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Geographical Information System Analysis of Great Blue Heron (*Ardea herodias*) Colony Site Selection in Northeastern Indiana

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GEOGRAPHICAL INFORMATION SYSTEM ANALYSIS OF GREAT BLUE HERON (*ARDEA HERODIAS*) COLONY SITE SELECTION IN NORTHEASTERN INDIANA

by

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ABSTRACT.—Seventeen Great Blue Heron (*Ardea herodias*) nesting colonies were studied in northeastern Indiana to determine which natural and human variables, within 15 km of each heronry, correlated with the size and location of this bird's nesting sites. The data collected in the field and with ArcMap, a Geographical Information System program, included: the types and distances to human disturbances and water/foraging sources; wetland size and type; the height, dbh, and species of nesting trees; and the number of active and total nests. This information was used to produce an individual map for each heronry as well as a regional map for all of northeastern Indiana. With the use of two statistical tests, a best subset regression and a multiple regression analysis, 13 variables were compared to the number of active nests, and three variables were found to be significant (p-value < 0.05): distance to the nearest population center of 0-1,000, dominant wetland type within 15 km, and distance to the nearest water body. A fourth variable, distance to the nearest human habitation, was found to be of some importance with a p-value of 0.059. The mean distance to the nearest population enter of 0-1,000 was 2.85 km, the dominant wetland type with 15 km was PFO1A, and the mean distance to the nearest water body was 64 m. It was also found that GBHE would frequently use American sycamores or American beeches when nesting in riverine or upland forest habitats respectively. These analyses showed the importance of forested buffer zones along all riverine and wetland habitats where nesting and foraging by Great Blue Herons occurs.

Key words: Great Blue Heron, heronry, nest site selection, Geographic Information System

Great Blue Herons (*Ardea herodias*) (GBHE) are one of the most common and recognizable species of heron in North America, as are their nesting colonies, aka heronries. They are a very common and widespread species of colonial waterbird in North America and have become an intimate part of the North American landscape (J. Castrale pers. comm., Horton 1999). However, during the late 19th and early 20th centuries, the GBHE, egrets, and terns nearly went extinct due to demand for their plumage to create decorative hats for women and soldiers (Allen 1991, Butler 1997). The public's desire for the plumage of these birds was great, but so was their outrage at the slaughter of these majestic birds. This outrage led to the first international treaty for bird conservation, and was instrumental in forming the British Royal Society for the Protection of Birds and the U.S. Audubon Society during the first decade of the 20th century (Allen 1991). In addition to these and other wildlife protection societies, conservation laws, including the Migratory Bird Treaty Act and the Lacey Act, have assisted in the recovery of the GBHE. Currently it has a breeding range extending from western Alaska to the Galapagos Islands and throughout most of North and Central America (Butler 1997, Horton 1999, Armstrong et al. 2001).

Great Blue Herons are found throughout Indiana during the spring and summer, and in southern Indiana year round (Sibley 2000). In 1983 the Indiana Nongame and Endangered Wildlife Program began gathering data on heron nesting colonies, primarily the GBHE. Surveys of all known heronries have been conducted approximately every two to five years since, and the number of active heronries as well as total nests has been steadily increasing. Reasons for the observed increase are twofold: (1) increased public awareness of heron colonies and (2) population growth (Castrale 1994, 2000, Forbes et al. 1985). The increase seen in Indiana's

GBHE populations coincides with increasing heron populations in Illinois as well as increases seen in the federal Breeding Bird Survey (Sauer et al. 2005).

Despite increasing populations, GBHE breeding colonies are not uniformly distributed throughout the counties of the northern, central, and southern areas of Indiana. The northern counties contain 24% of the colonies and 32% of the nests, the central counties contain 42% of the colonies and 41% of the nests, and the southern counties contain 34% of the colonies and 27% of the nests (Castrale 1994). The distribution of breeding colonies seen throughout Indiana may thus be attributed to differences in the quality and quantity of wetlands, which varies by ecoregions, as well as desirable nesting trees (Iverson 1993, Castrale 2000). Gibbs et al. (1991) observed that GBHE, in Maine, prefer wetlands of human and beaver origin (82% of colonies) compared to glacial wetlands. This preference is thought to arise from the need for shallow littoral areas for foraging, which are more limited in historically glaciated areas. Hydrologic features, like lakes, in northeastern Indiana were formed by glacial processes and therefore may be too deep for foraging GBHE, except around the perimeter (Melhorn 1997).

The GBHE has a wide breeding range, which makes it difficult to describe suitable habitat characteristics for this species (Henny and Kurtz 1978). However, Miller (1943) said a suitable nesting site must have four things: (1) the right species of trees, (2) tall trees, (3) adequate distance from human activities, and (4) natural buffer areas, which are either areas of forest or water that separates the herons from human disturbances. Another study reported that the unpredictability of nesting habitat selection is the result of variability in the vegetation in areas surrounding adequate foraging sites (Gibbs 1991). In fact, predominant habitat characteristics differ regionally and among studies (Gibbs and Kinkel 1997, Beaver et al. 1980, Gibbs et al. 1987).

With the different plant communities throughout North America, differences have been found in the habitat structures and tree species utilized for nesting between regions, and even between colonies in a single area (Kelsall and Simpson 1980, Beaver et al. 1980). Tree condition has also been considered as a factor. Carlson (1995) found that nests were located in tall trees with less damaged crowns, while Kelsall and Simpson (1980) found GBHE prefer particular tree species over others even when they are less dominant and of lower quality. Great Blue Herons have also been observed to nest in both dead and living trees, in bushes, among rocks, and on the ground (especially on islands), and even on man-made structures(Vermeer 1969, Carlson 1995, Henny and Kurtz 1978), which complicates the identification of ideal nest site vegetation even more.

Three important factors that determine where a GBHE will nest are the amount and size of foraging areas in the land surrounding a heronry and the distance to foraging areas. In Maine, herons preferred wetlands $\geq$ 8 ha (Gibbs et al. 1991). Custer and Galli (2002) found that herons foraged at feeding sites that were > 350 ha 50% of the time. This same study also found that regional use of wetlands by herons was less than expected in the 0-100 ha category and more than expected in the 201-400 ha category, especially if wetland size exceeded 300 ha. It was also determined that, in addition to size, the distribution of wetlands in an area is important. Both Gibbs (1991) and Gibbs et al. (1991) found that heronries were more often located near wetland complexes, rather than near isolated wetlands. Additionally, Custer et al. (2004) reported that feeding sites within distance categories of 0-1 and 1-5 km were used more than feeding sites 5-10 and 10-20 km away. The distances GBHE have been observed to fly to forage vary from region to region. They have been observed flying a maximum distance of 15 km in inland Maine (Gibbs 1991), 20 km for coastal Maine (Gibbs et al. 1987), 20 km in the upper

Mississippi River area (Thompson 1978), and 30 km for one heronry in southern Lake Erie (Parris and Grau 1979). While they are capable of flying long distances to forage, nearer foraging habitat is preferred and is used at a greater rate than distant foraging habitat (Parris and Grau 1979, Custer and Galli 2002). By foraging at sites within 5 km of the heronry, birds conserve energy, minimize flight time and time away from young, and have more successful nests (Gibbs and Kinkel 1997, Custer and Galli 2002, Simpson et al. 1987, Custer et al. 2004). In addition, the distance adult GBHE will fly to forage differs during the period of incubation and the period of raising the chicks (Custer et al. 2004). Gibbs (1991) found the size of a heronry is proportional to the availability of local foraging habitats. It must be noted that the area of a wetland or body of water is not always the primary characteristic used by GBHE to determine if it is a good place to forage. For example, water depth is an important factor, since GBHE are littoral feeders and are less likely to forage in areas > 0.5 m deep (Short and Cooper 1985, Gibbs et al. 1991). However, Miller (1943) occasionally observed GBHE foraging in deeper waters.

The usage of wetlands or other bodies of water by herons is influenced by different characteristics, such as, the type of vegetation present and water clarity. Thus, the availability of certain wetland types and specific wetland characteristics are conducive to GBHE foraging habits. Besides the area of wetlands, many studies have found that GBHE are more frequently found in wetlands containing emergent or submergent vegetation and longer shorelines than in wetlands containing more open water and shorter shorelines (Hoffman 1978, Thompson 1978, Gibbs and Kinkel 1997, Gibbs et al. 1991). Again this highlights the fact that GBHE are littoral feeders. Moreover, clarity and water disturbance are also important factors when selecting foraging sites (Thompson 1978).

Great Blue Herons are easily disturbed by the presence of humans within or near their heronries, especially during breeding and the raising of young. Human disturbances have been shown to decrease the fecundity of herons and cause heronry abandonment (Butler 1997, Watts and Bradshaw 1994, Gibbs and Kinkel 1997). In Indiana it has been shown that human disturbance plays a significant role in the status of the GBHE population because of the concentration of GBHE at a relatively small number of nesting sites (Castrale 1994).

The habitat preferred by GBHE is usually far from human disturbance, contains tall trees, and has wetlands or other water bodies nearby. However, of these habitat variables, proximity to wetlands or other water bodies is reported to be the least important factor while being farther from human disturbance is more important in the heron's choice of nesting location (Castrale 1994, Gibbs et al. 1987).

Similar research to this northeastern Indiana study took place in Maine, Oklahoma, Illinois, and Virginia. All examined heronry characteristics and how they influenced numbers of active and total nests. Three of the four studies **(**Clements 1995, Gibbs and Kinkel (1997), Gibbs et al. 1987**)** used null sites as well as predictive models to study the herons while the fourth study (Corley/Martinez 1991) only used a predictive model but also used Geographic Information System (GIS), which the other three did not use. A study along coastal Maine examined the possible determinants of GBHE colony distribution, colony size, food availability, and nest site selection. The data was compared between active heronries and random sites (Gibbs et al. 1987). The size, nest substrate, and landscape characteristics (distances to foraging sites and human disturbances) of heronries found throughout Oklahoma's different eco-regions were analyzed by Corley/Martinez (1991). His study was the only one that used a GIS program. Gibbs and Kinkel (1997) investigated the characteristics of nesting sites, substrates used for nesting, and foraging areas for GBHE in Illinois. They also examined usage of habitats compared to the availability of each habitat. In Virginia one study focused specifically on the area around the James and Chickahominy Rivers, examining the amount of foraging area and human disturbance around heronries and what influence the nearest heronry neighbor would have on each individual heronry (Clements 1995).

These four studies were carried out in different ecological regions and came to similar, and yet, different conclusions. These conclusions were influenced by where each study was conducted because not only was the environment different, but also the size of the human population and their influence on the surrounding landscape. Therefore, it is imperative to determine which habitat characteristics are essential to GBHE in any given specific region as these birds try to exist in an increasingly human-altered environment. While a large amount of data concerning GBHE colony locations exists, little information is available on how Indiana heronry locations are affected by specific habitat and human factors.

The purpose of this study was to (1) investigate what influence vegetation, wetland size and type, distance to foraging areas, and distance and types of human disturbance will have upon the size and location of heronries in northeastern Indiana, and (2) to use GIS to predict suitable GBHE colony locations based on the above variables. A secondary objective was to produce a single map for each heronry, and a regional heronry map to demonstrate the location and distribution of these northeastern Indiana heronries.

METHODS

Study area.—The study was located in the Lower Great Lakes Region, specifically the northeastern quarter of Indiana, with the borders delimited by the western and southern county borders of Marion County and the Michigan/Ohio state borders (Fig. 1). As of 2003, 45 active and 20 inactive GBHE colonies were located in this area; their locations were provided by John Castrale of the Indiana DNR (J. Castrale pers. comm.). The locations and information for each heronry came from surveys conducted mainly during the month of April, 2003, by volunteer surveyors. These heronries, classified as being two or more active nests (Gibbs and Kinkel 1997), ranged in size from 3 to 174 active nests (J. Castrale pers. comm.). Of these 45 GBHE colonies, I randomly chose 25, 24 on private property and 1 in a state park. Permission was granted to survey 17 colonies, 16 on private property and 1 in a state park. Of these 17 heronries, one was excluded from the final analysis and another was reclassified as two separate heronries. The excluded site was atypical because it is approximately ten times larger than the average heronry in Indiana, and was completely surrounded by urban Indianapolis (Castrale 2000). The other heronry was classified as two separate heronries because the two nesting trees at this location were separated by 369.5 m and a farm field. The literature indicates that both a distance of 400 m and 250 m have been used to separate nesting trees into unique heronries (McCrimmon 1981, Gibbs et al. 1987). Therefore, the number of heronries studied remained at 17 (Fig. 1).

Areas around each heronry were divided into five study zones: the Heronry Zone, the 0-5 Kilometer Zone, the 5-10 Kilometer Zone, the 10-15 Kilometer Zone, and the 0-15 Kilometer Zone. The 0-15 Kilometer Zone is a composite of the other four zones (Fig. 2).

Survey Methods.—Each heronry was surveyed from the middle of March to the end of April, 2005, to count the number of active nests before leaves emerged on the trees and obstructed views of the nests. Additionally, to minimize the disturbance to the herons, all preliminary surveying was completed before the peak mating and incubation period (Castrale 2000, J. Castrale pers. comm.).

Each GBHE colony was visited by either following maps provided by a previous surveyor, or by the guidance of the landowner (J. Castrale pers. comm.). To determine whether or not the heronry was > 50 or < 50 nests, a vantage point was chosen where most nests were visible (Gibbs and Kinkel 1997). If < 50 nests, a single vantage point and a point count survey method was used. If > 50 nests, a perimeter, or ground count, survey method was used to ensure all nests were counted (see Dodd and Murphy 1995 for further explanation on survey methods). An active nest is classified as being large, well formed, having herons either sitting, standing next to, or working on the nest, or having whitewash present on the nest, nesting tree or ground (Corley/Martinez 1991, J. Castrale pers. comm.).

Since previous research has shown that GBHE are more susceptible to disturbance during the time of nest building, egg laying, and hatching (Gebauer 1993, Vos et al. 1985, Simpson et al. 1987), heronry observation activity was suspended for 50 days (McAloney (1973) suggests 25-30 days) to avoid disturbing the birds and causing heronry abandonment (Forbes et. al. 1985). Additionally, these birds have been observed as less responsive to disturbances as the season progresses (Taylor et al. 1982, Vos et al. 1985). Thus, the second survey of the 17 heronries began in June 2005 when the presence of humans within the heronries no longer noticeably disturbed the GBHE (Vos et al. 1985, J. Kauffman pers. obs.).

The species of each nesting tree was determined during the two survey visits. The height of each nesting tree was also measured using a clinometer, and diameter at breast height (dbh) was measured using a 7.5 m dbh tape. The three most prevalent tree species within two times the heronry diameter, or no more than 100 m, were also identified. If 100 m did not exceed the perimeter of the heronry, then 50 m were added to the perimeter to determine the area from which the three dominant tree species would be identified. The identification of these tree species was necessary to know the composition of the surrounding forested area.

The perimeter of the heronry was delineated by waypoints using a Garmin eTrexVista GPS unit. The placement of each waypoint was determined by locating the perimeter nesting trees and marking their crown's outer edge. An additional waypoint marked the center of each heronry and served as the center point for distance measurements. The locations of trails, when present, throughout the surrounding forest were also marked. The GPS elevation reading was obtained at ground level and the latitude and longitude were recorded as near as possible to the center of the heronry. The latitude and longitude were later verified using ArcMap. Land type was classified as riverine, upland forest, or other.

Outside of each heronry the GPS unit was used to create additional waypoints to measure several circumjacent metrics: distances to the nearest road, human habitation, and water source. These waypoints were created by either marking a waypoint while walking through the forest, or by driving the roads surrounding each heronry. The nearest road waypoints were established with the help of GPS software (GARMIN 2000). The nearest human habitation, defined as a human dwelling or building where human activity regularly takes place, was determined by driving the roads surrounding the heronry; for each human habitation, a waypoint was created as near as possible to the building(s). The distance for each variable was determined using the GPS waypoints and then checked within ArcMap and corrected if necessary (Corley/Martinez 1991).

The nearest body of water was marked with a GPS waypoint, which was created along the water's edge nearest the heronry. The designation of the nearest body of water was checked by comparing the data collected in the field to the water bodies visible on aerial photos and the National Wetlands Inventory (NWI) maps. The Cowardin classification for each water body was then determined with the help of NWI maps in ArcMap (Corley/Martinez 1991, Center for Geospatial Data Analysis, Indiana Geological Survey 2003-2004, Indiana University 2005).

GIS Methods.— With the collected field data, an individual GIS map for each heronry was created. GPS waypoints were converted into an ArcGIS shapefile and loaded into ArcMap. Each heronry waypoint shapefile was used to create a heronry study zone (heronry polygon). The heronry polygon provided the starting place for the creation of the other study zones: 0-5 km, 5-10 km, 10-15 km, and 0-15 km. The study zones were used to clip and analyze several different data layers (Center for Geospatial Data Analysis, Indiana Geological Survey 2003-2004).

Using ArcMap, additional circumjacent metrics were measured. The distance to the nearest population center (PC) was measured from a heronry's center to the edge of the nearest PC of 0-1,000, 1,000-5,000, and > 5,000 people. A PC is defined as a place where many homes and buildings are located and a PC's edge is where the homes and buildings become densely arranged. Dominant land/crop cover was identified for each study zone, and the number of hectares of each type of cover was calculated. The total length of all streams/rivers was calculated for the 0-15 km study zone. The field observation of land type was compared to the GIS land cover layer to verify the maps created using ArcMap. The area of contiguous forest cover surrounding each heronry was digitized from aerial photos and defined as that area where the forest was at least 30 m at its narrowest and separated by < 30 m gaps. The digitized layer was then used to calculate the area of contiguous forest cover. Aerial photos were then used to verify distances to the nearest human habitations (Indiana University 2005).

After creating an ArcMap database, a map of suitable GBHE habitat was generated. Twenty-two additional heronries, not surveyed during the primary study, were plotted on the generated suitable habitat GIS map to verify the validity of the map. Around each latitude and longitude coordinate a heronry polygon 105 m long and 57 m wide, representing the average heronry polygon size, was created. From the heronry polygon, a 15 km buffer was created to use for analysis of the necessary variables.

Statistical Analyses.— The statistical analysis software, Minitab, was used to determine which variables were statistically significant ($p < 0.05$). These 13 predictor variables were run through 3 different multiple regression analysis to compare them against 3 different response variables to determine which variable would a model which best fits the data and includes only significant predictor variables (Table 1). First, a best subset regression was run to determine which variables produced a multiple regression model which best fit the data. Next, a multiple regression analysis was run with the selected predictor variables against the chosen response variable. This analysis determined if certain predictor variables were significantly different from the response variable. Additionally, a one way ANOVA was run on the three population center variables and their distances from the heronries' centers to test for significant difference between the distances to the three population center variables. A Tukey test for equal variance was then used to verify the results of the one way ANOVA test.

RESULTS

Indiana's Heronries.—The 17 GBHE colonies studied contained 825 nests with a mean colony size of 48.5 (± 40.9 SD) nests ranging from 4 to 125 nests. The number of active nests observed was 627 with a mean of 36.9 (± 34.6 SD) and a range of 0 to 99. Each heronry covered a specific forested area with a mean of 0.55 ha (± 0.75 SD) and a range of less than one ha up to nearly three ha (Table 2). The mean active nest density was 112 active nests per ha (± 83.3 SD) with a density range of 0 to 299 active nests per ha (Table 2).

Forested Habitat.—Great Blue Herons primarily use forested riverine and upland habitats. Therefore, the sites chosen by nesting GBHE were classified as riverine, upland forest, or other, which represents all other habitat types used. Seven (39%) heronries were located in riverine habitat, five (28%) in upland forest, and six (33%) in other habitat. Tree species used for nesting were classified as: American sycamore (*Platanus occidentalis*), American beech (*Fagus grandifolia*), or other, because sycamore and beech were the primary tree species used (Table 3). In 11 heronries (61%), the dominant nesting tree was sycamore, in two heronries (11%), beech was dominant, and in five heronries (28%), other was dominant. The mean nesting tree height was 31.2 m (± 5.8 SD) with a mean dbh of 70.0 cm (± 21.8 SD) (Table 3). Nesting areas were found in a wide range of forested area types, from small farm woodlots to large riparian forests. The size of these contiguous forested areas surrounding each heronry had a mean size of 557.6 ha (± 1,493 SD) and a range of 6.64 to 6,168 ha. The mean for the contiguous forest data for all the surveyed heronries is quite high because the contiguous forest surrounding the Lick Creek heronry was 6,168 ha, an area significantly larger then all other heronries. Thus, if Lick Creek is excluded, the mean contiguous forest area would be reduced to 206.9 ha (± 384.8 SD) with a range of 6.64 to 1,528 ha (Table 4).

Water Habitat.—Since GBHE primarily feed upon aquatic organisms, heronries are usually found near bodies of water. Eight of the 17 heronries have water bordering the crown diameter of at least one nesting tree or running directly through the heronry, while the remaining nine heronries have a mean distance of 121 m (± 66.4 SD) with an overall mean distance of 64.0 m (± 77.9 SD). In a given area, the more shallow water present, ≤ ½ m in depth, the more likely GBHE will be present. The length of all streams within 15 km of each heronry had a mean of 363.2 km (± 90.3 SD) and a range of 210.4 to 522.0 km. The dominant wetland type found within the foraging area of GBHE was classified as either Palustrine Forested (broad-leaved deciduous) Temporarily Flooded (PFO1A), Palustrine Forested (broad-leaved deciduous) Seasonally Flooded (PFO1C), or Other (represents all other wetland types). Ten GBHE heronries (56%) had PFO1A as the dominant wetland type within the 15 km foraging area, while both PFO1C and Other had four heronries (22%) each (Table 4). However, for two of the heronries of the Other classification, PFO1C was the second most dominant wetland type.

Human Disturbance Factors.—The mean distance to the nearest road was 393 m (±184.6 SD), with a range of 113 to 773 m. The mean distance to the nearest human habitation was 398 m (± 192.7 SD) and ranged from 142 to 859 m (Table 5). In northeastern Indiana the landscape is dominated by row crop agriculture. This dominant land cover was not broken down further since the type of row crop planted in a field can change from year to year while the heronries remain basically unchanged.

Human population centers (PC) might deter GBHE from foraging in a certain area. Therefore, the larger a PC is, the greater the distance will be between it and a heronry. Of the 17 heronries, 14 were nearest to a PC of 0-1,000 (82%) 2 heronries (12%) were located nearest to a PC of 1,000-5,000 people, and only 1 (6%) was located nearest to a PC of > 5,000. A one way ANOVA indicated a significant difference between the distances of different PC sizes. A Tukey test for equal variance further indicated heronry distances from a PC of 0-1,000 are significantly different from the distances to a PC of 1,000-5,000 or a PC of > 5,000. The mean distance to a

PC of 0-1,000 was 2.85 km (± 1.62 SD) and ranged from 0.22 to 6.28 km. For a PC of 1,000-5,000 the mean distance was 7.71 km (± 4.46 SD) and a range of 1.58 to 16.1 km. Finally, a PC of > 5,000 had a mean distance of 8.24 km (± 4.92 SD) and a range of 0.22 to 18.1 km.

The amount of traffic within five km of a heronry has a mean density of vehicles per day of 44,091 (± 40,768 SD) and a range of 0 to 151,213 vehicles per day. Mean density of vehicles per day within five km of the heronries is quite high because of the density of vehicles per day for the Bluffton heronry, which was 151,213. If Bluffton is excluded, the mean density of vehicles per day would be reduced to 37,396 vehicles per day (± 30,984 SD) with a range of 0 to 85,033 (Table 5).

Statistical Analysis.—A best subset regression was used to analyze all 13 variables. This analysis resulted in a model (R-sq (adj) = 36. 5%, residual standard error (S) = 27.583) containing seven variables: Distance to the nearest human habitation, Distance to the nearest population center of 0-1,000, Distance to the nearest population center of 1,000-5,000, Dominant wetland type within 15 km (as determined by NWI maps), Dominant colony habitat type, Distance to the nearest water body, and Surrounding forested area. The response variable that produced the best R-Sq (adj) value was the Number of active nests. When these seven predictor variables were run through a multiple regression analysis against the best response variable, variables two, distance to the nearest population center of 0-1,000; four, dominant wetland type within 15 km; and six, distance to the nearest water body, were significant at a p-value of 0.05. A fourth variable, variable one, distance to the nearest human habitation, was nearly significant, and may be useful in future studies, at a p-value 0.059 (Table 6). As Table 6 shows, only seven variables were used for the final multiple regression analysis because together they produced the highest R-Sq (adj) and the lowest S values.

The three significant variables were combined in ArcMap to form a map showing predicted locations of suitable GBHE habitats in northeastern Indiana. Twenty-two non-surveyed, GBHE colonies were inserted and analyzed to determine whether they fell within the predicted areas of suitable GBHE habitat (Fig. 3). Of the 22 heronries, 20 (91%) fell outside of the 2.85 km buffer around the nearest PC of 0-1,000 and 18 (82%) were within 64 m of the nearest water body. The dominant wetland type within 15 km of each heronry was PFO1A for 12 (55%) heronries, while the second dominant type was a three way tie between PFO1C, Lacustrine Limnetic Unconsolidated Bottom Permanently Flooded (L1UBH), and Lacustrine Limnetic Unconsolidated Bottom Permanently Flooded Diked Impounded (L1UBHH), with three heronries each. For the surveyed heronries, PFO1C was the second most common wetland type. Thus, eight heronries (36%) fell within all three variables, eleven heronries (50%) fell within two variables, and three heronries (14%) fell within one variable (Table 7). The original 17 heronries were also inserted into the map to see how well they fit the three significant variables. Seven heronries (41%) fell within all three variables, nine heronries (53%), fell within two variables, and one heronry (6%) fell within one variable (Table 8).

DISCUSSION

In this study, only three variables were found to be significant predictors of GBHE nest sites for northeastern Indiana when compared to the number of active nests in these heronries. These variables were: distance to the nearest population center of 0-1,000, dominant wetland within 15 km (as determined by NWI maps), and distance to the nearest water body. Another variable, distance to the nearest human habitation, was found to be nearly significant for heronries in northeastern Indiana. These same variables have been examined by the four studies mentioned above (Corley/Martinez 1991, Clements 1995, Gibbs and Kinkel 1997, Gibbs et al. 1987) but only in combination and not individually.

Many studies have examined the impact of human disturbance upon GBHE (Butler 1997, Watts and Bradshaw 1994, Carlson and McLean 1996, Gibbs and Kinkel 1997) and the distance at which human disturbance will begin to be detrimental to the nesting success of GBHE (Ikuta and Blumstein 2003). One way to determine this distance is to look at the distance to the nearest PC. In this study the PC size of 0-1,000 was significant. Of the other studies only the coastal Maine study focused on this variable (Gibbs et al. 1987). Gibbs et al. (1987) found that the islands inhabited by GBHE were distinctive from uninhabited islands by the distance to the nearest town (8.0 ± 2.66 SD km compared to 5.9 ± 3.12 SD km). For northeastern Indiana, the distance to the nearest PC of 0-1,000 was 2.85 km (± 1.62 SD) and this can be attributed to the differences of land type, amount of land, and land usages from coastal Maine to northeastern Indiana.

Other human disturbances may also impact the location and size of GBHE colonies. In northeastern Indiana the distance to the nearest human habitation was found to be nearly significant in the location and size of GBHE colonies while the distance to the nearest road was not found to have any influence on location and size. Watts and Bradshaw (1994), Clements (1995), and Gibbs and Kinkel (1997) found that GBHE colonies were located farther away from human disturbances (buildings, agriculture, lightly used roads, and rural development) than that of null sites. On the other hand, Corley/Martinez (1991) found no correlation between the distances to human disturbances and the study year's initial heronry population. It is also of some importance to note that the establishment of successful GBHE colonies has occurred in human dominated areas. Webb and Forbes (1982) provide one example of a heronry successfully established in a human dominated area, in close proximity to prime foraging habitats. Fort Harrison heronry is an example of such a heronry in northeastern Indiana. The herons were around long before the city of Indianapolis encroached on the bird's current location in the forested area that is now the park. Fort Harrison and other heronries established in urban areas show the potential versatility of GBHE to become accustomed to human activities and disturbances if certain conditions are present, an example being prime foraging habitat (Butler 1997, Webb and Forbes 1982, Forbes et al. 1985).

Differences exist in the dispersion of wetlands from region to region and, therefore, in the density of wetlands and water bodies (lake, river, or stream) around each heronry. In Maine it was found that the proximity of a heronry to wetlands was not important and, in fact, the null sites contained more wetland area within 20 km than the heronry sites (Gibbs et al. 1987). While in northeastern Indiana the proximity to wetlands or a body of water was found to be significant. That is, of the 17 heronries 8 of them were directly next to or on top of a body of water.

Great Blue Herons are mainly aquatic foragers and thus a heronry's proximity to water is important. Besides the proximity factor two other determining factors in the location and size of a heronry is the type of wetland the herons prefer to forage in. Thus, do the birds prefer more or less vegetation and more or less open water? Great Blue Herons have been observed to frequently visit wetlands with emergent or submergent vegetation and longer shorelines more than wetlands with more open water (less vegetation) and shorter shorelines (Hoffman 1978, Thompson 1978, Gibbs and Kinkel 1997, Gibbs et al. 1991). A study in Virginia found that swamp and shoreline habitats were more often found around colony sites than marsh habitat. Although, when looking at the number of active nests in a colony no specific wetland type was found to be significant (Clements 1995). In coastal Maine the proximity of a colony to foraging areas was not significant and instead the local availability of food is important for the size of GBHE. This is because it is beneficial for GBHE to conserve energy when foraging and 20 km is, energetically, as far as GBHE will fly. Thus, the establishment of a colony within 20 km of wetlands containing food was important and, therefore, so is the type of wetland that will provide the most amount of food (Gibbs et al. 1987). In northeastern Indiana the primary wetland type, PFO1A and PFO1C, within 15 km of each heronry was found to be significant. On the other hand, the length of the stream network (shoreline), measured by GIS, was not found to be significant within 15 km of a heronry.

While prime foraging habitat is important in selecting a heronry site the nesting substrate, or trees, are selected according to height, dbh, and physical condition of the crown (Carlson 1995, Gibbs et al. 1987). Interestingly enough the species of tree is often not significant when it comes to GBHE nesting (Miller 1943, Henny and Kurtz 1978, Gibbs and Kinkel 1997, Beaver et al. 1980). In one study, though, GBHE used only a single tree species for nesting even when moving from one heronry to another (Kelsall and Simpson 1980). Other studies observed that GBHE choose American sycamore trees in riverine habitats and American beech trees in upland habitats (Iverson 1993, Graber et al. 1978) (Table 3). One reason for the selection of the American sycamore as an ideal nesting tree is its resilience to breaking in strong winds because of its softer branches (Little 1985, cited in Corley/Martinez 1991, Corley/Martinez 1991). In our study of northeastern Indiana both the species of a tree and the height of a tree were not included in the final multiple regression analysis and were not found to be significant. This is because of the variability in tree species used as well as the fact that GBHE will almost always nest in the highest structure possible so tree height would not be significant between heronries since the herons would be nesting in the tallest trees possible (Carlson 1995, Graber et al. 1978, Gibbs et al. 1987).

Relevance of Results for Conservation.—The GBHE is a skittish bird early in the breeding season but it is also an adaptable bird to certain types of human disturbances, such as agriculture (Miller 1943, Gebauer 1993, Dixon and Sullivan 1996, Vos et al. 1985, Simpson et al. 1987). Carlson and McLean (1996) found GBHE did not react much, if at all, to mechanical disturbances while human disturbances by foot or horseback could disturb them. Reasons offered by these authors for this observation is that the repetitiveness, proximity to the perimeter of a heronry, and low occurrence of the mechanical disturbances allow the herons to become accustomed to agricultural disturbances. Additionally, in Indiana GBHE colonies are found in woodlots that are almost always surrounded by agriculture. This provides the ideal environment for GBHE to adapt to and live successfully in an area of woodlot islands surrounded by a sea of agriculture.

Given that 50% of the heronries studied in northeastern Indiana are within 64 m of a wetland or other body of water, the amount and quality of wetlands within certain distances of a heronry are very important to GBHE. In Virginia, all wetlands within 3-5 km of a heronry were shown to be significant for GBHE colony size (Clements 1995). Thus, protecting the wetlands within this area around each heronry is necessary. Additionally, our research in Indiana highlighted the importance of forested, riverine habitats for nesting and foraging sites for GBHE because 8 of the 17 heronries studied are located in this habitat type. Of the remaining nine heronries, three are found in forested areas containing a river or stream but are not located directly next to the river or stream. Thus, the forested areas around rivers and streams provide important nesting and foraging habitat. In this study, the Heronry forested area represented the forested area each heronry was surrounded by, but it was not found to be significant. Yet, it is useful to know the size of the forested areas GBHE use for nesting sites because the larger the forested area, the larger the existing buffer will be between the birds and human disturbances.

GIS Predictor Map for Suitable Habitat.—One of the goals of this study was to produce a GIS map that could serve as a predictor for suitable GBHE habitat. The predictor map showed that of the 22 heronries only 8 (37%) fell within the boundaries of all 3 variables, 11 (50%) fell within the boundaries of 2 variables, and 3 (14%) fell within the boundaries of 1 variable. If each variable is looked at individually it is found that 20 heronries (91%) fell outside of the 2.85 km buffer around each PC of 0-1,000, 18 heronries (82%) were within 64 m of a water source, and 15 heronries (68%) had either PFO1A or PFO1C as the dominant wetland within 15 km. Now if the original 17 heronries are inserted into the predictor map and analyzed it is found that 7 (41%) fell within all 3 variables, 9 (53%) fell within 2 variables, and 1 (6%) fell within 1 variable. If each variable is looked at individually it is found that 16 heronries (94%) fell outside of the 2.85 km buffer around each PC of 0-1,000, 15 heronries (88%) were within 64 m of a water source, and 13 heronries (76%) had either PFO1A or PFO1C as the dominant wetland within 15 km.

These results demonstrate that the use of GIS in wildlife studies can be a helpful tool for analyzing habitat characteristics and for predicting where additional suitable habitat may be found. GIS can help researchers create and produce many different kinds of maps providing useful information for researchers and wildlife management officials. This is especially important in cases where a species is endangered due to habitat destruction for use by humans due to the expansion of the human population. With the use of GIS and field data, a suitable habitat predictor map can be created and used to preserve the habitats necessary for the longterm survival of endangered species (Danks and Klein 2002). These maps can also be used for land development purposes by providing wildlife experts with the necessary information to determine where development will be the least harmful to specific endangered species (Warman and Sinclair 2000, Danks and Klein 2002). Furthermore, GIS maps can help manage wildlife in areas where people and animals are constantly in contact, such as rural Africa and the Pacific Northwest of the United States (Lewis 1995).

Conclusions and Recommendations for Future Research.—Two suggestions for future research are (1) to determine the effectiveness of natural or artificial buffers around Indiana heronries and (2) to focus on the preservation of the nesting and foraging sites of mid-range heronries through the use of GIS.

Natural buffer zones of forest and water exist around many GBHE colonies, but occasionally GBHE will establish heronries in unlikely places where they are exposed to human disturbances. Therefore, knowing the width of these natural buffers is very important. Previous research has shown that GBHE are more sensitive to disturbances occurring on land than to disturbances occurring on water (Short and Cooper 1985). Thus, terrestrial, aquatic, and aerial buffer zones have been suggested to protect GBHE from human disturbances from February to August. Past research has suggested buffer zone widths, which should be established around all heronries. These widths are 250-500 m for a terrestrial buffer zone, 150 m for an aquatic buffer zone, and 600 vertical m for an aerial buffer zone (Gebauer 1993, Clements 1995, Short and Cooper 1985). However, these buffer zones can be site specific and must be adjusted to fit the needs of the birds at each heronry in order to provide them with the protection necessary to prevent reduced fecundity and heronry abandonment (Vos et al. 1985). In areas where GBHE are found to be foraging, a 100 m buffer should be observed (Rodgers and Henry 1997). If the suggested buffer zones for an area around a heronry are too large and there is high human traffic, than another possibility is to install privacy fences which will reduce human traffic as well as block the herons' view of any humans close to the fence (Castrale 1994). Additionally, a couple of studies have found that fences or moat-like water formations will increase fledgling success as well as decrease flushing distances. These observations show that the distance to a human disturbance is not always as important as the effectiveness of the barrier/buffer. Thus, fences can be a good management tool for the preservation of GBHE and other wetland birds (Carlson and McLean 1996, Ikuta and Blumstein 2003).

A previous study on GBHE in Indiana completed in the late 1980s presented three conservation strategies (1) the statewide surveys of GBHE and other wading birds should continue in order that any population decreases be observed before the population decreases too far, (2) significant heronries, especially those of 200+ active nests, must be protected from all threats that endanger their existence, and (3) the establishment of a minimum viable population threshold level for GBHE must be determined (Iverson 1993). These strategies are important but a fourth strategy focusing on the middle range of heronries, 26-199 active nests, should be added. Data from 2005 shows that 40% of heronries in Indiana contain ≤ 25, 59% contain 26-199 active nests, and 1% ≥ 200+ active nests, with one being in northeastern Indiana (J. Castrale pers. comm.). This is a decrease from the 14 heronries containing 200+ nests in Indiana during the 1993 survey season and as of the 1998-1999 survey season 41% of all GBHE active heronries and 71% of all abandoned heronries contained ≤ 25 (Castrale 1994, 2000). Therefore, it is important to preserve the nesting and foraging habitat of the middle range because the lower range is more likely to be disturbed by humans while the upper range could possibly experience a natural disaster that would extirpate the entire heron population (Castrale 2000). Furthermore, the medium range heronries can always develop into heronries with 200+ active nests. To preserve the foraging habitats of the GBHE the drainage and alteration of wetlands within 3-5 km of a heronry should be monitored and minimized (Clements 1995, Dowd and Flake 1985).

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