NESTING ECOLOGY OF ARDEIDS, INCLUDING

CATTLE EGRETS, AND RESTORATION ON

RALSTIN ISLAND IN NORTHCENTRAL

OKLAHOMA

By

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Bachelor of Science

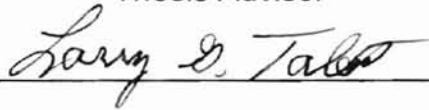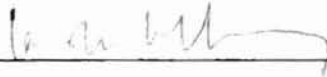University of Wisconsin - Stevens Point

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Additionally, I would like to thank all of my science teachers and professors from grade school through college; they made science intriguing and wonderful to learn. I also want to thank my parents Michael and Kathleen Feirer and my dearest friends, that were like grandparents, Robert and Jane Frautschy, who taught me that I could be anything that I wanted; they were supportive of everything that I have chosen to do with my life.

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Chapter 1

Potential impact of nesting patterns of Cattle Egrets (*Bubulcus* ibis) on other

ardeids

Abstract.—In 1998 and 1999, I assessed the potential of the Cattle Egret (*Bubulcus ibis*) to negatively impact 4 ardeid species (Great Egret, *Casmerodius albus*; Snowy Egret, *Egretta thula*; Little Blue Heron, *Egretta caerulea*; and Black-crowned Night Heron, *Nycticorax nycticorax*) through their nesting activities in a mixed-species colony. The colony was located on Ralstin Island in Salt Plains National Wildlife Refuge in northcentral Oklahoma. Weekly censuses were conducted throughout the breeding seasons; during each census, nests were counted and identified to species, and marked for later measurements. Those data were used to analyze species' arrival times, rate of colony build-up, length of breeding season, habitat selection, and nest characteristics. Results suggest that Cattle Egrets have the potential to negatively impact native ardeids through their nesting activities on Ralstin Island. Cattle Egrets arrived at the same time in the heronry as the other species, had a greater rate of build-up of nest numbers, and had a longer breeding season (May-August). Cattle Egrets selected the same nesting habitat as the other ardeids in at least 1 of 3 time periods during the breeding season. Cattle Egrets also had the same nest characteristics (e.g., nest height from ground, distance from nest to center of tree, percent canopy cover of vegetation above the nest, diameter of nest tree at breast height, and diameter of branch the nest is placed) as the similarly sized Snowy Egret and Little Blue Herons, making it possible that direct competition for nesting sites occurs on Ralstin Island.

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INTRODUCTION

Since the first sighting of Cattle Egrets (*Bubulcus ibis*) in Florida in 1941, they have spread throughout most of the contiguous United States and become 1 of the most numerous ardeid species in North America (Telfair 1994, 2000). This rapid range expansion is attributed to adaptations of Cattle Egrets to both aquatic and terrestrial habitats, unlike native North American ardeids that only use aquatic habitats, and the fact that Cattle Egrets readily nest in colonies of native ardeids. It has been shown that Cattle Egrets are attracted to breeding colonies initiated by other ardeids, such as Snowy Egret (*Egretta thula*), Little Blue Heron (*Egretta caerulea*), and Tricolored Heron (*Egretta tricolor* ; Dusi 1968, Dusi and Dusi 1987; Belzer and Lombardi 1989). Cattle Egrets quickly saturate the nesting habitat in such colonies (Telfair 1994) and potentially compete with native ardeids for nest locations, food, and other resources. Cattle Egrets in southern states arrive later than other ardeids and potentially only compete for food (Telfair 1980a). In contrast, Cattle Egrets in northern states arrive and start nesting in colonies at the same time as other ardeids, thereby competing directly for nesting sites and nesting material (Burger 1978a)--certainly, negatively impacting native ardeids in these colonies.

Cattle Egrets in mixed breeding colonies have the potential to directly impact ardeids in several ways; for example, they can take over nests of others directly because their nests are the same shape and size as small native ardeids,

such as Snowy Egret, Little Blue Heron (Stancill et al. 1988), and Tricolored Heron. Burger (1978b) showed that native ardeids stratify their nests according to body size. Cattle Egrets can take over space used by other species and nest higher than expected by body size. Cattle Egrets have the potential to nest on many different substrates (Telfair 1994). Cattle Egrets are nesting generalists and will use dead and live vegetation, nests from previous years, and ground (when space on vegetation is limiting) as substrates for nesting.

My objectives were to determine species composition and abundance of ardeids on Ralstin Island in northcentral Oklahoma and to assess the potential impact of nesting activities of Cattle Egret on other species of ardeids. Null hypotheses included: 1) Cattle Egrets start nesting at the same time, have an equal rate of build-up in nest numbers and an equal length of breeding season as other ardeids; 2) Cattle Egrets select the same nesting habitats (areas of island dominated by certain tree species) as other ardeids; and 3) Cattle Egrets use the same nesting locations in these trees as other ardeids.

STUDY AREA

The study was conducted on Ralstin Island (36°75' N, 98°18' W) in Salt Plains National Wildlife Refuge (NWR), Alfalfa County, northcentral Oklahoma. In 1997, Ralstin Island measured 500 m by 150 m (<3.23 ha), and its highest point was 3.05 m above mean lake level (Martinez 1998). The primary soil type was sand, and vegetation was predominantly exotic salt-cedar (*Tamarix gallia*)

but also included native cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), mulberry (*Morus laevigata*), western soapberry (*Sapindus drummondii*), black willow (*Salix nigra*), and American elm (*Ulmus americanus*). Forbs on the island included nightshade (*Solanum elaeagnifolium*) and pokeweed (*Phytolacca americana*).

The breeding bird community on Ralstin Island consisted of 11 species belonging to 3 orders, including 2 Anseriformes (Canada Goose, *Branta canadensis*, and Mallard, *Anas platyrhynchos*), 1 Passeriform (Great-tailed Grackle, *Quiscalus mexicanus*), and 8 Ciconiiformes (Great Blue Heron, *Ardea herodias*; Great Egret, *Casmerodius albus*; Little Blue Heron; Snowy Egret; Tricolored Heron, Feirer and Shepperd 1999; Cattle Egret; Black-crowned Night Heron, *Nycticorax nycticorax*; White-faced Ibis, *Plegadis chihi*, Koenen et al. 1996, Shepperd 1996).

Prior to the arrival of the Cattle Egrets on Ralstin Island in the late 1970s, the only Ciconiiformes breeding on the Island were Little Blue Herons, Snowy Egrets and Green Herons (*Butorides striatus*; L. Talent, pers. com., 1997). It has been suggested that Cattle Egrets act as a "beacon"; after they establish themselves in a colony they attract other ardeids to breeding sites with their large population numbers during their spring migration (Telfair 1980b). This appeared to be the case on Ralstin Island; in the years following their establishment, 5 species not previously known to breed on the Island joined the colony (Tricolored Heron, White-faced Ibis, Great Blue Heron, Snowy Egret, and Great Egret).

Green Herons no longer breed on the Island, but they are still known to breed elsewhere at Salt Plains NWR (Feirer 1999).

METHODS

Species Composition and Abundance

In 1998-1999, weekly censuses were conducted to estimate numbers of nests for each species in the colony. Sixty-nine 2-m by 2-m quadrats were distributed proportionally among 4 habitat types, using stratified-random sampling method (Ratti and Garton 1994). Initially, a random point was chosen on the edge of a habitat type. A random numbers table was used to establish the bearing and number of paces to be taken from the random point (if a heading took the observer into the water, out of the specific habitat, or to a previously identified quadrat, another heading was chosen). At the location of each random point, an object was tossed blindly to establish the northeastern corner of the 2-m by 2-m quadrat. From that point, a new heading and number of paces was taken from a random numbers table; the process was continued until all quadrats were located.

Four habitat types were identified based on their nesting substrate and structure: (1) salt-cedar (60% of the Island; number of quadrats = 39), (2) cottonwood and hackberry (10%; 10), (3) soapberry (16%; 10), and (4) forbs and

grasses (4%; 10). Effects of boundaries of adjacent habitat were minimized by spacing the quadrat >10 m from the edge of the 2 habitats.

Within quadrats, only active nests were counted and marked for later measurements (the colony on Ralstin Island has been active since the mid-1970s (Sullivan 1979), and old nests occur in many of the trees). Nests were characterized as active using several criteria: presence of fresh nest material, white wash on or below the nest, eggs and young in the nest, or presence of an incubating adult.

A nest was tallied only if the tree or shrub on which it was built was rooted in the quadrat, and active nests on vertical structure of the tree or shrub were counted, even if vertical structure extended beyond the perimeter of the quadrat. However, nests on vertical structure of trees or shrubs rooted outside of the quadrat that extend into the quadrat were not counted. All active nests within quadrats on down vegetation (vegetation that had fallen on the ground, whether dead or alive) were counted. In that case, if down material exceeded the perimeter of the quadrat, only those nests within the quadrat were counted. Active nests found on the ground within the quadrat also were counted.

Quadrats were censused weekly throughout the breeding season (May-August 1998, March-September 1999). The census was conducted from sunrise to early afternoon, or until the air temperature exceeded 34° C (chicks begin to overheat at 35° C; King 1978, Telfair 1994). Total numbers of nests of each species were recorded and averaged for quadrats in each habitat type. Average numbers of active nests per species per quadrats for each habitat type were

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used to estimate numbers of breeding pairs of ciconiiform species in different habitat types and the entire island. Presence of any rare species also was recorded, and their abundance was estimated when possible.

Colony Population Structure

Beginning in April 1998 and March 1999, arrival dates and nest initiation dates were recorded. Ages of nestlings and fledglings were estimated using guidelines of chick development used by McVaugh (1972) and Telfair (1994). Those guidelines describe morphologic and behavioral changes of ardeid young at different ages. When a nest initiation date was missed, it was approximated by back dating from known fledging dates and/or estimated age of chicks, based on information about number of days of incubation and fledging for each species from Ehrlich et al. (1988).

Regression analysis (PROC GLM and Indicator Variables, Cody 1997) was used to detect differences between species in rate of build-up in nest numbers, and an adapted inverse regression analysis (i.e., a test of the x-intercept instead of the y-intercept; W. Warde, pers. comm.) was used to detect differences in generalized nest initiation dates for each ardeid species from the regression analysis (not adjusted for absolute number of individuals for each species). When differences were found between species, pair-wise comparisons of x-intercepts, slopes, and the quadriatic coefficients were analyzed using t-tests. Weekly estimates of numbers of nests for each species from the 1999

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breeding season were used to analyze temporal patterns of nest initiation and rates of species build-up on the Island. Those estimates were included in the analysis until numbers of each species began to decline (i.e., end of "arrival"). Weekly estimates of nest numbers also were used to determine the temporal pattern of nesting in each species throughout the breeding season. Length of the breeding season for each species was determined as the first nest in the census until the last fledgling left the nest. Due to lack of field work in the early part of the nesting period in 1998, dates of nest initiation were estimated as described above.

Ciconiiform Habitat Selection

To test for habitat selection, I selected 3 census dates equally spaced throughout the duration of the breeding season: early (24-25 May), middle (21-22 June), and late (18-19 July). Census results for those 3 time periods were available for both years of the study. For each time period, estimates for each species in the plots were totaled and proportions of the species were calculated for each habitat (observed values). Those proportions were tested against the proportion of each habitat type available (predicted values). Chi-square tests were used to determine if each species present in the study plots used habitats in proportion to availability (Neu et al. 1974, Byers et al. 1984). When there was a significant Chi-square value ($P < 0.05$), habitat selection or avoidance was determined using Bonferonii confidence intervals (Neu et al. 1974, Byers et al.

1984). If the lower confidence limit was greater than the expected proportions, the habitat was selected, and if the upper confidence interval was lower, it was avoided.

Nest Characteristics

Measurements of nest characteristics were recorded for 5 of the common species of ardeids on the Island. Those measurements were recorded following the completion of the breeding season, after birds left the Island. Measurements included: tree height, nest height, distance to center of tree, canopy cover, diameter of nest branch, and diameter of tree, distance to other nearest nest (intraspecific and interspecific). T-tests were used to analyze the difference between distance to the nearest interspecific nest and intraspecific nests. The t-test quantified if ardeids were selecting nests closer to conspecific or another species. A 2-way analysis of variance was used to test effects of year and species on the other nest characteristics. If a year effect was found, I attempted to determine what caused the interaction. If there was no year effect, the 2 years were lumped, and species were compared with each other. Nest characteristics of 3 ardeids could not be analyzed: White-faced Ibis nests were predominantly located on the ground and not associated with trees, Great Blue Heron nests were inaccessible in high trees (>10 m), and only 4 Tricolored Heron nests were found on Ralstin Island in the 2 years of the study (Feirer, unpublished data), making statistical comparisons unfeasible. Least-square-mean (LSMEANS,

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Cody 1997) comparisons were used to assess differences among nest characteristics.

<center>RESULTS</center>

Species Composition and Abundance

Eight ardeid species nested on Ralstin Island in 1998 and 1999 (Table 1). There were 10 census weeks in 1998 and 17 census weeks in 1999; from those censuses, the highest numbers of breeding pairs of ardeids in any census week were 31,854 in 1998 and 24,469 in 1999 (Table 1). Cattle Egrets were the most abundant species in the colony in 1998 (81% of nests) and 1999 (62%). Individually, Great Egrets, Snowy Egrets, Little Blue Herons, and White-faced Ibises nests in the 2 years of the study never made up >20% of the colony. Black-crowned Night Herons, Great Blue Herons, and Tricolored Herons were relatively rare species in the colony. Tricolored Herons bred on Ralstin Island for the first time ever in 1998 (Feirer and Shepperd 1999), and 3 breeding pairs were found in 1999 (Feirer, unpublished data).

Colony Population Structure

Generalized nest initiation dates (x-intercept) did not differ among species (Figure 1). Cattle Egrets had a faster rate of build up than the other 5 species (P

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< 0.0001). Snowy Egrets had a faster rate of build-up than Little Blue Herons (t_{27} = 2.86. P = 0.008) and Black-crowned Night Herons (t_{27}= -2.46, P = 0.021).

Comparison of species-specific temporal patterns over the breeding season showed a difference between 1998 and 1999. Three of the 6 species had longer breeding seasons (quadratic equations) in 1998 than 1999: Cattle Egrets (intercept, t_{24} = -3.69, P = 0.0011; quadratic, t_{24} = -4.25, P = 0.0003), Snowy Egrets (intercept, t_{22} = -6.67, P < 0.0001; quadratic, t_{22} = 3.50, P = 0.002), and Black-crowned Night Herons (intercept, t_{13} = -2.04, P = 0.062; quadratic, t_{13} = -4.26, P = 0.0009; Figure 2). Because of those year effects, data pertaining to those species were analyzed separately for each year.

In 1998, Cattle Egrets had a longer breeding season than all other species on the Island; the other species did not differ from each other (intercept, P < 0.0001; quadratic, P < 0.0001; Figure 3). In contrast, Snowy Egrets had a shorter breeding season in 1999 than Little Blue Herons (intercept, t_{79} = 2.20, P = .004; quadratic, t_{79} = 3.00, P = 0.004) and Great Egrets (intercept, t_{79} = -2.02, P = 0.047; quadratic, t_{79} = 2.27, P = 0.0257). In 1999, Cattle Egrets had a longer breeding season than all other species (intercept, P < 0.0001; quadratic, P < 0.0001; Figure 3).

Ciconiiform Habitat Selection

Of 36 possible comparisons (6 species, 3 time periods, 2 years) of habitat selection, only 26 could be analyzed because of cases where a particular

species did not occur in the census ($n = 5$), or because a species was found in only 1 of the 3 habitat types ($n = 5$). Of those 26 cases, 18 suggested that habitat selection occurred ($P = 0.05$; Table 2) and were analyzed with Bonferonii confidence intervals to ascertain selection or avoidance (Table 3).

Not all species selected the same habitats, and habitat selection changed throughout the 3 time periods (Table 3). Across the 3 time periods and 2 years, Cattle Egrets selected salt cedar in 3 of 6 comparisons and cottonwood-hackberry in 2 of 6 but did not select soapberry. Great Egrets selected salt cedar in 1 of 5 comparisons and cottonwood-hackberry in 2 of 5 but did not select soapberry. Black-crowned Night Herons selected salt cedar in 4 of 4 comparisons and did not select cottonwood-hackberry or soapberry. Snowy Egrets selected cottonwood-hackberry in 2 of 5 comparisons and did not select salt cedar or soapberry. Similar to Snowy Egrets, Little Blue Herons selected cottonwood-hackberry in 4 of 5 comparisons and did not select salt cedar or soapberry. White-faced Ibises selected salt cedar in 3 of 6 comparisons and soapberry in 1 of 6 but did not select cottonwood-hackberry. Therefore, Cattle Egrets, Great Egrets, Black-crowned Night Herons, and White-faced Ibises selected similar habitat types in which to nest. In contrast, Little Blue Herons and Snowy Egrets were most similar in their selection of habitat types.

Nest Characteristics

Of the 8 measured nest characteristics (Figure 4), only distance to center of a tree differed between 1998 and 1999 ($F_{4,320} = 3.16$, $P = 0.014$), which was

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caused solely by Great Egrets' choice of distance to center of a tree. Data for Great Egrets in 1998 and 1999 were compared with the pooled data for the other species. In 1998, Great Egrets nested further from the center of the tree than all other species, including Great Egrets in 1999 ($F_{5,324} = 7.77$, $P < 0.0001$; Figure 5). Cattle Egrets nested closer to the center of the tree than Great Egrets (1998 and 1999) and Black-crowned Night Herons. The remaining 7 characteristics (Figures 4 and 5) were statistically different when looking at the species: nest height ($F_{4,354} = 6.89$, $P < 0.0001$), diameter of branch ($F_{4,332} = 8.97$, $P < 0.0001$), diameter of tree ($F_{4,321} = 4.22$, $P < 0.002$), percent canopy cover ($F_{4,354} = 17.69$, $P < 0.0001$), tree height ($F_{4,354} = 3.72$, $P < 0.006$), distance to other species ($F_{4,267} = 5.51$, $P = 0.0003$), and distance to conspecific ($F_{4,286} = 86.78$, $P < 0.0001$). The t-tests comparing the distance to intraspecific and interspecific nests by each ardeid species showed that all species ($P < 0.001$) except Snowy Egrets ($P = .153$) nested closer to another species of ardeid than to a conspecific. In general, nest characteristics for Great Egrets and Black-crowned Night Herons differed from the other species; Cattle Egrets, Snowy Egrets, and Little Blue Herons did not differ from each other for the characteristics measured.

Species Composition and Abundance

Ardeid species composition and abundance have changed since the first censuses of Ralstin Island in 1982 (Talent and Hill 1982). In 1982, there were 4 ardeid species present (Cattle Egret, Green Heron, Little Blue Heron, and Black-crowned Night Heron); 1982 was the first year that Cattle Egrets nested on the Island (L. Talent pers. comm.). By 1995, 7 ardeid species nested on the Island (Cattle Egret, Snowy Egret, Great Egret, Little Blue Heron, Great Blue Heron, Black-crowned Night Heron, and White-faced Ibis; Koenen et al. 1996). Shepperd (1996) documented the first breeding record of White-faced Ibis in Oklahoma in 1995, and Feirer and Shepperd (1999) documented the first nesting record of Tricolored Heron in 1998, on Ralstin Island. That increase in species richness may have been attributable to the arrival of Cattle Egrets in the late 1970s (Sullivan 1979). Cattle Egrets are known to follow other ardeids, especially Snowy Egrets and Little Blue Herons, from their over wintering grounds to their breeding sites and nest there (Dusi and Dusi 1968, 1987; Belzer and Lombardi 1989). Cattle Egrets quickly fill vacant nesting space and soon dominate a colony (Telfair 1994). After Cattle Egrets are established in a colony, they may attract other species to the colony when they return to the breeding site in the spring in large numbers – they act as a "beacon" to other ardeid species (Telfair 1980b). Species not known to have bred in northcentral Oklahoma, such

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as the White-faced Ibis and Tricolored Heron, may have followed migrating Cattle Egrets to the colony and nested.

Arrival of Cattle Egrets on Ralstin Island in the late 1970s (Sullivan 1979) may have caused Green Herons to leave. Green Herons bred regularly on Ralstin Island prior to the arrival of the Cattle Egrets (L. Talent pers. comm.). Although still at Salt Plains National Wildlife Refuge, Green Herons have not been observed on the Island since 1982 (Talent and Hill 1982), suggesting that they may have been competitively excluded by Cattle Egrets. Green Herons may arrive later than all other ardeids (Grybowski et al. 1992), including Cattle Egret and thus possibly their nesting sites are already filled by other ardeids, particularly Cattle Egrets (Wood and Schnell 1984).

Total numbers of breeding ardeids increased notably from 1982 to 1999. There were 63,662 and 48,872 breeding adults in 1998 and 1999, respectively, compared with 1,240 in 1982 (Talent and Hill 1982) and 22,966 in 1995 (Koenen et al. 1996). The large difference in the colony population between 1995 and 1998 may be caused, in part, by an underestimate of total island size used in the calculations by Koenen et al. (1996); the Island was thought to be 1.8 ha in 1995, but I calculated the Island to be 3.8 ha in the same year (see Chapter 3). Due to this discrepancy, species populations between years were compared with percentages. Cattle Egrets have made up > 80% of the Island population for the past 20 years; they made up 81%, 84%, 81%, and 62% of the ardeid population on the Island in 1982, 1995, 1998, and 1999, respectively. Prior to 1999, the

proportion of the colony made up of Cattle Egrets changed little, but the Cattle Egret population in 1999 decreased by about 11,000 pairs.

Refuge personnel at Salt Plains NWR currently are trying to halt the erosion of Ralstin Island by creating barriers on the southwestern corner of the Island (see Chapter 3). Following completion of restoration activities, personnel at Salt Plains NWR need to continue monitoring of ardeid populations on the Island and they need to propagate vegetation used by ardeids (e.g., cottonwood, hackberry, mulberry, elm) as nesting habitat. The relationship between Cattle Egrets and range expansion of native ardeids also needs to be analyzed using historical data; it may be found that since the arrival of Cattle Egrets to the New World (Crosby 1972; Weber 1972; Arendt and Arendt 1988), they may have facilitated range expansion of native ardeids (L. Talent pers comm.).

Colony Population Structure

Cattle Egrets have the potential to impact those species with the same nesting requirements, such as Little Blue Heron and Snowy Egret (see Nest Characteristics below). This is contrary to what was found in more southern states where Cattle Egrets nested later than all other ardeids (Dusi and Dusi 1968; Jenni 1969; Weber 1975; Telfair 1980a). In agreement with my study, Burger (1978a) found that Cattle Egrets in northern states started nesting at the same time as other ardeids and had potential to compete with other ardeids for nesting sites and materials.

Cattle Egrets have the potential to negatively impact small native ardeids via saturation of suitable nesting habitat. Cattle Egrets had significantly higher rates of build-up of nest numbers than all other species of ardeid on Ralstin Island (Figure 1). This high rate of build-up of nest numbers allows Cattle Egrets to saturate the colony (Telfair 1994) and displace other species of ardeids (Wood and Schnell 1984) from the colony or from their preferred nesting habitat.

During the study, Cattle Egrets were found to have a longer breeding season than all other species on the Island (Figure 3); this may have been caused by a continued influx of Cattle Egrets to the Island from other populations or, more likely, by renesting Cattle Egrets in the colony after nest loss. Cattle Egrets are generalists in terms of nest-site selection (McCrimmon 1978; Telfair 1983) and have nested at many different heights and upon many different substrates. Cattle Egrets have been recorded to nest on the ground and in small shrubs (Telfair 1994); both are susceptible to flooding and other adverse weather conditions. In 1999, Ralstin Island was inundated frequently with water from floods caused by above average seasonal rains, and ardeids with nests on or near the ground may have renested after inundation. After the floods in 1999, I noticed many new nests of both Cattle Egrets and White-faced Ibises (known to ground nest) higher in the vegetation above subsiding floodwaters. These new nests following flooding may have caused the lengthening of the breeding season in 1999 (Figure 2).

I found that Cattle Egrets on Ralstin Island began nesting at the same time as other ardeids and had a higher rate of build-up of nest numbers over a longer

breeding season, but this does not prove that they are negatively impacting other small native ardeids on the Island. However, this information is suggestive, especially because antagonistic behavior between the different species was noted frequently on the Island, and Cattle Egrets were seen on numerous occasions removing nest material from active nests containing eggs or young of other species, which possibly demonstrates direct competition for nesting material. Stealing of nest material by Cattle Egrets from other ardeids also has been recorded by Seigfried (1971) in Africa and Lancaster (1970) in Columbia, South America. McKirtrick (1975) found that Cattle Egrets in Alabama would directly harm chicks and take over nests of other species.

Ciconiiform Habitat Selection

The differences in rate of arrival and nesting may explain the different habitat selection of the ardeid species seen in this study. Location of a species' nests may be related to its body size, timing of initiation (Burger 1979, Naugle et al. 1996), and potential for competition for nesting sites (Burger 1979). Species arrive in a colony and begin nesting at different times. Great Egrets are one of the first ardeids to arrive (not necessarily begin nesting) on the Island in late March, and they nested in the center of the Island in the cottonwood–hackberry habitat. The other ardeid species began to arrive on the Island in late March–May. They saturated the center of the Island with their nests and later-arriving

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individuals nested in vacant habitat in the periphery (Burger 1979, Naugle et al. 1996).

Cattle Egrets at the end of the breeding season selected the same nesting habitat as other small native ardeids on Ralstin Island (Table 3). Cattle Egrets did not use the same nesting habitat as Little Blue Herons and Snowy Egrets in period 1 (24-25 May) or period 2 (21-22 June) of the breeding season. However, during the third period (18-19 July) of the breeding season, Cattle Egrets did use the same habitats as Little Blue Herons and Snowy Egrets; all used cottonwood–hackberry habitat in the center of the Island. This may demonstrate that Cattle Egrets, given the opportunity, will use cottonwood–hackberry (during the third period of the breeding season, most ardeids had finished breeding, and the center of the colony was no longer saturated with active nests; Figure 3) over the other habitats, like the Little Blue Heron and Snowy Egrets.

Cattle Egrets selected the same habitat (salt-cedar) as Black-crowned Night Herons, White-faced Ibises, and Great Egret, giving Cattle Egrets the potential to impact these species. Yet, even though Black-crowned Night Herons and White-faced Ibises used the same habitats of the Cattle Egret, they may be minimally impacted by Cattle Egrets. Black-crowned Night Heron adults and young are known to be aggressive in their nest territories and defend them against conspecifics and other ardeids (Davis 1993). Black-crowned Night Herons selected salt-cedar and avoided all other habitat; there were, however, nests in the cottonwood–hackberry habitat. None of these nests were in census plots; therefore, they were not included in the habitat preference analysis. White-

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faced Ibises nested on the ground in all habitats on the Island, unlike other ardeids. Nesting on the ground may minimize competition for nest sites with the other ardeids (including Cattle Egrets; Burger 1978a). It appeared that the only limiting factor for the White-faced Ibis was suitable nesting substrate that consisted of small pieces of driftwood and forbs. White-faced Ibises used driftwood and forbs in their nests, including small plant stalks and debris (Ryder and Manry 1994). Ibis were in close proximity to debris lines left on the Island by seasonal floods. Debris lines were most commonly found in the salt-cedar habitat, the lowest habitat on the Island and most susceptible to flooding.

In summary, Cattle Egrets used all habitats on Ralstin Island, but they selected the salt-cedar habitat that was also used by Great Egrets, Black-crowned Night Herons and White-faced Ibises. These species probably were not impacted greatly by Cattle Egrets because of their nesting or agnostic behaviors. When nesting activity of ardeids decreased during the third period of the breeding season, Cattle Egrets selected the same habitat (cottonwood-hackberry) as Snowy Egrets and Little Blue Herons, providing the potential for them to impact these species.

Nest Characteristics

It has been shown that ardeids stratify their nests based on body length (with larger ardeids nesting higher than the smaller ardeids; Burger 1978b). Cattle Egrets are about the same size as the small native ardeids, such as Little

Blue Herons and Snowy Egrets, so the potential for negative interaction over choice of nest sites exist.

For 5 of the 8 nest characteristics analyzed, there were no differences in nests of Cattle Egrets, Little Blue Herons, and Snowy Egrets (Figure 4). The 5 characteristics shared by Cattle Egrets, Little Blue Herons, and Snowy Egrets were nest height from ground, distance of nest to center of tree, percent canopy cover of vegetation above the nest, diameter at breast height of nest tree, and diameter of branch the nest was placed on. Cattle Egrets shared the remaining 3 nest characteristics with either Little Blue Herons or Snowy Egrets, but not both (Figure 4 and 5). Cattle Egrets do not appear to have as great a potential to impact the other ardeids on Ralstin Island through their nesting activities. In general, Cattle Egret nest characteristics differed from those of Great Egrets and Black-crowned Night Herons.

Stancill et al. (1988) found that Great Egrets were the highest nesting ardeid in a mixed colony in eastern Oklahoma. On Ralstin Island, Great Egrets nested the highest of all the species in this study. Cattle Egrets, Little Blue Herons, and Snowy Egrets nested at the same height, with Cattle Egrets nesting higher than expected based on body size. McCrimmon (1978) showed that Cattle Egrets nested at the same height as Little Blue Herons and Snowy Egrets; all 3 species have comparable body lengths. Burger (1978b) found that in general native ardeid species stratify their nest heights according to their overall body length. My data on nesting height concurs with that of Burger (1978b) and McCrimmon (1978).

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Cattle Egrets, Little Blue Herons, and Snowy Egrets nested near the center of trees with moderate canopy cover, possibly minimizing effects of weather, such as exposure of eggs and nestlings to wind, rain, and solar radiation (Welty 1975). Their smaller body size may allow them to nest near the center of trees that may be less accessible to the larger ardeid species such as the Great Egrets. Great Egrets nested high in vegetation with low canopy cover and farther from the center of the tree than all species in 1998 and Cattle Egrets in 1999. For Great Egrets, the difference between 1998 and 1999 may have been attributable to weather conditions. In 1998, Salt Plains NWR experienced a drought, but above average precipitation and floods occurred in 1999. Storms that brought precipitation also may have forced Great Egrets to nest closer to the center of the tree to minimize the effect of wind on their nests. McCrimmon (1978) found that Cattle Egret and Little Blue Heron nests were the same distance to the center of the tree and Great Egrets nested further from the center of the tree. He also found that Cattle Egrets and Little Blue Herons selected nest locations with high percentage of canopy cover, while Great Egrets selected nest locations with less canopy cover. Following observations of McCrimmon (1978), Cattle Egrets, Little Blue Herons, and Snowy Egrets on Ralstin Island placed their nests on branches that were the same diameter and in trees with the same diameter at breast height.

Nest of Cattle Egrets, Little Blue Herons, and Snowy Egrets differed in tree height, and distances to nest of conspecifics and other species. Cattle Egrets, Little Blue Herons, and Black-crowned Night Herons nested in trees of

the same height, with Snowy Egrets and Great Egrets nesting in trees that were slightly taller. In general, average height for nest trees of these species were >3 m, illustrating that there is not much variation in tree height on the Island. In terms of distance to conspecific and other ardeids, all of the species nested closer to another ardeid species than conspecifics, except Snowy Egret. Ardeids on Ralstin Island may be nesting further from conspecifics to minimize competition between themselves, with no regard to other ardeids.

I found that Cattle Egrets had the potential to negatively impact the similarly sized ardeids (Little Blue Herons and Snowy Egrets) and the other ardeids on Ralstin Island to some extent. Relative to colony population structure, other ardeid species could be impacted negatively because Cattle Egrets arrived at the same time in the heronry, had a greater rate of nest build-up, and had a longer breeding season. When habitat selection of ardeids was compared, it was found that Cattle Egrets used the same habitat as all other ardeids in at least 1 time period during the breeding season. Cattle Egrets also had the same nest characteristics as the similarly sized ardeids (Snowy Egret and Little Blue Heron) making it possible to impact negatively these species by their selection of nest sites. Although Cattle Egrets have the potential to impact the other ardeids on the Island, I feel that they have been beneficial to the colony on Ralstin Island. Since the arrival of Cattle Egrets in 1978 (Sullivan 1979), the colony population size has grown considerably and many new species may have been drawn to the colony by Cattle Egrets.

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Figure 1. Dates of nest initiation and the rate of colony build-up for 6 species of ardeids on Ralstin Island, Oklahoma, 1999: a) all 6 ardeid species and b) Cattle Egret removed to view other species at a larger scale. Julian dates of 100 and 200 correspond to 8 April and 19 July, respectively.

Little Blue Heron
Snowy Egret
Great Egret
White-faced Ibis
Black-crowned Night Heron
Cattle Egret
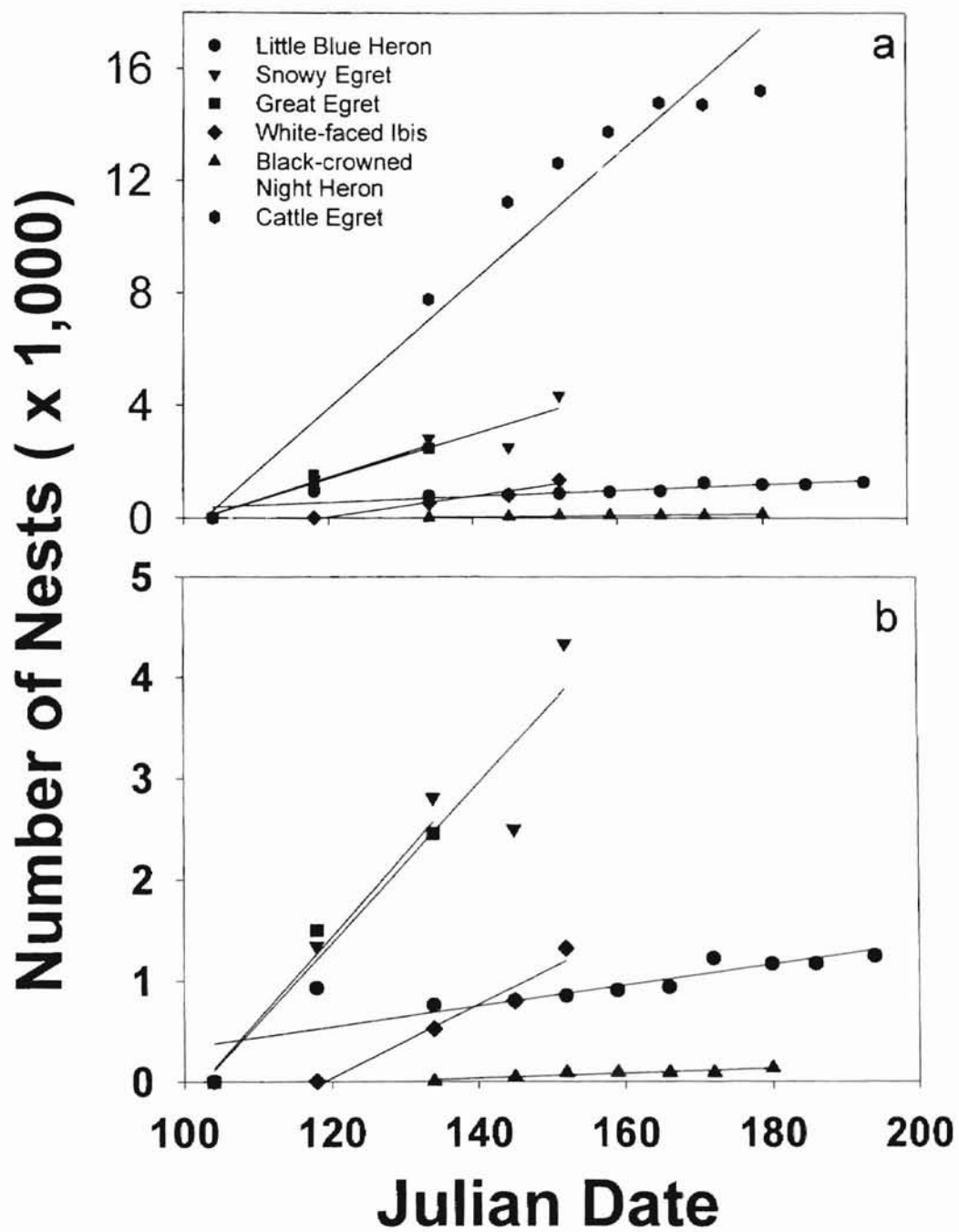
Figure 2. Temporal nesting patterns of the common species of ardeids on Ralstin Island, Oklahoma, 1998 and 1999: a) Cattle Egret, b) Little Blue Heron, c) Snowy Egret, d) Great Egret, e) White-faced Ibis, and f) Black-crowned Night Heron. Curves resulted from regression analyses. Julian dates of 100 and 260 correspond to 8 April and 17 September, respectively.

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Number of Nests

Julian Date

○ ------ 1998   ● ——— 1999   ◉ Estimated

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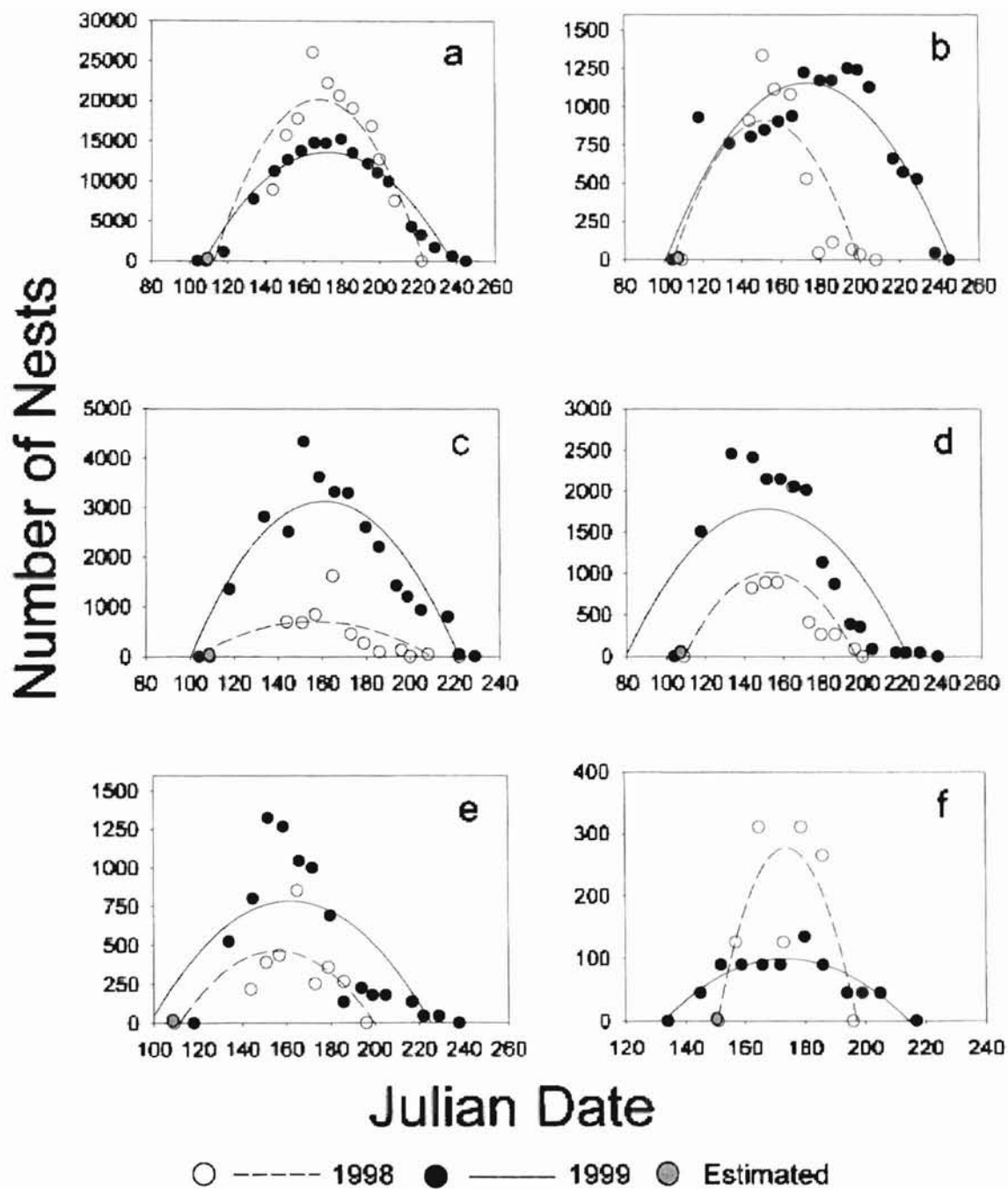
Figure 3. Temporal nesting patterns of common ardeids on Ralstin Island in a, c) 1998 and b, d) 1999, (a, b) with and (c,d) without Cattle Egrets. Julian dates of 100 and 240 correspond to 8 April and 28 August, respectively.

Number of Nests (x 1,000) — Julian Date

Legend:
- Little Blue Heron
- Snowy Egret
- Great Egret
- White-faced Ibis
- Black-crowned Night Heron
- Cattle Egret

○ Estimated

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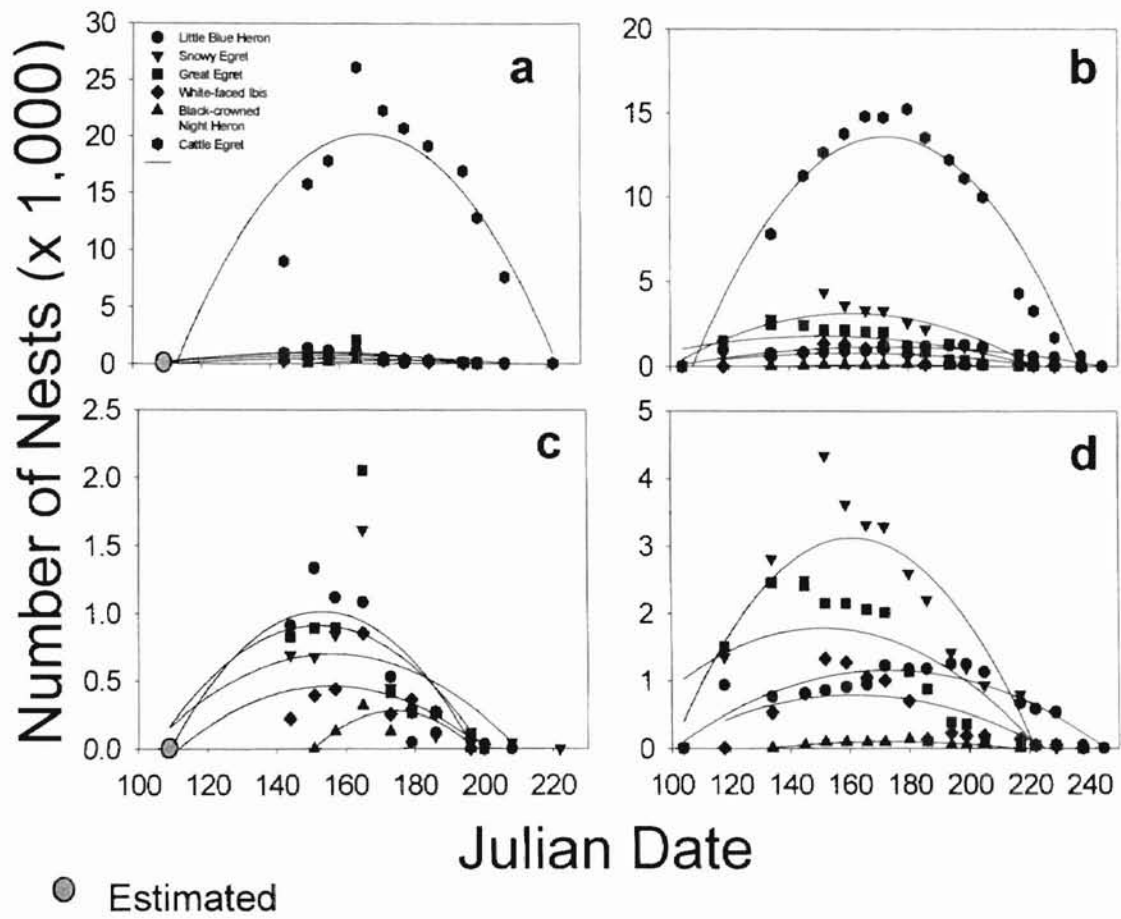
Figure 4. Nest-site characteristics for a) nest height, b) tree height, c) distance to center of tree, d) percent canopy cover, e) diameter of tree, d) diameter of branch. Species with different letters are significantly different (P <= 0.05). Species acronyms: get(*) = Great Egret (Year), lbh = Little Blue Heron, set = Snowy Egret, bcnh = Black-crowned Night Heron, and cet = Cattle Egret.
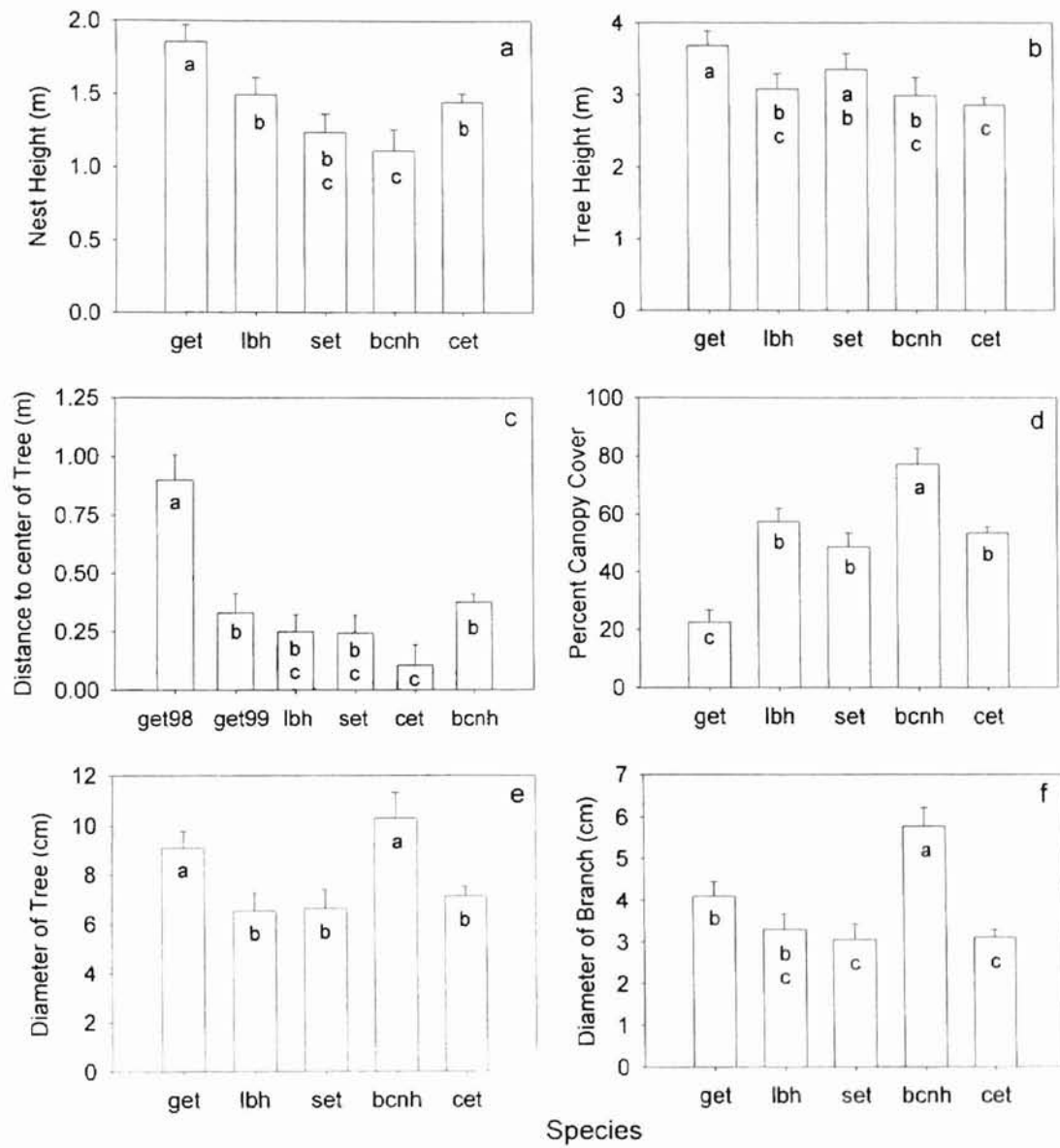
Figure 5. Distances to nest of conspecifics and other species for each of the

common ardeid species on Ralstin Island, Oklahoma. Asterisk indicates

significantly different ($P <= 0.05$) comparisons using t-tests. Species acronyms:

get = Great Egret, lbh = Little Blue Heron, set = Snowy Egret, bcnh = Black-

crowned Night Heron, and cet = Cattle Egret.
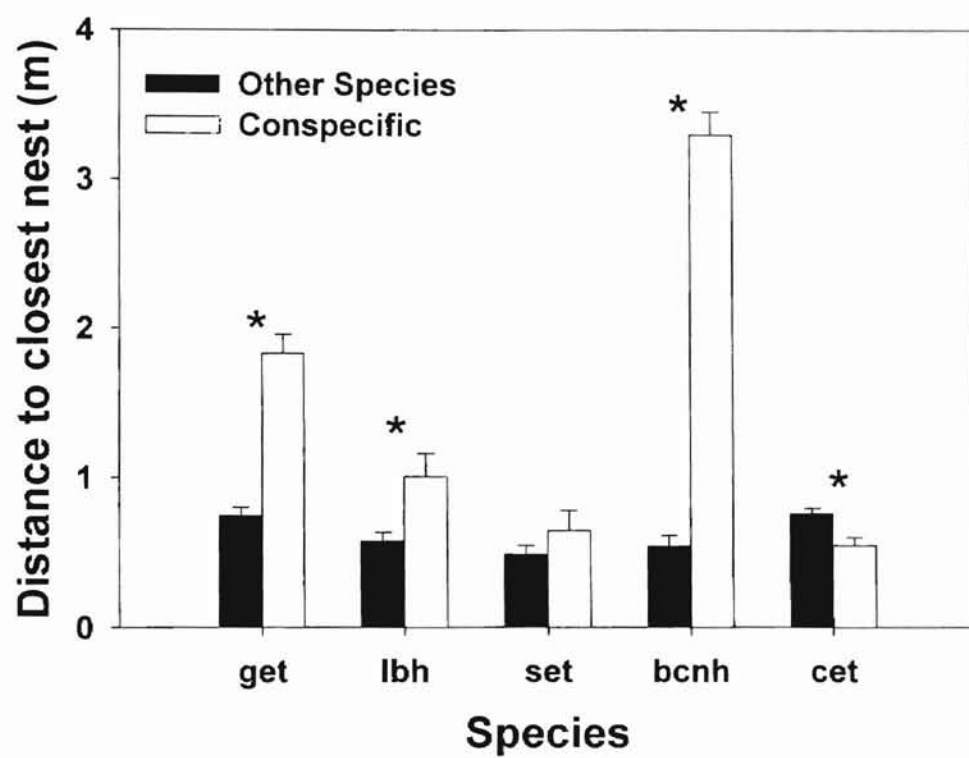
Table 1. Number[1] of Ciconiiform nests on Ralstin Island in northcentral Oklahoma in 1998 and 1999.

Species	1998	1999
Cattle Egret	25,971	15,214
Great Egret	2,049	2,255
Snowy Egret	1,316	4,339
Little Blue Heron	1,334	1,173
Black-crowned Night Heron	311	134
White-faced Ibis	850	1,321
Great Blue Heron	22^2	30^2
Tricolored Heron	1^2	3^2
Total	31,831	24,436

[1] Estimated: density of nests per meter by habitat, multiplied by the total area of habitat.

[2] Actual counts.

Table 2. Habitat use by ardeid species on Ralstin Island during different periods of the breeding season in 1998 and 1999, using chi-square goodness-of-fit tests.

Species	Year	24-25 May		21-22 June		18-19 July	
		X^2	P	X^2	P	X^2	P
Cattle Egret							
	1998	28.7	<0.001	7.31	0.007	27.17	<0.001
	1999	4.15	0.042	1.8	0.18	13.51	0.001
Great Egret							
	1998	0.02	0.884	21.8	<0.001	a	
	1999	39.13	<0.001	53.15	<0.001	1.96	0.161
Snowy Egret							
	1998	9.03	0.003	75.24	<0.001	a	
	1999	3.7	0.054	11.75	0.001	0	1
Black-crowned Night Heron							
	1998	a		9.14	0.003	a	
	1999	b		b		b	
Little Blue Heron							
	1998	20.08	<0.001	30.83	<0.001	a	
	1999	52.88	<0.001	17 95	<0.001	2.01	0.156
White-faced Ibis							
	1998	0.01	0.927	9.14	0.003	b	
	1999	30.99	<0.001	2.56	0.11	b	

a = No birds in survey; b = birds only found in 1 habitat

Table 3. Habitat preference of Ardeid species on Ralstin Island during different periods of the breeding season in 1998 and 1999, using Bonferonii confidence intervals.

Species	Year	Soapberry 24-25 May	21-22 Jun	18-19 July	Cottonwood 24-25 May	21-22 Jun	18-19 July	Salt Cedar 24-25 May	21-22 Jun	18-19 July
Cattle Egret										
	1998	0	0	0	-	-	+	+	+	-
	1999	-	0	0	0	0	+	+	0	-
Great Egret										
	1998	0	0	a	0	-	a	0	+	a
	1999	0	0	0	+	+	0	-	-	0
Snowy Egret										
	1998	0	0	a	+	0	a	-	-	a
	1999	0	0	-	0	+	0	0	-	0
Black-crowned Night Heron										
	1998	a	0	a	a	-	a	a	+	a
	1999	-	-	-	-	-	-	+	+	+
Little Blue Heron										
	1998	0	-	a	+	+	a	-	-	a
	1999	0	0	0	+	+	0	-	-	0
White-faced Ibis										
	1998	0	0	+	0	-	-	0	+	-
	1999	-	0	-	-	0	-	+	0	+

+ = selection, - = avoidance, 0 = no avoidance or selection, a = No birds in survey

Chapter 2

Dietary overlap among Cattle Egrets (*Bubulcus ibis*) and other North American

ardeids

Abstract—Since 1941, when Cattle Egrets (*Bubulcus ibis*) arrived in North America, they have expanded their range considerably. Cattle Egrets are known to breed in most of the contiguous United States and are still increasing their range northward, which has caused scientists to question the possible impact of Cattle Egrets on other ardeids in North America. I assessed the potential of Cattle Egrets to compete for food with other North American ardeids by quantifying food items eaten by nestlings on Ralstin Island in Salt Plains National Wildlife Refuge, one of the largest ardeid breeding colonies in Oklahoma. A total of 464 boluses were collected from nestlings of 5 species of ardeid. Cattle Egrets ate 21 food items in 6 classes. Diets of Cattle Egrets consisted primarily of terrestrial invertebrates; agricultural pests (Orthoptera) made up > 86% of the diet, thus making them beneficial to farmers. Cattle Egrets did not have a large potential to impact other ardeids in the study based on their choice of food items because there was little similarity in the food items consumed by Cattle Egrets and the other ardeids.

INTRODUCTION

Worldwide, populations of Cattle Egrets (*Bubulcus ibis*) have undergone significant range expansion in the past 150 years (Crosby 1972; Siegfried 1978; Telfair 1994). Cattle Egret populations were confined initially to Africa and Asia. In the mid-1800s, Cattle Egrets started to expand their range into southeastern Asia, Indonesia, Australia, and the New World (Telfair 1994). Researchers have

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speculated that expansions of agricultural lands and cattle grazing have helped the Cattle Egret expand their range (Telfair 1994). Cattle Egrets are a relatively new species to North and South America. They arrived in French Guinea in 1877 from Africa; following their initial arrival in South America, they expanded their range into southern Florida by 1941 (Crosby 1972; Siegfried 1978). After arriving in Florida, Cattle Egrets expanded their range considerably, are now known to breed in most of the contiguous United States, and are still increasing their range northward (Telfair 1994). This range expansion has caused scientists to question the possible impact of Cattle Egrets on other North American wildlife including other ardeids (Telfair 1994).

Cattle Egrets are mainly terrestrial predators that feed primarily on invertebrates and, opportunistically, small mammals, reptiles, and birds (Burns and Chapin 1969; Fogarty and Hetrick 1973; Telfair 1981, 1983). Cattle Egrets consume grasshoppers, crickets, moths, beetles, and other agricultural pests (Browder 1973; Telfair 1983). Their diets can contain >83% orthopterans (grasshoppers and crickets; Hanebrink and Denton 1969). In contrast, native ardeids are primarily aquatic predators feeding on fishes, amphibians, aquatic invertebrates, and occasionally, small mammals (Peifer 1979; Telfair 1981). Ardeids are known to partition food resources by size and foraging method (Willard 1977). Great Blue Herons (*Ardea herodias*) catch the largest prey, and although Great Egrets (*Casmerodius albus*) in general take prey that is larger or about the same size as the prey taken by smaller heron species, Great Egrets hunt in deeper water, thus minimizing direct interspecific competition (Willard

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1977). Smaller ardeids (Tricolored Heron, *Egretta tricolor*; Little Blue Heron, *Egretta caerulea*; Snowy Egret, *Egretta thula*) share the same prey base but utilize specialized hunting methods, which reduces competitive interactions (Willard 1977).

The objectives of this study were to quantify dietary overlap of ardeids in northcentral Oklahoma (with particular emphasis on the food habits of Cattle Egrets) and assess the potential of Cattle Egrets to impact other ardeids based on their diets. Dietary information will give refuge managers at Salt Plains National Wildlife Refuge (NWR) a measurement of what Cattle Egrets and other ardeids are eating so that they can respond to concerns of local residents about ardeids' feeding habits and their impact upon native wildlife.

STUDY AREA

The study was conducted on Ralstin Island (36°75' N, 98°18' W) in Salt Plains National Wildlife Refuge (NWR) in Alfalfa County in northcentral Oklahoma. Ralstin Island measured 500 m by 150 m (<3.23 ha) in 1998, and its highest point was 3.05 m above mean lake level (Martinez 1998). The primary soil type was sand, and vegetation was predominantly salt-cedar (*Tamarix gallia*) but also included cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), mulberry (*Morus laevigata*), western soapberry (*Sapindus drummondii*), black willow (*Salix nigra*), and American elm (*Ulmus americanus*). Forbs on the Island

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included nightshade (*Solanum elaeagnifolium*) and pokeweed (*Phytolacca americana*).

The breeding bird community on Ralston Island consisted of 11 species belonging to 3 different orders. Two Anseriformes were present: Canada Goose (*Branta canadensis*) and Mallard (*Anas platyrhynchos*). Passeriformes were represented by only 1 species, the Great-tailed Grackle (*Quiscalus mexicanus*). Eight Ciconiiformes bred on the Island: Great Blue Heron, Great Egret, Little Blue Heron, Snowy Egret, Tricolored Heron (Feirer and Sheppard 1999), Cattle Egret, Black-crowned Night Heron (*Nycticorax nycticorax*), and White-faced Ibis (*Plegadis chihi*; Koenen et al. 1996; Shepperd 1996).

METHODS

When nestling ardeids become disturbed or excited, they regurgitate food boluses, consisting of undigested food items from the most recent meal of the bird (Jenni 1969). Food items identified from regurgitated boluses from nestlings were representative of what adult ardeids consumed (Siegfried 1971; Telfair 1983, 1994). A total of 464 boluses were collected from chicks of 5 common species of ardeid on Ralstin Island: Great Egret, Snowy Egret, Cattle Egret, Little Blue Heron, and Black-crowned Night Heron. When boluses were found, the species that had regurgitated the bolus was identified. When a bolus consisted of large food items, it was dissected on the Island. If a bolus contained many food items or items that were not easy to identify, they were collected and taken

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back to the lab for later identification under a dissecting scope. All food items were identified to the Family level when possible. Their length in centimeters were noted, and their frequency tallied.

Following identification of food items in the boluses, their percent abundance in the diet of each species and percent frequency in the total number of boluses of each species were calculated.

Four analyses were conducted to ascertain the degree of similarity of diets of the 5 ardeids in the study. Detrended Correspondence Analysis (DCA) was used to show similarities of the 5 species (including Cattle Egrets) and their diets, and then another DCA was used to show the relationship of 4 ardeids (excluding Cattle Egret). DCA is a technique that predicts gradients from distributions of sites and sample scores in multivariate space (Hill and Gauch 1980; Gauch 1982). In this study, the 5 ardeids were the equivalent to sites and dietary items were the samples.

Pianka's measurement of niche overlap (Pianka 1973) was used to quantify overlap between dietary niches of ardeids. Pianka (1973) stated that niche overlap of >60% was considered high and the potential for competition between species was possible, but when 2 species have high overlap, it does not mean that they are competing because they may be using other resource partitioning to minimize competition.

Bray-Curtis Cluster Analysis (Bray and Curtis 1957) was used to obtain a quantitative measurement of dietary similarities between the 5 ardeids. The Bray-Curtis Cluster Analysis was obtained using the Bray-Curtis similarity index

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and Euclidian distances between diets of each species. The Bray-Curtis similarity index ranged from 0 to 100, with an index of 100 being equivalent to complete similarity.

RESULTS

Cattle Egrets consumed 21 food items in 8 Classes (Table 1). Insecta had the greatest percent abundance; 92.1% of items in Cattle Egret boluses were insects. Within the Insecta, Orthopterans (grasshoppers and crickets) had the highest percent abundance (87%) and frequency (94.7%) in boluses of Cattle Egrets. The Classes Arachnida and Amphibia also were important; both occurred in about 5% of boluses of Cattle Egret. Several mammals and reptiles were found in boluses of Cattle Egret, including 2 white-footed deer mice (*Peromyscus leucopus*), 1 ground skink (*Scincella lateralis*), and 2 western ribbon snakes (*Thamnophis proximus*).

Black-crowned Night Herons ate 8 food items in 2 Classes (Table 1). Black-crowned Night Herons were the only species in the study to consume other species in the Class Aves. Aves (all Ardeidae) made up 41.7% of the diet of Black-crowned Night Herons. The remainder of the diet (68.4%) was comprised of fishes; the Families Centrachidae and Cyprinidae were utilized equally (29.2%; Table 1). Black-crowned Night Herons predominantly ate fishes that were 10-15 cm in length (Table 2).

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Great Egrets ate 17 food items in 4 Classes (Table 1). Over 60% of their diet consisted of fishes; 34.4% were Centrachidae. Amphibians (20.3%) and Crustaceans (17.1%) also were common in the diets of Great Egrets. Great Egrets ate fishes that for the most part ranged in length from 2 to 7 cm (Table 2).

Snowy Egrets ate 15 food items in 5 Classes (Table 1). Snowy Egret diets were comprised predominantly of fishes (81%). Cyprinidae (54.4%) and Centrachidae (24.3%) were most commonly consumed by Snowy Egrets. Snowy Egrets ate fishes that mostly ranged in length from 2 to 5 cm in length (Table 2).

Little Blue Herons ate 13 food items in 5 Classes (Table 1). Fishes were the predominant (79.7%) class of prey in their diets. Similar to Snowy Egrets, Centrachidae (60.3%) and Cyprinidae (19.2%) were most abundant in the diets of Little Blue Herons. Little Blue Herons ate fishes that mainly ranged in length from 0 to 2.54 cm (Table 2).

The first DCA with the 5 ardeids (including Cattle Egrets) produced 2 distinct groups; Cattle Egrets in a group of their own, separated from the other ardeids (Figure 1A). The first 2 axes in the analysis were a gradient of size of aquatic prey and another of habitat of food item. Dietary items of Cattle Egrets were clustered toward the terrestrial end of the habitat of food-item gradient with the other 4 ardeids clustered toward the aquatic end of the gradient. The gradient of size of aquatic prey did not pertain to diets of Cattle Egrets; Cattle Egret diets showed little variation along that axis. The second DCA excluding Cattle Egrets showed a high degree of overlap among the 4 ardeids along gradients of size of aquatic prey and habitat of food item (Figure 1B).

Pianka's measurement of niche overlap showed that Cattle Egrets had little overlap with the other 4 species of ardeid; their niche overlap ranged from 0% with Black-crowned Night Herons to 1.3% with Great Egrets (Table 3). Generally, Black-crowned Night Herons had little overlap with the other species, ranging from 0% with Cattle Egret to a high of 8.3% with Great Egret. The other 3 species had overlap values ranging from 56.7% to 73.3% with each other. The similarly sized Snowy Egret and Little Blue Heron had a niche overlap of 58.5%, showing a high degree of niche overlap.

The Bray-Curtis Cluster Analysis yielded a dendrogram showing 2 distinct groups based on food items. Cattle Egrets were the sole member in 1 branch and the other Ardeids were on the other branch (Figure 2). Within the branch containing the 4 ardeids, the Black-crowned Night Heron was the least similar to the 4 others. The Great Egret was then broke out on to a branch of its own, leaving Snowy Egret and Little Blue Heron as the most similar in terms of diet.

DISCUSSION

Boluses of Cattle Egrets primarily contained terrestrial prey. Their diets were diverse and contained members of 21 Families in 8 Classes, including invertebrates (Crustacea, Annelida, Arachnida, and Insecta) and vertebrates (Amphibia, Reptilia, Mammalia, and Actinopterygii; Table 1). The most numerous food items found in Cattle Egrets boluses were from the Class Insecta,

composing >92% of the food items eaten; Orthopteran comprised >87% of the total food items found in boluses. Diets of Cattle Egrets in this study were consistent with those in the literature. Many studies have shown that Orthopterans are the main food items taken by Cattle Egrets (Burns and Chapin 1969; Hanebrink and Denton 1969; Telfair 1983). Orthopterans, considered agricultural pests (Browder 1973; Telfair 1983), were consumed in high percentages by Cattle Egrets on Ralstin Island, making these birds possibly beneficial to farmers. Browder (1973) and Telfair (1983) also speculated that Cattle Egrets were beneficial to farmers in Florida and Texas. Actinopterygii (<1%) and Crustacea (<1%) were the only prey in the diets of Cattle Egrets that were solely aquatic. I speculate that those items were scavenged by Cattle Egret chicks on the Island after an adult or chick of another ardeid regurgitated these items.

Boluses of Black-crowned Night Heron were the least diverse of the 5 ardeids in this study; members of only 8 Families and 2 Classes were found in their diets (Table 1). Black-crowned Night Herons ate fishes of larger size than all other species; the majority of the fishes consumed by Black-crowned Night Herons exceeded 10 cm in length. Black-crowned Night Herons were the only ardeids to consume Aves in this study, and they ate other ardeids on the Island. On numerous occasions, I witnessed Black-crowned Night Herons chicks forage on young of other ardeids around their nests. Black-crowned Night Herons are known to consume other birds and chicks of other ardeids (Marshall 1942; Kale 1965; Collins 1970; Wolford and Boag 1971; Shealer and Kress 1991).

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Great Egret, Little Blue Heron, and Snowy Egret diets contained primarily aquatic prey from 2 Families of fishes (Centrachidae and Cyprinidae) and amphibians (Table 1). Those 3 ardeid species differed somewhat in the proportions and size of aquatic prey eaten. Great Egret consumed these 3 types of food in relatively equal proportions (Table 1), and lengths of food items ranged from 2.54 to 10.16 cm (Table 2). Little Blue Herons and Snowy Egrets consumed amphibians in small amounts (<11%) compared with Great Egrets (20.3%). In contrast with the Great Egret, Little Blue Herons and Snowy Egrets used the 2 types of fishes in differing proportions; Centrachidae made up >60% of the diet of Little Blue Herons and Cyprinidae made up >54% of the diet of Snowy Egrets. The size of aquatic prey eaten by the two species differed; Little Blue Herons ate mostly fishes <3 cm in length, and Snowy Egrets ate fishes <8 cm in length (Table 2). The difference in size and use of prey among Great Egrets, Little Blue Herons, and Snowy Egrets may be caused by their use of different foraging habitat (Jenni 1969; Willard 1977; Hom 1983) or foraging behavior (Willard 1977). Jenni (1969), Willard (1977), and Hom (1983) found that these species foraged in different habitats (depth of water) and Willard (1977) found that these species ate prey that were of different sizes and they used different hunting techniques, thus minimizing competition.

In this study, fishes made up the majority of the diet for Great Egrets (60.3%), Little Blue Herons (79.7%) and Snowy Egrets (81.3%; Table 1). Frederick et al. (1999) found that large fishes made up >95% of the biomass in the diet of the Great Egret, and Miranda and Collazo (1997) found that most of

the Great Egrets diet consisted of fishes. In relation to other studies, diets of Little Blue Heron were considerable higher in the proportion of the diet that contained fishes than other studies. Rodgers (1982) found that fishes made up only 34% of the diet for Little Blue Herons in Florida, and Parsons (1994) found that fishes only made up 49% of the diet in Delaware. The aquatic system at Salt Plains National Wildlife Refuge may not be as diverse in aquatic prey as the habitat in these other studies, thus making the Little Blue Herons more dependent on fishes in this study. Snowy Egret diets in this study were similar to those found in the literature; in several studies, diets of Snowy Egrets contained >60% fishes (Jenni 1969; Telfair 1981; Post 1990). Jenni (1969) found that diets of Snowy Egrets in Florida contained 87% fishes. Post (1990) in South Carolina and Telfair (1981) in Texas found that fishes made up 64% and 60% of the diet of Snowy Egrets, respectively.

The first DCA placed the diet of Cattle Egrets separate from all other species, which were relatively clumped together (Figure 1). Cattle Egrets are known to feed primarily in terrestrial habitats (Telfair 1994), whereas the other 4 ardeids are known to forage in aquatic habitats (Willard 1977; Rodgers 1983; Heitmeyer 1986; Telfair 1994). The differentiation seen on the food item-habitat axis was not unexpected for Cattle Egrets, but the amount of overlap of the other ardeids was. The clumping of the other ardeids was caused by the aquatic prey that they consume, which caused them to clump together on the food-item-habitat axis, but I expected to see greater differentiation on the size-of-aquatic prey axis. Great Egrets, Little Blue Herons, and Snowy Egrets are known to

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partition resources based on the size of prey (Willard 1977). The second DCA was used to show the difference of the other ardeids with Cattle Egret excluded; the DCA continued to show high amounts of overlap in the diets of these species (Figure 1B). When I analyzed aquatic prey based on the relative abundance of the size classes of prey (Table 2), I found that the 4 aquatic ardeid species were eating differently sized prey within the same Families, as was found by Willard (1977); this was not illustrated by the DCA analysis.

Pianka's measurement of niche overlap quantified the amount of overlap between the 5 species (Table 3) and Bray-Curtis Cluster Analysis compared similarities of the 5 species' diets (Figure 2). Both of these analyses showed that Cattle Egrets had almost no overlap and relatively low similarity with any of the ardeid species in the study. Therefore, Cattle Egrets likely are not impacting other ardeids along a food-resource gradient. Black-crowned Night Herons also had low niche overlap and relatively low similarity with Great Egrets, Little Blue Herons, and Snowy Egrets in this study. Black-crowned Night Herons consumed other ardeid chicks, a food source that no other ardeids in this study used. In general, Great Egrets, Little Blue Herons, and Snowy Egrets had high overlap and similarity in their diets (>56 %). In a study by Miranda and Collanzo (1997), Great Egrets and Snowy Egrets were found to have a high degree of overlap (54%), and both species had low overlap with Little Blue Herons. However, high overlap does not necessarily indicate competition; they might be partitioning resources in some other way. As stated earlier, ardeids in this study may be partitioning resources along time, space, or behavioral gradients. Black-

crowned Night Herons are known to forage at different times of the day than "day herons" (Kushlan 1973; Willard 1977). The other ardeids are known to forage in different locations in the same habitat (Willard 1977).

In summary, Cattle Egret diets differed from the diets of the other ardeids in the study. Cattle Egrets ate terrestrial prey, and the other ardeids ate mostly aquatic prey. Cattle Egrets may be beneficial to agriculture because their diets contained high percentages of Orthopterans. The 4 analyses that were conducted on the diets of these ardeid species indicated that the diet of Cattle Egrets had little similarity to that of the other ardeids. Black-crowned Night Herons diets were not similar to the other ardeids; their diets were found to contain other ardeid nestlings and larger fishes. Diets of Snowy Egrets, Little Blue Herons, and Great Egrets were similar, but those species may have been partitioning food resources based on behavior or foraging location.

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Figure 1. Detrended Correspondence Analysis showing A) similarities of the 5 ardeid diets (Cattle Egret diets have no overlap with the other ardeids; in contrast, the other ardeids have high overlap) and B) dietary similarities excluding Cattle Egrets from the analysis.
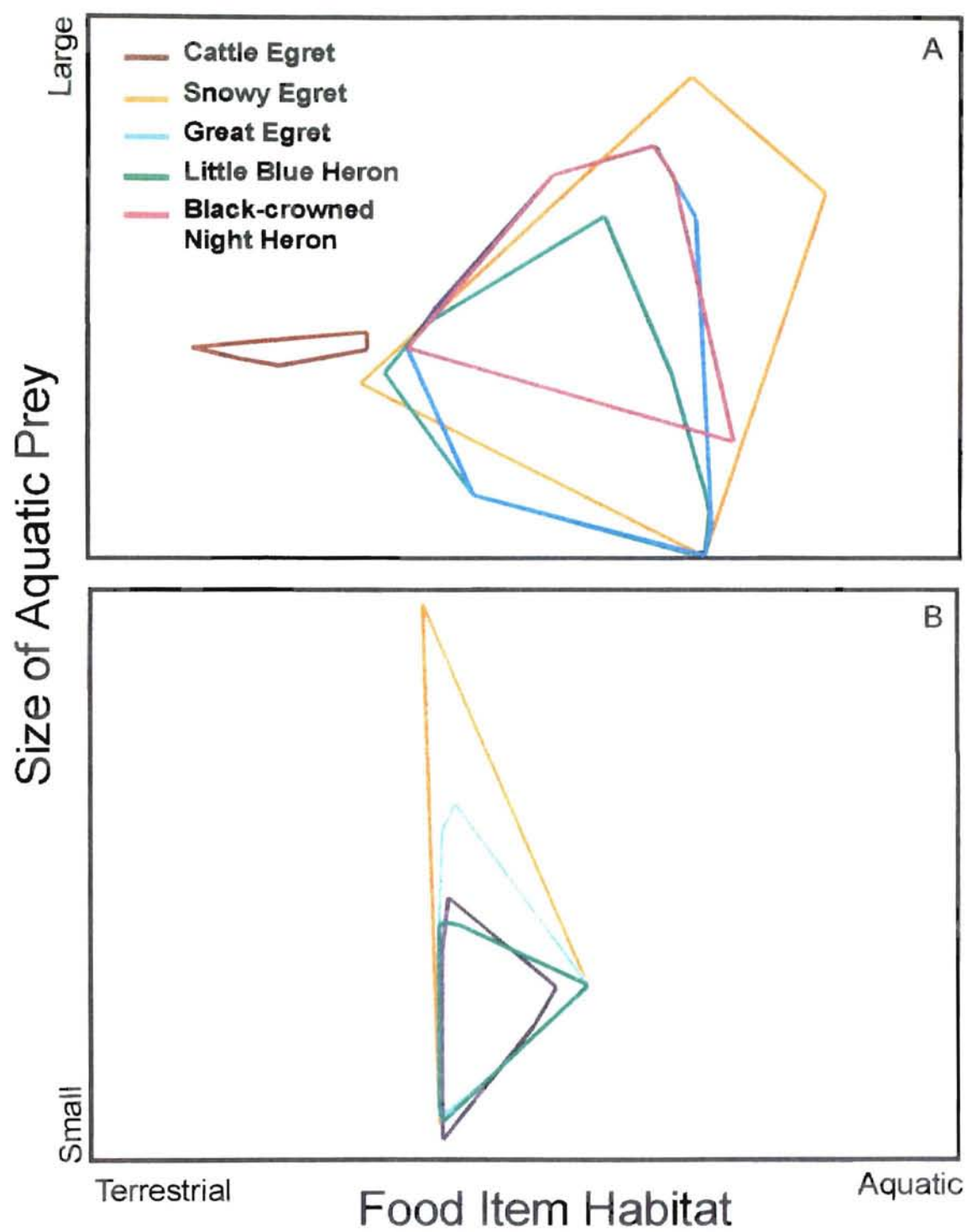
Figure 2. Dendrogram of the similarities of 5 ardeid diets on Ralstin Island using
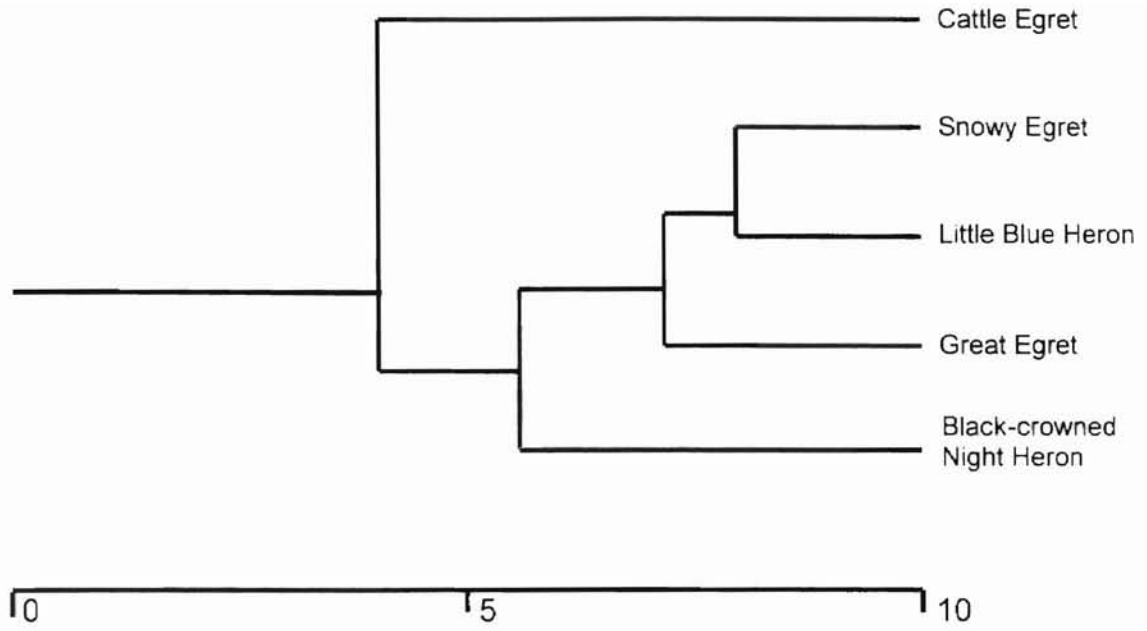
Bray-Curtis Cluster Analysis.

Cattle Egret

Snowy Egret

Little Blue Heron

Great Egret

Black-crowned
Night Heron

0   5   10

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Table 1. Dietary analysis of 5 ardieid species on Ralstin Island, based on regurgitated boluses from nestlings. Diets are expressed in both relative abundance (Rel. abun.; percentage of total number of food items) and relative frequency (Rel. freq.; percentage of boluses containing food item).

Class	Black-crowned Night Heron		Cattle Egret		Great Egret		Little Blue Heron		Snowy Egret	
	Rel. abun. (24)[a]	Rel. freq. (13)[b]	Rel. abun. (9553)[a]	Rel. freq. (281)[b]	Rel. abun. (1010)[a]	Rel. freq. (88)[b]	Rel. abun. (452)[a]	Rel. freq. (43)[b]	Rel. abun. (493)[a]	Rel. freq. (39)[b]
Insecta										
Orthoptera	0	0	87.0	94.7	0	0	0.2	2.3	0	0
Other Insects	0	0	5.1	50.2	2.4	5.7	3.5	20.9	1.0	7.7
Arachnida	0	0	5.3	50.9	0	0	1.4	2.3	0	0
Amphibia	0	0	2.0	35.9	20.3	27.3	10.6	44.2	6.1	15.4
Mammalia	0	0	0	0.7	0	0	0	0	0	0
Aves	41.7	53.8	0	0	0	0	0	0	0	0
Reptilia	0	0	0.1	1.8	0	0	0	0	0	0
Actinopterygii										
Cyprinidae	29.2	23.1	0	0	23.7	44.3	19.2	23.3	54.4	74.4
Centrachidae	29.2	46.2	0	0.4	34.4	54.5	60.3	53.5	24.3	17.9
Clupeidae	0	0	0	0	2.2	2.3	0.2	2.3	2.6	5.1
Crustacea	0	0	0	0.4	17.1	25.0	4.4	20.9	3.2	10.3
Annelida	0	0	0.4	0.7	0	0	0	0	8.3	2.6

[a] Total number of food items per species

[b] Total number of boluses per species

Table 2. Size of aquatic prey for 4 aquatic ardeids on Ralstin Island, based on regurgitated boluses from nestlings. Diets are expressed in both relative abundance (Rel. abun.; percentage of total number of food items) and relative frequency (Rel. freq.: percentage of boluses containing food item).

Size (cm)	Black-crowned Night Heron		Great Egret		Little Blue Heron		Snowy Egret	
	Rel. abun. $(14)^a$	Rel. freq. $(13)^b$	Rel. abun. $(608)^a$	Rel. freq. $(88)^b$	Rel. abun. $(361)^a$	Rel. freq. $(43)^b$	Rel. abun. $(401)^a$	Rel. freq. $(39)^b$
2.54	0	0	38.816	9.091	82.548	27.907	41.895	12.821
5.08	21.429	15.385	16.612	19.318	9.972	16.279	45.137	46.154
7.62	7.143	7.692	29.276	34.091	6.648	20.930	12.219	30.769
10.16	35.714	15.385	13.816	23.864	0.831	4.651	0.748	5.128
12.7	28.571	23.077	1.151	5.682	0	0	0	0
15.24	7.143	7.692	0.329	2.273	0	0	0	0

[a] Total number of food items per species

[b] Total number of boluses per species

Table 3. Pianka's measurement of niche overlap (Pianka 1973) for 5 ardeids on Ralstin Island, showing the amount of dietary overlap between the different species of ardeid.

	Black-crowned Night Heron	Cattle Egret	Great Egret	Little Blue Heron	Snowy Egret
Black-crowned Night Heron	0		8.315	3.650	4.226
Cattle Egret			1.257	0.882	0.444
Great Egret				73.268	56.686
Little Blue Heron					58.548

Chapter 3

GIS study of Ralstin Island and its rate of erosion and vegetative succession

Abstract—A Geographic Information System (GIS) was used to analyze the historical rate of erosion and vegetative change on Ralstin Island in Salt Plains National Wildlife Refuge, Oklahoma. Historical aerial photographs of Ralstin Island from 1941 to 1998 were used in the GIS analysis. The island size decreased by 89% in the past 57 years and went through rapid succession from a grass-covered island to being dominated by trees and shrubs. The Island became inhabited by ardeids in the mid-1970s when trees and shrubs made up >50% of the total Island area. In the 1990s, percentages of trees and shrubs on the Island began to decrease; nesting ardeids may decreasing the vegetation on the Island through destruction of trees for nesting material or guanofication, but the extent of this impact is currently unknown.

INTRODUCTION

Since the completion of the Great Salt Plains Dam in 1941, Ralstin Island has eroded continuously by wave action and effects of ice scouring. The United States Fish and Wildlife Service (USFWS) is currently taking an active role in preserving Ralstin Island and its diversity of Ciconiiformes (herons, egrets, and ibises). Personnel at Salt Plains NWR have tried several methods to halt erosion, including placement of large hay bales, a Quikcrete™ wall, and expandable wall structures from the Army Corps of Engineers. These methods were implemented to form a barrier intended to slow erosion caused by wave action and increase sedimentation; none were effective. The proposed solution

to this 57-year-old problem is the construction of 9 artificial islands (6.1 m by 30.5 m) off the southwestern corner of Ralstin Island (Figure 1). These islands are intended to stop current erosion by diverting waves from the southwest (the predominant direction of wind and waves) from hitting the Island and cause deposition of sand and silt behind them. These artificial islands themselves will provide 0.15 ha of new habitat (Martinez 1998), and potential sedimentation behind the islands could produce an additional 1 ha of land (Martinez 1998).

The size of Ralstin Island has been changed by erosion, and the Island's vegetation has been altered both by the ciconiiform community that it supports and vegetative succession. Many studies have found that nesting ciconiiforms have a negative impact on vegetation in a colony (Gilham 1960; Jenni 1969; Weseloh and Brown 1971; Burandt et al. 1977; Weise 1978; Arendt and Arendt 1988). Activity of ciconiiforms can cause minor to serious damage to twigs and green vegetation of trees in the colony (Jenni 1969; Arendt and Arendt 1988); they also may negatively impact vegetation through deposition of wastes on the soil substrate (Gilham 1960; Weseloh and Brown 1971; Weise 1978) and plant parts (Burandt et al. 1977). Weise (1978) found that 60% of shrubs in a colony in Delaware were defoliated and as many as 8% were killed by the birds' activities in a single breeding season. Such negative impacts on the vegetation of the colony require that colony locations be changed frequently (Telfair 1980).

This study had 2 goals. The first was to quantify the rate at which Ralstin Island has eroded, allowing an estimate as to how long the Island might persist given no intervention; managers at Salt Plains NWR require this information to

assess effectiveness of their attempts to restore the Island. The second goal was to provide a baseline habitat characterization, useful to refuge managers for quantifying habitat changes caused by Island remediation and ciconiiforms themselves.

LITERATURE REVIEW OF GIS AND ITS USE IN ORNITHOLOGY

The ability to fly has allowed birds to inhabit every continent on earth, from the hot and humid tropics to the frigid land of Antarctica (Welty 1975). Many species have developed complex migratory behaviors that often encompass thousands of kilometers (Welty 1975; Gill 1995). These flights usually are undertaken twice a year, primarily in the beginning and end of the breeding season. Not only has evolution of flight enabled the formation of complex migratory routes, it also has allowed birds to use greater amounts of their local environment (habitat) for breeding and foraging territory (Welty 1975; Gill 1995). In brief, birds migrate over great distances that involve large spatial scales at the geographic level, but description of use of their local habitat requires assessment at a micro–landscape scale. At each of these scales (geographic, landscape, and micro), GIS is an appropriate tool for discerning characteristics of habitats selected by birds, making it possible to predict species' distributions.

Baker et al. (1995) used a GIS to show how habitat requirements of the Sandhill Crane (*Grus canadensis*) change over spatial scales; as scale decreased, the information gained became less informative. Pearlstine et al.

(1995) used a GIS to spatially analyze the habitat of several Florida birds, including wading birds (Ciconiiformes) and Sandhill Cranes (Gruiformes). The species in the study were chosen because preservation of their habitat was of particular concern. The GIS was developed to analyze the impact of citrus developments in southwestern Florida on the habitat of these species; over 66% of the habitat used by the species studied was predicted to be lost.

By using classified Landsat images in a GIS, Lyon(1983) characterized potential nesting habitat of American Kestrel in Oregon, permitting prediction of where nesting kestrels would likely be found. The GIS was found to be 70% accurate in its characterization of breeding habitat of kestrels. Similarly, Stoms et al. (1993) used a GIS and recent historical sighting data of California Condors (*Gymnogyps californianus*) to evaluate loss of habitat and the concurrent decline of the species. The researchers found that only 58% of the California Condors' former habitat remained. Bosakowski et al. (1996) used GIS to spatially determine features of the nesting habitat of the Swainson's Hawk (*Buteo swainsoni*) and Red-tailed Hawk (*Buteo jamaicensis*). They used nest counts from an extensive search and plotted nests on a base layer created from landuse–landcover maps. They found that the 2 species had similar, overlapping nesting habitat requirements.

GIS was used by Carey et al. (1992) to characterize parameters affecting distribution of the Northern Spotted Owl (*Strix occidentalis caurina*). Many factors were compared, including prey availability and habitat preference. Owls preferred old-growth stands, which consequently had the highest densities of the

owl's principle prey, the Northern Flying Squirrel (*Glaucomys sabrinus*). Berbach et al. (1993) also examined the Northern Spotted Owl habitat requirements to assess the adequacy of the recovery plan; they examined landscapes in 3 Californian counties to see if the owls' habitat requirements could be met. The researchers found 91% of the counties' forested landscape would satisfy the needs of Northern Spotted Owls.

Liu et al. (1994) used GIS to examine the effects of managing South Carolina forests for Red-cockaded Woodpecker (*Picoides borealis*) on Bachman's Sparrow (*Aimophila aestivalis*). They combined a demographic model of the sparrow population with the GIS model of the forest-management scheme and found that it would negatively impact the sparrow but that with minor changes in the forest management scheme, the sparrow would be minimally impacted.

STUDY AREA

Ralstin Island (36°75' N, 98°18' W) is located in Salt Plains National Wildlife Refuge (NWR) in Alfalfa County in northcentral Oklahoma. The Island is situated in the northeastern corner of Great Salt Plains Lake. Ralstin Island was created when rising waters of the Salt Fork of the Arkansas River inundated the surrounding rangeland following completion of Great Salt Plains Dam in 1941. Since creation of Ralstin Island in 1941, erosion by wind and ice has reduced it in size from approximately 60 ha in 1941 (Koenen et al. 1996) to 3.23 ha in 1997

(Martinez 1998). Ralstin Island presently measures 500 m by 150 m (<3.23 ha); the highest point is 3.05 m above mean lake level (Martinez 1998). The primary soil type is sand, and vegetation is predominantly exotic salt-cedar (*Tamarix gallia*) but includes cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), mulberry (*Morus laevigata*), western soapberry (*Sapindus drummondii*), black willow (*Salix nigra*), and American elm (*Ulmus americanus*) (Figure 2). Forbs on the Island include nightshade (*Solanum elaeagnifolium*) and pokeweed (*Phytclacca americana*).

METHODS

In 1998 and 1999, the breeding bird community on Ralstin Island consisted of 11 species belonging to 3 different orders. Two Anseriformes were present: Canada Goose (*Branta canadensis*) and Mallard (*Anas platyrhynchos*). Passeriformes were represented by only 1 species, the Great-tailed Grackle (*Quiscalus mexicanus*). Eight Ciconiiformes bred on the Island: Great Blue Heron (*Ardea herodias*), Great Egret (*Casmerodius albus*), Little Blue Heron (*Egretta caerulea*), Snowy Egret (*Egretta thula*), Tricolored Heron (*Egretta tricolor*, Feirer and Shepperd 1999), Cattle Egret (*Bubulcus ibis*), Black-crowned Night Heron (*Nycticorax nycticorax*), and White-faced Ibis (*Plegadis chihi*; Koenen et al. 1996; Shepperd 1996).

Historical aerial photographs of Ralstin Island and the surrounding area from 1941, 1954, 1961, 1966, 1973, 1984, 1989, 1995, and 1998 were obtained

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from the USFWS at Salt Plains NWR and the Oklahoma State University Map Library. Aerial photographs were scanned digitally on a large format scanner at 300 dpi (dots per inch) in 256-bit grayscale (Figure 3). All aerial photographs were georeferenced with ground control points that were collected in summer 1998 using a military-grade global positioning system (GPS). Aerial photographs were georeferenced using Arcview© and the Image Analysis Extension. The coordinate system used in georeferencing was Universal Transverse Mercator (UTM) zone 14, North American Datum 1983 (Nad83), and the Clarke 1880 spheroid. Following georeferencing, aerial photographs were classified using the ISODATA /unsupervised classification scheme and a mask polygon of the Island (the outline of the Island was digitized using a digitizing tablet; this process constrained the classification to only the area covered by the polygon). Using Image Analyst, 30 classes were created that represented different vegetation types on the Island. After classification, the image was converted to a grid in Arcview©, using the "CONVERT TO GRID" command. The grid layer had a cell size of 2 m by 2 m to correspond with size of quadrats in 1998 and 1999 censuses of nesting ardeids (see Chapter 1). The grid was classified to the 3 habitat types of interest on the Island: sand, grass-forb, and tree-shrub. The GIS was used to calculate total area of the Island and each of the 3 habitat types for each year.

Regression analyses were conducted on the total area of island size versus year and percentage of each habitat type versus year. To remove the effect of decreasing island size from the analysis of vegetative change on the

Island, percentage of each habitat type per year was used instead of total area of each habitat type. Results of regression analyses provided an estimate of the rate (or slope) of erosion and habitat change on Ralstin Island.

RESULTS

By 1998, Ralstin Island had decreased in size by 89% from its size in 1941 (Figure 4 and 5). The decrease in island size was not distributed evenly over the entire Island; the Island predominantly eroded northward from its southern tip. The regression of total island size versus year yielded the best fit with a third-order polynomial regression ($r^2 = 0.99$, Figure 5).

$$y = 2437601.559 - 3687.845 \ (x) + 1.860 \ (x)^2 - 0.0003 \ (x)^3$$

Hence, the rate of Island erosion since 1941 has not been constant.

Vegetative succession progressed on Ralstin Island quite rapidly (Figure 6). Although the Island decreased in total area, trees and shrubs were still developing quickly. In 1941, there were no trees or shrubs on the Island, but by the early 1970s, > 50% of the Island was made up of trees and shrubs, and by 1998, 46% of the Island consisted of trees and shrubs. Trees and shrubs began to decrease on the Island in the 1990s. Trees and shrubs versus year had a regression line that best fit the data with a second-order polynomial equation ($R^2 = 0.87$, Figure 6).

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$$y = -1413.548 + 1.425\ (x) - 0.0004\ (x)^2$$

Grasses and forbs made up the majority of vegetation on the Island in 1941, decreasing over time to the present level of only 12%. Grass and forbs versus year had a regression line that best fit the data with a second-order polynomial equation ($R^2 = 0.90$, Figure 6).

$$y = 855.020 - 0.855\ (x) + 0.0002\ (x)^2$$

DISCUSSION

A constant rate of erosion on Ralstin Island was not noted from the regression analysis, but the different rates of erosion over time that were seen can be explained (Figure 5). In the years immediately following completion of the Great Salt Plains Dam in 1941, the Island's rate of erosion was high. The Island in 1941 eroded rapidly because it was primarily sand covered with sparse grasses; soils that lack vegetative cover (grasses and forbs) are known to erode quickly (Walker 1983). Following this initial rapid decrease in island size in the 1940s and early 1950s, the rate of erosion slowed, stabilized, and appeared to remain constant until about the mid-1980s, likely as a result of rapid vegetative succession of the Island (Figure 6). With the increase of trees and shrubs on the Island in the 1950s and 1960s, the extensive root layers and the organic

matter of these plants probably were better able to hold soil in place. During the 1990s, refuge personnel also began to take an active role in trying to halt erosion on the Island, which further explains the reduction in erosion. Although the rate of Island erosion has slowed, it is still eroding and potentially could be gone by the early part of the next century.

While vegetative succession possibly slowed the rate of erosion by making the substrate more stable, it also created suitable ardeid nesting habitat. A breeding colony was not known to exist on the Island until the late 1970s (Sullivan 1979). The first records of ardeids nesting on the Island coincide with the Island's trees and shrubs exceeding 50% cover. The vegetation allowed the ardeid population to increase, but now the ardeid colony may be having a negative impact on the vegetation. By the 1990s, trees and shrubs were decreasing on the Island. The ardeids may be killing the vegetation that they use for nesting by direct destruction of the vegetation for nesting material or through deposition of large amounts of feces (guanofication).

Previous estimates of island size for Ralstin Island in 1941 and 1995 (Koenen et al. 1996) were not consistent with findings of this study. The Island was estimated by Koenen et al. (1996) to be about 60 ha in 1941, 9 ha in 1966, 5 ha 1989, and 1.8 ha in 1995; I found the Island to be 34 ha, 11 ha, 5 ha, and 3.8 ha, respectively. The largest discrepancy between these 2 studies was in 1941 and 1995. Differences in 1941 may have been caused by differential delineation of the Island boundaries; I used only the area of the Island that was not inundated by the reservoir, whereas Koenen et al. (1996) may have considered

all the temporarily inundated area immediately surrounding the Island. Measurements of island size in 1995 may have been different because of different cell or pixel size and different methods of working with the historical aerial photographs. In 1997, Martinez (1998) found island size to be 3.23 ha, providing further evidence that my measure of 3.8 ha is accurate. Despite the discrepancies in island size, the same trends in erosion are seen in this study as in Koenen et al. (1996).

Future studies should quantify the rate of loss of plant species to understand impacts of ardeids on each of them. Additional studies also should be conducted following completion of restoration activities to assess effects of these activities (Martinez 1998), particularly deposition of sediment and vegetative colonization and succession. Such studies should examine post-restoration rate of erosion, bird community composition, and change of vegetation on the existing Island, artificial islands, and sedimentation that is deposited behind the artificial islands.

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Figure 1. Ralstin Island with proposed artificial islands (brown rectangles) and possible sedimentation (tan) superimposed, 1998.
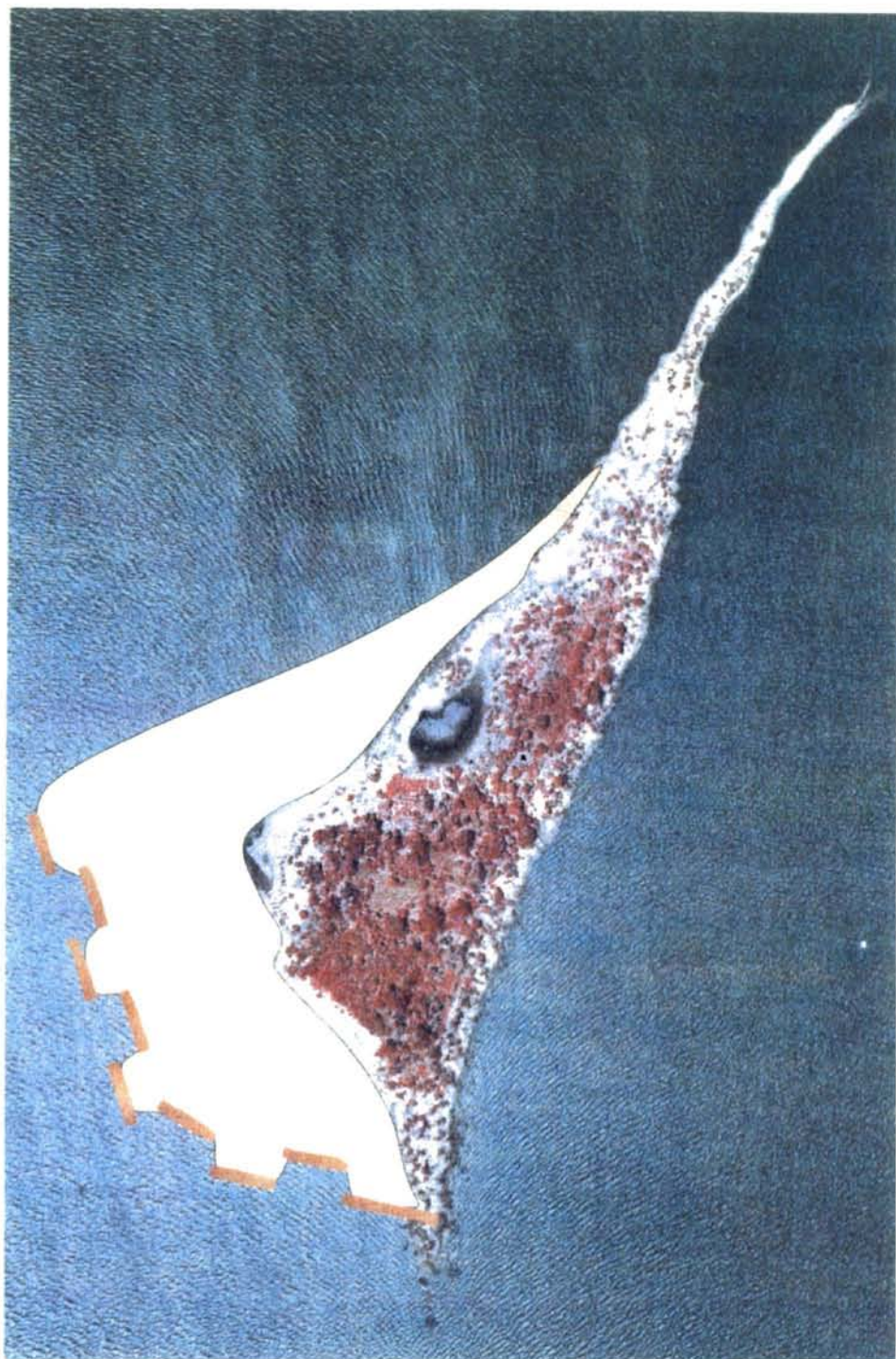
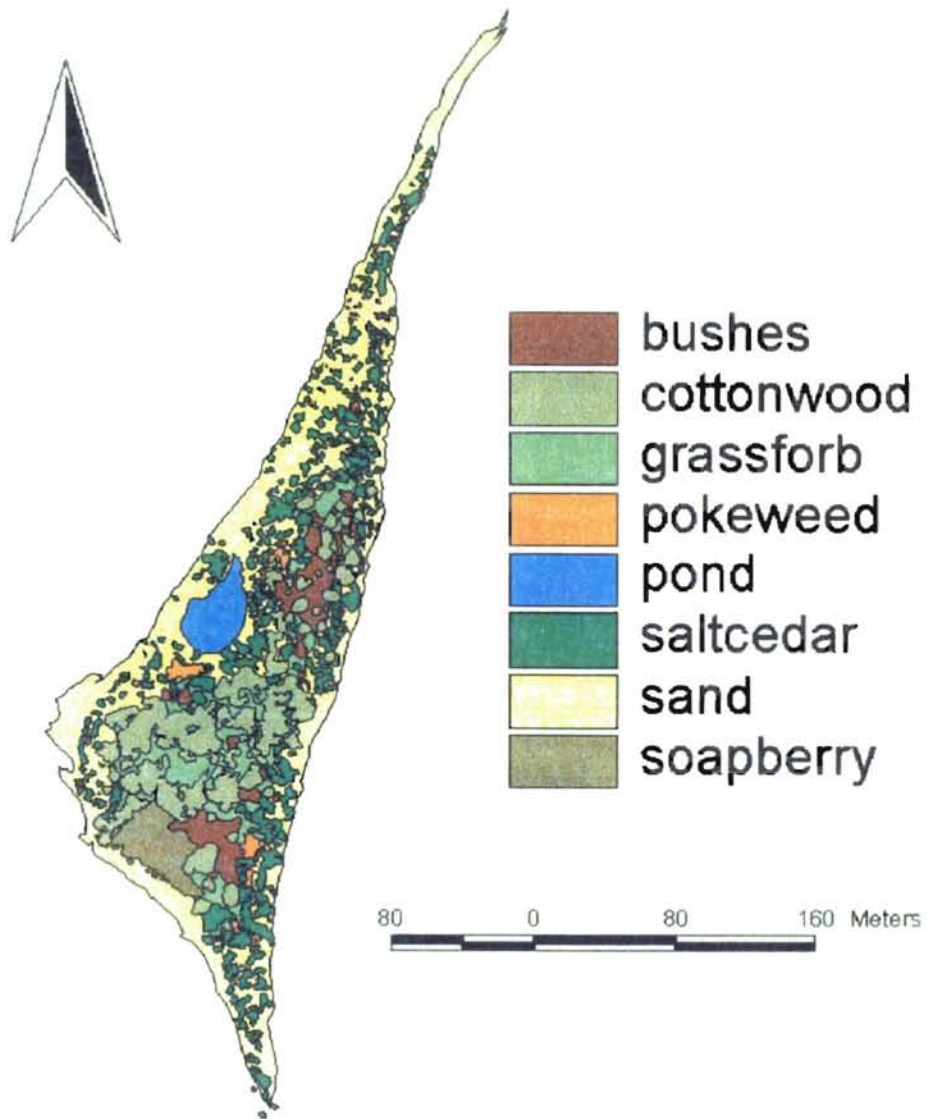Figure 2. Vegetative cover of Ralstin Island derived from a color infrared aerial photograph, 1998.

bushes
cottonwood
grassforb
pokeweed
pond
saltcedar
sand
soapberry

80   0   80   160 Meters

Figure 3. Flow chart to obtain rate of erosion and vegetative succession of Ralstin Island.
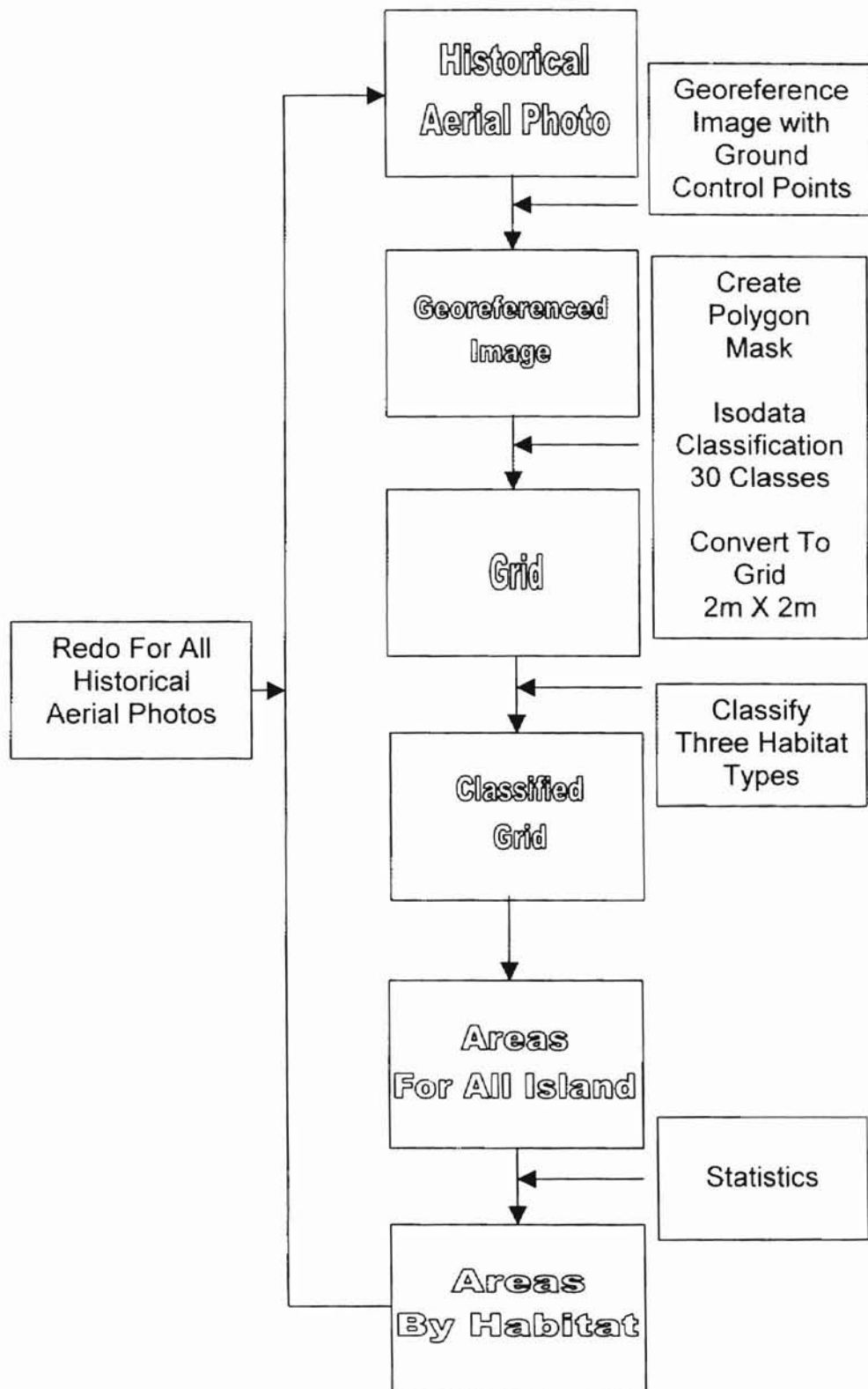
Figure 4. Incremental decrease in size of Ralstin Island from 1941 through 1998.

Year	Size (hectares)
1941	34.50
1954	17.73
1961	10.81
1966	10.70
1973	8.67
1984	5.84
1989	5.10
1995	3.70
1998	3.81

400   0   400   800 Meters

Figure 5. Decrease in the size of Ralstin Island from 1941 to 1998. A third-order polynomial regression fits the data best, showing that there have been different rates of erosion over time.
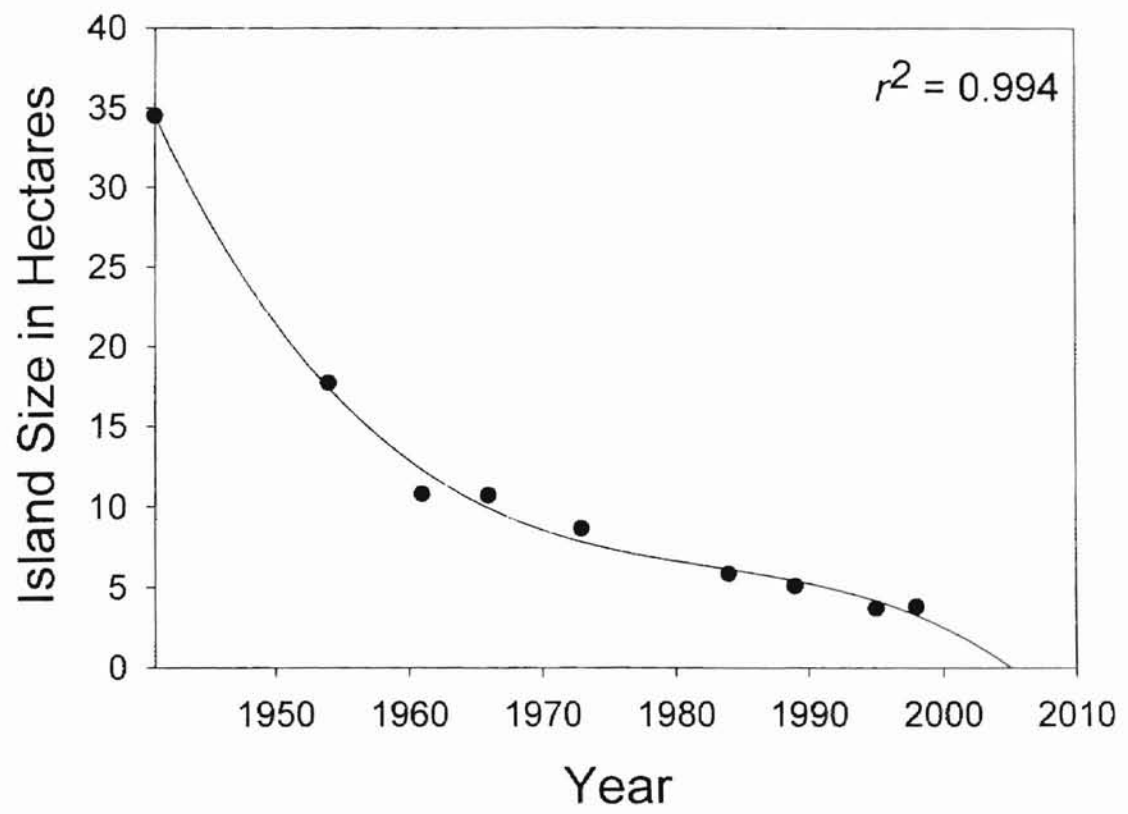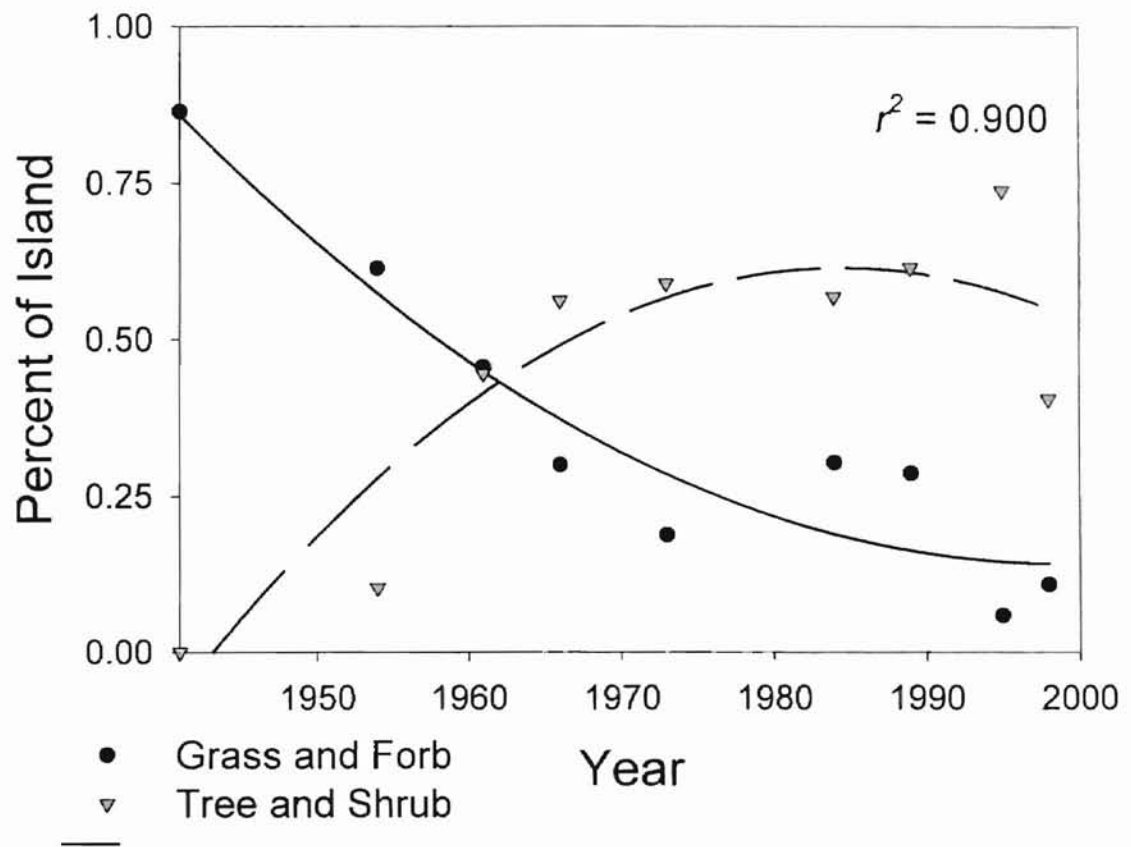
Figure 6. Vegetative succession of Ralstin Island. controlling for decrease in island size. Since Ralstin Island's creation in 1941, the island has changed from an island dominated by grass and forbs to an island dominated by trees and shrubs.

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VITA

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