness. Within the model itself, ENSO, the AMO, and Precipitation all had a weak, positive influence on the abundance of Species Richness, while at the same time the PDSI had a weak, negative influence. None of these weak signals are hardly noticeable or detectable in the ecological realm, yet there is some type of influence via the combination of variables within the model. Amazingly, temperature did not have a weak or a strong influence when in combination with the other explanatory variables in Model 3 (Table 6). This result suggests that when managing an area or vegetation patch for species richness that it might be wise to maintain plant diversity and plant structure, both horizontally and vertically, so soil moisture conditions can be maintained. Additionally, the diversity of plants and structural dynamics among patches may be advantageous when trying to simulate habitat. A reduction in habitat through landscape alterations may reduce the ability of birds to adequately locate appropriate microhabitats where specific physiological and behavioral adjustments can be attained under changing climatic conditions.

Like species richness, the Loggerhead Shrike additionally had one single best model (Model 11). This particular bird species appears to be highly influenced by a set of intrinsic parameters that combine to create optimal conditions during the late summer months (Table 13). All the explanatory variables investigated are included in this model, except that the PDSI appears to have a very strong positive influence upon the abundance of the Loggerhead Shrike. This might suggest that a certain amount of vegetation cover needs to be maintained in areas that are being managed for Loggerhead Shrike, since a certain amount of vegetation cover might be necessary to provide a specific soil moisture threshold for prey species that the Loggerhead Shrike and its young depend upon for food. Under an increasing climatic temperature regime, dryer conditions may not favor NPP during the summer months, which would ultimately affect the abundance of available insects. Hence, variable climatic conditions in the Mojave and Sonoran Deserts could alter the future abundance of Loggerhead Shrikes. Additionally, removal of Loggerhead Shrike open woodland habitat through landscape alterations may cause a reduction of vegetation patches that help to maintain soil moisture at optimal levels for their insectivorous prey, resulting in decreasing Loggerhead Shrike abundances.

As global temperatures increase, ENSO climatic shifts are expected to become more extreme. In fact, some models reported by the United States Global Change Research Program (USGCRP) indicate that El Nino events will become more frequent and La Nina events will become stronger (USGCRP 2000). Overall, the impact of El

Nino upon the bird dynamics in the Warm Deserts of the United States could alter the functional groups that presently occur within various vegetation patches during the breeding season. Additionally, with the teleconnections that occur between ENSO and the AMO (Chase et al. 2005), community assembly patterns of birds among habitat patches in the Mojave and Sonoran Deserts are likely to change. Some bird species might go extinct in different areas of the Mojave and/or Sonoran Deserts if climatic variables are extreme and or persist over long periods of time. It is likely that birds with a wider range of physiological tolerances will be able to persist, and possibly increase in abundance, while other bird species would decrease or become extinct in different areas and/or regions of the deserts. Ultimately, species sorting might occur due to abiotic requirements of different bird species (Holyoak et al. 2005), where some birds go extinct in a particular area of either desert, or they might move to other vegetation patches or to edges surrounding the Mojave and Sonoran Deserts. The bird species that are able to physiologically remain in arid and semi-arid regions would likely be bird species that have the genetic fitness and the phenotypic plasticity to withstand the abiotic changes. Charmantier and colleagues (2008) also indicate that phenotypic plasticity enables birds to respond to changing climatic conditions.

The models developed in this study do not incorporate extrinsic interactions suggested by the realized niche concept, although they do provide a glimpse into the role of fundamental niche parameters (Hutchinson 1957) that may be affecting the abundance of birds in the BCR of the Mojave and Sonoran Deserts in relation to climatic variables: MEI, AMO, precipitation, temperature, and the PDSI. Additionally, route effects indicate a need to further explore topographical and other landscape dynamics, such as habitat dynamics (Table 4), disturbance and/or land-use alterations, and spatial distribution and structural dynamics of vegetation growth. Additionally, spatially and temporally, rainfall is very variable in the southwestern semi-arid ecosystems (Austin et al. 2004, Reynolds et al. 2004, Collins et al. 2008, and Augustine 2010). If increasing global temperatures, dryer conditions, and less precipitation continue, birds may be forced to move to different locations each year where adequate resources might be available during the nesting season or go locally extinct in specific regions.

Other known intrinsic fundamental niche parameters that may be influencing the abundance and diversity of birds, but not incorporated into the present models, may include the influence of wind, solar radiation (Wolf and Walsberg 1996 and Wolf 2000), extreme heat waves (McKechnie and Wolf 2010), proximity to water sources (Grinnell 1928, Hensley 1954, Raitt and Maze 1968, Wolf and Martinez del Rio 2003, and Dean 2004) and dimensional structure and form of the habitat (Grinnell 1922, MacArthur 1958, MacArthur and MacArthur 1961, Karr 1967, Pianka 1967, Rosenzweig and Winakur 1969, Tomoff 1974, Mares et al. 1977, Collins 1983, Petit et al. 1985, Rotenberry 1985, Mills et al. 1989, Mills et al. 1991, Olechnowski and Debinski 2008, and Block and Morrison 2010).

It is interesting to point out that soil moisture conditions, in relation to the PDSI, appear to play an important role in species richness within the BCR of the Mojave and Sonoran Deserts (Table 13). This may suggest that food sources related to ground dwelling insects and other arthropods, and/or grass seeds, and other plants that provide food for adult and fledging desert birds and protein rich larvae for nestlings, are important factors, which may contribute to the fluctuating abundance of species richness from year-to-year. It has been noted that in most deserts throughout the world, species richness is highly correlated to the amount of precipitation (Maclean 1996 and Waide et al. 1999), but in the North American deserts MacMahon and Wagner (1985) found inconclusive evidence of a positive correlation. In the warm southwestern deserts, Wiens (1991) suggests that species richness may be due to the diversity of topography and landscape characteristics. In this study, a set of intrinsic parameters seem to be affecting not only species richness, but also the abundance of the other 12 species/indices, versus any one particular parameter.

Fluctuating species/indices observed to fluctuate year-to-year on the BBS routes may also be due to semi-desert birds that visit the desert regions on a daily, or transient, basis. A number of birds frequenting the Mojave and Sonoran Desert regions may move in and out of habitats adjacent to the deserts where vegetation is more prevalent (Dean 2004). Brown (1986) noted seeing birds commute between the desert ecosystem and adjacent habitats on a daily basis, and Severenty (1971) indicated that North American bird species observed in the deserts were merely able to adapt to desert conditions. This statement appears to be supported by the fact that the majority of North American desert birds may be more habitat generalists versus desert specialists (Dean 2004).

When investigating the influence of climatic variables in relation to the distributional movement of bird species at the border regions of a known range, or within a specific range, region, or locality itself, it may be important to take a more holistic approach to the analysis of the impacts of climate change. The results of this study indicate that it may not just be temperature or precipitation, independently or in relation to each other, playing a major role in the observed abundance of birds in a particular area.

This finding seems to indicate that a number of climatic variables, or a set of intrinsic parameters may be influencing the presence or absence of a bird species in a particular locality, indicating that bird species independently respond to climatic variables at different levels of significance and intensity during and between particular seasons, versus just responding to a single climatic variable.

APPENDICES

Appendix A. IT Results: AIC Models

Species Richness (SpR)

Model	*df*	AIC	ΔAIC	*ω*
1	7	288.8	2.022	0.193
2	5	293.26	6.484	0.021
3	8	286.78	0.000	0.530
4	6	292.86	6.087	0.025
5	7	289.52	2.742	0.135
6	5	297.42	10.639	0.003
7	8	290.87	4.098	0.068
8	6	299.39	12.615	0.001
9	7	293.64	6.864	0.017
10	5	301.88	15.106	0.000
11	8	295.56	8.789	0.007
12	6	303.74	16.966	0.000

Individuals (Indiv)

Model	*df*	AIC	ΔAIC	*ω*
1	7	1811.451	5.944	0.024
2	5	1820.179	14.672	0.000
3	8	1807.277	1.770	0.191
4	6	1818.714	13.207	0.001
5	7	1810.756	5.250	0.034
6	5	1819.151	13.645	0.001
7	8	1808.285	2.779	0.115
8	6	1820.336	14.829	0.000
9	7	1805.507	0.000	0.463
10	5	1828.945	23.438	0.000
11	8	1807.499	1.993	0.171
12	6	1830.932	25.426	0.000

Ash-throated Flycatcher (ATF)

Model	*df*	AIC	ΔAIC	*ω*
1	7	723.563	2.645	0.053
2	5	720.919	0.000	0.198
3	8	725.211	4.292	0.023
4	6	722.702	1.783	0.081
5	7	723.633	2.714	0.051
6	5	721.575	0.656	0.143
7	8	725.612	4.694	0.019
8	6	723.545	2.626	0.053
9	7	722.601	1.683	0.086
10	5	721.021	0.103	0.188
11	8	724.572	3.653	0.032
12	6	722.942	2.023	0.072

Burrowing Owl (BO)

Model	*df*	AIC	ΔAIC	*ω*
1	7	410.453	0.000	0.430
2	5	414.289	3.836	0.063
3	8	412.001	1.547	0.198
4	6	416.285	5.832	0.023
5	7	412.454	2.001	0.158
6	5	418.204	7.751	0.009
7	8	414.339	3.885	0.062
8	6	418.173	7.720	0.009
9	7	416.118	5.665	0.025
10	5	418.752	8.299	0.007
11	8	417.559	7.106	0.012
12	6	419.756	9.303	0.004

Black-throated Sparrow (BTS)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	1151.09	2.881	0.061
2	5	1153.537	5.325	0.018
3	8	1152.708	4.497	0.027
4	6	1155.403	7.191	0.007
5	7	1148.212	0.000	0.257
6	5	1149.073	0.862	0.167
7	8	1150.200	1.988	0.095
8	6	1150.890	2.678	0.067
9	7	1148.671	0.459	0.205
10	5	1158.039	9.827	0.002
11	8	1150.270	2.058	0.092
12	6	1159.881	11.669	0.001

Cactus Wren (CW)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	740.450	8.818	0.006
2	5	739.892	8.261	0.008
3	8	737.148	5.517	0.031
4	6	736.274	4.642	0.048
5	7	738.558	6.927	0.015
6	5	741.268	9.636	0.004
7	8	733.514	1.882	0.192
8	6	734.197	2.565	0.136
9	7	740.260	8.628	0.007
10	5	742.497	0.865	0
11	8	731.632	0.000	0.491
12	6	735.863	4.231	0.059

Gambel’s Quail (GQ)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	621.22	0.190	0.290
2	5	621.032	0.000	0.319
3	8	623.178	2.146	0.109
4	6	623.027	1.995	0.117
5	7	627.269	6.238	0.014
6	5	628.758	7.726	0.007
7	8	627.815	6.783	0.011
8	6	627.863	6.831	0.010
9	7	625.426	4.395	0.035
10	5	626.638	5.606	0.019
11	8	625.240	4.209	0.039
12	6	625.774	4.743	0.030

House Finch (HF)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	1171.7	3.130	0.050
2	5	1168.57	0.000	0.240
3	8	1173.42	4.857	0.021
4	6	1170.35	1.783	0.099
5	7	1171.95	3.382	0.044
6	5	1168.72	0.151	0.223
7	8	1173.39	4.825	0.022
8	6	1170.22	1.652	0.105
9	7	1174.13	5.565	0.015
10	5	1170.33	1.763	0.100
11	8	1174.71	6.144	0.011
12	6	1171.04	2.478	0.070

Horned Lark (HL)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	1255.65	0.223	0.228
2	5	1259.06	3.636	0.041
3	8	1255.42	0.000	0.255
4	6	1259.84	4.421	0.028
5	7	1256.28	0.856	0.166
6	5	1261.39	5.962	0.013
7	8	1257.52	2.094	0.090
8	6	1263.38	7.960	0.005
9	7	1257.52	2.099	0.089
10	5	1262.04	6.621	0.009
11	8	1258.05	2.631	0.069
12	6	1262.91	7.490	0.006

Loggerhead Shrike (LS)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	771.274	15.658	0.000
2	5	778.702	23.087	0.000
3	8	766.450	10.834	0.004
4	6	773.572	17.956	0.000
5	7	769.600	13.984	0.001
6	5	780.117	24.502	0.000
7	8	764.440	8.824	0.012
8	6	773.063	17.447	0.000
9	7	774.704	19.088	0.000
10	5	780.038	24.422	0.000
11	8	0.000	0.000	0.970
12	6	764.372	8.756	0.012

Mourning Dove (MD)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	1249.67	6.761	0.012
2	5	1261.761	18.857	0.000
3	8	1242.903	0.000	0.367
4	6	1255.902	12.998	0.001
5	7	1249.693	6.790	0.012
6	5	1260.017	17.114	0.000
7	8	1243.023	0.119	0.346
8	6	1254.613	11.710	0.001
9	7	1246.239	3.336	0.069
10	5	1263.303	20.399	0.000
11	8	1244.202	1.299	0.192
12	6	1259.881	16.978	0.000

Northern Mockingbird (NM)

Model	***df***	**AIC**	**ΔAIC**	***ω***
1	7	1028.23	13.84	0.000
2	5	1045.859	31.476	0.000
3	8	1014.829	0.445	0.269
4	6	1039.142	24.758	0.000
5	7	1030.064	15.680	0.000
6	5	1043.195	28.811	0.000
7	8	1014.384	0.000	0.336
8	6	1037.874	23.491	0.000
9	7	1015.337	0.953	0.208
10	5	1044.330	29.946	0.000
11	8	1015.551	1.167	0.187
12	6	1044.032	29.648	0.000

Red-tailed Hawk (RH)

Model	***df***	**AIC**	**ΔAIC**	**ω**
1	7	470.874	0.000	0.261
2	5	473.931	3.057	0.057
3	8	472.691	1.818	0.105
4	6	475.447	4.573	0.027
5	7	471.006	0.132	0.244
6	5	475.471	4.597	0.026
7	8	472.482	1.608	0.117
8	6	475.437	4.563	0.027
9	7	475.477	4.603	0.026
10	5	474.220	3.347	0.049
11	8	475.996	5.122	0.020
12	6	474.592	3.718	0.041

Verdin (V)

Model	***df***	**AIC**	**ΔAIC**	**ω**
1	7	493.845	0.971	0.248
2	5	505.554	12.680	0.001
3	8	495.049	2.176	0.136
4	6	507.552	14.679	0.000
5	7	492.873	0.000	0.403
6	5	505.219	12.346	0.001
7	8	494.330	1.456	0.195
8	6	507.172	14.298	0.000
9	7	499.991	7.118	0.011
10	5	508.330	15.456	0.000
11	8	501.610	8.736	0.005
12	6	510.283	17.409	0.000

Western Kingbird (WK)

Model	***df***	**AIC**	**ΔAIC**	**ω**
1	7	669.389	9.191	0.005
2	5	665.506	5.307	0.035
3	8	671.382	11.183	0.002
4	6	667.483	7.284	0.013
5	7	669.127	8.928	0.006
6	5	665.289	5.090	0.039
7	8	671.117	10.918	0.002
8	6	667.289	7.090	0.014
9	7	664.160	3.961	0.068
10	5	660.199	0.000	0.493
11	8	665.264	5.065	0.039
12	6	661.301	1.102	0.284

Appendix B. IT Results: Fixed Effects. Observed Level Random Effects = OLRE

Species Richness (SpR) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.000000	0.000000	
Route	(Intercept)	0.183380	0.428230	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.306318	0.231953	14.2540	<2e-16
MEILagMayJune	0.028233	0.013210	2.1370	0.0326
AMOLagMayJune	0.095827	0.047709	2.0090	0.0446
PrecipLagWinter	0.021659	0.009492	2.2820	0.0225
TempDifLagMayJune	-0.017882	0.012419	-1.4400	0.1499
PDSILagMayJune	-0.007345	0.003668	-2.0030	0.0452

Species Richness (SpR) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.000000	0.000000	
Route	(Intercept)	0.182380	0.427060	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.319741	0.231595	14.334	<2e-16
MEILagMayJune	0.024019	0.013033	1.8430	0.0653
AMOLagMayJune	0.091965	0.047501	1.9360	0.0529
PrecipLagWinter	0.011730	0.008112	1.4460	0.1482
TempDifLagMayJune	-0.016021	0.012380	-1.2940	0.1956

Species Richness (SpR) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.00000	0.00000	
Route	(Intercept)	0.18367	0.42857	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.42001	0.23973	14.266	<2e-16
MEILagMayJune	0.02689	0.012700	2.1170	0.0343
AMOLagMayJune	0.10681	0.04792	2.2290	0.0258
PrecipLagAprilMay	-0.01245	0.01064	-1.1710	0.2418
TempDifLagMayJune	-0.018580	0.01269	-1.4650	0.1430

Individuals (Indiv) Model 9				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.149700	0.386910	
Route	(Intercept)	1.174100	1.083550	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	5.653800	0.479530	11.790	< 2e-16
MEILagJulAug	0.112210	0.021740	5.161	2.45E-07
AMOLagJulAug	0.103180	0.086660	1.191	0.234
PrecipLagSummer	-0.013440	0.018170	-0.740	0.46
TempDifLagJulAug	-0.012410	0.024010	-0.517	0.605

Individuals (Indiv) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.148760	0.385690	
Route	(Intercept)	1.339710	1.157460	
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	6.138240	0.510970	12.013	< 2e-16
MEILagMayJune	0.105180	0.026690	3.941	8.13E-05
AMOLagMayJune	-0.014920	0.095220	-0.157	0.8754
PrecipLagWinter	0.021860	0.019300	1.133	0.2574
TempDifLagMayJune	-0.050350	0.024910	-2.021	0.0432
PDSILagMayJune	-0.018	0.007	-2.498	0.0125

Individuals (Indiv) Model 11				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.14970	0.38691	
Route	(Intercept)	1.17400	1.08350	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	5.655480	0.479944	11.784	< 2e-16
MEILagJulAug	0.112153	0.021751	5.156	2.52E-07
AMOLagJulAug	0.103880	0.087065	1.193	0.233
PrecipLagSummer	-0.013649	0.018340	-0.744	0.457
TempDifLagJulAug	-0.012530	0.024053	-0.521	0.602
PDSILagJulAug	-0.000564	0.006630	-0.085	0.932

Ash-throated Flycatcher (ATF) Model 2				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.23797	0.48783	
Route	(Intercept)	4.47763	2.11604	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	0.996410	0.897730	1.110	0.267
PrecipLagWinter	0.023950	0.027620	0.867	0.386
TempDifLagMayJune	-0.018780	0.042170	-0.445	0.656

Ash-throated Flycatcher (ATF) Model 10				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.24131	0.49123	
Route	(Intercept)	4.55512	2.13427	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.11412	0.91462	1.218	0.223
PrecipLagSummer	0.02382	0.03303	0.721	0.471
TempDifLagJulAug	-0.02524	0.04466	-0.565	0.572

Ash-throated Flycatcher (ATF) Model 6				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.240830	0.490750	
Route	(Intercept)	4.532960	2.129070	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.18300	0.91909	1.287	0.198
PrecipLagAprilMay	-0.01099	0.03806	-0.289	0.773
TempDifLagMayJune	-0.02443	0.04345	-0.562	0.574

Burrowing Owl (BO) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.36461	0.60383	
Route	(Intercept)	10.95693	3.31013	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-4.59390	1.90826	-2.407	0.0161
MEILagMayJune	0.19258	0.09158	2.103	3.55E-02
AMOLagMayJune	0.62692	0.34262	1.830	0.0673
PrecipLagWinter	0.10496	0.07103	1.478	0.1395
TempDifLagMayJune	0.08005	0.10150	0.789	0.4303

Burrowing Owl (BO) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.35275	0.59393	
Route	(Intercept)	11.10494	3.33241	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-4.63840	1.89958	-2.442	1.46E-02
MEILagMayJune	0.20185	0.09163	2.203	2.76E-02
AMOLagMayJune	0.66558	0.34263	1.943	0.0521
PrecipLagWinter	0.13628	0.08504	1.603	0.109
TempDifLagMayJune	0.07445	0.10072	0.739	0.4598
PDSILagMayJune	-0.01803	0.02614	-0.690	0.4904

Burrowing Owl (BO) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.356650	0.597200	
Route	(Intercept)	10.371320	3.220500	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-4.15476	1.94887	-2.132	0.033
MEILagMayJune	0.22855	0.08711	2.624	8.70E-03
AMOLagMayJune	0.58132	0.34099	1.705	0.088
PrecipLagAprilMay	-0.03974	0.09509	-0.418	0.676
TempDifLagMayJune	0.08093	0.10281	0.787	0.431

Black-throated Sparrow (BTS) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.36472	0.60392	
Route	(Intercept)	4.13092	2.03247	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	4.87970	0.93393	5.225	1.74E-07
MEILagMayJune	0.10030	0.04660	2.152	0.031359
AMOLagMayJune	-0.18999	0.17561	-1.082	0.279322
PrecipLagAprilMay	-0.06493	0.03767	-1.723	0.084826
TempDifLagMayJune	-0.15102	0.04541	-3.325	0.000883

Black-throated Sparrow (BTS) Model 9				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.36458	0.60381	
Route	(Intercept)	5.10747	2.25997	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.70491	0.91812	2.946	0.003218
MEILagJulAug	0.14474	0.03923	3.690	0.000224
AMOLagJulAug	-0.09423	0.15760	-0.598	0.549883
PrecipLagSummer	-0.09610	0.03260	-2.948	0.003204
TempDifLagJulAug	-0.01063	0.04323	-0.246	0.805752

Black-throated Sparrow (BTS) Model 6				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.373800	0.611390	
Route	(Intercept)	4.001100	2.000290	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	5.45562	0.89286	6.110	9.94E-10
PrecipLagAprilMay	-0.08255	0.03682	-2.242	0.025
TempDifLagMayJune	-0.18216	0.04313	-4.224	2.40E-05

Cactus Wren (CW) Model 11				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.37510	0.61245	
Route	(Intercept)	6.05700	2.46110	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.76113	1.14900	-0.662	0.507696
MEILagJulAug	0.13903	0.05148	2.701	6.92E-03
AMOLagJulAug	-0.29012	0.21614	-1.342	0.179508
PrecipLagSummer	-0.01497	0.04281	-0.350	0.726494
TempDifLagJulAug	0.06657	0.05850	1.138	0.255186
PDSILagJulAug	0.054700	0.016290	3.358	0.000785

Cactus Wren (CW) Model 7				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.38353	0.61930	
Route	(Intercept)	6.15282	2.48050	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.85806	1.19698	-0.717	4.73E-01
MEILagMayJune	0.11938	0.06340	1.883	5.97E-02
AMOLagMayJune	-0.36312	0.23962	-1.515	0.12967
PrecipLagAprilMay	0.09897	0.05124	1.932	0.05342
TempDifLagMayJune	0.05580	0.05918	0.943	0.34574
PDSILagMayJune	0.04059	0.01511	2.687	0.00722

Cactus Wren (CW) Model 8				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.404230	0.635790	
Route	(Intercept)	6.185880	2.487140	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.38223	1.16937	-0.327	0.74377
PrecipLagAprilMay	0.07577	0.05116	1.481	1.39E-01
TempDifLagMayJune	0.03238	0.05764	0.562	0.574
PDSILagMayJune	0.04513	0.01475	3.060	0.002

Gambel's Quail (GQ) Model 2				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	1.10480	1.05110	
Route	(Intercept)	10.64880	3.26330	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-2.48728	1.88794	-1.317	1.88E-01
PrecipLagWinter	0.19369	0.06932	2.794	0.0052
TempDifLagMayJune	0.02223	0.09928	0.224	0.8228

Gambel's Quail (GQ) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	1.06250	1.03080	
Route	(Intercept)	10.59590	3.25510	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-3.11381	1.96962	-1.581	0.1139
MEILagMayJune	0.01713	0.11411	0.150	0.8807
AMOLagMayJune	0.76203	0.39649	1.922	0.0546
PrecipLagWinter	0.17576	0.07126	2.467	0.0136
TempDifLagMayJune	0.06595	0.10587	0.623	0.5334

Gambel's Quail (GQ) Model 4				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	1.1044	1.0509	
Route	(Intercept)	10.6411	3.2621	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-2.4899	1.88816	-1.319	1.87E-01
PrecipLagWinter	0.19022	0.08591	2.214	0.0268
TempDifLagMayJune	0.02331	0.10052	0.232	8.17E-01
PDSILagMayJune	0.00209	0.03092	0.0680	0.9461

House Finch (HF) Model 2				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.79524	0.89176	
Route	(Intercept)	1.50789	1.22796	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.28281	0.97738	3.359	0.000783
PrecipLagWinter	0.01976	0.04003	0.494	6.22E-01
TempDifLagMayJune	-0.09625	0.05567	-1.729	0.083841

House Finch (HF) Model 6				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.79366	0.89088	
Route	(Intercept)	1.52734	1.23585	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.49807	1.00986	3.464	5.32E-04
PrecipLagAprilMay	-0.01640	0.05458	-0.300	7.64E-01
TempDifLagMayJune	-0.10382	0.05744	-1.807	0.07071

House Finch (HF) Model 8				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.791990	0.889940	
Route	(Intercept)	1.517730	1.231960	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.44184	1.01147	3.403	0.000667
PrecipLagAprilMay	-0.02168	0.05503	-0.394	6.94E-01
TempDifLagMayJune	-0.09895	0.05777	-1.713	0.087
PDSILagMayJune	0.01110	0.01560	0.711	0.477

Horned Lark (HL) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.97790	0.98889	
Route	(Intercept)	2.53450	1.59201	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.08926	1.18394	1.765	7.76E-02
MEILagMayJune	0.21772	0.07506	2.901	0.00373
AMOLagMayJune	-0.24392	0.27209	-0.896	0.37002
PrecipLagWinter	0.08142	0.05521	1.475	0.1403
TempDifLagMayJune	-0.04396	0.06718	-0.654	0.51291
PDSILagMayJune	-0.031050	0.02067	-1.5020	0.1331

Horned Lark (HL) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.98910	0.99454	
Route	(Intercept)	2.52540	1.58916	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.20686	1.18510	1.862	0.06258
MEILagMayJune	0.20122	0.07458	2.698	0.00697
AMOLagMayJune	-0.26832	0.27272	-0.984	0.32519
PrecipLagWinter	0.03793	0.04722	0.803	0.42185
TempDifLagMayJune	-0.03973	0.06738	-0.590	0.55541

Horned Lark (HL) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.9900	0.9950	
Route	(Intercept)	2.5040	1.5824	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.30825	1.23757	1.865	6.22E-02
MEILagMayJune	0.21895	0.07211	3.036	0.0024
AMOLagMayJune	-0.25691	0.27598	-0.931	3.52E-01
PrecipLagAprilMay	0.00468	0.06217	0.0750	0.9400
TempDifLagMayJune	-0.03906	0.06966	-0.561	0.575

Loggerhead Shrike (LS) Model11				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.43061	0.65621	
Route	(Intercept)	0.62697	0.79181	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.24892	0.83265	-0.299	0.76498
MEILagJulAug	0.10345	0.05144	2.011	0.04433
AMOLagJulAug	-0.65822	0.20956	-3.141	0.00168
PrecipLagSummer	0.10536	0.0427	2.468	0.0136
TempDifLagJulAug	0.05108	0.05011	1.019	0.30804
PDSILagJulAug	0.07298	0.01543	4.731	2.23E-06

Mourning Dove (MD) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.56717	0.75310	
Route	(Intercept)	1.72497	1.31340	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.12143	0.91134	3.425	6.15E-04
MEILagMayJune	0.14520	0.05690	2.552	1.07E-02
AMOLagMayJune	-0.76176	0.20741	-3.673	0.00024
PrecipLagWinter	0.02786	0.04118	0.676	0.498734
TempDifLagMayJune	-0.07018	0.05138	-1.366	0.171979
PDSILagMayJune	-0.04765	0.01602	-2.974	0.002938

Mourning Dove (MD) Model 7				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.567740	0.753490	
Route	(Intercept)	1.701740	1.304510	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.36195	0.94869	3.544	0.000394
MEILagMayJune	0.14434	0.05732	2.518	1.18E-02
AMOLagMayJune	-0.73669	0.20892	-3.526	0.000
PrecipLagAprilMay	-0.02718	0.04686	-0.580	0.562
TempDifLagMayJune	-0.07599	0.05292	-1.436	0.151046
PDSILagMayJune	-0.04088	0.01382	-2.957	0.003103

Mourning Dove (MD) Model 11				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.57434	0.75785	
Route	(Intercept)	1.50602	1.22720	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.16650	0.86016	2.519	0.011779
MEILagJulAug	0.16534	0.04627	3.573	3.52E-04
AMOLagJulAug	-0.53653	0.18979	-2.827	0.004699
PrecipLagSummer	-0.023472	0.03926	-0.598	0.549936
TempDifLagJulAug	0.001164	0.049905	0.023	0.981386
PDSILagJulAug	-0.029479	0.014624	-2.016	0.043821

Northern Mockingbird (NM) Model 7				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.81095	0.90053	
Route	(Intercept)	0.54331	0.73710	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.56904	0.94556	1.659	9.70E-02
MEILagMayJune	0.37850	0.07179	5.272	1.35E-07
AMOLagMayJune	-0.03543	0.264	-0.134	0.893
PrecipLagAprilMay	-0.04336	0.05789	-0.749	0.454
TempDifLagMayJune	-0.03143	0.05491	-0.572	0.567
PDSILagMayJune	-0.074320	0.01744	-4.2600	0.0000

Northern Mockingbird (NM) Model 3				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.81359	0.90199	
Route	(Intercept)	0.53277	0.72991	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.25168	0.90029	1.390	0.164
MEILagMayJune	0.38468	0.07134	5.392	6.96E-08
AMOLagMayJune	-0.06746	0.26160	-0.258	0.796
PrecipLagWinter	0.01667	0.05030	0.332	0.74
TempDifLagMayJune	-0.02027	0.05280	-0.384	0.701
PDSILagMayJune	-0.079840	0.0201	-3.971	0.000

Northern Mockingbird (NM) Model 9				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.8169	0.9038	
Route	(Intercept)	0.5253	0.7248	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.89791	0.88075	2.155	3.12E-02
MEILagJulAug	0.34469	0.0589	5.852	4.86E-09
AMOLagJulAug	0.14816	0.23726	0.624	5.32E-01
PrecipLagSummer	-0.08922	0.04886	-1.8260	0.0679
TempDifLagJulAug	-0.03668	0.05339	-0.687	0.4921

Red-tailed Hawk (RT) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.17345	0.41647	
Route	(Intercept)	1.72014	1.31154	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.54528	1.034	-5.27E-01	0.5979
MEILagMayJune	0.08868	0.06758	1.312	1.89E-01
AMOLagMayJune	0.55302	0.25739	2.148	0.0317
PrecipLagWinter	0.03190	0.03987	0.800	0.4237
TempDifLagMayJune	0.00013	0.05949	0.002	0.9983

Red-tailed Hawk (RT) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.169040	0.411150	
Route	(Intercept)	1.765450	1.328700	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.67630	1.07128	-0.631	0.5278
MEILagMayJune	0.10907	0.06537	1.669	9.52E-02
AMOLagMayJune	0.52779	0.26362	2.002	0.045
PrecipLagAprilMay	0.03725	0.05240	0.711	0.477
TempDifLagMayJune	0.01052	0.06089	0.173	0.8629

Red-tailed Hawk (RT) Model 7				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.16904	0.41114	
Route	(Intercept)	1.77893	1.33377	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.66973	1.07277	-0.624	0.5324
MEILagMayJune	0.09618	0.06770	1.421	1.55E-01
AMOLagMayJune	0.51327	0.26376	1.946	0.0517
PrecipLagAprilMay	0.03281	0.05277	0.622	0.5342
TempDifLagMayJune	0.01162	0.06096	0.191	0.8489
PDSILagMayJune	0.01164	0.01596	0.729	0.4658

Verdin (V) Model 5				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.47417	0.68860	
Route	(Intercept)	6.10379	2.47060	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.51489	1.54710	-0.333	0.739278
MEILagMayJune	0.12352	0.08753	1.411	1.58E-01
AMOLagMayJune	1.15564	0.31419	3.678	0.000235
PrecipLagAprilMay	-0.08461	0.08317	-1.017	0.308999
TempDifLagMayJune	-0.05206	0.08262	-0.63	0.528599

Verdin (V) Model 1				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.47521	0.68935	
Route	(Intercept)	6.23979	2.49796	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.85238	1.51341	-0.563	5.73E-01
MEILagMayJune	0.13414	0.08943	1.500	1.34E-01
AMOLagMayJune	1.11261	0.31049	3.583	0.000339
PrecipLagWinter	-0.01280	0.05664	-0.226	0.821232
TempDifLagMayJune	-0.03779	0.08145	-0.464	0.64268

Verdin (V) Model 7				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.474280	0.688680	
Route	(Intercept)	6.135810	2.477060	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	-0.52242	1.54804	-0.337	0.735761
MEILagMayJune	0.14336	0.09158	1.565	1.17E-01
AMOLagMayJune	1.18399	0.31706	3.734	0.000
PrecipLagAprilMay	-0.07603	0.08398	-0.905	0.365
TempDifLagMayJune	-0.05422	0.08269	-0.656	0.512006
PDSILagMayJune	-0.01556	0.02094	-0.743	0.457469

Western Kingbird (WK) Model 10				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.22651	0.47593	
Route	(Intercept)	4.21907	2.05404	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.05245	0.91651	2.239	2.51E-02
PrecipLagSummer	-0.01824	0.03443	-0.530	5.96E-01
TempDifLagJulAug	-0.10820	0.04600	-2.352	0.0187

Western Kingbird (WK) Model 12				
Random effects:				
Groups	**Name**	**Variance**	**Std.Dev.**	
OLRE	(Intercept)	0.226360	0.475770	
Route	(Intercept)	4.227500	2.056090	
Fixed effects:				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.04382	0.91627	2.231	0.0257
PrecipLagSummer	-0.01525	0.03455	-0.441	6.59E-01
TempDifLagJulAug	-0.10709	0.04597	-2.330	0.020
PDSILagJulAug	0.01215	0.01275	0.953	0.341

REFERENCES

Archer, S.R. and K.L. Predick. June 2008. Climate change and ecosystems of the southwestern United States. *Society for Range Management.* 30: 23-28.

Asmerom, Y., V.J. Polyak, and S.J. Burns. 2010, January 24. Variable winter moisture in the southwestern United States linked to rapid glacial climate shifts. *Nature Geoscience.* Macmillian Publishers Limited. 3: 114-117.

Augustine, D.J. 2010.Spatial versus temporal variation in precipitation in a semiarid ecosystem. *Landscape Ecology.* 25: 913-925.

Austin, A.T., L. Yahkjian, J.M. Stark, J. Belnap, A. Porporato, U. Norton, D.A. Ravetta, and S.M. Schaeffer. 2004. Water pulses and biogeochemical cycles in arid and Semiarid Ecosystems. *Oecologia.* 141: 221-235.

Ball, G.F. 1993. The neural integration of environmental information by seasonally breeding birds. *Am. Zoology.* 33: 185-199.

Baylis, A.M.M., A.F. Zuur, P. Brickle, and P.A. Pistorius. 2012. Climate as a driver of population variability in breeding Gentoo Penguins *Pygoscelis papua* at the Falkland Islands. *Ibis.* 154: 30-41.

Block, G. and M.L. Morrison. 2010. Large-scale effects on bird assemblages in desert Grasslands. *Western North American Naturalist.* 70: 19-25.

Bolker, B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M. Henry, H. Stevens, and Jada-Samone S. White. January 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution.* 24(3): 127-135.

Bowers, J.E. 2005. El Nino and displays of spring-flowering annuals in the Mojave and Sonoran Deserts. *Journal of the Torrey Botanical Society*. 132(1): 38-49.

Brown, J.H. 1986. The roles of vertebrates in desert ecosystems. In: Whitford WG (ed) Pattern and process in desert ecosystems. *University of New Mexico Press,* Albuquerque. 51-71.

Brown, J.H., Valone, T.J., and Curing, C.G. September 1997. Reorganization of an arid ecosystem in response to recent climate change. *Ecology: Natl. Acad. Sci. USA.* 94: 9729-9733.

Brown, J. H. and Morgan Ernest, S. K. November 2002. Rain and Rodents: Complex Dynamics of Desert Consumers. *BioScience*. 52(11).

Burnham and Anderson. 2002. Model selection and multimodel inference: A practical Information theoretic approach. 2nd Edition, *Springer*, New York.

Burnham and Anderson. 2004. Multimodel inference: Understanding AIC and BIC in model selection. *Sociological Methods & Research.* 33(2): 261-304.

Carey, C. 2009. The impacts of climate change on the annual cycles of birds. *Philosophical Transactions of the Royal Society*.364:3321-3330.

Charmantier, A., R.M. McCleery, L.R. Cole, C. Perrins, L.E.B. Kruuk, and B.C. Sheldon. 2008. Adaptive phenotypic plasticity in response to climate change in a wild bird population. *Science.* 320: 800-803.

Chase, M.K., N.Nur, and G.R. Geupel. 2005. Effects of weather and population density on reproductive success and population dynamics in a song sparrow (*Melospizamelodia)* population: A long-term study. *The Auk.* 122(2): 571-592.

Chase, T.N., R.A. Pielkesr, and R. Avissar. 2005. Teleconnections in the Earth System. Encyclopedia of Hydrological Sciences, Edited by M.G. Anderson. *John Wiley & Sons, Ltd*.

Collins, S.L. 1983. Geographic variation in habitat structure of the Black-throated Green Warbler (*Dendroica virens). The Auk.* 100: 382-389.

Collins, S.L., R.L. Sinsabaugh, C.Crenshaw, L.Green, A. Porras-Alfaro, M. Stursova and L.H. Zeglin. 2008. Pulse dynamics and microbial processes in arid land ecosystems. *Journal of Ecology*. 96: 413-420.

Dean WRJ. 2004. Nomadic desert birds. Adaptations in desert organisms. *Springer-Verlag*, Berlin, Heidelburg and New York.

Deviche, P., T. Small, P. Sharp, and K. Tsutsui. 2006. Control of luteinizing hormone and Testosterone secretion in a flexibly breeding male passerine, the Rufous-winged Sparrow. *Aimophioa carpalis. General and Comparative Endocrinology.* 149: 226-235.

Dunning, Jr., J.B. and J.H. Brown. 1982. Summer rainfall and winter sparrow densities: A test of the food limitation hypothesis. *The Auk.* 99: 123-129.

Enfield, D.B., A.M. Mestas-Nunez, and P.J.Trimble. 2001. The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental US. *Geophysical Research Letters.* 28(10): 2077-2080.

Ernest, S.K., J. H. Brown, and R. R. Paramenter. 2000. Rodents, plants, and precipitation: spatial and temporal dynamics of consumers and resources. *Oikos* 88: 470-482.

Ernest, S.K.M., J.H. Brown, K.M.Thibault, E.P. White and J.R. Goheen. 2008. Zero sum, the niche, and metacommunities: Long-term dynamics of community assembly. *The American Naturalist.* 172(6):E257-E269.

Gill, F.B. 2007. Ornithology, 3rd Ed. *W.H. Freeman and Company.* New York. 758.

Gleason, H. A. 1926. The individualistic concept of the plant association. *Bulletin of the Torrey Botanical Club.* 53: 7-26.

Grant, P.R. and P.T. Boag. April 1980. Rainfall on the Galapagos and the demography of Darwin’s finches. *The Auk.* 97(2): 227-244.

Grantz, K., B. Rajagopalan, M. Clark and E. Zagona. 2007. Seasonal Shifts in the North American Monsoon. *Journal of Climate. 20: 1923-1935.*

Grinnell, J. 1922. The trend of avian populations in California. *Science.* 56(1459): 671-676.

Grinnell, J. 1928. The presence and absence of animals. *Univ. Calif. Chronicle.* 30: 429-450.

Guido, Z. September 14, 2008. Climate: Climate dynamics. *Southwest Climate Change Network.* Retrieved on March 5, 2010 from www.southweclimatechange.org/climate/global/dynamics.

Hahn, T.P. and S.A. MacDougall-Shackleton. 2008. Adaptive specialization, conditional plasticity and phylogenetic history in the reproductive cue response systems of birds. *Philosophical transactions-Royal Society.* 363(1490): 267-286.

Heffelfinger, J.R., F.S. Guthery, R.J. Olding, C.L. Cochran, Jr., and C.M. McMullen. 1999. Influence of precipitation timing and summer temperatures on reproduction of Gambel’s Quail. *Journal Wildlife Management.* 63(1):154-161.

Hensley, M. 1954, April. Ecological relations of the breeding bird population of the desert biome In Arizona. *Ecological Monographs.* 24(2): 185-208.

Holyoak, M., M.A. Leibold, and R.D. Holt. 2005. Metacommunities: Spatial dynamics and Ecological communities. *The University of Chicago Press.*

Hu, Q. and G.D. Willson. Effects of temperature anomalies on the Palmer Drought Severity Index in the Central United States: A theoretical analysis. *International Journal of Climatology*. 20: 1899-1911.

Hutchinson, G. E. 1957. Concluding remarks. *Cold Spring Symposia on Quantitative Biology*. 22: 415-427.

IPCC (Intergovernmental Panel on Climate Change). 2007. IPCC Fourth Assessment Report: Working Group II Report "Impacts, Adaptations, and Vulnerability". Retrieved Online March 7, 2009 from http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter14.pdf.

Landscheidt, T. 2001. Trends in Pacific Decadal Oscillation subjected to solar forcing. Retrieved on March 3, 2010 from: http://www.john-daly. com/theodor/pdotrend.htm.

Lloyd, M. 1960. Statistical analysis of Marchant's data on breeding success and clutch-size. *Ibis.*102: 600-611.

MacArthur, R.H. 1958. Population ecology of some warblers of northeastern coniferous forests. *Ecology*. 39: 599-619.

MacArthur, R.H. and J. MacArthur. 1961. On bird species diversity. *Ecology*. 42: 594-598.

Maclean, G.L. 1976. Arid-zone ornithology in Africa and South America. *Proc. 16th Internationl Ornithological Congress, Canberra.* 1974:468-480.

Maclean, G.L. 1996. Ecophysiology of desert birds. *Springer*, Berlin Heidelberg New York.

MacMahon J.A. and FH Wagner. 1985. The Mojave, Sonoran and Chihuahuan Deserts of North America. In: Evenari M, Noy-Meir I, Goodall DW (eds) *Ecosystems of the World*, 12 A hot deserts and arid shrublands. Elsevier, Amsterdam. 105-202.

Mantua, N. 2011. PDO Index. Retrieved online March 7, 2011 from http://jisao.washingtonedu/pdo/PDO.latest

Mares, Michael A., Editor. 1999. Encyclopedia of Deserts. *University of Oklahoma Press: Norman.*

Mares, M.A., W.F. Blair, F. Enders, D. Greegor, A. Hulse, D. Otte, R. Sage, and C. Tomoff. 1977. Strategies and community patterns of desert animals. In: Solbrig O, Orians G (eds) convergent evolution in warm deserts: an examination of strategies and patterns in deserts of Argentina and the United States. Dowden Hutchinson and Ross, Stroudsburg. 107-163.

McGinnies, William G. February 4, 1976. Sonoran Desert: An overview of the Sonoran Desert. Second Annual Conference of the Consortium of Arid Lands Institutions (CALI), Tucson, Arizona. Http://alic.arid.arizona.edu/sonoran/documents/mcginnies//mcginniesmap.html.

McKechnie, A.E. and B.O. Wolf. 2010. Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. *Biology Letters.* 6(2): 253-256.

MDEP. 2010. Mojave Desert Initiative. Retrieved on March 4, 2010 from www.mojavedata.gov/mdi.html

Meserve, P.L., D.A. Kelt, W.B.Milstead, and J.R.Gutierrez. Thirteen years of shifting top-down and bottom-up control. *Bioscience.* July 2003. 53(7): 633-646.

Mills, G.S., J.B. Dunning, Jr., and J.M. Bates. 1989. Effects of urbanization on breeding bird community structure in southwestern desert habitats. *The Condor.* 91: 416-428.

Mills, G.S., J.B. Dunning, Jr., and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. *Wilson Bulletin.* 103(3): 468-479.

Mock, P.J. 1998. Energetic constraints to the distribution and abundance of the California Gnatcatcher. *Western Birds.* 29: 413-420.

Moller, A.P., Fieldler, W., and Berthold, P. 2006. Birds and climate change. USA: *Academic Press.*

Montgomery, D.C. and E.A. Peck. 1992. Introduction to linear regression analysis. New York: Wiley. 504 pp.

NOAA. 2009. El Nino Theme Page. Retrieved online December 10, 2009 from www.pmel.noaa.gov/tao/elnino/faq.html

NOAA. 2011a. Atlantic Oceanographic and Meteorological Laboratory: Frequently asked questions about the Atlantic Multidecadal Oscillation (AMO). Retrieved on Sept 9, 2011 from www.aoml.moaa.gov/phod/amo_faq.php.

NOAA. 2011b. NOAA Earth system research laboratory indices and forecasts: Atlantic Multidecadal Oscillation. *NOAA Earth System Research Laboratory, Physical Sciences Division.* Retrieved on December 29, 2011 from http://www.esrl.noaa.gov/psd/data/timeseries/AMO/

NOAA. 2011c. National Climatic Data Center. Pacific Decadal Oscillation (PDO). Retrieved online March 7, 2011 from http://www.ncdc.noaa.gov/teleconnections/pdo/

NOAA. 2011d. Multivariate ENSO Index (MEI). Retrieved online March 7, 2011 from http://www.cdc.noaa.gov/people/klaus.wolter/MEI

NOAA. 2012. NOAA/National Weather Service/Climate Prediction Center. Explanation. Retrieved on September 20, 2011 from http://www.cpc.ncep.noaa.gov/

Odum, E.E. 1959. Fundamentals of Ecology. *W.B. Saunders Company.*

Olechnowski, B.F.M. and D.M. Debinski. 2008. Response of songbirds to riparian willow habitat structure in the greater Yellowstone ecosystem. *The Wilson Journal of Ornithology.* 120(4): 830-939.

Overland, J.E. October, 2008. Pacific Decadal Oscillation. Retrieved online March 3, 2009 from: http://www.beringclimate.noaa.gov/data/BCinclude.php?filename=In_PDO

Parmesan, C., S. Gaines, L. Gonzalez, D.M. Kaufman, J. Kingsolver, A. Townsend Peterson, R. Sagarin. 2005. Empirical perspectives on species borders: from traditional biogeography to global change. *OIKOS. 101: 58-75.*

Patten, M.A., and J. T. Rotenberry. 1999. The proximate effects of rainfall on clutch size of the California Gnatcatcher. *The Condor.*101: 876-880.

Petit, D.R., K.E. Petit, and T.C. Grubb, Jr. 1985. On atmospheric moisture as a factor influencing Distribution of breeding birds in temperate deciduous forest. *Wilson Bulletin.* 97(1): 88-96.

Pianka, E.R. 1967. On lizard species diversity, North American deserts. *Ecology*. 48: 333-351.

PRISM Climate Group. 2010. Oregon State University, http://www.prismclimate.Org Created 4 Feb 2004.

PWRC. 2012. Raw BBS Data Search Menu. U.S. Geological Survey: Patuxent Wildlife Research Center. Retrieved online January 30, 2009 from: http://www.pwrc.usgs.gov/BBS

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Raitt, J.R. and R.L. Maze. 1968. Densities and species composition of breeding birds of a Creosotebush community in southern New Mexico. *The Condor.* 70: 193-205.

Reynolds, F.R., P.R. Kemp, K. Ogle, and R.J. Fernandez. 2004. Modifying the ‘pulse-reserve’ paradigm for deserts of North America: precipitation pulses, soil water, and plant responses. *Oecologia* 141:194-210.

Rosenzweig M.L., and J. Winakur. 1969. Population ecology of desert rodent communities: habitats and environmental complexity. *Ecology*. 50: 558-572.

Rotenberry, J.T. and J.A. Wiens. 1991. Weather and reproductive variation in shrub steppe sparrows: A hierarchical analysis. *Ecology.* 72(4): 1325-1335.

Scanlon, B.R., D.G. Levitt, R.C. Reedy, K.E.Keese, and M.J. Sully. 2005. Ecological controls on water-cycle response to climate variability in deserts. *PNAS.* 102(17): 6033-6038.

Scanlon, B.R., K.E. Keese, A.L. Fling, L.E. Flint, C.B. Gaye, W.M. Edmunds, and I. Simmers. 2006. Global synthesis of groundwater recharge in semiarid and arid regions. *Hydrological Processes.* 20: 3335-3370.

Severenty, D.L. 1971. Biology of desert birds. In: Farner DS, King JR (eds) *Avian biology* Academic Press, London. 287-339.

Simmons, R.E., P. Barnard, WRJ. Dean, G.F. Midgley, W. Thuiller, and G. Hughes. Climate change and birds: perspectives and prospects from southern Africa Ostrich 5(4): 295-308.

Small, T.W., Sharp, R.J., and Deviche, P. 2007. Environmental regulation of the reproductive system in a flexibly breeding Sonoran Desert bird, the Rufous-winged Sparrow, Aimophila carpalis. *Hormones and Behavior*. 51: 483-495.

Strand, C.R., T.W. Small, and P. Deviche. Plasticity of the Rufous-winged Sparrow, *Aimophila carpalis,* song control regions during the monsoon-associated summer breeding period. *Hormones and Behavior.* 52: 401-408.

Taper, M.L., K. Bohning-Gaese, and J.H. Brown. 1995. Individualistic responses of bird species to environmental change. *Oecologia.* 101: 478-486.

Tingley, M.W., W.B. Monahan, S. R. Beissinger, and C. Moritz. 2009. Birds track their Grinnellian niche through a century of climate change. *PNAS.* 106(2): 9637-19639.

Tomoff, C.S. 1974. Avian species diversity in desert scrub. *Ecology.* Vol. 55, pp. 396-403.

USGS. August 2004. Climatic Fluctuations, Drought, and Flow in the Colorado River Basin. *USGS: Science for a changing world.* USGS Fact Sheet 2004-3062 version 2.

Waide, R.B., M.R. Willig, C.F. Steiner, G. Mittelbach, L. Gough, S.I. Dodson, G.P. Juday, and R. Parmenter. 1999. The relationship between productivity and species richness. *Annun Rev Ecol Syst.* 30: 257-300.

Wiens, J.A. 1991. Ecological similarity of shrub-desert avifaunas of Australia and North America. *Ecology*.72 (2): 479-495.

Wolf, B. 2000. Global warming and avian occupancy of hot deserts; a physiological and Behavioral perspective. *Revista Chilena de Historia Natural.*73: 395-400.

Wolf, B.O. and C. Martinez del Rio. 2003. How important are columnar cacti as sources of water and nutrients for desert consumers? A review. *Isotopes Environ. Health Stud.* 39(1): 53-67.

Wolf, B.O. and G.E. Walsberg. 1996. Respiratory and cutaneous evaporative water loss at high environmental temperatures in a small bird. *J. Exp. Biol.* 199: 451-457.

WWF.2012. Wildfinder Terrestrial Ecoregions. http://www.worldwildlife.org

Zaan, R. 1996. The zebra finch: synthesis of field and laboratory studies. Oxford, UK: Oxford University Press.

Zuur, AF, Ieno, EN, and Smith, GM. 2007. Analyzing ecological data. *Springer*.

Zuur, AF, Ieno, EN, Meesters, EHWG. 2009a. A Beginner's Guide to R. *Springer*.

Zuur, AF, Ieno, EN, and Elphick, CS. 2009b. A protocol for data exploration to avoid common Statistical problems. *Methods in Ecology & Evolution.*1-11.

Zuur, AF, Ieno, EN, Saveliev, AA, and Smith, GM. 2009c. Mixed effects models and extensions in ecology with R. *Springer*.