# THE EVALUATION OF CHRISTMAS BIRD COUNTS AS AN INDICATOR OF POPULATION TRENDS AND HABITAT SELECTION IN BLACKBIRDS AND STARLINGS

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Matthew David Strassburg

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**Title**

The Evaluation of Christmas Bird Counts as an Indicator of Population

Trends and Habitat Selection in Blackbirds and Starlings

**By**

Matthew D. Strassburg

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

**MASTER OF SCIENCE**

SUPERVISORY COMMITTEE:

George M. Linz
Chair (typed)

Mario Biondini

Mark E. Clark

William J. Bleier

Approved by Department Chair:

11-17-2011
Date

William J. Bleier
Signature

# ABSTRACT

*Agelaius phoeniceus* (red-winged blackbird), *Quiscalus quiscula* (common grackle), and *Sturnus vulgaris* (European starling) are three of the most abundant bird species found in North America, and along with *Euphagus carolinus* (rusty blackbird) and *Euphagus cyanocephalus* (Brewer's blackbird), make up a significant proportion of the avian population.

Population trends of these four blackbird species and European starlings (EUST) were analyzed from the Christmas Bird Count (CBC) data collected between 1988 and 2008. Population analyses were conducted using linear mixed-effect regressions from the Lmer package of Program R. This approach was effective in modeling the population trends of widespread species with large populations. However, it was not as effective in modeling species with smaller populations and distributions.

Only RWBL had significant change in population during the study period, showing a positive increase in mean count number of approximately 2.4% each year. Habitat selection showed some parallels among species.

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# INTRODUCTION

Red-winged blackbirds (*Agelaius phoeniceus*, RWBL), common grackles (*Quisculus quiscula*, COGR) and European starlings (*Sturnus vulgaris*, EUST) are among the most common birds on the North American continent, making up a significant portion of the avian community. During winter months, these species form mixed-species roosts ranging in size from a few dozen birds to several million individuals. These species are well known for their ability to damage commercial crops, such as rice sprouting in early spring and ripening rice in late-summer in the southern US and ripening corn and sunflower in the northern US prior to their southern migration (Werner *et al.*, 2009; Werner *et al.*, 2011). On the other hand, the European starlings is a species that is sometimes problematic at feedlots and grain storage facilities. Rusty blackbirds (*Euphagus carolinus*, RUBL) and Brewer's blackbirds (*Euphagus cyanocephalus*, BRBL) are two blackbird species that do not damage crops or feedlots, mostly due to their relatively low abundance, but are often present in mixed-species flocks during the wintering months.

Although still one of the most numerous birds on the North American continent, it is widely reported that RWBL populations have been in decline for a number of years (Yasukawa & Searcy, 1995). Blackwell & Dolbeer (2001) correlated declines of RWBL populations to decreases in crop diversity, the early mowing of hay, and proportional decreases in suitable nesting habitat. Falling blackbird populations in the Dakotas were similarly connected to the tilling of breeding habitat for agricultural purposes (Besser *et al.*, 1984). Other study species, with the exception of the RUBL, have had relatively stable population levels for the last several decades according to both the Breeding Bird Survey (BBS) and the Christmas Bird Count (CBC). RUBL populations, however, have been declining steadily for several decades with no discernable cause. Rarer than previously believed, RUBL was uplisted from a species of Least Concern to Vulnerable in the 2007 International Union for the Conservation of Nature (IUCN) Red List (IUCN, 2007).

The occupancy of any species in an area is influenced by a large number of habitat variables. These may include vegetation type, food and water availability, quality of available food, surrounding habitat, weather, climatic conditions, and competitors (Beletsky & Orians, 1996). Areas with favorable conditions attract large numbers of birds in both the wintering and breeding seasons, as opposed to areas with poor conditions. Positive associations were found between wetland breeding birds and the total amount of contiguous wetland and grassland in the surrounding landscape (Naugle *et al.*, 2001; Naugle *et al.*, 1999). The nesting suitability of wetlands was reported to increase with the amount of surrounding cropland (Creighton *et al.*, 1997), which may be due to abundant food resources such as waste grains and insects found within crop fields. The amount of cropland, rather than wetlands, in a landscape was also found to have a greater effect on the density of nesting RWBL (Clark & Weatherhead, 1986; Clark *et al.*, 1986).

This thesis reports results intended to develop a better understanding of blackbirds and starlings at the population and landscape levels. The primary objectives of this study were to 1) analyze trends in Christmas Bird Count data for RWBL, COGR, BRBL, RUBL, and EUST obtained from the CBC, 2) to identify landscape-level factors influencing blackbird and starling winter roost site selection, and 3) to evaluate the Christmas Bird Count as an indicator of chronological and climate related patterns of blackbird and starling roost selection.

# LITERATURE REVIEW

Research in avian ecology studies is primarily conducted during the breeding season and early fall, after the breeding season has concluded but before migration begins in earnest, resulting in an inadequate understanding of avian ecology at other times of the year (Tankersley, 2003; Hagy *et al.,* 2010). Most studies conducted on blackbirds and starlings during this time focus primarily on avian-human interactions and the agricultural damage and human health problems blackbirds and starlings can cause; the birds are often a secondary focus of studies aimed at improving asset protection methods (Mott, 1984). Because of this disparity in understanding, the wintering ecology of blackbirds and starlings has largely been ignored, limiting knowledge of this portion of the avian life cycle.

## Red-Winged Blackbirds

The RWBL is one of the most abundant species of birds on the North American continent (Stewart & Kantrud, 1972; Dolbeer, 1978). Population estimates vary depending on the time of year and the methodology used in the estimation process. These estimates range from 100 million individuals to over 300 million individuals depending on what methods are used and who is using them. In 1974, the population was estimated at approximately 190 million individuals (Weatherhead, 2005). In 2003, estimates of the North American population were at a low of 100 million individuals during the pre-breeding period and 200 million in the post-breeding period (Blackwell *et al.,* 2003). These studies suggest a natural yearly reduction and rebound in population commensurate with that seen in other species of migratory birds (Blackwell *et al.,* 2003). Current estimates by the Audubon Society place the global population at approximately 210 million individuals (Audubon Society, 2011). Several studies, such as Blackwell & Dolbeer (2001) and Weatherhead (2005), have reported significant widespread declines of RWBL populations. Blackwell & Dolbeer (2001) suggested those declines might be the result of changes in agricultural practices and habitat loss, whereas Weatherhead (2005) cited a loss of nesting habitat and climate change as possible reasons. These studies, however, did not use current population estimates. Weatherhead (2005) and Blackwell & Dolbeer (2001) used data obtained from 1975 to 1995 and 1966 to 1996, respectively.

During the nesting and rearing period, RWBL are commonly seen in wetlands from southern Texas north to the southern Yukon province and central Northwest Territories in Canada (Yasukawa & Searcy, 1995). These birds migrate south in the fall, over-wintering in the southern United States, with the bulk of the population congregating in the southeastern United States (Figure 1, Yasukawa & Searcy, 1995); some stay in more northerly areas where food is available and conditions are favorable. Dimorphic in their plumage, males are a solid glossy black and have bright red epaulets with a yellow lower border in the central regions (Figure 2). Female coloration is a striped brown, making their coloration cryptic in cattail wetlands and upland grasslands. Males are also larger than females, being 22-24 cm in length and weighing between 65 and 85 g; females are approximately 20% smaller at 17-18 cm in length and 40 to 55 g in weight (Beletsky & Orians, 1996). Both morphology and behavior show flexibility over the range of the RWBL, with subtle variations in the various regional populations, which differ from the“normal” plumage and habits. The most obvious of these variations is the “bicolored blackbird” of coastal California, which shows no yellow border on the red epaulets. Other variations seen include the size of male territories, size of male harem (level of polygyny),

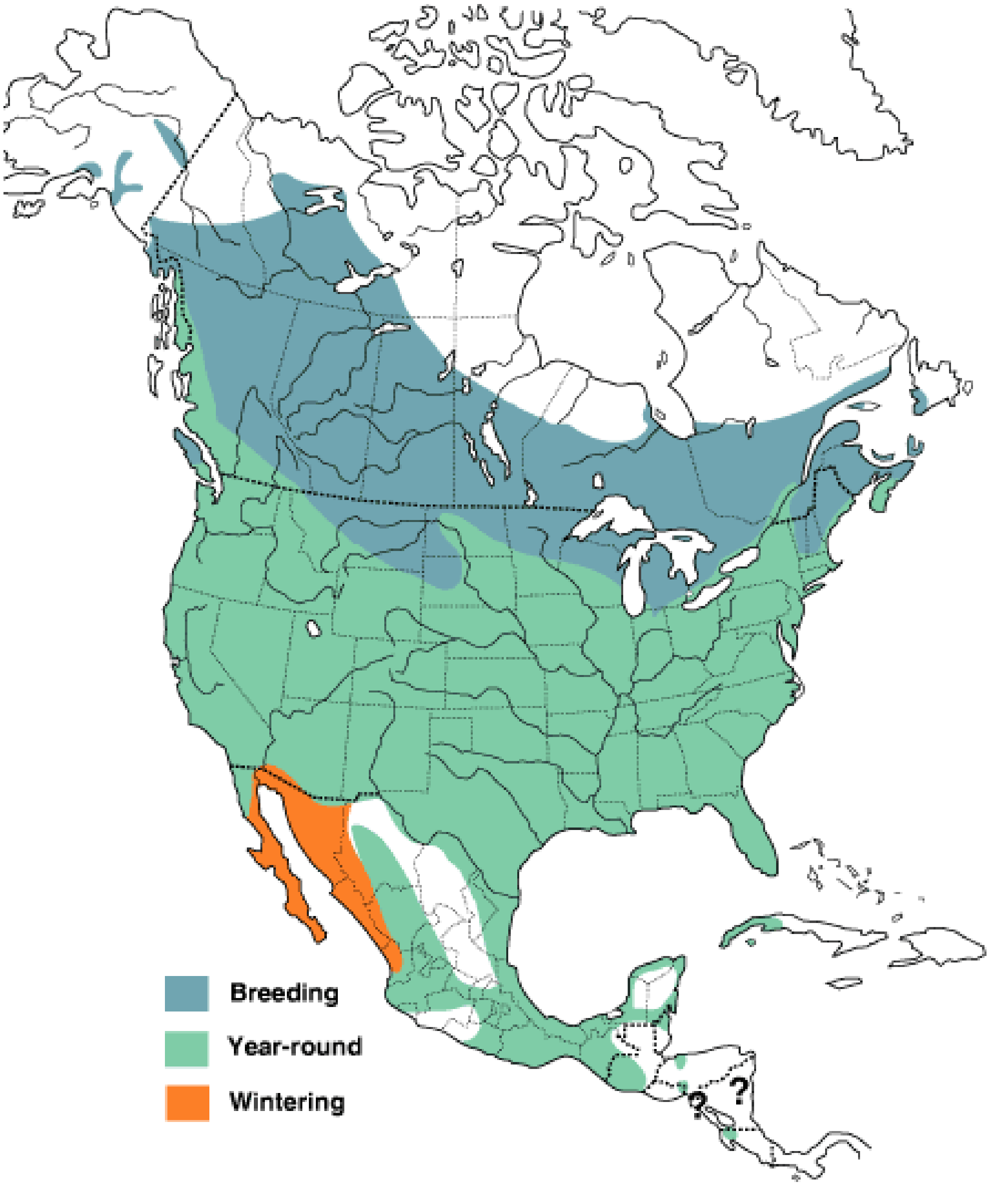

Figure 1. Distribution of the red-winged blackbird (*Agelaius phoeniceus)* in North and Central America. Northern limits of breeding and non-breeding ranges are approximate. Map courtesy of Birds of North America.

the role of the male in feeding nestlings, and extra-pair copulations in females (Beletsky, 1996).

The RWBL is a polygynous species, with males attempting to attract multiple mates into their territories each year. Pairs form quickly, females settling on territories without obvious pairing behavior with the male, sometimes prospecting among several males' territories before settling on one (Nero, 1956; Yasukawa, 1990). The male performs high-intensity song displays in response to new females, and pairing is indicated by a female's continued residence (Nero 1956) and answering of the male's song (Beletsky, 1985). A female does not answer a male's call initially, but will do so frequently once she becomes a regular resident (Yasukawa, 1990). Migrating males usually arrive in late March or early April to establish breeding territories that they will vigorously defend for the next three to four months. Male RWBL will mob much larger birds, such as crows, ravens, birds of prey, and herons, if they enter this territory. These territories are often near open water, with nests hidden in emergent vegetation such as cattails (*Typha spp.*) or bulrushes (*Scirpus spp.*) (Kantrud & Stewart, 1984; Turner *et al.*, 1998). In regions with fewer wetlands, male territories can often be found in sedge meadows, alfalfa fields, fallow fields, and occasionally in sparsely wooded areas bordering waterways (Yasukawa &

Figure 2. Male and female red-winged blackbirds in breeding plumage. Photos by Daniel Cadieux

Searcy, 1995). Within a male's territory, females build cup-shaped nests using vegetation as their primary substrate, which usually takes between four and six days, but can occur in less than two (Beer & Tibbitts, 1950). Incubation lasts 10 -12 days, during which females spend most of their time on their nests. Incubation is interrupted for turning eggs and foraging (Searcy & Yasukawa, 1995). Young fledge about 12 days after hatching but can remain longer if the environment is uncharacteristically harsh (Beletsky, 1996).

RWBL, COGR, EUST, and brown-headed cowbirds (*Molothrus ater*) form roosts during every month of the year, with roost size varying considerably depending on the season (Heisterburg *et al.*, 1984; Morrison & Caccamise, 1990). The low point in roosting numbers is usually reached during the breeding season, when birds are dispersed over their summer range and breeding territories. Conversely, the high point in roost numbers is usually seen during the early wintering season with more than 100 major roosts, each containing one million or more blackbirds, reported yearly in the southeastern United States (Meanley & Royall, 1977). Blackbird populations are highly regulated by food (Orians, 1985); as such, roosts are often found in relatively close proximity to food sources (White *et al.*, 1985) such as agricultural fields, feedlots, pastures, and grasslands. Though RWBL have been known to travel up to 80 km from a roost site to a feeding site (Meanley, 1965), the total distance flown during the day averages approximately 14 km (White *et al.*, 1985).

Diets of most blackbird species consist primarily of insects during the breeding season, when they are plentiful, and cultivated grain, weed seeds, and waste grains during the post-breeding and wintering seasons (Snelling, 1968). The RWBL, being no exception, forages largely on aquatic insects, focusing primarily on odonates (Orians, 1980), but will also forage on waste grain during the summer. During the post-breeding season, RWBL primarily eat plant matter, taking advantage of the rice crop in southern states (Cummings *et al.,* 2002) and corn and sunflower in northern states, resulting in severe damage (Klosterman *et al.,* 2011). Newly sprouting rice crops in the spring and ripening corn, sunflower and rice crops in the post-breeding season are an ideal source of food for blackbirds not only because of their seeds' high-energy content, but also because of the proximity to communal roosting sites (Cummings *et al.,* 2002; Bruggers *et al.,* 1992; Klosterman *et al.,* 2011). RWBL and COGR are well known for depredating corn, sunflower, and rice crops due to their proximity and the sheer size of their roosts (Yasukawa & Searcy, 1995; Peer & Bollinger, 1997).

## Common Grackles

Though less common than RWBL, COGR are still one of the most populous birds in North America. A common North American resident, the COGR ranks eleventh in terms of total number of individuals counted in Breeding Bird Survey (BBS) routes in 1992-1993 (Peterjohn *et al.*, 1994). The Audubon Society currently estimates the COGR population to be approximately 73 million individuals. This is much lower than the 190 million individuals estimated approximately 40 years ago, a reduction of just over 60% (Bystrack & Robbins, 1977). There is also some debate as to whether populations are currently declining or rising, with several studies indicating declines (Peer & Bollinger, 1997; Bystrack & Robbins, 1977) while others indicate stable or slightly increasing populations (Nelms *et al.,* 1994; Robbins *et al.,* 1986).

COGR are known to exploit a much wider range of habitats than RWBL both for nesting and loafing purposes. COGR occur in a wide variety of areas such as open or partially open woodlands, alder, and cedar-dominated swamps (Peer & Bollinger, 1997). COGR also make use of urban and man-made areas such as lawns, golf courses, parks, city streets, agricultural fields, and power line rights-of-way. They have a broad breeding range, with individuals reported as far north as Mackenzie County in northern Alberta, east to Nova Scotia, down the coast to the southern tip of Florida, including the Florida Keys (Figure 3). This range extends west following the gulf coast west into far western Texas (Peer & Bollinger, 1997). These birds winter over much of this range as well, occurring in a band from southern Minnesota, to southern central Texas, east to the gulf coast and ending along the Atlantic coast. Generally far less numerous and very local in the northern parts of the wintering range, the population tends to be focused mainly in the southeastern states (Peer & Bollinger, 1997).

COGR are large blackbirds, both taller and longer than RWBL. Both sexes have a glossy, iridescent black plumage, long, keel-shaped tails, pale yellow irises, and a large black bill (Figure 4). The iridescent sheen covers the head, neck, and breast of the bird in a glossy purplish-blue or bluish-green. Throughout most of their range, their glossy heads contrast with the bronze or brass coloration found on their back and wings; however, breeding birds east of the Appalachian Mountains and south of New England show a purple gloss on their backs and wings which distinguishes them from the western populations. Males are slightly longer and heavier than females, averaging approximately 34-35 cm and weighing around 120 g, as compared with females, which average 28 cm in length and weigh approximately 90 g. Males also have slightly larger tails, which normally “keel”, or fold their tail feathers into a shallow “V” in flight. Females usually show less iridescence than the male and do not usually show the keeling behavior seen in males.

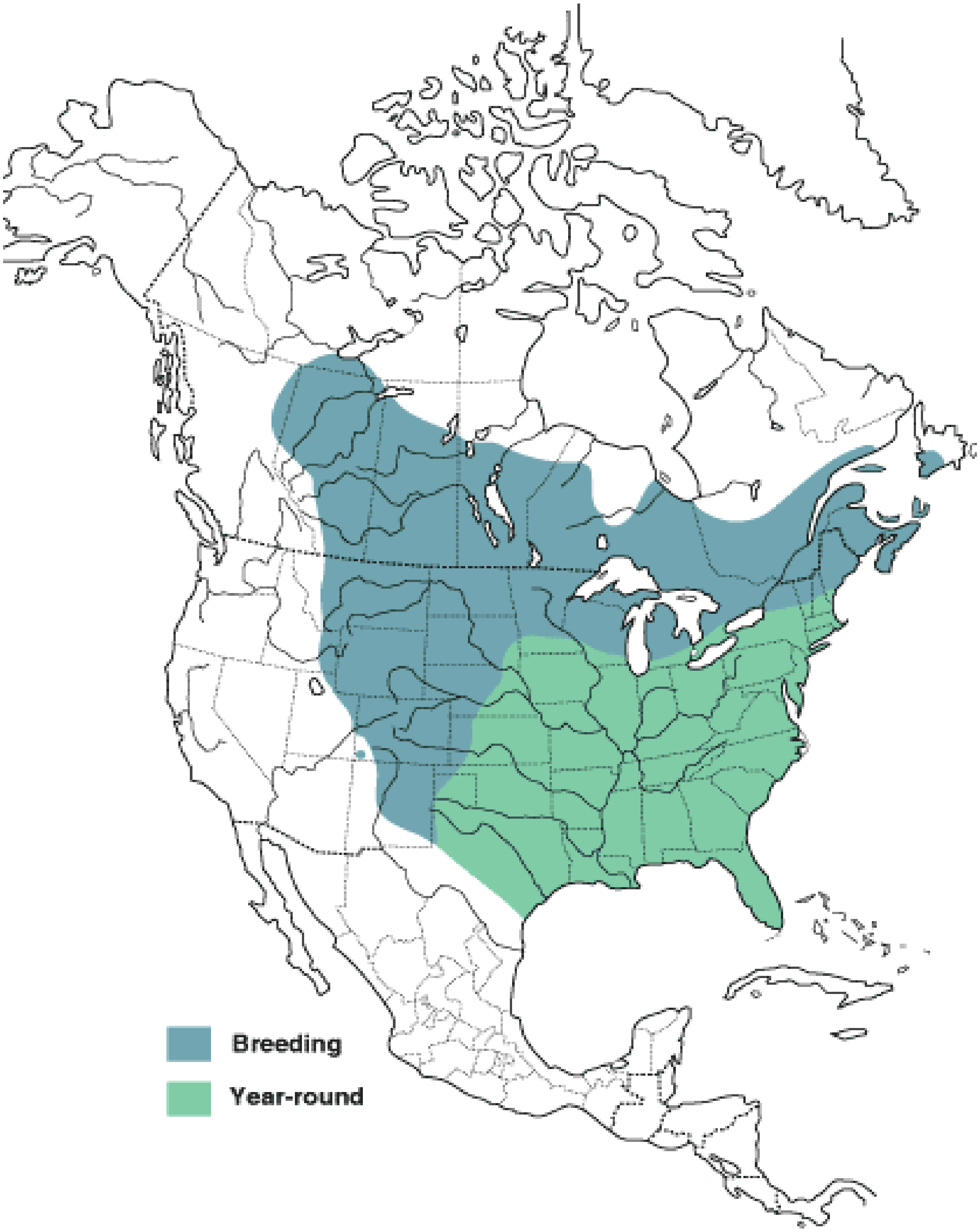

Figure 3. Distribution of the common grackle (*Quisculus quiscula*) in North and Central America. Map courtesy of Birds of North America.

Figure 4. Plumage of the common grackle. Photo by Bird control Products

The COGR is typically a monogamous species, with males arriving at the breeding grounds approximately one week prior to the females. Flocks of migrants begin arriving at most breeding locations between mid-February and early March; migration in most places is typically finished by mid-April (Dolbeer, 1982). Pairs begin to form as soon as females arrive at the breeding grounds. Pair formation generally involves flights and mutual displays between a single female and multiple males. Flights can be characterized as one of three types: Leader Flight, where a female is followed closely by a group of males at slow to moderate speed (Ficken, 1963); Chase, where the female flies quickly and evasively; and Together Flight, in which flight is slow to moderate and males may be ahead of, behind, below, or to the side of the female. Mutual displays begin after flights have ended and may involve a myriad of visual and auditory displays by both sexes (Ficken, 1963). Grackles are gregarious, both in the wintering season and in the breeding season, sometimes forming very loose “colonies” with up to 200 pairs (Peck & James, 1987). The female typically builds the nest after “exploring” for nest sites, sometimes before she pairs with a male (Maxwell, 1970). If already paired, the male will follow her as she inspects different locations (Maxwell, 1970). Males have been observed with nest building materials, and building and repairing nests (Maxwell, 1970), though females do the majority of the construction. The nest itself takes between one and six weeks to build, with females often abandoning sites under construction in favor of a new location (Maxwell, 1970). Clutches range in size from 1-7 with 4 eggs being typical; incubation times range between 11.5 days to 15 days, depending upon how many eggs are laid (Peer & Bollinger, 2000). Young remain in the nest for 12-15 days after hatching and usually remain near the nest for several days after departure (Howe, 1976).

Usually seen foraging in flocks with other blackbirds, the diet of COGR is similar to that of other blackbirds, generally consisting of insects, other invertebrates, and plant seeds during the breeding season and agricultural grain, weed seeds, and tree seeds during the post-breeding and wintering seasons. During the breeding season, they have occasionally been observed taking other prey items such as crustaceans, mollusks, fish, frogs, salamanders, mice and other birds. Resourceful and opportunistic, COGR often follow plows and lawn mowers to catch invertebrates and other prey items agitated by the disturbance. Another adaptation that COGR have for food acquisition is a hard keel (Figure 5) that projects downward from the horny upper palate and extends beyond the tomia, or the sharp ventral edges of the upper maxilla (Beecher, 1951). This keel is used to saw open acorns, which are often completely scored around their shorter diameter and cracked open by biting (Beecher, 1951). During migration and wintering, agricultural

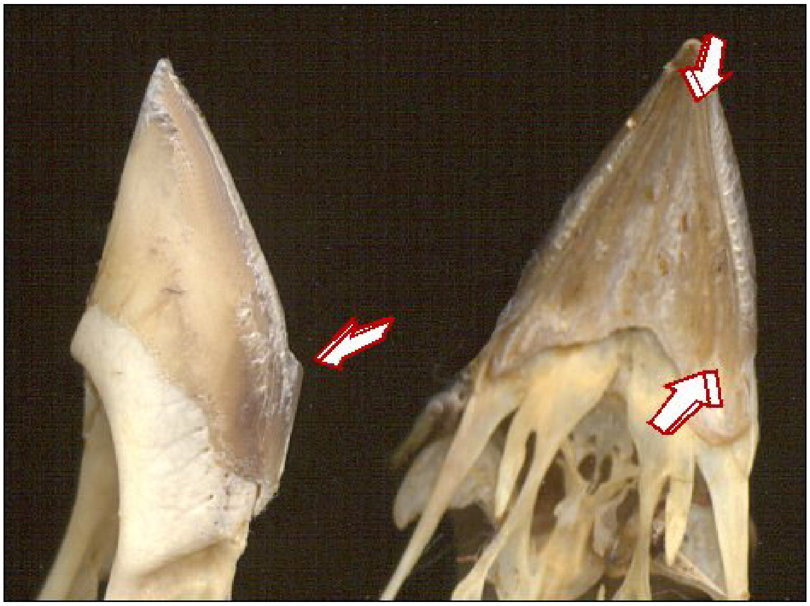

Figure 5. Seed opening "keel" found in the mouths of many seed eating birds used to saw open the hard cover found on many seeds. Many seed eaters have a specialized set of structures to aid in shedding the seed coats of seeds, allowing them to get at the otherwise protected kernel. The seed fits into the groove in the palate (marked by the arrows at the ends) and rolled against the "blade" (marked by the arrow) of the lower jaw, splitting the seed coat. The tongue then separates and discards the seed coat. Photo Courtesy of The Centennial Museum.

grains and seeds make up the bulk of the COGR diet, with corn seeming to be the most commonly consumed grain; but the dominant agricultural grain consumed varies regionally and seasonally, likely in response to availability (White *et al.*, 1985). For example, the dominant food consumed in the fall in North Dakota was sunflower seeds (Homan *et al.*, 1994), and in Arkansas in the fall and winter the main crop grain consumed was rice (Meanley, 1971).

## European Starlings

In 1890 and 1891, between 60 and 100 EUST were released in New York's Central Park by Eugene Schieffelin, then head of the American Acclimatization Society, a group founded in 1871 and dedicated to introducing European flora and fauna into North America for both economic and cultural reasons. The group's charter explained its goal was to introduce "such foreign varieties of the animal and vegetable kingdom as may be useful or interesting." Schieffelin, a great admirer of Shakespeare, was the society's driving force. Some accounts of his efforts claim that he had resolved, as an aesthetic goal, that the organization should seek to introduce every bird species mentioned in Shakespeare's works. Though undocumented, the group did have some success with EUST and several other species. One of the most numerous birds in North America, Feare (1984) estimated the overall population size of the EUST in North America at more than 200 million individuals by extrapolating from British data.

The EUST is a widely distributed species occurring over nearly the whole of the North American continent (Figure 6). The birds have a relatively uniform distribution over the eastern half of the continent, but populations are patchier in the west, particularly in heavily forested and mountainous habitats. Along the northern margins of their range, starlings are found primarily around cities and towns where supplemental food is available, and where buildings provide protection from the elements (Feare 1984). Having a relatively close association with humans and high behavioral plasticity, starlings can inhabit a wide variety of habitats as long as their essential needs are met (Feare, 1984; Cabe, 1993). They usually forage in open habitats, on short, mowed, or grazed fields which are abundantly produced in many urban areas and by many types of agriculture (Feare, 1984; Cabe, 1993). Starlings avoid large expanses of undisturbed non-grassland native habitats such as forested areas, arid chaparral, and deserts. These areas offer starlings few food sources nesting areas and limited water (Feare, 1984). Migration and population movement in starlings is regionally, and sometimes individually, variable. In some areas, many breeding pairs are sedentary (Kessel, 1953) while others may migrate short distances and others much farther. Some juveniles migrate, while their nest mates may not; some individuals apparently migrate in some years and not in others (Kessel, 1953).

Often mistaken for blackbirds, EUST are members of the starling family, Sturnidae, which includes mynas, starlings, and occasionally oxpeckers, depending on the taxonomist doing the classification. Predominantly glossy black, in the breeding season they show a purplish-green iridescence, especially on the most of the head; body feathers have whitish terminal spots (Figure 7). Following the annual molt, most of the head and body feathers have whitish terminal spots; these wear down to produce the glossy black appearance starlings have during spring. Males and females have similar plumage and are easily distinguished from North American blackbirds by their long pointed yellow beaks in the spring, their distinctly shorter tails, and their long pointed wings; most blackbird species have fairly long tails and rounded wingtips. Similarities between males and females are more than just plumage coloration, as both are approximately the same length and weight, between 19-22 cm long and weighing between 60-90 g.

EUST are generally monogamous, but polygyny is common in many populations (Feare, 1984; Pinxten *et al.*, 1989) though the second mates of males generally receive little to no help in rearing young and as a result fledge significantly fewer young than primary nests. Resident males begin investigating suitable nesting cavities in late winter; migratory males usually begin searching soon after arrival, usually in late February or early March. Females choose mates and may make choices based upon the males’ song, but they may also choose a mate based upon the male’s territory and the nest site a male has chosen (Kessel, 1957). Nests can be found virtually anywhere there are cavities (including cliffs

Figure 6. Distribution of the European Starling (*Sturnus vulgaris*) in North and Central America. Distribution is based on Godfrey (1986). The species may be expanding its range along the southern edge of its distribution. Map courtesy of Birds of North America.

and burrows), and occasionally outside of cavities in dense vegetation in trees or on the ground (Weitzel, 1988). Common locations include openings in buildings, nest boxes, cavities usurped from other birds such as woodpeckers, and natural cavities in trees. Males begin depositing nest materials soon after site selection, and systematic construction begins immediately after pair formation, usually between early February and late March (Kessel, 1957). Males typically accumulate materials slowly, generally before pair formation; females may remove a portion or all of the material accumulated by the male and supplement materials brought by the male with her own (Kessel, 1957).

Figure 7. European starling summer plumage. Photo by Lloyd Spitalnik

Egg laying is generally synchronized within a population, with most of the first eggs laid within 3 to 4 days of each other, especially for the first brood of the season. Dates range from 15 March in the southern reaches of their range to 15 June in the northern areas (Kessel, 1957). Egg laying is often variable in the face of spring weather (Kessel, 1957).

Full-time incubation begins with the last, or penultimate, egg laid, commonly 4 to 6 days after the first egg. Hatching usually occurs 11.5 to 12 days after incubation, with the chicks fledging 21 or 22 days after hatching. At least one parent may continue to care for the fledglings for at least a day or two after leaving the nest. Second broods are attempted in many areas, but not usually north of $48^{o}$ north latitude and are more likely when the first clutch is early (Kessel, 1953). If a second brood is attempted, activity begins immediately; the first eggs are usually laid within 6 to10 days after the first brood fledges, but may be laid in as little as 1 or 2 days (Kessel, 1953).

Starlings have a diverse diet that varies regionally, with the age of individuals and with season. An immense variety of invertebrates are taken when available, frequently including Orthoptera, Coleoptera, Diptera, and Lepidoptera, in addition to snails, earthworms, millipedes, and arachnids (Tinbergen, 1981). During the breeding season, invertebrates are the preferred food sources as they have a higher level of nutrition for developing offspring (Tinbergen, 1981). In the fall and winter periods, considerable amounts of plant material are included in the EUST diet; fruits and berries, grains, and certain seeds are consumed when invertebrate material is not readily available. Other more intermittent food items such as periodic influxes of arboreal insects (Tinbergen, 1981), garbage, nectar and livestock feed are also frequently exploited (Feare, 1993). Adults spend much of their foraging time in open areas with short vegetation such as pastures, mown fields, and lawns (Feare, 1984) and may differentiate between habitat types based on the availability of prey items and types (Tinbergen, 1981).

## Brewer's Blackbirds

A historically common and conspicuous species, population estimates in 1974 and 1975 placed the population at approximately 10.3 million individuals (Meanly & Royall, 1977). Before and since then, there have been several studies that have used BRBL as research subjects, owing largely to its ease of study, broad ecological plasticity, and its occupancy of environments that can be unpredictable over brief, as well as long, periods (Sauer *et al.,* 1999). Sauer *et al.* (1999) found relatively stable or non-significantly decreasing population trends over most of the range of the BRBL, and significant increases in population sizes in North Dakota and Minnesota between 1966 and 1998. Trend estimates over a more recent period (1980-1998), however, have shown a statistically significant decline of approximately 2% per year in the breeding population, with only populations in North Dakota showing significant increases (Sauer *et al.,* 1999).

A widespread species with high environmental flexibility and adaptability(Figure 8), BRBL occupy a range of habitats and a large distribution on the North American continent. Their breeding range reaches from British Columbia and central Alberta, east to Michigan and Quebec, and south to northern Baja California, southern California, central Nevada and Arizona. Their principal wintering range extends from southern British Columbia southeast to the western reaches of Montana, and stretches east to South Carolina and parts of Florida (Stevenson & Anderson, 1994; Stepney, 1975). BRBL occupy a wide range of habitats, but prefer open, often human modified habitats such as residential lawns, cemeteries, and golf courses. Within nesting habitats, there appear to be three crucial features needed across the species' breeding range: foraging areas, suitable nest sites, and guard perches (Horn, 1968). In Ontario, birds were most commonly found along highway and railroad grades that had utility lines and also offered nearby short grass foraging sites (Stepney, 1971).

A medium sized blackbird, BRBL are dimorphic in size and plumage coloration. Males are between 21 and 25 cm long and on average weigh approximately 67 g, while females are between 20 and 22 cm long and average approximately 57 g. Adult males are

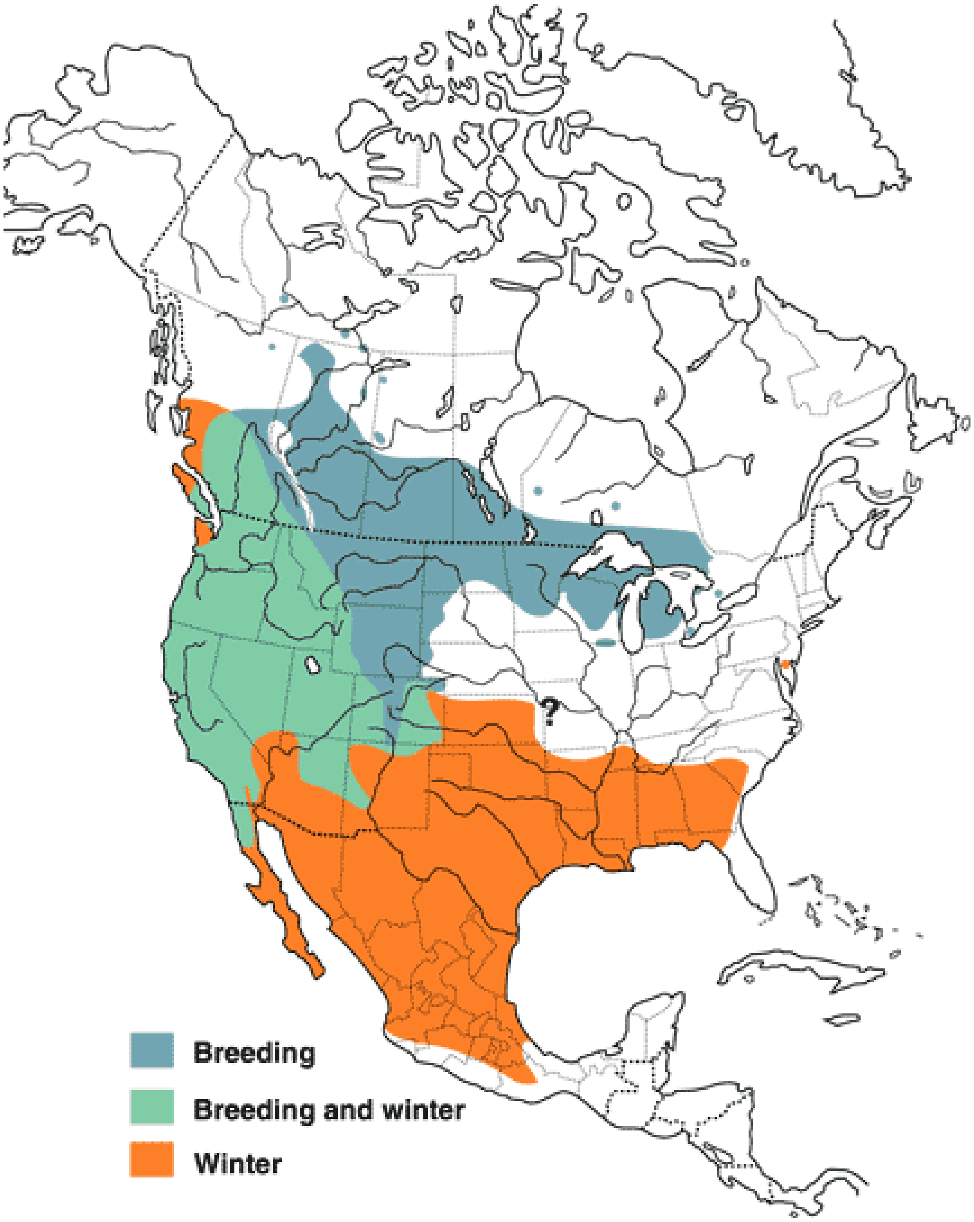

Figure 8. Distribution of Brewer's Blackbird (*Euphagus cyanocephalus*) in North and Central America. The northern boundary of its winter range is fluid, with individuals occasionally wintering in low densities well north of the depicted range. Isolated breeding localities in northwestern Canada are indicative of continued northward range expansion. Map courtesy of Birds of North America.

black with a blue to violet iridescence on their heads and necks under strong lights, and a very dark brown to matte black appearance in duller light (Stevenson & Anderson, 1994). The body normally shows a balance of iridescent colors that can range from blue to green, with most males showing a mix somewhere between the two. The feathers of the wings and tail are edged in a metallic, olivaceous brown and are typically similar in color to the body (Figure 9). Females are a grayish brown with a light velvet gloss on the head and neck with a faint metallic sheen similar to the male over the rest of their body. The wings and tail of the female are darker and glossier than the body, and the sides of the head are paler than the crown with a postocular streak and lores slightlydarker than the rest of the face (Stevenson & Anderson, 1994).

Figure 9. Male and female Brewer's blackbirds in summer plumage. Photos by Scott Streit and Dana Kenneth Johnson

Usually monogamous, pair formation in BRBL begins as a gradual process in late winter or early spring flocks. Resident birds spend more time in the vicinity of colonies, where they begin to associate in pairs, but will resort to flocking behavior if the colony is disturbed (Williams, 1952). As the season advances, the time spent in paired configurations increases, with paired birds eventually becoming segregated from the rest of the flock. Afterwards, pairs are almost always together, and the male increasingly defends the female from the approaches of other males, using visual displays and physically chasing them off (Horn, 1970). Mutual displays by the male and female become a frequent and conspicuous component of pair formation at this time, and may last several minutes. Unlike many species, the female is not dominated by the male, and these mutual displays are often mistaken as a confrontation between two males. A highly social species, BRBL nest in fairly compact colonies numbering from a few pairs to over 100 pairs in some colonies (Horn, 1970). Well-studied colonies in eastern Washington commonly number between 10 and 60 pairs (Horn, 1970), and in California, Williams (1952) tallied 14 to 23 nests in the colony he monitored during the 6 years of his investigations. Solitary pairs sometimes do nest outside of a colony, but this is relatively rare. Due to their highly social nature during pair formation, nesting is highly synchronous in BRBL colonies. The extent to which colonies synchronize is thought to be a factor of how compact the colony itself is (Horn, 1968). Highly compact colonies promote a higher degree of social interchange between nests, which can easily lead to display contagion where singular or mutual displays at one nest leads other nests nearby to emulate that behavior (Horn, 1968).

The nests of BRBL are constructed without male assistance beginning directly after the pairing phase and take anywhere from a few days (Grummt, 1972) to up to ten days (Williams, 1952). Nest sites are chosen by the female late in the pairing phase; she will lay claim to a site and show aggressive defense of the area. Females show high flexibility when choosing nest sites which have been reported on the ground, over water in emergent vegetation, over dry ground, and occasionally in tree cavities (Furrer, 1975). Females have been known to alter the type of nest site they will choose from one year to the next (e.g., placing nest in sagebrush once and locating it on the ground or elsewhere in the following seasons) (Furrer, 1975). This type of behavioral flexibility is viewed as adaptive in the fluctuating environments that BRBL typically inhabit, as opposed to a strong genetic fixation other species tend to show (Orians, 1985; Furrer, 1975).

Eggs are usually laid one or two days after nest completion with subsequent eggs laid at 24-hr intervals (Grummt, 1972). Typical clutch sizes are approximately five eggs (Furrer, 1975). Egg laying is highly synchronous within colonies, as copulatory displays of one pair often stimulate other nearby pairs via display contagion (Horn, 1968, 1970). Incubation begins with the laying of the last egg (Grummt, 1972) and is performed by the female alone, though the male will infrequently bring food to the nest while the female is incubating (Williams, 1952). Incubation generally lasts 12-13 days, though extremes of 11-17 days are occasionally reported (Furrer, 1975). Young hatch asynchronously, with the degree of synchrony decreasing as the season progresses (Hansen & Carter, 1963). Young typically leave the nest between 12 and 16 days of age, with fledging occurring over a period of several days (Hansen & Carter, 1963). After fledging, the young join their parents in family groups and are fed by parents for up to an additional three weeks (Stepney, 1971). One or two weeks after fledging, several family groups will often coalesce into a small flock that will remain in the general breeding vicinity as fledglings develop independence. Second broods are fairly rare over most of the range of BRBL and usually only attempted if the first nest fails; however, in certain populations where weather permits, such as in coastal California and Oregon, second nests can be fairly common (Williams, 1952).

The diet of BRBL is similar to that of other blackbird species already mentioned; a high percentage of invertebrates are consumed when they are plentiful or available

(Knowlton & Telford, 1946), supplemented with grains and weed seeds, with a limited consumption of small fleshy fruits such as berries. During migration and the wintering season, BRBL concentrate primarily on waste grains (wheat, barley, rice, oats, and corn), weed and grass seeds, and stockyard spillage (found in cattle, hog, and domestic fowl feed lots) and leavings (Stepney, 1971). BRBL are extremely opportunistic during this period, readily reverting to an invertebrate diet should they become available. When fields are plowed, they will follow machinery to glean exposed invertebrates and respond quickly to local population irruptions. Based upon their aggressive responses to insect infestations, several crop depredation researchers have considered the species to be highly beneficial in controlling outbreaks of insect pests (Bryant, 1911; Munro, 1929; La Rivers, 1941; Cowan, 1942; Knowlton & Telford, 1946). Occasionally, they also take vertebrate prey such as leopard frogs, sub-adult voles (Beasley & Carothers, 1974), and nestling and juvenile birds (Anthony, 1923).

## Rusty Blackbirds

Arguably one of the least well-known of North America’s blackbirds, the RUBL is thought to be one of the continent’s most rapidly declining bird species. It is estimated that the population has suffered an 85-99% reduction over the last 40 years, and no one knows precisely why. With a global population of approximately two million individuals (Audubon Society, 2011), it is the rarest species in this study. While most studies agree that there has been a severe decrease in the population of the RUBL, there is also evidence to the contrary (Ellison, 1990; Peck & James, 1987; Niven *et al.,* 2004). Even in the heart of their breeding range, population density has typically been low. In the initial 15-year BBS compilation, the RUBL was not numerous enough to merit a discussion (Robbins *et* *al.*, 1986). This is likely due to its relatively inaccessible breeding distribution, most of which is far north of BBS routes. Because of the scarcity of data regarding RUBL populations, confident analyses using the BBS are difficult. These difficulties are only compounded by the fact that analyses using winter data can be skewed by the flocking of blackbird species, where the numbers of less common species can be obscured by the multitudes of more abundant species. Ellison (1990) found that the species did not decline significantly in Caledonia and Essex counties in Vermont between 1981 and 1990. Populations in the Maritime Provinces of Canada have also showed stability, with 17,000 ± 2,600 pairs between the years of 1986 and 1990 (Erskine, 1992).

No North American blackbird breeds as far north as the RUBL, whose range extends north to the tree-line in wet forests of northern Alaska and Canada, specifically northern Yukon province and the Northwest Territories, southwest through Manitoba, Ontario, Quebec and Newfoundland (Figure 10). Their range extends south from this line to central British Columbia slightly east of the coastal regions. Their wintering range extends south from a northern border that begins in southern Massachusetts and extends southwest to southern West Virginia. From the northern border, the winter range extends south through Kansas, Oklahoma, and eastern Texas to the Gulf of Mexico. RUBL wintering habitat primarily consists of wooded vegetation along streams, river bottomlands, and flooded woodlands (Greenberg & Droege, 1999). They are also often found wintering in anthropogenic habitats such as livestock feedlots and manure fields.

During the breeding season, male RUBL have a uniform black plumage similar to that of BRBL, but with a greenish to blue green iridescence instead of purplish. The female has a similar plumage and shares the male’s iridescence, though usually a slightly lighter shade, sometimes as light as slate gray. It is their winter plumage, however, that gives RUBL their name. In their fresh basic (fall and winter) plumage, males are characterized by their rust-edged tertials and the rusty brown feathering on their crown, nape, and back with a lighter brown to buff coloration over their eyes and on their cheeks, throat, breast, and sides on otherwise black feathering (Figure 11). In females, the tertials, crown, nape, and back are all edged with a rusty brown. The cheeks, chin, throat, breast,

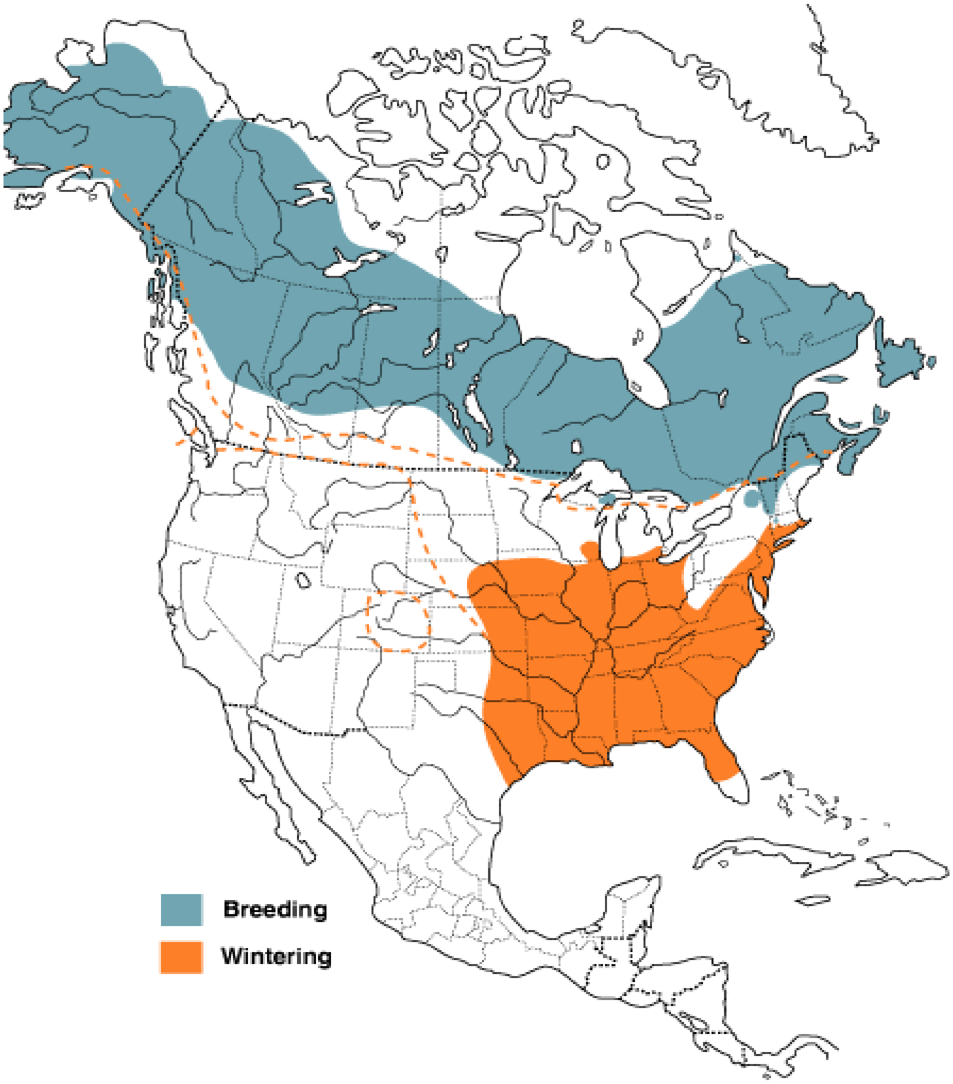

Figure 10. Distribution of the rusty blackbird (*Euphagus carolinus*) in North and Central America. This species winters locally and irregularly within the dotted lines and to the southern tip of Florida. Map courtesy of Birds of North America.

and sides of females all have buff-brown edgings similar to, but lighter than, male plumage. A generally monogamous species, RUBL sometimes nest in very loose colonies which can give rise to occasional extra-pair matings (Ellison, 1990). The pair bonding of RUBL is not fully understood, but is possibly maintained through vocal behavior as that of other blackbird species. Males bring food to incubating females which is delivered to a nearby perch (Kennard, 1920). The female joins the male there and assumes a begging posture with fluttering wings, takes the food, and flies off (Hoffman & Hoffman, 1982).

Figure 11. Rusty blackbird in summer and winter plumage. Photos by Doug Lloyd and Mario Olteanu

Most RUBL populations do not colonize, but when birds do colonize, the breeding colonies are loose, with nests located at least 0.4 km apart (Kennard, 1920). In Vermont, Ellison (1990) noted that “colonial groups” typically occur in areas where water tends to fluctuate, while isolated pairs, in contrast, occupied wetlands near ponds where water levels were more stable. Nests themselves are presumably constructed by the female (Orians, 1985) over a period of approximately seven days, based on renesting intervals (Kennard, 1920). It is unknown what role males play in nest construction; females have been seen carrying nest materials while males are perched nearby (Hoffman & Hoffman, 1982); therefore, it is assumed the males have only a minor role. Nests are typically close to a water source, sometimes directly over water, and situated in dense vegetation (Kessel, 1989). Nest height is variable; nests have been reported on the ground in Alaska and Ontario (Peck & James, 1987; Kessel, 1989) and as high as six meters in other locations.

Eggs are laid daily and are approximately 18.6 mm wide and 25.8 mm long (Kennard, 1920). They have a pale blue to pale gray coloration and have markings that can range from light to dark brown and can vary from light to heavy incidence. Clutch sizes can be variable but most often consist of four or five eggs with incubation beginning with the laying of the first egg, especially if the weather is cold (Kennard, 1920). Incubation is thought to last approximately 14 days (Bendire, 1895), but this has not been confirmed. Young are brooded by the female only, though the male frequently stays in the vicinity, and both parents feed the young, which can fledge as early as 11 days after hatching (Kennard, 1920) followed by their first flight several days afterward. Ellison (1990) observed fledglings still with parents at least several weeks after fledging and leaving the nest.

Like other blackbirds, RUBL will feed opportunistically on insects, but generally lack the population numbers to be beneficial to agriculture like BRBL or a detriment to it like RWBL. Throughout the year, aquatic beetles and their larvae, grasshoppers, spiders, snails, and crawfish make up a large part of RUBL diets (Meanly, 1995). During the breeding season, they tend to selectively focus on aquatic insects and other animal food, and have been occasionally seen foraging alongside gulls in municipal dumps. During the winter months, RUBL are often seen in feedlots, agricultural fields, and pastures where they feed primarily on plant matter consisting mainly of crops and weed seeds (Martin *et al.,* 1951). In the fall, willow oak acorns are a favorite food in the Great Dismal Swamp, VA, but they have also been known to eat loblolly pine, the seeds and fruits of the American holly, Hercules club, flowering dogwood, and blackgum (Meanley, 1995). Vertebrate prey items include salamanders and small fish, and very occasionally they will attack and eat other birds. This is very rare, however, and reports are often accompanied with poor weather. Attacks on other birds are almost never committed by individuals, usually several RUBL and occasionally COGR are involved. In May of 1974, several were reported attacking white crowned sparrows (*Zonotrichia leucophrys*) and tree sparrows (*Spizella arborea*) after a cold snap, killing at least two white crowned sparrows and feeding on the carcasses (Campbell, 1974).

## Human-Blackbird Interaction

For as long as there has been agriculture in the United States, blackbird populations have been an influence, some species by being crop pests, and other species by mitigating damage by other pests. In northern states, sunflower and corn are often the crops of concern when it comes to depredating blackbirds (Figure 12). In some years 2-4% losses of the total crop of sunflower (Hothem *et al.*, 1988; Kleingartner, 2003; Linz *et al.*, 2009; Klosterman *et al.*, 2011) and damages totaling $25 million for corn crops are reported. In southern states, however, blackbirds more often depredate rice crops, with losses of $21.5 million dollars reported in a single year (Avery *et al.*, 2005). RWBL and COGR are well known for selectively predating rice crops; the damage they cause has the potential to be substantial due to the size of the roosts they form (Yasukawa & Searcy, 1995; Peer & Bollinger, 1997). The overall damage caused by blackbirds in 2002 to sunflower was approximately $11.3 million; however, not all farmers received the same amount of damage (Wilson 1985, Linz *et al.*, 1996; Klosterman *et al.*, 2011). Damage by blackbirds is not distributed uniformly, but is localized and proportional to the size of roosts and distance from roost sites. In North Dakota, 46% of surveyed farmers received more than 5% damage and 6% of participants reported 10-25% damage (Lamey *et al.,* 1997). In some areas of Louisiana, damage to newly planted rice can be quite severe; some growers reported total losses, which required expensive replanting (Wilson, 1985). Escalated crop losses have initiated management techniques that aim to reduce resident and migratory blackbird populations. These techniques include avicides (Linz & Bergman, 1996; Linz *et al.,* 2002), cattail management (Linz *et al.,* 1995; Linz *et al.,* 1996), repellent seed treatments (Mason, 1993; Linz *et al.,* 2006), bird-resistant sunflowers (Mah *et al.,* 1991; Mah & Nuechterlein, 1991), and scare tactics (Linz *et al.,* 1996; Linz *et al.,* 2011).

Figure 12. A flock of red-winged blackbirds above a cornfield. Photo by Melissa Dowland

Wintering blackbirds and EUST can cause more problems than just crop damage. The presence of large numbers of birds can lead to economic, nuisance, and health concerns for people not related to agriculture. Roost sites can be almost anywhere and are often found near urban areas, especially with species that use developed areas such as starlings and grackles. When winter roosts are established, there is often a rapid accumulation of droppings, sometimes reaching up to 7.5 cm deep in the course of a single season (Chick *et al.,* 1980). This accumulation can kill the deciduous and evergreen undergrowth in forest roost sites, and it creates an environment conducive to the growth and sporulation of *Histoplasma capsulatum* (Chick *et al.,* 1980; Stickley & Weeks, 1985), the fungus that causes histoplasmosis. *H. capsulatum* grows in soils that have come into contact with large amounts of bird and bat excreta; as such, chicken houses with accumulated manure are notorious sources of the fungus. Birds and bats are not the cause of the fungus, but do provide a nutrient rich environment for its growth. More often than not, individuals infected show no symptoms and suffer no ill effects. When the fungus is present in the eyes of humans, it can lead to blindness. In cases where individuals inhale *H. capsulatum*, they may develop non-specific respiratory symptoms, often cough or flu-like in appearance which, in rare cases, can be fatal if left untreated.

In natural situations, *H. capsulatum* is often found where gregarious birds and bats congregate, such as blackbird and starling roosts, nesting colonies of gulls, rock dove roosts, and oilbird nesting colonies. The fungus can also be found in caves, hollow trees, and attics where bats roost. Histoplasmosis is most often contracted when soils in affected areas are disturbed, and spores are inhaled into the lungs; however, it can also result from contact with contaminated items (Chick *et al.*, 1980). There were several outbreaks in the 1970's that were related to the disturbance of blackbird roosts by bulldozing (Chick *et al.*, 1980); the mechanical disturbance allowed the fungal spores to become airborne, after which inhalation became possible. The fungus *H. capsulatum* has been cultured from bird roosts in Kentucky, Tennessee, Illinois, Indiana, Ohio, Wisconsin, Missouri, South Carolina, Arkansas, and Mississippi (Chick *et al.,* 1980). Health hazards posed by blackbird and starling droppings are not merely human problems either; during the winter of 1978-1979, an outbreak of Transmissible Gastro Enteritis (TGE) occurred in southeast Nebraska, with over 10,000 pigs lost in one month in Gage County alone (Gough *et al.,* 1979). Starlings were implicated because the TGE outbreak was concurrent with large flocks of starlings feeding at the same facilities. Several more recent studies have shown that starlings are indeed capable of carrying diseases in their feces (Gaukler *et al.,* 2008; Carlson *et al.,* 2011), though the role of starlings in disease transfer requires further study.

The problem caused by blackbird and starling droppings is not only a health hazard, but also an aesthetic and functional one as well. Bird droppings are rich in uric acid which can be corrosive to stone, metal, and masonry. On Air Force bases, hangers often provide excellent roosting habitat for a number of bird species. Even when hanger doors are closed, birds are often able to find access through small holes, broken windows and ventilation ducts (Will, 1985). Once inside, birds nest or roost in the overhead trusses which hold the roof in place. This allows them to avoid most dangers and also to produce the most damage (Will, 1985). Damage occurs when their droppings land on aircraft and equipment parts, which then require extensive cleaning and repairs, taking valuable time away from actual aircraft maintenance. Where droppings are numerous, components often have to be replaced, costing thousands of dollars in new parts and man hours (Will, 1985). Another expensive item is the replacement of aircraft paint, which is designed to withstand a wide range of temperatures to maintain a smooth surface for flight. Bird droppings speed up the corrosion and chipping and peeling of the paint, often requiring the whole aircraft to be repainted (Will, 1985). To repaint a single F-15 fighter in 1985 cost over $1000 in paint and supplies, and almost 800 man hours are necessary before it can be flown again; larger aircraft are proportionately more costly (Will, 1985). Similar situations affect cities, when large deposits of droppings clog machinery, drainage, and even air vents when roosts are inside of or on top of commercial or industrial structures (Figure 13).

Starling and blackbird roosts located near airports pose an aircraft safety hazard because of the potential for birds to be ingested into jet engines, resulting in aircraft damage or loss and, at times, in human injuries (Barras *et al.*, 2002). In 1960, an Electra aircraft in Boston collided with a flock of starlings soon after takeoff, resulting in a crash landing and 62 fatalities. Although only about 6% of bird-aircraft strikes are associated

Figure 13. Droppings and feathers found in an air duct of a public school. Buildup can be a severe problem for building owners as droppings and feathers can contaminate vents of buildings, as well as food destined for human consumption. Droppings can also lead to structural damage from the high uric acid content; bacteria, fungal agents and parasites in the droppings also pose a health risk. Photo by Greg Ballard.

with starlings or blackbirds, these species represent a substantial management challenge at airports. These concerns often result in requests to alleviate these bird-related problems. Information regarding roosting bird behavior is, therefore, required before effective management decisions can be implemented.

## Population Models

A model is a simplified representation of a system or a phenomenon, often mathematically expressed. When models are used to represent populations of organisms, they can be used to evaluate how organisms or guilds respond to habitat and environmental changes. They can also be used to predict the results of differing species-specific management techniques (Starfield, 1997). This allows researchers to assess landscape level influences on populations, which can provide information that field experiments or surveys can not (Turner *et al.,* 1995). Structured population models determine how abundance and distribution of individuals will change over time (Gurney & Nibset, 1998). There are, however, many stochastic variables in population dynamics, which make it important to include probability into these models (Engen & Saether, 1998). As with all models, population models are only valid if certain assumptions are made. The main assumption of any population model is that the reasons for a change in the population of a certain species can be sufficiently described by a few variables (Easterling *et al.,* 2000). This results in most models being a relative oversimplification of the true system (Schamberger & O’Neil, 1986; Engen & Saether, 1998). This, however, does not mean that the population dynamics in question are not adequately described (Royama, 1992); analysis of simple linear regression models has shown that even a few variables can adequately describe population changes. A model typically serves one purpose, and attempts to use the model for tasks for which it was not intended may render the results invalid (Starfield, 1997).

Population models have been developed for many species of birds (e.g., Rothery *et al.*, 1984; Smith & Reynolds, 1992; Carroll *et al.*, 1995; Flint *et al.*, 1995; Miller, 2000; Wemmer *et al.*, 2001; Forcey *et al.*, 2007). These models vary in their complexity and typically examine how population dynamics are affected by changes in life history characteristics (Dunning *et al.*, 1995). The red grouse (*Lagopus scoticus*) population model proposed by Rothery *et al.* (1984) is based on winter survival, chick production, and mortality. More involved models, such as one proposed for the piping plover (*Charadrius melodus*), involve similar parameters, but also include factors such as breeding site selection, dispersal, and habitat capacity (Wemmer *et al.*, 2001). Smith & Reynolds (1992) examined how mallard survival was affected by hunting by comparing recovery and survival rates of mallards between years when hunting regulations were liberal to years where bag limits were more restrictive.

Several density and habitat suitability models have been developed for RWBL and yellow-headed blackbirds (*Xanthocephalus xanthocephalus*, YHBL). Fairbairn & Dinsmore (2001) developed models to estimate densities of RWBL and YHBL in Iowa wetlands. Densities of RWBL were most influenced by the wetland perimeter: area ratio, and the amount of wet meadow vegetation in an area. Yellow-headed blackbird densities were most influenced by the amount of emergent vegetation, the vegetation evenness, and the wetland perimeter: area ratio (Fairbairn & Dinsmore, 2001). Özesmi & Mitsch (1997) designed a spatial habitat model to predict distributions of RWBL in coastal wetlands. Their model showed that increasing vegetation stability, water depth, and decreasing distance to open water had a positive influence on RWBL distributions. Schafer (1996) developed models for predicting nest success of RWBL and YHBL. Her results found nest success for both species to be affected by distance to shore, water depth, and nest height.

In addition to population models that operate on a relatively small scale, many landscape-level models have been developed to assess avian response to a variety of environmental factors (Miller, 2000; Thompson, 1993; Link & Sauer, 2002; Temple & Cary, 1988). Population modeling offers a means to study landscape-level population changes that would not be possible with field studies due to logistical constraints (Hunt, 1998). Miller (2000) examined mallard production across the Prairie Pothole Region in the northern Great Plains by using historical data on climate, wetland abundance, land use, and the estimated size of mallard populations. This information was used to determine if relationships existed between these variables and mallard production. Other avian landscape-level models examined bird populations in fragmented and forested landscapes. Thompson (1993) developed a model to predict bird population size in forested landscapes by using information on numbers of breeding adult females, floating females, fecundity, survival, and immigration. Temple & Cary (1988) developed a landscape-level model to determine the effects of fragmentation on forest-interior bird species. They included variables similar to those in Thompson (1993), but also included clutch size and territory occupancy.

# STUDY AREA

My study area is over two million square kilometers; as such, variability in climate, weather, and land use types can be substantial over both time and space. There are 333 CBC (Christmas Bird Count) sites in 10 states in the south and southeastern United States: Alabama, Arkansas, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, and Texas that make up my study area (Figure 14). Overall, this area (2,018,766 km$^2$) is well known for its large winter blackbird and starling roosts, and this region is where the most overlap in blackbird and starling wintering occurs (Orians, 1985; Cueto & de Casenave, 1996; Martin, 2002). This area is subdivided into 12 Bird

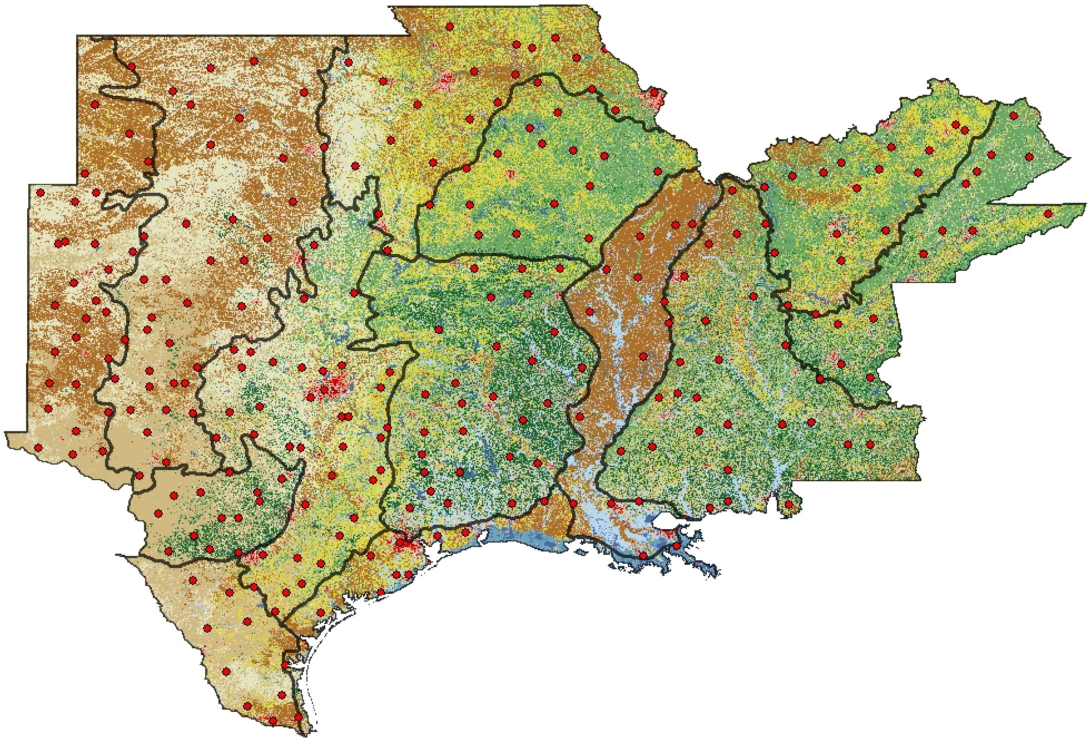

Figure 14. Distribution of study sites over the study area.

Conservation Regions (BCR),which are ecologically divergent regions in North America with similar bird communities, habitats, and resource management issues. So far, 67 BCR have been assigned by the North American Bird Conservation Initiative (NABCI), with 35 entirely or partially in the United States, three in Canada, and 29 in Mexico (www.nabci-us.org). For my study, portions of BCR 18, 19, 22, 24, 27, 28, and 36 were used, and the entirety of BCR 20, 21, 25, 26, and 37 were employed.

The study area has high quantities of valuable blackbird roosting and foraging habitat. Corn and rice are both prominent crops throughout the region. Corn is in the northern areas and rice has been commercially grown in Missouri, Arkansas, Louisiana, and Texas since the mid 19th century. Large feedlots are also fairly common in the area and serve as an alternative feeding site for many blackbirds and starlings. There are large expanses of wetlands for roosting RWBL, BRBL, and RUBL, and at least 15 large urban centers and over 200 suburban areas for roosting COGR and EUST.

An area this large has a vast range of habitat types (Figure 15), including large expanses of cropland in the central, southern, and northwestern regions. Large tracts of forest cover most of the eastern and west-central areas, and brushland is common in the southwest. Wetlands are common in the eastern, central, and southern regions, and developed areas are a regular fixture dotting the landscape in all areas. For the purposes of this study, land use was narrowed to eight categories, some of which are more common than others.

Southern coastal areas tend to receive more precipitation than northern landlocked areas, and eastern areas typically receive more precipitation than the western parts of my study area. These differences in precipitation are expressed by the types and quantities of

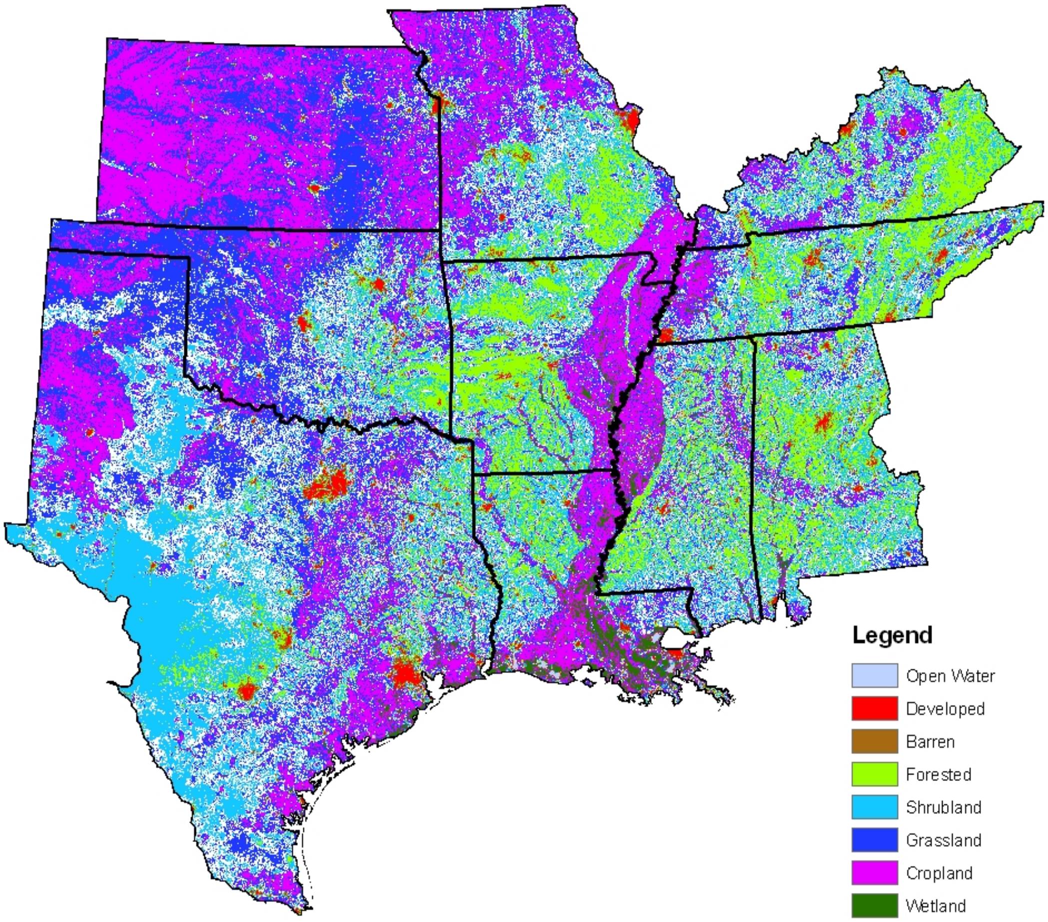

Figure 15. Map of the study area and dominant land types used for analysis.

vegetation present in an area (Cueto & de Casenave, 1996). Precipitation can also be variable across years, with some years experiencing drought conditions while others experience high precipitation levels, as can be seen in the example site, Birmingham, AL in Table 1.

Temperature is another factor that can influence vegetation types and quantities (Cueto & de Casenave, 1996). Coastal areas generally have less variability in temperature, as large bodies of water have a buffering or stabilizing effect. Coastal areas have cooler summers and warmer winters than landlocked areas at similar latitudes (http://earthguide.ucsd.edu/weather), as can be seen in Table 2. These are yearly averages as well, not including the variation seen on a day to day or even a month to month basis.

Table 1. Summary of climatalogical variables for Birmingham, AL.

| Year | MXMT | MNMT | MEMT | TYP |
|---|---|---|---|---|
| 1988-1989 | 25 | 13.4 | 19.2 | 158.115 |
| 1989-1990 | 24.9 | 13.7 | 19.3 | 162.56 |
| 1990-1991 | 26.28 | 14.4 | 20.3 | 142.1638 |
| 1991-1992 | 25.1 | 14.6 | 19.9 | 207.4418 |
| 1992-1993 | 24.9 | 13.8 | 19.3 | 178.9684 |
| 1993-1994 | 24.7 | 13.6 | 19.1 | 153.416 |
| 1994-1995 | 25.2 | 14.2 | 19.7 | 139.4968 |
| 1995-1996 | 25.6 | 14.1 | 19.8 | 187.5282 |
| 1996-1997 | 24.7 | 13.8 | 19 | 169.5196 |
| 1997-1998 | 24.5 | 13.9 | 19.2 | 177.9778 |
| 1998-1999 | 25.7 | 14.9 | 20.3 | 219.7608 |
| 1999-2000 | 26 | 14.1 | 20.1 | 129.286 |
| 2000-2001 | 26 | 13.7 | 19.8 | 116.1796 |
| 2001-2002 | 25.3 | 13.9 | 19.6 | 138.811 |
| 2002-2003 | 24.9 | 14 | 19.5 | 184.0992 |
| 2003-2004 | 25.3 | 14.1 | 19.7 | 180.1622 |
| 2004-2005 | 25.5 | 14.6 | 20 | 193.4464 |
| 2005-2006 | 25.6 | 14.1 | 19.8 | 187.5282 |
| 2006-2007 | 26.2 | 13.9 | 20 | 125.349 |
| 2007-2008 | 25.9 | 13.9 | 19.9 | 140.335 |
| 2008-2009 | 25.1 | 13.6 | 19.3 | 175.514 |

MXMT= maximum monthly temperature (Celsius)
MNMT= minimum monthly temperature (Celsius)
MEMT= mean monthly temperature (Celsius)
TYP= total yearly precipitation (cm)

The southern coastal areas in my study area are no exception and have much lower variability than northern areas; they have hot summers and cool winters. Temperatures in the south are also generally higher on average during all seasons. Northern areas tend to have far higher variability in seasonal temperature than coastal areas, experiencing hotter summers and colder winters, sometimes including significant snow accumulation, unlike southern areas where it rarely snows.

Table 2. Comparison of temperatures ($C^o$) of San Angelo, TX, a landlocked site, and lake Charles, LA, a coastal site.

| Year | San Angelo, TX (31.43, -100.48) | Lake Charles, LA (30.15, -93.3) |
|---|---|---|
| 1988-1989 | 26 | 25.4 |
| 1989-1990 | 25.9 | 25.1 |
| 1990-1991 | 25.6 | 25.8 |
| 1991-1992 | 25.1 | 24.9 |
| 1992-1993 | 25.3 | 25.3 |
| 1993-1994 | 25.4 | 25.1 |
| 1994-1995 | 26.4 | 25.7 |
| 1995-1996 | 25.9 | 25.9 |
| 1996-1997 | 25.9 | 25.2 |
| 1997-1998 | 24.2 | 24.8 |
| 1998-1999 | 26.9 | 26.3 |
| 1999-2000 | 25.3 | 26.6 |
| 2000-2001 | 26.7 | 26.1 |
| 2001-2002 | 25.5 | 25.4 |
| 2002-2003 | 25.2 | 25.3 |
| 2003-2004 | 25.7 | 25.5 |
| 2004-2005 | 24.7 | 26 |
| 2005-2006 | 25.7 | 26.4 |
| 2006-2007 | 27.4 | 26.3 |
| 2007-2008 | 24.7 | 25.5 |
| 2008-2009 | 27 | 25.9 |
| Average Temp | 26 | 25.4 |
| Temp Std. Dev. | 0.81 | 0.52 |

# METHODS AND MATERIALS

The Christmas Bird Count (CBC) has common elements that are seen in a large assortment of surveys.  For example, the Breeding Bird Survey (BBS) covers large portions of the United States (excluding Hawaii), Canada, and portions of Mexico (Link & Sauer, 2002).  Project Feederwatch is a winter survey of birds, facilitated by the Cornell Lab of Ornithology, that visit birdfeeders and lasts from November till the beginning of April (Dhondt *et al.*, 2005).  The Midwinter Waterfowl Survey is a yearly survey conducted where the exact sampling methods are not defined, and an aerial crew decides the best method of survey coverage from year to year (Eggeman & Johnson, 1989).  The CBC is a survey similar to these and in 2010 consisted of 2160 survey circles in Canada, the United States, and Mexico, with 60,753 volunteers participating (Audubon Society, 2010).  Any variety of methods may be used to collect data.  Most data are collected on foot, in cars, or by people watching birds coming to feeders (USGS, 2002); however, some counts have employed bicycles, boats, canoes, snowmobiles, and even airplanes to count birds (USGS, 2002).  The results from the CBCs are submitted to the National Audubon Society, which has compiled the data since the inception of the survey.  The results are currently published in an issue of the National Audubon Society Field Notes.

## Population Data

I obtained survey data for blackbirds and starlings from the CBC archives from the 1988-89 to 2008-09 seasons via the Audubon Society website, which also houses the data from every CBC that has ever been conducted.  Survey data in this study included the number of birds observed for a given species in a count circle, the number of birds seen per hour spent on the survey, the number of volunteer hours accrued while conducting the survey, and the number of volunteers that conducted the survey (Link & Sauer, 1999). CBC circles themselves are relatively large areas, each one being 15 miles in diameter; each CBC circle is 176.7 mi$^2$ (457.7 km$^2$). These data were then entered into an Excel spreadsheet and arranged with global positioning system (GPS) coordinates provided in each CBC report. This was done to integrate survey data and location data for use in spatial modeling. I selected CBC sites based upon the midpoint of the CBC circle; if the midpoint was inside of the study area, then that circle was included in data collection. If a significant amount of that CBC site was in the survey area, but not its midpoint, then that CBC site was ignored. CBC site location in the study area was determined via ArcInfo 9.3; potential CBC sites were entered into a shape-file and compared for geographic location. Potential CBC sites that were shown to be outside the study area were then excluded. Overall, CBC site data were obtained for 333 sites over 21 years.

Preliminary analyses of these data showed positive results (Figure 16 and 17), which were done by taking the log of the number of birds seen in a CBC circle and plotting it against the year of the study in a scatter-plot (Figure 16). Figure 17 was constructed by taking the log of the number of birds seen per hour and plotting it against the study year. Figure 17 was plotted in an attempt to account for effort effects on population data, since increased effort can have a pronounced effect on the amount and quality of data collected (Link & Sauer, 1999, Link *et al*. 2006). These simple dataplots gave me the idea that perhaps RWBL populations are not declining in all areas, as is widely characterized and reported by other studies. Though these analyses were crude, they gave me a starting point from where I could form my basic hypotheses.

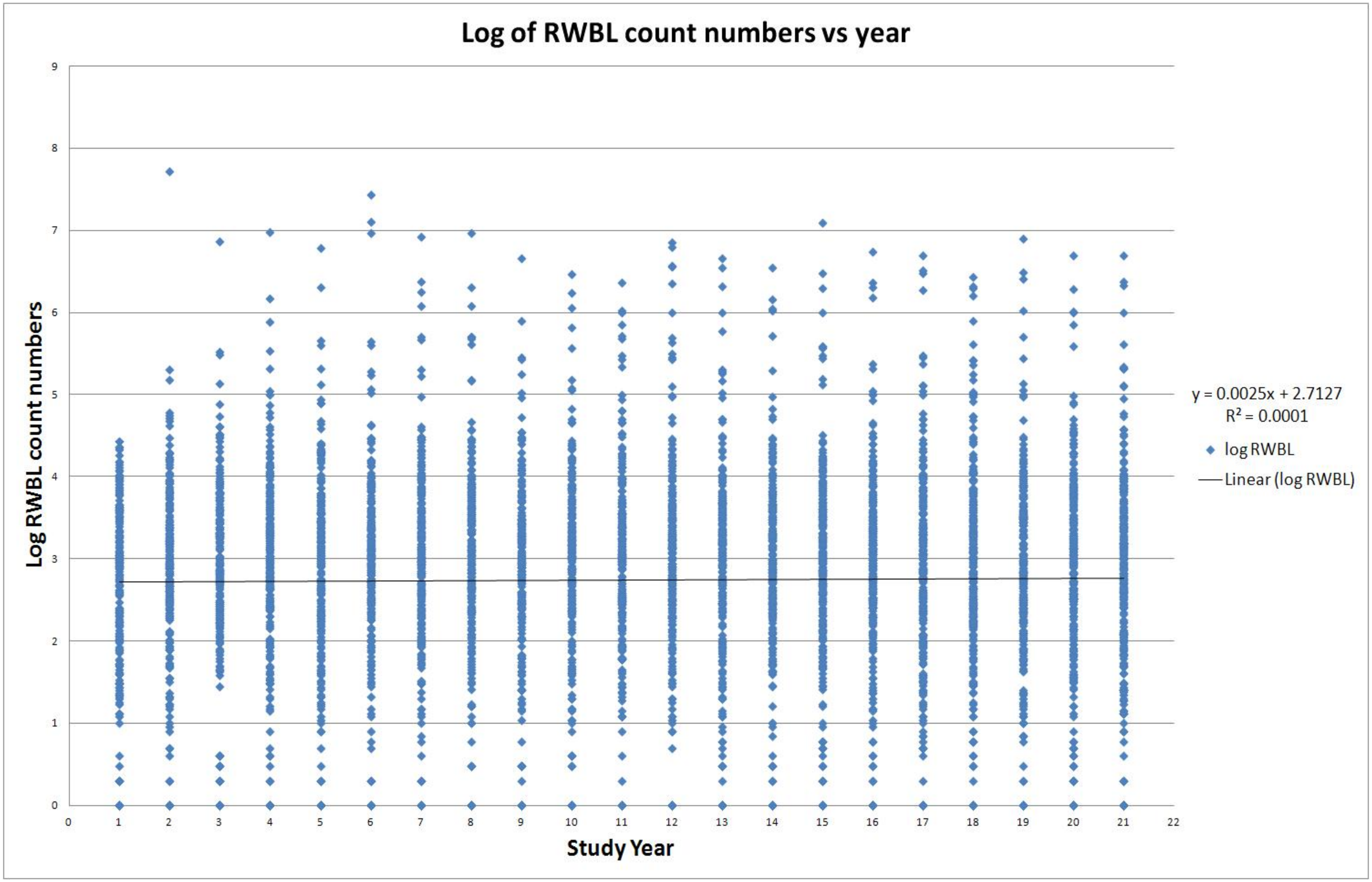

Figure 16. Scatterplot of the Log of RWBL data vs. time. A linear trend-line and equation is also provided to show direction.

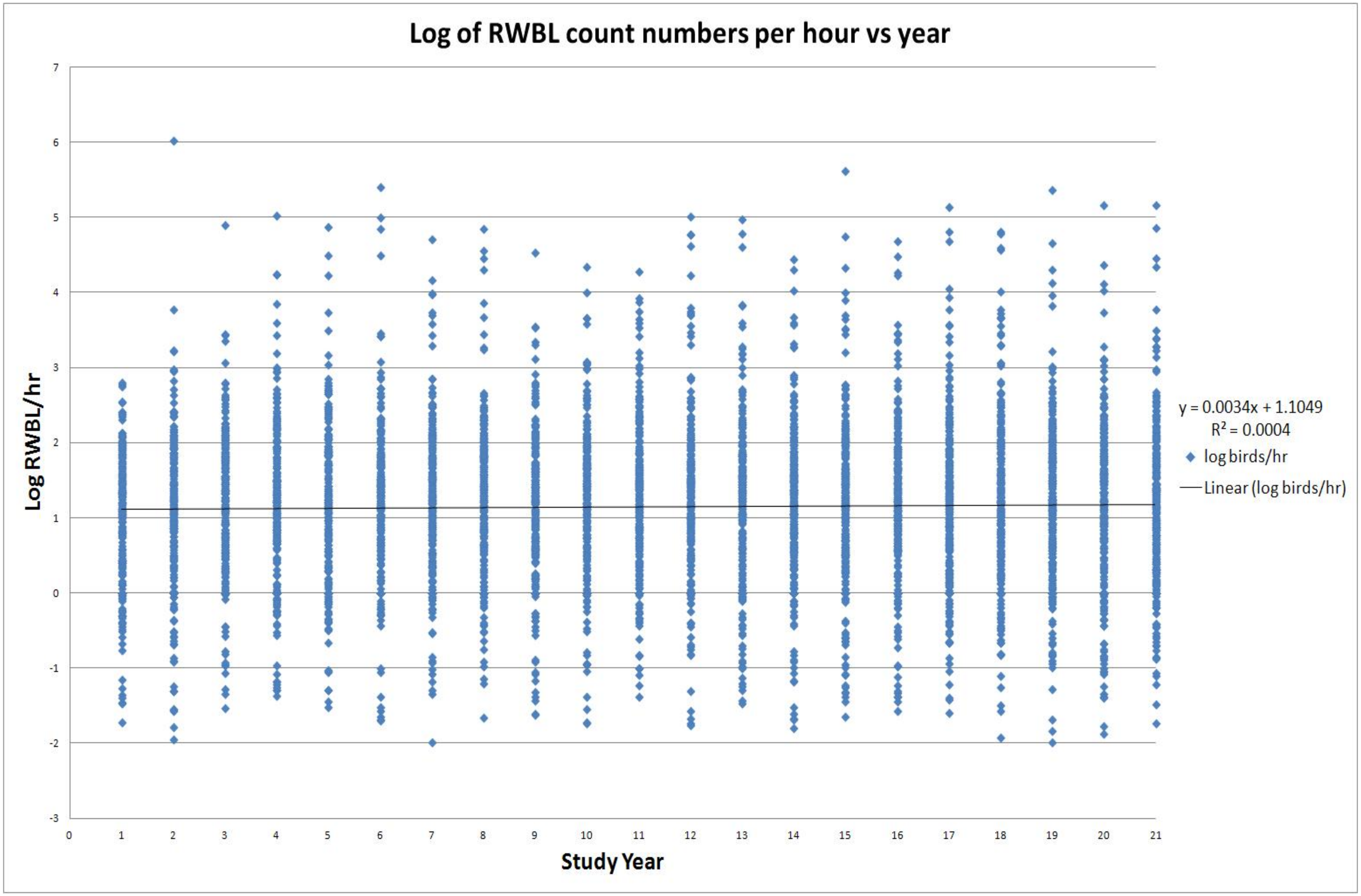

Figure 17. Scatterplot of the Log of RWBL data per hour vs. time. A linear trend line and equation are provided showing direction.

## Study Sites

The National Land Cover Database (NLCD) was obtained from the Land Cover Institute (LCI) for the study years 1992 and 2001, the years landcover maps were made available. Both years were downloaded in a raster format, in a 21 class landcover classification scheme applied consistently over the United States and Puerto Rico (NLCD, 2001). For use in my GIS analyses, all raster files for 1992 or 2001 were initially merged into a single map file and “cookie cut” to an outline of the study area for relative ease of use. This was done slightly differently for the two different years as they came in slightly different geographical formats. The 1992 rasters were made up of singular states, while the 2001 rasters were made up of regional areas and had no adherence to traditional political borders. After the raster files were merged, similar land uses were consolidated into nine basic landcover types consisting of open water, developed, barren, forested upland, shrubland, non-natural woody, herbaceous upland, herbaceous planted/cultivated (cropland), and wetlands. These landcover types were modified from Anderson *et al.* (1976) and are all likely to be found within the study region (Flather & Hoekstra, 1985; Flather & Sauer, 1996; USDI Geological Survey, 1992 and 2001). CBC count circle shapefiles for each CBC site were made by creating a buffer area around the reported center-point of each site and saving them as individual shapefiles. These shapefiles were then used to “cookie cut” the land use characteristics for that CBC site out from the surrounding area. Finally, these data were entered into a spreadsheet as a percentage of total area within that survey circle and arranged with CBC survey and GPS data. In order to account for the missing years of landscape data, multiple years of population data had to be used for a single year of landscape data. This was done by splitting the years of the survey and using the NLCD data obtained from 1992 for the first 10 years of the study, and the NLCD data obtained for 2001 for the last 11 years.  In order to avoid pseudoreplication issues due to using the same landcover data for multiple years of population data, models were also run with only those years that landcover data were made available.

## Climate Data

Climate and weather data were also collected for use in population modeling and habitat selection.  Data were obtained from the National Oceanic and Atmospheric Administration (NOAA) website for annual climatalogical summaries.  Weather data including precipitation, average maximum monthly temperature, average minimum monthly temperature, and average monthly temperatures were obtained (Root, 1988; Morschel, 1999).  These averages were taken for November, December, and January-- the month before the CBC could be conducted, and the two months when the actual survey could take place.  Data were collected for these months as they were thought to be the most influential on presence or absence of birds during CBC surveys (Root, 1988; Newton, 1998; Morschel, 1999; Forcey, 2006).  Climatalogical data were obtained in a similar fashion; averages for maximum monthly temperature, minimum monthly temperature, and mean monthly temperature were taken for the entire year and not just the months before and after the survey.  This was done to get a better idea of longer term weather trends over the whole of years, instead of focusing on just the months of the survey (Cotgreave, 1995). These data were then arranged into a spreadsheet and combined with the survey, landcover, and GPS data to form a database for use in modeling.

## Linear Mixed Effect Models

The model type used for my purposes is a linear mixed-effect model, which, like many other types of statistical models, describes a relationship between a response variable and covariates that have been measured or observed along with that response (Fox, 2002). Linear mixed-effect models feature a combination of fixed-effects and random-effects; the combination of these effects in one model is where mixed effect models get their name (Bates, 2010). Fixed-effects explain change in the response variable within levels or groups, while random-effects correspond to particular observational or experimental units such as geographical areas in a study. Parameters associated with particular levels of a covariate are called the effects of the levels (Bates, 2010). If the set of possible levels of the covariate are fixed and reproducible (e.g., a covariate for sex that has levels male and female), covariates are modeled using fixed-effects parameters, called fixed-effects. If the levels that are observed represent a random sample from the set of all possible levels, random-effects are incorporated to describe those levels of the model (Fox, 2002). My model is no different, treating the response variable as Gaussian (normally distributed) and as a function of environmental covariates (fixed-effects) and level (or blocking) effects (random-effects). Generally, fixed-effects are independent variables that would normally be included in an analysis. For birds, habitat and climatalogical variables are commonly used as they are in my model. In other studies, for instance sociolinguistic studies, age, gender, and phonological environment would be used. Random-effects, on the other hand, are variables that are specific to a particular data sample. In my model they describe changes between locations, geographical areas, and the years of the study. Once again using sociolinguistic studies as an example, the random effects might include the individual speaker, listener, and the words that were spoken.

This model was constructed and used in R, which is a free software environment for statistical computing and graphics. For my purposes, the lmer function of the lme4 package was used, as it is designed to fit linear mixed-effect models (Bates, 2010). Environmental covariates collected from the NOAA and NLCD databases are considered fixed-effects, and random-effects in the model were included to account for population variation between BCR, years, and the individual-effects of circles. A random-effect to compensate for overdistribution (error) in the data was also included. Survey data collected from CBC circles were offset for the number of hours invested in each count, as the effort put into a count can have a pronounced effect on the number of birds counted in a circle (Link & Sauer, 1999). The more effort put into a survey, the greater the number of birds that are counted; however, double counting and other errors can and sometimes do occur (Link & Sauer, 1999). In the models that were used, an offset is a term added to a linear predictor, such as in a generalized linear model, with a known coefficient of 1, rather than an estimated coefficient. In mathematics, a coefficient is a multiplicative factor in a term of a numerical expression or series. It is usually a number, but is not involved in any variables of the expression. For instance in

$$7x^2 - 3xy + 1.5 + y$$

the first three terms have coefficients of 7, -3, and 1.5 (in the third term the variables are hidden [raised to the 0 power], so the coefficient is the term itself; it is called the constant term or constant coefficient of this expression). The final term does not have any explicitly written coefficient, but is considered to have a coefficient of 1, since multiplying by that factor would not change the term.

Years were considered to be a random effect because  there is random variation within that year (due to weather, population cycles, etc.) which the year random effect reflects.  Roughly, the mean counts in each year is the ‘random effect’ for that year (after accounting for all the other fixed and random effects).  These random effects are all assumed to come from the same distribution, in this case, a normal distribution with a mean set to zero and an estimated variance.  So when there are multiple random effects, by examining these respective variances, it is possible to assess the relative contribution of each grouping (years, BCR, and sites) to the variation in the counts.  By accounting for these groupings (random effects), the fixed effect estimates and standard deviation will be more accurately estimated.  By making the assumption that all the years come from and use the same distribution, and the manner in which they are mathematically estimated, I am imposing a mathematical correlation structure onto all the members of this group (years). This flexibility allows me to modify this correlation matrix to more accurately reflect the dependence of each group member on other group members.  Although I did not do this in this model, in future endeavors it would be possible to change this structure to say that one year's mean count is dependent on the previous year's count (an AR-1 structure).

In this model, random effects were not constrained using posterior distributions but were evaluated using Restricted (or Residual or Reduced) Maximum Likelihood (REML) approach, which is the default criterion used when employing linear mixed-effect models. Unlike maximum likelihood estimation, REML does not base estimates on a maximum likelihood fit of all the information, but instead uses a likelihood function calculated from a transformed set of data, so nuisance parameters have no-effect. For balanced data, REML reproduces the statistics familiar to those who use ANOVA, but the algorithm is not dependent on balance. It allows for spatial and/or temporal correlations, so it can be used for repeated measures or field-correlated data (O'Neil, 2010). Unlike ANOVA, REML allows for changing variances, and so can be used in experiments where some treatments (e.g., different spacing arrangements, crops growing over time, treatments that include a control) have a changing variance structure (O'Neil, 2010). This allows estimates obtained using REML to be less biased than estimates obtained using maximum likelihood.

There is a significant distinction that must be made between fixed-effects parameters and random-effects. The difference between fixed and random is a property of the levels of the categorical covariate, not a property of the effects associated with them (Bates, 2010). Fixed does not mean that these parameters do not vary over space and time, but rather there is no systematic or directional component to that variation; they focus mainly on differences within levels (Fox, 2002). For example, if I see gradients in species response with latitude, that response would possibly be expressed by higher abundances in the southernmost BCR and lower abundances in the northernmost BCR. Similarly, if there were gradients in abundance developing over time that were not explained by environmental covariates (fixed-effects, within levels), they would express themselves in the year random-effect (between levels). In the absence of a mechanism or covariate in the model for accommodating directional change, the random-effects serve this purpose (Fox, 2002). Linear mixed-effect models are statistical models that incorporate both fixed-effect parameters and random-effects. Because of the way that random-effects are defined here, a model that incorporates random-effects will always include at least one fixed-effect parameter; therefore, any model that incorporates some variety of random-effects is technically a type of mixed-effect model (Fox, 2002).

# RESULTS

Population trends were estimated for all species within the study, all of which have different life histories and wintering distributions. Because of this, these species showed differing patterns of population change. Species also varied greatly in the amount and quality of information gathered; several species had no observations over many years of surveys, while others had extremely high population estimates in several places as shown in Table 3. Area weights and sample sizes vary greatly among strata (Table 3) ranging from 2% of total area to 11% of total area, as do the proportions of surveys in which species were encountered (Table 4).

Table 3. Description of Bird Conservation Regions by the number of surveys conducted, site numbers, and area within the study for use as stratum in linear mixed effect modeling.

| Bird Conservation Region | N | S | A | PA |
|---|---|---|---|---|
| Shortgrass Prairie (18) | 251 | 16 | 7238.23 | 0.048 |
| Central Mixed-grass prairie (19) | 419 | 27 | 12214.51 | 0.081 |
| Edwards Plateau (20) | 78 | 7 | 3166.73 | 0.021 |
| Oaks and Prairies (21) | 538 | 32 | 14476.46 | 0.096 |
| Eastern Tallgrass Prairie (22) | 566 | 33 | 14928.85 | 0.099 |
| Central Hardwoods (24) | 815 | 51 | 23071.86 | 0.153 |
| West Gulf Coastal Plain/Ouachitas (25) | 588 | 37 | 16738.41 | 0.110 |
| Mississippi Alluvial Valley (26) | 438 | 30 | 13571.68 | 0.090 |
| Southeastern Coastal Plain (27) | 461 | 28 | 12666.9 | 0.084 |
| Appalachian Mountains (28) | 288 | 20 | 9047.79 | 0.060 |
| Tamaulipan Brushlands (36) | 205 | 13 | 5881.06 | 0.039 |
| Gulf Coastal Prairie (37) | 648 | 39 | 17643.18 | 0.117 |

N= number of surveys during study period
S= number of sites in stratum
A=area of sites in stratum (km$^2$)
PA= proportion of area of stratum in total survey area

## Red-Winged Blackbirds

Of 5,295 surveys conducted over 21 years, there were 4,928 surveys produced by 65,421 observers where at least one RWBL was observed. Few surveys (7%) had no observations, while 54 surveys observed single RWBL, and 90.2% of surveys yielded five or more birds. As Table 4 shows, most regions had high incidences of RWBL; only two BCR (Central Hardwoods (24) and Appalachian mountains (28)) had a proportion of survey sites where RWBL were reported under 0.9. These two BCR had the second and third lowest instances of RWBL for the entire study area. The highest counts reported in these two BCR were 195,414 and 50,225 individuals, respectively; the only BCR with

Table 4. Proportions of counts where species were observed by BCR.

| Bird Conservation Region | RWBL | COGR | EUST | BRBL | RUBL |
|---|---|---|---|---|---|
| Shortgrass Prairie (18) | 0.96 | 0.45 | 0.92 | 0.60 | 0.06 |
| Central Mixed-grass prairie (19) | 0.97 | 0.65 | 0.99 | 0.63 | 0.20 |
| Edwards Plateau (20) | 0.94 | 0.49 | 1.0 | 0.37 | 0.03 |
| Oaks and Prairies (21) | 0.99 | 0.95 | 0.99 | 0.75 | 0.28 |
| Eastern Tallgrass Prairie (22) | 0.98 | 0.85 | 0.99 | 0.29 | 0.56 |
| Central Hardwoods (24) | 0.79 | 0.81 | 0.98 | 0.09 | 0.38 |
| West Gulf Coastal Plain/Ouachitas (25) | 0.95 | 0.95 | 0.98 | 0.54 | 0.42 |
| Mississippi Alluvial Valley (26) | 0.99 | 0.98 | 0.99 | 0.48 | 0.66 |
| Southeastern Coastal Plain (27) | 0.98 | 0.96 | 0.98 | 0.39 | 0.58 |
| Appalachian Mountains (28) | 0.66 | 0.61 | 0.95 | 0.03 | 0.44 |
| Tamaulipan Brushlands (36) | 0.96 | 0.78 | 0.98 | 0.70 | 0.0 |
| Gulf Coastal Prairie (37) | 0.99 | 0.87 | 0.98 | 0.51 | 0.19 |

lower survey numbers was the Edwards Plateau (BCR 20) which has seven survey sites, from which the largest count reported 914 birds in one season. All three of these BCR have high proportions of forested area, a landscape type that RWBL generally avoid in favor of areas with close proximity to both roosting sites and food items (Orians 1980). BCR with higher RWBL survey reports generally had lower proportions of forested habitat and development, and higher proportions of farmland, wetland, grassland, and shrubland. These observations were supported by my analysis, which shows that RWBL numbers increase as the proportion of farmland in a count circle increases ($p < 0.001$) and that RWBL numbers decrease as the proportion of forested area increases ($p=0.0377$) as seen in Table 5. The fixed effects included in the RWBL model were used because they provide the model with the lowest Akaike Information Criterion (AIC) possible. Inclusion of other fixed effects in previous models produced higher AICs, as did the removal of fixed effects from the finalized RWBL model. With higher numbers of model parameters, the effects of one fixed effect became difficult to discern from others, with few variables showing as

Table 5. Environmental fixed effects used for analysis of RWBL population trends and their influence on RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| (Intercept) | 2.1500 | 0.3970 | 5.410 | 6.41E-08 |
| Population Trend | 0.0240 | 0.0077 | 3.130 | 0.0018 |
| Developed Area | 0.0340 | 0.0659 | 0.514 | 0.6070 |
| Farmland | 0.2780 | 0.0446 | 6.220 | 4.94E-10 |
| Forested Area | -0.1060 | 0.0512 | -2.078 | 0.0377 |
| Open Water | 0.1680 | 0.0870 | 1.940 | 0.0530 |
| Total Precipitation | 0.0425 | 0.0252 | 1.687 | 0.0920 |

statistically significant and resulting in the inability to tell which landscape variables were significant predictors of RWBL occupation or absence.

Population Trends

My data also show that observations of RWBL are increasing within the study area and that the rise is significantly positive ($p=0.002$). The trend estimate is a log transformation of the change in mean count number, which is converted to a percentage increase in mean count number per year. These results are more easily interpreted if converted to a percentage increase per year, so the estimates are adjusted to deal with the mean count instead of the natural log of the mean count. The following formula allows for calculation of the percent increase per year in mean count number.

$$y = (e^{x}-1)*100$$

In this formula **y** is the average percent increase in mean count number per year and **x** is the estimate provided in the model output. An example of this process using the RWBL population trend gives a 2.42% increase in mean count number per year for RWBL, after accounting for all fixed and random effects. Calculation of the 95% confidence interval (CI) is done before using the above formula and gives mean count increases a range between 0.92% and 3.90%. Because I have also offset RWBL observation numbers for the amount of effort put into each survey and the CI does not cross zero, this suggests that populations of RWBL within the survey area are on the rise.

Habitat Selection

How landscape affects blackbird and starling occupancy in an area was another feature of interest in this study. There have been many studies that have analyzed how birds use their environments. Beletsky & Orians (1996) attributed bird occupancy to a large number of variables including vegetation, food and water availability, weather patterns, competition for mates and food, predator, and parasites.  Similar studies done over the years generally tend to look at relatively smaller, more localized scales than this study, which operates on a multiple-region scale, covering a large portion of the southeastern United States and parts of the southern Midwest.

Similar to the population trend, the estimates provided in Table 5 for habitat variables are log transformations of the change in mean count number.  They are standardized by whole numbers near the standard deviation in the case of weather and climate variables, and by 0.1 in the case of landscape variables since they were converted to proportions.  The landscape variable with the largest influence on RWBL mean count number proved to be farmland, the estimate for which is provided in Table 5. Exponentiating this estimate produces an average increase of 32% in mean count number for every 10% increase in farmland in CBC circles (10%, 20%, 30%, etc.).  The 95% CI for mean count number increases related to farmland lies between 23.25% and 40.75%.  Since this interval does not cross zero, it is considered to be significant ($p < 0.001$). Exponentiating the other fixed effect estimates for habitat variables gives values of -10.1% (95% CI= -20.1%, -0.0600%) for forested areas, 3.45% (95% CI= -9.5%, 16.4%) for developed area, 18.31% (95% CI= -0.2%, 36.9%) for open water, and 4.3% (95% CI= -0.6%, 9.3%) for precipitation.  Only forested area was considered significant, which indicated a 10.1% decrease in RWBL mean count number for every 10% increase in area ($p = 0.038$).  Developed area provided estimates that were not significant ($p = 0.610$), while open water ($p = 0.053$), and total yearly precipitation ($p = 0.091$) provided estimates that approached significance, but gave only weak evidence of true effects on mean count numbers. As I mentioned before, models were restricted to run for the years that habitat data were available to try to avoid pseudoreplication. These results for these models were similar to the results for models run for all years (Table 6). These analyses were run in a slightly different way than the original models, but can be interpreted in the same fashion. Positive estimates in this analysis represent positive associations and negative estimates reflect land types that RWBL avoid. The results are similar but with two noticeable differences. First, the negative effect that forested area has on mean count number is significantly more pronounced. Second, the positive association of RWBL with total precipitation is substantially higher and is statistically significant.

Table 6. Restricted analysis of environmental fixed effects used for analysis of RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| Developed Area | -0.0590 | 0.1052 | -0.558 | 0.5700 |
| Farmland | 0.2650 | 0.0812 | 3.262 | 0.0010 |
| Forested Area | -0.3500 | 0.0891 | -3.944 | 8.03E-05 |
| Open Water | 0.0470 | 0.1213 | 0.387 | 0.7000 |
| Total Precipitation | 0.2530 | 0.1072 | 2.362 | 0.0180 |

### Common Grackles

Of the 5,295 counts conducted over 21 years in my study area, 4,400 had at least one observation of a COGR. Surveys that observed no COGR were a minority, making up 16.9% of the total number of surveys; 172 surveys yielded single observations and 75% yielded five or more individuals. Areas with low COGR counts typically had high levels of grassland, which is a landscape variable common in the shortgrass prairie, central mixed-grass prairie, and Edwards plateau, all of which had lower incidences of COGR than average (Table 4). The Appalachian Mountains BCR also had a relatively low incidence of COGR and is characterized by low levels of grassland; this region also has low levels of farmland, a landscape variable that is positively associated with COGR in both literature reports and my research (Table 7). These observations were supported by my model analysis, which shows that COGR numbers increase as the proportion of farmland in a count circle increases (p = 0.0045) and that COGR numbers decrease as the proportion of grassland increases (p < 0.001).

Table 7. Environmental fixed effects used for analysis of COGR population trends and their influence on COGR residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| (Intercept) | -0.1610 | 0.5050 | -0.319 | 0.749 |
| Population Trend | -0.0081 | 0.0079 | -1.014 | 0.3110 |
| Developed Area | 0.1870 | 0.0801 | 2.340 | 0.0193 |
| Farmland | 0.1720 | 0.0604 | 2.840 | 0.0045 |
| Grassland | -0.3710 | 0.0794 | -4.670 | 3.04E-06 |
| Open Water | -0.1940 | 0.1130 | -1.720 | 0.0856 |
| Total Precipitation | 0.0634 | 0.0320 | 1.980 | 0.0474 |

## Population Trends

Population trends seen in this model for COGR show neither significant increases nor decreases in mean count number over the study period. As seen in Table 7, the population trend estimate was -0.0808, which can be adjusted similarly to RWBL numbers to give a percentage increase per year, yielding a -0.81% (95% C.I. 0.76% to -2.4%) increase in mean count number over the study period. Because this CI crosses zero, I assume that there is no significant change in mean count number.

## Habitat Selection

Landscape variables for COGR were calculated in the same fashion that they were for RWBL. The most influential landcover type by far was grassland with an estimate of -0.371 (Table 7 and Table 8). Exponentiation of this estimate gives a 31% decrease in COGR mean count number for every 10% increase in the amount of grassland in a count circle. Calculation of the 95% CI provides a range of 46.6% to 15.4% decrease in mean count number; since this range does not cross zero, it is considered to be significant (p< 0.001). Farmland also had significant effects on mean count numbers, with an estimate of 0.172; mean count numbers increased an average of 18.8% for every 10% increase in farmland. The 95% CI for farmland had a lower limit of 6.9% and an upper limit 30.6% and does not cross zero, making it significant (p= 0.005). Other significant effects included developed area with an increase of 20.6% (95% CI= 4.9%, 36.3%) in mean count number for every 10% increase in developed area (p= 0.019) and total precipitation. Total precipitation, however, was only weakly significant with an increase in mean count number of 6.6% (95% CI= 0.28%, 12.8%) for every 25.4 cm of rain that fell (p= 0.0474). The last

Table 8. Restricted analysis of environmental fixed effects used for analysis of RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| Developed Area | 0.3845 | 0.1248 | 3.082 | 0.0021 |
| Farmland | 0.3435 | 0.0963 | 3.567 | 0.0004 |
| Grassland | -0.6154 | 0.1532 | -4.017 | 5.89E-05 |
| Open Water | -0.0764 | 0.1423 | -0.537 | 0.5916 |
| Total Precipitation | 0.3033 | 0.1363 | 2.226 | 0.0260 |

fixed effect included in the COGR model was open water, causing a -17.6% (95% CI= -39.7%, 4.5%) increase in mean count number, which approaches significance, but gives only weak evidence of effects on mean count number. A restricted analysis for COGR was also run (Table 8) that showed several interesting differences with the original models. Developed area showed a significantly more pronounced effect, as did farmland and grassland. The effect of open water decreased by approximately half but was still not statistically significant.

## European Starlings

The vast majority of the 5,295 counts reported at least one EUST during the study period, (5,195 to be exact), easily outpacing every other species in terms of distribution in this study. Fewer than 2% of counts had zero observations, 12 counts had single observations, and over 97% of the counts had at least five EUST observations. EUST are distributed fairly evenly over the study area (Table 4), with all areas having more than 90% incidence of EUST during surveys. Areas with low EUST counts had large quantities of shrubland, a landscape type common in the shortgrass prairie, (BCR 18) which had the lowest incidence of EUST. Large counts were associated with high levels of farmland and development, two of the most common landcover types. These observations were supported by my analysis (Table 9) which shows that EUST are positively associated with farmland and development ($p < 0.001$) and negatively associated with wetlands ($p = 0.015$) and shrubland ($p = 0.035$).

### Population Trends

Population trends seen in this model for EUST show neither significant increases nor decreases in mean count number over the study period. As seen in Table 9, the population trend estimate was -0.00547, which when adjusted in a similar fashion as done for the RWBL and COGR numbers, provided a -0.55% increase in mean count number over the study period. Calculating a 95% CI gives us an upper limit 0.4% and a lower limit of -1.5%. Since this CI crosses zero the assumption can be made that there is not a significant change in mean count number.

Table 9. Environmental fixed effects used for analysis of EUST population trends and their influence on EUST residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| (Intercept) | 2.2800 | 0.1680 | 13.57 | 2.00E-16 |
| Population Trend | -0.0055 | 0.0048 | -1.139 | 0.2600 |
| Developed area | 0.2100 | 0.0397 | 5.296 | 1.18E-07 |
| Farmland | 0.1420 | 0.0269 | 5.293 | 1.20E-07 |
| Shrubland | -0.0760 | 0.0364 | -2.105 | 0.0350 |
| Total winter precip | 0.0570 | 0.0206 | 2.775 | 0.0055 |
| Wetland | -0.1100 | 0.0452 | -2.422 | 0.0150 |
| Winter max temp | -0.1220 | 0.0317 | -3.870 | 0.0001 |

### Habitat Selection

The impact of landscape variables was calculated using the same techniques that were used for other species in this study. The most influential landcover type was developed area, causing a 23.4% increase in mean count number for every 10% increase in area (Table 9). Calculation of the 95% CI gives a range of 15.6% to 31.2%; since this range does not cross zero, it is significant ($p< 0.001$). Farmland also had a significant effect on mean count number, averaging a 15.3% increase for every 10% increase in area. The 95% CI for farmland had a lower limit of 10.01% and an upper limit 20.5% and does not cross zero, making it significant ($p< 0.001$). Other significant landscape effects included shrubland with an increase of -7.4% (95% CI= -14.5%, -0.24%) and wetland with an increase of -10.37% (95% CI= -1.5%, -19.24%) for every 10% increase in area. Neither of these 95% CI cross zero; both are considered significant ($p < 0.05$). Climatalogical variables also had significant impacts with total winter precipitation averaging a 5.88% increase (95% CI= 1.84, 9.9%) for every 12.5 cm of rainfall ($p = 0.0055$), and average winter maximum temperature causing a -11.53% increase (95% CI= -17.7%, -5.3%) for every ten degree increase ($p < 0.001$). The restricted analysis done for EUST (Table 10) also shows some significant differences from the original models. The positive effects of farmland and developed area and the negative effects of winter maximum temperature are greater, while the effects of wetland, shrubland, and total winter precipitation are no longer statistically significant.

Table 10. Restricted analysis of environmental fixed effects used for analysis of RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| Developed area | 0.3955 | 0.0660 | 5.989 | 2.11E-09 |
| Farmland | 0.2201 | 0.0447 | 4.928 | 8.31E-07 |
| Shrubland | -0.1350 | 0.0769 | -1.754 | 0.0790 |
| Total winter precip | 0.0968 | 0.0704 | 1.376 | 0.1690 |
| Wetland | 0.0614 | 0.0845 | 0.726 | 0.4680 |
| Winter max temp | -0.6285 | 0.1354 | -4.641 | 3.47E-06 |

### Brewer’s Blackbirds

Out of 5,295 surveys, 2,271 reported at least one observation of a BRBL, 57% of surveys reported no observations, and only 36% of surveys reported more than five BRBL. As Table 4 shows, BRBL incidence was highly variable over the study area, ranging from 3% of surveys in the Appalachian Mountains (BCR 28) to 75% of surveys in Oaks and

Prairies (BCR 21). Areas where BRBL were more common generally had high levels of shrubland, grassland, and/or farmland, and low amounts of forested area and development. These observations were mostly supported by my analysis, with birds being attracted to areas with high levels of farmland, shrubland, and grassland (Table 8) and were also positively associated with forest ($p < 0.001$).

Population Trends

Population trends seen in this model for BRBL show neither significant increases nor decreases in mean count number over the study period. As seen in Table 11, the population trend estimate was 0.01029 which is calculated with the equation used above to give us a 1.03% increase in mean count number over the study period. Calculating a 95% CI gives us an upper limit 3.5% and a lower limit of -1.4%. Since this CI crosses zero, I can assume that there is not a significant change in mean count number from year to year.

Table 11. Environmental fixed effects used for analysis of BRBL population trends and their influence on BRBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| (Intercept) | -5.3300 | 0.6630 | -8.032 | 9.61E-16 |
| Population Trend | 0.0103 | 0.0125 | 0.826 | 0.4090 |
| Developed area | -0.0234 | 0.1340 | -0.174 | 0.8620 |
| Farmland | 0.7640 | 0.1000 | 7.590 | 3.20E-14 |
| Forested area | 0.4690 | 0.1040 | 4.499 | 6.82E-06 |
| Grassland | 0.9530 | 0.1260 | 7.557 | 4.11E-14 |
| Min monthly temp | 0.8400 | 0.2320 | 3.615 | 0.0003 |
| Shrubland | 0.6060 | 0.1290 | 4.700 | 2.60E-06 |
| Total precipitation | -0.0653 | 0.0494 | -1.322 | 0.1860 |

Habitat Selection

The most influential habitat type seen for BRBL was grassland, which gives a 159.5% (95% CI= 137.7%, 184.2%) increase in mean count number per 10% increase in area ($p< 0.001$). Farmland, forested area, and shrubland also had significant positive effects with 114.6% (CI= 94.9%, 134.4%), 59.8% (95% CI= 39.4%, 80.3%), and 83.3% (95% CI= 58.03%, 108.6%) increases in mean count number per 10% increase in area, respectively. Developed area was the only landscape type to have a negative effect, though it was not significant ($p= 0.8616$). Of the two climatic variables in the model, only minimum monthly temperature was significant, giving a 131.7% (95% CI= 86.1%, 177.2%) increase in mean count number for every $10^{o}$F increase ($p= 0.0003$). Total precipitation had a negative association, but was not significant ($p= 0.186$). Restricted analyses for BRBL (Table 12) had similar results that restricted analyses for other species showed with some effects being similar and others showing differences. Farmland, shrubland, grassland, and minimum monthly temperature all had positive values similar to those found in the original analyses, while forested area lost some effect and is no longer

Table 12. Restricted analysis of environmental fixed effects used for analysis of RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| Developed area | 0.0800 | 0.2019 | 0.397 | 0.6900 |
| Farmland | 0.7600 | 0.1578 | 4.824 | 1.41E-06 |
| Forested area | 0.2000 | 0.1649 | 1.218 | 0.2230 |
| Grassland | 0.9600 | 0.1262 | 7.557 | 4.11E-14 |
| Min monthly temp | 0.8500 | 0.2324 | 3.615 | 0.0003 |
| Shrubland | 0.7500 | 0.2118 | 3.548 | 0.0004 |
| Total precipitation | 0.3400 | 0.2314 | 1.458 | 0.1450 |

considered statistically significant. Development and total precipitation both show positive effects in the restricted analysis; this is a change from the originals, but neither is statistically significant.

## Rusty Blackbirds

Of 5,295 surveys, 1,938 had at least one observation of a RUBL; 63% of surveys reported no observations, and only 26% of surveys reported five or more RUBL observations. As Table 4 shows, variability in RUBL incidence is high, ranging from zero reported incidences in the Tamaulipan Brushlands (BCR 36) to 66% of surveys reporting at least one individual in the Mississippi Alluvial Valley (BCR 26). Areas that had relatively high survey numbers typically had more farmland, forest, and development than areas with lower count numbers. These observations were mostly supported by my analysis, which positively associated development and developed area with RUBL count numbers ($p<0.05$), but not forested area, which showed only weak effects that were not statistically significant, as seen in Table 13.

### Population Trends

Population trends for RUBL have been shown in other literature to be significantly negative, and CBC data suggest population decreases between 1966 and 1991 however, populations have been relatively stable since then. My analysis agreed with the latter, showing a close to significant rise in mean count number over the study period. Counts averaged a 2.7% (95% CI -0.004%, 5.4%) increase in mean count number. This interval crosses zero, but p is close to 0.05; while not significant, there is weak evidence of a small rise in mean count number in the study area.

Table 13. Environmental fixed effects used for analysis of RUBL population trends and their influence on RUBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| (Intercept) | -6.9800 | 0.6060 | -11.52 | 2.00E-16 |
| Population Trend | 0.0264 | 0.0135 | 1.960 | 0.0500 |
| Developed area | 0.2750 | 0.1120 | 2.470 | 0.0136 |
| Farmland | 0.2860 | 0.0798 | 3.590 | 0.0003 |
| Forested area | 0.0837 | 0.0935 | 0.895 | 0.3710 |
| Winter Min temp | -0.5310 | 0.1360 | -3.920 | 8.88E-05 |
| Shrubland | -0.2310 | 0.1550 | -1.490 | 0.1360 |
| Total winter precip | -0.0048 | 0.0646 | -0.074 | 0.9410 |

### Habitat Selection

According to the analysis, the most influential habitat type is farmland with a 33.1% increase in mean count number per 10% increase in area. Calculation of the 95% CI gives an interval of 16.2% on the lower end and 50.1% on the higher end; since this interval does not cross zero, it is considered significant ($p<0.001$). Other landscape categories that had positive associations included development and forested area with 31.7% (95% CI= 7.2%, 56.1%) and 8.7% (95% CI= -9.6%, 27.1%) increases in mean count number per 10% increase in area, respectively, though only development was significant ($p= 0.014$). The only landscape type used in the model that had a negative association was shrubland, with a -25.9% (95% CI= -61.3%, 9.4%) increase in mean count number per 10% increase in area. Weather variables used in the model included average minimum winter temperature and total winter precipitation. While total winter precipitation was not found to be significant, average minimum winter temperature was significant with a -41.2% (95% CI= -67.9%, -14.5%) increase in mean count number for every 5.6$^{o}$C increase in temperature ($p< 0.001$).

The restricted analysis of RUBL data seen in Table 14 shows results similar to those seen in the restricted analysis of the other species in the study. Farmland and development both remained significantly positive, while winter minimum temperature remained significantly negative ($p < 0.05$). Shrubland maintained its negative effects but was no longer statistically significant (p= 0.341), while forested area had almost no change. The change of the effects of total winter was rather surprising, going from a low negative effect that was not statistically significant to a high positive effect that is statistically significant (p =0.0048).

Table 14. Restricted analysis of environmental fixed effects used for analysis of RWBL residence in habitats.

| Fixed Effect | Estimate | Std. Error | Z - value | p |
|---|---|---|---|---|
| Developed area | 0.4570 | 0.1910 | 2.387 | 0.0170 |
| Farmland | 0.3470 | 0.1620 | 2.144 | 0.0320 |
| Forested area | 0.1620 | 0.1440 | 1.123 | 0.2600 |
| Winter Min temp | -0.4850 | 0.1350 | -3.579 | 0.0004 |
| Shrubland | -0.4110 | 0.4320 | -0.952 | 0.3410 |
| Total winter precip | 0.7300 | 0.2590 | 2.822 | 0.0048 |

# DISCUSSION

There are a wide variety of methods for the analysis of population data taken from large bird surveys (Peterjohn & Sauer, 1994; Link & Sauer, 2002; Link *et al.,* 2002; Niven *et al.,* 2004; Dunn *et al.,* 2005; Thogmartin *et al.,* 2006; Link & Sauer, 2006). Many of them do not use CBC data, which sometimes requires manipulation to make it a viable resource. The hierarchical model I present for analysis of CBC data has several advantages over alternative approaches. First, this type of model allows for hierarchical modeling on a much larger scale than surveys that have more rigid protocols, but are not conducted on large scales. It permits the modeling of environmental factors that may influence population change and spatial variation in abundance on large scales. This type of model allows for the accommodation of over-dispersion that is observed among outcomes that have nominally binomial or Poisson distributions (Williams, 1982; Breslow, 1984). Hierarchical modeling also allows for the controlling of nuisance covariates that may influence counts, such as effort, while providing a framework for estimation and the regional summary of surveys (Link & Sauer, 2006).

The model that was constructed for this project uses environmental features as fixed effects and random effects for combinations of circle, BCR, and year. It is fundamentally a log-linear pattern of population change with fixed year effects adjusting for departures from the log-linear pattern. Alternative models might be considered with variable amounts of inherent structure, all within the hierarchical framework that is suggested here (Link *et al.,* 2002). For example, it would be relatively easy to construct a model where site/circle effects are modeled as fixed effects without any underlying log-linear pattern or association. This type of model would have the advantage of great flexibility in modeling abrupt geographical changes by large numbers of birds, such as have been documented in blackbirds and starlings in the past (Dolbeer, 1978). But this model would require more and better data than the model presented here. Another alternative would be to treat site effects as a stationary auto-regressive process as Breslow & Clayton (1993) did for year effects, which would serve to smooth the site effects without specification of a particular pattern in geographical change. These alternatives would fit well within the hierarchical modeling approach detailed here.

Several of the results for this study were rather surprising; others were more predictable but still interesting. The most notable surprise seen in RWBL data was the significant observed rise in mean count numbers over the study area (Figure 16, Figure 17, Table 5). Several studies that have been mentioned (Blackwell & Dolbeer, 2001; Weatherhead, 2005) have reported significant decreases of RWBL numbers over the last few decades. Other unexpected results included the negative association RWBL had with forested area and the level of positive association seen with farmland. Going into this project, I, of course, had some predictions about how landscape could affect the occupancy of these birds. One was the assumption that RWBL preferred roosting in and around wetlands. While there was a positive association between RWBL and wetlands found during modeling, it was not significant in any of the models that were run. During the breeding season, wetlands are extremely important, as they form the substrate for a significant number of nesting RWBL (Kantrud & Stewart, 1984); in winter, wetlands appear to be less important.

As I mentioned, farmland had a rather surprising effect; I had assumed that there would be some positive effect, as RWBL derive a significant amount of their winter diet from grains (Snelling, 1968). However, I did not realize that the effect would be as robust as it was, with a 23-41% increase in mean count number for every 10% increase in area. Farmland also had a significant positive impact on every other species included in these analyses, meaning that occupancy of blackbirds and starlings increased universally as the amount of farmland increased. No other habitat or environmental variable had such a distinct effect on bird occupancy in an area. Another interesting development that I saw was that weather had relatively little effect on RWBL occupancy in an area in the original models, no matter the combination of variables that were run, although some variables did have a significant effect on other blackbird species and European starlings. Possible explanations for this include RWBL prefer areas with food as opposed to shelter from the elements, choosing to roost closer to farmland than areas that would provide cover, or perhaps farmlands already provide adequate protection that I could not observe during my modeling.

Three species in this analysis showed significant positive associations with development. COGR, EUST, and RUBL all showed that developed area was not a hindrance to occupancy. This was not particularly surprising in the case of COGR or EUST, as these species are often observed in anthropogenically altered habitats, often thriving in them (Feare, 1984; Peer & Bollinger, 1997). But RUBL is not a species known to be associated with a great deal of development, nesting in the relatively impenetrable boreal forests of northern Canada. RUBL winter primarily in woody vegetation, river bottomlands, and flooded woodlands (Greenburg & Droge, 1999), although they are sometimes found in rather light development such as feedlots and manure fields. Another surprise I found was that BRBL were not significantly associated with development.

BRBL are known for the wide range of habitats they occupy and their high environmental plasticity, and are often found on residential lawns, cemeteries, and golf courses. RWBL similarly showed no significant effects for developed area, though they are often found in close proximity to humans and near human-altered habitats (Turner *et al.,* 1998). It is possible that the associations that both species have with development are random and that when they are seen within or by development, they are using a habitat or patch of habitat of a different variety that they prefer, which is merely in close proximity to development.

As they are, large scale surveys do not readily support estimations of total population size, but they can and have been used to estimate population change over annual cycles (Link *et al.*, 2008). The CBC is no different in this aspect, providing information on distribution and change in the populations of many species over long time periods (Niven *et al.,* 2004; Dunn *et al.,* 2005; Link & Sauer, 2006; Link & Sauer, 2007). The timing of the CBC places it after the fall migration, making it difficult to directly tie survey data to major events influencing survival and reproduction (Link *et al.,* 2008). Consequently, it is not possible to estimate seasonal or year-specific rates of population change (Link *et al.,* 2008). With the model that I present, I can estimate variation in yearly rates of population change over longer periods of time. However, accommodating the large differences in quality of information among regions, and even between years at the same site, has sometimes made aggregation of results problematic (Link & Sauer, 2002). Many CBC surveys have relatively few birds counted in a year, even in species that are common (RWBL, COGR, and EUST). On the other hand, there are several sites where relatively improbable numbers of birds were counted in certain years (52,915,010 RWBL were reported by the CBC in Pine Prairie in 1989). Despite this, linear mixed effect models provide a powerful and flexible tool for the analysis of a broad variety of data such as longitudinal data, repeated measures, blocked or multilevel spatial data and geostatistics, and bioinformatics data (Stiratelli *et al.*, 1984; Zeger *et al.*, 1988; Gumedze & Dunne, 2011).

The analysis of nuisance factors provides insight into the mechanics of surveys, showing that effort in counting for the CBC can have a large influence over our views of population change (Link *et al.,* 2006). In comparison, the BBS startup effects for new routes can cause counts to be 6.3% lower during their first year, and changes in observer quality introduces a positive observer effect of approximately 0.9% per year in estimates of change (Link *et al.,* 2008). Effort effects on CBC counts are well known (McCulloch, 1990; Link & Sauer, 1999; Butcher *et al.,* 2005), and several analyses show that standard effort adjustments, such as simple division by effort, are often not sufficient for the analysis of population data over large areas (Link & Sauer, 1999; Dunn *et al.,* 2005; Link *et al.,* 2006). Other factors may influence survey numbers and subsequent estimates that are based on of those surveys. Observer bias is one such factor; in the social sciences, observer bias is a confounding variable that introduces error into measurement when observers over emphasize behavior they expect to find and fail to notice behavior they do not expect (Graham & Bell, 1989). In their study, Graham & Bell (1989) found that the chances of detecting a group of horses was influenced more by the number in the group than the size of individual members. This means that it is the size of the group and not its individual members that is the determining factor when it comes to detection. Because of this effect, in areas where large blackbird roosts are common, it would be reasonable to expect some amount of overestimation in local population numbers due to the expectation of large numbers of birds (Balph & Balph, 1983). In areas that do not have large local populations or large numbers of migrants, individuals and small groups of birds may go completely unnoticed (Balph & Balph, 1983).

With any large scale model, there has to be some type of spatial implement in place. Any geographic summary of CBC data must in some way accommodate some regional variation in populations (Link *et al.,* 2006). Some models use spatial correlation between count sites in combination with random and/or fixed effects to describe the distribution of those sites (Link & Sauer, 2002; Link *et al.,* 2006; Thogmartin *et al.,* 2004). In this analysis, that is accomplished through the use of random effects: one for the spatial location of each CBC circle, one for each BCR, and one for temporal variability in annual counts. This allows for a great amount of flexibility when modeling the effects and interactions of fixed and random effects on population data.

The original intent of this project was to run models in WinBUGS using Markov chain Monte Carlo (MCMC) techniques, in which I would use environmental factors obtained for the model as explanatory variables to describe changes in bird populations (Link *et al.,* 2002). This did not change when our focus switched to using Program R; the main difference between the original attempts and final products were that the original models were Bayesian in structure and written for WinBUGS, and the final models that were used were linear mixed effect regressions (lmer) written for R. Both forms are linear mixed-effect models, and both had a mix of fixed and random effects used as explanatory variables. Both are also hierarchical, though my model did not employ the use of prior distributions in order to constrain random effects. When posterior distributions are used, one level of effects are described by prior distributions (Tenenbaum *et al.,* 2006) and another level, that of the variance components associated with those distributions, is described by hyper-priors (Jonsen *et al.*, 2003); this is the hierarchy of Bayesian models. The variance priors of WinBUGS are amendable by the author and can be fairly obvious, though they are not used in the case of LMER. In this study, random effects were not constrained but were evaluated using restricted maximum likelihood.

The only problem I experienced using WinBUGS is the time it would have taken to run through the models with different combinations of fixed-effects. WinBUGS has a great capacity for iterative simulation, but it comes at a cost of time for the calculations to run, sometimes on the order of several days for a single model. Since I did not feature a spatial correlation among CBC counts, I did not need to leverage WinBUGS when lmer works just as well, but faster. If I had needed to accommodate spatial correlation, as models run in WinBUGS sometimes do, then it would not have been possible to use the lmer function. Lmer does not have the capacity for handling complex spatial correlation structures. There are several new approaches that are becoming available in R, such as Laplace approximations, but they too come at a cost of time.

The limitation of data taken from the CBC, specifically those data for species of relatively low abundance or uncommon species such as BRBL and RUBL, can present problems for modeling attempts such as these (Link & Sauer, 2002). Relatively few individuals of these species are encountered in circles throughout their range, and the CBC surveys cover a limited amount of area within a count circle. This, coupled with the roosting habits of blackbirds and starlings which often form large multi-species roosts (Glahn & Otis, 1986), makes it fairly easy for smaller numbers of less populous species to be obscured by the assemblage of other more common species. Because of these limitations, large surveys are not particularly well suited for monitoring uncommon species; blanket surveys such as the CBC and BBS do not have the finesse to detect less numerous species at the same efficiency as they do species with larger populations (Link & Sauer, 2002). Annual CBCs are often repeated by the same observers, but just as often they are not, which can make the effects of observers somewhat confounded. Link & Sauer (2002) call for a model-based exercise to distinguish them with additional modeling of observer/route effects conducted into the hierarchical framework. They used BBS data to analyze surveys for Cerulean Warblers; the BBS, having a more stringent protocol than the CBC, makes this possible since the BBS records observers, their locations, and the number of times they have done the survey previously. The CBC also includes volunteer data, but has not done so for as long-- the names of compilers only relatively recently being added to survey data. It is also not apparent what routes were taken by individuals or groups of observers in CBC circles, or where individual birds or larger flocks were encountered; data are not distributed by location, but pooled over the entirety of the CBC circle, which is a large area. There is also evidence that the pool of observers is not temporally stationary and that new observers tend to count more birds and be less accurate with identification than the individuals that they replace (Sauer *et al.,* 1994; Link & Sauer, 1998; Link & Sauer, 2002). These deficiencies could be addressed by modifying the survey design in order to detect survey numbers closer to the actual population of birds in the CBC circle. This would effectively turn the survey into a census, but would make the CBC superfluous and consume more resources than would be necessary.

This brings me to the intrinsic weakness of models that use large scale surveys for data. Models like these are effective at modeling highly visible species with large populations, because I can assume the data they are based on are normally distributed due to Central Limit Theorem (CLT) and the large number of counts used (Rice, 1995). Counts can be modified by offsetting and accounting for any number of fixed or random variables, such as effort, number of observers, landscape, year effects, site, geographic location, etc., in an attempt to get as close as possible to actual population size. But there are limitations to what is possible, and in the end all that can be done is model the data that are available.

Despite the limitations of the CBC, it still remains a valuable resource for researchers, conservationists, and wildlife managers in both North America and South America. No other data set provides such a broad temporal and geographic coverage of bird population data. Every year more than 50,000 volunteers at more than 2,000 sites donate their time and money to the purpose of the Christmas Bird Count. For over 100 years, volunteers, armed only with binoculars, a desire to make a difference, and a need to experience the beauty of nature, have been making enormous contributions to both science and conservation. Without their help, projects like this one would not be possible, and the CBC would not be what it is today, the oldest and largest survey conducted on two continents.

There have been several influential papers in the last few decades (Besser *et al.*, 1984, Blackwell & Dolbeer, 2001; Weatherhead, 2005) that have shown declines in RWBL numbers. These studies are still widely cited and used to support the argument that RWBL population numbers are declining. Weatherhead (2005) used population data from wetlands in Eastern Ontario between the years of 1974 and 1995. All studies he did were conducted using the same group of marshes, though not every marsh was used every year; multiple marshes were used each year and each marsh was used in multiple years

(Weatherhead, 2005). During that time period, he detected a noticeable decline in RWBL populations in his study area. This finding mirrored results seen in the CBC, in which there was a significant negative trend seen even with only a simple offset for effort in the CBC (Figure 18). This graph was taken directly from the CBC website and has not been visually manipulated. As one can see, there is a distinct negative trend for the time period which starts at CBC 75 (1974-1975) and ends at CBC 96 (1995-1996). The graph for Ontario would have been preferable for this purpose, but RWBL are somewhat infrequent in that area when the CBC is conducted.

Blackwell & Dolbeer (2001) also showed significant declines in RWBL population between the years of 1965 and 1996 in Ohio. Blackwell & Dolbeer (2001) used BBS data in combination with landscape and climatic data, similar to this study, and used step-wise linear regressions to relate RWBL numbers to environmental variables. In their study, a similar trend in CBC data over that time period is seen, CBC survey 65 (1964-1965) to CBC survey 97 (1996-1997) even without significant correction in population numbers for effort (Figure 19). It would be preferable to use CBC data from the original study area, but RWBL are relatively uncommon in Ohio during that time and generally roost farther south during the winter months. I do not disagree or argue the fact that at the time the overall population of RWBL was declining, but I also understand that the data used for these analyses were several years to several decades old at the time of analysis. When conditions are favorable to either population increases or decreases, trends can change over a relatively short time (Kaji *et al.,* 2004) as in species that experience frequent population irruptions and crashes (Kaji *et al.,* 2004). The detection of trends in population data

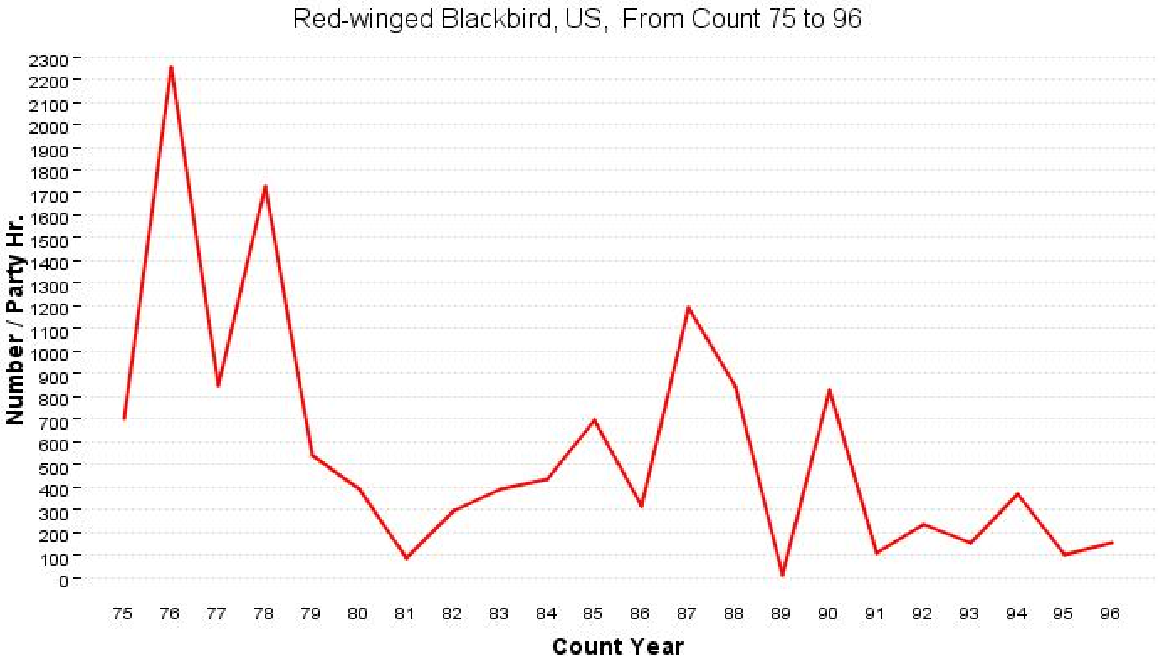

Figure 18. CBC figures for red-winged blackbirds from 1974-75 to 1995-96.

depends upon the timeframe in which one is looking at them; longer time-frames generally allow for a better idea of how a population is changing (Shea & Mangel, 2001), while shorter time periods can decrease the ability of a model to detect a trend (Shea & Mangel, 2001). That being said, both of the above examples have relatively long time frames, 21 and 31 years, respectively. The model created during this project has a 21-year time period, covers a greater area than both of these projects combined, and uses more current survey and environmental data. Both are still useful in showing blackbird population trends, but I do not think that they should be used as the definitive voice in RWBL population studies outside of the time period for which the models were constructed. Both studies used data that are more than 15 years old at this point, and are still cited as though RWBL trends could not have changed over that time period.

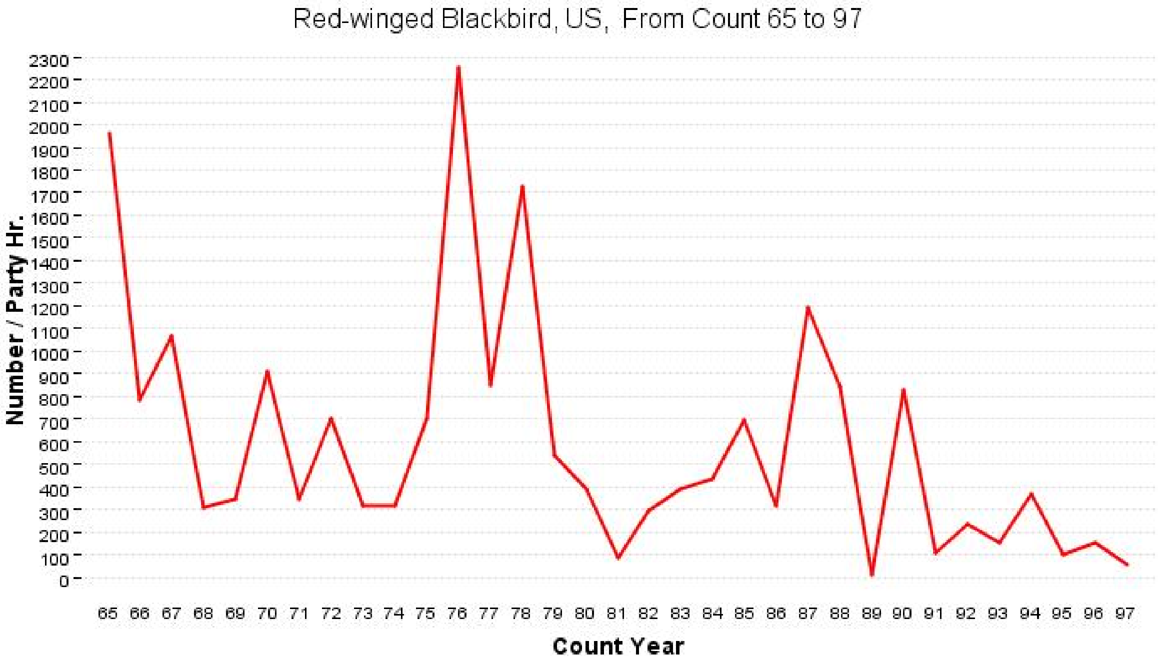

Figure 19. CBC figures for red-winged blackbirds from 1964-65 to 1995-96.

The necessity of models like these stems from the problems that blackbirds often cause for agriculture, which can cost millions to farmers and other interested parties every year. The cost to crop insurance companies can be significant, as payouts to farmers have increased in recent years, though historically, wildlife damage is not usually one of the larger causes for insurance payouts. Sunflower and corn are the crops of concern in northern states; 2-4% losses were reported in some years (Kleingartner, 2003; Linz *et al.*, 2009). During the wintering period, blackbirds depredate rice crops. The damage caused by blackbirds in 2002 was $11.3 million, though not all farmers received the same amount of damage (Wilson, 1985; Linz *et al.*, 1996). Damage observed during surveys is localized and proportional to the size of and distance to nearby roost sites, with some growers reporting total losses (Wilson, 1985). Escalated crop losses have initiated management techniques with the purpose of reducing the damage caused by resident and migratory blackbird and starling populations. These techniques include avicides (Linz & Bergman, 1996; Linz *et al.,* 2002), cattail management (Linz *et al.*, 1995; Linz *et al.,* 1996; Linz & Homan, 2010), repellent seed treatments (Mason, 1993; Linz, 2006), bird-resistant sunflowers (Mah *et al.*, 1991; Mah & Nuechterlein, 1991), and scare tactics (Linz *et al.*, 1996). Other types of damage caused by birds have also been outlined earlier, including the cost to human health through histoplasmosis and other communicable diseases, while not usually reported, can be significant. Livestock health, both mammalian and avian, can easily be influenced by blackbirds and starlings and the transmissible diseases they carry. The Transmissible Gastro Enteritis (TGE) outbreak of 1978-79 is only one example of how blackbirds and starlings can affect livestock. The cost to military and municipal institutions affected by blackbirds and starlings often incurs a significant cost when they have to clean up the droppings of these species. These models give agricultural, municipal, and military planners a better idea of what to expect, allowing them to better plan for and anticipate future problems.

Currently, our knowledge of the wintering ecology of blackbirds and starlings is fairly limited, as most projects that study these birds focus on breeding biology or damage prevention and mitigation. Understanding the habitat and environmental requirements of these species is a fundamental part of wildlife management. Abrupt changes in landscape and climate tend to affect species in predictable ways, if we know what and where to look. Studies like this can improve our understanding of what we are looking for; several rather interesting results were generated from this project alone, augmenting our knowledge and our ability to interpret population change in these and other species. In the future, I would like to introduce a broader geographical range and more land types into my analysis, allowing for a better interpretation of the requirements that species have in their wintering ecology. I would also like to adjust the model so that population trends that were less apparent might be easier to detect, both spatially and in bird populations.

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# APPENDIX 1. CHRISTMAS BIRD COUNT SITES USED IN ANALYSES

Appendix Table A1. Christmas Bird Count Sites used in Analysis

| **Site Name** | **State** | **BCR** | **Latitude** | **Longitude** |
|---|---|---|---|---|
| Birmingham | AL | 28 | 33.45 | -86.75 |
| Cullman | AL | 28 | 34.1 | -86.53 |
| Dauphin Island | AL | 27 | 30.3333 | -88.1333 |
| Eufala NWR | AL | 27 | 32 | -85.0833 |
| Ft. Morgan | AL | 27 | 30.2333 | -87.9 |
| Gulf Shores | AL | 27 | 30.3767 | -87.6333 |
| Guntersville | AL | 28 | 34.3833 | -86.2167 |
| Mobile-Tenshaw | AL | 27 | 30.75 | -87.95 |
| Montgomery | AL | 27 | 32.35 | -86.3833 |
| Perdido Bay | AL | 27 | 30.3333 | -87.3667 |
| Tuscaloosa | AL | 27 | 33.239 | -87.5755 |
| Waterloo | AL | 27 | 34.8333 | -88 |
| Wheeler NWR | AL | 24 | 34.6 | -86.8833 |
| Arkadelphia | AR | 25 | 34.1333 | -93.05 |
| Bayou DeView | AR | 26 | 34.86 | -91.17 |
| Big Lake | AR | 25 | 33.58 | -91.6 |
| Buffalo NRE | AR | 24 | 36.0833 | -92.5667 |
| Conway | AR | 25 | 35.0833 | -92.45 |
| Crooked Creek | AR | 24 | 36.1715 | -93.1425 |
| Fayetteville | AR | 24 | 36.1 | -94.15 |
| Fort Smith | AR | 24 | 36.3667 | -94.4167 |
| Holla Bend | AR | 25 | 35.1667 | -93.1333 |
| Hot Springs Village | AR | 25 | 34.7167 | -92.9667 |
| Jonesboro | AR | 26 | 35.9167 | -90.7 |
| Lake Georgia | AR | 25 | 33.15 | -92.0667 |
| Lake Village | AR | 26 | 33.4 | -91.3167 |
| Little Rock | AR | 25 | 34.75 | -92.2667 |
| Lonoke | AR | 26 | 34.7667 | -91.8833 |
| Magnolia-Lake | AR | 25 | 33.2667 | -93.2833 |
| Mena | AR | 25 | 34.5833 | -94.2333 |
| Monuntain Home | AR | 24 | 36.3833 | -92.45 |
| North Fork | AR | 24 | 35.6167 | -93.0167 |
| Pine Bluff | AR | 26 | 34.25 | -92 |
| Texarkana | AR | 25 | 33.4667 | -93.9 |
| VanBuren | AR | 24 | 35.6167 | -92.2667 |
| Village Creek | AR | 26 | 35.1667 | -90.7167 |
| Wapanocca | AR | 26 | 35.35 | -90.2333 |
| White River | AR | 26 | 34.3833 | -91.1333 |

| Appendix Table A1 (Continued) | | | | |
|---|---|---|---|---|
| Arkansas city | KS | 19 | 37.0333 | -97.0333 |
| Baldwin | KS | 22 | 38.7333 | -95.2667 |
| Cedar Bluff | KS | 19 | 38.75 | -99.7667 |
| Cimmaron NG | KS | 18 | 37.1167 | -101.8667 |
| Dodge City | KS | 19 | 37.7667 | -99.9667 |
| Emporia | KS | 22 | 38.45 | -96.0833 |
| Halstead-Newton | KS | 19 | 38.0667 | -97.4667 |
| Jetmore | KS | 19 | 38.03 | -99.53 |
| Kirwin Resivoir | KS | 19 | 39.7 | -99.1333 |
| Lawrence | KS | 22 | 39 | -95.3 |
| Liberal-Seward | KS | 18 | 37.1333 | -100.833 |
| Linn county | KS | 22 | 38.2833 | -94.75 |
| Olathe | KS | 22 | 38.9167 | -94.85 |
| Oskaloosa | KS | 22 | 39.2 | -95.4 |
| Parsons | KS | 22 | 37.5 | -95.25 |
| Quivira NWR | KS | 19 | 38.15 | -98.4833 |
| Red Hill | KS | 19 | 37.13 | -98.4199 |
| Reno County-Yoder | KS | 19 | 37.9 | -97.8667 |
| Salina | KS | 19 | 38.8333 | -97.6333 |
| Scott Lake | KS | 18 | 38.5833 | -100.933 |
| SE Minedland | KS | 22 | 37.2333 | -94.9667 |
| Topeka | KS | 22 | 39.0333 | -95.6667 |
| Udall-Winfield | KS | 22 | 37.2667 | -96.9833 |
| Wakonda Lake | KS | 19 | 39.4667 | -98.3667 |
| Webster | KS | 19 | 39.4167 | -99.4 |
| Wichita | KS | 19 | 37.6833 | -97.3333 |
| Wilson Resivoir | KS | 19 | 38.9333 | -98.5667 |
| Ashland | KY | 28 | 38.46478 | -82.69786 |
| Bowling Green | KY | 24 | 36.9167 | -86.4333 |
| Breaks Interstate park | KY | 28 | 37.25 | -82.2167 |
| Calloway | KY | 24 | 36.6 | -88.2 |
| Danville | KY | 24 | 37.6333 | -84.7667 |
| Daviess County | KY | 24 | 37.35 | -87.0199 |
| Evansville | KY | 24 | 37.9833 | -87.5667 |
| Frankfort | KY | 24 | 38.2333 | -84.85 |
| Hopkinsville | KY | 24 | 36.8667 | -87.4667 |
| Kleber WMA | KY | 24 | 38.4667 | -84.7833 |
| Land Between the Lakes | KY | 24 | 36.9333 | -88.1167 |
| Lexington | KY | 24 | 37.9167 | -84.4667 |
| Lincoln's Birthplace | KY | 24 | 37.573 | -85.74 |
| London | KY | 28 | 37.1264 | -84.0963 |
| Louisville | KY | 24 | 38.2667 | -85.65 |
| Otter Creek park | KY | 24 | 37.9 | -86.0667 |
| Red Bird | KY | 28 | 36.9333 | -83.5333 |

| Appendix Table A1 (Continued) | | | | |
|---|---|---|---|---|
| Somerset | KY | 24 | 37.1 | -84.6 |
| Wayne County | KY | 24 | 36.8972 | -84.8213 |
| Baton Rouge | LA | 26 | 30.3667 | -91.1167 |
| Bogue Chitto | LA | 27 | 30.4833 | -89.8 |
| Bossier Cado | LA | 25 | 32.3 | -93.4833 |
| Butte la Rose | LA | 26 | 30.2833 | -91.6833 |
| Catahoula | LA | 26 | 31.5 | -92.0333 |
| Cheneyville | LA | 26 | 31.1 | -92.3667 |
| Clairborne | LA | 25 | 32.78 | -92.95 |
| Creole | LA | 37 | 29.8 | -93.1 |
| Crowley | LA | 37 | 30.1 | -92.3776 |
| D'Arbonne | LA | 25 | 32.6667 | -92.25 |
| Fort Polk | LA | 25 | 31.334 | -93.439 |
| Grand Isle | LA | 37 | 29.2 | -90.05 |
| Houma | LA | 26 | 29.6 | -90.7167 |
| Johnson's Bayou | LA | 37 | 29.8 | -93.7167 |
| Lassicine | LA | 37 | 30.05 | -92.8167 |
| Lafayette | LA | 37 | 30.2 | -92.1 |
| Lake Charles | LA | 37 | 30.15 | -93.3 |
| Lake Ophelia | LA | 26 | 31 | -91.9 |
| Natchez | LA | 26 | 31.5833 | -91.4 |
| Natchitoches | LA | 25 | 31.8167 | -93.05 |
| New Iberia | LA | 26 | 30 | -91.55 |
| New Orleans | LA | 37 | 30.0333 | -89.9167 |
| Northshore-Slidell | LA | 26 | 30.25 | -89.7933 |
| Pine Prairie | LA | 37 | 30.8 | -92.35 |
| Reserve-Bonnet | LA | 26 | 30.0833 | -90.45 |
| Sabine | LA | 37 | 29.85 | -93.3833 |
| Shreveport | LA | 25 | 32.5333 | -93.8833 |
| St. Tammany | LA | 26 | 30.4 | -90.0833 |
| Tensas River NWR | LA | 26 | 32.2833 | -91.3667 |
| Thibodaux | LA | 26 | 29.8167 | -90.75 |
| Tunica | LA | 26 | 30.75 | -91.3833 |
| Venice | LA | 37 | 29.3333 | -89.4333 |
| Big Oak Tree | MO | 26 | 36.6667 | -89.2667 |
| Big Spring | MO | 24 | 36.95 | -91 |
| Clarence Cannon | MO | 22 | 39.1667 | -90.7808 |
| Columbia | MO | 24 | 38.8833 | -92.3333 |
| Confluence | MO | 22 | 38.8224 | -90.2434 |
| Dallas county | MO | 24 | 37.7167 | -92.9833 |
| Diamond Grove | MO | 24 | 37.0667 | -94.35 |
| Grand River | MO | 22 | 40.0333 | -93.9667 |
| Hannibal | MO | 22 | 39.7 | -91.35 |
| Horton | MO | 22 | 38.1167 | -94.4833 |

Appendix Table A1 (Continued)

| | | | | |
|---|---|---|---|---|
| Jackass Bend | MO | 22 | 39.2167 | -94.25 |
| Jefferson City | MO | 24 | 38.5833 | -92.1833 |
| Joplin | MO | 24 | 37.0333 | -94.4667 |
| Kansas City | MO | 22 | 38.95 | -94.4 |
| Keokuk | MO | 22 | 40.4667 | -91.45 |
| Knob Knoster | MO | 22 | 38.7333 | -93.65 |
| Laclede County | MO | 24 | 37.6333 | -92.6167 |
| Liberal | MO | 24 | 37.28 | -94.29 |
| Maramec Springs | MO | 24 | 37.9667 | -91.5667 |
| Maryville | MO | 22 | 40.35 | -94.9167 |
| Mingo | MO | 26 | 36.9833 | -90.2 |
| Montrose | MO | 22 | 38.25 | -93.8167 |
| NCCC | MO | 22 | 38.7333 | -94.3333 |
| Orchard Farm | MO | 22 | 38.8793 | -90.4462 |
| Patterson | MO | 24 | 37.1833 | -90.55 |
| Poplar Bluff | MO | 24 | 36.7667 | -90.4167 |
| Springfield | MO | 24 | 37.2167 | -93.2333 |
| Squaw Creek | MO | 22 | 40.0833 | -95.2667 |
| St. Joseph | MO | 22 | 39.7833 | -94.85 |
| Sullivan | MO | 24 | 38.1667 | -91.1 |
| Swan Lake | MO | 22 | 39.6667 | -93.2167 |
| Taney | MO | 24 | 36.6167 | -93.1667 |
| Ted Shanks | MO | 22 | 39.4667 | -91.1833 |
| Trimble | MO | 22 | 39.4667 | -94.5667 |
| Union County | MO | 24 | 37.4667 | -89.4 |
| Weldon Spring | MO | 22 | 38.7 | -90.75 |
| Arkabutla | MS | 27 | 34.7667 | -90.1333 |
| Church Hill | MS | 27 | 31.75 | -91.1833 |
| Corinth | MS | 27 | 34.9387 | -88.5189 |
| Dahomey | MS | 26 | 33.4636 | -90.5736 |
| Eagle lake | MS | 27 | 32.5458 | -90.58 |
| Grenada | MS | 27 | 33.85 | -89.7167 |
| Hattiesburg | MS | 27 | 31.35 | -89.3333 |
| Jackson | MS | 27 | 32.45 | -90 |
| Jackson County | MS | 27 | 30.33 | -88.71 |
| Lauderdale County | MS | 27 | 32.4667 | -88.75 |
| Moon lake | MS | 26 | 34.5 | -90.4833 |
| Noxubee | MS | 27 | 33.2833 | -88.8 |
| Pearl River | MS | 27 | 30.48 | -89.69 |
| Sardis | MS | 27 | 34.45 | -89.7 |
| South Hancock | MS | 37 | 30.2 | -89.45 |
| Sumner | MS | 26 | 33.9667 | -90.3667 |
| Tupelo | MS | 27 | 34.2167 | -88.6667 |
| Vicksburg | MS | 26 | 32.3167 | -90.9 |

| Appendix Table A1 (Continued) | | | | |
|---|---|---|---|---|
| Washington County | MS | 26 | 33.1167 | -90.9833 |
| Arcadia | OK | 21 | 35.5667 | -97.2167 |
| Arnett | OK | 19 | 36.05 | -99.8 |
| Broken Bow | OK | 25 | 34.05 | -94.7167 |
| Fort Gibson | OK | 22 | 35.85 | -95.3167 |
| Hulah | OK | 21 | 36.9333 | -96.0833 |
| Kenton | OK | 18 | 36.9 | -102.9 |
| Lake Atoka | OK | 25 | 34.5497 | -95.97 |
| Norman | OK | 21 | 35.2333 | -97.35 |
| Oklahoma City | OK | 19 | 35.5333 | -97.5833 |
| Rogers County | OK | 22 | 36.3667 | -95.6333 |
| Salt Plains | OK | 19 | 36.6667 | -98.1667 |
| Sequoyah | OK | 25 | 35.5 | -94.9667 |
| Sooner lake | OK | 19 | 36.3833 | -97.0833 |
| Spavinaw | OK | 24 | 36.4 | -94.95 |
| Stephen County | OK | 21 | 34.5667 | -97.7833 |
| Stillwater | OK | 19 | 36.1667 | -97.1667 |
| Tallgrass | OK | 22 | 36.85 | -96.4333 |
| Tishimingo | OK | 21 | 34.1833 | -96.65 |
| Tulsa | OK | 22 | 36.3167 | -95.9 |
| Washita | OK | 19 | 35.6 | -99.25 |
| Wichita Mountains | OK | 19 | 34.7333 | -98.6667 |
| Bristol | TN | 28 | 36.583 | -82.1 |
| Buffalo River | TN | 24 | 35.3 | -87.47 |
| Cades Cove | TN | 28 | 35.6 | -83.83 |
| Cahtanooga | TN | 28 | 35.1 | -85.23 |
| Clarksville | TN | 24 | 36.5 | -87.38 |
| Clay County | TN | 24 | 36.5 | -85.37 |
| Columbia | TN | 24 | 35.6 | -87.17 |
| Cookeville | TN | 24 | 36.15 | -85.47 |
| Cross Creek | TN | 24 | 36.467 | -87.75 |
| Crossville | TN | 28 | 35.862 | -85.02 |
| DeKalb | TN | 24 | 36.02 | -85.83 |
| Dresden | TN | 27 | 36.283 | -88.7 |
| Elizabethton | TN | 28 | 36.333 | -82.13 |
| Fayette County | TN | 27 | 35.2 | -89.42 |
| Franklin Coffee | TN | 24 | 35.302 | -86.06 |
| Great Smokey Mountain | TN | 28 | 35.717 | -83.48 |
| Hickory-Preist | TN | 24 | 36.2 | -86.67 |
| Hiwassee | TN | 28 | 35.367 | -84.9 |
| Jackson | TN | 27 | 35.617 | -88.82 |
| Kingsport | TN | 28 | 36.5 | -82.52 |
| Knoxville | TN | 28 | 35.917 | -84.08 |
| Memphis | TN | 27 | 35.15 | -89.93 |

| Appendix Table A1 (Continued) | | | | |
|---|---|---|---|---|
| Nashville | TN | 24 | 36.05 | -86.93 |
| Nickajack Lake | TN | 28 | 35.067 | -85.52 |
| Norris | TN | 28 | 36.217 | -84.08 |
| Reelfoot Lake | TN | 26 | 36.417 | -89.38 |
| Roan Mountain | TN | 28 | 36.106 | -82.11 |
| Savannah | TN | 27 | 35.133 | -88.15 |
| Shady Valley | TN | 28 | 36.5 | -81.85 |
| Warren County | TN | 24 | 35.667 | -85.77 |
| White County | TN | 24 | 35.908 | -85.6 |
| Abilene | TX | 19 | 32.35 | -99.75 |
| Alice | TX | 36 | 27.7167 | -98.1333 |
| Amarillo | TX | 18 | 34.9833 | -101.7 |
| Anzalduas | TX | 36 | 26.2233 | -98.3943 |
| Aransas NWR | TX | 37 | 28.25 | -96.8667 |
| Armand | TX | 37 | 29.55 | -95.05 |
| Attwater | TX | 21 | 29.6833 | -96.2833 |
| Austin | TX | 21 | 30.15 | -97.7 |
| Balcones | TX | 20 | 30.6 | -98.0167 |
| Balstrop | TX | 21 | 30.0833 | -97.25 |
| Beech creek | TX | 25 | 30.7667 | -94.2 |
| Bell County | TX | 21 | 30.9667 | -97.45 |
| Big Spring | TX | 18 | 32.25 | -101.4167 |
| Boerne | TX | 20 | 29.8667 | -98.7833 |
| Bolivar | TX | 37 | 29.55 | -94.4667 |
| Brazoria | TX | 37 | 29.15 | -95.55 |
| Brazos Bend | TX | 37 | 29.3667 | -95.6667 |
| Brownsville1 | TX | 37 | 25.9333 | -97.4667 |
| Brownsville2 | TX | 37 | 25.9333 | -97.45 |
| Buffalo Bayou | TX | 37 | 29.7667 | -95.5667 |
| Buffalo Lake 1 | TX | 18 | 34.8667 | -102.133 |
| Buffalo Lake 2 | TX | 18 | 34.8667 | -102.067 |
| Burnet County | TX | 20 | 30.7667 | -98.2667 |
| Caddo NG | TX | 25 | 33.75 | -96.0667 |
| Calaveras | TX | 21 | 29.2833 | -98.3167 |
| Canadian River | TX | 19 | 35.9217 | -100.273 |
| Cedar Hill | TX | 21 | 32.6167 | -97 |
| Chaparral WMA | TX | 36 | 28.3667 | -99.3333 |
| Choke Canyon | TX | 36 | 28.2333 | -98.3 |
| Coastal Trip | TX | 37 | 26.0333 | -97.2333 |
| College Station | TX | 21 | 30.5833 | -96.3167 |
| Cooper lake | TX | 21 | 33.3333 | -96.6833 |
| Corpus Christi | TX | 36 | 27.8333 | -97.5833 |
| CC Flower Bluffs | TX | 37 | 27.65 | -97.3 |
| Crawford | TX | 21 | 31.55 | -97.3333 |

| Appendix Table A1 (Continued) | | | | |
|---|---|---|---|---|
| Cyprus Creek | TX | 37 | 29.9333 | -95.8167 |
| Dallas County | TX | 21 | 32.8167 | -96.8167 |
| Del Rio | TX | 36 | 29.4333 | -100.95 |
| Falcon Dam | TX | 36 | 26.5 | -99.0833 |
| Fort Worth | TX | 21 | 32.7667 | -97.4667 |
| Freeport | TX | 37 | 29.0167 | -95.35 |
| Galveston | TX | 37 | 29.3333 | -94.8333 |
| Georgetown | TX | 20 | 30.6999 | -97.7395 |
| Gibbons Creek | TX | 21 | 30.5833 | -96 |
| Granger | TX | 21 | 30.7063 | -97.4019 |
| Guadalupe RD | TX | 37 | 28.35 | -96.858 |
| Hagerman NWR | TX | 21 | 33.7833 | -96.7333 |
| Harlingen | TX | 36 | 26.1833 | -97.6667 |
| Houston | TX | 37 | 29.75 | -94.95 |
| Huntsville | TX | 25 | 30.7167 | -95.55 |
| Kerrville | TX | 20 | 30.07 | -99.18 |
| Kingsville | TX | 37 | 27.4667 | -97.85 |
| Le Sal Vieja | TX | 36 | 26.4833 | -97.95 |
| Laguna Atacosta | TX | 37 | 26.25 | -97.3833 |
| Lake Houston | TX | 25 | 29.94 | -95.18 |
| Lake Livingston | TX | 25 | 30.7167 | -95.0833 |
| Lake Meridith East | TX | 18 | 35.6833 | -101.6167 |
| Lake Meridith West | TX | 18 | 35.5167 | -101.7833 |
| Lake O' the Pines | TX | 25 | 32.8 | -94.6 |
| Lake Ray Hubbard | TX | 21 | 32.9167 | -96.5333 |
| Lake Tawakoni | TX | 21 | 32.7667 | -95.9167 |
| Laredo | TX | 36 | 27.5 | -99.4167 |
| Lewisville | TX | 21 | 33.0333 | -96.9833 |
| Longview | TX | 25 | 32.4333 | -94.7 |
| Lubbock County | TX | 18 | 33.5849 | -101.793 |
| Matador WMA | TX | 19 | 34.05 | -100.2 |
| Matagorda | TX | 37 | 28.6833 | -95.9833 |
| McKinney | TX | 21 | 33.1667 | -96.6167 |
| Midland | TX | 18 | 31.95 | -102.0333 |
| Muleshoe NWR | TX | 18 | 33.95 | -102.7667 |
| Nacogdoches | TX | 25 | 31.5167 | -94.65 |
| New Braunfels | TX | 25 | 29.7 | -98.1167 |
| Old River | TX | 37 | 29.8667 | -94.7333 |
| Orange County | TX | 37 | 30.0741 | -93.905 |
| Osage | TX | 25 | 29.7333 | -96.7167 |
| Padre Island | TX | 37 | 27.3333 | -97.3333 |
| Palestine | TX | 25 | 31.7333 | -95.7667 |
| Palmetto | TX | 21 | 29.5833 | -97.5833 |
| Palo Pinto | TX | 21 | 32.7667 | -98.3 |

Appendix Table A1 (Continued)

| | | | | |
|---|---|---|---|---|
| Paris | TX | 21 | 33.75 | -95.5667 |
| Portaransas | TX | 37 | 27.85 | -97.1 |
| Quanah | TX | 19 | 34.3333 | -99.6833 |
| Quitaque | TX | 18 | 34.4333 | -101.083 |
| Robert Lee | TX | 19 | 31.9167 | -100.5 |
| Rockport | TX | 37 | 28.0667 | -97.1167 |
| San Angelo | TX | 19 | 31.4333 | -100.483 |
| San Antonio | TX | 21 | 29.3167 | -98.6333 |
| San Bernard NWR | TX | 37 | 28.8667 | -95.5667 |
| San Jacinto NWR | TX | 25 | 30.74 | -95.24 |
| Santa Anna NWR | TX | 36 | 26.1667 | -98.1833 |
| Sea Rim SP | TX | 37 | 29.7333 | -93.9667 |
| Spring Creek | TX | 25 | 30.1167 | -95.45 |
| Stanton | TX | 18 | 32.0833 | -101.7 |
| Tenaha | TX | 25 | 31.95 | -94.4167 |
| Texarkana TX | TX | 25 | 33.1 | -94.25 |
| Trinidad | TX | 21 | 32.15 | -96.1 |
| Trinity River | TX | 25 | 30.3333 | -94.9167 |
| Turkey Creek | TX | 25 | 30.5167 | -94.3167 |
| Tyler | TX | 25 | 32.2667 | -95.2833 |
| Uvalde County | TX | 36 | 29.2167 | -99.7833 |
| Victoria | TX | 37 | 28.8667 | -97.0833 |
| Village Creek | TX | 21 | 32.7667 | -97.1167 |
| Waco | TX | 21 | 31.5167 | -97.05 |
| Welder wildlife refuge | TX | 37 | 28.1167 | -97.3667 |
| Weslaco | TX | 36 | 26.0909 | -97.5633 |
| West Kerr County | TX | 20 | 30.09 | -99.46 |
| Westcave Prairie | TX | 20 | 30.22 | -98.02 |
| White River | TX | 18 | 33.5 | -101.1 |
| Wichita Falls | TX | 21 | 33.8833 | -98.6333 |
| Wise County | TX | 21 | 33.25 | -97.6667 |

# APPENDIX 2. RANDOM EFFECTS FOR BIRD CONSERVATION REGIONS

Appendix Table A2. Random Effects for Bird conservation Regions

| BCR | RWBL | COGR | EUST | BRBL | RUBL |
|---|---|---|---|---|---|
| **18** | 0.404156 | -1.25323 | -0.20499 | 1.461656 | 0.322483 |
| **19** | 0.697387 | -0.71582 | 0.589428 | 2.161034 | 1.073275 |
| **20** | -0.76804 | -1.53834 | -0.24646 | -0.45052 | -0.33611 |
| **21** | 0.758569 | 1.370799 | -0.00786 | 3.239695 | 1.280641 |
| **22** | -0.3436 | -0.89129 | 0.485351 | -0.37458 | 2.297447 |
| **24** | -1.96838 | -0.11229 | 0.758222 | -1.7486 | 1.596196 |
| **25** | 0.512547 | 1.826208 | -0.70518 | 2.945812 | 2.39042 |
| **26** | 1.40177 | 2.272818 | 0.410435 | 2.512289 | 3.730903 |
| **27** | 0.634639 | 2.096247 | -0.24192 | 2.576523 | 4.055652 |
| **28** | -2.54883 | -1.86024 | 0.188578 | -1.56737 | 1.881965 |
| **36** | 0.400151 | 0.455898 | -0.69317 | 1.079787 | -1.57688 |
| **37** | 1.393851 | 1.322945 | -0.24499 | 2.975156 | 1.017441 |

# APPENDIX 3. RANDOM EFFECTS FOR STUDY YEARS

Appendix Table A3. Random Effects for Study Year

| **Project Year** | **RWBL** | **COGR** | **EUST** | **BRBL** | **RUBL** |
|---|---|---|---|---|---|
| **1** | -0.30902 | -0.03772 | -0.1355 | -0.1022 | 0.131002 |
| **2** | 0.013994 | 0.032674 | -0.05011 | 0.199913 | 0.19168 |
| **3** | 0.099508 | 0.037591 | 0.000386 | 0.07634 | 0.067999 |
| **4** | 0.090749 | 0.034757 | 0.003679 | -0.05992 | -0.00698 |
| **5** | -0.07443 | -0.03629 | 0.005763 | -0.11181 | 0.044943 |
| **6** | 0.097263 | 0.087949 | 0.006369 | -0.02093 | -0.14578 |
| **7** | 0.105971 | -0.02212 | 0.037963 | -0.08065 | -0.10871 |
| **8** | 0.166171 | 0.017749 | 0.11591 | -0.11621 | 0.049371 |
| **9** | -0.19349 | -0.19251 | 0.00782 | -0.13443 | -0.08112 |
| **10** | -0.05335 | -0.02895 | -0.01839 | -0.12365 | -0.14044 |
| **11** | 0.090063 | 0.004448 | 0.037261 | 0.095924 | 0.142725 |
| **12** | 0.087354 | 0.059821 | 0.083698 | 0.096349 | 0.03651 |
| **13** | 0.087812 | -0.01847 | -0.05798 | 0.255071 | -0.01867 |
| **14** | -0.05885 | -0.02134 | 0.0203 | 0.065223 | -0.2172 |
| **15** | -0.04056 | 0.037482 | 0.124817 | 0.001808 | 0.078718 |
| **16** | 0.036332 | 0.063877 | 0.015818 | 0.078322 | 0.136957 |
| **17** | -0.02038 | 0.005744 | 0.077583 | -0.01055 | -0.09572 |
| **18** | 0.041373 | 0.035052 | -0.12103 | 0.011605 | 0.154064 |
| **19** | 0.015225 | 0.05505 | -0.00989 | 0.02528 | 0.064558 |

| Appendix Table A3 (Continued) | | | | | |
|---|---|---|---|---|---|
| **20** | -0.12801 | -0.06822 | -0.04664 | -0.03463 | 0.075474 |
| **21** | -0.04658 | -0.03415 | -0.09521 | -0.00611 | -0.06866 |

# APPENDIX 4. RANDOM EFFECTS FOR CHRISTMAS BIRD COUNT SITES

| Appendix Table A4. Random Effects for Christmas Bird Count Sites | | | | | |
|---|---|---|---|---|---|
| **Site Name** | **RWBL** | **COGR** | **EUST** | **BRBL** | **RUBL** |
| Birmingham | 3.997517 | 4.987289 | 0.370592 | 1.249959 | 2.438015 |
| Cullman | 2.568988 | 3.498548 | 0.369447 | 0.98241 | 0.480092 |
| Dauphin Island | -1.39148 | -0.42732 | 0.187856 | 0.264169 | -2.7456 |
| Eufala NWR | 0.819677 | 0.547408 | -1.14446 | -0.75168 | 1.861569 |
| Ft. Morgan | -1.9249 | -1.98974 | -0.98773 | -1.03982 | -2.51785 |
| Gulf Shores | 1.242968 | 0.036359 | 0.161946 | -1.59651 | -2.88482 |
| Guntersville | 2.925425 | 3.877866 | 1.150678 | 1.016401 | 3.190906 |
| Mobile-Tenshaw | 0.809578 | -1.94104 | 0.561435 | -0.87108 | -1.83072 |
| Montgomery | 1.666662 | 1.160889 | 1.966893 | 1.329708 | 2.04207 |
| Perdido Bay | -0.4728 | 0.966874 | 0.194336 | 0.404238 | -3.32996 |
| Tuscaloosa | 0.887866 | 0.574581 | 0.853114 | 1.332434 | 0.981804 |
| Waterloo | 0.210013 | 0.416139 | 0.411251 | -1.95605 | 0.997817 |
| Wheeler NWR | 3.580401 | 3.481206 | 0.562307 | 5.333348 | 4.827537 |
| Arkadelphia | 1.564551 | 0.854977 | -0.14622 | 0.992507 | 1.795465 |
| Bayou DeView | -0.30365 | 0.74786 | -0.72714 | -0.97172 | 1.212185 |
| Big Lake | 0.675269 | 0.370628 | 2.139699 | -1.5462 | 0.815916 |
| Buffalo NRE | -1.91394 | -2.44369 | -2.27557 | -1.35429 | -0.66531 |
| Conway | -1.91461 | 0.724967 | 1.130116 | -1.36347 | 0.10916 |
| Crooked Creek | -0.93316 | -1.92224 | -0.41424 | -1.25299 | -0.78521 |
| Fayetteville | 1.647899 | 0.885859 | 0.816298 | 3.067962 | 2.260388 |
| Fort Smith | 2.998314 | 2.868971 | 0.206748 | 0.57766 | 1.283185 |
| Holla Bend | 2.132651 | 1.311754 | 0.909924 | -0.22129 | 2.19515 |
| Hot Springs Village | -3.62499 | -3.44559 | -1.68583 | -2.24008 | -1.92737 |
| Jonesboro | 0.119821 | 0.749292 | 0.668197 | -4.13883 | -1.14921 |
| Lake Georgia | -0.44437 | 0.668977 | -0.12434 | 2.448295 | 1.143423 |
| Lake Village | -0.58262 | -0.11545 | 0.049787 | 0.716341 | 0.279503 |
| Little Rock | 0.865469 | 1.393206 | 1.186416 | -1.59099 | 0.826891 |
| Lonoke | -0.0654 | 0.057099 | 0.267978 | 0.912702 | -0.80438 |
| Magnolia-Lake | 1.713036 | 1.237118 | 0.920777 | 2.344968 | 0.944278 |
| Mena | -1.81365 | -0.98332 | 0.23255 | 1.410839 | -1.8613 |
| Monuntain Home | 0.129733 | 0.190446 | -0.07834 | 2.159382 | -0.56229 |
| North Fork | -2.16574 | -2.70045 | -3.82954 | 0.092895 | -0.63333 |
| Pine Bluff | -0.19198 | 0.073077 | 0.325684 | 0.966938 | -1.30902 |
| Texarkana | 1.231056 | 1.23644 | 0.486401 | 4.708185 | 1.68218 |
| VanBuren | -1.40922 | -0.22548 | -1.40921 | 1.522132 | -1.32289 |
| Village Creek | -0.86249 | -2.132 | 0.562331 | -1.71473 | -2.74962 |
| Wapanocca | -1.42035 | 1.141011 | 0.364159 | -3.66921 | 1.59726 |
| White River | 1.157067 | 1.241794 | 0.319384 | 2.325357 | 0.314739 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Arkansas city | 2.354513 | 2.128025 | 2.060759 | 3.107648 | 3.718168 |
| Baldwin | 0.60148 | -1.43602 | 0.444521 | -0.37933 | 0.149036 |
| Cedar Bluff | 0.237491 | -2.68714 | 1.211314 | -2.4802 | 0.942596 |
| Cimmaron NG | 0.132743 | -0.41611 | -0.13397 | -3.27256 | -0.2966 |
| Dodge City | -2.73715 | 1.901004 | -0.00223 | -2.56266 | -2.52505 |
| Emporia | 0.939935 | -0.17237 | 0.846927 | 1.479459 | 0.787467 |
| Halstead-Newton | 0.091342 | -2.8519 | 0.229395 | -1.43098 | 0.397624 |
| Jetmore | -1.04546 | -0.42191 | -0.37947 | -3.25019 | -0.93254 |
| Kirwin Resivoir | -0.88862 | -2.11876 | -0.4945 | -3.60087 | -1.62846 |
| Lawrence | 0.557707 | -0.97173 | 0.483193 | -1.1967 | 0.739903 |
| Liberal-Seward | 2.940532 | 1.678879 | 4.302436 | -1.70895 | 1.96414 |
| Linn county | 1.71173 | 0.542658 | 0.096337 | 0.760652 | 2.176283 |
| Olathe | -1.60963 | -1.65078 | 0.428815 | -0.95183 | -1.73579 |
| Oskaloosa | -0.01616 | -1.83421 | -0.08523 | 0.565355 | 0.655318 |
| Parsons | 0.791427 | -0.6357 | -0.48267 | 2.054501 | 0.713793 |
| Quivira NWR | 4.501881 | 2.330937 | 0.06711 | -0.56618 | 0.841693 |
| Red Hill | -0.40802 | -0.15961 | -0.3692 | 1.926468 | -0.20812 |
| Reno County-Yoder | 0.728594 | -1.016 | -0.07457 | -2.2148 | -0.58842 |
| Salina | -1.12722 | -0.95505 | 0.663421 | -0.80361 | 0.651538 |
| Scott Lake | -1.07672 | -0.89991 | 0.682708 | -2.75687 | -1.95182 |
| SE Minedland | 0.867389 | 0.873645 | -0.05474 | 2.310313 | 1.548608 |
| Topeka | -1.84731 | -2.57184 | 0.078275 | 1.131461 | -2.12661 |
| Udall-Winfield | 3.056187 | 1.001342 | 1.5914 | 5.179212 | 4.287965 |
| Wakonda Lake | 0.31301 | -2.17227 | 0.737547 | -2.83097 | 0.079893 |
| Webster | 0.675146 | -1.72645 | 0.140051 | -1.15365 | 1.955539 |
| Wichita | -0.32808 | 0.402895 | 0.662779 | -0.3418 | -2.16577 |
| Wilson Resivoir | 0.399905 | 0.873597 | 0.353554 | -0.30218 | 2.062536 |
| Ashland | -1.1683 | -1.17212 | 0.302029 | -0.04608 | -0.96091 |
| Bowling Green | -0.32235 | -0.07506 | 0.784057 | -1.08396 | 0.32043 |
| Breaks Interstate park | -1.78216 | -1.34327 | -2.5869 | -0.66443 | 0.164638 |
| Calloway | 0.926623 | 1.128775 | 0.346858 | -0.36279 | 0.040471 |
| Danville | -3.53206 | -0.04137 | 0.683242 | 0.270678 | -0.85413 |
| Daviess County | -0.27517 | 3.284969 | 0.492306 | -0.68806 | -0.55999 |
| Evansville | 1.533035 | 2.270802 | 0.660481 | 2.697347 | 1.679534 |
| Frankfort | -4.56055 | -4.33315 | -0.00442 | -1.34742 | -1.87896 |
| Hopkinsville | 0.569018 | 0.884481 | 0.682786 | -1.58159 | -2.17955 |
| Kleber WMA | -2.5556 | -3.60003 | -0.13499 | -1.05228 | -2.41496 |
| Land Between the Lakes | 1.202601 | 0.550514 | -0.60512 | 1.264449 | 0.969834 |
| Lexington | -3.57184 | -3.38666 | 0.541981 | 0.104985 | -2.06286 |
| Lincoln's Birthplace | -2.64904 | -0.69841 | 0.247015 | -0.8529 | 0.267134 |
| London | -1.8942 | -1.56564 | 0.982446 | -0.2196 | -0.73269 |
| Louisville | -1.3728 | -2.33183 | 0.861182 | -0.51982 | 0.191449 |
| Otter Creek park | -1.59709 | -2.78418 | -0.1509 | -1.02041 | 1.56068 |
| Red Bird | -3.05503 | -3.53152 | -3.32884 | 1.938218 | -1.70052 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Somerset | -1.11661 | 2.463772 | 1.444277 | -1.16475 | -0.63134 |
| Wayne County | -1.28638 | 1.113824 | 1.252059 | -0.45192 | 1.81434 |
| Baton Rouge | 1.209039 | 0.19825 | 0.097754 | 1.930192 | 1.008081 |
| Bogue Chitto | -0.72211 | -0.3688 | -0.93972 | 0.319003 | 1.275201 |
| Bossier Cado | 2.182266 | 1.257177 | 1.190763 | 3.506323 | 2.953759 |
| Butte la Rose | 1.911507 | 1.117746 | 0.535105 | 2.749361 | 1.25965 |
| Catahoula | -0.64975 | -1.40412 | -1.38634 | 1.614853 | -0.29219 |
| Cheneyville | 0.787579 | -0.26302 | -0.5766 | 2.829072 | 1.237172 |
| Clairborne | -1.39836 | -1.05156 | -1.10924 | -1.58639 | -0.41541 |
| Creole | 0.867331 | 0.349662 | 2.263088 | 5.276158 | 2.531804 |
| Crowley | 3.897316 | 0.356537 | 0.268716 | -0.17765 | 1.750661 |
| D'Arbonne | -0.27428 | -1.21775 | -1.3039 | 0.362535 | -0.4213 |
| Fort Polk | -1.18717 | -2.67917 | -0.74566 | -1.76383 | -0.53292 |
| Grand Isle | -2.46597 | -1.20357 | 1.308748 | -1.3713 | -0.69228 |
| Houma | 0.448646 | 0.610474 | 0.836386 | -1.77103 | -1.9932 |
| Johnson's Bayou | 0.504617 | -1.75874 | 0.836208 | -1.03528 | -1.10348 |
| Lassicine | 3.70752 | 1.642995 | 0.760445 | -4.63919 | 0.560886 |
| Lafayette | 2.778541 | 1.23197 | 0.82396 | -1.51093 | 0.819772 |
| Lake Charles | -0.87241 | 1.1787 | -0.91727 | 1.145204 | -0.83756 |
| Lake Ophelia | -0.08921 | -1.21998 | -1.05954 | -2.43864 | -1.851 |
| Natchez | -0.08308 | -0.82165 | -0.5696 | 0.640936 | -1.48173 |
| Natchitoches | 0.812247 | 1.161134 | 0.046457 | 1.594793 | 0.841893 |
| New Iberia | 2.759109 | 1.707608 | 0.650403 | 2.478485 | -0.7217 |
| New Orleans | -0.82089 | 1.486976 | 1.269339 | -1.4166 | 0.670523 |
| Northshore-Slidell | -0.56702 | -0.99239 | -0.66613 | -0.57785 | -1.38339 |
| Pine Prairie | 5.168614 | 3.678057 | 3.676936 | 3.50135 | 2.599498 |
| Reserve-Bonnet | -0.1522 | 0.601502 | 0.522685 | -0.56445 | 1.452211 |
| Sabine | -0.07278 | 0.903276 | 1.163725 | -0.54509 | 1.777119 |
| Shreveport | 1.503752 | 2.108675 | 0.400817 | 0.436292 | 2.3704 |
| St. Tammany | 0.087973 | -0.23524 | -1.11369 | 1.570653 | 2.946904 |
| Tensas River NWR | 1.057243 | 1.718166 | 0.065588 | 2.705613 | 2.369405 |
| Thibodaux | 0.060352 | -0.82555 | 0.323984 | 0.592804 | -1.83588 |
| Tunica | 0.206384 | 0.504934 | -0.10481 | -2.33627 | 2.092517 |
| Venice | -1.04154 | 1.41068 | 0.619855 | -0.57818 | -0.58327 |
| Big Oak Tree | -0.95143 | -0.84828 | 0.832545 | -1.76268 | 1.201884 |
| Big Spring | -2.54522 | -3.81294 | -2.64197 | -0.52134 | -2.11758 |
| Clarence Cannon | 0.702747 | 0.768019 | 0.574341 | 1.191093 | 1.860218 |
| Columbia | 0.932813 | 0.467128 | 0.105283 | 0.015698 | -1.01779 |
| Confluence | -0.77156 | -0.41934 | 0.015183 | -0.08644 | -0.98864 |
| Dallas county | 0.918842 | -2.38457 | 0.500112 | -1.07388 | 0.19151 |
| Diamond Grove | 0.330774 | -0.3809 | -0.24859 | -0.60616 | -0.85821 |
| Grand River | -0.07971 | -3.01489 | -0.69627 | -2.19902 | -0.11 |
| Hannibal | -3.30997 | 0.327803 | 0.429889 | -0.89423 | -1.8289 |
| Horton | 1.631265 | 1.454712 | -0.37171 | -0.66156 | 2.846797 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Jackass Bend | -1.88615 | -1.03848 | 0.487631 | -1.28341 | -0.62132 |
| Jefferson City | 1.166143 | -0.23088 | -0.13325 | -1.17427 | -0.36601 |
| Joplin | 1.203284 | 0.093266 | 0.484949 | -1.22833 | 1.546752 |
| Kansas City | -1.17849 | -2.50162 | 0.011044 | -0.07633 | -2.81794 |
| Keokuk | -2.95626 | -1.46821 | 0.652505 | -0.7498 | -2.18898 |
| Knob Knoster | -0.80983 | 0.964925 | -0.11924 | -2.64602 | -3.56612 |
| Laclede County | -1.80893 | -1.18812 | 0.771775 | -1.08178 | -2.49905 |
| Liberal | 1.907696 | 0.136835 | -0.39671 | 2.179065 | 1.974056 |
| Maramec Springs | -1.39165 | -0.92986 | -0.69906 | -1.07207 | -0.75338 |
| Maryville | -2.05076 | -2.90286 | -0.97793 | -1.62469 | -0.90189 |
| Mingo | -1.59779 | -1.9746 | -0.52544 | -0.52922 | 0.869033 |
| Montrose | 1.042945 | 1.753953 | 0.482048 | -1.42297 | -0.50325 |
| NCCC | -0.49298 | -0.23992 | -0.13703 | -2.75243 | -0.02931 |
| Orchard Farm | 0.544936 | 1.663241 | 0.61618 | -1.79703 | 2.99813 |
| Patterson | -2.69134 | -3.3312 | -1.85835 | -0.359 | -1.51385 |
| Poplar Bluff | 0.976471 | 0.212638 | 0.721125 | -1.14048 | 0.26788 |
| Springfield | -1.14644 | 0.195418 | 0.600233 | 0.524393 | -0.86876 |
| Squaw Creek | 0.663455 | 1.547092 | -0.74607 | -1.55754 | -1.19668 |
| St. Joseph | -1.21462 | -1.10307 | 0.229604 | -2.2288 | -2.25075 |
| Sullivan | -0.38122 | -1.35213 | -1.22255 | -0.54269 | -0.13983 |
| Swan Lake | -0.68867 | -0.40616 | -0.61215 | 0.142647 | 0.57551 |
| Taney | 1.264962 | 0.39501 | 0.868728 | -1.00087 | 0.308915 |
| Ted Shanks | -0.41194 | 0.006943 | -0.19681 | -1.26256 | -1.26687 |
| Trimble | -0.2805 | -1.09043 | -0.05327 | -1.08189 | 0.111669 |
| Union County | 3.217542 | 2.800512 | -0.30138 | 0.269976 | 3.415795 |
| Weldon Spring | 0.374289 | 0.809879 | -0.08593 | -2.36254 | -1.3163 |
| Arkabutla | 0.707393 | 2.091259 | 1.115481 | -2.07004 | -0.08034 |
| Church Hill | -0.5306 | -1.03118 | -1.99708 | -0.91941 | 0.192928 |
| Corinth | -4.26592 | -0.62483 | -0.23026 | 3.239312 | -0.98446 |
| Dahomey | -0.08506 | 0.230662 | -0.83952 | 3.504522 | 1.254054 |
| Eagle lake | 2.827993 | 0.324972 | 0.043346 | -2.99636 | 1.595429 |
| Grenada | 0.095839 | 1.875117 | 0.027835 | 1.471872 | 1.327091 |
| Hattiesburg | -0.93186 | -1.16525 | -0.58725 | 0.716854 | 0.036602 |
| Jackson | 1.889786 | 1.706557 | -0.10868 | 1.256816 | 0.460813 |
| Jackson County | -0.3818 | -0.37392 | -0.10309 | 2.181056 | -0.97588 |
| Lauderdale County | -0.55629 | -0.69955 | -1.22951 | 1.868067 | 0.512128 |
| Moon lake | -1.23982 | -0.1308 | 0.895893 | -1.45346 | 1.981651 |
| Noxubee | 0.164068 | 0.761848 | -0.66745 | 2.266304 | 1.052385 |
| Pearl River | -2.14911 | -2.27641 | -1.26134 | 2.65985 | 5.095245 |
| Sardis | 0.246298 | 1.791658 | -0.40547 | -1.00191 | 1.156044 |
| South Hancock | -1.08523 | -0.26107 | -0.20085 | 2.585283 | 3.290035 |
| Sumner | 0.14668 | 1.12403 | 0.505186 | 0.855389 | -0.56098 |
| Tupelo | -1.58851 | -1.63595 | -0.8578 | 1.485307 | -0.2779 |
| Vicksburg | 0.311841 | 0.721448 | -0.14654 | -1.33862 | 1.101816 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Washington County | 0.01259 | 0.746888 | 0.092187 | 0.587238 | 0.371234 |
| Arcadia | 0.624103 | 0.494597 | 0.979752 | -2.80254 | -0.57158 |
| Arnett | 0.28448 | -2.39104 | -1.14157 | 1.121092 | 1.792347 |
| Broken Bow | 0.207653 | 0.409974 | 0.128282 | -1.30657 | 1.084999 |
| Fort Gibson | 1.387202 | 1.873281 | 0.175098 | 3.904211 | 2.038612 |
| Hulah | 0.974782 | -3.28775 | -0.88214 | -0.45387 | 2.315355 |
| Kenton | -0.63078 | -1.47766 | -1.05159 | -5.37379 | 0.19304 |
| Lake Atoka | 0.175493 | -0.62399 | -0.63967 | 1.555269 | 0.308779 |
| Norman | 0.528222 | -0.53365 | 0.699095 | -3.21484 | -1.10574 |
| Oklahoma City | 0.673883 | 1.816789 | 0.964763 | -0.4889 | -2.33391 |
| Rogers County | 1.680675 | 3.444496 | 1.058193 | 3.587431 | 3.067932 |
| Salt Plains | 1.074541 | 0.020467 | -0.51758 | 2.439877 | -1.08665 |
| Sequoyah | 1.692311 | -0.35074 | 0.584149 | -0.93292 | 2.38373 |
| Sooner lake | 2.005041 | 3.21045 | 0.46671 | 2.782316 | 3.806947 |
| Spavinaw | -0.66662 | -1.71584 | -0.86222 | 1.472123 | -0.55837 |
| Stephen County | -0.55829 | -1.90283 | -0.37288 | 2.022787 | 1.291083 |
| Stillwater | -1.02668 | 1.34623 | -0.00873 | 3.144231 | -0.0943 |
| Tallgrass | -0.50493 | 0.407709 | -3.49354 | 2.013218 | 0.34202 |
| Tishimingo | 0.079502 | 0.592902 | -1.11222 | -1.73871 | 1.969869 |
| Tulsa | 2.93239 | 4.29385 | 1.77923 | 2.269919 | 3.577504 |
| Washita | 0.77503 | 0.697427 | -0.00339 | 3.433427 | 0.652777 |
| Wichita Mountains | -3.03898 | -2.73271 | -2.56645 | 0.292531 | -1.84355 |
| Bristol | -2.20522 | -1.36184 | 1.088924 | 0.26792 | -1.22739 |
| Buffalo River | 2.061931 | 0.853103 | -0.02087 | 2.439373 | 0.488349 |
| Cades Cove | -1.75208 | -3.33154 | -1.04009 | -0.72232 | -1.0637 |
| Cahtanooga | 1.779927 | 2.65179 | 0.743769 | -0.77876 | 2.868652 |
| Clarksville | 0.419275 | 0.569596 | 0.342797 | -1.33074 | -0.86801 |
| Clay County | 0.49038 | 0.380946 | 0.003564 | -0.77084 | -0.7207 |
| Columbia | 0.91799 | 2.378381 | 1.187341 | -1.44975 | 2.010031 |
| Cookeville | -0.16323 | 2.54682 | 1.199505 | 0.44518 | 0.369977 |
| Cross Creek | 3.232911 | 1.854877 | -0.97997 | -1.13364 | 2.0414 |
| Crossville | -1.92817 | -1.8824 | 0.713742 | -0.65903 | 1.565032 |
| DeKalb | 2.033045 | 1.806823 | 0.808787 | -0.60668 | -1.54265 |
| Dresden | -0.08642 | 1.351214 | 1.115937 | -2.26325 | -1.31931 |
| Elizabethton | -2.75847 | -3.17309 | 0.810223 | -1.09177 | -2.05745 |
| Fayette County | -0.71526 | -0.65619 | -0.69388 | -3.3174 | 1.263986 |
| Franklin Coffee | 0.913699 | 1.847585 | 0.668109 | -0.54087 | -0.80509 |
| Great Smokey Mountain | -2.07913 | -4.35792 | -1.31465 | 0.334801 | -2.18484 |
| Hickory-Preist | 1.893965 | 0.855052 | 1.174831 | -0.44373 | 2.763041 |
| Hiwassee | 2.71803 | 1.683249 | 0.410456 | -0.28073 | 1.775516 |
| Jackson | 2.163974 | 2.815695 | 2.510729 | 0.526968 | 0.482148 |
| Kingsport | -0.80519 | 1.667551 | 0.332912 | -0.43463 | 0.004038 |
| Knoxville | 0.233661 | -0.19789 | 1.037208 | -1.05006 | -0.61345 |
| Memphis | 1.585825 | 0.376713 | -0.11189 | 0.20644 | 2.697419 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Nashville | 1.497763 | 1.492751 | 0.59997 | 0.262248 | -0.33641 |
| Nickajack Lake | 3.475834 | 4.246039 | 0.502938 | 0.184301 | 3.575544 |
| Norris | -1.51693 | -1.00098 | 0.465632 | -1.18215 | -0.20025 |
| Reelfoot Lake | 1.110651 | 2.067832 | 1.802434 | 0.482618 | 1.747196 |
| Roan Mountain | -1.91875 | -1.94961 | -0.29854 | -0.76834 | -1.41354 |
| Savannah | 1.551177 | 0.447941 | 0.995213 | 1.558785 | 2.791009 |
| Shady Valley | 0.53734 | -1.34302 | 0.208023 | -0.69414 | 0.210544 |
| Warren County | -1.7536 | 1.318246 | 1.351805 | 0.349385 | 0.94162 |
| White County | 0.269468 | 0.323158 | 0.995768 | 0.841258 | 1.475098 |
| Abilene | -0.8726 | 2.113343 | 0.539536 | -2.42545 | -1.64309 |
| Alice | -3.75158 | -3.02726 | -1.45863 | -2.04959 | -0.00411 |
| Amarillo | 1.418876 | -1.4789 | 0.086801 | -2.01412 | -1.02204 |
| Anzalduas | 0.964197 | 2.447767 | 0.030748 | -0.43925 | -0.56109 |
| Aransas NWR | -0.97326 | -0.70088 | -4.18816 | 0.049418 | -0.38329 |
| Armand | -2.80795 | 0.070067 | 0.469366 | -0.72902 | -0.97372 |
| Attwater | 1.539463 | 1.416367 | -0.8971 | 1.172685 | -1.1286 |
| Austin | 1.111418 | 0.766181 | 1.344942 | 2.323807 | 0.65936 |
| Balcones | 0.304649 | -2.32285 | -1.14168 | 0.6311 | -0.79843 |
| Balstrop | -0.73808 | 0.585667 | -1.33576 | 1.290012 | -1.27408 |
| Beech creek | -0.81799 | 0.028075 | -1.61275 | -0.8843 | -1.66634 |
| Bell County | -0.73386 | 1.096046 | 0.408511 | 1.438881 | -0.7985 |
| Big Spring | -1.7253 | 0.887108 | -0.37579 | 3.131068 | -0.32347 |
| Boerne | -0.27725 | -1.27756 | -0.7377 | -1.01279 | 1.798387 |
| Bolivar | 0.533753 | 0.363267 | 0.721253 | 0.32627 | -0.20142 |
| Brazoria | 1.065931 | 1.99976 | -0.45768 | 0.040749 | -1.54629 |
| Brazos Bend | 1.239018 | 1.03579 | -0.34871 | 0.104842 | -1.08841 |
| Brownsville1 | -1.65772 | -5.12222 | -0.97795 | -2.54862 | -0.2454 |
| Brownsville2 | -1.36345 | -4.15402 | -2.02326 | -0.49228 | -0.32076 |
| Buffalo Bayou | -1.25097 | -0.02508 | 0.060022 | 1.536945 | 2.036279 |
| Buffalo Lake 1 | 0.284172 | -1.21706 | 0.33553 | 0.85765 | -0.27428 |
| Buffalo Lake 2 | 0.771439 | 1.04233 | 0.079882 | 1.159757 | -0.82041 |
| Burnet County | 0.595033 | -0.81669 | -0.05899 | 3.027489 | -0.82371 |
| Caddo NG | 0.743096 | 2.188505 | 1.077016 | 0.264125 | -0.84191 |
| Calaveras | 1.25963 | -0.13354 | -0.54733 | -0.28804 | -0.52749 |
| Canadian River | 1.105253 | 2.255627 | 0.102854 | 1.049331 | 1.940783 |
| Cedar Hill | 0.962141 | -0.71498 | 0.740323 | -0.23807 | -0.96459 |
| Chaparral WMA | -2.61941 | -4.01422 | -0.91899 | 2.928706 | -0.07244 |
| Choke Canyon | 1.376932 | -0.26832 | -0.56038 | 1.016235 | -0.083 |
| Coastal Trip | -1.14615 | -4.84519 | -0.85455 | 0.399829 | -0.06368 |
| College Station | -1.59009 | 1.165855 | 0.640007 | -0.89413 | 0.147323 |
| Cooper lake | 0.695097 | 1.143339 | 0.041931 | 0.563953 | 1.349515 |
| Corpus Christi | 0.70726 | 2.747832 | -0.0211 | 1.651691 | -0.51083 |
| CC Flower Bluffs | 0.826929 | 2.876494 | 0.347435 | -1.59156 | 0.184168 |
| Crawford | -0.37366 | 0.233104 | 0.704353 | 1.083165 | 0.330591 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Cyprus Creek | -0.06086 | 0.240884 | -0.10211 | 1.893734 | 1.30529 |
| Dallas County | -0.1318 | -0.27382 | 0.426234 | 1.693557 | -0.00192 |
| Del Rio | 0.228158 | 3.830983 | 0.657398 | 3.211947 | -0.03269 |
| Falcon Dam | 0.751949 | 3.789219 | -1.24526 | -3.38727 | -0.02242 |
| Fort Worth | -0.1713 | 0.193826 | -0.33165 | 2.606669 | -0.56902 |
| Freeport | 0.299125 | 1.805557 | -0.05769 | 3.447578 | -1.03544 |
| Galveston | -2.51152 | 0.470994 | 1.252397 | -2.88135 | 0.272822 |
| Georgetown | 1.012559 | 2.795818 | 0.519881 | 2.212489 | -0.08052 |
| Gibbons Creek | -2.27703 | -0.90931 | -2.36155 | -2.92112 | 0.247757 |
| Granger | 0.078356 | 1.848701 | -1.23781 | 1.96516 | -1.65479 |
| Guadalupe RD | 1.407263 | 1.25162 | -0.72563 | 2.553664 | -0.39464 |
| Hagerman NWR | -0.29196 | -0.03558 | 0.361649 | 0.636328 | -0.76812 |
| Harlingen | 0.756615 | 3.998649 | 1.549782 | -0.37063 | -0.61294 |
| Houston | -0.94541 | 1.568247 | 0.01391 | 0.384233 | -0.53448 |
| Huntsville | -2.33088 | -2.11881 | 0.545693 | 0.170989 | -2.87483 |
| Kerrville | 0.219304 | 1.08949 | 0.676525 | -1.96859 | -0.39624 |
| Kingsville | -0.22237 | 2.883571 | 0.24555 | 2.033041 | -1.40374 |
| Le Sal Vieja | 2.017925 | 2.188913 | -1.25693 | 1.215482 | -0.37001 |
| Laguna Atacosta | -0.96321 | 2.185249 | -1.95942 | -3.1965 | -0.49149 |
| Lake Houston | 1.493828 | 0.564449 | 0.24165 | -0.58537 | -1.28035 |
| Lake Livingston | -0.45333 | -0.29741 | 0.127709 | 1.162596 | 1.076918 |
| Lake Meridith East | -0.35691 | 0.665819 | 1.070771 | 0.020503 | -0.0587 |
| Lake Meridith West | 1.210541 | 0.009635 | -0.22731 | 0.529951 | -0.18357 |
| Lake O' the Pines | 0.036324 | 0.607203 | -1.02435 | -3.0087 | -3.12031 |
| Lake Ray Hubbard | 0.160157 | -0.02209 | 1.0321 | 1.30057 | -0.17914 |
| Lake Tawakoni | -0.38782 | 0.279991 | -0.16738 | 1.060523 | 1.822493 |
| Laredo | -0.52597 | 3.30854 | -1.17806 | -3.86183 | -0.01598 |
| Lewisville | -0.13503 | 0.332385 | 0.816637 | -0.66739 | -0.58855 |
| Longview | 2.233289 | 2.223659 | 0.637433 | -0.86273 | 2.308935 |
| Lubbock County | 0.79702 | 4.828021 | 1.132181 | 1.372997 | 0.383964 |
| Matador WMA | -2.19134 | -2.19286 | -0.79595 | 2.609181 | -0.08975 |
| Matagorda | 4.306458 | 3.313586 | 0.584843 | 5.976149 | -0.21472 |
| McKinney | 0.782497 | 1.354843 | 0.840599 | 0.011652 | 1.574019 |
| Midland | 1.024398 | 1.758789 | 0.173102 | 4.89064 | -0.43591 |
| Muleshoe NWR | -3.97683 | -3.24703 | -4.55032 | -0.20598 | 0.890724 |
| Nacogdoches | 2.100888 | 0.777422 | -0.26557 | -2.61318 | 1.448336 |
| New Braunfels | 0.198743 | 1.134108 | 1.10273 | 3.130366 | -1.75962 |
| Old River | 0.993726 | 0.9883 | -0.28685 | 1.600217 | 0.694369 |
| Orange County | -0.69527 | 0.900423 | -0.28085 | -2.03941 | -1.12254 |
| Osage | -1.76531 | -0.5655 | -1.56965 | -1.63228 | -0.58808 |
| Padre Island | -1.04829 | -2.67269 | -1.95789 | -1.20899 | -0.07238 |
| Palestine | 0.315285 | 0.412549 | -0.9242 | 2.092377 | 0.302861 |
| Palmetto | 0.455975 | 0.647312 | -1.1363 | 0.892274 | 0.013414 |
| Palo Pinto | -0.03885 | -3.23484 | -1.0769 | -3.99274 | -1.16122 |

| Appendix Table A4 (Continued) | | | | | |
|---|---|---|---|---|---|
| Paris | -4.18618 | -0.86429 | -1.52232 | -0.36992 | 1.116789 |
| Portaransas | -0.84643 | -5.3259 | 0.000496 | -1.88129 | -0.8823 |
| Quanah | 0.333703 | -0.47786 | 0.519259 | 3.586083 | -0.26513 |
| Quitaque | -0.1926 | -2.21053 | -0.50427 | -0.8618 | -0.39506 |
| Robert Lee | -1.28011 | -3.66168 | -0.29538 | -2.44057 | -0.1813 |
| Rockport | -0.65519 | -3.83593 | 0.647581 | 2.224244 | -1.02065 |
| San Angelo | 0.656423 | 5.083753 | 0.80553 | 5.010499 | -0.9078 |
| San Antonio | 0.876451 | -1.5688 | 0.082919 | 1.181262 | -1.36055 |
| San Bernard NWR | 0.107203 | 1.854388 | 0.008614 | 2.75466 | -0.65517 |
| San Jacinto NWR | 0.599361 | -1.01675 | -0.79843 | 1.370241 | -1.14478 |
| Santa Anna NWR | 1.57646 | -5.90679 | -0.33 | 1.531103 | -0.85487 |
| Sea Rim SP | -0.36545 | -0.36386 | 0.097059 | -2.00587 | 0.330178 |
| Spring Creek | -0.14327 | -1.20566 | 0.021969 | 0.277852 | -2.74624 |
| Stanton | -0.47102 | -0.69425 | -1.10194 | 4.567561 | -0.0552 |
| Tenaha | 1.53561 | 1.018813 | -1.05269 | -1.21541 | 1.380837 |
| Texarkana TX | -1.9975 | 0.252369 | -0.39035 | 0.45094 | 0.688964 |
| Trinidad | 1.71538 | 2.761867 | 0.420724 | 3.09827 | 1.202541 |
| Trinity River | -2.12941 | -0.7764 | -1.11845 | -0.0128 | -1.20457 |
| Turkey Creek | -4.13012 | -2.9991 | -2.85167 | -2.03701 | -0.44181 |
| Tyler | 1.343493 | 0.922237 | 0.812175 | 2.044533 | 1.395122 |
| Uvalde County | -1.07025 | -1.80927 | 1.65842 | 1.721971 | -0.04366 |
| Victoria | -0.53943 | 1.750195 | 0.350614 | 1.89677 | 0.817087 |
| Village Creek | 0.815127 | -2.18215 | -0.16362 | -2.32936 | 1.863593 |
| Waco | 0.482841 | 1.495834 | 1.055606 | 1.573783 | -0.20386 |
| Welder wildlife refuge | -0.76133 | -4.96895 | -3.64647 | -4.9117 | -1.54697 |
| Weslaco | 0.314118 | -6.40415 | -0.3087 | -1.36495 | -0.26658 |
| West Kerr County | -1.64395 | -0.54894 | -0.1767 | -2.44517 | -0.12968 |
| Westcave Prairie | -1.60457 | -1.89506 | -0.28369 | -1.19706 | -0.3053 |
| White River | 0.584104 | -1.65339 | -0.91831 | 2.105406 | 3.090869 |
| Wichita Falls | -0.2434 | 0.779071 | 1.670562 | -1.58613 | -1.7982 |
| Wise County | 0.09324 | 1.127437 | 0.840666 | 0.992926 | 1.554652 |

# APPENDIX 5. NOTATION AND FORMULA FOR THE COMPUTATION OF LINEAR MIXED-EFFECT MODELS

Notation:

- $y_{ij}$ the value of the response variable for the jth of $n_i$ observations in the ith of M groups or clusters.
- $\beta_1, \ldots, \beta_p$ are the fixed-effect coefficients, which are identical for all groups.
- $x_{1ij}, \ldots, x_{pij}$ fixed-effect regressors for observation j in group i; the first regressor is usually for the constant, $x_{1ij} = 1$.
- $b_{i1}, \ldots, b_{iq}$ random-effect coefficients for group i, assumed to be multivariately normally distributed.
- $z_{1ij}, \ldots, z_{qij}$ random-effect regressors.
- $\psi^2_k$ are the variances and $\psi_{kk'}$ the covariances among the random effects, assumed to be constant across groups.
- $\varepsilon_{ij}$ is the error for observation j in group i which are assumed to be multivariately normally distributed.
- $\sigma^2\lambda_{ijj}$ are the covariances between errors in group i. Generally, the $\lambda_{ijj}$ are parameterized in terms of a few basic parameters, and their specific form depends upon context.

$$
\begin{aligned}
(1)\qquad y_{ij} &= \beta_1 x_{1ij} + \cdots + \beta_p x_{pij} \\
&\quad + b_{i1} z_{1ij} + \cdots + b_{iq} z_{qij} + \varepsilon_{ij} \\
b_{ik} &\sim N(0, \psi^2_k),\ \mathrm{Cov}(b_k, b_{k'}) = \psi_{kk'} \\
\varepsilon_{ij} &\sim N(0, \sigma^2\lambda_{ijj}),\ \mathrm{Cov}(\varepsilon_{ij}, \varepsilon_{ij'}) = \sigma^2\lambda_{ijj}
\end{aligned}
$$

# APPENDIX 6. PROGRAM R CODES FOR LINEAR MIXED-EFFECT MODELS BY SPECIES

## Red-winged blackbird (RWBL)

```
(1) mRWBL=lmer(RWBL~fixedyr+farm +fore +devel +totpr +openwa
+offset(log(hrs))+(1|noise)+(1|circle)+(1|BCR)+(1|year),

(2) data=d,

(3) family=poisson,

(4) control=list(maxIter=100000),REML=T)
```

(1) The code form of a generalized Linear Mixed-Effect Regression which is comprised of RWBL counts as a function of temporal trend (fixedyr) and environmental covariates (farm, fore, devel, openwa, and totpr). These covariates are fixed effects. There is also an offset for the number of hours (hrs) each circle is surveyed which is an adjustment for effort. There are four random effects, one for the spatial location of each CBC (circle), one for each region (BCR), one for temporal variability in annual counts (year), and one for noise which is an accommodation for overdispersion. Random effects consist of two expressions separated by a vertical bar | and are enclosed in parentheses. The effect on the right side of the bar | is evaluated as a factor, often described as a grouping factor. The one on the left side of the bar | generates one random effect for each level of the grouping factor. If a covariate were placed in the position of the one, the grouping factor would vary as a function of the covariate (e.g. distance | year would suggest the response varies as a function of distance within year); this type of structure allows for great flexibility in modeling the interactions of fixed and random effects.

(2) This specifies the Lmer code to use the database compiled for the model.

(3) This section describes the distribution of the response as a Poisson distribution. However, because there is a random effect for error, the model is effectively an over-dispersed Poisson distribution.

(4) This piece of code simulates the equation for 100,000 iterations with restricted maximum likelihood (REML) methods. The consequence of REML=T is that anova procedures cannot be used to distinguish between models of differing fixed effects (though

information criteria such as AIC and BIC are still available). Andrew Gelman refers to REML as pseudo-Bayesian since empirical Bayes methods make similar, but slightly different, uncertainty adjustments to the variance parameters as REML (i.e., the Morris expansion).

**Common Grackle (COGR)**

(1) mCOGR=lmer(COGR~fixedyr +farm +totpr +grass +openwa +devel +offset(log(hrs))+(1|noise)+(1|circle)+(1|BCR)+(1|year),

(2) data=d,

(3) family=poisson,

(4) control=list(maxIter=100000),REML=T)

(1) All species will have code similar to RWBL, the differences are in the fixed effects used, which is to be expected as all of these species have different life histories and use slightly different sets of resources in their environments.

**European Starling (EUST)**

(1) mEUST=lmer(EUST~fixedyr+farm+ wmaxmt+wet+ shrub+ttwp +devel +offset(log(hrs))+(1|noise)+(1|circle)+(1|BCR)+(1|year),

(2) data=d,

(3) family=poisson,

(4) control=list(maxIter=100000),REML=T)

**Brewer’s Blackbird (BRBL)**

(1) mBRBL=lmer(BRBL~fixedyr+farm+fore+shrub+minmt+devel+totpr +grass+offset(log(hrs))+(1|noise)+(1|circle)+(1|BCR)+(1|year),

(2) data=d,

(3) family=poisson,

(4) control=list(maxIter=100000),REML=T)

**Rusty Blackbird (RUBL)**

(1) mRUBL=lmer(RUBL~fixedyr+farm+ ttwp+wmint +fore+devel +shrub +barr +offset(log(hrs))+(1|noise)+(1|circle)+(1|BCR)+(1|year),

(2) data=d,

(3)family=poisson,

(4) control=list(maxIter=100000),REML=T)