HABITAT AND POPULATION CHARACTERISTICS OF GREAT BLUE HERON ROOKERIES IN THE SOUTH CENTRAL GREAT PLAINS: PARTIAL VALIDATION OF THE GREAT BLUE HERON HABITAT SUITABILITY INDEX MODEL

By

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Bachelor of Science

Eastern New Mexico University

Portales, New Mexico

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Submitted to the Faculty of the
Graduate College of
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER III

CHAPTER IV

LIST OF FIGURES

CHAPTER III

CHAPTER IV

HABITAT AND POPULATION CHARACTERISTICS OF GREAT BLUE HERON ROOKERIES IN THE SOUTH CENTRAL GREAT PLAINS: PARTIAL VALIDATION OF THE GREAT BLUE HERON HABITAT SUITABILITY INDEX MODEL

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CHAPTER I

INTRODUCTION

This thesis is composed of four chapters. Chapter I is an introduction to the remaining text. Chapter II, "Habitat suitability index (HSI) models and great blue heron ecology: a review," is written as a thesis literature review. Chapter III, "Habitat structure, landscape characteristics, and populations attributes of great blue heron rookeries in the southcentral Great Plains," is written in manuscript form for submission to *Colonial Waterbirds*. Chapter IV, "Partial validation of the great blue heron HSI model for the southcentral Great Plains," is written in manuscript form for submission to the *Journal of Wildlife Management*. Each manuscript is complete and needs no supportive material.

CHAPTER II

Habitat suitability index models and great blue heron ecology: a review

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HSI MODELS

Habitat Suitability Index (HSI) models were developed by the U.S. Fish and Wildlife Service to address the increasing need to manage and monitor biological resources. HSI models assess wildlife habitat relationships and predict species sensitivity to perturbations (Berry 1986; Van Horne and Wiens 1991). Model construction was achieved largely by literature reviews and professional consultations. By 1987, 150 species models were published, but no more are to be constructed until existing models have been validated through field studies. Typically, HSI models are species-specific and based on generalized physical and biological attributes of a species' habitat, which are assumed to be related to a population's carrying capacity (Berry 1986; Schamberger and O'Neil 1986). Models are designed to be simple, applicable in a timely manner with minimum costs, and to generate understandable outputs (Schamberger and O'Neil 1986). They are used in conjunction with Habitat Evaluation Procedures (HEP) to provide guidance in management decisions. Because of the need for simplicity and generality, models contain only those factors that are easily measured and to which a species is known to respond (Schamberger and O'Neil 1986).

GREAT BLUE HERON HSI MODEL

Short and Cooper (1985) developed the Great Blue Heron (*Ardea herodias*) HSI model to evaluate habitats (i.e., herbaceous, shrub, and forested wetlands, and riverine, lacustrine, and estuarine deep water habitats) used or potentially used for foraging and nesting during the breeding season in spring and summer. The model consists of two life requisite components that rate the quality of foraging and reproductive habitats. Within each component, model variables are formulated into mathematical equations that generate qualitative HSI ratings between 0.0

(poor) to 1.0 (optimum).

Because the great blue heron model was constructed from the literature and professional consultation, it is a hypothesis of species-habitat relationships and not a statement of proven cause and effect (Short and Cooper 1985). Major assumptions of the model are: 1) published research and professional advice were correct, 2) no significant variables were overlooked, 3) appropriate value ranges were assigned to model variables, and 4) adequate interrelationships of variables were identified (Short and Cooper 1985). Because information on herons nesting in inland habitats away from water was lacking, the model may have inherent limitations for interior great blue heron populations (Short and Cooper 1985).

The great blue heron HSI model consists of six variables believed to represent the species' foraging and reproductive habitats. Each variable is assigned a Suitability Index (SI) rating based on the quality of the habitat parameter being measured, 0.0 for poor and 1.0 for optimum. Variable V1 rates a potential nest site with respect to a foraging area. Potential nest sites within 1 km of a foraging area are given a SI rating of 1.0; SI values decrease linearly as the distance between foraging areas and potential nest sites increase. The rate of decrease is 0.1 for each additional 1-km increase. The rate of decrease was chosen to compensate for the increased energy expenditure associated with longer foraging flights (Short and Cooper 1985). Variable V2 rates the quality of potential foraging areas. A potential foraging area is defined as shallow (≤50 cm), clear water areas with firm substrates and huntable fish populations (≤25 cm in length). If the previous conditions are usually met, V2 = 1.0, if not V2 = 0.0. Variable V3 rates a potential foraging area with respect to human activity. Foraging areas are considered optimum (V3 = 1.0) if there is usually no human activity within 100 m or vehicular activity within 50 m during four hours following sunrise or preceding sunset. If human activities are usually apparent, V3 = 0.0. Variable V4 defines a potential nest site as a grove of trees ≥0.4 ha located near water and in trees ≥5 m tall with structured limbs sturdy enough to support weight of the birds and their nests. Nest trees also must contain an open canopy for nest access. If the previous conditions are usually met, V4 = 1.0, if not V4 = 0.0. Variable V5 describes human disturbance zones within 150 m of a potential nest site located over water or 250 m of one located on land. If the buffer zone is usually free from human disturbance during the nesting season, V5 = 1.0, if not V5 = 0.0. Variable V6 rates a potential nest site with respect to a traditional nest site. If the potential nest site is within 1 km of an active nest site, V6 = 1.0. As the distance between a potential and traditional nest site increases, the value of V6 decreases linearly. The rate of decrease is 0.1 for each additional 1-km increase. Short and Cooper (1985) chose this rate of decrease arbitrarily.

The Foraging Index (FI) is obtained by combining three variables (FI = V1 * V2 * V3); the Reproductive Index (RI) is obtained by combining four variables ($RI = (V1 * V4 * V5 * V6)^{1/2}$); and the overall HSI rating is a combination of all six variables ($HSI = (V1 * V2 * V3 * V4 * V5 * V6)^{1/2}$). The square root is computed for the RI and HSI equations because variables V1 and V6 are continuous functions. Tree species and height are not considered important for nest site selection in the model. Critical site selection attributes include tree limb structure, proximity to traditional rookeries, foraging areas, and frequency of human disturbance during nesting. The model identifies shallow-water aquatic habitats as the most significant foraging areas, but Short and Cooper (1985) could not find conclusive evidence for a correlation between colony size and area of surface water or fish biomass.

HSI MODEL VALIDATION

Model validation is an essential process of model construction. Models should not be used for crucial management decisions until they have been field tested and modified, if necessary, to be applicable in a particular region. The validation process achieves two goals: 1) it tests model performance in a particular geographic region and 2) it identifies model weaknesses and improves them (Schamberger and O'Neil 1986). The ability of a model to predict effects of perturbations on populations and their reproductive success depends on how accurately model assumptions meet the actual life requisites of the species (Van Horne and Wiens 1991). Models can be tested on four levels: 1) tests of model assumptions; 2) tests of individual model variables; 3) tests of interactions of model variables; and 4) overall evaluation of model output (Schamberger and O'Neil 1986).

Allen et al. (1991) modified and validated the dormant-season (mid-September to mid-May) component of the moose (*Alces alces*) HSI model in the Lake Superior region with Geographic Information System (GIS) technology. This portion of the model addressed forage and cover quality for lactating cows with respect to browse biomass and diversity, canopy cover, species composition of trees, and estimated the distance between forage and cover resources. A 490-km^2 habitat map of the Superior National Forest was constructed and digitized into a GIS. The actual study area equaled 344-km^2 and was comprised of 10 Minnesota Department of Natural Resource moose survey units. Aerial surveys of the study area resulted in sightings of 235 moose. Moose were classified as adult male or female, young, and unknown. All adult positions and 175 randomly selected points were plotted on the GIS with 200-, 500-, and 1000-m radii buffer zones. Additionally, areas with high quality late-winter forage and cover (i.e., SI $\geq$ 0.5) with a 100-m buffer were stored in the GIS. With the aid of the GIS, SI values were quantified, areas computed, and moose locations compared to random points in conjunction with late-winter forage and cover habitat quality. The dormant-season portion of the HSI model was found to be a reasonable predictive tool. The GIS enabled analysis of a large geographic region, and the effects of future forest management on moose habitat in the Lake Superior region could be simulated without gathering additional data.

Conway and Martin (1993) conducted a habitat suitability study for Williamson's Sapsucker (*Sphyrapicus thyroideus*). Two non-use sites adjacent to each active nest site were compared to identify limiting factors associated with nest site selection. Thirty-three nest sites and 66 non-use sites were evaluated. One non-use site was located within the drainage of an active nest, and other was located on a ridge perpendicular to the active nest. For each use/non-use site, four HSI reproductive requisites were measured: 1) percent canopy cover, 2) percent of canopy dominated by aspen, 3) diameter at breast height (dbh) of overstory aspen trees, and 4) snag density. The study confirmed the model's ability to predict nesting preferences of sapsuckers for drainages rather than ridgetops, but revealed the inability of the model to distinguish between use and non-use sites within the same drainage.

Cook and Irwin (1985) conducted a validation study of the pronghorn (*Antilocapra americana*) HSI model on 29 winter ranges that included portions of Montana, Idaho, Colorado, and Wyoming. Vegetation, topography, and pronghorn population density data were collected to confirm the validity of five variables that the pronghorn HSI model assumed important for winter ranges: 1) canopy cover, 2) shrub height, 3) shrub diversity, 4) availability of winter wheat, and 5) topographic cover. Pronghorn winter ranges were evaluated according to HSI model specifications. Overall HSI values and several SI values for each winter range were regressed against corresponding pronghorn density estimates. An evlauation of published data suggested that the original pronghorn model did not have an optimal structure or adeuate ranges of variable values; therefore, additional regression models were developed to identify weaknesses of the model (Cook and Irwin 1985). Several modifications, including the addition of a new variable, were incorporated into the model, which validated it and improved its performance.

GREAT BLUE HERON ECOLOGY

The great blue heron ranges over much of North America, occupying freshwater, saltwater, and inland habitats near water (Robbins et al. 1983). In inland habitats of the southcentral Great Plains, herons typically nest in bottomland hardwood forests near foraging areas such as reservoirs, streams, creeks, and floodplains.

Great blue herons exhibit solitary behavior, except during the breeding season. Although they usually nest colonially, Walbeck (1988) noted that single nests occurred in areas that once contained numerous nesting herons. Herons nest on many structures: ground, bushes, rock ledges, trees, and man-made structures such as power poles (Lahrman 1957; Vermeer 1969; Soots and Landin 1978; Wiese 1978). No specific tree species is preferred throughout their range, but in the southcentral Great Plains, they commonly nest in bottomland hardwood areas in either live or dead trees. Nest trees must contain an open canopy for nest access. Colonies will not form in areas with abundant nesting structures if suitable foraging areas are absent or human disturbance is prominent (Mosely 1936; Miller 1944; Soots and Landin 1978; Gray et al. 1980; Gibbs et al. 1987; Gibbs 1991).

During the onset of the breeding season, males arrive at the rookery first and claim a nest (Mock 1976). Nests located most centrally and highest in nest trees are among the first to be selected and defended (Parker 1980). Females arrive shortly thereafter and courtship begins. After pair formation, females assume responsibilities of nest construction and maintenance; males supply nest materials (Cottrille and Cottrille 1958; Mock 1976). Long, small sticks are used for nest structure and herbaceous stems for nest lining (Mosely 1936). Nest construction or maintenance strengthens pair bonds and stimulates copulation (Cottrille and Cottrille 1958). Typically, herons reuse and reinforce old nests each year with additional material, creating large, sturdy platforms (Mosely 1936; Cottrille and Cottrille 1958; Pratt 1970; McAloney 1973). Construction of new nests may occur when old nests fall from trees, nest trees die, or breeding pairs outnumber available nests (Mosely 1936).

Although herons typically use traditional rookeries, colony abandonment occurs. Most colony abandonment has resulted from habitat fragmentation caused by human disturbances; e.g., logging, road construction, commercial development, residential development, mechanized agriculture, and recreational land use (Thompson 1979; Custer et al. 1980; Kelsall and Simpson 1980; Parker 1980). Other factors related to colony abandonment are ground predators (Jenni 1969), death to surrounding vegetation resulting from excretion, or shifts in feeding habitats (Mosely 1936; Custer et al. 1980). Although herons are wary of humans, they are particularly sensitive to disturbance before nest initiation until shortly after eggs hatch (Soots and Landin 1978). A disturbance during this period may result in nest failures or complete colony abandonment.

Great blue herons are primarily piscivorous but are opportunistic feeders that eat other birds, amphibians, reptiles, and terrestrial prey (Dennis 1971; Krebs 1974; Willard 1977; Peifer 1979; Brooks and Loftin 1987). In aquatic environments, herons typically feed in areas ≤50 cm deep with firm substrates that support their weight (Short and Cooper 1985). Prey usually is ≤25 cm in length (Willard 1977; Hoffman 1978), but herons have suffocated on items too big for them to swallow (Wolf and Jones 1989). Prey is usually consumed in proportion to its relative abundance in foraging habitats (Willard 1977; Forbes 1986). Areas of abundant prey or preferred foraging habitat may influence colony size (Miller 1944; Gibbs et al. 1987; Gibbs 1991).

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CHAPTER III

Habitat structure, landscape characteristics, and population attributes of great blue heron rookeries in the southcentral Great Plains

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ABSTRACT

From February through July 1993, 18 great blue heron (*Ardea herodias*) rookeries throughout Oklahoma were monitored to assess population size and productivity. Geographic Information System (GIS) technology was used to aid in the evaluation of rookery habitat structure and surrounding landscape features. This study was conducted to identify relationships between population sizes and habitats (rookery and landscape) and aid future conservation efforts for the species in the southcentral Great Plains. Rookeries, which occurred in four different vegetational ecoregions, were composed of habitats ranging from secluded hardwood forests to exposed patches of live or dead trees. Predominant nest trees were sycamore (*Platanus occidentalia*) (65%) and less frequently short-leaf pines (*Pinus echinata*)(10%), cottonwoods (*Populus deltoides*)(9%), unidentifiable snags (7%), baldcypress (*Taxodium distichum*)(5%), pecan (*Carya illinoensis*)(3%), and a single water oak (*Quercus nigra L.*)(1%). Rookery population sizes ranged from 14-160 breeding adults ($\bar{x}$=66.2 ± 43.5 [SD]), and estimated mean productivity for 14 successful rookeries ranged from 1.3 ± 1.1 (SD) to 2.4 ± 0.91 (SD) fledglings. For the 18 rookeries, the estimated mean productivity was 1.7 ± 1.1 (SD) fledglings for each initiated nest. Estimated mean rookery productivity differed within and among ecoregions. Landscape features varied with proximity to nesting herons, coverage amount, and their frequency of occurrence suggesting that rookeries are comprised of individual populations that have adapted to local landscape alterations and some types of human distrubances.

Key words.- Great blue heron, productivity, rookery, nest trees, Oklahoma, human disturbance, Geographic Information System.

Colonial Waterbirds 00(0):00-00, 0000

INTRODUCTION

Throughout North America, reproductive habitats and corresponding populations of great blue herons (*Ardea herodias*) have been well documented. Existing studies indicate that rookery habitat features, such as nesting substrates and rookery locations (e.g., island versus mainland rookeries), vary widely within and among regions throughout the geographic range of this species (Mosely 1936, Miller 1943, Vermeer 1969, Henny and Kurtz 1978, Wiese 1978, Gray et al. 1980, Collazo 1981, Gibbs et al. 1987, Kelly et al. 1993). Because of this variation, these features presumably are not major determinants of where a rookery may occur nor do they directly influence reproductive success. Great blue heron populations, however, are strongly influenced by the amount of aquatic foraging area available during the reproductive season (Werschkul et al. 1977, Gibbs et al. 1987, Gibbs 1991).

Human disturbances (e.g., recreational landuse and landscape alterations) during critical phases of the nesting season can result in partial or complete rookery abandonments (Thompson 1979, Custer et al. 1980, Kelsall and Simpson 1980), which may severely affect the reproductive success of a given population. Therefore, it is thought that rookeries will not form in areas even with abundant nesting substrates if suitable foraging areas are absent or human disturbance is prominent (Miller 1943, Soots and Landin 1978, Gibbs et al. 1987, Gibbs 1991). To enhance future management goals and conservation efforts for the species, investigations into the geographic relationships and interactions among rookery populations, habitat structure, and anthropogenic disturbances are needed.

In the southcentral Great Plains of North America, great blue heron rookeries have been common historically (Sutton 1967, Wood and Schnell 1984). However, information on rookery habitat structure, surrounding landscape features, and population attributes for this region are generally lacking. I describe the habitat structure, surrounding landscape features, and population attributes of 18 great blue heron rookeries located throughout Oklahoma. My objectives were to: 1) determine rookery population characteristics, 2) assess rookery habitat structure and surrounding landscape features with the aid of Geographic Information System (GIS) technology, and 3) identify relationships between rookery features and populations that will aid future conservation efforts in this region.

STUDY AREA

Data on rookery habitat characteristics, surrounding landscape features, and heron populations were collected at 18 rookeries located throughout Oklahoma (Fig. 1) from January 1993 through May 1994. These rookeries occurred in four vegetational ecoregions, as described by Bailey (1980). Western Oklahoma rookeries were located in the Bluestem (*Andropogon spp.* and *Schizachyrium spp.*)-Grama (*Bouteloua spp.*) Prairie section of the Tall-Grass Prairie Province. Annual precipitation for this region ranges from 380-1,000 mm; temperatures range between 4°-18°C. Regional vegetation consists mostly of tall grasses, but woody vegetation occurs in the floodplains. Eastcentral rookeries were located in the Oak (*Quercus spp.*)-Hickory (*Carya spp.*)-Bluestem Parkland and Oak-Bluestem Parkland sections of the Prairie Parkland Province. Regional annual precipitation ranges from 600-1,000 mm; temperatures range from 12°-21°C. Vegetational communities are comprised of prairies and forested groves, or strips of deciduous trees. Northeastern rookeries were located in the Oak-Hickory Forest section of the Eastern Deciduous Forest Province. Annual precipitation ranges from 900-1,500 mm; temperatures range between 4°-15°C. Regional vegetation is comprised of temperate deciduous forests. Southeastern Oklahoma rookeries were located in the Southeastern Mixed Forest Province with an annual precipitation of 1,000-1,500 mm; temperatures range between 15°-21°C. Vegetation types range from medium height to tall forest stands of broadleaf deciduous and evergreen trees.

METHODS

POPULATION SIZE AND PRODUCTIVITY

From February to July 1993, 18 rookeries were monitored to assess population sizes and productivity attributes. Rookeries were divided into two groups for logistical reasons, and each group was monitored on alternating weeks. Observations of nesting herons were made with a 15-60 X spotting scope and 20-50 X binoculars at distances ranging from 68-365 m. Observation distances were based on the logistical constraints at each rookery (e.g., dense foliage and water barriers) and were maintained until offspring fledged to reduce observer-induced disturbance and possible rookery abandonment. To further reduce observer disturbance, rookery monitoring ceased for approximately 25-30 days during incubation (McAloney 1973) when ≥50% of active nests contained incubating herons.

During rookery initiation (February-March), active nests were identified by the presence of at least one heron conducting nest maintenance or displaying egg-laying behavior. On subsequent visits, active nests were identified by the presence of incubating herons. The maximum number of active nests recorded during a monitoring session, before trees developed leaves, was multiplied by two to estimate initial rookery population sizes. As the breeding season progressed, an attempt was made to count chicks; however, because of long observation distances and obtuse angles, these counts shouls be considered conservative. During the fledgling period about 42-60 days after hatching (Pratt 1970, McAloney 1973), each accessible rookery was entered and individuals from visible nests were counted, and the number of successful and unsuccessful nests determined. Successful nests were identified by the amount of white wash (heron guano), nest condition, and presence of herons.

Assuming productivity of successful visible nests represented productivity of successful non-visible nests, successful non-visible nests were randomly assigned fledgling numbers determined from visible nests, and the overall mean for each rookery was computed. Although this was the standard approach used by Kelly et al. (1993) to calculate productivity of successful breeding pairs , I took the calculation one step further by incorporating nest failures identified during the fledgling period, which yielded a more realistic estimated mean rookery productivity than a productivity based just on successful breeding pairs. Differences in the estimated mean productivity of successful rookeries within and among ecoregional groupings were analyzed with the Kruskal Wallis non-parametric procedure (SAS Inst. 1985). A Student-Newman-Keuls multiple comparison test was used to identify differences among individual successful rookeries, both within and among ecoregions. Spearman rank correlation analysis was used to identify relationships between initial rookery population size and corresponding estimated mean productivity. My null hypotheses were: great blue heron rookery productivity was equivalent within and among ecoregions, and initial rookery population size was not related to corresponding estimated mean productivity.

HABITAT CHARACTERISTICS

During the 1993 post-breeding season, the boundaries and spatial features of each rookery were mapped using a Magellan Nav1200 Global Positioning System (GPS), 300-m tape, compass, and clinometer. A reference latitude and longitude position fix was obtained with the GPS in a clearing adjacent to each rookery. The distance to the nearest nest tree was measured, and compass bearings were recorded. From the initial nest tree, the distance and compass bearing to the next closest nest tree was recorded. That procedure was followed until all nest trees were mapped. A digital data layer for each rookery, based on spatial distributions of all nest trees, was created from the reference latitude and longitude coordinates. These coordinates were converted to Universal Transverse Mercator (UTM) coordinates to facilitate GIS analyses. I constructed a minimum area polygon of each rookery using all nest trees as points on the perimeter.

Nest tree characteristics were measured according to Hays et al. (1981) and included: tree species, tree height, lowest branch height, crown diameter (N-S and E-W), density at breast height (dbh), number of nests, and height of the lowest and highest nest per tree. Crown area and crown diameter were derived from actual nest tree measurements (Hays et al. 1981). Differences in nest tree characteristics within and among ecoregions were tested with the Kruskal Wallis non-parametric procedure (SAS Inst. 1985) and a Student-Newman-Keuls multiple comparison test. Spearman rank correlation analysis was used to evaluate relationships between nest tree characteristics and corresponding numbers of nests. Bonferroni correction analysis (Rice 1989) was used for relationships identified between the numbers of nests and corresponding nest tree characteristics. My null hypotheses were: rookery nest tree characteristics (i.e., tree height, dbh, crown area, and crown diameter) did not differ within or among ecoregions, and rookery nest tree characteristics were not related to corresponding numbers of nests.

LANDSCAPE FEATURES

Landscape features surrounding each rookery were identified from 1:40,000 Agricultural Stabilization Conservation Service aerial photographic enlargements taken during 1990-1991. Interpretation of aerial photographs was conducted for a 5.76-km^2 area centered on each rookery. That size was chosen because herons are influenced by human activities and landscape alterations within a 1-km radius of rookery locations (Short and Cooper 1985). Landscape features that were delineated on acetate overlays were: types of human disturbance, water bodies, and generalized vegetation features (e.g., forest, rangeland, and old field regeneration). Acetate overlays were digitized and landscape features labeled for subsequent analysis with GIS Geographic Resource Analysis Support System 4.0 (GRASS 4.0) software. Two digital GIS layers of landscape features were created from each aerial photograph. One data layer contained linear features too narrow for areal delineation (e.g., dirt roads and railroad tracks); such features were needed for subsequent distance measurements to rookeries. The other data layer contained features with polygon areas large enough for areal delineation (e.g., forests, water bodies, and human dwellings). The three data layers (i.e., rookery nest trees, linear features, and minimum area rookery polygons) were combined and used for distance and area computations with respect to rookeries.

To analyze the relationship between nesting herons and available foraging habitats, water types within a 15-km radius of rookery locations were obtained from 1:100,000 United States Geological Survey (USGS) Digital Line Graphs (DLG) and incorporated as a layer in GIS. Water features extracted from DLG medium were reclassified into three categories: 1) area of ponds, lakes, streams, and reservoirs, 2) area of land area exposed to flooding, and 3) linear distances (km) of streams that had no areal delineation.

Spearman rank correlation analysis was used to identify relationships between rookery population sizes and corresponding distances to human disturbance, amount of land-use coverage, and amount of potential foraging areas within a 15-km radius of rookery locations.

My null hypothesis was landscape elements (e.g., human disturbance types, forested area, and water features) were not related to rookery population sizes.

RESULTS

POPULATION SIZE AND PRODUCTIVITY

Initial heron population size at the 18 rookeries (Fig. 1) ranged from 14-160 breeding adults (Table 1) and was not correlated ($P>0.05$) with estimated mean productivity. Although nesting was initiated at all rookeries and breeding progressed to some degree, four were abandoned: Beavers Bend, Fort Sill, Lenapah 2, and Little River. Mean productivity of successful visible nests ranged from 1.8 fledglings ± 0.79 (SD) at the Sand Springs rookery to 2.8 fledglings ± 0.50 (SD) at the Sweetwater 2 rookery. Estimated mean productivity of successful rookeries ranged from 1.3 fledglings ± 1.1 (SD) at the Walters rookery to 2.4 ± 0.91 (SD) fledglings at the Alexandria rookery for each initiated nest. The overall estimated great blue herons fledged per initiated nest for the 18 rookeries was 1.7 ± 1.1 (SD). The incorporation of nest failures that were identified during the fledgling period accounted for the decrease in estimated mean productivity compared to the productivity of visible successful nests.

Estimated mean productivity differed among rookeries within ecoregions (Table 1). Within the Tall-Grass Prairie Province productivity among rookeries differed ($F=4.84$, $df=3$, $P=0.003$); the Walters rookery had the lowest estimated mean productivity. Estimated mean productivity differed within the Prairie Parkland Province ($F=2.67$, $df=6$, $P=0.015$), with the Sand Springs rookery having the lowest. Estimated mean productivity among within the Eastern Deciduous Forest Province did not differ ($F=2.13$, $df=2$, $P=0.122$). No productivity occurred at the monitored rookeries in the Southeastern Mixed Forest

Province because of abandonment.

No differences in initial population size (F=1.45, df=3, P=0.272) or estimated successful population size (F=0.35, df=2, P=0.712) occurred among ecoregions (Table 1). However, estimated mean productivity differed among ecoregions (F=14.75, df=2, P=0.0001). The Tall-Grass Prairie Province had the highest estimated mean productivity with 2.2 fledglings ± 1.1 (SD) based on 124 initiated nests. The Eastern Deciduous Forest Province had the second highest estimated mean productivity with 2.0 fledglings ± 1.0 (SD) based on 191 initiated nests, and the Prairie Parkland Province had the lowest with 1.7 fledglings ± 1.0 (SD) based on 339 initiated nests. Because of rookery abandonments, the Southeastern Mixed Forest Province had no productivity, based on 29 initiated nests.

HABITAT CHARACTERISTICS

Herons were observed nesting in six tree species in Oklahoma (Table 2). Sycamore (*Platanus occidentalia*) trees were the primary nesting substrate in the Eastern Deciduous Forest Province and the Prairie Parkland Province; cottonwood (*Populus deltoides*) trees and unidentifiable snags were primarily used in the Tall-Grass Prairie Province. Herons nested in two conifer species [i.e., baldcypress (*Taxodium distichum*) and short-leaf pine (*Pinus echinata*)] in the Southeastern Mixed Forest Province. Secondary nest trees were occasionally used by herons when the primary nest tree species were not abundant or nesting opportunities in those available were exhausted. Nest tree mean heights by species ranged from 19.4 m ± 3.6 (SD) for snags to 32.0 m ± 2.1 (SD) for pecans with little variability within species. Density at breast height (dbh) was highly variable with averages ranging from 37.7 cm ± 6.8 (SD) for short-leaf pines to 130.7 cm ± 45.0 (SD) for cypress. Crown diameters ranged from 8.0 m ± 3.3

(SD) for snags to 19.1 m for the single water oak. Crown area was highly variable, ranging from an average of 56.7 m^2 ± 33.0 (SD) for short-leaf pines to 286.00 m^2 for the water oak. The number of nests per tree species ranged from 1.0 nests ± 0.2 (SD) for short-leaf pines to 8.0 nests ± 5.3 (SD) for cottonwoods with little variability among short-leaf pines and snags; these latter nesting substrates did not provide multiple nest placement opportunities. Numbers of nests per tree were positively related to tree height (r=0.378, n=189, P=0.0001), dbh (r=0.595, n=189, P=0.0001), crown diameter (r=0.566, n=189, P=0.0001), and crown area (r=0.565, n=189, P=0.0001).

Except for rookeries in the Eastern Deciduous Forest Province, nest tree characteristics differed among rookeries within ecoregions (Table 3). For example, all of the nest tree measurements (i.e., nest tree heights, dbh, crown diameters, and crown areas) of the Sweetwater 1 rookery in the Tall-Grass Prairie Province were less than those of the Alexandria and Walters rookeries. However, differences in individual characteristics (i.e., nest tree heights and dbh) were not consistent among rookeries throughout the Tall-Grass Prairie Province and Prairie Parkland Province. For example, the Kubik rookery in the Prairie Parkland Province had nest tree mean heights similar to the Terelton rookery; however, the nest tree mean dbh was significantly different between these two rookeries. Mean crown diameter and mean crown area were rather consistent within ecoregions, and differences were attributable to the various nesting substrates used. Differences in nest tree characteristics within the Southeastern Mixed Forest Province were consistent between the two rookeries because of the morphological differences between baldcypress and short-leaf pine trees, which were the only nesting substrates used.

Differences in nest tree characteristics varied among ecoregions (Table 4). Nest tree height differed among three of the four ecoregions

(F=27.23, df=3, P=0.0001); nest trees in the Eastern Deciduous Forest Province were taller than those in the Prairie Parkland Province ($P \leq 0.05$) which were taller ($P \leq 0.05$) than those in the other two provinces where tree heights were similar ($P > 0.05$). Nest tree dbh differed among only one of the four ecoregions (F=9.06, df=3, P=0.0001); it was greatest ($P \leq 0.05$) in the Prairie Parkland Province and equivalent ($P > 0.05$) among the other three provinces. Nest tree crown diameter differed among three of the four provinces (F=15.93, df=3, P=0.0001). Tree crown diamter was greatest in the Prairie Parkland Province ($P \leq 0.05$) and least in the Southeastern Mixed Forest Province ($P \leq 0.05$); crown diameter was similar ($P > 0.05$) in the other two provinces. Crown area of the nest trees differed in three of the four provinces (F=15.94, df=3, P=0.0001); the largest crowns occurred in the Prairie Parkland Province and Eastern Deciduous Forest Province, which were similar ($P > 0.05$), followed by the Tall-Grass Prairie Province ($P \leq 0.05$) and the Southeastern Mixed Forest Province ($P \leq 0.05$).

Rookery area, based on the minimum area polygon of all nest trees, ranged from 0.002-1.99 ha ($\bar{x}$=0.37 ha ± 0.54 [SD]) (Table 5) and was positively correlated with numbers of nests identified during the post-breeding season (r=0.566, n=18, P=0.0143). Additionally, rookeries tended to be larger the closer they were to water (r=0.593, n=16, P=0.015). Two rookeries were surrounded by water, and the remaining 16 were located within 35 m of a water source. On average, the closest nest tree was 8.28 m ± 7.60 (SD) from water and the furthest was 42.67 m ± 48.37 (SD).

LANDSCAPE FEATURES

Types of landscape alterations and anthropogenic disturbances that occurred around the 18 rookeries were unimproved dirt roads, human dwellings, rangeland or grazing activities, agricultural practices, paved roads, maintained dirt roads, oil production, railroad tracks, utilities, and recreational activities (Table 6). Three categories of disturbance were delimited based on their potential impact to nesting herons: 1) passive disturbance (e.g., pre-existing agricultural activities, vehicular transportation, and cattle management activities) was indexed by unimproved dirt roads, 2) intermediate disturbance (e.g., residential areas and recreational activities) was indexed by human dwellings, and 3) critical disturbance (i.e., newly created landscape alterations) (see Chapter IV). The Prairie Parkland Province contained the greatest variety of disturbance types, the Tall-Grass Prairie Province and Eastern Deciduous Forest Province contained less disturbance types, and the Southeastern Mixed Forest Province contained the fewest. No correlations were identified between distances to disturbance types and initial population size, successful population size, visible productivity of successful nests, or estimated mean rookery productivity ($P>0.05$).

Landscape elements varied by coverage amount among ecoregions; however, forested areas and water bodies occurred around all rookeries (Table 7). Amount of forested land and water increased and the amount of rangeland decreased from western to eastern Oklahoma. The Tall-Grass Prairie Province, Prairie Parkland Province, and Eastern Deciduous Forest Province contained heterogenous rookery landscapes with a predominance of human dwellings, old field regeneration, rangeland, and agriculture. The Southeastern Mixed Forest Province was extremely homogenous with minimal coverage of old field regeneration, human dwellings, utilities, and recreational activities occurring at only one of the two rookeries. No correlations between landscape element coverage (ha) and initial rookery population sizes, successful population sizes, visible productivity of successful nests, or estimated mean rookery productivity were identified ($P>0.05$).

Estimates of the amount of potential foraging area within a 15-km radius of rookeries were conservative because of limitations of the DLG files and the inherent difficulties using vector data on a raster-based GIS (Table 5). There were 2279.36 ha ± 2159.30 (SD) of inundated land around 11 of the rookeries, 618.28 ha ± 1157.60 (SD) of water around 18 rookeries, and 693.90-km ± 262.38 (SD) of stream around 18 rookeries. These data did not accurately represent available foraging habitats; therefore, no further analysis was attempted.

DISCUSSION

Productivity estimates of successful rookeries were conservative because renesting attempts could not be identified due to the time span between monitoring sessions. However, these results are more realistic than the standard reported productivity of successful nests (Kelly et al. 1993) because nest failures identified during the fledgling stage were incorporated into estimated rookery productivity. Significant differences in estimated mean productivity within and among ecoregions must be viewed with caution because only one field season of population data was collected, and baseline data about the species in this region are lacking. Therefore, no data were available for identifying reproductive trends or ecological factors that may have influenced 1993 reproduction (Pratt and Winkler 1985). Furthermore, Van Horne (1983) warned about using density as an indicator of habitat quality because a population may be controlled by temporary or unexplainable events (e.g., human or environmental disturbance) that do not normally limit the population on a long-term basis.

The lack of a significant relationship between initial rookery population sizes and corresponding productivity has been observed by others (Werschkul et al. 1976, Quinney 1983, Kelly et al. 1993), thus supporting evidence that heron recruitment into rookeries may follow a pattern of an "ideal-free" distribution (Gibbs 1991). Fretwell's (1972) "ideal-free" distribution hypothesis suggests that if individuals of a species are free to colonize areas, they will presumably first gather in high quality habitats until their numbers start to reduce its quality due to resource depletion and social crowding. Subsequent individuals will then move into areas of lower initial quality that appear preferable because of light use. The end result is an equilibrium of costs and benefits to all individuals, and equal productivity regardless of initial habitat quality. Rosenzweig (1991) emphasized that an important but subversive assumption of the "ideal-free" distribution is that densities must correlate "perfectly" with available resources, although "perfect" ecological correlations are unrealistic. Several studies have identified strong but imperfect relationships between the amount of available foraging area and heron colony size (Gibbs et al. 1987, Gibbs 1991). Kelly et al. (1993) were unable to establish a similar relationship because they did not analyze all potential foraging areas available, but rather only the extent of tidal marshes. Furthermore, my study also failed to identify a relationship between population density and foraging area, in part due to the limitations of DLG data. However, continued investigations regarding relationships between rookery population sizes and foraging area need to be undertaken.

Herons nest on many structures: ground, bushes, rock ledges, trees, and man-made structures such as power poles (Lahrman 1957; Vermeer 1969; Soots and Landin 1978; Wiese 1978). No specific tree species is preferred throughout its range; however, herons typically occupy the tallest trees in a given stand even though they may be the least abundant (T. Meier pers. comm.). In the Prairie Parkland Province and the Eastern Deciduous Forest Province of the southcentral Great

Plains, herons mostly selected sycamore trees for nesting. Based on the distribution of Oklahoma trees (Little 1985), cottonwood trees occur throughout the state, and sycamores are restricted to the eastern portion of the state. Herons nesting in eastern Oklahoma predominantly used sycamore nest trees even though cottonwoods were available; snags and cottonwood trees were used in western Oklahoma. Although cottonwood trees typically contained more nests than sycamore trees, the latter were used instead of the former when available. A possible explanation for the preference for sycamore trees is that their branches are softer and less likely to break than are cottonwood branches (Little 1985) and thus, more resilient during adverse weather, providing greater security for nesting herons.

Other studies have shown that herons will persist in an area of a traditional rookery even if nesting opportunities are exhausted or have deteriorated (Henny and Kurtz 1978, Blus et al. 1980). I suspect the attraction of herons to traditional rookeries and colonial nesting are so strong that secondary nest trees were used in several of the ecoregions because nest placement opportunities in the primary nest trees were exhausted. The attraction to traditional rookeries and the hypothesis of individual populations associated with certain tree species (Simpson 1984) is explained in part by Klopfer and Ganzhorn (1985). Habitat preference may be associated with the environment (e.g., ecoregion and nest tree species) in which individuals spent their juvenile period. Furthermore, old nest sites may provide herons with visual cues that an area can sustain reproduction. However, this does not restrict herons to a particular nest site if habitat quality deteriorates, but it does provide crucial congregation areas for herons to find mates (Mock 1976).

Although human disturbances (e.g., recreational landuse and landscape alterations) during critical phases of the nesting season can result in partial or complete rookery abandonments (Thompson 1979, Custer et al. 1980, Kelsall and Simpson 1980), all of the rookeries in this study were located within 1 km of some form of human disturbance, indicating that herons are adaptable to landscape alterations. Only one rookery abandonment (i.e., Lenapah 2) could be attributed solely to human disturbance; however, circumstantial evidence suggested human activities influenced two other abandonments (Fort Sill and Beavers Bend). The landowner was clearing herbaceous and woody vegetation under and around the Lenapah 2 nest trees approximately two weeks after rookery initiation, which undoubtedly caused abandonment. The Fort Sill rookery was located in an area used for military training maneuvers and was productive the previous year (S. Orr pers. comm.). However, there were recent signs of human activity (e.g., fox holes) approximately 25 m away from the rookery after nesting began, which likely influenced abandonment. The Beavers Bend rookery was located in an area used for recreational activities (i.e., horse back riding); however, the rookery had been active the previous year and riding activities had not deterred nesting in the past. Moreover, I have no documented evidence suggesting that riding activities influenced rookery abandonment. The Little River rookery was located in a remote national wildlife refuge in southeastern Oklahoma. Potential causes of abandonment are unknown; however, one rookery on the refuge was abandoned for no apparent reason in the same manner the previous nesting season (B. Heck pers. comm.).

Although abandonments did occur during my study, it is apparent that herons have habituated to certain forms of non-threatening disturbance (e.g., existing landscape alterations). Habituation to various human activities has been observed in other parts of the species breeding range (Simpson 1984, Breault pers. comm.) and shows that herons can adapt to human encroachment. Although habituation is possible, each rookery must be viewed individually in this respect. Exposure to a new disturbance during critical phases of nesting is likely to disrupt rookery activities and cause possible nest failures and or subsequent abandonment.

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Table 1. Great blue heron population attributes of 18 rookeries throughout Oklahoma.

Ecoregion	Rookery[1]	Initial population size	Estimated successful population size	Visible nest productivity (± SD)	Number of nests	Estimated rookery productivity[2] (± SD)	Number of nests
Tall-Grass Prairie Province	1. Sweetwater 1	104	207	2.7 ± 0.71	36	2.3 ± 1.2[a]	52
	2. Sweetwater 2	14	24	2.8 ± 0.50	4	2.0 ± 1.4[a]	7
	3. Fort Sill[3]	32	0	0.0	0	0.0	0
	4. Alexandria	76	206	2.7 ± 0.56	21	2.4 ± 0.91[a]	49
	5. Walters	32	40	2.2 ± 0.75	6	1.3 ± 1.1[b]	16
Prairie Parkland Province	6. Kubik	60	140	2.1 ± 0.73	14	2.0 ± 1.0[a]	37
	7. Terelton	160	381	1.9 ± 0.62	38	1.7 ± 0.82[a]	108
	8. Sand Springs	122	179	1.8 ± 0.79	19	1.4 ± 1.1[b]	61
	9. Ramona	18	39	2.2 ± 0.75	6	1.8 ± 1.2[a]	12
	10. Copan	104	179	1.9 ± 0.59	20	1.5 ± 0.96[a]	58
	11. Lenapah 1	54	141	2.3 ± 0.73	19	1.9 ± 1.1[a]	39
	12. Lenapah 2[3]	24	0	0.0	0	0.0	0
	13. Hugo	48	87	2.1 ± 0.76	13	1.9 ± 1.0[a]	24
Eastern Deciduous Forest Province	14. Wyandotte	80	134	2.1 ± 0.80	15	1.7 ± 1.0[a]	40
	15. Murphy	134	449	2.3 ± 0.80	30	2.1 ± 1.0[a]	115
	16. Horse Shoe	72	131	2.3 ± 0.77	18	1.9 ± 1.0[a]	36
Southeastern Mixed Forest Province	17. Beavers Bend[3]	30	0	0.0	0	0.0	0
	18. Little River[3]	28	0	0.0	0	0.0	0

[1]Rookery numbers coincide with numbers on Fig. 1
[2]Estimated means with like letters are not significantly different wihtin each provice
[3]Abandoned rookeries

Table 2. Nest tree features of 18 great blue heron rookeries throughout Oklahoma.

Ecoregion[1]	Tree species	No. of nest trees (n=189)	Tree height (m) ± SD	dbh (cm) ± SD	No. nests per tree	Crown diameter (m) ± SD	Crown area (m^2) ± SD
Tall-Grass Prairie Province (n=5)	Cottonwood	16	27.93±6.21	91.51±31.82	8.75±5.16	16.38±6.02	18.94±5.60
	Pecan	1	29.26	73.60	1.00	25.00	19.26
	Snag	13	18.83±3.11	41.97±22.72	1.92±0.86	8.00±3.43	58.34±55.16
Prairie Parkland Province (n=8)	Sycamore	60	30.24±4.15	87.13±28.00	6.90±5.01	16.30±4.00	218.24±97.40
	Water oak	1	30.24	81.50	1.00	19.08	286.00
	Cottonwood	1	32.43	103.7	2.00	11.14	97.55
	Pecan	2	34.02±0.17	57.55±3.61	1.00	16.80±1.40	222.34±36.64
	Snag	1	26.58	79.20	2.00	7.81	47.90
Eastern Deciduous Forest Province (n=3)	Sycamore	62	32.83±3.12	70.52±19.50	6.03±6.01	12.86±4.10	142.50±90.40
	Cottonwood	1	35.36	88.7	2.00	14.33	161.33
	Pecan	3	31.46±1.80	58.40±13.30	2.00±1.73	11.72±4.23	117.33±82.00
Southeastern Mixed Forest Province (n=2)	Short-leaf pine	19	26.48±2.64	37.68±6.82	1.00±0.23	8.09±2.70	56.71±33.00
	Cypress	9	28.70±4.01	130.66±45.03	3.67±3.30	14.42±1.23	164.40±27.10

[1]The number of rookeries within an ecoregion is signified by n.

Table 3. Great blue heron rookery nest tree characteristics. Number of trees per rookery is denoted by n. Mean charateristics with different letters are significantly different (P≤0.05) within each province.

Ecoregion	Rookery	n	Nest tree mean height (m) ± SD	Nest tree meandbh (cm) ± SD	Nest tree mean crown diameter (m) ± SD	Nest tree mean crown area (m^2) ± SD
Tall-Grass Prairie Province						
	Sweetwater 1	10	18.33 ± 2.87^{c}	33.87 ± 7.84^{c}	6.62 ± 1.90^{d}	36.97 ± 19.50^{d}
	Sweetwater 2	3	15.52 ± 1.89^{c}	$51.63 \pm 13.25^{b,c}$	$8.92 \pm 3.31^{d,c}$	$68.29 \pm 43.23^{d,c}$
	Fort Sill	4	$25.97 \pm 2.71^{b,c}$	63.50 ± 17.53^{b}	12.60 ± 1.64^{c}	126.30 ± 32.06^{c}
	Alexandria	9	28.12 ± 4.07^{b}	100.22 ± 28.81^{a}	17.03 ± 4.60^{b}	242.42 ± 127.18^{b}
	Walters	4	33.59 ± 1.51^{a}	108.48 ± 26.95^{a}	23.46 ± 4.63^{a}	446.11 ± 171.14^{a}
Prairie Parkland Province	Kubik	10	$30.00 \pm 3.19^{a,b}$	$102.66 \pm 22.97^{a,b}$	18.13 ± 4.70^{a}	273.66 ± 137.04^{a}
	Terelton	24	$30.61 \pm 3.47^{a,b}$	$75.59 \pm 14.42^{b,c}$	15.28 ± 2.41^{a}	187.68 ± 57.24^{a}
	Sand Springs	5	33.01 ± 6.23^{a}	$81.10 \pm 22.86^{b,c}$	15.29 ± 2.21^{a}	186.63 ± 52.23^{a}
	Ramona	4	24.81 ± 3.10^{b}	72.48 ± 26.10^{c}	12.81 ± 3.36^{a}	135.57 ± 69.88^{a}
	Copan	4	$27.00 \pm 5.13^{a,b}$	132.70 ± 33.01^{a}	18.08 ± 4.94^{a}	271.16 ± 127.99^{a}
	Lenapah 1	5	32.14 ± 5.17^{a}	$97.12 \pm 25.47^{a,b}$	15.47 ± 4.02^{a}	198.08 ± 111.22^{a}
	Lenapah 2	4	33.41 ± 1.34^{a}	$115.60 \pm 41.26^{a,b}$	19.17 ± 5.03^{a}	303.42 ± 134.52^{a}
	Hugo	9	$30.02 \pm 2.67^{a,b}$	65.83 ± 9.22^{c}	16.28 ± 3.83^{a}	218.39 ± 85.64^{a}
Eastern Deciduous Forest Province	Wyandotte	14	33.00 ± 1.46^{a}	76.01 ± 23.80^{a}	12.64 ± 4.58^{a}	140.82 ± 97.11^{a}
	Murphy	35	32.97 ± 3.77^{a}	71.17 ± 13.48^{a}	13.28 ± 3.37^{a}	147.06 ± 74.56^{a}
	Horse Shoe	17	32.29 ± 2.47^{a}	63.59 ± 24.28^{a}	12.06 ± 4.79^{a}	131.16 ± 111.55^{a}
Southeastern Mixed Forest Province	Beavers Bend	19	26.48 ± 2.64^{a}	37.67 ± 6.82^{a}	8.09 ± 2.67^{a}	56.71 ± 32.99^{a}
	Little River	9	28.69 ± 4.00^{b}	130.66 ± 45.03^{b}	14.42 ± 1.23^{b}	164.36 ± 27.09^{b}

Table 4. Great blue heron rookery nest tree characteristics by ecoregions. Means with different letters are significantly different ($P \leq 0.05$).

Ecoregion	Nest tree mean height (m) ± SD	Nest tree mean dbh (cm) ± SD	Nest tree mean crown diameter (m) ± SD	Nest tree mean crown area (m^2) ± SD
Tall-Grass Prairie Province	24.03 ± 6.74^{c}	69.45 ± 36.67^{b}	13.02 ± 6.80^{b}	168.20 ± 165.59^{b}
Prairie Parkland Province	30.33 ± 4.07^{b}	86.27 ± 27.40^{a}	16.13 ± 3.70^{a}	214.93 ± 97.51^{a}
Eastern Deciduous Forest Province	32.80 ± 3.07^{a}	70.25 ± 19.30^{b}	12.83 ± 4.01^{b}	141.64 ± 88.89^{a}
Southeastern Mixed Forest Province	27.19 ± 3.24^{c}	67.56 ± 50.87^{b}	10.12 ± 3.78^{c}	91.32 ± 59.70^{c}

Table 5. Great blue heron rookery size (ha) and potential foraging area within a 15-km radius.

Ecoregion	Rookery	Rookery size (ha)	Water area (ha)	Inundated land (ha)	Stream (km)
Tall-Grass Prairie Province	Sweetwater 1	0.055	0.50	0.0	955.79
	Sweetwater 2	0.003	0.31	0.0	710.20
	Fort Sill	0.002	2.74	0.0	980.62
	Alexandria	1.994	2.15	0.0	1025.27
	Walters	0.209	1.85	0.0	873.05
Prairie Parkland Province	Kubik	0.287	0.94	1.77	785.34
	Terelton	0.435	1.45	37.83	670.89
	Sand Springs	0.003	4.51	9.85	812.55
	Ramona	0.015	3.95	0.0	649.79
	Copan	0.270	16.95	25.46	329.35
	Lenapah 1	0.103	1.56	8.04	478.50
	Lenapah 2	0.027	1.54	8.13	466.79
	Hugo	0.506	49.47	77.58	456.00
Eastern Deciduous Forest Province	Wyandotte	0.380	10.89	13.66	357.63
	Murphy	0.644	2.20	33.61	322.28
	Horse Shoe	1.459	0.61	25.37	1063.82
Southeastern Mixed Forest Province	Beavers Bend	0.379	5.65	9.43	490.40
	Little River	0.298	4.02	0.0	1062.09

Table 6. Mean distances of great blue heron rookeries to human disturbance types. The number of disturbance types within an ecoregion is in parantheses.

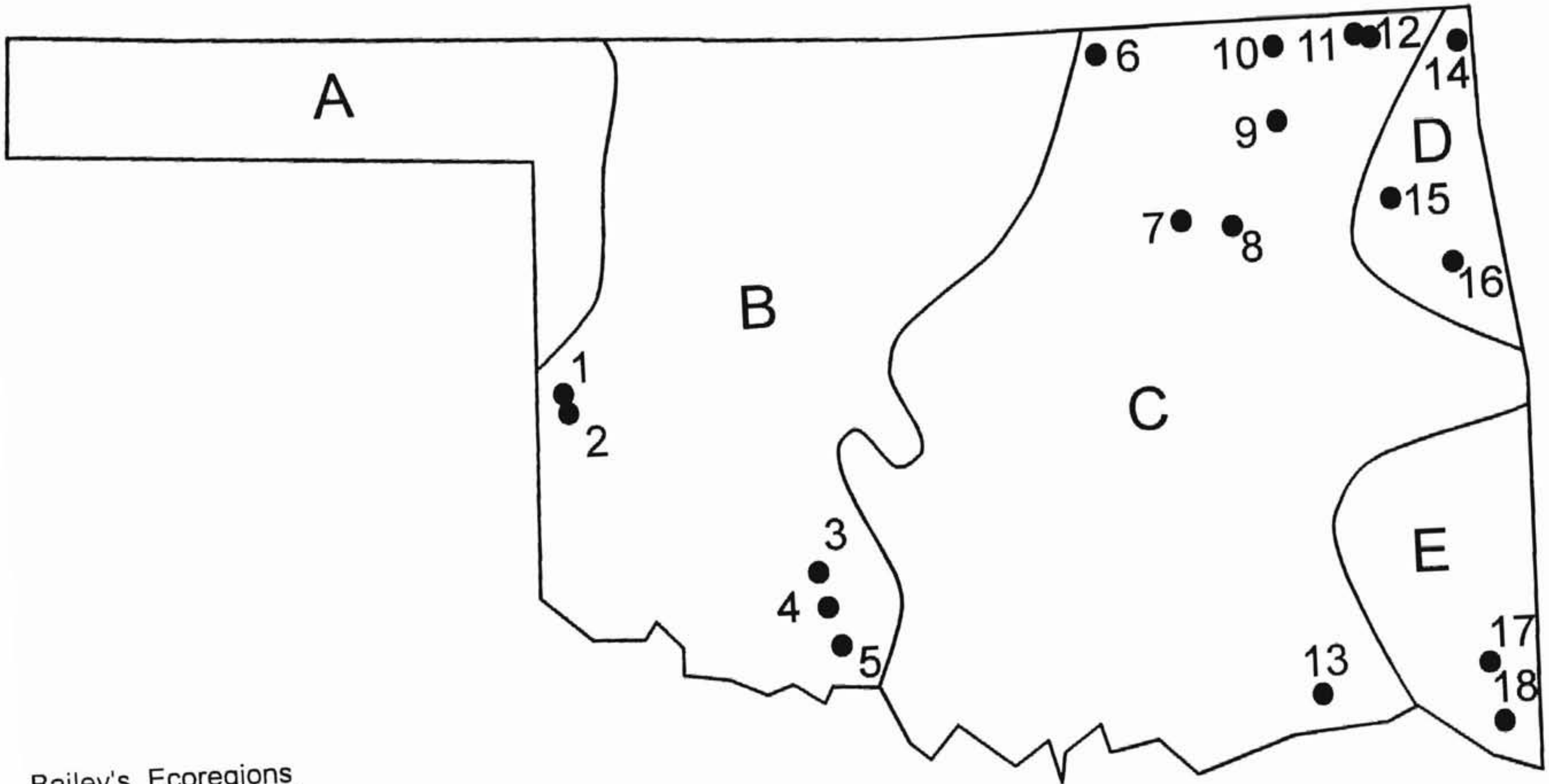
Disturbance type	Tall-Grass Prairie Province	Prairie Parkland Province	Eastern Deciduous Forest Province	Southeastern Mixed Forest Province
Dirt road	185.82 ± 59.36 (n=5)	212.00 ± 163.63 (n=8)	140.31 ± 51.96 (n=3)	328.05 ± 130.04 (n=2)
Human dwelling	345.21 ± 147.42 (n=5)	479.60 ± 144.12 (n=8)	273.07 ± 85.50 (n=3)	316.30
Rangeland	76.03 ± 67.00 (n=5)	205.75 ± 208.07 (n=8)	171.07 ± 157.84 (n=2)	..
Agriculture	125.31 ± 118.77 (n=5)	388.65 ± 322.41 (n=7)	60.60 ± 22.70 (n=2)	..
Paved road	502.17 ± 429.70 (n=4)	317.12 ± 212.90 (n=6)	301.26 ± 150.30 (n=3)	133.73
Maintained dirt road	367.50 ± 212.22 (n=5)	538.48 ± 195.09 (n=7)	..	..
Oil production	761.17 ± 31.62 (n=2)	419.64 ± 444.04 (n=2)	..	..
Railroad tracks	653.25	477.60 ± 262.03 (n=2)	401.19	..
Utilities	..	415.67	765.45	840.29
Recreation	..	..	131.71	242.64

Table 7. Landscape types by mean coverage (ha) ± SD within 1 km radius of great blue heron rookeries. The number of landscape types within an ecoregion is in parantheses.

Landscape type	Tall-Grass Prairie Province	Prairie Parkland Province	Eastern Deciduous Forest Province	Southeastern Mixed Forest Province
Forest	65.62 ± 61.47 (n=5)	141.45 ± 68.28 (n=8)	174.12 ± 90.40 (n=3)	262.50 ± 28.13 (n=2)
Water	5.61 ± 3.32 (n=5)	7.56 ± 3.00 (n=8)	18.22 ± 12.93 (n=3)	28.61 ± 3.56 (n=2)
Human dwellings	0.27 ± 0.36 (n=5)	3.33 ± 8.85 (n=8)	12.20 ± 9.09 (n=3)	0.56
Old field	31.06 ± 40.44 (n=4)	34.71 ± 38.20 (n=8)	20.02 ± 30.56 (n=3)	2.53
Rangeland	95.24 ± 75.68 (n=5)	89.37 ± 87.83 (n=8)	45.00 ± 1.63 (n=2)	..
Agriculture	111.47 ± 63.76 (n=5)	38.24 ± 53.34 (n=7)	82.02 ± 42.55 (n=2)	..
Oil production	1.71 ± 2.10 (n=2)	0.001 ± 0.001 (n=2)	..	..
Utilities	..	0.16	0.0004	2.72
Recreation	..	..	0.16	3.30

FIGURE CAPTION

1. Locations of 18 monitored great blue heron rookeries within Bailey's (1980) vegetational ecoregions.



Bailey's Ecoregions

A. Great Plains-Shortgrass Prairie Province
B. TAll-Grass Prairie Province
C. Prairie Parkland Province
D. Eastern Deciduous Forest Province
E. Southeastern Mixed Forest Province

CHAPTER IV

Partial validation of the great blue heron HSI model for the southcentral Great Plains

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Abstract: Habitat Suitability Index (HSI) models are major components of the Habitat Evaluation Procedures (HEP) used by the U.S. Fish and Wildlife Service to assess, manage, and monitor habitats of biological resources. The great blue heron (*Ardea herodias*) HSI model was developed to evaluate wetland habitats used or potentially used during the species life cycle. I field-tested and validated the Reproductive Index (RI) of the model in the southcentral Great Plains with the aid of Geographic Information System (GIS) technology. From January 1993 through May 1994, populations of great blue herons in 18 rookeries located throughout Oklahoma were monitored, and GIS was used to evaluate data on rookery habitat structure and surrounding landscape features. For validation purposes, the 18 rookeries were classified as potential nest sites and RI ratings were determined for each rookery according to model criteria. Initial rookery population sizes ranged from 14-160 breeding adults ($\bar{x}$=66.2 ± 43.5 SD); rookery population sizes at the end of the breeding season ranged from 0-449 ($\bar{x}$=129.8 ± 128.0 SD). Fourteen (78%) of the 18 rookeries had successful reproduction. The RI identified 3 (17%) of the 18 rookeries as suitable habitat for reproduction, and it was not related (P>0.10) to rookery population sizes (initial or at the end of the breeding season), indicating it was not a reliable predictor of suitable nesting habitats in Oklahoma. I incorporated several modifications into the RI based on habitat and landscape data collected from the 18 rookeries. The partially modified RI output was not related to initial rookery population sizes nor to rookery population sizes at the end of the breeding season. Suggested modifications should be viewed cautiously if used outside of the southcentral Great Plains.

Habitat Suitability Index (HSI) models are major components of the Habitat Evaluation Procedures (HEP) used by the U.S. Fish and Wildlife Service to assess, manage, and monitor habitats of biological resources (Schamberger and Farmer 1978, Schamberger and Krohn 1982). These models are used to assess wildlife habitat relationships and predict species sensitivity to perturbations (Berry 1986, Van Horne and Wiens 1991). The ability of a model to predict effects of perturbations on populations and corresponding reproductive success depends on how accurately model assumptions meet species life requisites (Van Horne and Wiens 1991). Typically, HSI models are species-specific, based on the generalized physical and biological attributes of a species' habitat and assumed to be related to carrying capacity of a particular habitat (Berry 1986, Schamberger and O'Neil 1986). Because most HSI models were constructed from information in existing literature and professional consultations, few have been objectively field-tested and validated. Model validation achieves two goals: model performance is tested in a particular region and model weaknesses are identified for subsequent improvement (Schamberger and O'Neil 1986).

Short and Cooper (1985) developed the Great Blue Heron (*Ardea herodias*) HSI model to evaluate wetland habitats (i.e., herbaceous, shrub, and forested wetlands and riverine, lacustrine, and estuarine deepwater habitats) used or potentially used for foraging and nesting throughout the species life cycle. Great blue herons were targeted because of their sensitivity to human disturbances during spring and summer breeding. Anderson and Hubert (1988) evaluated the Foraging Index (FI) of the model; however, no formal validation of the index was conducted. Furthermore, there is no published validation of the HSI model or its Reproductive Index (RI).

I present results from a field validation study of the RI of the great blue heron HSI model. My objectives were to: 1) assign RI values to 18 active rookeries, based on Short and Cooper's (1985) criteria, with the aid of Geographic Information System (GIS) technology; 2) relate model output to corresponding population attributes for identification of model strengths and weaknesses; and 3) modify the model as needed for use in the southcentral Great Plains. Validation and possible modification of the RI will aid state, federal, and private organizations in the preservation of great blue heron breeding populations in the southcentral Great Plains.

STUDY AREA

Population, habitat, and landscape data were collected at 18 rookeries throughout Oklahoma during the breeding and post-breeding season of 1993. Rookeries occurred in four different vegetational ecoregions (Fig. 1), as defined by Bailey (1980), which ranged from secluded hardwood forests in eastern Oklahoma to exposed riparian patches in western Oklahoma. All rookeries were located within approximately 35 m of a water source. Rookery nest trees were predominantly sycamores (*Platanus occidentalia*) and less frequently cottonwoods (*Populus deltoides*), baldcypress (*Taxodium distichum*), short leaf pines (*Pinus echinata*), pecan (*Carya illinoensis*), unidentifiable snags, and a single water oak (*Quercus nigra L.*). Detailed descriptions of rookery habitats and surrounding landscape features are presented in Chapter III.

METHODS

For the purpose of model validation, 18 active rookeries were classified as potential nest sites as defined by Short and Cooper

(1985), and RI ratings were determined for each. I assumed that active rookeries provided an optimal setting for evaluating the RI variables developed by Short and Cooper (1985). The RI variables in Short and Cooper (1985) are: distance between potential nest sites and foraging areas (V1), potential nest site characteristics (V4), disturbance free buffer zones (V5), and distance between a potential nest site and a traditional nest site (V6). Suitability Indices (SI) for these variables range from 0.0 (unsuitable habitat) to 1.0 (optimum habitat). Variables V4 and V5 are binary, and variables V1 and V6 are continuous.

As described in the model, the distance between a potential nest site and nearby foraging areas (V1) is assigned a SI value of 1.0 if there are adequate foraging areas within 1 km of a potential nest site. An adequate foraging area is defined as a clear water body with areas ≤0.5-m in depth, firm substrates, and huntable fish populations for herons (i.e., fish ≤25-cm in length). For every 1-km increase in distance that the potential nest site is from an adequate foraging area, the SI is decreased by 0.1; distances ≥10 km receive a SI rating of 0.1. A potential nest site (V4) is assigned an SI value of 1.0 if it is a woody patch ≥0.4 ha in size, with trees ≥5-m in height, and located within 250-m of water. If these site features are absent, the SI value is 0.0. Variable V5 is assigned an SI value of 1.0 if there is no human disturbance within 250 m of a potential nest site on land or within 150 m for a site surrounded by water. If these conditions do not exist, the SI value is 0.0. Variable V6 rates a potential nest site with respect to a traditional nest site. If the potential nest site is within 1 km of an active nest site, the SI value assignment is 1.0. As the distance to a potential nest site increases, the SI decreases. Potential nest sites ≥20 km away from active nest sites receive an SI of 0.1. This linear rate of decrease was chosen arbitrarily by Short and Cooper (1985).

A GIS with Geographic Resource Analysis Support System (GRASS) 4.0 software was used to quantify three of Short and Cooper's (1985) RI variables (i.e., V1, V4, and V5). Because I classified active rookeries as potential nest sites, variable V6 was not evaluated in my study. Three digital data layers were combined to generate a landscape rendition of each rookery that was used to obtain SI values for model variables: 1) landscape element polygons (e.g., forests, water bodies, and human dwellings), 2) linear features (i.e., dirt roads and railroad tracks), and 3) a rookery minimum area polygon based on all nest trees. Detailed descriptions of digital data acquisition are presented in Chapter III.

To obtain SI values for V1, a 1-km radius buffer around the center of each rookery was analyzed for the amount and distance to foraging areas with GRASS 4.0 routines. The SI values for V4 were obtained by analyzing rookery habitat data, and GRASS 4.0 generated the area of each rookery and its distance to water. If the criteria set by Short and Cooper (1985) for V4 were usually met, the SI value was assigned 1.0, otherwise it was 0.0. The SI values for V5 were determined with GRASS 4.0 by generating 250-m radius buffers around rookeries located over land and 150-m radius buffers around rookeries surrounded by water. Buffers were generated around each nest tree that comprised the minimum area polygon of a rookery. If no apparent human disturbance was evident within the given buffer, an SI value of 1.0 was assigned; otherwise, it was 0.0.

Suitability Index values obtained for each rookery were incorporated into Short and Cooper's (1985) RI equation:

$$RI=(V1 * V4 * V5 * V6)^{1/2}.$$

An SI value of 0.0 for any of the RI variables would subsequently result in an RI of 0.0, meaning unsuitable great blue heron reproductive habitat. Rookery RI values were correlated with corresponding population sizes (i.e., initial and end of the breeding season) with Spearman rank correlation procedure on Statistical Analysis System (SAS) software (SAS Inst. 1985). My null hypothesis was great blue heron rookery population sizes, both initial and at the end of the breeding season, were not related to Short and Cooper's (1985) RI values.

RESULTS AND DISCUSSION

When applied to active great blue heron rookeries in the southcentral Great Plains, Short and Cooper's (1985) RI generated values of 0.0 (unsuitable habitat) or 1.0 (optimum habitat); there were no intermediate values (Table 1). Variable V1 described all rookeries as optimum relative to the proximity of potential foraging areas. Variable V4 identified 17 (94%) of the 18 rookeries as optimum with respect to potential nest site characteristics. However, variable V5 classified only 3 (17%) of the 18 rookeries as optimum breeding habitats because of the overemphasis placed on human disturbance. Therefore, only 3 (17%) of the 18 rookeries were classified as optimum reproductive habitat for great blue herons, despite the fact that 14 (78%) of 18 had successful reproduction. The RI was not correlated with rookery populations, either initially or at the end of the breeding season ($P>0.10$).

The use of population attributes as indices of habitat quality can be misleading (Van Horne 1983). However, data used for this study were adequate for identifying model weaknesses because herons typically use traditional rookeries. The 18 rookeries used for validation were located prior to the 1993 breeding season and confirmed to be active during the previous year through personal communication with local residents. Validation and subsequent modifications based on these populations must be viewed with caution because they may not represent populations in other regions. However, modifications that I present are presumably representative of great blue heron rookeries in Oklahoma and the southcentral Great Plains and, therefore, can be used to aid conservation efforts in this region.

Short and Cooper's (1985) great blue heron HSI model did not predict suitable reproductive habitats in Oklahoma. Due to mathematical and categorical limitations of the RI and SI variables, the model failed to generate reliable results. Variables V1 and V4 classified >90% of the 18 rookeries as optimum breeding habitats because of the simplicity of the herons reproductive life requisites as described in the model. Variable V5 and the subsequent RI classified 83% of the rookeries as poor reproductive habitats because of its overemphasis of anthropogenic disturbance. Short and Cooper's (1985) model identified relevant reproductive life requisites (see Chapter III) but failed to integrate them (i.e., individually and overall) in a manner that produced meaningful results, which is not uncommon for HSI models (Van Horne and Wiens 1991).

Great blue herons are primarily piscivorous but opportunistic feeders that eat other birds, amphibians, reptiles, and terrestrial prey (Dennis 1971, Krebs 1974, Willard 1977, Peifer 1979, Brooks and Loftin 1987). Although a versatile diet is adaptive, aquatic habitats provide primary food sources that should enhance reproductive success more than terrestrial habitats. Short and Cooper (1985) recognized this relationship; however, they dismissed the possibility that the amount and quality of aquatic habitats influenced rookery size or reproductive success because of uncertainty about strength of the relationship between these variables identified by Werschkul et al. (1977). Short and Cooper (1985) did develop a variable to reflect this in V1: distance from a potential nest site to foraging area. In its present form, V1 is too conservative and unrealistic in rating a rookery's foraging demands.

Gibbs (1991) identified a positive relationship between colony size (number of nests) and the amount of available foraging habitat (ha) within a 15-km radius of 29 inland rookeries throughout Maine, which provided evidence that V1 needed modification. However, I could not legitimately synthesize information from Gibbs (1991) into a quantitative form because physiographic features in Maine (i.e., marshes, flooded meadows, estuaries, and bogs, and his model calculated 5-m exploitable littoral zone around lakes, rivers, streams, and ponds) are not consistent throughout the herons' breeding range. Kelly et al. (1993) were unable to corroborate this relationship because they only analyzed the extent of tidal marshes available for foraging and not all available aquatic habitats. Nor was I able to identify a relationship between foraging area and the number of breeding birds (see Chapter III). Clarification and quantification of the interaction between great blue heron foraging areas and rookery population size are needed before a reliable model variable can be devised that is representative throughout the species' breeding range.

Nesting characteristics of great blue herons are difficult to describe because of the species' extensive breeding range (Henny and Kurtz 1978). According to Short and Cooper (1985), potential nest site characteristics (V4) are a combination of several parameters, each of which may affect heron nest site selection. Furthermore, V4 is a subjective binary variable that is optimal if potential treeland habitats usually fulfill all of the conditions, or unsuitable if potential treeland habitats usually do not fulfill all of the conditions. I separated V4 into component parts: nest tree characteristics, minimum area of rookery polygon, and distance from the rookery polygon to water. Nest tree characteristics were further divided into four parameters: tree height, tree density at breast height (dbh), crown diameter, and crown area. Because of the positive relationship of nest tree characteristics to the mean number of nests per tree at each rookery (established in Chapter III), I incorporated them into the model. Similarly, because the rookery polygon area (ha) and its proximity to water (m) were positively related to the total number of nests per rookery, these relationships also were synthesized into new model variables describing a potential nest site.

The method that I used to devise potential nest site suitability curves was based on the percentiles of the measured data (Fig. 2 and 3). For example, mean nest tree heights for the 18 rookeries had a 100^{th} percentile of 33.59 m and a 75^{th} percentile of 32.97; therefore, this range was declared 1.0 on the SI curve. A straight line from the 75^{th} percentile was drawn to the 25^{th} percentile (i.e., 26.48 m), which was given an SI value of 0.5. From the 25^{th} percentile a straight line was drawn to the point of 0.1 and 5 m because this is the lowest hypothesized distance herons will nest off the ground (Short and Cooper 1985). This procedure was repeated for the remaining potential nest site variables, except the 0.1 points were chosen arbitrarily. I used two equations to obtain a new SI value for potential nest sites (V4):

$$NT = (V4A * V4B * V4C * V4D)^{1/4} \tag{1}$$

where:

V4A is the average height (m) of potential nest trees,

V4B is the average dbh (cm) of potential nest trees,

V4C is the average crown diameter (m) of potential nest trees,

V4D is the average crown area (m^2) of potential nest trees, and

$$V4 = (NT * V4E * V4F)^{1/3} \tag{2}$$

where:

NT is the result from equation (1),

V4E is potential nest tree patch size (ha), and

V4F is the distance the patch of potential nest trees is to a water source.

I developed these two equations for determining potential nest site characteristics because nest tree characteristics (NT) dictate the number of nest placement opportunities available for herons and, therefore, deserve equal weight in the computation of V4 (U.S. Fish and Wildlife Service 1981). With increasing size, the area of the potential nest tree patch (V4E) will compensate for trees with minimal nest placement opportunities. Furthermore, due to the close association between nesting herons and water sources, V4F will target areas needed to be ground-truthed for locating potential nest trees that may be used by herons.

Great blue herons are wary of humans especially during early phases of nesting, and human disturbances (e.g., recreational landuse and landscape alterations) can cause partial or complete rookery abandonments (Thompson 1979, Custer et al. 1980, Kelsall and Simpson 1980). However, individual rookeries in my study have habituated to certain forms of disturbance (see Chapter III). Although habituation appears to be rookery specific, less emphasis needs to be placed on anthropogenic disturbance when evaluating potential nesting habitats, at least in the southcentral Great Plains. Variable V5 was separated into three variables (Fig. 4): 1) passive disturbance (e.g., pre-existing agricultural activities, vehicular transportation, and cattle management activities) was indexed by unimproved dirt roads, 2) intermediate disturbance (e.g., residential areas and recreational activities) was indexed by human habitation, and 3) critical disturbance (i.e., newly created landscape alterations).

Two suitability curves for disturbance types (i.e., V5A, V5B) were constructed. One was based on the same methodology (i.e., percentile distribution) used for potential nest site characteristics, except the zero point was obtained by dividing the 0 percentile by two (Fig. 4). The other was based on a regression line of the minimum distances herons nested from passive and intermediate disturbances in Oklahoma (Fig. 4). Because of insufficient data on critical disturbance, I based the corresponding SI curve on Short and Cooper's (1985) variable V5. The equation for obtaining a new SI value for V5 was:

$$V5 = (V5A * V5B * V5C)^{1/3} \quad (3)$$

where:

V5A = distance (m) to passive disturbance,

V5B = distance (m) to intermediate disturbance, and

V5C = distance (m) to critical disturbance.

I believe the regression method for determining SI values for V5 was more conservative and beneficial to the species than the percentile method; therefore, I suggest that the former method be used when using these modified variables.

No distinction was made between rookeries located over land and those surrounded by water with respect to human disturbance because no island rookeries were studied. In the southcentral Great Plains of Oklahoma, I observed that heron rookeries were typically located in trees within riparian areas along water features (e.g., reservoirs, rivers, or streams) on the side of the water opposite of human disturbances. Therefore, I presumed that nesting herons used natural landscape features to buffer themselves from human activities. Regardless of the natural buffer size or degree of habituation of the rookery, birds will flush when humans intrude into the buffer.

The RI value for a potential nest site was derived by incorporating results of potential nest site characteristics (V4) and distance to human disturbance (V5) into the following equation:

$$RI = (V4 * V5)^{1/2} \tag{4}$$

where:

V4 = potential nest site characteristics and

V5 = distance (m) to human disturbance.

This equation generated a value of 0.0 when human disturbance was in close proximity to nesting herons.

Values for modified variables and the resulting RI ranged from 0.0 to 1.0 (Table 2). However, values for the critical disturbance variable (V5C) were either 0.0 or 1.0 with no intermediate values because of the small sample size pertaining to critical disturbances. Variable V5C was 0.0 at only two rookeries (i.e., Lenapah 2 and Fort Sill) where abandonment resulted from a critical disturbance; the RI values for these rookeries were 0.0. There were no relationships ($P<0.05$) between SI variables and rookery populations (initial or at the end of breeding season). Similarly, no relationships ($P<0.05$) existed between nest tree characteristics (NT) or human disturbance (V5) and rookery population sizes (initial or at the end of breeding season), or between the modified RI and initial rookery population sizes and rookery population sizes at the end of the breeding season (Fig. 5).

Although the modified RI was not correlated with heron population sizes, the index variables were scaled based on habitat characteristics of rookeries throughout Oklahoma and can be used to identify areas that may be potential nesting sites if a traditional rookery needs to relocate. However, to meet modification assumptions, it is important to identify primary nest tree species used by herons that are relocating because herons are likely to seek out familiar nesting substrates (see

Chapter III). After the primary nest tree species is identified, only a sample of this tree species needs to be measured for potential nest site characteristics. Additionally, evaluations should be limited to areas within a 1-km radius of a traditional because heron rookeries are known to split up into satellite rookeries within this distance of traditional rookeries (Custer et al. 1980, Kelly et. al. 1993). I recommend that areas meeting the prescribed criteria with RI values ≥0.5 should be protected from landscape alterations because no successful rookeries in my study generated modified RI values ≤0.5.

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Table 1. Great blue heron population size and corresponding SI and RI values from Short and Cooper's (1985) HSI model for 18 rookeries in Oklahoma.

Ecoregion	Rookery[1]	Initial population size	End of the breeding season population size	SI variables				RI
				V1	V4	V5	V6	
Tall-Grass Prairie Province	1. Sweetwater 1	104	207	1.0	1.0	1.0	N/A	1.0
	2. Sweetwater 2	14	24	1.0	0.0	0.0	N/A	0.0
	3. Fort Sill[2]	32	0	1.0	1.0	0.0	N/A	0.0
	4. Alexandria	76	206	1.0	1.0	0.0	N/A	0.0
	5. Walters	32	40	1.0	1.0	0.0	N/A	0.0
Prairie Parkland Province	6. Kubik	60	140	1.0	1.0	0.0	N/A	0.0
	7. Terelton	160	381	1.0	1.0	0.0	N/A	0.0
	8. Sand Springs	122	179	1.0	1.0	0.0	N/A	0.0
	9. Ramona	18	39	1.0	1.0	0.0	N/A	0.0
	10. Copan	104	179	1.0	1.0	0.0	N/A	0.0
	11. Lenapah 1	54	141	1.0	1.0	0.0	N/A	0.0
	12. Lenapah 2[2]	24	0	1.0	1.0	0.0	N/A	0.0
	13. Hugo	48	87	1.0	1.0	1.0	N/A	1.0
Eastern Deciduous Forest Province	14. Wyandotte	80	134	1.0	1.0	0.0	N/A	0.0
	15. Murphy	134	449	1.0	1.0	0.0	N/A	0.0
	16. Horse Shoe	72	131	1.0	1.0	0.0	N/A	0.0
Southeastern Mixed Forest Province	17. Beavers Bend[2]	30	0	1.0	1.0	0.0	N/A	0.0
	18. Little River[2]	28	0	1.0	1.0	1.0	N/A	1.0

[1] Rookery numbers coincide with numbers on Fig. 1
[2] Abandoned rookeries

Table 2. Revised SI and RI values for 18 great blue heron rookeries throughout Oklahoma.

	Nest site variables								Disturbance variables				
Rookery[1]	V4A	V4B	V4C	V4D	V4E	V4F	NT	V4	V5A	V5B	V5C	V5	RI
1. Sweetwater 1	0.4	0.3	0.2	0.1	0.6	1.0	0.2	0.5	1.0	1.0	1.0	1.0	0.7
2. Sweetwater 2	0.3	0.4	0.3	0.3	0.2	1.0	0.3	0.4	1.0	0.3	1.0	0.5	0.5
3. Fort Sill[2]	0.5	0.5	0.5	0.5	0.1	0.5	0.5	0.3	1.0	1.0	0.0	0.0	0.0
4. Alexandria	0.6	1.0	1.0	1.0	1.0	0.5	0.9	0.8	1.0	0.2	1.0	0.4	0.6
5. Walters	1.0	1.0	1.0	1.0	0.7	0.7	1.0	0.8	0.3	1.0	1.0	0.5	0.7
6. Kubik	0.8	1.0	1.0	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
7. Terelton	0.8	0.7	0.8	0.8	1.0	1.0	0.8	0.9	0.5	1.0	1.0	0.7	0.8
8. Sand Springs	1.0	0.7	0.8	0.7	0.2	1.0	0.8	0.5	0.2	1.0	1.0	0.4	0.5
9. Ramona	0.5	0.6	0.5	0.5	0.3	0.9	0.5	0.5	1.0	1.0	1.0	1.0	0.7
10. Copan	0.6	1.0	1.0	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	0.9
11. Lenapah 1	0.9	0.9	0.8	0.8	0.6	0.7	0.8	0.7	0.8	1.0	1.0	0.9	0.8
12. Lenapah 2[2]	1.0	1.0	1.0	1.0	0.6	1.0	1.0	0.8	0.6	1.0	0.0	0.0	0.0
13. Hugo	0.8	0.5	0.9	0.9	1.0	0.8	0.8	0.8	1.0	1.0	1.0	1.0	0.9
14. Wyandotte	1.0	0.7	0.5	0.5	1.0	0.7	0.6	0.8	1.0	0.3	1.0	0.5	0.6
15. Murphy	1.0	0.6	0.5	0.6	1.0	0.5	0.7	0.7	0.3	0.8	1.0	0.5	0.6
16. Horse Shoe	0.9	0.5	0.5	0.5	1.0	0.5	0.6	0.7	1.0	1.0	1.0	1.0	0.8
17. Beavers Bend[2]	0.5	0.3	0.3	0.2	0.9	0.1	0.3	0.3	1.0	1.0	1.0	1.0	0.6
18. Little River[2]	0.6	1.0	0.6	0.6	0.9	1.0	0.7	0.8	1.0	1.0	1.0	1.0	0.9

[1]Rookery numbers coincide with numbers on Fig.1
[2]Abandoned rookeries

FIGURE CAPTIONS

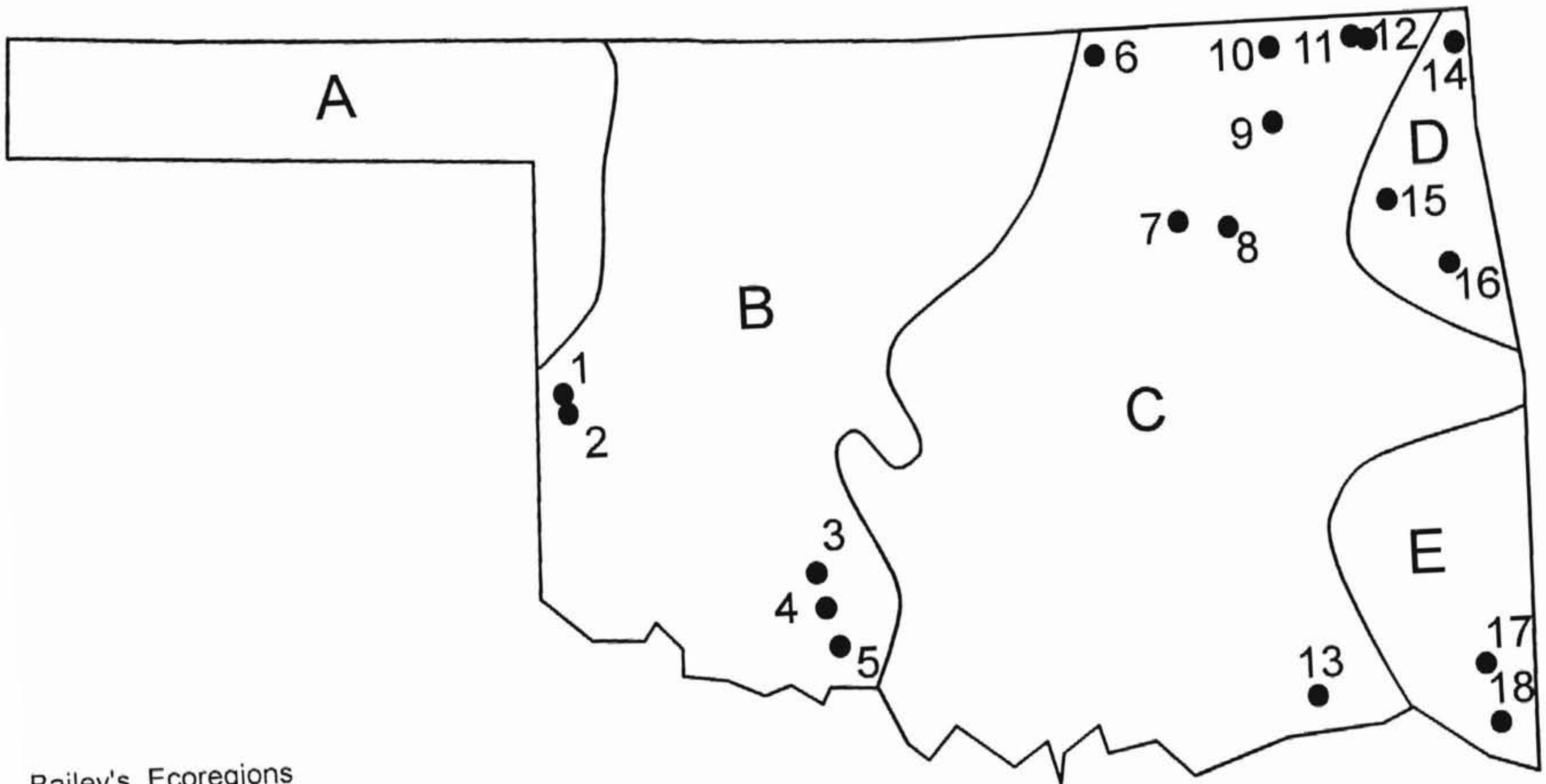
1. Locations of 18 great blue heron rookeries used for model validation within Bailey's (1980) vegetational ecoregions.

2. Suitability of A) rookery nest tree mean heights (V4A), B) rookery nest tree mean dbh (V4B), and C) rookery nest tree mean crown diameters (V4C) based on corresponding numbers of nests.

3. Suitability of A) rookery nest tree mean crown area based on corresponding numbers of nests (V4D), B) rookery size (ha) (V4E), based on the total number of per rookery, and D) rookery proximity to water (V4F).

4. Suitability of A) rookery proximity to passive disturbance (V5A), B) rookery proximity to intermediate disturbance (V5B), and C) rookery proximity to critical disturbance (V5C). Dashed lines represent the percentile method of curve construction, and solid lines represent the regression method of curve construction.

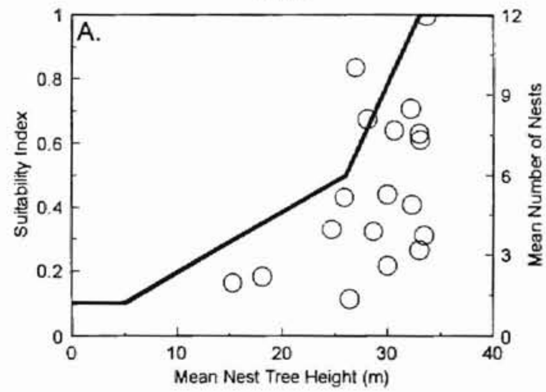
5. Relationship between modified RI model output and A) initial population size and B) end of the breeding season population size.



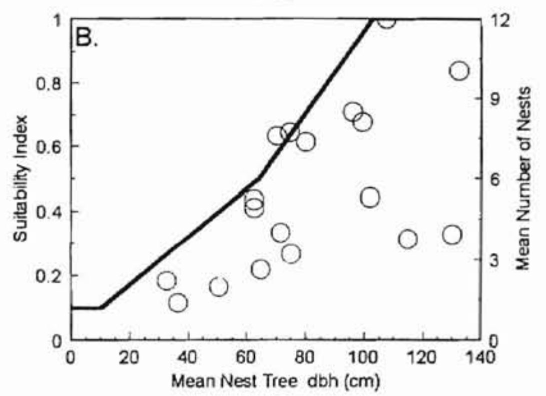
Bailey's Ecoregions

A. Great Plains-Shortgrass Prairie Province
B. TAll-Grass Prairie Province
C. Prairie Parkland Province
D. Eastern Deciduous Forest Province
E. Southeastern Mixed Forest Province

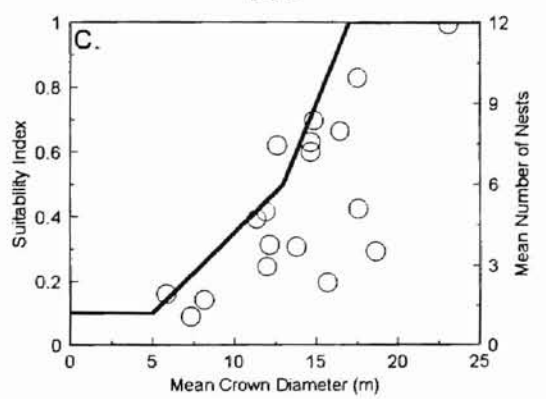
V4A

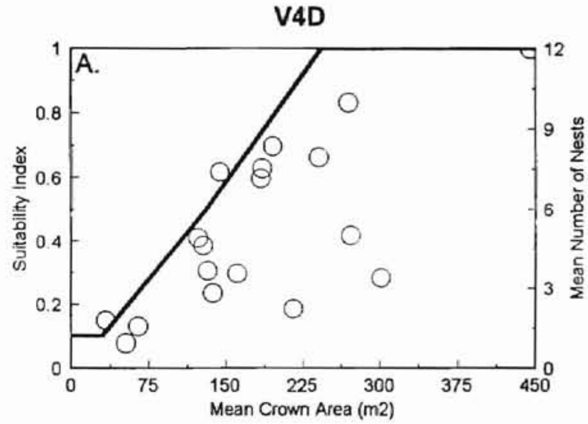

A.
Suitability Index
Mean Number of Nests
Mean Nest Tree Height (m)

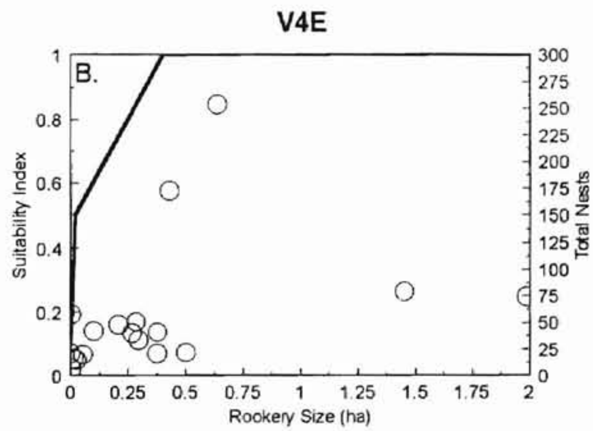
V4B

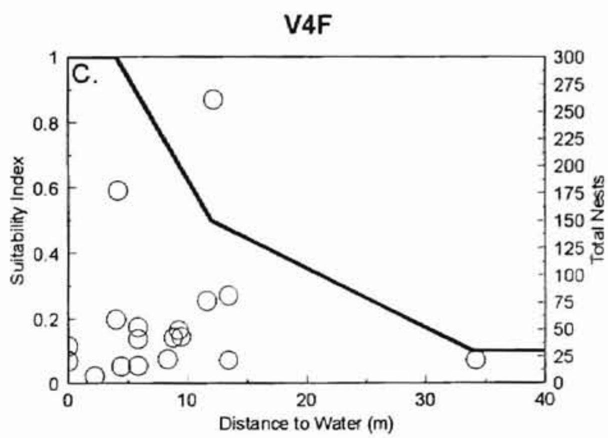

B.
Suitability Index
Mean Number of Nests
Mean Nest Tree dbh (cm)

V4C

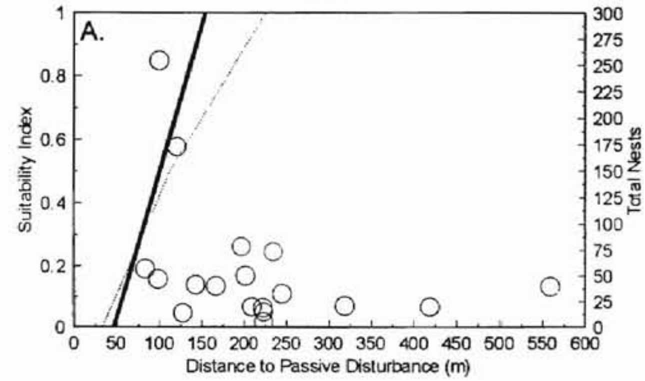

C.
Suitability Index
Mean Number of Nests
Mean Crown Diameter (m)


V4D
A.
Suitability Index
Mean Number of Nests
Mean Crown Area (m2)
0
75
150
225
300
375
450
0
0.2
0.4
0.6
0.8
1
3
6
9
12

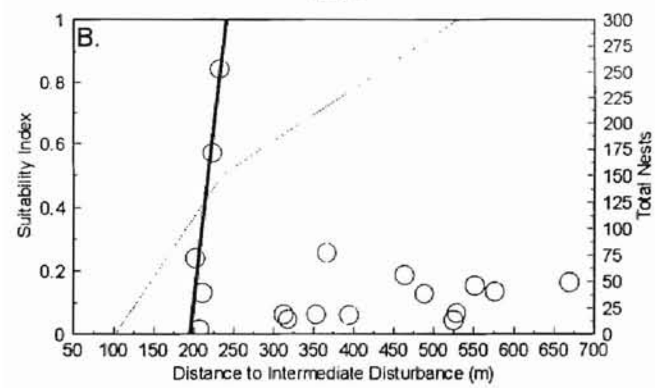

V4E
B.
Suitability Index
Total Nests
Rookery Size (ha)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
25
50
75
100
125
150
175
200
225
250
275
300


V4F
C.
Suitability Index
Total Nests
Distance to Water (m)
0
10
20
30
40

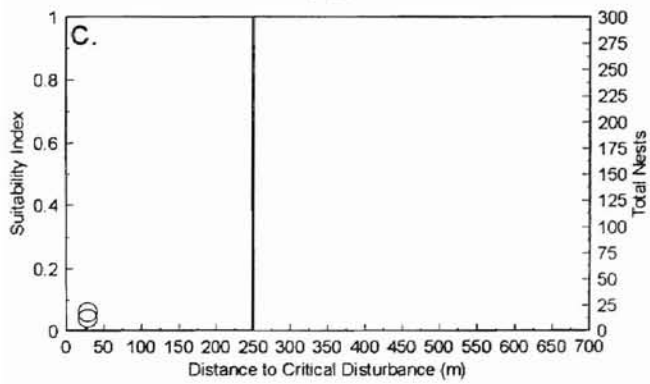
V5A

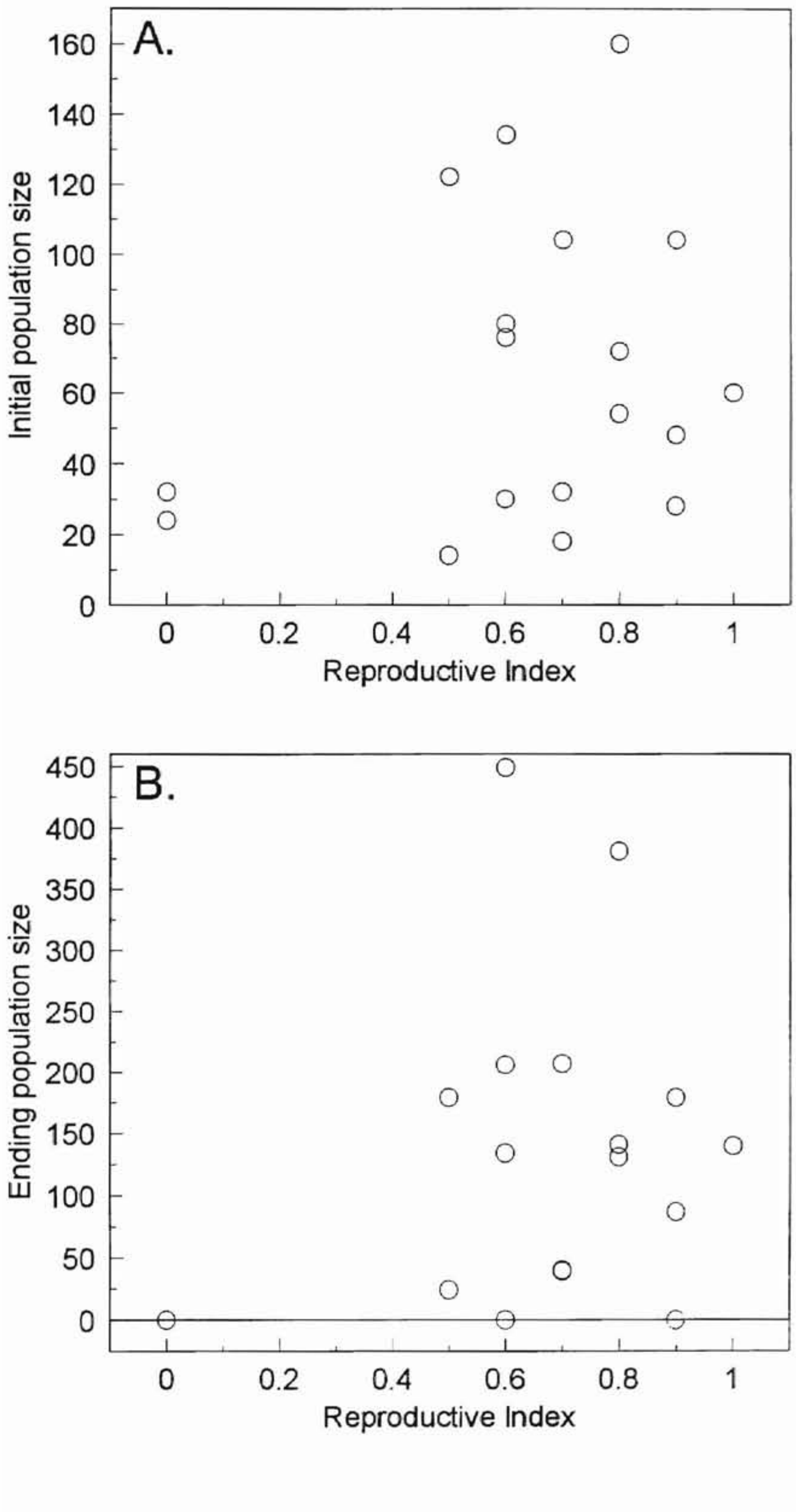

A.
Suitability Index
Total Nests
0 50 100 150 200 250 300 350 400 450 500 550 600
Distance to Passive Disturbance (m)

V5B


B.
Suitability Index
Total Nests
50 100 150 200 250 300 350 400 450 500 550 600 650 700
Distance to Intermediate Disturbance (m)

V5C


C.
Suitability Index
Total Nests
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
Distance to Critical Disturbance (m)


A.
Initial population size
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
Reproductive Index
B.
Ending population size
450
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
Reproductive Index

VITA

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Master of Science

Thesis: HABITAT AND POPULATION CHARACTERISTICS OF GREAT BLUE HERON ROOKERIES IN THE SOUTH CENTRAL GREAT PLAINS: PARTIAL VALIDATION OF THE GREAT BLUE HERON HABITAT SUITABILITY INDEX MODEL

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