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Carotenoid- based plumage and its effects on the immune system of Northern Cardinals (Cardinalis cardinalis) within an Urban-rural gradient

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Does urbanization influence coloration of Northern cardinals (*Cardinalis cardinalis*)?

A Senior Honors Thesis

By

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Abstract

Anthropogenic effects can alter the natural life history strategies of individuals to determine mates based on honest ornamental signals making evolved behavior maladaptive. For example, in comparison with natural habitats, some urban areas might be more abundant in carotenoid-rich vegetation that determines the coloration of birds during a major life history event: molt. The individuals that molt the earliest following breeding in a natural population claim the best territories (i.e. rich carotenoid vegetation, ideal nest material, etc.) and therefore are most successful at reproduction the following year. Urbanization, however, can delay the timing of molt due to the possible abundance of carotenoids in the environment as well as have a major influence on the feather coloration of all individuals within the population. In this study, we examined whether urbanization affected plumage coloration and molt timing in the highly chromatic Northern Cardinals (*Cardinalis cardinalis*), which is commonly found in both urban and rural environments. Molt timing and intensity varied between the two populations, where the rural population molted earlier and more intensely. However, standard deviation of coloration was more variable in rural than in urban individuals possibly due to limited carotenoid-rich resources, even though mean traits were not affected. Redder individuals in the rural population occupy the highest quality territories and are more "fit" than others within this same population. Females choose these redder individuals as an indicator of quality. The reduced variation on urban individuals provide evidence that changing environments result in altered strategies for urban populations and may suggest that urban males are cheating selection by advertising false color to females.

Introduction

Urbanization is one of the most extreme transformations of landscapes by human habitation, and is known to have significant impacts on the local wildlife. Many studies thus far particularly on avian species in urban areas have described the obvious patterns (i.e., habitat fragmentation, air pollution, etc.) of impact on the abundance and diversity of a species within urban-rural gradients and why a species can successfully colonize in an urban habitat (Beissinger and Osborne, 1982; Blair, 1996; Burhans, 2006; Møller, 2009; Rutz, 2008; Leston and Rodewald, 2006). For example, Leston and Rodewald (2006) found that the Northern cardinal (*Cardinalis cardinalis*) may respond positively to urbanization due to the observation of increased fruit availability, increased number of bird feeders and higher temperatures in urban forests compared to rural.

These are all parameters that positively influence the species in this developed habitat. In particular, we explore if these human-dominated landscapes house bird populations that differ in coloration and molt strategy as compared to their rural counterparts. The abundance of resources available by increased fruit and bird feeders should cause significant differences in the coloration of the populations. These differences, in turn, can alter life history strategy in the selection of mates based on an “honest signal” of coloration that females use to determine individual quality for breeding as well as interspecific competition for territory (Jawor, 2003). An “honest signal” is one that accurately portrays the quality and potential of an individual in terms of immunocompetence (McGraw and Ardia, 2003), territory quality (Wolfenbarger, 1999), and ability to provide parental care (Linville et al., 1998). These are all criteria that females of this species choose for based on the color represented by the males.

Three possible pigmentary colors, or biochromes, can determine the coloration of a particular species of bird: porphyrins, melanins, or carotenoids (Ginn and Melville, 1983). Here I will focus on carotenoids, a fat-soluble compound generally responsible for the yellow, orange, red or violet pigmentation in birds. This compound cannot be synthesized and must be obtained in the diet (Ginn and Melville, 1983). If this compound is lacking in the diet, it will affect the coloration of the feather plumage. Also in order to retain feather quality and coloration, all are replaced annually in an overall process termed molt. This annual event is subject to considerable variation both within and between species (Ginn and Melville, 1983; Ginn, 1975).

However, relatively little is characterized about absolute differences in carotenoid-based plumage between urban and rural sites and how this distribution could be reflected both within and between populations during molt. Molt occurs annually following breeding season in the Northern Cardinal (Halkin and Linville, 1999) and is when the carotenoid abundance in the diet dictates red feather coloration for the following year (Møller et al., 2000; McGraw and Hill, 2001; McGraw et al., 2006; Hill et al., 2002). It has also been shown that within this period, the brightest males are those that are in the best nutritional condition, as well as the ones that have the most reproductive success the following breeding season (Hill & Montgomerie, 1994; Hill, 2000; Wolfenbarger, 1999). Wolfenbarger (1999) showed this in the Northern Cardinal (*Cardinalis cardinalis*) by examining coloration and vegetation density of the individual's corresponding territory. Redder males had the best territory and were paired with early breeding females, resulting in increased reproductive success (Wolfenbarger, 1999). Differences in the timing and extent of molt among and within natural populations are well known (Jenni and Winkler, 1994), but here, we will determine if these same molt and coloration hypotheses hold for the populations in a developing urban zone.

Development in urban areas may alter plumage coloration through numerous routes. Most evident would be the affect that urbanization has on the health of the individual. Increased interactions with competitors over limited space, increased variety of diseases communicable due to increased density, and possible contaminants by humans may all be factors that could influence coloration during molt (Bradley et al., 2008). Urbanization may influence plumage coloration by altering the abundance of food sources as shown by the increased amount of birdfeeders and exotic plants in urban yards (Leston and Rodewald, 2006). Some scientists have reported that the carotenoid-based plumages reflect higher fitness in individuals (Hill and Montgomerie, 1994; Wolfenbarger, 1999) as well as the quality of territory the individual occupies (Wolfenbarger, 1999). In species that depend on carotenoids for their coloration, the increased amount of available food resources for all individuals may blur the line of determining which individuals are more “fit”.

Here, I aim to characterize the differences between coloration and molt timing and intensity in the Northern Cardinal. I asked the following three questions: 1) does plumage coloration differ between an urban and a rural population?; 2) does plumage coloration vary significantly within the individual? and 3) does molt differ significantly between these two sites? I predicted that the urban population would be redder due to the possible increased carotenoid availability to all individuals. I also expected to see increased variability in plumage coloration within individuals in the rural population due to increased competition for more limited carotenoid rich territory. Lastly, I expect to see that the molt patterns differ between the two populations with the urban population molting more intensely due to the increased food resource availability.

Materials and Methods

Determination of Study Sites

Using Google Maps, two areas were scored as urban and rural in the greater Tampa Bay area (Brooker Creek Preserve [rural] and USF Claw Golf Course [urban]). Study sites were determined using percent cover of buildings, impervious ground surface, pervious ground surface, water, and tree cover within a 1 km radius. Using principle component analysis (PCA), urbanization scores were generated using the data provided. Brooker Creek Preserve was allocated an urbanization score of -1.426, and the USF Claw golf course possessed an urbanization score of 1.753. A more negative PCA value determines a rural location, and a more positive value determines a more urban location.

Animal Capture and Care

Birds were caught with mist nets between October and December, the time of year cardinals are molting (Halkin and Linville, 1999). Once captured, the individuals were removed from the net and banded.

Body molt and each primary, secondary and tail feather were scored using a scale from 0-5. Scores were determined based on wear and barb density with 0 indicating an old feather and 5, a new one. Photographs of the breast were taken for coloration analysis.

Tarsus length (0.1mm), weight (g), and wing chord (0.5mm) were recorded for the each individual. Upon completion of data collection, the individual was released at the site of capture.

Data Analysis

Coloration Determination

A frontal photograph was taken of each individual captured at both sites. These images were then imported into Adobe Photoshop 10. Approximately 2,500 pixels were randomly isolated from the front breast of the individual just below the bib, the area of the cardinal known to be important in mate selection (Jawor, 2003; Wolfenbarger, 1999). This process standardized each image to eliminate differences based on distance at which each photograph was taken. Hue, saturation and brightness were the three variables measured for each of these areas to assess coloration. In this program, hue is described as the color reflected from or transmitted through an object; it is expressed as a degree between 0° and 360°. Saturation is defined as the strength or purity of the color; it is measured as a percentage of 0% (gray) to 100% (fully saturated). Also in this program, brightness is characterized as the relative darkness or lightness of the color; it is measured as a percentage between 0% (black) and 100%

(white). Twenty of these pixels (approx. 1% of total) were randomly chosen and analyzed using the eye dropper tool. The averages were taken to generate one score for each variable for each individual, and standard deviations were calculated for each.

Molt Scoring

Upon capture, each individual was scored for body molt, tail feather molt, secondary feather molt, and primary feather molt. The feather scoring system described in Ginn and Melville (1983) was utilized as previously described. To examine the relationships between the molt timing of the populations, averages of primary, secondary and tail feathers were calculated to determine one score for each set of feathers per individual.

Results

Molt timing and intensity differed between urban and rural populations of male Northern Cardinals (Figure 1). In particular, the primary (Prim) and tail (Ret) feathers molted sooner in the rural population than in the urban during the time of capture as determined by an independent t-test (Prim, p = 0.006; Ret, p = 0.001). However, the secondary feathers were marginally significant in the same pattern of molt timing (p = 0.069). Body molt was similar between the two populations of approximately 1 on the molt scale (p = 0.536).

Standard deviation of brightness differed significantly between the two populations (Figure 7; p = 0.041). The standard deviation of hue and saturation were both insignificant (Figure 5; hue SD p>0.05; Figure 6, saturation SD p = 0.835). However, mean values of all three coloration parameters did not. The difference between the two populations in mean hue, saturation and brightness was insignificant (Figure 2, hue p = 0.613; Figure 3, mean p = 0.989; Figure 4, brightness p = 0.337).

Discussion

This study provides evidence that urbanization may be a factor that significantly alters life history strategies in the Northern Cardinal. Molt timing differences are known to exist between species (Homgren et al., 1995). However, significant differences in molt between the two populations were observed, with the urban population having a dramatically different time of feather molt. Other studies have pointed out that molt timing of birds would change due to increased predation (Barta et al., 2006), increased disease prevalence (Møller et al., 2010), temperature differences (Repenning et al., 2011), and food abundance (Barta et al., 2006). In a novel environment, it is very important for individuals to time the major life history events properly in order to maximize their personal fitness.

Although molt timing was significantly different between the two populations, the mean coloration between populations was non-significant in hue, saturation and brightness. The results seen in this study correspond to those found by Serra et al. (2007) in which the differences of molt timing do not affect coloration as described by hue and brightness. However, the most striking result observed in the coloration analysis was regarding the significant variation in brightness on an individual breast in rural birds.

My findings that variation within individuals in mean plumage coloration was not consistently related to urbanization provide insight into underlying dynamics of urban environments. Because carotenoids are a limiting resource for the plumage coloration of Northern Cardinals (Linville and Breitwisch, 1997; Møller et al. 2000), areas in which this resource is altered due to environmental differences or species density should affect individuals. My results were consistent with this hypothesis, and urban birds did not seem to be limited in carotenoid-rich resources. The increased resources that accompany an urban environment such as bird feeders and exotic plants could allow the more dense population a similar or increased amount of food as a rural population. This is consistent with the recent results observed by Rodewald and Shustack (2008) that have shown that in Northern Cardinals survival, reproductive productivity, and energetic condition were similar across an urban-rural gradient (Rodewald and Shustack 2008).

Male cardinals have clumps of orange, yellow or tan feathers within a background of red feathers (Wolfenbarger, 1999). Rural individuals had increased spatial variability due to this fact. Also, because "brighter" birds in Wolfenbarger's study (1999) exhibited less variation within the breast feathers, the pattern or increased mean brightness in urban individuals could be related to this finding and reinforce the significant decreased variation in this population.

Although the absence of a relationship between coloration and urbanization suggests that developed areas do not significantly influence their ability to acquire foods rich in carotenoids, there are a few important limitations. First, populations were only studied at two sites, and additional sites on this gradient will need to be analyzed to increase statistical viability. Second, the coloration analysis method used was basic. Although high repeatability has been proven (Hill and McGraw, 2006), the most advanced method of coloration analysis is that of the spectrophotometer. Finally, cardinal coloration increases with age (Wolfenbarger, 1996) thus differences in age structure between these two populations may be significant.

In conclusion, cardinals from rural sites differed from the urban in terms of molt and variation in feather brightness. Reduced standard deviation in the brightness among urban individuals confirms that increased availability of carotenoid-rich resources may serve as an evolutionary trap in mate choice by honest ornamental signals. Also, different molt intensities in urban birds as compared to rural may infer reduced competition for abundant high-quality territories and more intense plumage color during the following breeding season for all individuals. Although anthropogenic impacts through urbanization do not appear to significantly affect the overall coloration of the Northern Cardinal, significant differences in molt and individual color variation require additional study to identify and characterize the impacts that urbanization may be triggering in this and other avian species.

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Figures

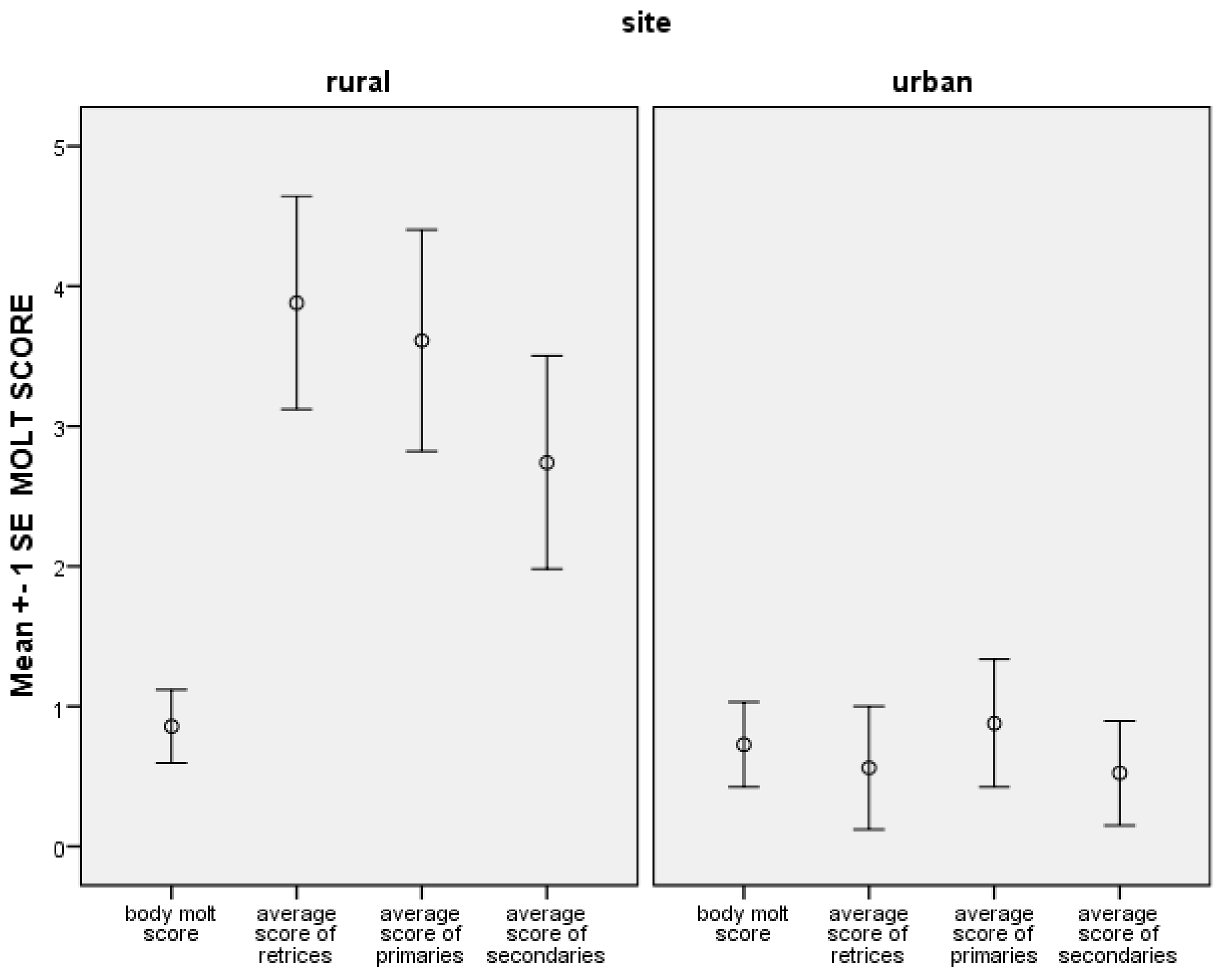

Figure 1: Molt comparisons between the urban and rural population of the Northern cardinal in body, primary, secondary and tail feather molt in Tampa, FL, Fall 2011 (means ±SE are provided; n=7 birds in each group).

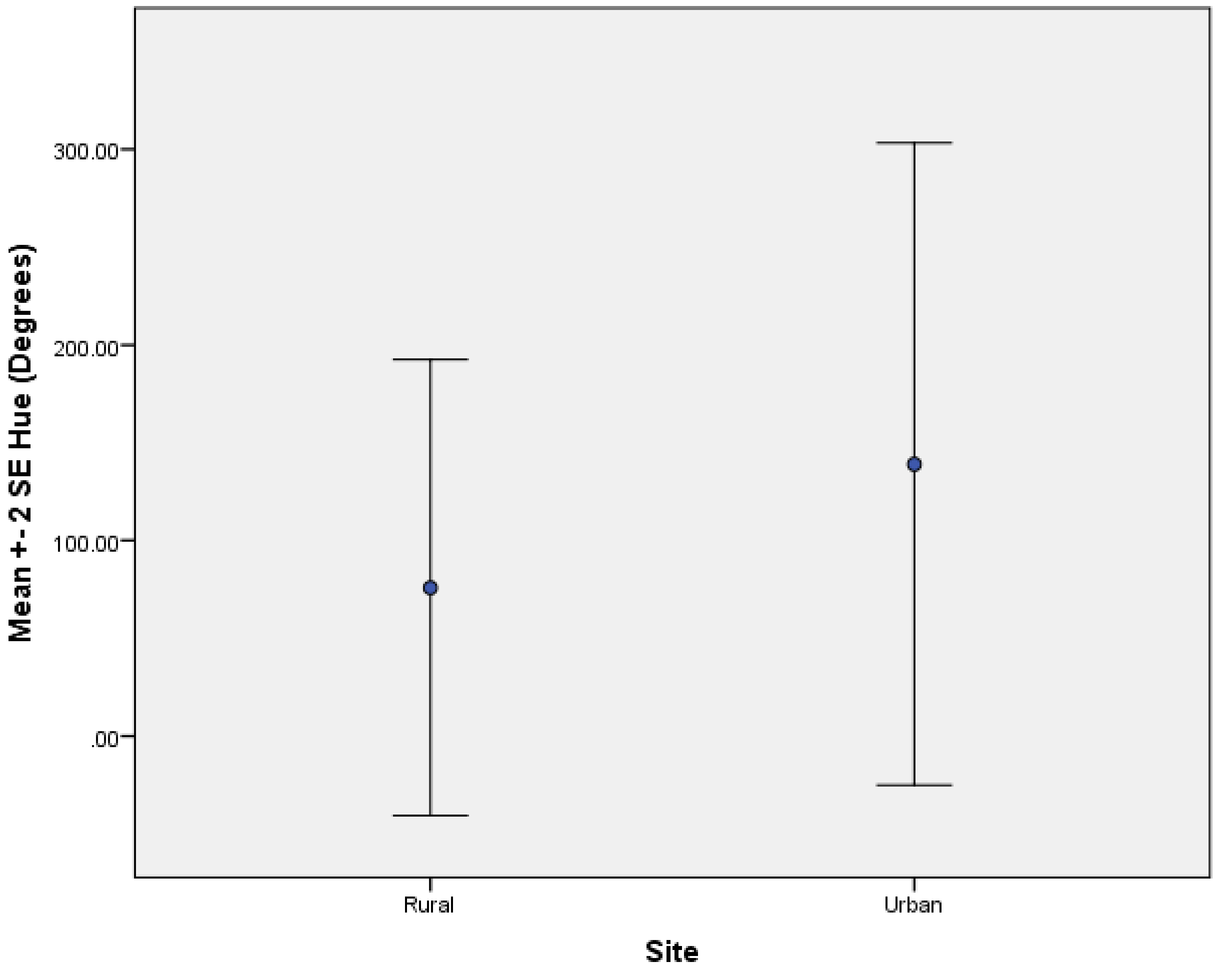

Figure 2: Mean hue of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).

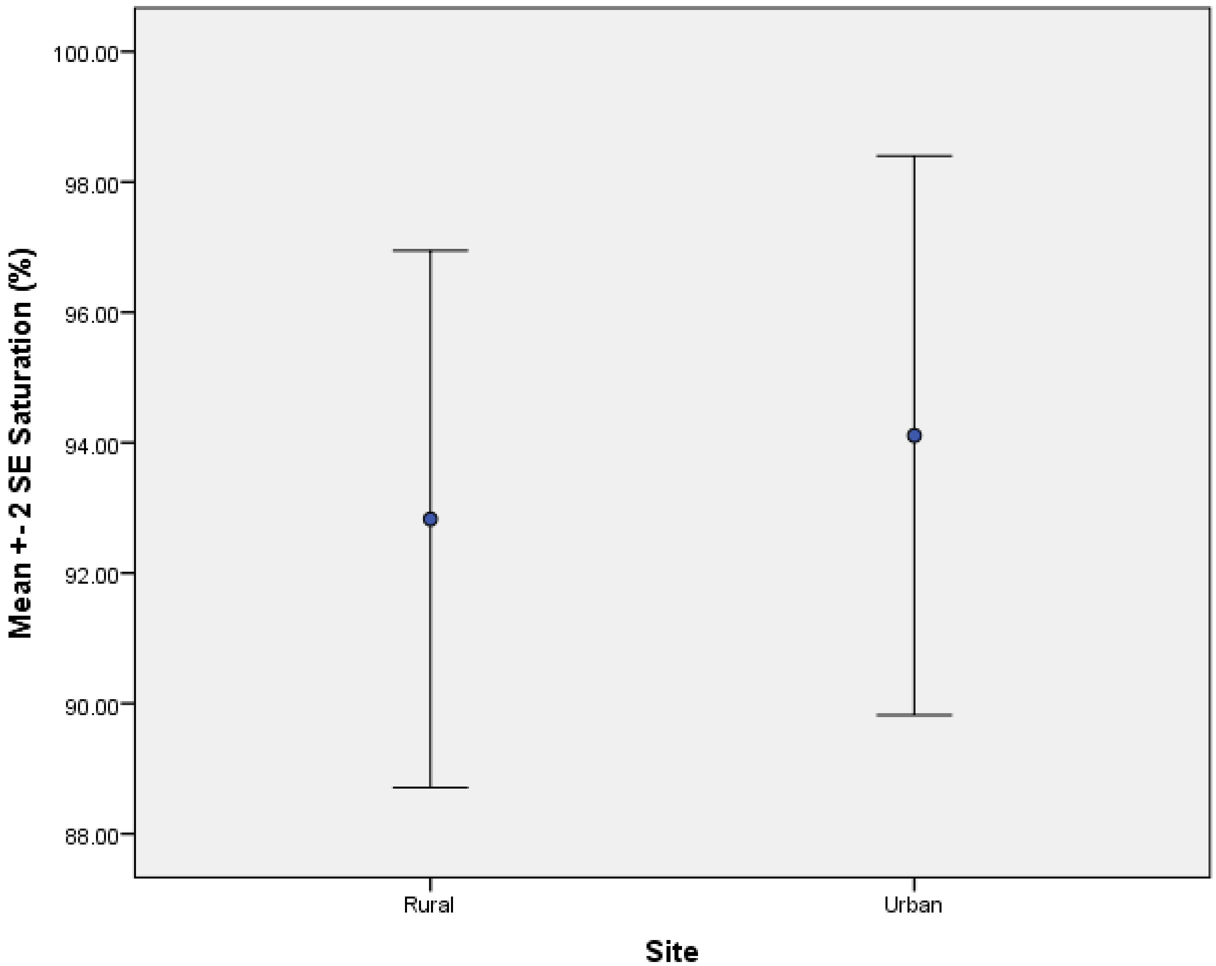

Figure 3: Mean saturation of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).

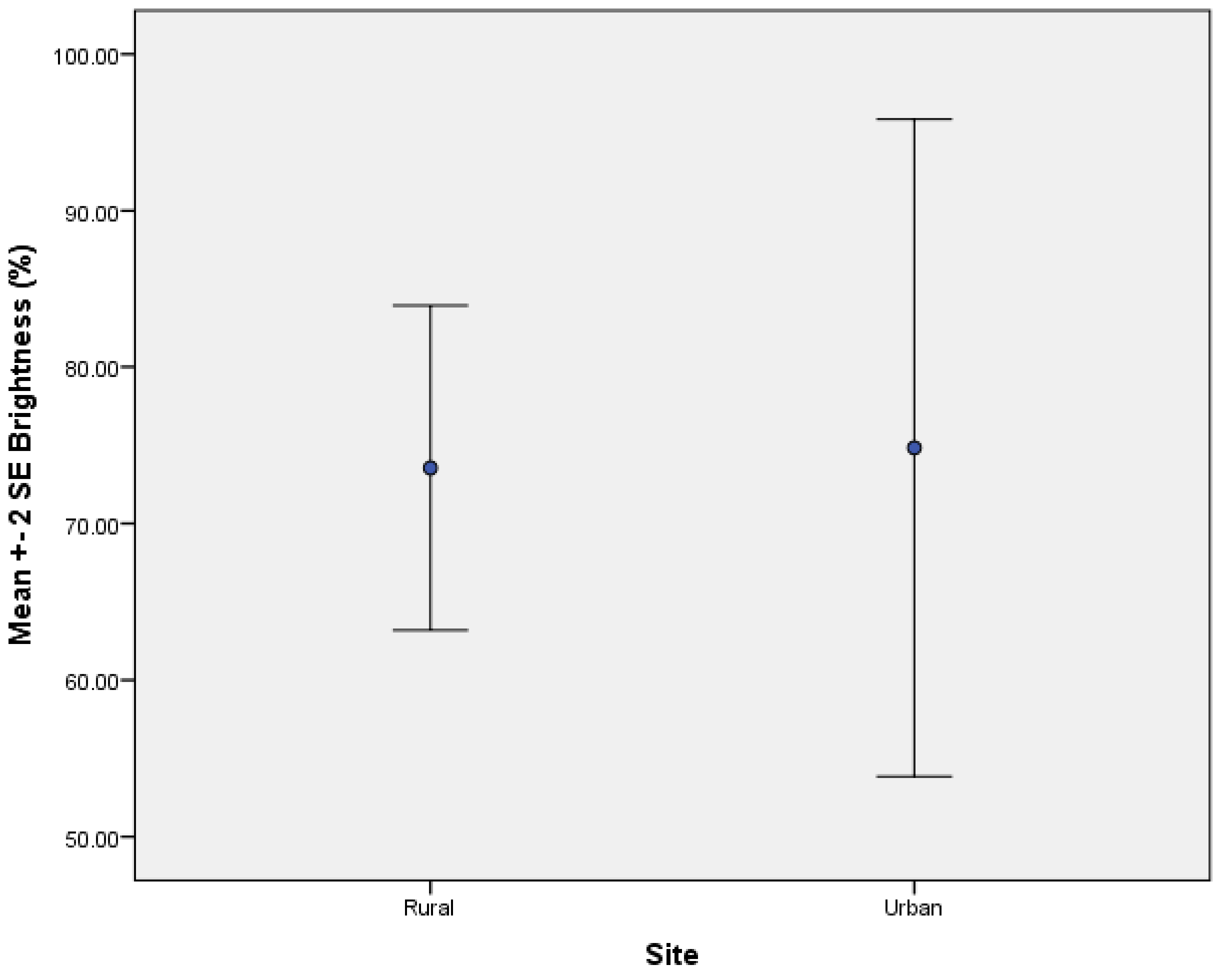

Figure 4: Mean brightness of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).

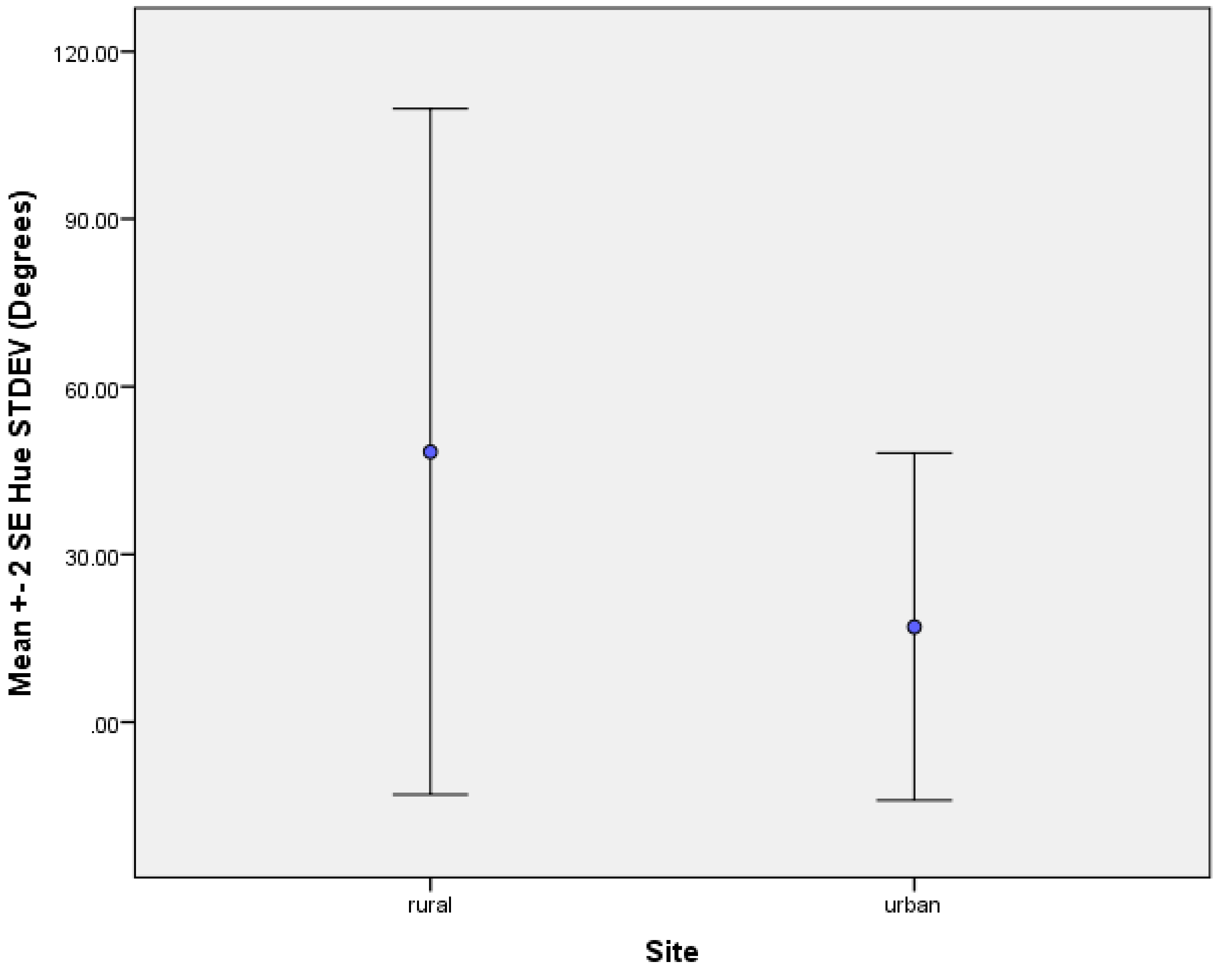

Figure 5: Standard deviation of hue of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).

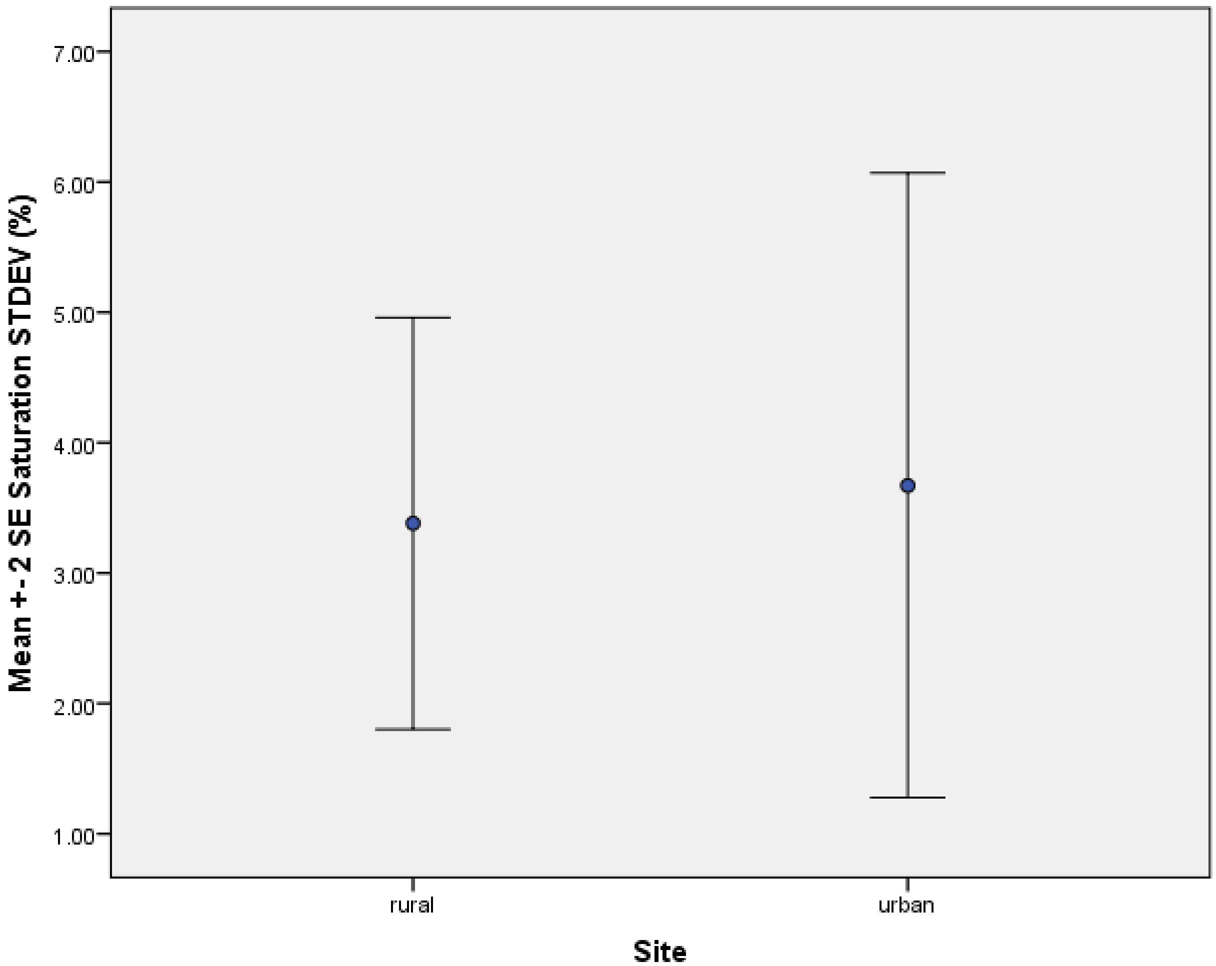

Figure 6: Standard deviation of saturation of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).

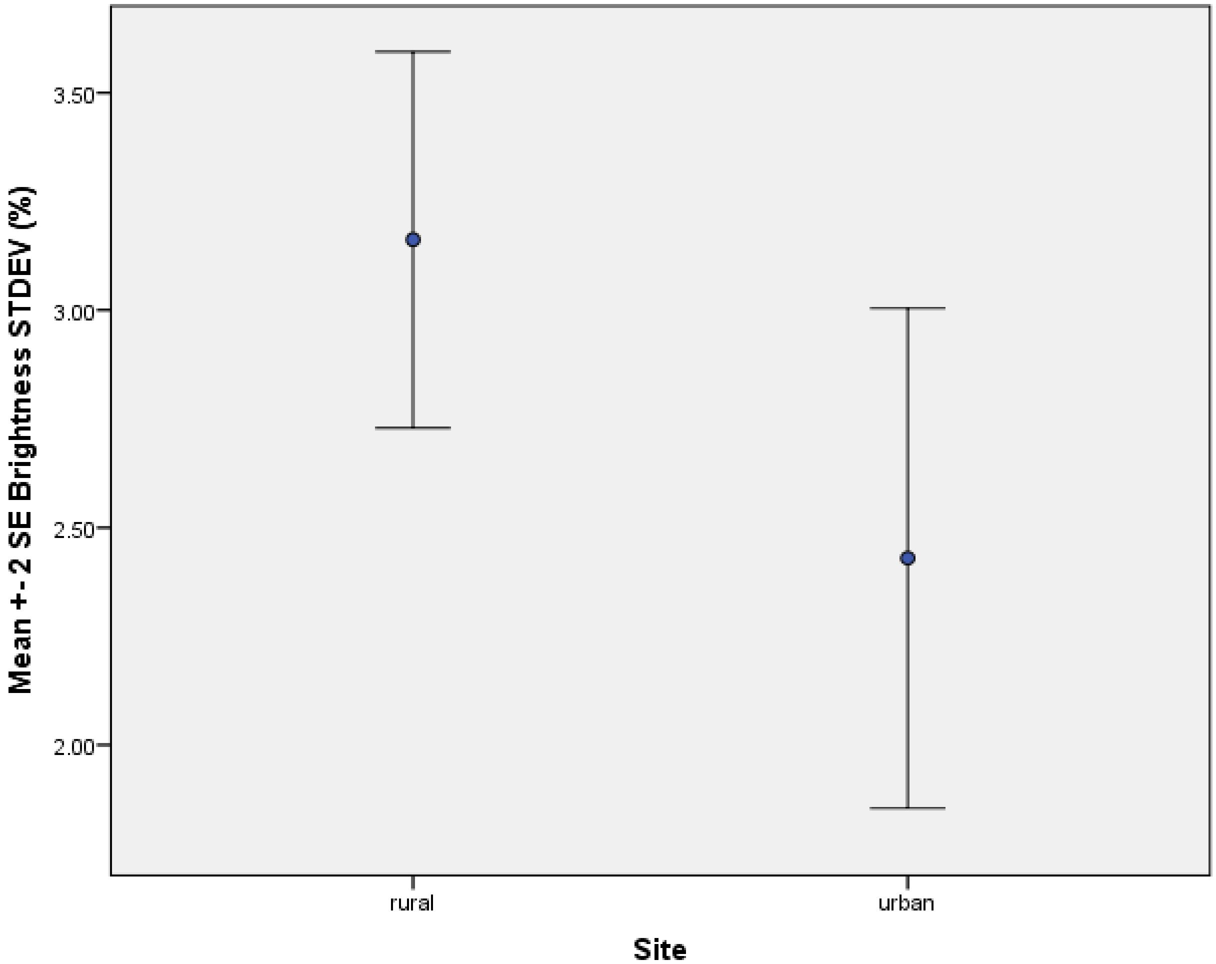

Figure 7: Standard deviation of brightness of male Northern cardinals in Tampa, FL, Fall 2011 (means ±SE are provided; n=7).