TEMPORAL AND SPATIAL PATTERNS OF BIRD MIGRATION IN THE LOWER GULF REGION

A Dissertation

by

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Migration is a mechanism that allows birds to enhance their fitness through either greater reproductive success or increased survival. Each year millions of birds migrate long distances between their northern breeding grounds in temperate regions to southern wintering grounds in tropical regions to benefit from seasonal environments. The advantages of seasonal movements between different regions include greater resource abundance, favorable weather, and extended day length; however, these advantages are offset by the challenges associated with migration (Moore et al. 1993, Alerstam et al. 2003, Pulido 2007*a*, Ramenofsky and Wingfield 2007). Migratory birds have to respond to the high energy demand of migration, as well as, adapt to new environments, vie for common resources, avoid predation, and react to adverse weather conditions (Moore and Simons 1990, Moore et al. 1993). Despite these challenges, migration has evolved because the benefits are greater than the risks (Able 1972).

Migratory birds have developed different strategies to balance the benefits and costs of migration. Optimal migration theory assumes time, energetic cost, and safety from predators are the most important factors that influence these strategies (Alerstam and Lindström 1990). Migration requires energy, in the form of fat reserves, to power migratory flight. Most migratory birds must break up their flight time into shorter segments to replenishment energy reserves and rest between flights (Moore et al. 1990, Moore et al. 1993, Schaub and Jenni 2001*a*). The rate at which migratory birds accumulate energy has an impact on the pace and successful completion of migration. In general, migratory birds that can build energy at faster rates have brief stopovers that result in a faster migration rate. Whereas, a slower migration rate is associated with extended stopover periods at which migratory birds accumulate energy at a lower rate (Schaub and Jenni 2001*a*, Schaub and Jenni 2001*b*).

Migratory strategies differ in how long and often migratory birds use stopover sites along their migration route. In energy-selected migration, birds gain as much fat reserves as necessary to reach and investigate the next stopover area (Alerstam and Lindström 1990). It can be expensive for a migratory bird to maintain and carry substantial fat reserves, and the energetic requirements can be reduced by accumulating less energy and stopping more frequently to refuel (Alerstam and Lindström 1990, Alerstam et al. 2003). In time-selected migration, birds acquire larger amounts of fat reserves to enable longer nonstop flights and decrease frequency of stopover area use. The strategy to lessen the time spent migrating results in a faster migration rate so birds arrive earlier at breeding or wintering grounds (Alerstam and Lindström 1990). Migratory birds, particularly those with large fat reserves, may select stopover areas based upon safety as a strategy to avoid predators (Alerstam and Lindström 1990, Alerstam et al. 2003). Flight power is inversely related to mass in migratory birds. As a result, predation risk is predicted to be lower for birds carrying smaller reserves because they are generally more agile and are able to accelerate quicker, thus able to elude predation (Alerstam and Lindström 1990, Alerstam et al. 2003). Birds that employ a predation-selected strategy accumulate less energy for migration than the extent needed for the time-selected strategy (Alerstam and Lindström 1990).

The constraints on energy, time, and safety become greater if migratory birds must cope with ecological barriers during migration (Henningsson and Alerstam 2005).

Migratory birds may acquire significantly greater fat reserves that enable them to complete a single continuous flight across a barrier (Alerstam 2001, Åkesson and Hedenström 2007). Fat reserves may account for 40 - 90% of the mass of migratory songbirds prior to crossing a barrier (Alerstam and Lindström 1990). While it may be advantageous for migratory birds to have additional fat reserves to respond to adverse weather, the expense of migration is higher due to the added mass of the store fuel (Alerstam and Lindström 1990, Alerstam 2001, Alerstam et al. 2003). However, prevailing winds may decrease the energy expenditure of migratory birds in flight and are critical to those that negotiate barriers during migration. Migratory birds may select to fly over barriers to benefit from tail winds that lower energetic cost, shorten duration of migration, and reduced predation risk which allows them to arrive at breeding or wintering destinations in a timely manner (Gauthreaux 1999). Other birds choose to avoid traveling across an ecological barrier even if they have the ability to negotiate the barrier or have a slower migration rate as a result of using a detour (Alerstam et al. 2003, Åkesson and Hedenström 2007). While the energy costs to confront an ecological barrier can be high, the energy cost to travel along detours can be met by stopping more frequently, in which an energy-minimization strategy is employed by birds (Alerstam and Lindström 1990, Alerstam 2001, Alerstam et al. 2003). However, time and safety costs of migration can be greater because birds travel a greater extent along detours (Alerstam 2001, Henningsson and Alerstam 2005).

Migration strategies to overcome ecological barriers have enabled migratory birds to successfully navigate the Gulf of Mexico (Kerlinger 1995). Trans-Gulf migrants journey across the Gulf of Mexico between temperate breeding grounds in North

America and wintering grounds in Central and South America. Contrarily, circum-Gulf migrants detour along the coastline between Mexico to the United States. Birds that have strong flight capability often use trans-Gulf routes while birds with weaker flight capability and soaring birds that rely upon thermals use circum-Gulf routes (Kerlinger 1995). Most studies have examined bird migration along the Gulf of Mexico during spring in greater detail than fall (Able 1972, Buskirk 1980, Gauthreaux 1999). Spring migration in the Gulf of Mexico region generally starts around mid-March, with greatest number of birds at the end of April through the first part of May, and extends to late May (Buskirk 1980, Gauthreaux and Belser 1998, Gauthreaux 1999). Fall migration begins in mid-August and ends in early November (Gauthreaux 1999). Previous studies have shown that the highest number of fall migrants is found in October (Buskirk 1980, Arnold 2009).

Most migratory birds travel during the night compared to the day. Nocturnal migration enables migratory birds to take advantage of cool air temperatures and escape predation. It also allows birds to efficiently use their time by travelling when they are unable to feed (Kerlinger 1995, Lincoln et al. 1998, Moore 1999). Migratory birds often initiate flight a half hour following dusk. Arrivals appear at stopover sites prior to sunrise, and arrivals stop by late daytime with greatest numbers arriving prior to mid-day (Gauthreaux and Belser 1998, Gauthreaux 1999). Trans-Gulf migrants undertake a 600-mile trip of 15 to 17 hours to travel over the Gulf of Mexico to land along the northern Gulf shore from Texas to Florida (Kerlinger 1995). For most migratory birds, males arrive ahead of females, and adults come before juveniles (Moore 1999). The timing of migration in the Gulf region has been shown to be related to the velocity of prevailing winds (Gauthreaux 1999).

During migration, trans-Gulf migrants are primarily found at altitudes between 580 to 2,500 m (Gauthreaux 1999). Migratory birds may choose altitudes based on wind characteristics that will optimize travel time and energy expenditure during migration (Richardson 1978, Richardson 1990, Gauthreaux 1991). Trans-Gulf migrants are known to fly at lower altitudes when traveling across land than when migrating over the Gulf of Mexico (Gauthreaux 1999). Waterfowl, shorebirds, and songbirds, that use powered flight often migrate at altitudes higher than migratory birds that use soaring flight, such as hawks or pelicans (Kerlinger 1995).

Weather has a profound influence on movements of migratory birds (Richardson 1978, Richardson 1990). Wind can be used to estimate the timing and magnitude of bird migration. Large numbers of migratory birds are known to initiate flight when winds correspond to their migratory heading and may not migrate when wind conditions are in opposition to their heading (Richardson 1978, Richardson 1990, Lincoln et al. 1998). Liechti and Bruderer (1998) have shown that migratory birds can experience 30% increase in flight speed with tailwinds. Migratory birds may exploit tailwinds as a strategy to curtail energy expenditure and duration of migration (Gauthreaux 1999, Gauthreaux et al. 2005). Whereas, migratory birds that must migrate in opposing winds are subjected to relatively greater flight cost, due to the slower migration speed and longer time to complete migration (Lincoln et al. 1998, Gauthreaux et al. 2005).

Frontal activity in spring and fall has an effect on the timing of migration (Able 1973, Richardson 1978, Richardson 1990, Kerlinger 1995, Lincoln et al. 1998). Spring migration is initiated before or after a warm front (Richardson 1978, Richardson 1990). Warm fronts are associated with a high pressure area that brings warmer temperatures and lower barometric pressure (Richardson 1978, Richardson 1990, Lincoln et al. 1998). Migratory movements in fall have been shown to take place after a cold front (Able 1973, Richardson 1978, Richardson 1990). Cold fronts during fall have a passing low pressure that causes the air temperature to decrease and barometric pressure to increase (Richardson 1978, Richardson 1990, Lincoln et al. 1998).

Weather in the Gulf of Mexico region may also affect the stopover patterns and body condition of migratory birds (Moore and Simons 1990, Gauthreaux 1999, Simons et al. 2004). Good weather conditions allow migratory birds to travel faster at a lower energetic cost (Gauthreaux 1999). Several advantages to migrating birds may arise from a timely appearance at their destination. Early arrival typically improves an individual's odds to secure a high quality mate, breeding territory, or wintering area, which may give rise to an increased chance of reproduction and survival for migratory birds (Pulido 2007*b*). During spring, adverse weather conditions arise when cold fronts push across the Gulf of Mexico, which inhibits migratory movements and increases the probability of mortality during migration. Heavy rain and unfavorable winds produce fallouts where migratory birds settle into available stopover areas, causing trans-Gulf migrants to seek safety along the coast (Gauthreaux and Belser 1998, Gauthreaux 1999). Late appearance on breeding or wintering grounds could have a number of effects on fitness of migratory birds (Moore and Simons 1990, Gauthreaux 1999). Migrants in poor energetic condition engage in more feeding activity to meet energy demands, which results in extended stopover durations and greater exposure to predators (Moore and Simons 1990, Moore et al. 1993, Moore 1999, Moore and Aborn 2000). Late appearance at their destination may make it difficult for migratory birds to obtain quality mates or territories, and may hinder their reproductive success or survival (Moore and Simons 1990, Moore et al. 1993, Moore 1999). Whether a bird completes its migration journey is contingent upon numerous competing factors, therefore, the safe arrival of birds to their breeding and wintering grounds every year is of great importance to their populations.

JUSTIFICATION

There is limited information currently available on movement patterns of migratory birds in the lower Gulf region. The Texas Gulf Coast is a major migration route for millions of birds travelling annually between their breeding and wintering grounds. Migratory birds use coastal areas in the Gulf region as stopover habitat to gain energy during spring and fall migration (Moore 1999). Weather influences the timing and magnitude of migrating birds (Richardson 1978, Richardson 1990), and these stopover habitats become more critical to migrants during unfavorable weather. The reproductive success and survival of migratory birds is influenced by migration, and the successful completion of migration is dependent upon the use of stopover areas. Future development along the lower Texas Coast, which has remained undeveloped and pristine, may substantially alter availability and quality of stopover habitat that millions of migratory birds depend upon during migration. The loss of stopover habitat along the lower Texas Coast may have significant impacts to migratory bird species at a continental level. A greater understanding on the movements of migratory birds and the factors that influence their movements along the lower Texas Coast is needed to make ecologically informed decisions for long-term management and conservation of migratory birds. This knowledge on migration dynamics will provide the framework for future comparisons to monitor migratory birds in this region.

OBJECTIVES

I propose a research project that will investigate the migration dynamics of birds at multiple scales along the lower Gulf Coast of Texas. The primary goal of this project is to examine the spatial and temporal patterns of migratory birds during fall and spring migration at two sites along the lower Texas Gulf Coast. Specifically, my research objectives are to: (1) assess the timing, magnitude, flight direction, and altitude of migratory birds along the lower Texas Gulf Coast; and (2) investigate the effects of weather on the movements of migratory birds along the lower Texas Gulf coast.

HYPOTHESES

No formed hypotheses will be developed for the first objective as this is a descriptive component providing baseline information on the timing, magnitude, direction, and altitude of bird migration along the lower Gulf Coast. My hypothesis for the second objective is that the timing, magnitude, direction, and altitude of migrating birds will be influenced by different weather conditions. I predict that wind and precipitation would be weather variables that will account for most variation in migration characteristics. Specifically, I would expect an increase in passage rates to occur during favorable winds and be related to frontal passage. I also predict that precipitation in the form of fog will reduce the magnitude and altitude of migration.

STUDY AREA

This study will be conducted along the lower Gulf Coast on private and federal lands. This area of the Texas coastal region has remained relatively undeveloped due to the lands belonging to large private ranches and federal government (Judd 2002). The lower Gulf Coast stretches from Corpus Christi approximately 200 km south to Brownsville. The region is bounded on the east by the Laguna Madre, Padre Island, and Gulf of Mexico, and is found within the eastern portion of the Tamaulipan Biotic Province (Blair 1950, Judd 2002). It is characterized by a diverse array of habitats including wetlands, native prairies, shrublands, and woodlands (Fulbright and Bryant 2002). The climate of the lower Gulf coast is subtropical and semi-arid (Norwine and Bingham 1986), and mean temperature is greater than 70˚ F (Fulbright and Bryant 2002). Along the lower Texas coast, average temperature is greater in southern areas; whereas, northern areas have higher average rainfall (Hatch et al. 1999). The greatest amounts of rain typically occur in May and September (Taylor et al. 1997). Thunderstorms may account for the largest part of rainfall, and torrential rain may result from tropical weather (Tunnel 2002).

Two study sites were selected within the lower Texas Coast to examine bird migration. A northern site on the Laureles Division of King Ranch and a southern site on Laguna Atascosa National Wildlife Refuge (LANWR) are located approximately 134 km apart. The Laureles Division of the King Ranch is in Kleberg County located east of Kingsville, and is bordered on the south by Baffin Bay. The 333,873-ha King Ranch is one of the largest enduring ranches in southern Texas (Fulbright and Bryant 2002), and has been managed by the King Ranch Corporation since the early 1900s (Hilbun and Koltermann 2002). Of the 4 divisions that comprise the ranch, the Laureles Division remains the largest section. Oil and gas exploration, hunting, farming, and cattle ranching are the major land use activities on the King Ranch (Hilbun and Koltermann

2002). The Laureles Division contains tributaries from Petronila Creek, and two lakes known as Laguna Larga and Parra. It occurs in the Gulf Prairie and Marshes ecoregion, and vegetation is characterized as Mesquite-Granjero Parks (*Prosopis glandulosa-Celtis pallida*). Plant species within this community type include common lantana (*Lantana horrid*), prickly pear (*Opuntia* spp.), lotebush (*Zizyphus obtusifolia*), and guayacan (*Guaiacum angusti-foilium*), which are found in loamy or sandy soils (McMahan et al. 1984).

The LANWR is east of Rio Hondo and adjacent to the Gulf Intracoastal Waterway in Cameron County within the Lower Rio Grande Valley (LRGV). It is part of the National Wildlife Refuge System managed by the U.S. Fish and Wildlife Service and was established in 1946 to protect migrating waterfowl (Butcher 2008). Agriculture is the primary land use in the LRGV (Tunnel et al. 2002), and native brushland represents only 5 percent of the habitat (Jahrsdoerfer and Leslie 1988). Wildlife observation and hunting are permitted activities at the LANWR. Important water features within the LANWR include Laguna Atascosa Lake, Rescaca de los Cuates, and the Harlingen Ship Channel. LANWR is located within the Gulf Prairie and Marshes and South Texas Brush Country or South Texas plains ecoregions. Vegetation of the LANWR is described as Mesquite-Blackbrush (*Prosopis glandulosa-Acacia rigidula*), Marsh/Barrier Islands, and crops. Desert olive (*Forestiera angustifolia*), kidneywood (*Eysenhardtia texana*), and hairy gram (*Bouteloua hirsuta*) are characteristic vegetation within this area and occur on loamy or gravelly soils (McMahan et al. 1984).

METHODS

MARINE RADAR

This study will use 2 Merlin Avian Radar Systems (Detect, Inc., Panama City, FL) to monitor diurnal and nocturnal movements of migratory birds along the lower Gulf Coast of Texas. Each radar unit is a mobile system that has a dual radar setup. A 30-kW JRC S-band radar fitted with a 12-ft T-bar antenna operates in the horizontal mode (horizontal radar). The horizontal radar will collect information on flight direction and flight speed of bird targets at each study site. A 25-kW JRC X-band radar fitted with a 9-ft T-bar antenna is tilted 90 degrees to operate in a vertical mode (vertical radar). The vertical radar will provide data on passage rates and altitudes of bird targets at each study site. The horizontal and vertical radars are connected with a computer network station and Merlin software to automate data collection. The Merlin software has specialized algorithms that reduce ground and static clutter and automatically saves data from the horizontal and vertical radars into a Microsoft Access database for future data analysis. A radar interface card records (RIC) the raw vertical radar data in a digital format.

The study will be initiated on the King Ranch site in fall 2007, and will be expanded in the fall of 2008 to incorporate the LANWR site. Both units will be operated during the spring and fall migration periods through the spring 2010 season. The radars will be scheduled to collect information from August 15 to November 15 and March 15 to June 1 to include peak migration periods (Buskirk 1980, Gauthreaux 1999). The radar units will operate continuously for 24 hours per day/ seven days per week during fall and spring migration except during short periods for routine maintenance. Data will be collected at 2.0 nm range by the horizontal radar and at a 0.75 nm range by the vertical radar. Digital RIC recordings of the raw vertical radar showing biological activity will be collected at a 1.5 nm range.

Biological organisms that are identified on radar are referred to as targets since it is difficult to discern the number and species (Magbee et al. 2006). The term echo is used to identify an image of a target on the radar display (Cooper 1996). During operation, the Merlin software records geometric attributes for each target echo that becomes a track after plotting 3 of 4 consecutive echoes. Ground-truth exercises incorporating visual observations will be used to help identify types of birds recorded by the radars. Observers stationed at known points within the radar coverage will convey known bird targets to a radar operator stationed inside the radar unit. The radar operator will use the ground truth tool bar in Merlin software to add species identification to target tracks within the database.

Each RIC recording will be reviewed to identify specific start and stop times of weather events that may provide false positives (i.e. rainfall can track in the vertical radar. Start and stop times will be used to remove these periods from horizontal and vertical databases. Passage rates will be expressed as the mean number of tracks that cross through a 1-km front per hour (Mabee et al. 2006). Flight direction helps differentiate migratory movement from general bird movement within the radar coverage and will be evaluated using the methods for circular statistics (Mabee et al. 2006). The horizontal radar data will be geo-referenced using a GPS unit (Detect, Inc., Panama City, FL), and may be entered as a theme in geographic information system using ArcView ® software (ESRI, Redlands, CA). Bird tracks from the horizontal radar can be overlaid on a map of the study site to show migratory bird movements relative to landscape features in the coverage area.

During spring and fall migration, a Davis Vantage Pro2 weather station (Davis Instruments, Hayward, CA) will be connected to each radar unit. Site specific weather data will be obtained every 5 minutes for temperature, humidity, dew point, barometric pressure, rainfall, wind speed, and wind direction. Additionally, winds aloft data of the Corpus Christi and Brownsville National Weather Service stations will be acquired from the National Climatic Data Center.

Statistical analyses will be performed using SAS 9.1 procedures (SAS Institute, Inc. 1999), and analyses at $\alpha \leq 0.05$ will be regarded as significant. Data will be adjusted for level of effort, and tested for normality. Data may be transformed if it fails to fulfill normality assumptions. The differences in timing, magnitude, direction, and altitude will be compared among hours, nights, seasons, and locations as fixed factors using general linear model ANOVA. The relationship between migration characteristics and weather variables will be tested using stepwise linear multiple regression. Weather variables will serve as the independent variables, and would include temperature (ºC), relative humidity (%), barometric pressure (mm), rainfall (mm), wind speed (m/s), and wind direction (degrees). Geometric variables describe the radar signature of a track and are collected for each individual track within the Microsoft Access database. Discriminant Analysis will test ground-truth observations to determine whether bird targets can be differentiated into groups (i.e. small, medium, large, and flock) and identify the geometric variables that account for the most differences among bird targets.

TIME SCHEDULE

TABLE 1. Timeline of dates and project tasks for this study conducted from August 15, 2007 to June 1, 2010.

Date		Project Task
2007		
	Jan - Aug	Radar unit construction and field testing, preparation for 1st fall season.
	Aug - Nov	Begin 1st fall collection, ground truth of radar observations.
	Nov - Dec	Preparation for 1st spring season, data analysis.
2008		
	Jan - Mar	Preparation for 1st spring season, second radar unit construction and field testing, site selection for second radar unit, data analysis.
	Mar - Jun	Begin 1st spring collection, ground truth of radar observations.
	Jun - Aug	Preparation for 2nd fall season, data analysis.
	Aug - Nov	Begin 2nd fall collection, ground truth of radar observations.
	Nov - Dec	Preparation for 2nd spring season, data analysis.
2009		
	Jan - Mar	Preparation for 2nd spring season, data analysis.
	Mar - May	Begin 2nd spring collection, ground truth of radar observations.
	Jun - Aug	Preparation for 3rd fall season, data analysis.
	Aug - Nov	Begin 3rd fall collection, ground truth of radar observations.
	Nov - Dec	Preparation for 3rd spring season, data analysis.
2010		
	Jan - Mar	Preparation for 3rd spring season, data analysis.
	Mar - May	Begin 3rd spring collection, ground truth of radar observations.
	Jun - Dec	Final data analysis and submission of dissertation and reports.

LITERATURE CITED

ABLE, K. P. 1972. Fall migration in coastal Louisiana and the evolution of migration patterns in the Gulf region. Wilson Bulletin 84:231-242.

ABLE, K. P. 1973. The role of weather variables and flight direction in determining the magnitude of nocturnal bird migration. Ecology 54:1031-1041.

ÅKESSON, S. AND A. HEDENSTRÖM. 2007. How migrants get there: migratory performance and orientation. BioScience 57:123-133.

ALERSTAM, T. AND A. LINDSTRÖM. 1990. Optimal bird migration: the relative importance of time, energy and safety, p. 331-351. *In* E. Gwinner [ED.], Bird migration: physiology and ecophysiology. Springer Verlag, Berlin, Germany.

ALERSTAM, T. 2001. Detours in bird migration. Journal of Theoretical Biology 209:319-331.

ALERSTAM, T., A. HEDENSTROM, AND S. AKESSON. 2003. Long-distance migration: evolution and determinants. Oikos 103:247-260.

ARNOLD, A. J. 2009. Chronology and terrestrial habitat use of migrating birds in southern Texas. M. S. Thesis, Texas A&M University-Kingsville, Kingsville, Texas. 214 pp.

BLAIR, W. F. 1950. The biotic provinces of Texas. Texas Journal of Science 2:93-117.

BUSKIRK, W. H. 1980. Influence of meteorological patterns and trans-Gulf migration on the calendars of latitudinal migrants, p. 485-491. *In* A. Keast and E. S. Morton [EDS.], Migrant birds in the neotropics: ecology, behavior, distribution, and conservation. Smithsonian Institute Press, Washington, D.C.

BUTCHER, R. D. 2008. America's National Wildlife Refuges: A compete Guide. Taylor Trade Publishing, Lanham, MD.

COOPER, B. A. 1996. Use of radar for wind power-related avian research, p. 58-73. *In* Proceedings of National Avian-Wind Power Planning Meeting II. RESOLVE, Inc., Washington, D.C.

FULBRIGHT, T. E. AND F. C. BRYANT. 2002. The last great habitat. Caesar Kleberg Wildlife Research Institute Special publication no. 1., Texas A&M University-Kingsville, Kingsville, TX.

GAUTHREAUX, S. A. 1991. The flight behavior of migrating birds in changing wind fields: radar and visual analyses. American Zoologist 31:187-204.

GAUTHREAUX, S. A., AND C. G. BELSER. 1998. Displays of bird movements on the WSR-88D: patterns and quantification. Weather and Forecasting 13:453-464.

GAUTHREAUX, S. A. 1999. Neotropical migrants and the Gulf of Mexico: the view from aloft, p. 27-49. *In* K. P. Able [ED.], A gathering of angels: the ecology and conservation of migrating birds. Cornell University Press, Ithaca, NY.

GAUTHREAUX, S. A., J. E. MICHI, AND C. G. BELSER. 2005. The temporal and spatial structure of the atmosphere and its influence on bird migration strategies, p. 182-193. *In* R. Greenburg and P. P. Marra [EDS.], Birds of two worlds: the ecology and evolution of migration. Johns Hopkins University Press, Baltimore, MD.

HATCH, S. L., J. L. SCHUSTER, AND D. L. DAWE. 1999. Grasses of the Texas Gulf Prairies and Marshes. Texas A&M University Press, College Station, TX.

HENNINGSSON, S. S., AND T. ALERSTAM. 2005. Barriers and distances as determinants for the evolution of bird migration links: the arctic shorebird system. Proceedings of the Royal Society B Biological Sciences 272:2251-2258.

HILBUN, N. L. AND A. E. KOLTERMANN. 2002. Ranching Heritage, p. 59-70. *In* J. W. Tunnell, Jr. and F. W. Judd [EDS.], The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, TX.

JAHRSDOERFER, S. E. AND D. M. LESLIE, JR. 1988. Tamaulipan Brushland of the Lower Rio Grande Valley of South Texas: Description, Human Impacts, and Management Options. U.S. Fish and Wildlife Service Biological Report No. 88, Washington D. C.

JUDD, F. W. 2002. The Tamaulipan Biotic Province, p. 38-58. *In* J. W. Tunnell, Jr. and F. W. Judd [EDS.], The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, TX.

KERLINGER, P. 1995. How birds migrate. Stackpole Books, Mechanicsburg, PA.

LIECHTI, F. AND B. BRUDERER. 1998. The relevance of wind for optimal migration theory. Journal of Avian Biology 29:561-568.

LINCOLN, F. C., S. R. PETERSON, AND J. L. ZIMMERMAN. 1998. Migration of birds. U.S. Department of the Interior, U.S. Fish and Wildlife Service Circular 16, Washington, D.C.

MABEE, T. J., B. A. COOPER, J. H. PLISSNER, AND D. P. YOUNG. 2006. Nocturnal bird migration over an Appalachian ridge at a proposed wind power project. Wildlife Society Bulletin 34:682-690.

MCMAHAN, C. A., R. G. FRYE, AND K. L. BROWN. 1984. The vegetation types of Texas, including cropland (map and illustrated synopsis). Texas Parks and Wildlife Department, Austin, TX.

MOORE, F. R. AND D. A. ABORN. 2000. Mechanisms of *en route* habitat selection: how do migrants make habitat decisions during stopover? Studies in Avian Biology 20: 34-42.

MOORE, F. R. AND T. R. SIMONS. 1990. Habitat suitability and the stopover ecology of Neotropical landbird migrants, p. 345-355. *In* J. Hagen and D. Johnston [EDS.], Ecology and conservation of neotropical migrant landbirds. Smithsonian Institute Press, Washington, D. C.

MOORE, F. R., S. A. GAUTHREAUX, JR., P. KERLINGER, AND T. R. SIMONS. 1993. Stopover habitat: management implications and guidelines, p. 58-69. *In*: D. Finch and P. Stangel [EDS.], Status and Management of Neotropical Migratory Birds. USDA Forest Service General Technical Report RM-229, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

MOORE, F. 1999. Neotropical migrants and the Gulf of Mexico: the Cheniers of Louisiana and stopover ecology, p 51-62. *In* K. P. Able [ED.], A gathering of angels: the ecology and conservation of migrating birds. Cornell University Press, Ithaca, NY.

NORWINE, J. AND R. BINGHAM. 1986. Frequency and severity of droughts in South Texas: 1900–1983, p. 1-17 *In* R. D. Brown [ED.], Livestock and wildlife management during drought. Caesar Kleberg Wildlife Research Institute, Kingsville, TX.

PULIDO, F. 2007*a*. The genetics and evolution of avian migration. BioScience 57:165-174.

PULIDO, F. 2007*b*. Phenotypic changes in spring arrival: evolution, phenotypic plasticity, effects of weather and condition. Climate Research 35:5-23.

RAMENOFSKY, M. AND J. C. WINGFIELD. 2007. Regulation of migration. BioScience 57:135-143.

RICHARDSON, W. J. 1978. Timing and amount of bird migration in relation to weather: a review. Oikos 30:224-272.

RICHARDSON, W. J. 1990. Timing of bird migration in relation to weather: updated review, p. 78-101. *In* E. Gwinner [ED.], Bird migration: ecology and ecophysiology. Springer-Verlag, Berlin, Germany.

SCHAUB, M. AND L. JENNI. 2001*a*. Variation of fuelling rates among sites, days, and individuals in migrating passerine birds. Functional Ecology 15:584-594.

SCHAUB, M. AND L. JENNI. 2001*b*. Stopover durations of three warbler species along their autumn migration route. Oecologia 128:217-227.

SIMONS, T. R., F. R. MOORE, AND S. A. GAUTHREAUX. 2004. Mist-netting trans-Gulf migrants at coastal stopover sites: the influence of spatial and temporal variability on capture data. Studies in Avian Biology 29:135–143.

TAYLOR, R. B., J. RUTLEDGE. AND J. G. HERRERA. 1997. A field guide to common south Texas shrubs. Texas Parks and Wildlife Press, Austin, TX.

TUNNELL, J.W., JR. 2002. Geography, Climate, and Hydrography, p. 7-27. *In* J. W. Tunnell, Jr. and F. W. Judd [EDS.], The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, TX.

TUNNELL, J.W., JR., K. WITHERS, AND E. H. SMITH. 2002. Conservation Issues and Recommendations, p. 275-288. *In* J. W. Tunnell, Jr. and F. W. Judd [EDS.], The Laguna Madre of Texas and Tamaulipas. Texas A&M University Press, College Station, TX.