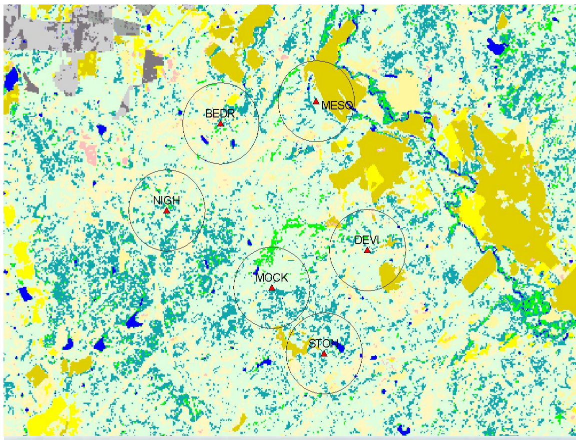
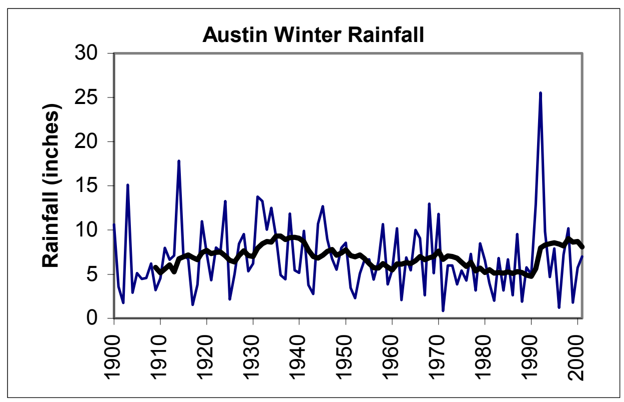
Climate, weather and landscape effects on landbird survival and reproductive success in Texas





a report to the

Texas Army National Guard Command: Adjutant General's Department and U.S. Department of Defense Legacy Resources Management Program

prepared by

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in collaboration with

Introduction

Over 600 bird species have been recorded in the state of Texas, which provides important stopover and breeding habitat for many neotropical migrant species. The nearly 360 breeding birds of Texas include 21 state threatened taxa and 12 federally endangered species, four of which are neotropical migratory songbirds. Threats to the survival of many of these species, such as the federally endangered Black-capped Vireo (*Vireo atricapillus*) and the Golden-cheeked Warbler (*Dendroica chrysoparia*), include breeding habitat loss or alteration, grazing, and fire suppression. In addition, these factors probably affect the Central American wintering habitat of these and other migrant species such as the Painted Bunting (*Passerina ciris*), which also falls

victim to the pet trade. Recent studies have also shown that seasonal weather conditions can dramatically affect adult survival and reproductive success. Effective management of avian communities in Texas requires that we quantify the relationships between avian population dynamics, the patterns and features of the landscape they inhabit, and the effects of fluctuations in environmental conditions.

The Institute for Bird Populations (IBP), through its Monitoring Avian Productivity and Survivorship (MAPS) program, collects breeding season banding data from 36 active constant-effort monitoring stations in Texas, including 18 stations divided equally among the two Texas Army National Guard training installations of Camp Swift and Camp Bowie, and the US Department of Army's Fort Hood. Of these, 17 stations have operated since 1994 and one since 1995. During this period we captured approximately 8,000 individual birds representing 35 landbird species. We banded each bird and identified it to species, age, and sex, as well as recording standard morphometrics (e.g., wing-chord length and weight). In addition we determined the breeding status of all species seen or heard within the boundaries of the monitoring station. We analyzed the banding data from each station to provide station-, year- and species-specific counts of the numbers of adults and young captured for ten of the most commonly captured species.

In this study, we related annual indices of reproductive success and apparent annual survival rates to seasonal climate indices, and also to Texas-wide temperature and precipitation data. We then related station- and species-specific indices of reproductive success, counts of adults and young, and several estimates of avian diversity to landscape variables obtained from analyses of 1-kilometer radii National Land Cover Data maps surrounding each station.

Background

Reproductive success and habitat

A critical management goal of MAPS is to identify management actions and conservation strategies to reverse population declines by quantifying relationships between MAPS reproductive indices and landscape-level habitat characteristics on the breeding grounds. Ideally, these habitat variables should be measured in the landscapes surrounding the stations that include the area from within which the dispersing juveniles captured by the MAPS protocol have originated. The size of this area varies somewhat from species to species, and probably varies geographically and among habitats for populations of a given species.

Previously (Nott 2000a), IBP established relationships between bird captures and landscape metrics based upon coverages provided by 30-m resolution National Land Cover Data (NLCD 2000, Bara 1994, Vogelmann et al. 2001) surrounding six MAPS stations at Big Oaks National Wildlife Refuge (NWR), Indiana (previously U.S. Department of Defense Jefferson Proving Ground). For four "forest interior" species (Acadian Flycatcher, Wood Thrush, Ovenbird, Kentucky Warbler) the numbers of adults and young captured varied as a function of mean forest patch size, the single class level landscape metric that showed the strongest correlation for each species.

Most importantly, that study revealed the existence of threshold values of woodland/forest patch size above which productivity levels were maximal. For each species, a threshold was found below which reproductive indices decreased rapidly with decreasing forest patch size and above which increases in forest patch size produced relatively small increases in reproductive indices. Both the threshold patch size and the sharpness of the threshold varied among species. The reproductive index for Ovenbird was the most sensitive to mean forest patch size; that is, its threshold patch size was highest (about 30 ha) and its threshold was least sharp of the four species. This is in accordance with Ovenbird literature (Porneluzi et al. 1993, Yahner 1993, Burke and Nol 1998). Reproductive indices for Acadian Flycatcher, Wood Thrush, and Kentucky Warbler were also sensitive to mean forest patch size but to a lesser degree.

Quantifying the relationships between landscape structure and vital rates is an essential step towards identifying the proximal causes of population change and developing management strategies to reverse local avian population declines. In this case levels of productivity for forest species could be increased in fragmented forest habitat by closing gaps between smaller forest patches. The landscape model we used to identify these relationships can now be used to predict the likely effects of alternative patterns of reforestation or proposed forest cutting regimes on local populations of forest birds.

Climate, weather and reproductive success

Weather and climate also play an important role in avian population dynamics (Sillett et al. 2000, Both and Visser 2001, Nott et al. in press) by affecting environmental conditions on both the breeding and wintering grounds. These conditions can affect survival as well as the condition of the birds prior to the breeding season, and the availability of food for nestlings and hence reproductive success. If, as many scientists predict, the global climate is shifting, it is imperative that we know how climate change will affect bird populations. Another reason for quantifying relationships between climate/weather and avian population dynamics is that considerable spatial heterogeneity exists in the effects of climate on local weather conditions. Therefore, we must be able to control for this spatial variation when we attempt to identify the relationships between landscape level attributes and avian population dynamics across regional scales.

Sillett et al. (2000) proposed that for the black-throated blue warbler (*Dendroica caerulescens*), drier conditions reduced invertebrate prey abundance on both their Caribbean wintering grounds, leading to increased adult mortality, and their New Hampshire breeding grounds, leading to reduced productivity. Although this mechanism is intuitive and could apply to many species breeding in Texas, there is a lack of supportive data for it. Nott et al. (in press) revealed stronger evidence for the link between invertebrate biomass and reproductive success. They found that drier, warmer conditions in the Pacific Northwest during the months March to May are associated with increased forest defoliation caused by lepidopteran larvae. In addition, during those years temperate wintering bird species, and to a lesser extent neotropical migrants, produced more juveniles per adult.

Expected results

Although there is considerable spatial variation in Texas weather, the summers are generally hot and humid and the winters mild and drier. In this kind of climate, where primary productivity may be limited by moisture during the growing season, we might expect higher rainfall prior to and during the breeding season to benefit avian productivity. For instance, in the arid Karoo region of South Africa local bird abundance increased as a function of new plant growth (Dean and Milton 2001). Also, because Texas is drought prone we might expect the presence of water to be an important determinant of avian abundance and diversity.

The Texas landscapes within which MAPS stations are located are very different from that of Big Oaks NWR, which is more densely forested. The 3 locations containing the 18 MAPS stations lie within the Prairie Parkland (Subtropical) Province as defined by Bailey et al. (1994). Typically, this province is represented by gently rolling to hilly oak woodlands and prairies. Elevations range from 300 to 800 feet and rainfall averages 35 to 45 inches per year. May or June usually brings a peak in monthly rainfall distribution. Big Oaks NWR, on the other hand, lies within the previously glaciated Bailey's Eastern Broadleaf Forest (Continental) Province typified, as the MAPS stations are, by a beech-maple forest with oak and hickory on drier sites with poorer soils. We expect that in Texas the relationships between landscape metrics and avian diversity, abundance, and reproductive success will be very different from Big Oaks NWR reflecting the ecological needs of species pre-adapted to utilizing more open habitat types in a more spatially heterogeneous landscape.

Methods

We collected bird-banding data from 18 Monitoring Avian Productivity and Survivorship (MAPS) constant-effort bird banding stations (DeSante *et al.,* 1995) distributed among 3 military installations in Texas: the Texas Army National Guard training installations of Camp Swift and Camp Bowie, and the US Department of Army's Fort Hood. Of these, 17 stations have operated since 1994 and one since 1995 (Table 1). We also collected seasonal climate indices and Texas-wide temperature and precipitation data (1994-2001). In addition we mapped and analyzed 1 km radii landscape surrounding each MAPS station. These data were extracted from the United States Geological Survey's (USGS) 30m resolution National Land Cover Dataset (NLCD).

Table 1. Names and geographic coordinates of 18 Monitoring Avian Productivity and Survivorship (MAPS) bird-banding stations located in Texas at US Department of the Army's Fort Hood (HOOD) and two Texas National Guard installations: Camp Swift (SWIFT) and Camp Bowie (BOWIE).

Location	Station	Station Abbr.	Latitude	Longitude
HOOD	Taylor Branch*	TABR	31.19	-97.57
HOOD	Shorthorn	SHOR	31.36	-97.66
HOOD	Taylor Field	TAYL	31.18	-97.56
HOOD	Engineer Lake	ENGI	31.15	-97.67
HOOD	Vireo	VIRE	31.16	-97.63
HOOD	Brookhaven Mountain	BROO	31.18	-97.62
SWIFT	Pipeline	PIPE	30.28	-97.33
SWIFT	East Loop East	EALE	30.26	-97.26
SWIFT	Wine Cellar Loop	WCLO	30.28	-97.32
SWIFT	Sandy Junction	SAJU	30.29	-97.29
SWIFT	McLaughlin Creek	MCCR	30.27	-97.28
SWIFT	East Loop West	EALW	30.26	-97.27
BOWIE	Stonehouse	STON	31.59	-98.91
BOWIE	Mockingbird Lane	MOCK	31.61	-98.92
BOWIE	Nighthawk	NIGH	31.62	-98.95
BOWIE	Bedrock	BEDR	31.64	-98.94
BOWIE	Mesquite	MESQ	31.65	-98.91
BOWIE	Devil's hill	DEVI	31.61	-98.89

* established in 1995 to replace the Deer Camp station that was discontinued because of extreme disturbance after the 1994 season.

MAPS protocol and assumptions

MAPS stations consist of ten 12 m, four-tier, 36 mm mesh nets distributed among the central 8 hectares of a 20-hectare area. Effort was standardized in that each station was operated each year for six morning hours once during each of nine ten-day periods. In most of Texas, the first ten-day period starts May 10th after the majority of spring migrants have passed through and breeding territories have been established. The last period ends August 8th during post-fledgling dispersal but before birds have amassed enough fat to begin their fall migration (IBP unpublished data). We assume, therefore, that the majority of captures consist of breeding (or unmated) adults and young from within the boundaries of the station and from the local landscape surrounding the station. This assumption is supported by an analysis of data from six stations located at Big Oaks National Wildlife Refuge, Indiana, that showed reproductive indices for four forest-interior species increased as a function of mean size of woodland patches within a 4 km radius of the station (Nott 2000a). Clearly, if migrating individuals biased the numbers of adults and young captured, these relationships would not exist.

Annual and station-specific productivity indices

For those species for which an average of at least four young were captured each year across all stations pooled, we calculated relative annual productivity indices (Peach *et al.,* 1996), representing the proportion of young in the annual catch (PI), using eight years (1994-2001) of landbird banding data (Appendix 1.1). Note that not all of these species (Table 2) were captured in sufficient numbers at each installation to be included in installation-specific analyses.

Table 2. List of nine landbird species commonly captured at some or all of 18 Texas MAPS stations during the summer breeding season (1994-2001). Three species winter primarily in Mexico and Central America, and six species are year-round residents (RESI).

Common Name	Scientific Name	Species Code	Migration Strategy
White-eyed Vireo*	*Vireo griseus*	WEVI	Mexico
Carolina Chickadee	*Poecile carolinensis*	CACH	Resident
Tufted Titmouse*	*Baeolophus bicolor*	TUTI	Resident
Carolina Wren	*Thryothorus ludovicianus*	CARW	Resident
Bewick's Wren*	*Thryomanes bewickii*	BEWR	Resident
Blue-gray Gnatcatcher	*Polioptila caerulea*	BGGN	Mexico
Northern Mockingbird	*Mimus polyglottos*	NOMO	Resident
Northern Cardinal*	*Cardinalis cardinalis*	NOCA	Resident
Painted Bunting*	*Passerina ciris*	PABU	Mexico

* enough data exists for these 5 species to construct time-dependent regional survival rate estimates

In order to relate reproductive success to landscape metrics associated with each station we needed a measure of species-specific reproductive success in terms of the lifetime of the station. For each of 7 species that breed at ten or more stations, we calculated a station-specific reproductive index (SRI) as the ratio of all individual young captured to all individual adults captured for the entire period (1994-2001) of operation. This index also incorporates an element of annual survival rate (or site fidelity). If, for instance a single pair lived for 10 years and produced three young every year the SRI would be 30/2=15. If individual adults and young were counted by year (year specific productivity indices), thereby removing the element of annual survival, then for the same pair the reproductive index would be 30/20=1.5. Of course, this example is extreme and in practice the differences between these indices are far smaller. In this study for each of seven species captured at 18 stations the SRI was an average of 17% higher than the year specific reproductive indices. Perhaps, for management purposes, such an index is more useful when identifying landscape patterns that correspond to demographic parameters that incorporate survival as well as reproduction. Annual counts of adults and young and reproductive indices are given for all stations pooled and by installation in Appendices 1.2-1.5.

Time-dependent survival rate estimates

For 5 species (see Table 2), it was possible to obtain time-dependent (1994-2001) estimates of adult survival probability by entering the capture histories of all adult birds captured at 18 MAPS stations into the mark-recapture model LOSSURVIV (designed and implemented by IBP in collaboration with Jim Nichols and Jim Hines of Patuxent Wildlife Research Center, MD). This model is a modification of SURVIV (White 1983) and provides survival rate estimates based on both between-year and within-year information (*sensu* Pradel 1997, Nott and DeSante *in press*). These estimates are unbiased by the numbers of transient adults captured each year (i.e. those individuals captured in only one year and, if captured more than once, all captures spanned a period less than seven days apart)

Species richness by migratory and breeding status

In accordance with the MAPS protocol every species banded, seen or heard during a visit to the station are recorded and assessed as to whether or not they are likely breeding at the station. Species are classified as migrants if they are recorded at a station that lies outside of their breeding range; transients if the station lies within the breeding range but there is no evidence of summer residency at the station in any year; occasional breeders are summer residents or suspected summer residents for half or fewer of the years the station was operated; usual breeders are summer residents for more than half of the years the station was operated, but not all years; and regular breeders are summer residents during all years the station was operated. We counted the number of species in each category, summed the total numbers of migrants and transients as “visitors”, summed all the breeding categories as “breeders”, and summed the total number of species detected at each station (Table 3). We related these numbers to landscape metrics measured within a 1 km radius of each station.

Table 3. Summary of numbers of species recorded at each of 18 Texas MAPS stations by migratory status and breeding status.

	TABR	SHOR	TAYL	ENGI	VIRE	BROO	PIPE	EALW	EALE	WCLO	SAJU	MCCR	STON	NIGH	MOCK	BEDR	MESQ	DEVI
Migratory Status																		
Migrants	12	18	14	13	14	13	8	8	17	14	6	10	9	5	8	12	3	13
Transients	22	34	27	39	24	26	18	23	31	26	21	21	22	23	27	30	29	33
All Visitors	34	52	41	52	38	39	26	31	48	40	27	31	31	28	35	42	32	46
Breeding Status																		
Occasional Breeders	10	12	14	7	12	10	6	7	5	8	4	8	17	11	8	11	18	15
Usual Breeders	8	9	9	3	3	8	5	4	9	3	5	6	11	5	9	8	5	8
Regular Breeders	19	13	13	13	14	13	14	11	6	14	10	11	15	16	11	14	17	15
All Breeders	37	34	36	23	29	31	25	22	20	25	19	25	43	32	28	33	40	38
All Species	71	86	77	75	67	70	51	53	68	65	46	56	74	60	63	75	72	84

Climate and weather data

For the period 1994-2001 we calculated fall, winter, spring and summer seasonal El Nino Southern Oscillation (ENSO) Precipitation Indices (ESPI) and North Atlantic Oscillation Indices (NAOI). We collected monthly ESPI values from the National Aeronautics and Space Administration (NASA 2001). ESPI is a satellite-based measure of large-scale atmospheric circulation (Curtis and Adler 2000) that determines the wind and storm patterns that likely affect birds' breeding or wintering habitat as well as their migratory routes. ESPI is positive during ENSO events when precipitation increases in the subtropical and tropical Pacific Ocean. We collected monthly NAOI values that reflect broad scale spatial atmospheric pressure patterns that affect northerly latitudes (Barnston and Livezy 1987) from the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center website, (www.cpc.ncep.noaa.gov/data/teledoc/nao.html; December 2001)..

We also collected seasonal accumulated precipitation and average temperature data for Texas from NOAA's NCDC website (http://lwf.ncdc.noaa.gov/oa/climate/research/cag3/TX.html). These data included fall (Sept-Nov), winter (Dec-Feb), spring (Mar-May), and summer (Jun-

Aug) seasonal datasets. These data are a spatial average of data from individual weather monitoring stations distributed across the whole state and represent a relative measure of seasonal conditions. These climate and weather data are shown in Table 4.

Table 4. Seasonal (1994-2001) Texas-wide precipitation and temperature provided by the National Weather Service, and climate indices provided by NASA (ENSO Precipitation Index) and NOAA (North Atlantic Oscillation Index). Fall and annual data are calculated starting in September the previous year, and winter starting in December the previous year. Win-Spr denotes December-May period, Fall-Spr denotes September-May, and year denotes September-August period. Those periods marked with an asterix (*) are only used for those analyses that include annual survival rate estimates (see below).

Climate variable	Season	1994	1995	1996	1997	1998	1999	2000	2001
Cumulative	Fall*		9.14	6.10	8.62	7.49	11.78	3.13	10.29
Seasonal	Winter	4.58	6.00	2.23	6.23	7.85	3.83	3.37	6.38
Precipitation	Spring	8.28	9.41	3.64	11.01	3.86	8.57	7.63	7.13
(inches)	Summer	6.09	7.80	10.60	8.39	6.11	7.34	6.45	7.18
	Win-Spr*		15.41	5.87	17.24	11.71	12.40	11.00	13.51
	Fall-Spr*		24.55	11.97	25.86	19.20	24.18	14.13	23.80
	Year*		32.35	22.57	34.25	25.31	31.52	20.58	30.98
Mean	Fall		66.50	65.93	65.13	65.53	68.80	67.03	65.27
Seasonal	Winter	48.30	50.60	49.40	47.90	49.10	51.70	52.10	46.10
Temperature	Spring	64.90	64.20	65.30	63.20	65.20	65.80	68.00	65.10
(degrees F)	Summer	82.30	81.00	81.80	80.70	84.30	81.90	82.30	83.10
	Win-Spr		57.88	58.05	56.52	56.18	58.05	59.58	56.03
	Fall-Spr		59.02	58.37	57.47	56.33	59.53	59.12	56.12
	Year		65.81	65.96	64.73	65.54	66.70	67.13	65.11
ENSO	Winter	-0.04	0.35	-1.11	-0.62	1.97	-1.06	-1.11	-0.93
Precipitation	Spring	-0.46	-0.35	-0.63	1.21	0.74	-1.53	-1.18	-0.88
Index	Summer	0.66	-0.69	-0.62	2.46	-0.90	-1.16	-1.04	-0.20
North Atlantic	Winter	0.77	0.90	-0.47	-0.07	-0.57	1.37	1.53	0.40
Oscillation	Spring	0.60	-0.87	-0.53	-0.90	0.20	-0.03	0.40	-0.13
Index	Summer	1.53	0.17	0.63	-0.03	-1.63	0.13	-0.53	-0.20

Landscape data and scale

In previous studies we looked at the relationships between station-specific productivity indices and landscape metrics of 2 or 4 km radii "local landscapes" around each MAPS station. These local landscapes are taken from the 30-m resolution National Land Cover Dataset (NLCD, http://landcover.usgs.gov/natllandcover.html, 2001). We mapped the geographic locations of 18 MAPS stations (Table 1) onto the NLCD coverage for southeast Texas (Figure 1).

Unfortunately, the MAPS stations used in this study are geographically close together and in many cases 2 or 4 km radii would overlap and introduce considerable spatial autocorrelation into the results. Also, because the Texas landscape in this study is spatially heterogeneous and very "patchy" we might expect ecological relationships to exist at smaller scales. For these reasons we chose to analyze local landscapes of 1 km radii around each station as denoted by the circles in Figures 2-4. Each radii was spatially analyzed using Arcview 3.2 (ESRI 1996) in conjunction with the Patch Analyst 2.2 extension (McGarigal and Marks 1994, Elkie et al. 1999).

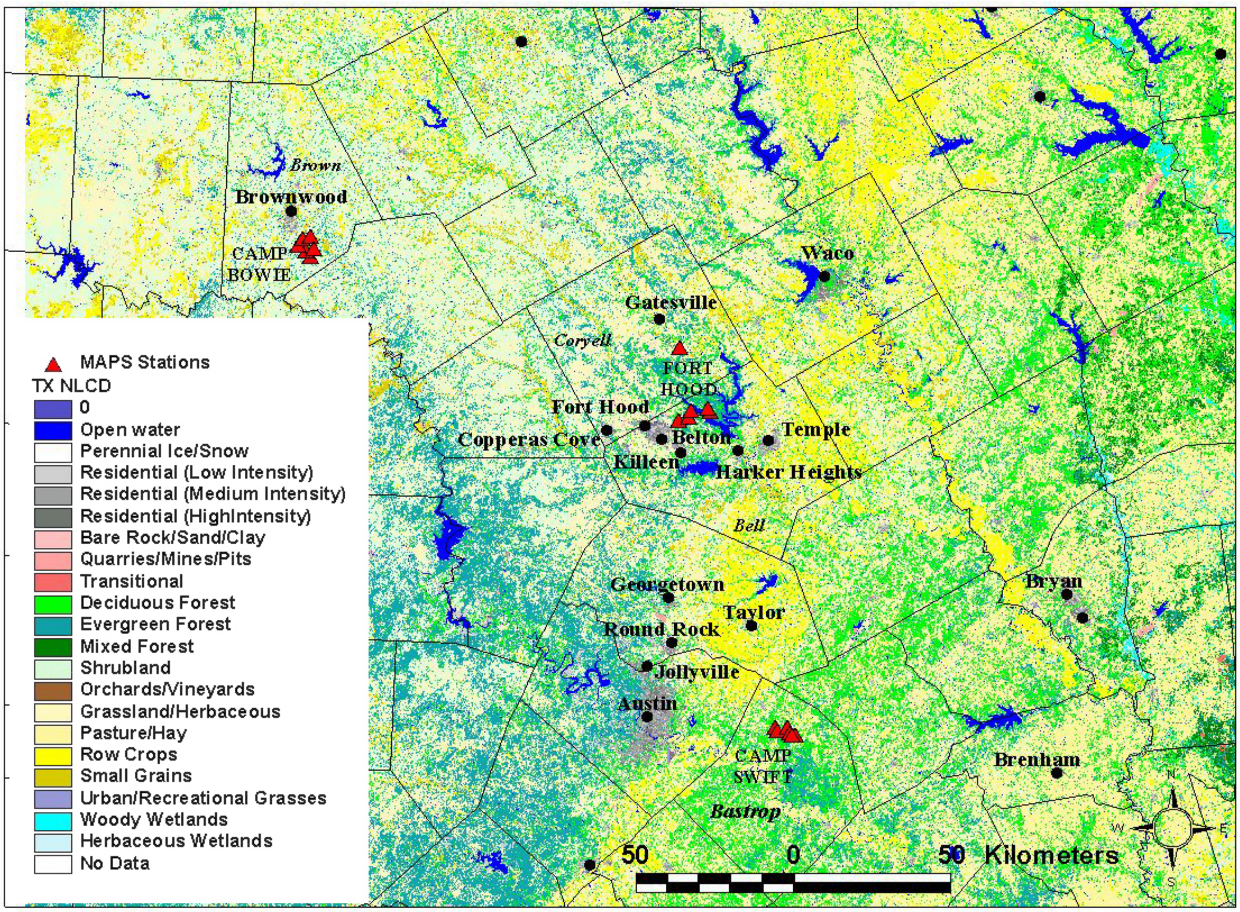

Figure 1. Map of central eastern Texas showing locations of 18 Monitoring Avian Productivity and Survivorship (MAPS) stations (red triangles) located on 3 military installations: Fort Hood in Bell and Coryell counties, Camp Swift in Bastrop County, and Camp Bowie in Brown County. Counties are outlined with black lines and names of cities (black dots) are also given. The land cover classifications are provided by the 30m resolution USGS National Land Cover Dataset (TX NLCD of 21 land cover classes (see key and Appendix 4.1). At this scale the landscape is dominated by deciduous woodland (green), evergreen woodland (dark green) and agricultural land (yellow).

It is important to note that we analyzed the landscapes at two different levels: the ”landscape” level and the “class” level. At the landscape level, statistics from Patch Analyst reflect the number, size and spatial distribution of all patches (including all cover classes) that provide measures of landscape heterogeneity (alpha diversity of patch size and class) and levels of landscape fragmentation. At the class level, statistics from Patch Analyst reflect the size, shape and distribution (within the rest of the landscape) of each cover class (e.g., deciduous forest) listed in Appendix 4.1 in the context of the rest of the landscape.

In addition, we aggregated NLCD cover types to produce 4 new cover types of possible biological significance as follows. Combining the *Herbaceous Planted/Cultivated* types (Classes 81, 82, and 83; see Appendix 4.1) with *Herbaceous Upland* grassland (Class 71) provided an agricultural/grassland type (**Agr/Gr**). This was further combined with *Shrubland* (Class 51) to provide an **Open** habitat cover type. We combined deciduous and evergreen *Forested Upland* types to represent total **Forest** cover. Finally, we combined the coverage of open *Water* (Class 11) with *Wetlands* Emergent Herbaceous type (Class 92) to provide a **Wet** habitat type. We then only calculated the area (hectares) covered (CA) and mean patch size (MPS) of each new type (Appendix 4) within a 1 km radius of each MAPS stations. High resolution maps (1 pixel = 30m x 30m) depicting the landscapes surrounding clusters of MAPS stations (and 1 km radii) at each installation are shown in Figures 2-4. Within the scope of this investigation there was no opportunity to manipulate the NLCD datasets to express edge statistics for the aggregate types.

The percentages of water, forest, and shrub cover as well as the identities of dominant species associated with each station were recorded as part of the MAPS Habitat Structure Assessment (Nott 2000b) which assesses the pattern and composition of the habitats within the 20 ha area of each banding station (Tables 5-7). Various deciduous and evergreen oak species, combined with juniper, cedar and/or mesquite, dominate these stations. MAPS stations at Fort Hood and Camp Bowie are located in Bailey (Bailey et al. 1994) sub-ecoregion 255A (western cross timbers and prairie) and are characterized by open woodland and savannah habitats (<40% forest cover) featuring species more typical of the southwestern region of the United States. Camp Swift, which lies in Bailey sub-ecoregion 255C (oak woods and prairie), is more densely wooded with taller trees (~50% forest cover) such as post oak and other species more typical of the southeastern United States.

Fort Hood

Table 5. List of station names, abbreviations, a brief description of the habitat and estimates of the percent cover of water forest and shrub within the boundaries of each MAPS station at Fort Hood.

Station	Abbr.	Description	%water	%forest	%shrub
Taylor Branch	TABR	Mixed hardwood (juniper, oak, pecan) forest, open field, pecan bottomland, juniper scrub/grassland.	0	40	40
Shorthorn Landing Strip	SHOR	Mesquite/juniper/cedar successional oldfield, mesquite flat, dense mixed live oak woodland	0	40	60
Taylor Field	TAYL	Sumac/oak/juniper, oldfield, dense mixed oak/juniper woodland	0	35	45
Brookhaven Mountain	BROO	Oak/juniper/ash scrub woodland, open rocky, brushy field	0	35	65
Engineer Lake	ENGI	Mixed oak/elm/juniper woodland, willow lacustrine edge, field with scattered oak.	0	55	20
Vireo	VIRE	Open oak/juniper woodland, juniper/live oak/ash scrub	0	40	60

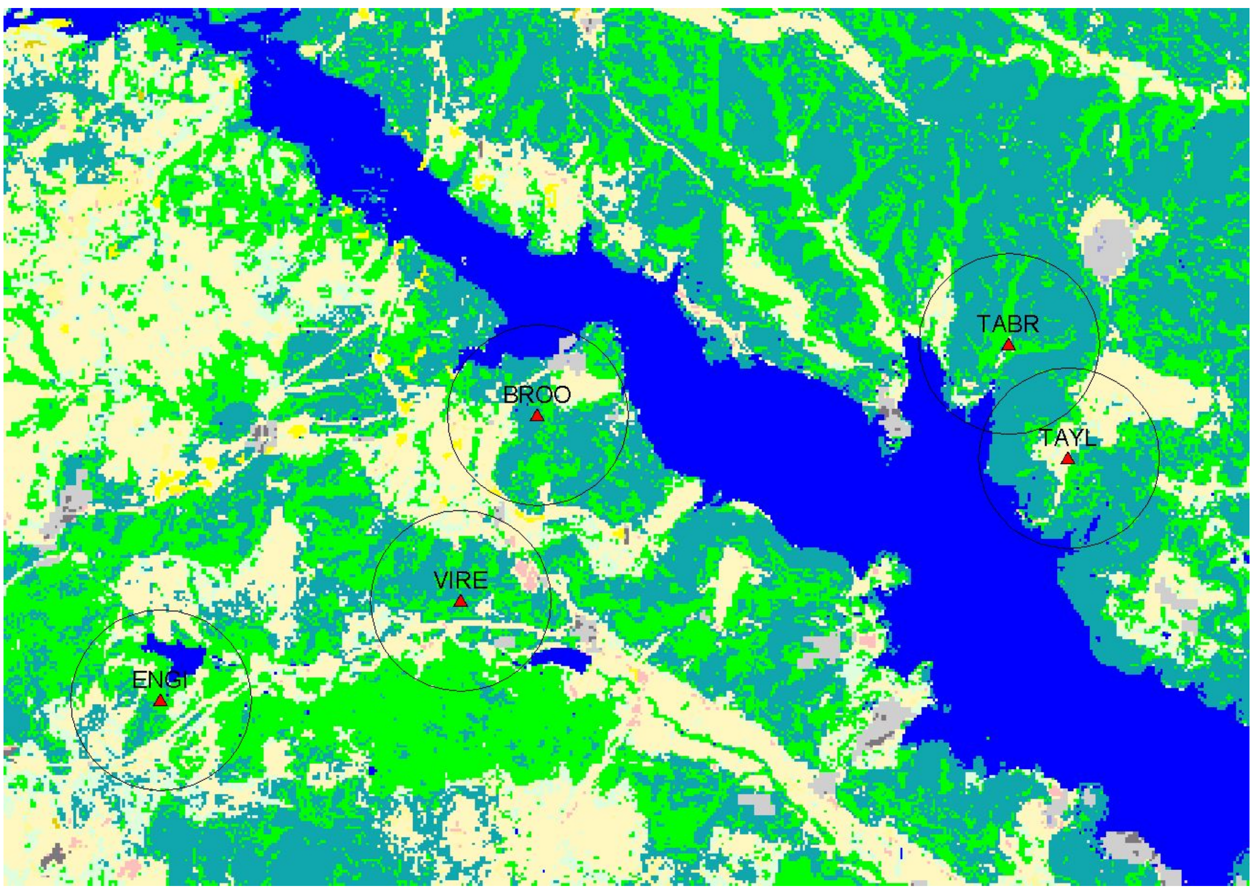

Figure 2. Map of the locations of 5 of the 6 Monitoring Avian Productivity and Survivorship (MAPS) stations (red triangles) located on the U.S. Department of Army's Fort Hood installation in Bell county, Texas. The land cover classifications are provided by the 30m resolution USGS National Land Cover Dataset which provides 21 land cover classes (Appendix 4.1). Black circles represent 1 km radii surrounding each station. The sixth station (SHOR) is located approximately 20 km north (see Figure 1).

Camp Swift

Table 6. List of station names, abbreviations, a brief description of the habitat and estimates of the percent cover of water forest and shrub within the boundaries of each MAPS station at Camp Swift.

Station	Abbr.	Description	%water	%forest	%shrub
Wine Cellar Loop	WCLO	Post oak/juniper woodland open field	5	65	20
McLaughlin Creek	MCCR	American elm bottomland successional oak/ cedar oldfield, dense oak/cedar woodland	0	60	30
Pipeline	PIPE	Post oak/juniper woodland, successional oak/juniper oldfield	1	50	40
East Loop East	EALE	Successional oldfield, oak/ cedar woodland	0	25	25
East Loop West	EALW	Open oak/cedar woodland, dense oak/cedar woodland, early-successional oldfield	0	25	20
Sandy Junction	SAJU	Post oak/juniper woodland	0	60	30

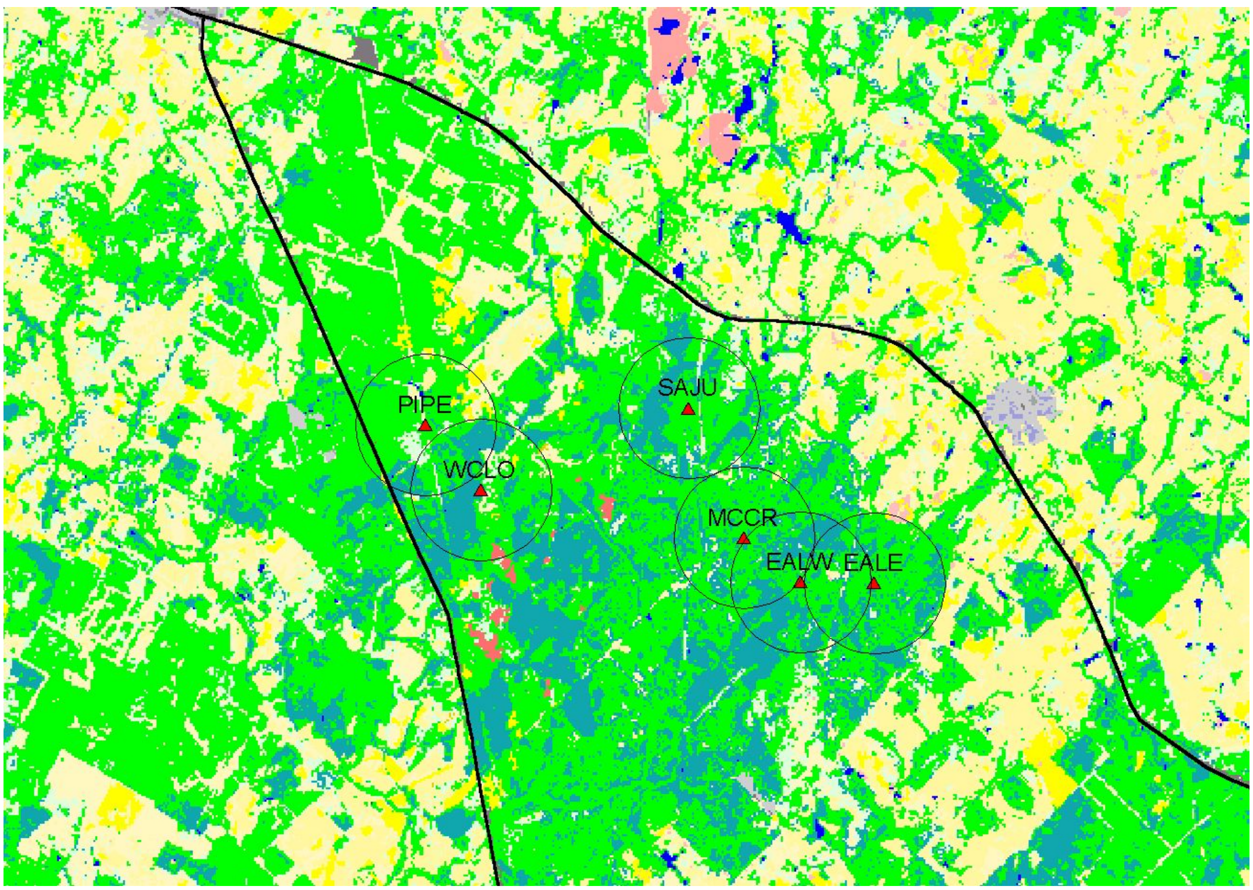

Figure 3. Map of the locations of 5 of the 6 Monitoring Avian Productivity and Survivorship (MAPS) stations (red triangles) located on the Texas Army National Guard's Camp Swift installation in Bastrop county, Texas. The land cover classifications are provided by the 30m resolution USGS National Land Cover Dataset which provides 21 land cover classes (Appendix 4.1). Black circles represent 1 km radii surrounding each station.

Camp Bowie

Table 7. List of station names, abbreviations, a brief description of the habitat and estimates of the percent cover of water forest and shrub within the boundaries of each MAPS station at Camp Bowie.

Station	Abbr.	Description	%water	%forest	%shrub
Mesquite Flat	MESQ	Disturbed open mesquite savannah, open cedar/elm woodland	0	30	45
Devil's Hill	DEVI	Live oak/post oak savannah, open mesquite savannah	0	35	60
Stonehouse	STON	Live oak/post oak savannah riparian areas	1	30	60
Bedrock	BEDR	Mixed oak (post, blackjack, live, Texas) woodland, mesquite savannah	3	60	35
Mockingbird Lane	MOCK	Arid live oak/juniper highland	0	20	50
Nighthawk	NIGH	Open live oak/Texas oak woodland	0	25	50

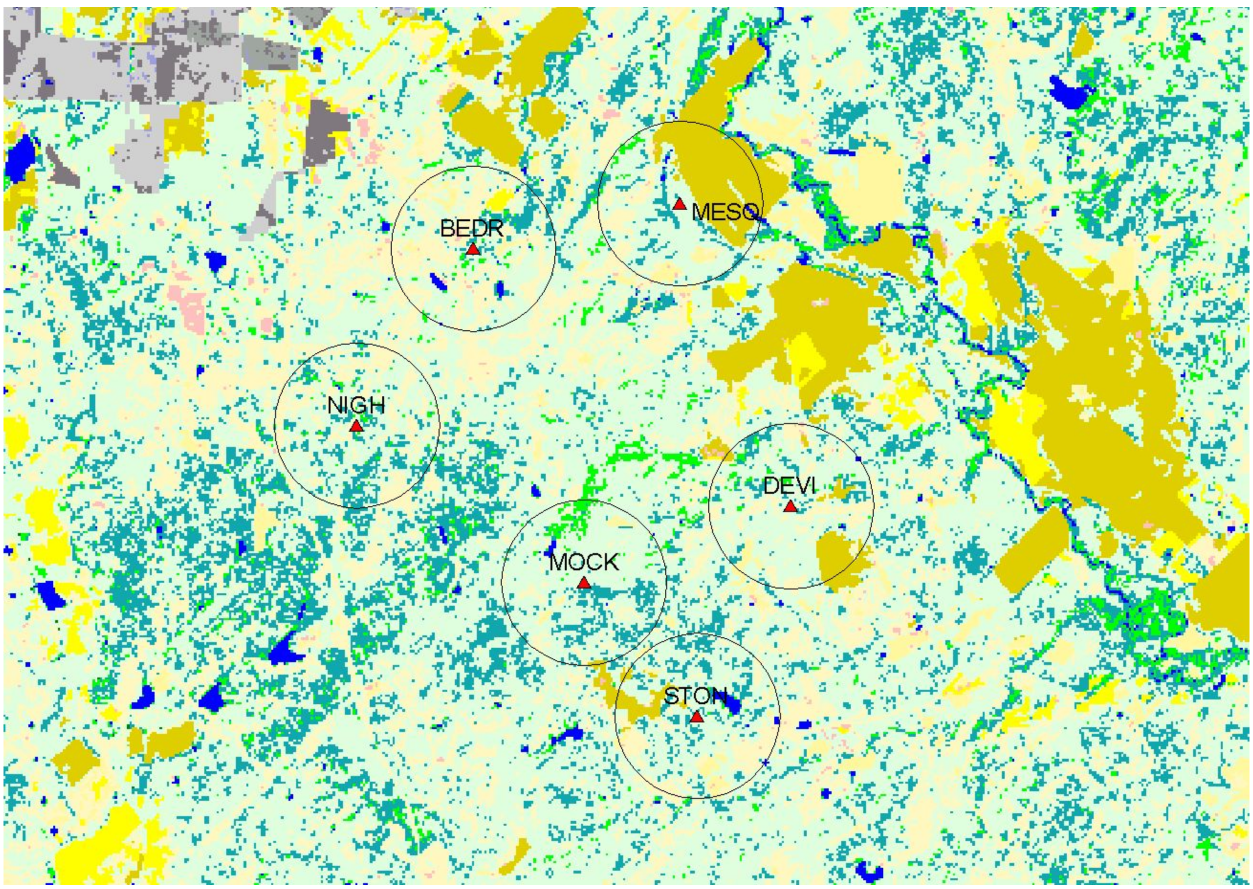

Figure 4. Map of the locations of 5 of the 6 Monitoring Avian Productivity and Survivorship (MAPS) stations (red triangles) located on the Texas Army National Guard's Camp Bowie installation in Brown county, Texas. The land cover classifications are provided by the 30m resolution USGS National Land Cover Dataset which provides 21 land cover classes (Appendix 4.1). Black circles represent 1 km radii surrounding each station.

Analyses

Using the datasets described above we tested the following hypotheses:

a) Avian productivity is sensitive to seasonal weather. For each of 10 species (captured at 17 MAPS stations; Table 2) we tested for correlations between annual productivity (Appendix 1.1) and annual seasonal (winter, spring and summer) precipitation and temperature (Table 4, Appendix 3.2)

b) Avian survival is sensitive to seasonal weather. For 5 species we tested for correlations between annual survival rate estimates (Appendix 1.5) and annual periodic precipitation and temperature (Table 4, Appendix 3.3).

c) Avian species richness (Table 3) is a function of one or more landscape variables (Appendix 4). For each of 18 MAPS station we tested for correlations (Apendices 4.6, 4.8) between the numbers of avian species (by migratory and breeding status) recorded at each station and a suite of both “landscape” and “class” level attributes derived from spatial analyses of 1-km radii landscapes surrounding each station.

d) Avian productivity is a function of one or more landscape variables. For each of 7 species breeding at 10 or more MAPS stations we tested for correlations (Table 8) between station-specific reproductive indices (Appendix 2.1) and a suite of both “landscape” and “class” level attributes derived from spatial analyses of 1-km radii surrounding each station.

Results and Discussion

Weather and avian demographics

Seasonal weather

Since the beginning of the century, the statewide average Texas winter (December-February) precipitation varied between a minimum of 1.82 inches in the La Nina winter of 1970-71 to a maximum of 13.23 inches in the El Nino winter of 1991-92. Averaged over decadal time periods since 1902 the 1932-41 decade was associated with the highest winter precipitation (6.3 inches) and low annual variability, but between 1962 and 1981 Texas experienced its driest winters this century (Fig. 5). Importantly, over the last two decades the winters have become wetter and year-to-year variability has increased to its highest level this century. Presumably, this increased winter precipitation and annual variability was due to the severe El Nino winters experienced before the spring time months of 1983, 1992, 1993, 1997 and 1998. In these years winter precipitation averaged 8.03 inches – over four times the 1.93 inches winter precipitation experienced in all the other years since 1982.

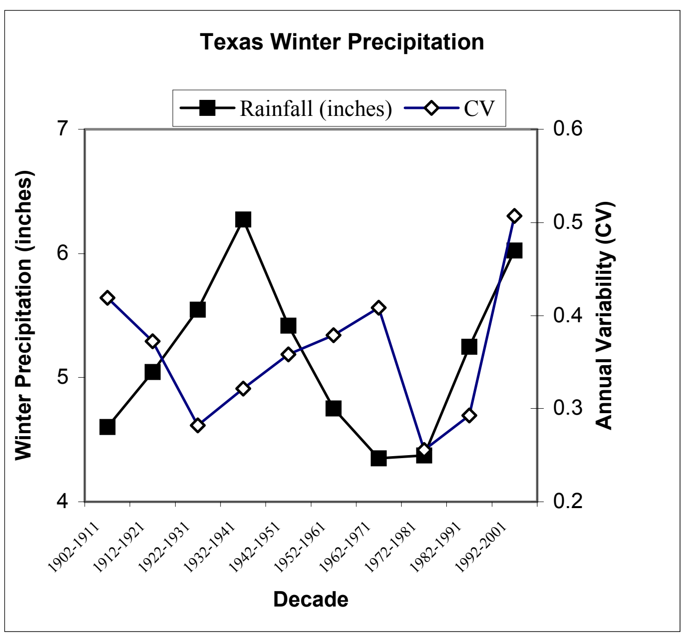

Figure 5. Decadal averages of winter precipitation and annual variability (expressed as the coefficient of variation) in winter precipitation for the state of Texas since 1902

Seasonal precipitation varied considerably between 1994 and 2001 (Fig. 6). Generally, spring (March-May) precipitation exceeded that of the following summer months (June-August), which exceeded that of the preceding winter months (December-February). The wettest winters were

2000-2001 and the El Nino winters of 1996-97 and 1997-98 and the wettest year (December-August) occurred following the 1996-97 El Nino winter (Figure 6). During the winter of 1995-96 and the following spring Texas experienced anomolous drought conditions with wind and a few severe hail storms occurring throughout April, May and into June, and excessive heat early in June. Jettj et al. (1998) suggest that these harsh conditions were responsible for declines in the abundance of Golden-cheeked Warbler in 1996.

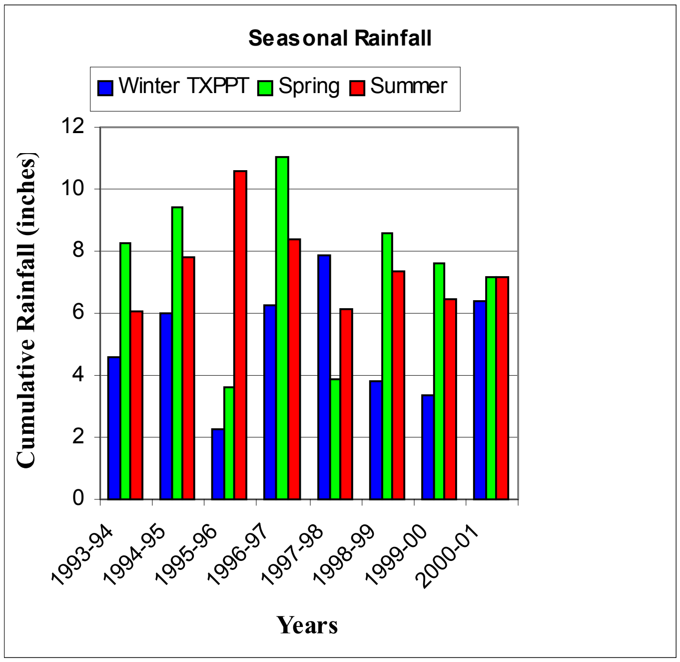

Figure 6. Seasonal Texas precipitation (1994-2001)

Correlating climate, weather, and productivity

For each of 10 species, for which enough data existed to calculate annual productivity indices for the period 1994-2001, we found positive correlations between annual productivity indices and either (or both) winter and spring precipitation (Appendix 3.2). The relationship with winter precipitation was statistically significant ($P<0.05$) for Tufted Titmouse, Bewick's Wren, Golden-cheeked Warbler (spring precipitation), and Painted Bunting, and near statistically significant ($P<0.10$) for White-eyed Vireo, and Carolina Chickadee (Figure 7). This suggests that these species are sensitive to moisture regimes during the winter and/or spring and produce fewer fledglings in drier years and more fledglings in wetter years. The winter ESPI index correlates significantly ($P<0.05$) springtime precipitation (Appendix 3.1) suggesting that these relationships are primarily driven by ENSO activity

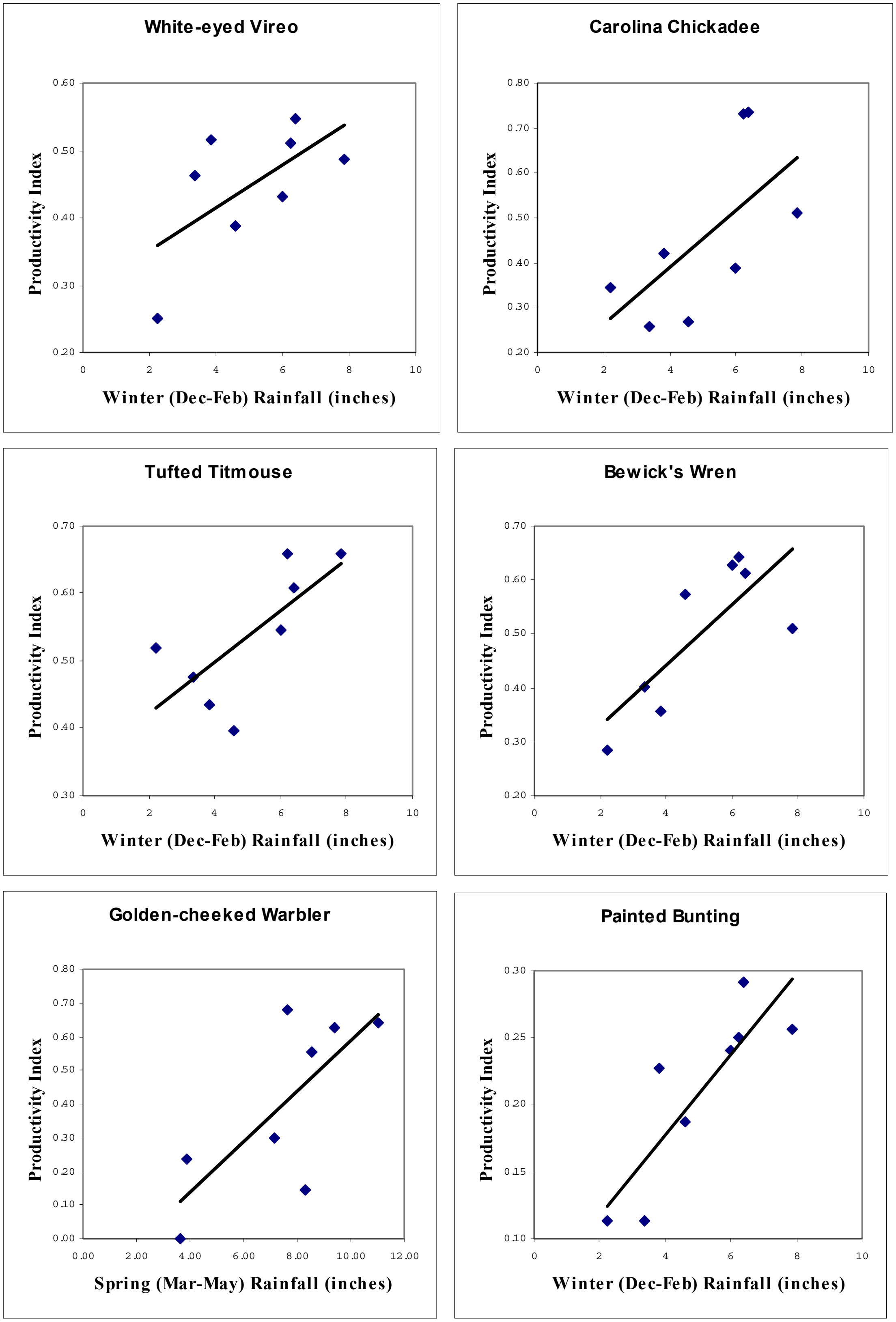

Figure 7. Regressions of annual productivity indices (1994-2001) and winter precipitation for the White-eyed vireo (R^2 = 0.40, P<0.10), Carolina Chickadee (R^2 = 0.40, P<0.10), Bewick's Wren (R^2 = 0.59, P<0.05), Tufted Titmouse (R^2 = 0.52, P<0.05), Golden-cheeked Warbler (spring precipitation: R^2 = 0.52, P<0.05), and Painted Bunting (R^2 = 0.73, P<0.01).

Correlating climate, weather, and survival rates

For 4 of 5 species (Appendix 1.5), significant ($P<0.05$) correlations exist between apparent adult annual survival from breeding season to breeding season and seasonal weather variables (Table 4, Appendix 3.3). Figure 8 shows regression plots between annual survival and seasonal precipitation. However, correlations in Appendix 3.3 suggest that for Northern Cardinal and Tufted Titmouse annual survival, stronger relationships exist with seasonal temperatures. Bewick's Wren shows no significant relationship with any of the environmental variables but correlates positively with pre-breeding seasonal temperatures suggesting that it is sensitive to cold conditions.

Although the LOSSURV mark-recapture models (Nott and DeSante in press) used to provide these estimates account for transient individuals they do not account for emigration of individuals. A bird caught one year that fails to return the next year because it has relocated to another area is indistinguishable from a bird that fails to return because it dies. For this reason two possible alternative hypotheses may be proposed: a) that drier conditions increase adult mortality as Sillett et al. (2000) suggested, or b) that individuals desert their breeding territories during drought conditions.

Interestingly, Appendix 3.2 shows that, for 8 of 10 species, the annual numbers of adults captured tended to decrease with increasing spring precipitation. Perhaps the reason for this is that food resources are likely lower during drought years forcing birds to forage farther away from their territories. Therefore, an individual net may catch adults from more distant territories in drier years than they do in wetter years. However, annual captures of juvenile birds are lower in drier years and overall productivity indices increased as a function of spring precipitation.

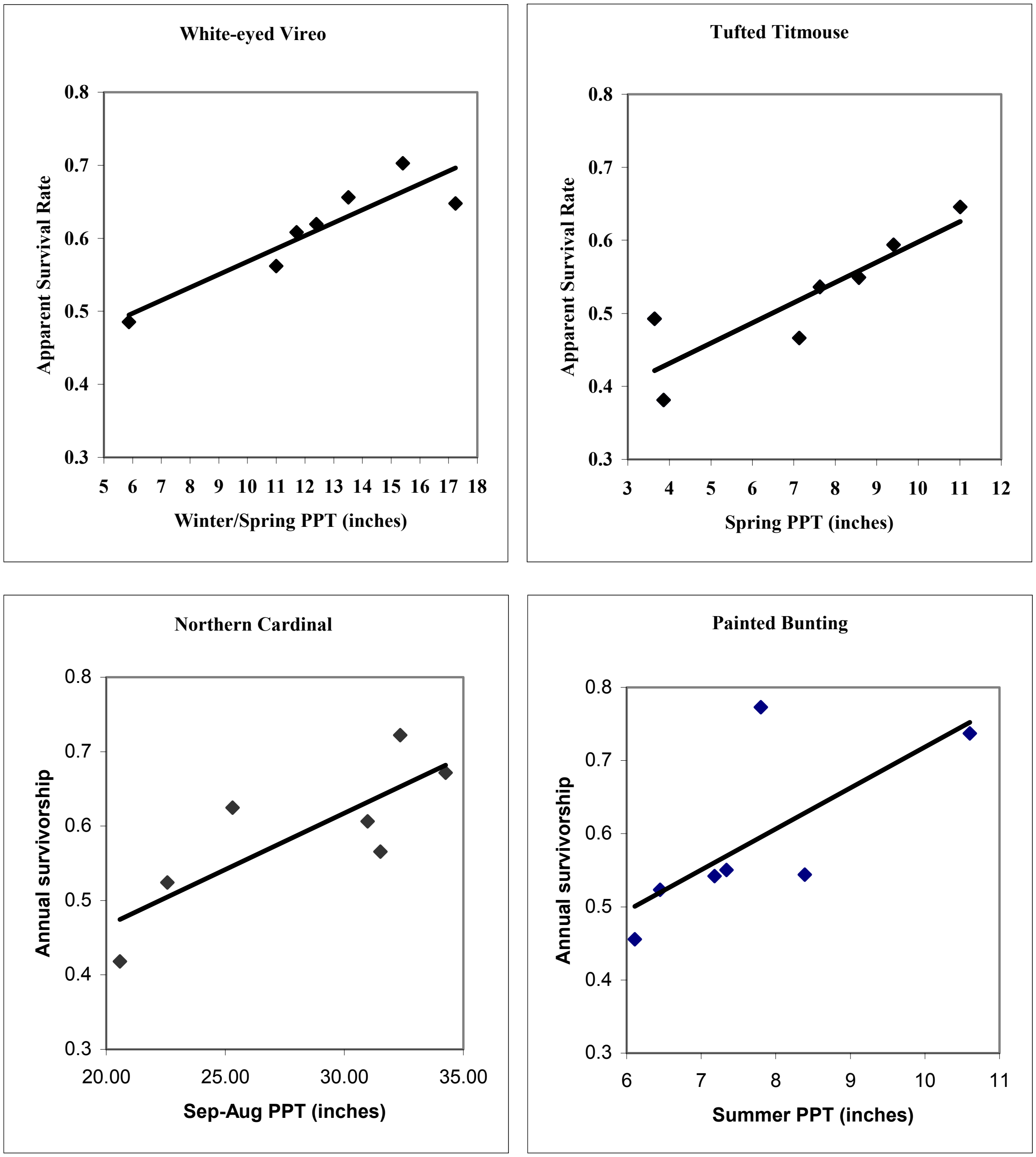

Figure 8. Regressions of annual survival rate estimates (1994-2001) with seasonal precipitation (PPT) data for White-eyed vireo (R^2 = 0.83, P<0.05), Tufted Titmouse (R^2 = 0.77, P<0.05), Northern Cardinal (R^2 = 0.66, P<0.05), and Painted Bunting (R^2 = 0.50, P<0.05).

Avian species richness and habitat diversity

Birds utilize different habitat types in ways dependent upon the time of the year and their predominant behavior. For instance, many species that breed in forests may be found in riparian habitats outside of the breeding season. It follows that we might expect that certain spatial arrangements of habitat or landscape features within a local landscape would be particularly attractive to birds during migration or post-fledging dispersal.

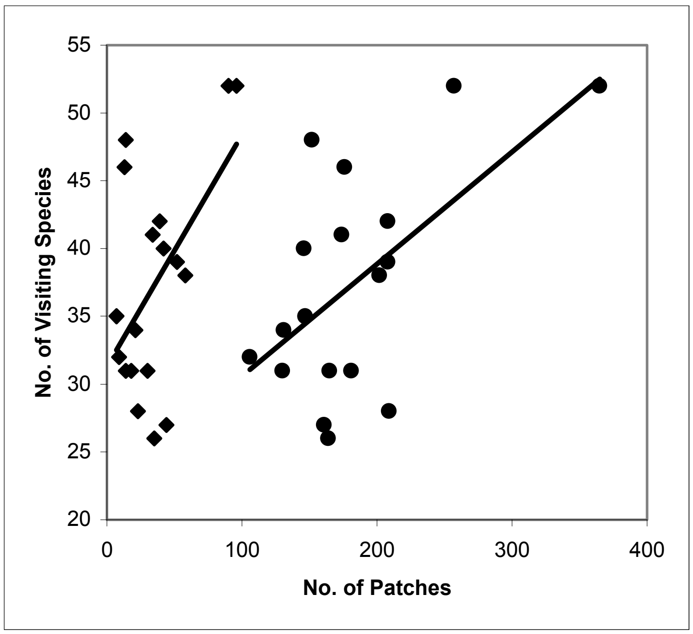

Figure 9. Regression plots of the number of non-breeding species (transient and migrant) that visit MAPS stations against the total number of patches (circles), and the number of patches of shrubland (diamonds) in a 1km radius surrounding the station.

Based on breeding status data, the MAPS stations at Fort Hood attract an average total of 74 species per station (86 species recorded at SHOR), followed by Camp Bowie with 71 species per station, and Camp Swift with only 56 species per station (Table 3). We detected the fewest number of breeding species per station (23) at Camp Swift, followed by Fort Hood (32), and then Camp Bowie with an average of 36 breeding species per station. SHOR and ENGI (Fort Hood), each attract the most visiting species (51) but STON (Camp Bowie) attracts the most breeding species (43). What features of the landscape determine this attractiveness? Considerable differences exist in the strength of correlations between landscape-level metrics and the numbers of visiting and breeding bird species (Table 3). Statistically significant (P<0.05) correlations exist between the numbers of visiting species and the number of patches (regardless of cover types) in the landscape (Appendix 4.6; Figure 9).

However, the number of breeding species recorded at each station correlate significantly ($P<0.05$) with Shannon's Diversity Index (SDI, Figure 10) and Shannon's Eveness Index (SEI, Appendix 4.6). SDI is a relative measure of patch diversity that equals zero when there is only one patch in the landscape and increases as the number of patch types or proportional distribution of patch types increases (McGarigal and Marks 1994). SEI is equal to zero when the observed patch distribution is low and approaches one when the distribution of patch types becomes more even. Shannon's evenness index is only available at the landscape level.

We interpret these results to mean that transients and migrants tend to utilize heterogeneous landscapes made up of smaller patches, and therefore more habitat edge. Furthermore, by inspecting the relationships between landscape level variables and landscape class level variables (Appendix 4.7) and between landscape class variables and the numbers of species visiting MAPS stations (Appendix 4.8), we conclude that they are attracted to landscape heterogeneity comprised of patches of shrubland (NUMP51), water (NUMP11), and to a less significant extent ($P<0.10$) the emergent herbaceous wetland (NUMP92) in the local landscape.

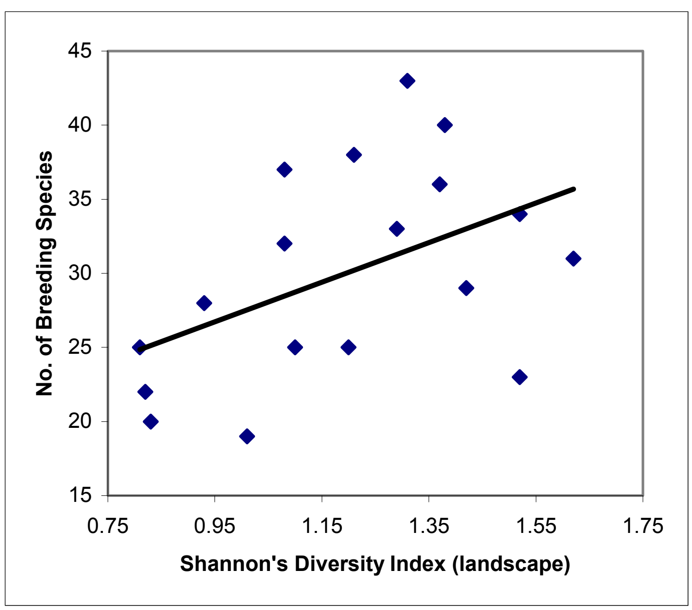

Figure 10. Regression plot of the number of breeding species recorded at MAPS stations against Shannon's Diversity Index of all patches in a 1km radius surrounding the station.

For breeding species, landscape diversity and evenness correlate significantly and positively with the coverage of agricultural and grassland (Agr/Gr), the coverage (CA Wet) and patch size (MPS Wet) of wet habitat types, and the number of patches of shrubland (NUMP51); and significantly and negatively with forest variables. This suggests that in east-central Texas the number of breeding bird species are highest in heterogeneous landscapes of shrubland among agricultural or grasslands and lowest in forest-dominated landscapes.

Individual species models

The 7 species shown in Table 8 appear to respond differently to the areal extent and arrangement of different habitat types in the landscapes surrounding the MAPS stations at which they were captured. Within species, the numbers of adults may correlate most strongly with one habitat type(s) while productivity indices most strongly correlate with another habitat type(s). For instance, numbers of Bewick's Wren adults correlate positively with open habitat cover but productivity correlates negatively with open habitat cover but positively to mean patch size of forest. It is possible that this result reflects the difference between source (forest) and sink (open) habitats. This would mean that in forested habitats Bewick's Wren are found in low densities but produce more young per adult than in more open habitats where adults are found in higher densities. A similar case is found for the Tufted Titmouse except that high productivity correlates positively with the patches of water in the landscape.

Numbers of White-eyed Vireo adults show no strong associations with any habitat type but correlate positively with the patch size of agricultural/grassland and wet habitats. For Carolina Chickadee, both numbers of adults and productivity correlate positively with wet habitat types, and especially strongly with the number of patches of water in the landscape.

Higher numbers of Carolina Wren adults are associated with more forested landscapes but again productivity correlates positively with moist habitat types in which adults occur in fewer numbers. Numbers of Northern Cardinal adults positively correlate with the extent of forest but high productivity is associated with wet habitat types. Painted Buntings are considered habitat generalists in all regions of their breeding range. In accordance, these results show that numbers of adults weakly correlate with the extent of most habitat types but both numbers of adults and productivity correlate positively with the number of patches of water in the landscape.

Table 8. Correlation coefficients between numbers of adults (AD) and productivity indices (PI) and landscape metrics from 1km radii surrounding each of 18 MAPS station (* denotes only 12 stations used). Statistical significance (16 d.f.) is given in bold italics (P<0.1), bold (P<0.05), and bold underlined (P<0.01).

Species		CA Agr/Gr	MPS Agr/Gr	CA Open	MPS Open	CA Forest	MPS Forest	CA Wet	MPS Wet	CA Water	NUMP Water	SDI	SEI
WEVI*	AD	0.17	0.41	0.02	0.44	-0.14	-0.20	0.36	0.41	0.37	-0.12	0.16	0.22
	PI	***0.57***	0.31	0.46	**0.69**	***-0.63***	***-0.61***	**0.83**	**0.83**	**0.84**	***0.59***	***0.63***	***0.63***
CACH	AD	0.31	-0.13	0.20	0.05	-0.27	-0.31	**0.51**	0.36	**0.50**	**<u>0.69</u>**	**<u>0.73</u>**	**<u>0.63</u>**
	PI	-0.09	-0.19	-0.21	-0.23	0.19	0.26	0.24	0.28	0.24	**0.50**	0.13	0.01
TUTI	AD	**0.56**	**<u>0.81</u>**	**<u>0.67</u>**	**0.46**	**<u>-0.65</u>**	**-0.59**	-0.27	-0.13	-0.26	-0.25	0.08	0.21
	PI	0.02	-0.04	0.12	0.16	-0.15	0.04	0.30	0.38	0.30	***0.42***	0.09	0.12
CARW*	AD	-0.39	-0.36	-0.38	-0.45	0.40	0.37	-0.38	-0.40	-0.38	-0.09	-0.19	-0.38
	PI	0.32	0.14	0.23	0.51	-0.34	-0.24	**0.67**	**0.76**	**0.68**	0.30	0.21	0.27
BEWR*	AD	0.43	0.26	***0.63***	**0.70**	***-0.64***	-0.54	-0.37	-0.19	-0.36	-0.32	-0.24	-0.15
	PI	-0.49	-0.22	-0.46	-0.44	0.49	***0.57***	0.25	0.34	0.24	-0.16	-0.3	-0.05
NOCA	AD	***-0.45***	**-0.58**	**<u>-0.63</u>**	**<u>-0.72</u>**	**<u>0.61</u>**	**0.49**	0.24	0.05	0.23	**0.56**	0.20	0.02
	PI	0.00	-0.09	-0.02	0.08	-0.02	0.06	**0.50**	**0.59**	**0.51**	0.22	0.15	0.19
PABU	AD	-0.05	***-0.45***	-0.08	-0.06	0.07	0.08	0.11	0.06	0.11	**0.50**	0.18	0.03
	PI	0.07	-0.30	0.04	-0.07	-0.05	-0.11	0.13	0.08	0.12	**<u>0.73</u>**	0.19	0.03

Management issues

Clearly, water plays an important role in the avian population dynamics of many landbird species that breed in east-central Texas. Both reproductive success and annual survival rates are negatively affected by winter (or spring) drought conditions. Furthermore, for several species higher station-specific productivity levels are associated with higher areal coverages of standing water and/or emergent herbaceous wetlands. Threats to the health of wetland and riparian include nitrification through agricultural run-off and the direct effects of grazing which disturbs littoral and understory vegetation leading to decreased diversity and abundance of nesting birds (Popotnik, and Giuliano 2000). Proximity of grazing to nesting areas can also seriously affect songbird population dynamics through cowbird parasitism (Goguen and Mathews 2000). Exclusion or reduction of grazing pressure and wetland restoration might therefore benefit the avian communities of those installations. Cowbird eradication and reduction of grazing pressure are already active management policies at Fort Hood where all MAPS stations except Brookhaven (BROO) showed evidence of grazing in the 2000 breeding season (IBP MAPS station summaries unpublished). At Camp Bowie the Nighthawk (NIGH), Mesquite (MESQ) and Bedrock (BEDR) MAPS stations are located on state lands and also show evidence of cattle grazing. There is no grazing at Camp Swift.

This study also shows that the diversity of breeding birds is an increasing function of landscape diversity. Hence, a management goal designed to increase breeding bird diversity would be to restore parts of the landscape to reflect the historical woodland-prairie mosaic. In highly fragmented areas increasing the sizes of habitat patches without decreasing the number of habitats would increase the Shannon's Diversity Index for the area and hopefully lead to increased diversity of breeding birds. Management actions to achieve this are already proposed in the Integrated Natural Resource Management Plan (2001-2005) for Camp Bowie. In grassland areas that are experiencing shrub invasion, frequent burning, herbicide treatment and/or physical removal of some shrub species (especially mesquite), and in extreme cases reseeding are recommended grassland restoration techniques. Restoring forested or wooded areas requires longer-term management policies that might include suppressing fire control and excluding grazing from gaps between existing patches of woodland or forest. These areas will hopefully undergo natural succession towards adjacent habitat types but the process may be accelerated with tree planting. These areas must be continually surveyed and treated for the spread of non-native plant species. TXARNG and the U.S. Army Corps of Engineers developed a forest management plan for Camp Swift to increase loblolly pine (*Pinus taeda*) to replace the juniper (*Juniperus virginiana*) that was historically controlled by fire. The impact of these and other management plans on avian communities of Texas military installations should be monitored by establishing MAPS stations in control and experimental areas. Towards adaptive ecosystem management, it would be sensible to apply management protocols to some areas containing MAPS stations and leave others as control stations.

Future Research

Several future research directions emerged during the writing of this report. For instance, we found that higher apparent mortality is suffered by some species during drier winters. To understand how this mortality may affect population dynamics it is essential to know how annual survival rate differs among age classes in the population in response to fluctuating environmental stressors. It would be possible to investigate this by applying two slightly different mark-recapture models (TMSURVIV and LOSSURV) to Texas banding and find out whether after-second-year birds survive better than second-year birds. Then we could construct age-class matrix population models, verify them against existing data (MAPS, BBS and BBIRD data) and predict the effects of changing climate on population size. Furthermore, although extreme weather events (i.e., freeze, hailstorm, rainstorm) are inherent in the seasonal averages calculated in this study, some species may have a limited tolerance to the magnitude of these events. A larger bird, for instance, may tolerate cold better than a smaller bird but may be more sesnsitive to extreme heat. NOAA Cooperative metereological station data contain various parameters relating to such events and could be used to better model species-weather relationships.

With regard to landscape issues recent literature emphasizes the importance of edge habitat (e.g., Hawrot and Neimi 1996). The utilization of edge habitat may vary by age class or, as suggested by this study, migratory status. Are species that pass through the landscapes and not breeding there may be attracted to certain kinds of edges? We could investigate this hypothesis by developing spatial statistics describing multiple edge types in the landscapes surrounding MAPS stations and relate them to species richness or abundance of individual species. Although in this study we were able to aggregate cover classes to reveal area and patch size statistics it would require further manipulation of NLCD coverage data and reanalysis of species-landscape relationships to reveal the relative importance of different edge types.

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