DISSERTATION

A SPATIAL MODEL OF WATERFOWL NEST SITE SELECTION IN GRASSLAND NESTING COVER

Submitted by
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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DUANE BRUCE POOL ENTITLED A SPATIAL MODEL OF WATERFOWL NEST SITE SELECTION IN GRASSLAND NESTING COVER BE ACCEPTED AS FULLFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF **DISSERTATION**

A SPATIAL MODEL OF WATERFOWL NEST SITE SELECTION IN GRASSLAND NESTING COVER

Ducks Unlimited's (DU) Mission statement is focused on providing for the annual lifecycle needs of migratory waterfowl. The largest impacts to the success and numbers of continental populations are determined by their activities on the breeding grounds. To model and therefore manage habitats and landscapes for ducks (*Anas* and *Aythya* spp.) it is necessary to understand several characteristics of their behavior. This research builds a model of nest site selection from nest probability based on remotely sensed data, presence data and minimum threshold theory. The methods used are applicable to other sensor platforms as well as other target species or phenomenon. Using data compression techniques, logistic regression, and spatial statistical functions (Ripley's k-function, a global k-function, and Multiple Response Permutation Procedure) we tested the observed point patterns and developed a point process model to predict nesting patterns. The application of this type of fine resolution database, validated by empirical data, will be more powerful than either classified remote sensing data or field level nest demographic data alone.

In the largest of the five study sites, which was also the site with the greatest number of observations, the pattern of nests were significantly different from Poisson.

The model developed to fit these data was tested using the other sites and the observed data on the other four sites were not shown to be significantly different from the model. The tests for spatial association showed some evidence negative association between Blue-winged Teal and Gadwall as well as between successful and unsuccessful nest. There is some evidence that a process of natural selection may exist and the future studies should be designed with this in mind.

These data will be used as a baseline for future habitat manipulation and controlled experiments on the DU Goebel Ranch complex. The results of this and future studies will be used as the basis for DU strategic planning of habitat programs in the Missouri Coteau.

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The research field crew at the Goebel Ranch and Ordway Prairie worked many long days and collected additional data on my behalf. I would like to thank the members of the field crew, Deanna Tello, Ted Miller, Josh Couch, and Mike Noone, for their attention to detail and long hours. There are several others at Ducks Unlimited, Inc. who have provided assistance in many ways to my work. They are in no specific order Deric Morgando, Rick Warhurst, Gillian Turney, Bruce Reinarts,

Kevin Brown, Alyssa Martin, and Renee Herman. Thank you to each and every one of you.

Finally, without the support of my family I would not have had the strength to persevere in this endeavor. I want to thank my wife Mary, daughters Christina and Deanna, sisters Laura and Anita and my parents Marlon and Sylvia. Each of my family members has supported me in many ways and often at their own inconvenience.

A dissertation is supposed to be independent research. Though the bulk of the design and analysis was independent, it is not possible for a project that takes this long and so many resources to be independent. This research was quite dependent on the contributions of the people and organizations I have named here.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

1 INTRODUCTION

1.1 Background

One of the major problems facing scientists and managers who work to protect waterfowl (*Anas and Aythya* spp.) is the preservation of suitable habitat for successful reproduction. Understanding what constitutes suitable habitat and how it is selected or used by waterfowl are key uncertainties for science based resource management. Habitat selection and nest site selection are nested processes. Much emphasis has been placed on breeding/nesting habitat selection with little knowledge or research on how birds disperse themselves within those habitats and whether the patterns of dispersal influence vital rates (J. Ringelman, 2001, Personal Communication).

The greatest limiting factors to population growth in migratory waterfowl life cycles occur during the breeding season (Ringelman 1996). Waterfowl biologists have gone to great lengths to understand the limitations to production on the breeding grounds. Upland nesting studies have been conducted for years with emphasis placed on collection of data to describe vital rates of species nesting in these habitats. Review of these studies indicates that research on waterfowl is plagued by imprecise estimates of vital rates (Howerter 2003). Other waterfowl breeding ground research has been devoted to wetland use or attractiveness to breeding pairs. The focus on wetlands is predicated by the dependence on invertebrate resources for both egg production and brood rearing (Krapu and Rieneke 1992). Breeding waterfowl studies also indicate that, in many instances, nesting ducks have higher nest success in a landscape containing an abundance of dense undisturbed grasses and forbs (Duebbert and Kantrud 1974, Kirsch et al. 1978, Stephens 2003). Greenwood (1995) found an inverse relationship between the percentage of the landscape in cropland and waterfowl nesting success in the Canadian Prairies. The remaining land cover in Greenwoods study area was dominated by grassland and parkland. However, grassland-nesting habitat alone may not be enough for breeding ducks to be successful. During the breeding season, mallard pairs are attracted to landscapes based on the abundance and diversity of wetlands (Reynolds et al. 1996b). Nest locations are chosen after establishment of a home range that contains a diverse complex of wetlands. In order to be attractive to nesting hens, upland nesting cover needs to be located within a probable travel distance of the wetland complex or home range (Cowardin et al. 1985). The landscape mosaic needs to be comprised of an interspersion of grassland cover and diverse wetland communities in order to provide an attractive home range for breeding hens (Kaminski and Weller 1992). In the prairie pothole region, the density of wetlands does not tend to be a limiting factor during non-drought years.

Loss of grassland cover through agricultural practices has been shown to have a negative impact on duck recruitment (Cowardin et al. 1985). In the US and Canada, wetland losses from agricultural practices continue to outpace restoration efforts

(Dahl 2000). Loss of native grasslands in the north central Great Plains continues as changes in agricultural production technology and capital open the door for new commodities in regions where they were once not profitable. The transition from grassland to agricultural cropland causes changes in the vegetation structure in upland landscapes and increases the level of disturbance during the nesting season. Miller et al. (2001) suggested that the lands targeted for conversion to row crops may have had a disproportionately higher number of productive shallow wetlands. These changes to wetland and upland habitats have an adverse effect on breeding waterfowl (Miller et al. 2001). Upland vegetation structure appears to be more critical in determining the suitability of upland habitat to nesting ducks than either plant species composition or plant diversity (Devries 1998). The fact that land is in undisturbed grassland nesting cover is more important than the mix of grassland species in the undisturbed cover.

Statistics on historic agricultural land use and wetland numbers have been tracked by State and Federal agencies for at least the last decade. Breeding waterfowl surveys and May pond surveys have been conducted by the United States Fish and Wildlife Service (USFWS) and the Canadian Wildlife Service (CWS) since the 1950's. Austin et al. (2001) found some relationship between landscape composition and local breeding populations and indicated that intensive agricultural tillage tends to degrade, drain and alter wetland numbers, size and function. A good indicator of changes in agricultural land use in the PPR is farm size. For example, the average farm size in South Dakota from 1955 to 1998 has grown from 717 acres to 1354 acres with the total land in farms remaining relatively consistent and a marked shift from grass based agricultural practices to crop production (South Dakota Agricultural Statistical Service 1999). This trend supports the assertion that grassland fragmentation and landscape evolution are continuing toward larger farms dominated by row crops (Higgins 1977, Greenwood 1995, Miller and Nudds 1996).

Current thought suggests that fragmentation and increased agricultural disturbance, besides directly impacting nesting activities, have affected the composition of the mammalian predator community (Seargent, Greenwood, Sovada and Shaffer 1993), e.g. increasing predator densities that lead to a potential increase in waterfowl nest depredation. Predation has been shown to increase nest desertion during incubation, hen mortality and egg loss (Belrose 1980). Predation on the breeding grounds is the major factor limiting waterfowl populations (Belrose 1980, Seargent and Raveling 1992, Johnson, Nichols and Schwartz 1992). Landscapes have both direct (choice of nesting habitat) and indirect (predator and alternate prey communities) effects on waterfowl breeding activities (Miller and Duncan 1999; Miller, Duncan, Guyn, Flint and Austin 2001). A relationship between nest location and predator foraging patterns, or nest success as a proxy, has not yet been established and spatial patterns in nest site selection are the first step to understanding this potential relationship. These changes in landscape composition and use suggest the need for management to focus on protecting and maximizing production in the remaining grass dominated landscapes.

Current waterfowl management thought postulates that improved upland habitat conditions are required to obtain substantial gains in waterfowl production. Another phenomenological occurrence that supports current management thoughts can be seen in the central flyways dabbling duck response to the combination of the 1985 Farm Bill and a significant climatologic change from drought to above average annual total precipitation. A marked response in waterfowl recruitment in the prairies was preceded by widespread delivery of habitat through the Conservation Reserve Program (CRP), and the climatic wet cycle that began in 1993 (United States Fish and Wildlife Service 2001). Breeding waterfowl surveys indicate a substantial response to the increase wetland counts. The combined effect of a return to wet conditions and the broad application of CRP have led many managers to theorize that the magnitude of the boom cycle in production was greatly enhanced by the presence of CRP (United States Fish and Wildlife Service 2001, Reynolds et al. 1996a, Nelson 2000). CRP grasslands tend to be undisturbed and relatively dense, making it difficult for small mammalian predators to penetrate and hunt effectively (Phillips 2001). The Conservation Reserve Program limits grazing, haying or mechanized interaction in these habitats except during extreme climatic emergencies such as haying or grazing emergencies due to drought or wild land fire. The waterfowl response to CRP grasslands seems to indicate that cover condition and level of disturbance potentially play a significant role in nest success and nest site selection.

In landscapes dominated by grass-based agriculture, wetland alterations are less prevalent. The majority of the remaining grasslands are located in more undulating terrain making tillage very difficult and therefore these landscapes are better suited to pastureland and hay production for the livestock industry. Assessments of these lands for book valuation by the banking sector give disproportionate credit if they are tilled, even when they are only marginally productive for row crops, leaving these marginal lands at risk of conversion for borrowing power and solvency calculations. Land managers are building extensive and costly land protection programs to protect these lands from conversion. Land managers need information to target lands for protection and direction on how to best manage them for waterfowl production. Given the limited uses of grasslands for economic gain, programs designed around grazing are presently the only viable options. Systems can be designed and implemented that target the level of disturbance, timing of the disturbance and the amount of residual cover left after animal use. The issue in grass-dominated landscapes is whether or not disturbance and cover quality influence nest site selection or nest success. If these relationships can be established, wildlife managers can use this knowledge to manage these landscapes for increased waterfowl production and conduct future scientific research for applied management.

Components of any management recovery plan generally include efforts to identify essential habitats for restoration, rehabilitation projects, and population monitoring. The ability to model the spatial relationship of the hen with its habitat can provide vital information to predict the net effects of management plans and practices on nesting ducks. Such a model can be used to monitor the efficiency of certain components of the management plan, as well as a general prediction of how the population is changing in time and space (Dunning et al. 1995).

The powers of a spatially explicit model are realized when population dynamics are predictable based on a set of multivariate habitat parameters. We currently have an accepted model for predicting the number of ducks in an area based on wetland densities and conditions (Reynolds et al. 1996b). Understanding the spatial patterns in nest site selection is the next step to address the more complex problems for future management decisions and research needs.

Over the years, numerous techniques have been developed for assessing landscape level habitat features using a combination of classified remotely sensed imagery, digital image processing and GIS (Reynolds et al. 1996a). The disadvantages of the current products are the coarse resolution (16 hectare minimum mapping unit) of the system and the inability to model the spatial relationship of selected wildlife species with their habitats at multiple scales. These products also have inference limitations based on the data collection and modeling techniques. One of the objectives of this project is to develop a methodology that uses an approach to overcoming these limitations. As a result, we have produced a spatially explicit probability model of hen nest site selection derived from remote sensing. The application of this type of fine resolution database, validated by empirical data, will be more powerful than either classified remote sensing data or field level nest success data alone.

1.2 Habitat Selection versus Spatial Statistical Modeling

Current waterfowl research efforts are strongly focused on the relationships between habitat characterization, scale and waterfowl vital rates (Stephens 2003). Many consider habitat characterization the equivalent of spatial statistical modeling when in fact no spatial correlation or dependencies are tested or accounted for in the modeling process. These models are better described as landscape or habitat characterization models as opposed to spatial statistical models. Even though placement and juxtaposition are not accounted for in these models, they can still add to the knowledge base and be used to derive spatially explicit habitat targeting tools and programs. This approach creates relationships through habitat characterizations that can be applied to spatial data to create spatial applications. The semantic use of terminology such as, spatial modeling versus spatial application, are the main issue.

However, others have attempted to account for space by including latitude and longitude as parameters in regression models of species density or landscape attractiveness to waterfowl (Cox et al. 2001). These have been applied at a very fine scale across huge landscapes. The results of these models have been questioned because the spatial parameters are more closely characterizing the direction and orientation of the breeding grounds relative to the spatial design of the sampling. Another issue facing this type of model is the methodology. It is more appropriate to build the biological model first and then test for spatial associations or dependencies and then apply techniques to decompose the spatial effects using, for example, a spatial autoregressive model much like time series or vector autoregressive techniques (R. Reich 2003). A third critique of current "spatial" applications is that some researchers are applying spatial interpolation methods to data used for prediction without ever having tested the data for any spatial relationships (Cox et al. 2001). The problem with this approach is the potential for a biased error term. Without having tested for spatial correlation in the error component, the error term of these models will possess three possible states:

- Significance when in fact there is none,
- No significance when in fact there is significance, or
- No effect at all.

After testing for any spatial dependency, the correct approach is to ignore it if there is no significant relationship (the mean would be applied to all locations) or if a relationship exists it needs to be fitted and accounted for in the final model. These errors should not be repeated and caution should be used when making management decisions based on products derived using these techniques.

1.3 The Goebel Ranch Experimental Study Area

In August 2000 Ducks Unlimited, Inc. purchased the 3,437 ha Goebel Ranch. The ranch represents one of the largest contiguous tracts of native prairie and intact prairie pothole wetlands remaining in the Missouri Coteau. The Goebel Ranch is located in Edmunds and McPherson counties in north central South Dakota (Figures 1 and 2).

Figure 1. Study Site in North Central South Dakota.

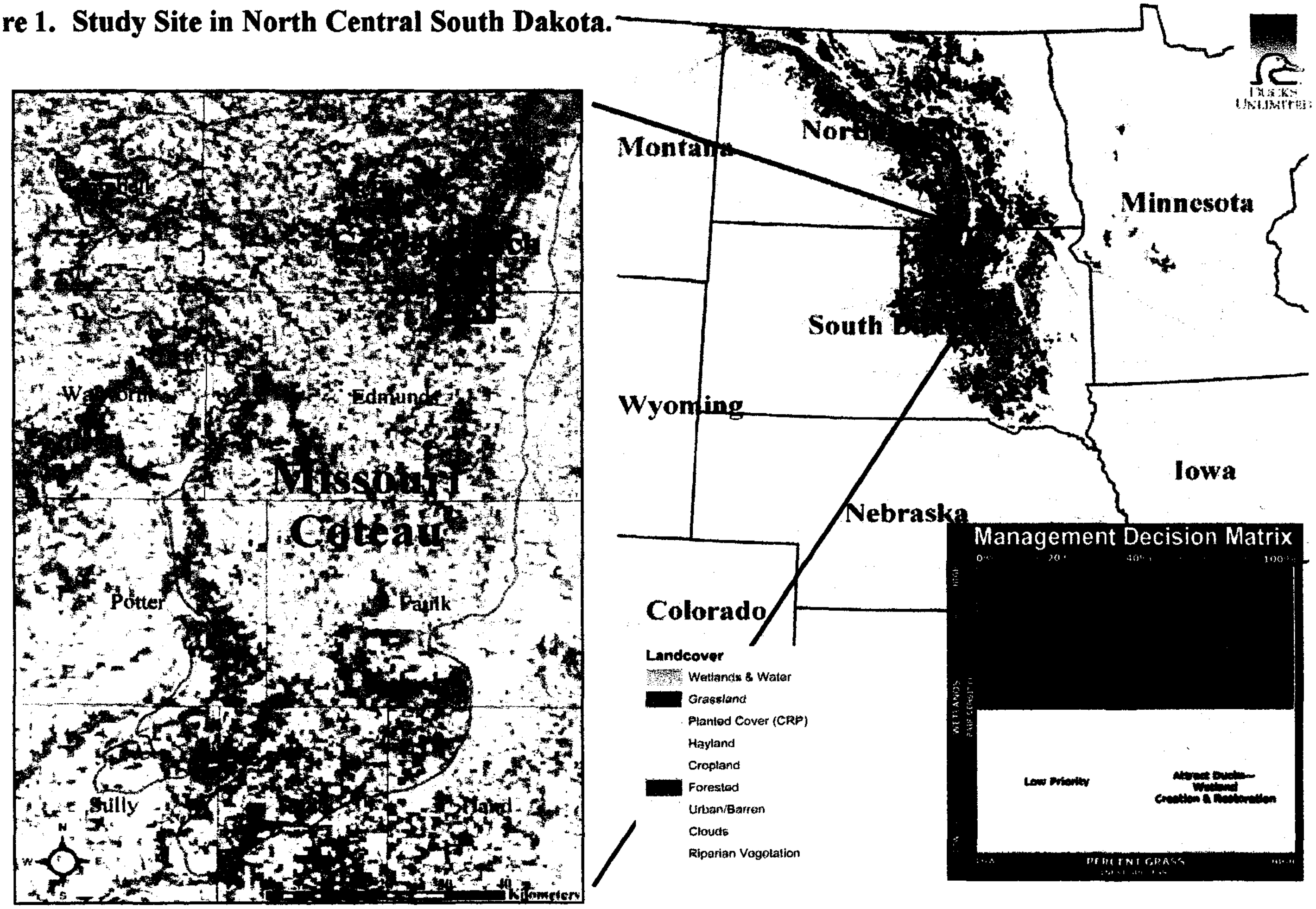
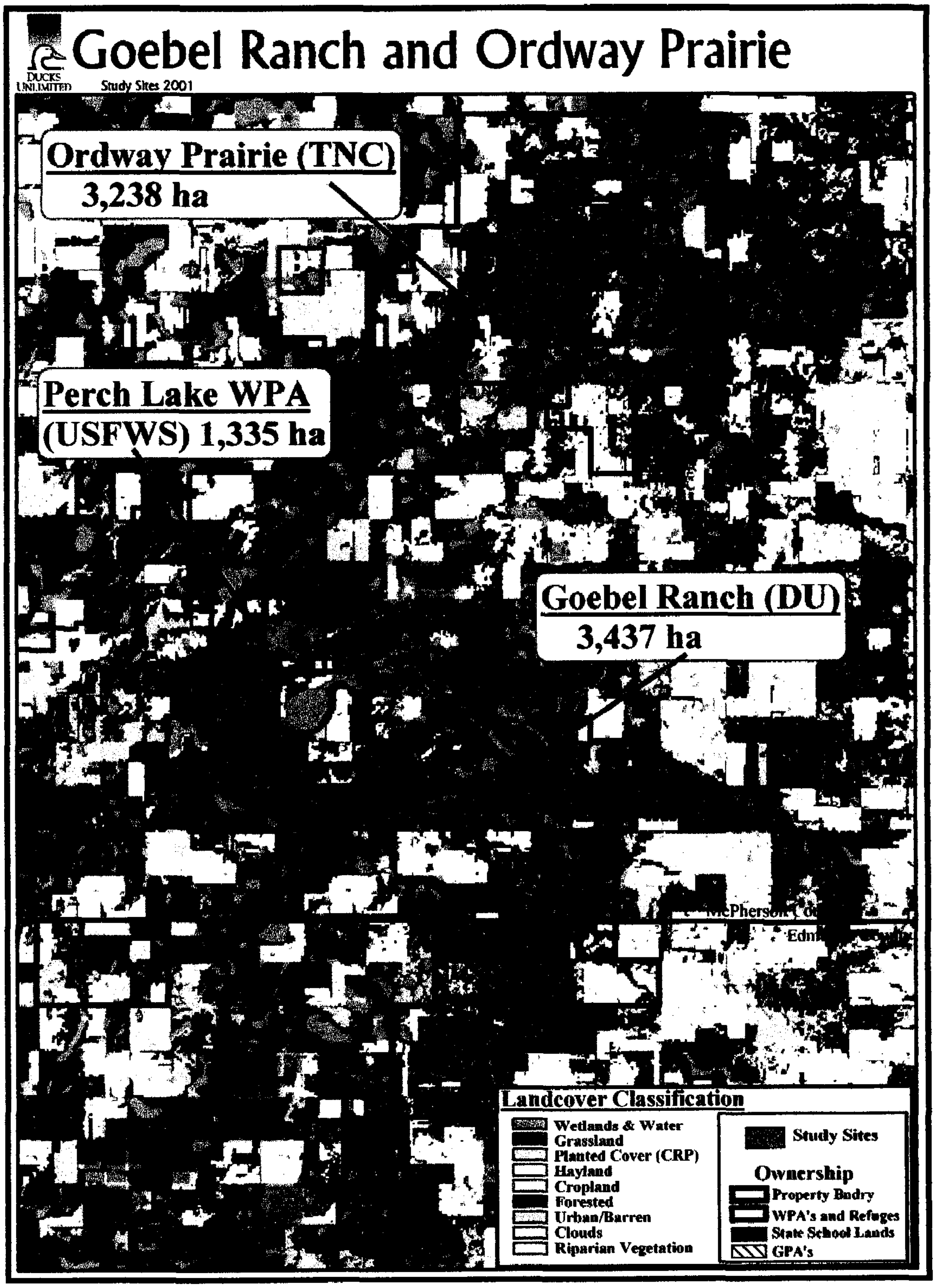


Figure 2. Study Area and Site Selection Set.



Goebel Ranch was originally purchased as a part of the Ducks Unlimited, Inc. Revolving Lands Acquisition Program (RLAP). The RLAP is designed to purchase, restore and/or enhance, and protect properties before eventually returning them to private ownership. The property is in close proximity to Ordway Prairie, a 3,238 ha prairie preserve managed by the Nature Conservancy (Figure 2).

The Goebel Ranch also borders the Perch Lake Waterfowl Production Area (WPA) to the northeast, which is owned and managed by the United States Fish and Wildlife Service (USFWS). These three properties represent nearly 81,000 ha of some of the best waterfowl-breeding habitat in North America (Figure 2).

Unlike most RLAP properties, Ducks Unlimited, Inc. plans to maintain ownership of the Goebel Ranch for a minimum of 20 years. The Goebel Ranch offers a unique opportunity to design, and implement programs and monitor the long-term responses from waterfowl and other wildlife. The Goebel Ranch provides the rare opportunity to design and implement controlled experiments at a landscape scale.

The Goebel Ranch has been an operational livestock ranch for nearly a century. Years of intensive, season-long grazing coupled with an extended climatic wet cycle have transformed the once native prairie into a landscape dominated by cool-season exotic grasses, mainly Kentucky bluegrass (Figures 3 and 4). The initial management options for the ranch include: 1) maximize revenue, 2) resale to conservation buyers or cattle producers, or 3) restore native vegetation and transfer

Figure 3. Example of Grazing Effect on Study Sites With the Same Land Cover Type at Goebel Ranch.

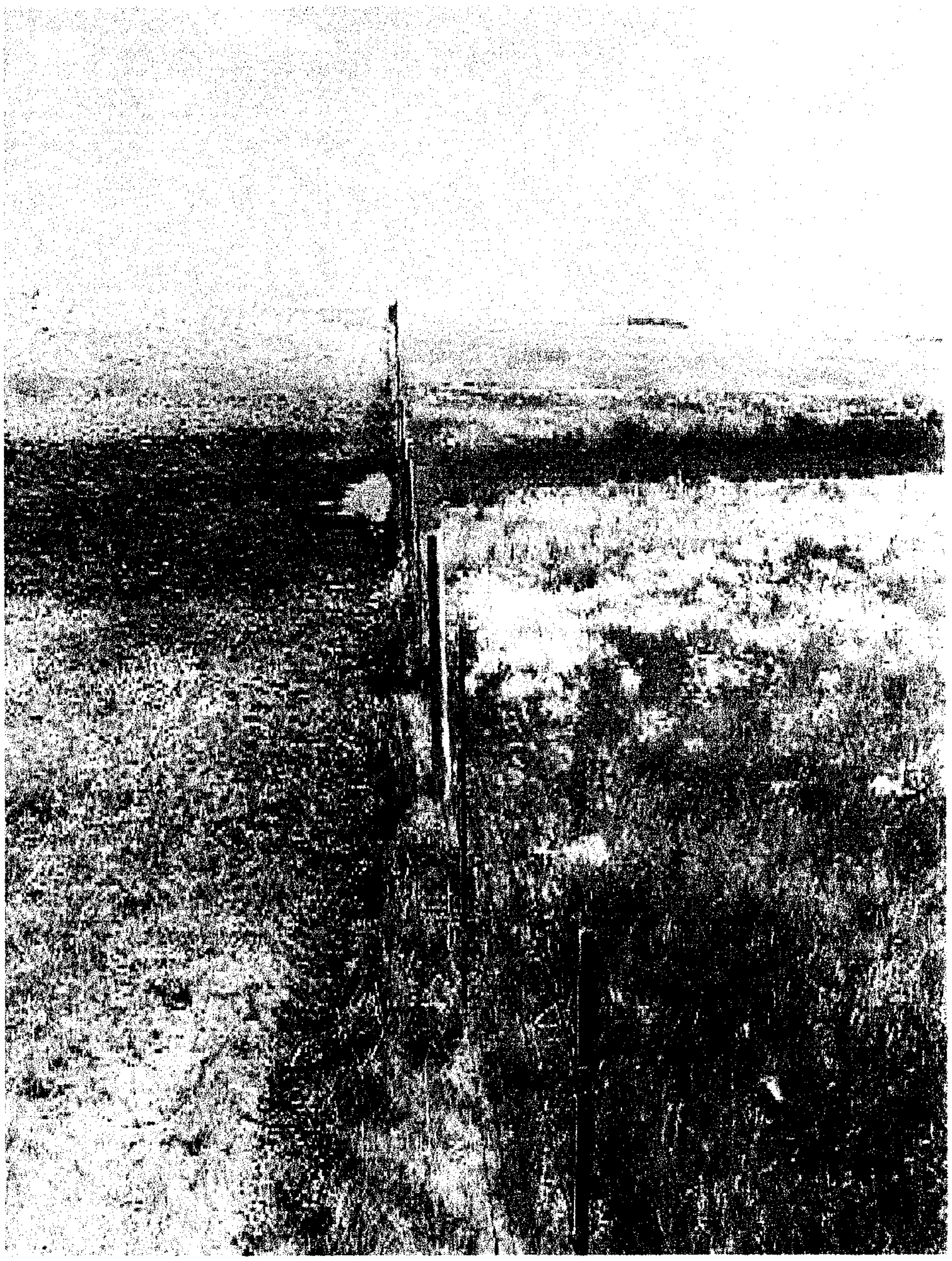


Figure 4. Example of Grazing Impact on Study Sites at Goebel Ranch.

the property back to private ownership. Ducks Unlimited, Inc. management recognized the unique research opportunities afforded through ownership. It was determined that management of the ranch is to focus on maximizing the benefits to waterfowl through adaptive management (Walters and Hilborn 1978, Walters and Holling 1990). A science-based research program was developed to measure waterfowl responses to management practices. Baseline data were collected in 2001 prior to changes from the current livestock production practices. A long-term research project was initiated to fill the knowledge gaps surrounding the waterfowl productivity differences between grassland types and conditions. The results of this and other studies will provide the basis for adaptive management of Goebel Ranch as well as future RLAP property management and acquisition. Through such studies, management practices will be developed to maximize the objectives of targeted duck recruitment and maintaining the operational fiscal viability on RLAP properties. The data collected for this project are a part of the baseline level data compiled by Ducks Unlimited, Inc. research staff. These baseline data will be assessed before any experimental changes are introduced.

It is important to know how the landscape has functioned prior to implementing managed manipulations. Initially, the type of information being collected in this study includes:

- Predator sightings (anecdotal, this was not a formal measure of abundance)
- Habitat composition

- Wetland conditions
- Waterfowl breeding pair densities
- Nest success
- Waterfowl and Alternate Prey Species composition
- Remote sensing imagery
- Nest locations

1.4 Objectives

The objective of this study is to address several key uncertainties surrounding waterfowl nest site locations in the context of the habitat in which it is located. This objective leads to several specific questions that are addressed in this research.

- Are nest site selections of ducks random?
- If they are not random do they fit a known point pattern?
- If they do not fit a known point pattern can we develop a model capable of describing the spatial patterns of duck nest locations on the selected assessment sites? More specifically, we evaluate the effectiveness of a probabilistic estimation model to describe the spatial distribution of duck nesting sites with its habitat. To do this we use an alternative approach, modeling the spatial distribution of potential nesting sites of hen ducks using fine resolution remotely sensed imagery.
- How does understanding these patterns further our understanding of either

duck habitat interactions or behavior?

- Are there spatial relationships either between species or between nest successes in the spatial arrangement of duck nests?
- Can and/or should the techniques used in this study be applied to other research?

1.5 Justification

A relationship between nest location and predator foraging patterns, or nest success as a proxy, has not yet been established and spatial patterns in nest site selection are the first step to understanding this potential relationship. The ability to model the spatial relationship of the hen with its habitat can provide vital information to predict the net effects of management plans and practices on nesting ducks. Such a model can be used to monitor the efficiency of certain components of the management plan, as well as a general prediction of how the population will change in time and space (Dunning et al. 1995).

The powers of a spatially explicit model are realized when population dynamics are predictable based on a set of multivariate habitat parameters (i.e., distance to wetland, habitat edge, distance to edge, size of patch, habitat composition, etc.). We currently have an accepted model for predicting the number of ducks in an area based on wetland densities and conditions (Reynolds et al. 1996b). Ducks

Unlimited, Inc. and the Institute for Wetlands and Waterfowl Research (IWWR) are investigating multivariate habitat models (i.e., patch specific and nest specific habitat metrics and distances) and waterfowl vital rates in the breeding grounds (Howerter 2003). Predicting nest site locations is the next step to applying these more complex models either to a specific study area or when the model are applied programmatically across the landscape. These models are viewed by DU planning staff as an essential component for informed future management decisions and research needs.

The spatial distribution of nesting ducks is influenced by both coarse and fine-scale spatial variability. Terrain variables such as wetland density and type, general land cover type and mosaic describe habitat at the coarse-scale, while more detailed characteristics such as vegetative species, canopy cover, and density are used to describe habitat at a fine-scale. Because of the coarseness of the vegetative data used in most GIS approaches, fine-scale characteristics fail to appear in final habitat models (Aspinall and Veitch 1993, Howerter 2003, Stephens 2003). In this research we use an alternative approach, modeling the spatial distribution of potential nesting sites of hen ducks using fine resolution remotely sensed imagery and GIS. The application of this type of fine resolution database, validated by empirical data, will be more powerful than either classified remote sensing data or field-level nest success data alone.

Pereira and Itami (1991) identified potential breeding habitat using environmental variables for red squirrels. Even though suitable breeding habitat may be identifiable at coarse scales, it does not ensure habitat use or that ducks will be successful in their breeding effort in these areas. It has been shown for curlew and other migratory birds the value of a habitat is dependent upon the arrangement of coarse-scale vegetation and other characteristics (Aspinal and Veitch 1993, Reich et al. 2000). In the case of ducks, wetland characteristics influence food resources, predator communities and field site selection, as well as fine-scale grassland issues for alternate prey communities and influences on the selection of a nest site. Typically, this information is unavailable over large geographic regions (Ormsby and Lunette 1987) and lacks the resolution to provide information in enough detail to develop a spatially explicit model (Pereira and Itami 1991; Herr and Queen 1993). Nesting waterfowl (i.e., ducks) use prairie habitats that are often difficult to classify beyond generalized habitat descriptions. Most areas in the study site would be reduced to a single class of "grassland". Raw Landsat Thematic Mapper (TM) imagery contains variation within and between bands even within generalized classes in the prairie grassland eco-zone. It will be necessary that any model development be applicable to raw data. For the model to have applicability to planning and management, the process must be expandable to predicting across the larger landscape.

Current predator foraging behavior theory suggests edges and less dense cover are more efficiently searched (Phillips, 2001). The prediction then is for the current IWWR research to find edge, distance and density parameters to be significant in estimations of nest success and hen survival in prairie breeding habitats.

If these predator foraging efficiency theories are correct then nest location becomes important. If these habitat measures differ under various grazing and cover regimes, then wildlife managers can implement systems to favor the most productive field characteristics for appropriate dispersal and placement of nests.

Spatial statistics provide insight into the development of a spatially explicit model capable of modeling spatial variability of duck nesting characteristics. In this study when the number of nest observations for a site is sufficient, we propose to test for patterns within species, between species and between successful and unsuccessful nests. These tests are necessary because if significant spatial associations do exist the point process model must account for them or the error component assumption of independence is not valid.

In the case of successful versus unsuccessful nests, results indicating spatial association will assist in the design of future research to investigate the causes of localized success or loss. This may lead to the incorporation of additional predator or alternate prey studies. These could include studies radio-tracking predators, small mammal trapping, or vegetation density or height measures. The key is that the identification of a relationship will help identify and target both waterfowl and non-waterfowl research on the experimental ranch.

Using threshold theory and presence data (Reich et al. 2000), probability surfaces will be created based on the observed data and a point process model will re-populate the landscape for comparison. This class of models provides a tool for exploring possible implications of management plans on the species prior to their implementation.

The application of such a model can be updated yearly with current information that can quantify the progress of management plans. Information can be very specific, such as how the locations of various species are changing over time, to more general questions relating to the effects of wetland availability, vegetative succession, and landscape treatment. Information derived from the model may also be used to facilitate the efforts of field investigators studying the ecology of migratory waterfowl. This model, when combined with information on population dynamics and demographic information, and linked to a habitat succession or change model, can provide land managers with valuable insight for the development of management plans. Such a model may be used to address species viability and minimum habitat requirements. The problem of land fragmentation and population isolation creates further complications that could possibly be addressed with such a model.

This is a unique approach to modeling the spatial distribution of nesting waterfowl in relation to specific landscape elements. The use of spatially explicit models can be used to monitor the efficacy of certain components of the management plan as well as to provide a general prediction of how the population is changing in space. For example, are nesting patterns changing in response to habitat conditions? This study could benefit ecosystem maintenance and preservation by providing greater insight into changes in the landscape at multiple scales, and more importantly, to the consequential impact these changes may have on nest site selection, nest success and ultimately duck populations.

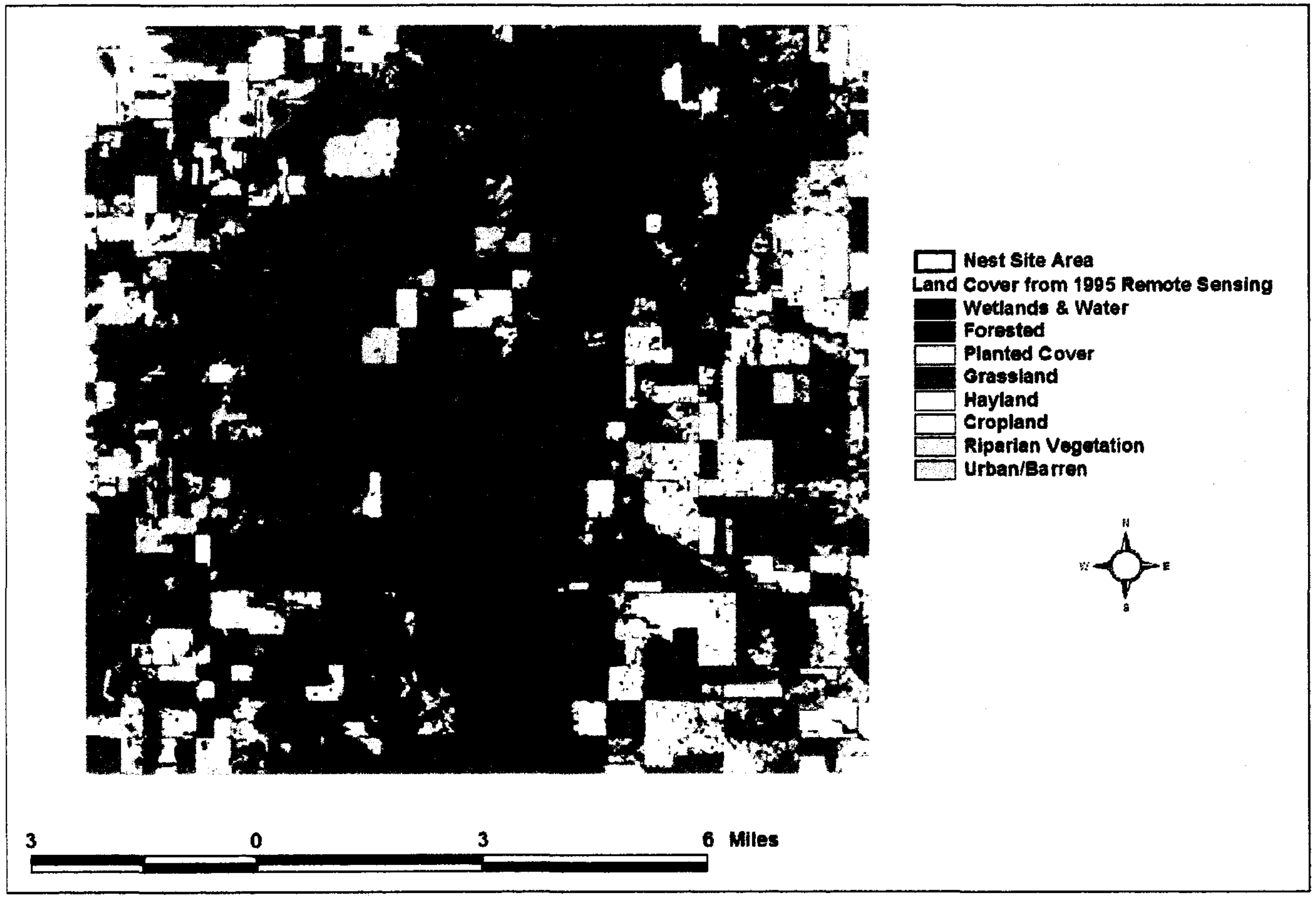
2 STUDY SITE DESCRIPTIONS AND DATA COLLECTION METHODS

2.1 Study Area and Study Plots

The study area covers more than 8,000 hectares in north-central South Dakota. The five study sites (Figure 5) were selected from a pool of study sites that were part of another on-going research project. Data collection was coordinated with other Ducks Unlimited, Inc. (DU) staff. Randomly selected qualifying sites were required to have adequate fencing to control livestock use and for future grazing experiments. The sites were evenly distributed between known grazing intensities from the previous year and between native grasslands and grasslands dominated by Kentucky blue grass.

Grazing intensity from the previous year was a subjective judgment based on visual assessment of residual cover in late March and early April 2001. Grazing from the previous season impacted only residual vegetation. During the study season, grazing was prohibited and re-growth was dynamic across fields. Aerial digital photography for each site was contracted from an outside provider. Two-meter resolution aerial imaging had been ordered to account for the changes in vegetation at a very fine scale.

Figure 5. Goebel Ranch and Ordway Prairie Selected Study Site Spatial Arrangement.



DU range scientist assisted with data collection timing targets so that data were collected during peak green-up for cool season grasses and while warm season species remained in a senesced state. The company hired to collect the information erroneously flew a flight line 6 miles to the east of the study and the data was not usable. These aerial data were re-acquired later in the growing season but were then judged temporally inaccurate and the sensor calibration was not consistent between photo areas. The aerial digital photography is not included in the data for these analyses. The ability to relate these data back to residual cover or re-growth resulting from past years grazing management for quantitative cover quality measurements was lost as a result. The loss of these critical data may limit the ability of the final models to differentiate between higher and lower probability nest locations within the same cover type.

2.2 Geographic Information Systems (GIS) Databases

GIS databases currently maintained by DU were used in this study. Various GIS coverages thought to be important in describing large-scale spatial variability in the distribution of nesting sites, or required for the development of the spatial model were assembled (Table 1).

Table 1. Data collected for the Goebel Ranch Study Area.

Description	Available	Contracted	Future Research
Landsat Thematic Mapper imagery	Yes	Yes	Yes
Robel's Visual Obstruction Rating (VOR)	Yes	Yes	Yes
Landcover	Yes	Yes	Yes
Geology	Yes	Public	Yes
Aerial Photograph/Imaging	No	Yes	Yes
Location of active and inactive nesting sites	Yes	Yes	Yes
Nest demographics	Yes	Yes	Yes
Predator locations and foraging patterns	No	No	Yes
Alternate prey densities	No	No	Yes

Point data were collected with a Trimble GEO II or GEO III handheld Global Positioning System (GPS) receiver and data recorder. Post-differential correction of GPS data was accomplished using Trimble published horizontal and vertical control data from collection stations at Clay County Station Moorehead MN, Itaska County Station Grand Rapids MN or the United States Army Corp of Engineers Clarke SD. All correction stations were within the Trimble recommended 400 km of the study sites. Differential correction predominately accounted for clock error and atmospheric disturbances. The United States military use of "selective availability" was inactive at the time of this data collection. Post-processing was accomplished using Trimble Pathfinder Version 2.51.

Landsat 7, Thematic Mapper (TM) data spanning 7 digital bands of reflectance and one panchromatic band were collected over the study area during the nest initiation period. The TM image collection is dated May 14, 2001. The TM data was registered to identifiable ground features using USGS DOQ's and post corrected Global Positioning System (GPS) coordinates collected, root mean square error (RMSE) for the Landsat scene was less than 1 pixel for the panchromatic band (<15 meters).

DU and the US Fish and Wildlife Service have an existing land-cover database created by Earth Satellite Corporation from 1996 to 1998. The imagery used for these classifications were collected from 1992 to 1995. The low rate of land-use conversion in the local agricultural area allowed use of these data for characterization of landscapes without great risk in classification errors or changes between classes since the products completion date (SDASS 1999). These data were used for reference to land cover type and large contextual habitat categorizations and descriptions within the geophysical landform of the Missouri Coteau. The focus of Ducks Unlimited programs for the primary US breeding grounds is the Missouri Coteau of North and South Dakota. DU has focused their conservation efforts to areas in the Coteau that exhibit similar habitat characteristics in the area of this study. The results from this study are expected to be applicable to future applied management in the Missouri Coteau.

2.3 Collection of Field Data

Within each randomly selected site, all suitable nesting habitats were searched for duck nests. There was no cropland cover type in the study area and emergent wetlands were not searched as the study focused on upland nesting species. A two- or three-person crew was responsible for collecting information on all study sites using standard methodologies (Klett 1986). Nest searching began 23 April 2000 and terminated on 3 August 2000. During the search period, daily searches were conducted between the hours of sunrise and 1400. These hours correspond to the times that hens will most likely be attending. On each study site, as many selected quarter sections were searched as time would allow each day. On the following day, searches would resume and a 4-week rotation among all sites occurred during the data collection period.

Two all-terrain vehicles were used to search all suitable upland vegetation with chain drags (9.5 mm-diameter by 61 m-length) using the procedures described by Higgins et al. (1969). Where chain drags could not be used effectively, willow switches were used to beat the vegetation and flush nesting hens. There were very few areas requiring the alternative flushing technique. These areas were predominately steep slopes and very rocky terrain.

A nest was defined as a bowl or scrape with one or more eggs present. Each nest location was marked with a pole (willow or fiberglass) 1 –1.5 m in length and a small piece of white flagging placed near the base of the pole with the pole placed approximately 5 m north (magnetic) of the nest. Nest locations were recorded on current photocopy replicates of United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) biennial aerial compliance photos and they were recorded into a digital database using a Trimble GeoExplorer III Global Positioning System (GPS) receiver.

Nests were revisited every 7 days until one or more eggs hatched or the nest was abandoned or destroyed. Demographic data were collected at each nest upon initial discovery and incubation or fate information was collected on revisits. The data collected at each nest included species, date, location coordinates, habitat type, vegetation type within a 2-m x 2-m sampling frame, number of eggs and incubation stage (Weller 1956). Habitat characteristics collected at each nest site included a description of the field and a measure of the visual obstruction rating (VOR), the height and density of vegetation around the nest. The VOR measures were recorded as a modification of Robel (1970). Readings from a Robel pole were taken from each of the four cardinal directions at 1-m height and 4-m distance from the Robel pole. Habitat classes are a measure of the dominant plant community in the nest or control area in Edmunds and McPherson Counties, South Dakota (Table 2). One class was assigned based on canopy coverage obtained from a 2-m x 2-m sampling grid centered over the nest or randomly tossed for control data.

Table 2. Habitat Classes Goebel Ranch Research Data Collection

ID	**Exotic and Native Grass-Forbs Types**
1	Kentucky bluegrass >95%
2	Kentucky bluegrass and native grass-forbs, bluegrass 75-95%
3	Kentucky bluegrass and native grass-forbs, bluegrass 50-75%
4	Kentucky bluegrass and native grass-forbs, bluegrass 25-50%
5	Kentucky bluegrass and native grass-forbs, bluegrass 5-25%
6	Kentucky bluegrass and native grass-forbs, bluegrass <5%
7	Brome and Kentucky bluegrass co-dominant (25-75% each)
8	Kentucky bluegrass and other cool-season exotics co-dominant (25-75% each)
9	Canada thistle dominant >75%
10	Canada thistle and native grass-forbs co-dominant (25-75% each)
11	Canada thistle and Kentucky bluegrass and other cool-season exotics co-dominant (25-75% each)
12	Wet meadow (temporary wetland zones)

All data were recorded in a data dictionary in a Trimble Geo-Explorer III. The data were then exported to Microsoft Excel spreadsheets for portability between GIS and S-Plus software. The available information was incorporated into a GIS database. Observed nest location data are mapped in Figures 6 – 10. The vector and grid analysis functions performed using ARC/INFO v.8.2 (Environmental Services Research Information, Corp. 2001) and IMAGINE v. 8.3 (ERDAS Inc. 2001) software products.

Figure 6. Site 1 Observed Nest Locations.

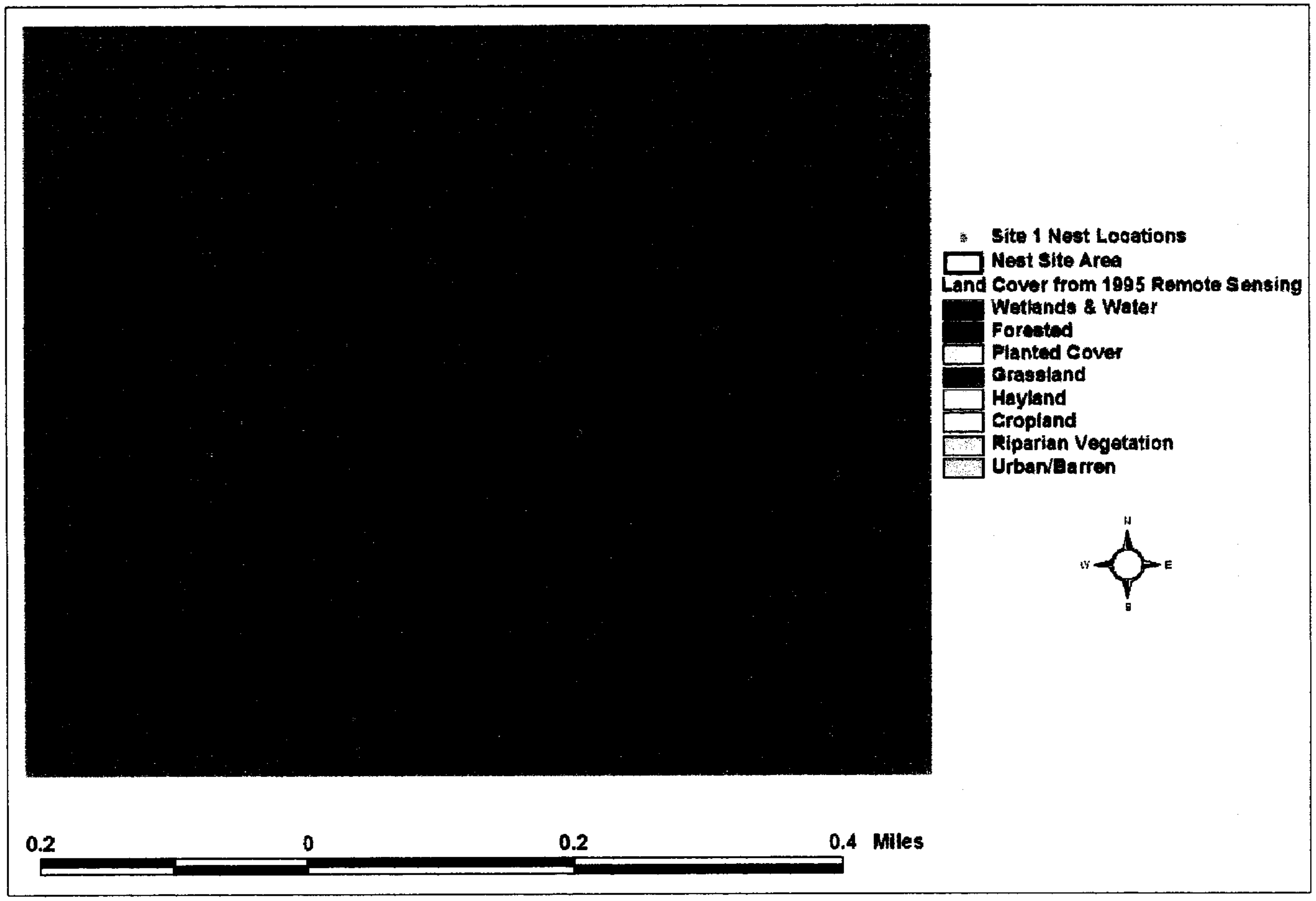


Figure 7. Site 2 Observed Nest Locations.

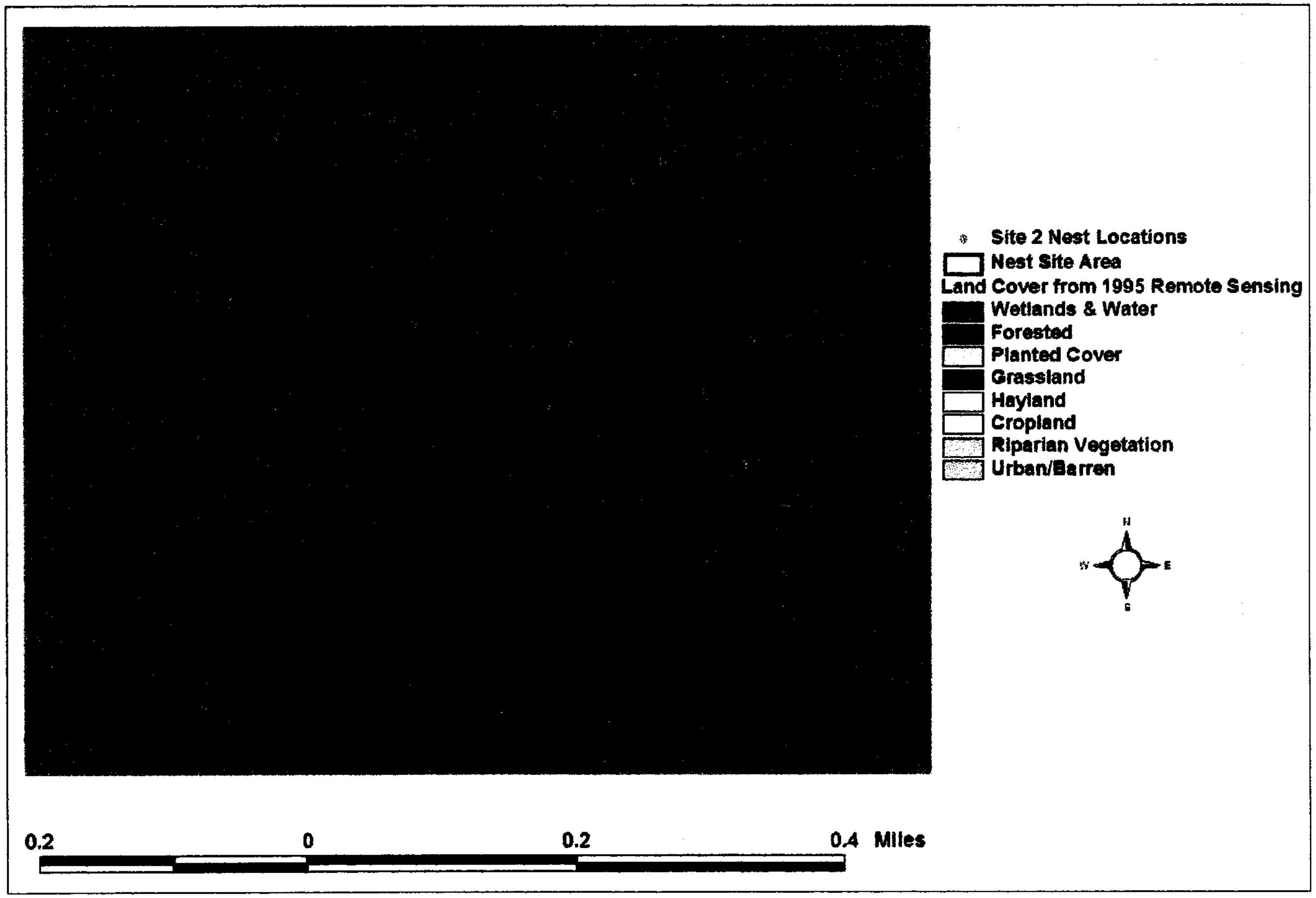


Figure 8. Site 3 Observed Nest Locations.

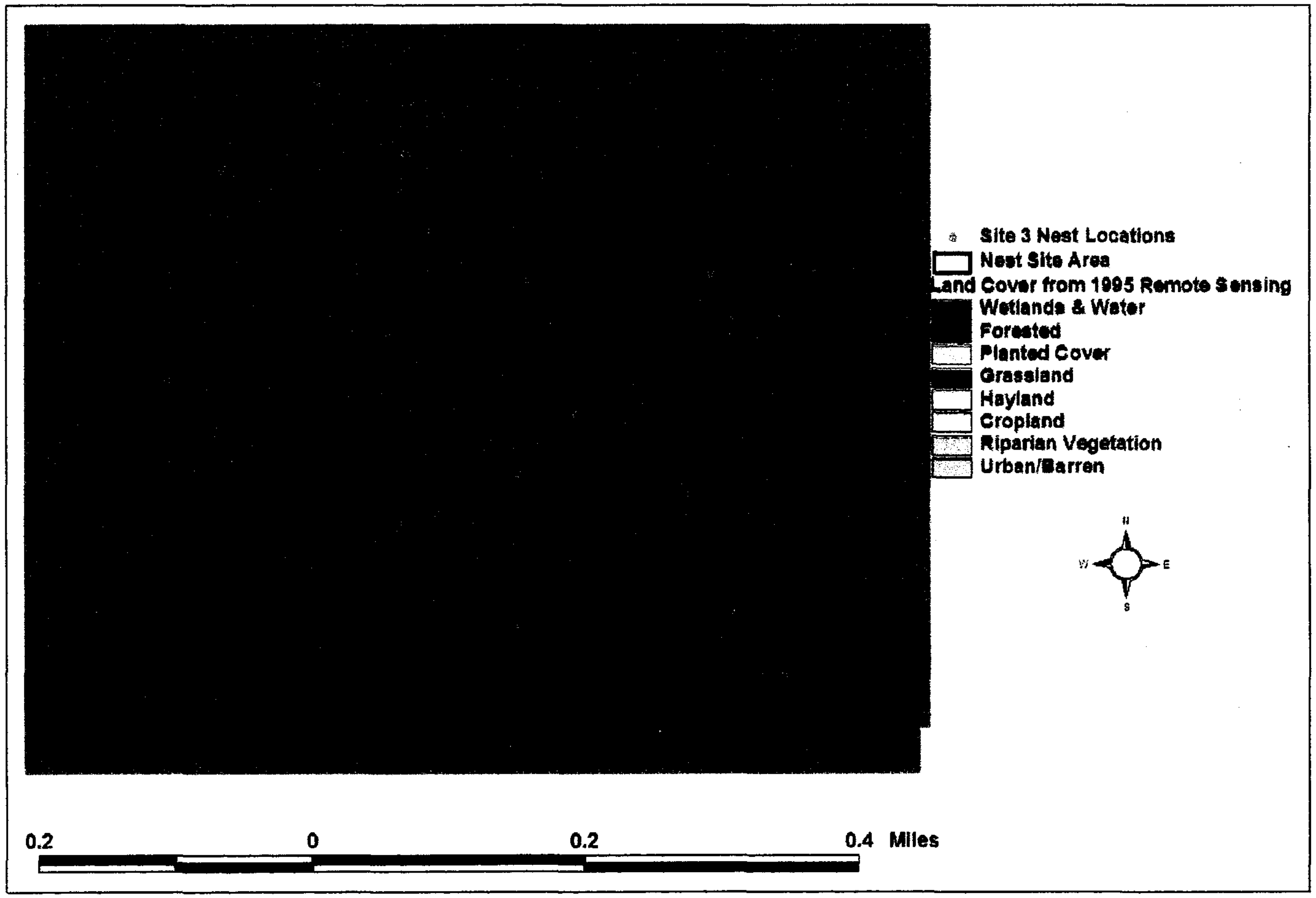


Figure 9. Site 4 Observed Nest Locations.

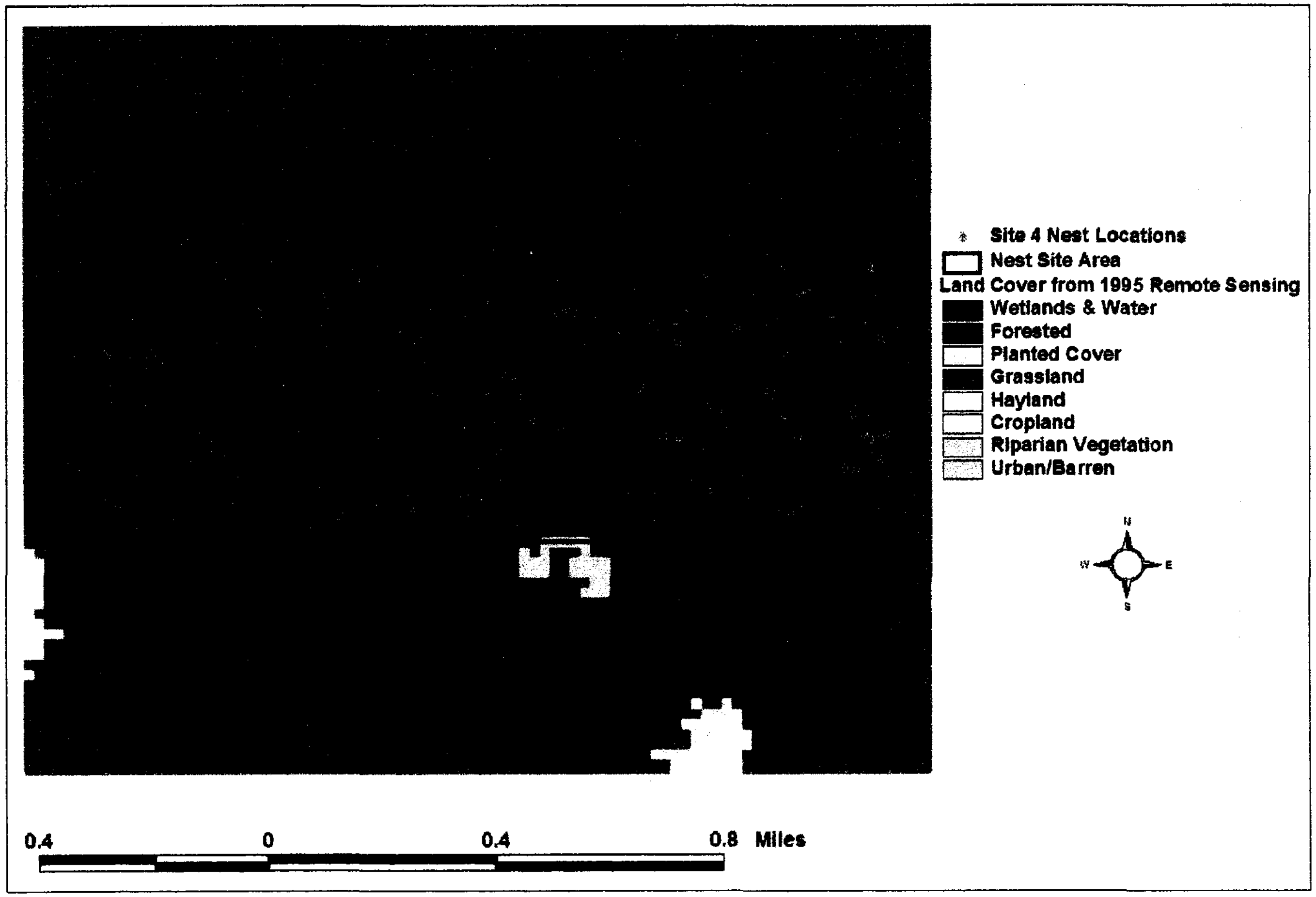
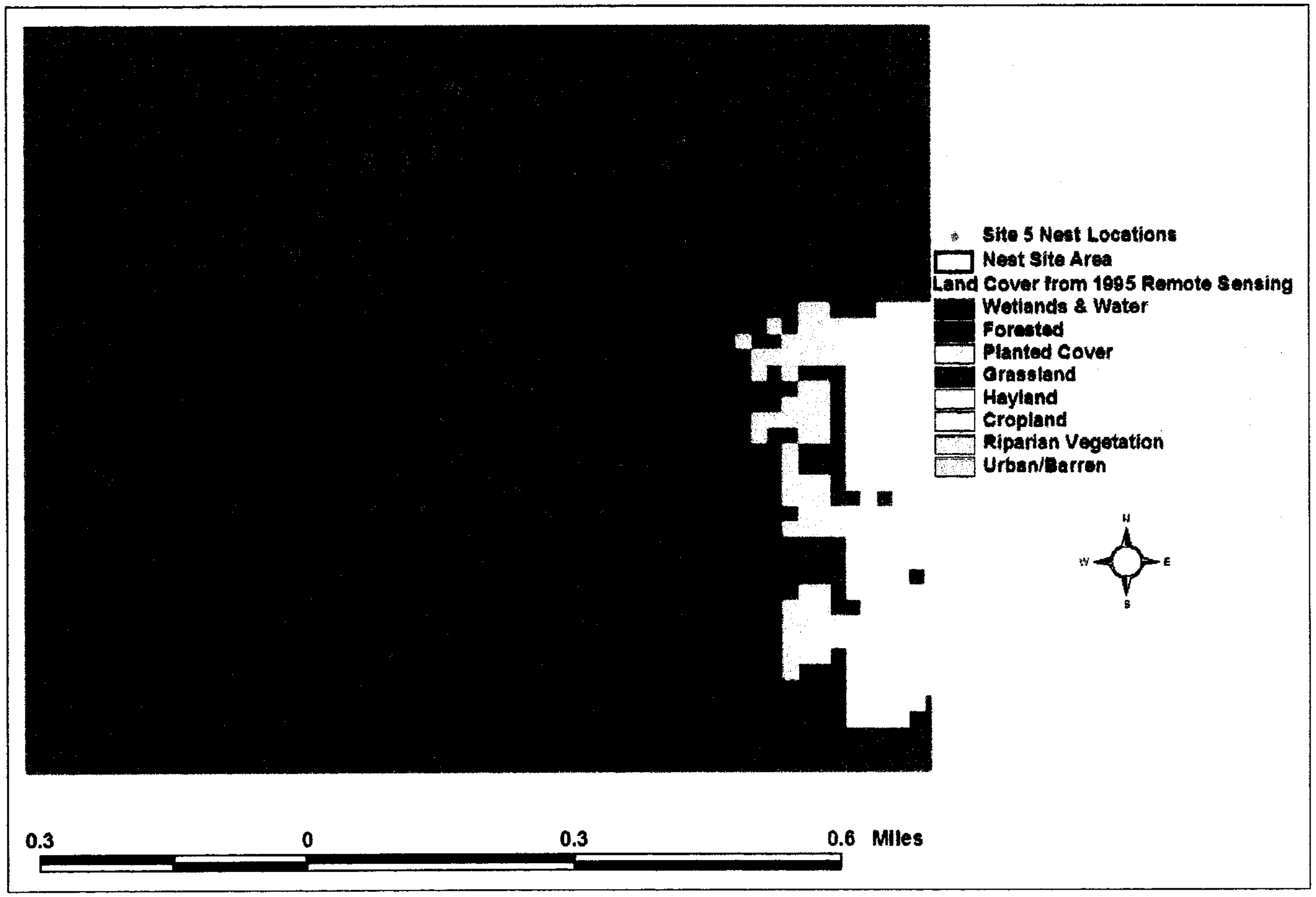


Figure 10. Site 5 Observed Nest Locations.



3 METHODS

3.1 Evaluating Point Data

The nest demographic and location data were segregated by study site and data from all other sources were spatially joined to the nest data. The combined data set was exported from ArcView (ESRI 2001) into S-Plus (Insightful Corporation 2001). These mapped data were evaluated using exploratory data analysis programs from the spatial libraries distributed by Reich and Davis (1998) and Venebles and Ripley (1997).

Two exploratory methods for comparing known spatial point patterns were used. Ripley's K-function was used to test against known point process patterns at various scales (Ripley 1976). K-function plots with simulation envelopes indicating divergence from a Poisson process allowed for comparison at non-fixed scales of the second-order characteristics of the observed point pattern (Getis and Franklin 1987). A Cramer-von Mises type global application of the k-function was used to test the null hypothesis that the point pattern demonstrates complete spatial randomness (CSR) (Diggle et al. 1979, Ord 1990). These are both second-order tests that use all paired point distances in the data set with Ripley's k-function being a local graphical representation of the distance functions (Isaaks and Srivastava 1989).

Species and nest success data were collected at each site. Multiple response permutation procedures were used to test for significant association between these classified parameters. If significant spatial association exists either between species or between successful and unsuccessful nests, the point processes will be re-evaluated to account for the repulsive or attractive behavior (Pielou 1977).

3.1.1 Ripley's K-Function

Ripley's k-function $F(t)$ is a cumulative distribution function. $F(t)$ is the distribution of distances between all permutations of paired points in the map.

$$\hat{F}(t) = \frac{\sum_{i \neq j} I_{ij}(t)}{N(N-1)} \qquad [1]$$

Where $I_{ij}(t) = 1$ if the distance, t_{ij}, between points *i* and *j* are less than some specified distance, *t*, and 0 otherwise, and *N* is the total number of points in the population. To account for a downward bias due to edge effect, the following correction factors are used:

$$K(i,j) = \left[1 - \cos^{-1}\left(\frac{e_1}{t}\right) / \pi\right]^{-1} \text{ or} \qquad [2]$$

$$K(i,j) = \left\{1 - \left[\cos^{-1}\left(\frac{e_1}{t}\right) + \cos^{-1}\left(\frac{e_2}{t}\right) + \frac{\pi}{2}\right] / 2\pi\right\}^{-1} \qquad [3]$$

where e_1 and e_2 are distances to the nearest borders, otherwise $K(i,j)=1$ for $e_i=t$. Substituting and taking into consideration the area of the population (A) being analyzed the k-function becomes

$$\hat{K}(t)=\frac{A\sum K(i,j)}{N(N-1)}. \qquad [4]$$

For a Poisson process, the expectation is that $\hat{K}(t)$ will equal the area of a circle of radius *t*, shown as $\hat{K}(t)=\pi t^2$. Transforming $\hat{K}(t)$ as follows

$$\hat{L}(t)=\left(\frac{\hat{K}(t)}{\pi}\right)^{1/2}=t \qquad [5]$$

we see that $\hat{L}(t)$ is a linear function of the distance *t*. Under the null hypothesis of CSR a plot of $\hat{L}(t)$ against *t* should have a slope of ~ 1 (or a 45 degree angle).

3.1.2 Cramer-von Mises Goodness-of-fit Test

A Monte-Carlo simulation for a Cramer-von Mises goodness-of-fit test statistic was performed against the second-order k function. Within a given distance *t* you would expect a certain number of points or events in a mapped data set. The number of expected events would be dependent on the density or intensity of events and whether the points in the population exhibit clustering, regularity or randomness. R. Reich developed S-code to perform a Monte Carlo goodness-of-fit test based on the Cramer-von Mises-type statistic, where *h* is the number of simulations and k is the sum of the square differences in the number of nests found versus expected at distance t:

$$k = \int_0^h \left\{ \left(\hat{K}(t) \right)^{1/2} - \pi^{1/2} t \right\}^2 dt \quad . \qquad [6]$$

First k is calculated from the observed data and then, k_i, $i = 2, \ldots, R$ as a realization from a Poisson process of R Monte Carlo simulations. All k_i are ranked and r is the rank of k_1. The p-value for significance regarding the goodness-of-fit is estimated using

$$\hat{p} = \frac{(R+1-r)}{R} . \qquad [7]$$

A small $\hat{p}$ would suggest rejecting the null hypothesis of CSR and a small k_1 would support the null hypothesis.

3.1.3 Tests for Spatial Association

Next we consider whether the spatial distribution of nests grouped by duck species and then by success influences or interacts with the distribution of another duck species or unsuccessful outcome. Data was examined as a whole, and as individual groupings. If there are interactions then we must look at the groups of data together but with distinction between groups rather than just individuals (Pielou 1977). An adaptation of the multi-response permutation process (MRPP)(Mielke 1986) was used as a test.

An applied example for successful versus non-successful nests follows: Let $\Omega = \{\omega_1,...,\omega_N\}$represent a finite population of nests categorized into g+1 disjoint groups. $(S_1,...,S_{g+1})$, and $x_1 = (x_{1I}, x_{2I})$ are the projected coordinates of each nest $\omega_I(I = 1,...,N)$. The total number of individuals, $N = \sum_{i=1}^{g+1} n_i$, where $n_i \geq 2$ is the number of nests in group $S_i(I = 1,...,g)$, K is the number of unclassified nests $K = \sum_{i=1}^{g} n_i$, and $n_{g+1} = N - K$ in the excess group S_{g+1}, and the proportion of classified nests in group S_i is $C_i = n_i / K$, and $\sum_{i=1}^{g} C_i = 1$. If $\Delta_{I,J}$ is the Euclidean distance between ω_I and ω_J, the MRPP statistic can be defined as the weighted average of the within group distances (over groups):

$$\delta = \sum_{i=1}^{g} C_i \xi_i \qquad [8]$$

where $\xi_i = \binom{n_i}{2} \sum_{I<J} \Delta_{I,J} \Psi_i(\omega_I)\Psi_i(\omega_J)$is the average distance between all pairs of nests in group $S_i(I = 1,...,g)$ summed over all *I* and *J* such that $1 \leq I < J \leq N$, and $\Psi_i(\omega_I)$=1 if ω_I belongs to S_i and 0 otherwise. An equal probability is given to each of the *M* discrete allocations of *N* nests to the *g*+1 groups. The permutation distribution of δ under the null hypothesis is the collection of all δ values associated with the *M* allocations. The p-value of an unsuccessful nest δ_0 is given by

$P(\delta \leq \delta_0)$. For cases with a large number of distinct combinations, the exact moments of δ can be approximated using the Pearson Type III distribution. The distribution of δ is likely to be negatively skewed under the null hypothesis and standardization may be required (Berry and Mielke 1983). A large p-value would suggest that the successful and unsuccessful nests are un-segregated. To add constraints for known clustering under specified conditions see Reich et al. (1990) and Mielke (1991). MRPP methods were applied between duck species where the number of observations was adequate.

3.2 Modeling Habitat Association using Presence Data and Threshold Theory

An assumption in the project is that there are limits to the availability of good nesting habitat or that there is sufficient variation in the grasslands such that waterfowl will nest in best habitats first and then sub-optimal habitats as densities increase. The relationship between the grassland cover quality and the spatial distribution of waterfowl nests can be modeled using minimum threshold theory (Neter et al. 1985, Reich et al. 2000). The minimum threshold value is the value, or quality of habitat, below which a hen will not choose a specific location for nesting. Because we did not radio track birds, we could not examine re-nesting in other upland areas. Therefore, we assume that there is threshold value T_i above which a piece of habitat will be suitable for nesting or not suitable. To apply T_i to a nesting decision at a spatially located point (s_i) in the field, let $Y_i = 1$ whenever $T_i \leq x_i$ (i.e. nest location within distance T_i), and 0 whenever $T_i \geq x_i$, where x_i is a modeled habitat quality index at s_i. For the modeled habitat quality index the first principle component (Section 3.3) of the Landsat TM data was used. The observed values were rank ordered based on nest sightings and probabilities then assigned. The probability of observing a nest at any given threshold value x_i is

$$\pi_i = P(Y_i = 1 \mid x_i) = P(T_i \leq x_i) \qquad [9]$$

where $P(T_i \leq x_i)$ is the cumulative probability distribution for all possible s_i. A number of functional forms were evaluated (Akaiki 1977) using Generalized Linear Models (GLM) and Generalized Additive Models (GAM). The results indicated that the use of logistic regression was appropriate for these data. Using logistic regression the model can be parameterized for estimation (Neter et al. 1985). Each of the β are the coefficients of the regression equation and x is the value of the first principle component. The logistic function is then described as the natural log of the ratio of the probability of observing an event (π) and the nonevent probability (1 - π) as a function of an intercept (β_0) and the coefficient (β_1) times the principle component value (x_1) and the regression residual (ε).

$$\ln\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 x_1 + \varepsilon \qquad [10]$$

3.3 Principle Components Analysis

To simplify the analysis and for the ability to solve multiple root equations the information contained in the Landsat imagery was reduced to a single band of descriptive data using the linear combination reduction technique Principle Components Analysis (PCA) (Mardia et al. 1979, Insightful Corporation 2001). PCA is a generally accepted technique used to compress the dimensionality of remotely sensed data (Ingegritsen and Lyon 1985, Thomas et al. 1987, Jensen 1996, Maxwell et al. 1997).

Each component or transformed variable is independent of the other components. They are mutually orthogonal and ordered such that the first component contains the largest percentage of total variation the second component the next largest and so on. The importance of the first principle component is that it accounts for the majority of the variation (> 70%) in the TM data used for this study. This makes PCA an efficient substitute for the multiple bands of data because the information loss is relatively minimal.

4 RESULTS

4.1 Point Patterns

Nest densities at each study site as well as the total area of each study site varied slightly (Table 3). Nest densities were fairly consistent except for site 2 which had a slightly higher density (n = 5, $\mu = 0.722$, $\sigma = 0.00927$). The area of the samples varied because contiguous plots meeting the design requirements were rare. The distance-based techniques applied here require a convex shape and few areas had the required connectivity restraints for such a shape. Three of the sample sites are approximate public land survey system quarter sections. Only two sites (4 and 5) had convex connectivity with adjacent sites. These two sites had areas larger than a quarter section but they were consistent with the mean nest density of the smaller sites. The density calculation does not discount for the area of wetlands in each site.

Table 3. Number of observed nests, area and observed nest density on the study sites.

Site	Number of Observed Nests	Area (*ha*)	Nest Density per ha
1	43	60.84	0.71
2	54	60.84	0.89
3	42	63.18	0.66
4	135	196.83	0.69
5	71	107.01	0.66

Results of the K-Functions and Cramer-von Mises goodness-of-fit test gave both a numeric and graphical representation of the spatial point patterns. Each site is evaluated independently. Only site 4 differed significantly from CSR based on the Cramer-von Mises goodness-of-fit test (Table 4).

Table 4. Cramer-von Mises Goodness-of-fit and associated p-values for each site based on 100 simulations.

Site	Test Statistic	*p*-value
1	44128	0.20
2	5925	0.74
3	9273	0.82
4	23844	0.01
5	16143	0.21

The transformed K-functions L(*t*) were plotted over distance (*t*) for each site using a step function to represent the empirical data and the smoothed lines showing the average, upper and lower bounds for a random spatial pattern. The bounds of the envelope represent a 99% simulation envelope. Each simulation envelope is constructed using the same number of points as the observed data set for each site. The data set under the null hypothesis of CSR, were produced using a Poisson point process. Deviations from the confidence envelope above the line representing the upper bound indicate clustering at the distance (*t*) read from the horizontal axis of the graph. Deviations below the lower-limit, suggest regularity at the distance read from the horizontal axis. The point with the greatest vertical height above or below the envelope is usually the point measured for estimating distance.

Site 1 starts to deviate from the simulated CSR data at distances of about 60 meters and remains above the mean for the remainder of the sampled distances (Figure 11). The step function above the CSR data average suggests the possibility of some clustering but it is not significant at the 99% level unless it extends above the upper simulation bound.

Site 2 shows little deviation from the CSR average (Figure 12). The observed data weave back and forth across the average without much vertical deviation at any distance. The k-function results are consistent with the results of the Cramer-von Mises goodness-of-fit test.

Site 3 and Site 5 also confirm the results of the Cramer-von Mises goodness-of-fit test (Figures 13, 15). There is no deviation outside the envelope and no support for the rejection of CSR. Site 4 does show significant deviation from the null hypothesis of CSR (Figure 14). This site has the largest total area measured and the largest number of observed nests but is also similar in nest density to the other sites. The k-function suggests evidence of clustering among observed nests. This confirms the result from the Cramer-von Mises goodness-of-fit test where Site 4 had a small p-value, p-value = 0.01. Further investigation may help us understand if site 4 is anomalous or if the additional area and/or observations are allowing the tests to better describe the spatial patterns of nests.

Figure 11. Site 1. Transformed K- function L(t) over distance t. Envelope boundaries and smooth mean are derived from 200 Poisson simulations. Bounds represent 99.5% confidence envelope for complete spatial randomness.

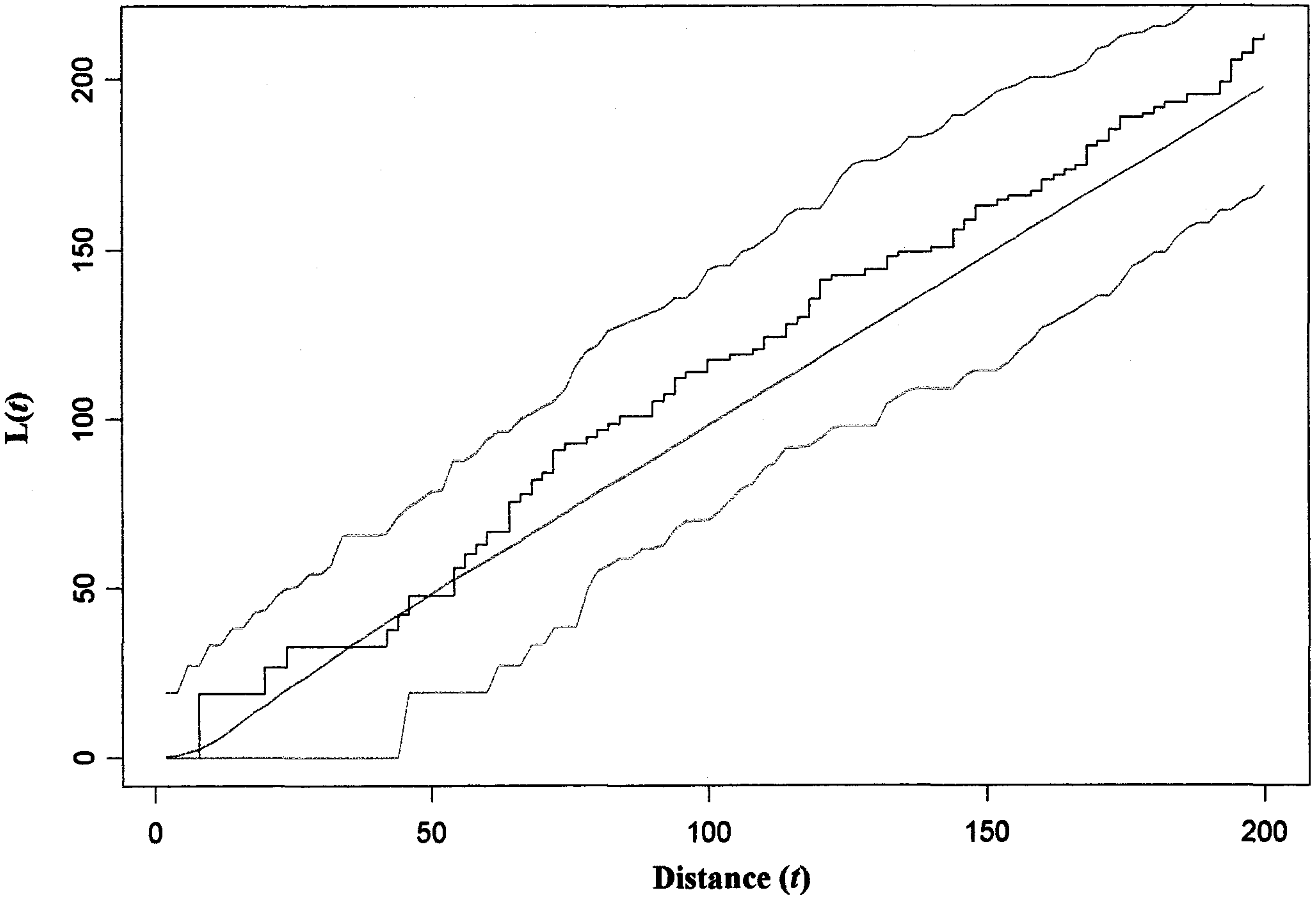


Figure 12. Site 2. Transformed K- function L(t) over distance t. Envelope boundaries and smooth mean are derived from 200 Poisson simulations. Bounds represent 99.5% confidence envelope for complete spatial randomness.

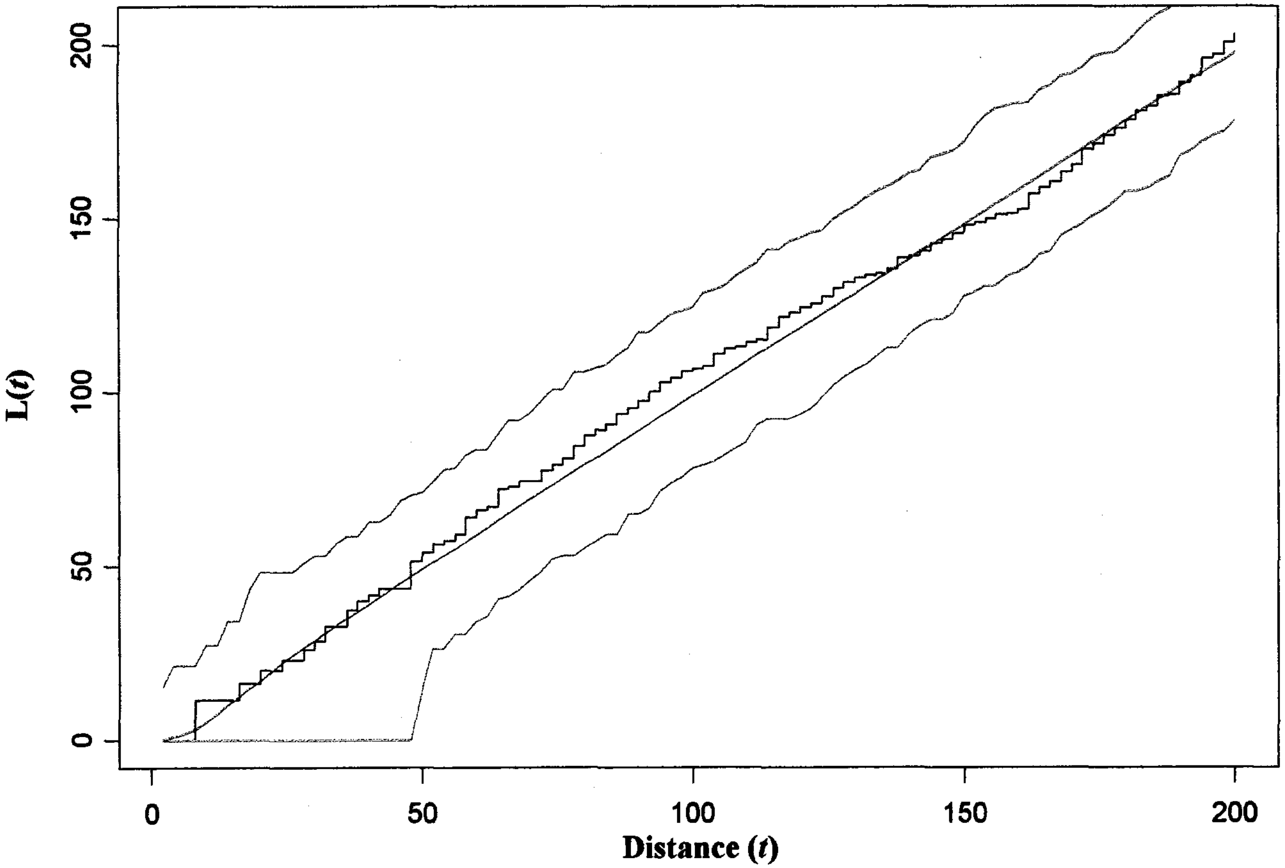


Figure 13. Site 3. Transformed K- function L(t) over distance t. Envelope boundaries and smooth mean are derived from 200 Poisson simulations. Bounds represent 99.5% confidence envelope for complete spatial randomness.

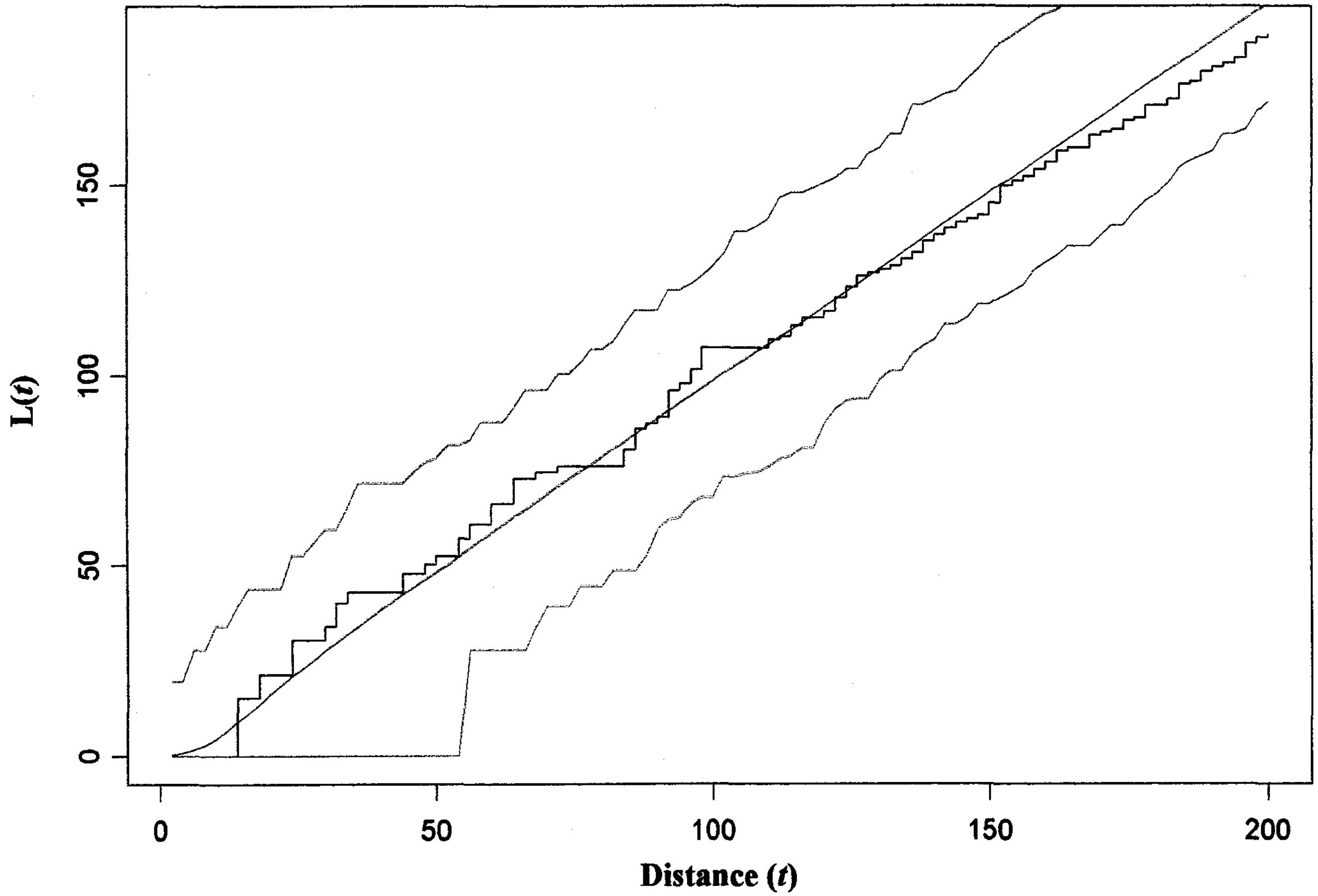


Figure 14. Site 4. Transformed K- function L(t) over distance t. Envelope boundaries and smooth mean are derived from 200 Poisson simulations. Bounds represent 99.5% confidence envelope for complete spatial randomness.

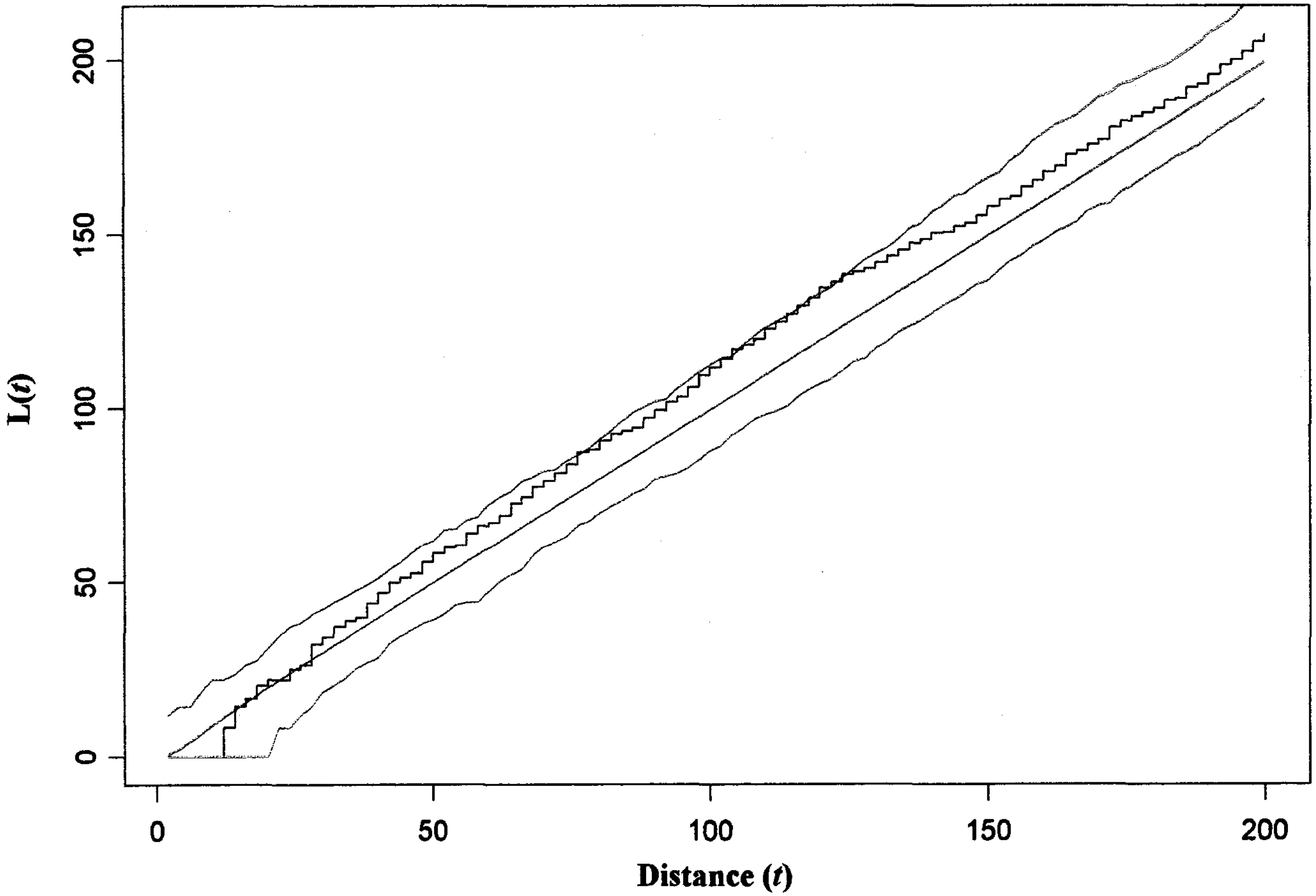
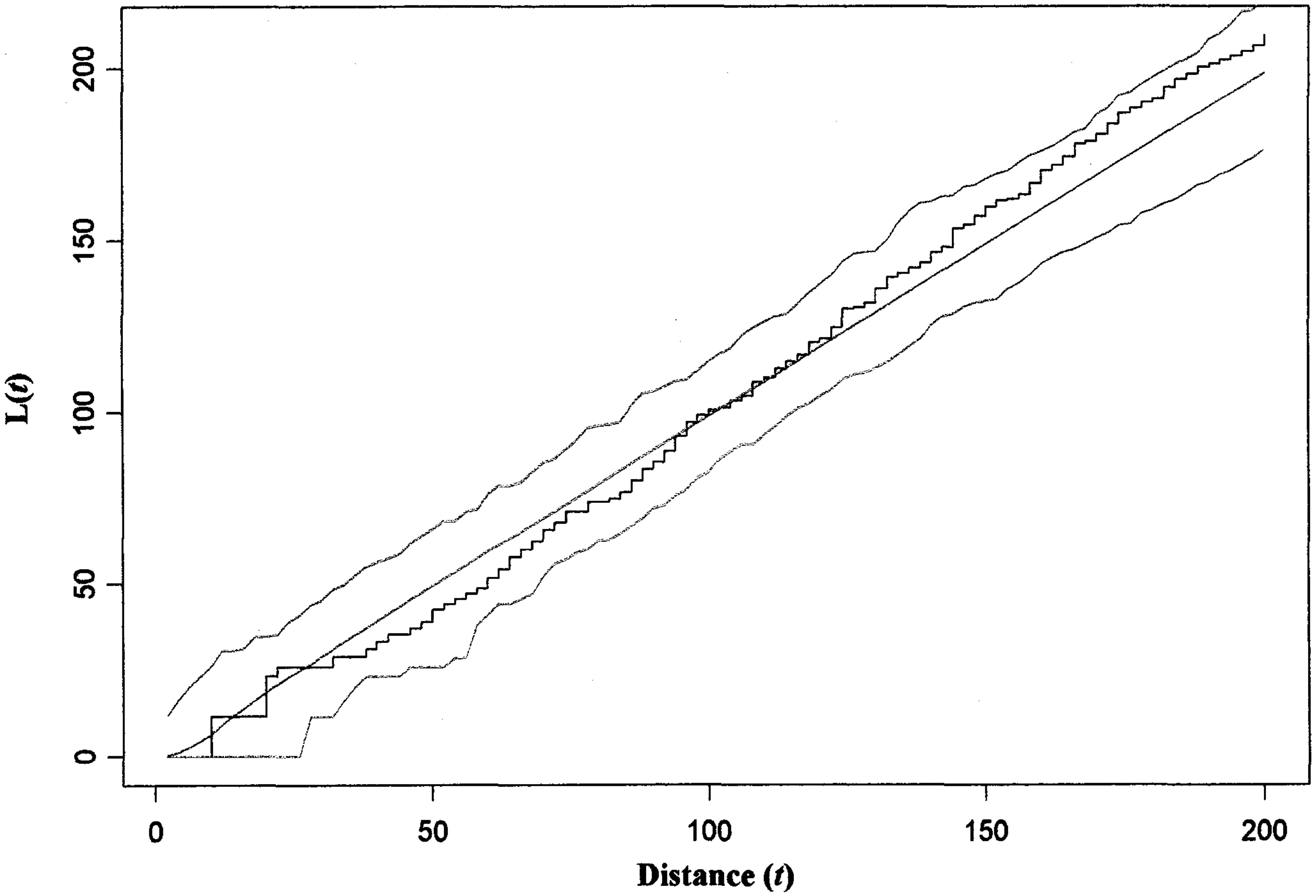


Figure 15. Site 5. Transformed K- function L(t) over distance t. Envelope boundaries and smooth mean are derived from 200 Poisson simulations. Bounds represent 99.5% confidence envelope for complete spatial randomness.



4.2 Spatial Association (Multiple Response Permutation Process)

MRPP was used to test for spatial association between successful and unsuccessful nest locations, and between species at each site. Site 2 showed slight evidence of negative spatial association between successful and unsuccessful nesting waterfowl. All other sites showed no evidence of spatial association (Table 5).

Table 5. MRPP test of spatial association between successful and unsuccessful nest locations.

Site	Successful Nests	Unsuccessful Nests	MRPP Test Statistic	*p*-value
1	29	62	0.71	0.747
2	21	33	-1.41	0.091
3	15	27	-0.09	0.355
4	27	115	-0.22	0.274
5	28	43	0.37	0.530

Tests for spatial associations between species for nest site selection were analyzed using the available data. Observation of sufficient nest numbers to test for spatial association limited the analysis to those between Gadwall and Blue Winged Teal. These were the most common species among all study sites both in observed nests and census counts on the wetlands during the breeding season. Sites 4 and 5 showed some evidence of negative spatial association (Table 6).

Table 6. MRPP test of spatial association between Blue Winged Teal and Gadwall nest locations.

Site	Blue Winged Teal	Gadwell	MRPP Test Statistic	*p*-value
1	28	25	0.51	0.613
2	22	14	0.84	0.818
3	9	16	0.44	0.580
4	71	39	-1.52	0.079
5	26	23	-1.76	0.063

Though there was some evidence for spatial associations the resulting evidence is weak and there was little consistency between plots to warrant inclusion in the spatial models. The spatial models were then approached from the standpoint that regardless of species, a waterfowl nest is a nest and segregation is not warranted at this point. The test for spatial association between successful and unsuccessful tells us that there may have been some relationship between lost and hatched nests. This will be addressed in future research.

4.3 Nest Probability Surfaces and Point Process Model

PCA's were derived in Erdas Imagine and only the first principle component was exported for analysis. The resulting Eigen matrix shows the loading and the Eigenvalues shows the percent of total variance described by each principle component (Table 7).

Table 7. Eigen matrix showing the principle component loading for 6 bands of Landsat 7 Thematic Mapper Imagery, Eigenvalues and the total variance explained by each principle component (PC).

Band	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Band 1	0.335	-0.536	-0.137	0.217	0.586	-0.438
Band 2	0.340	-0.370	-0.134	-0.030	0.082	0.850
Band 3	0.433	-0.379	0.104	-0.456	-0.610	-0.279
Band 4	0.321	0.297	-0.799	0.296	-0.274	-0.088
Band 5	0.573	0.575	0.162	-0.408	0.384	-0.005
Band 6	0.391	0.114	0.537	0.700	-0.236	0.025
Eigenvalues	1237.47	220.04	78.58	10.52	2.44	1.04
Variance (%)	79.8	14.2	5.1	0.7	0.2	0.1

For each nest site location the corresponding PCA was extracted and then ranked and ordered to build a cumulative density function (CDF, Figure 16). The probability density function (PDF, Figure 17) was generated using the first derivative of the cumulative distribution function (cdf).

$$cfd = \frac{\exp(\beta_0 + \beta_1 x_1)}{1 + \exp(\beta_0 + \beta_1 x_1)}. \qquad [11]$$

$$pfd = \frac{\beta_1 \exp(\beta_0 + \beta_1 x_1)}{(1 + \exp(\beta_0 + \beta_1 x_1))^2} \qquad [12]$$

The coefficients of the logistic function where estimated using a general linear model with a logistic link:

β_0= -16.12069, SE = 1.24504 β_1=0.1058905, SE = 0.008181
Degrees of Freedom: 791 Total; 789 Residual
Residual Deviance: 1.023993

The logistic equation was then used to generate a probability surface showing the probability of observing a nest site for each of the five field sites. A point process model was developed to allocate nest points with probability proportional to chance of observing a nest. Each set of observed data was then tested using a k-function and the point process model to calculate a Monte Carlo simulation envelope. Plots of the probability surfaces with modeled and observed nests (Figure 18 – 22) and associated k-functions (Figures 23 – 27) follow at the end of this chapter. Study site 4, which differed significantly from CSR, is well tracked by the point process model (Figure 26). The point process model was also fit to the remaining sites. In all cases, the observed transformed k-function was contained within the simulation envelopes (Figures 23 - 25, 27).

Observed and modeled nests demonstrate similar behavior by excluding much of the low probability areas (Figures 17 – 22). The modeled data has seemingly more points in the highest probability areas but it is not statistically different from the observed. Some divergence at larger distances is common and in the case of the fitted model, these trends are minimal. These trends are often caused by the reduction in the number of observations at the greater distances. The distance dependence of the divergence is evident in plots of the mapped probability surface with observed nests and modeled nests.

Figure 16. Cumulative Distribution of Principle Component Values.

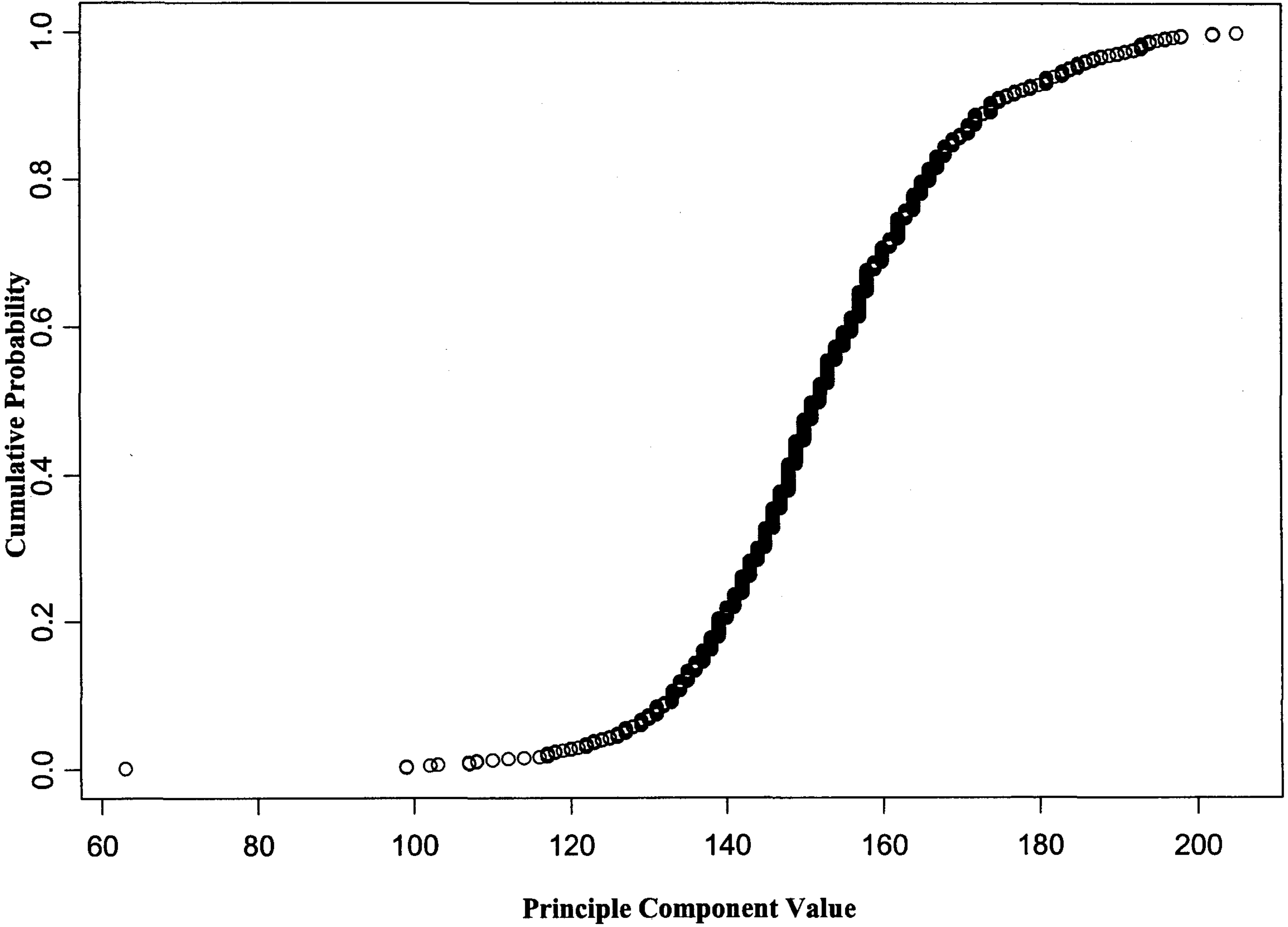
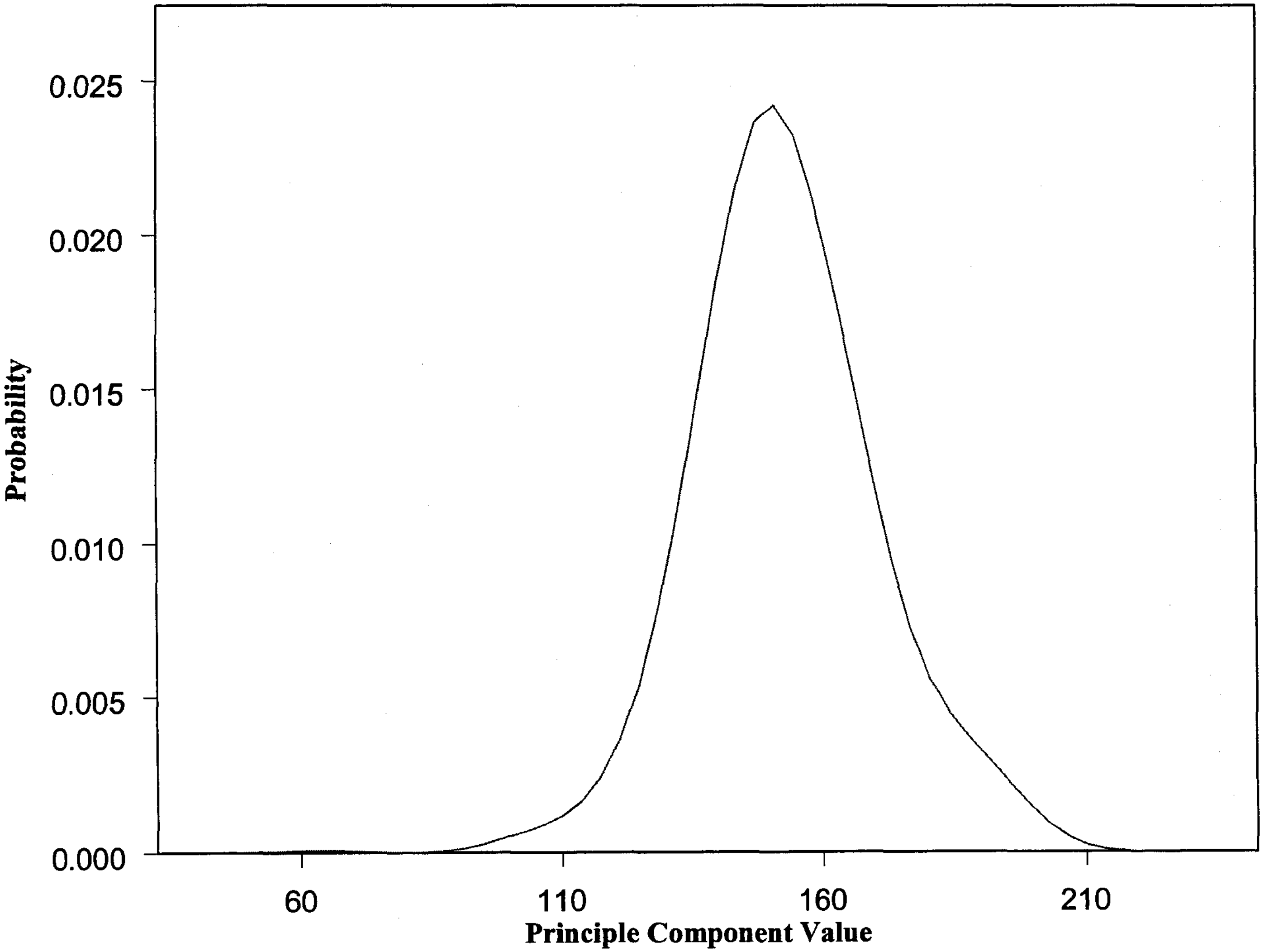


Figure 17. Probability Density Function of Principle Component Values.



The results demonstrate that the point process model, derived from the remote sensing data, captures the spatial interactions that the Poisson simulations in the earlier data exploration did not capture on site 4. The significance of site 4 to the modeling effort is quite evident. Site 4 is the largest area with the greatest number of observations. The Poisson envelopes in the data explorations did not capture the nest site 4 empirical data at several distances. As expected, these data were very well described with the modeled envelope and mean. The site 4 model was not significantly different from the observed data on the other sites as demonstrated by the k-function plots.

Based on the probability surfaces, suitable habitat is not a limitation in the prairie grasslands for waterfowl nest site selection. The empirical data is fairly well characterized by a Poisson point processes at several study sites. The behavior of the point patterns may be dominated by the exclusion of non-viable nesting habitat such as open water or bare ground. These areas were accounted for in the site 4 model because of the low probabilities assigned to them.

Visual inspection of the probability surfaces with both the observed and modeled nests shows the spatial distribution on each plot. Modeled nests tend to be located in the higher probability (blue/cyan) areas with very few in the low probability (magenta) regions (Figures 17 – 22). The magenta regions tend to represent open water and/or bare ground. The spatial arrangement, of the modeled nests, shows little observable differences from the empirical nest locations (Figures 28 – 32). The nest site 4 model seems to capture the clustering behavior over the larger observed landscapes. The modeled nest maps follow the results of the k-functions used to validate these modeled data.

Figure 18 Nest Site 1 Probability Surface with Observed Nests (circles) and Modeled Nests (diamonds). Magenta is low and cyan is high probability.

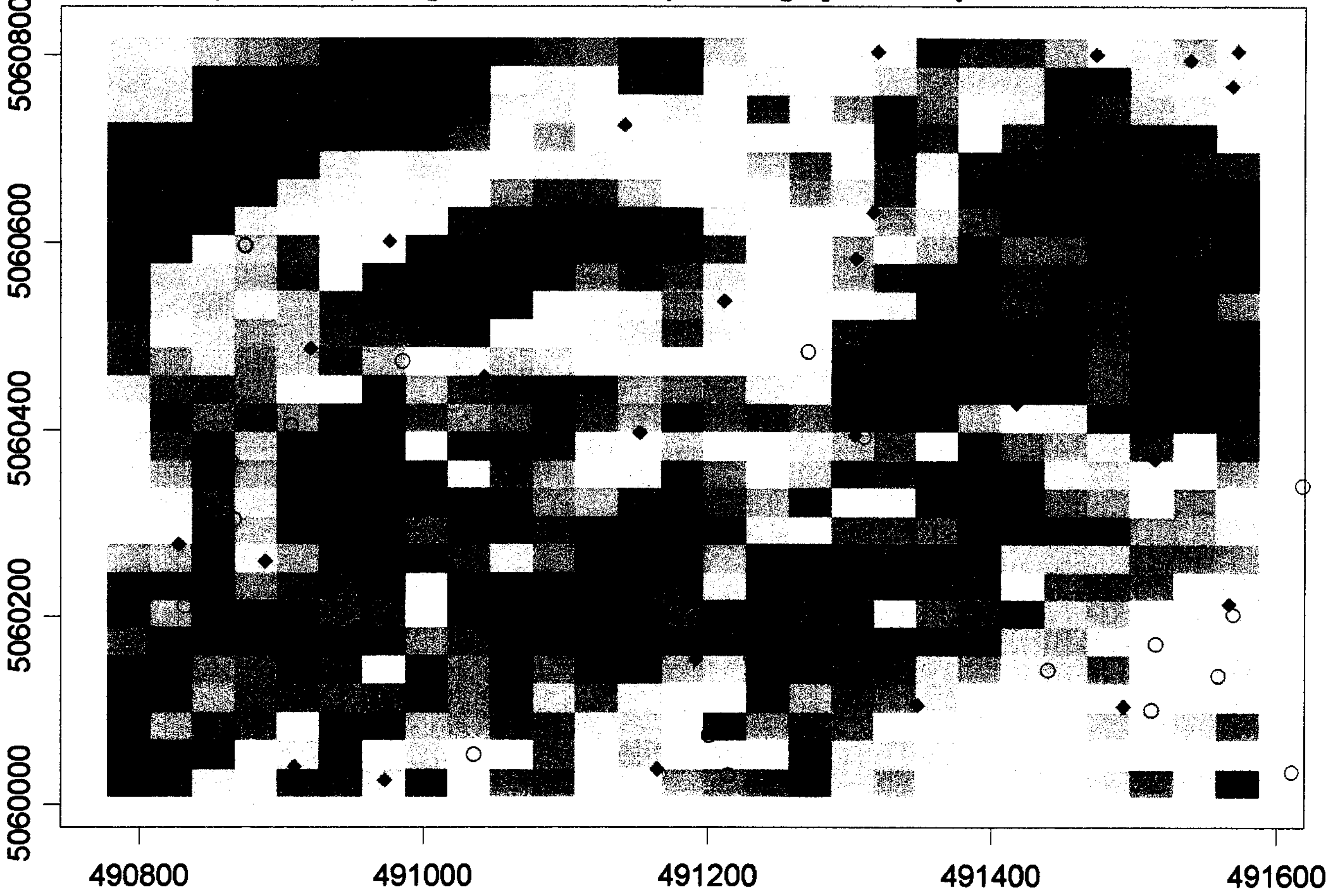


Figure 19 Nest Site 2 Probability Surface with Observed Nests (circles) and Modeled Nests (diamonds). Magenta is low and cyan is high probability.

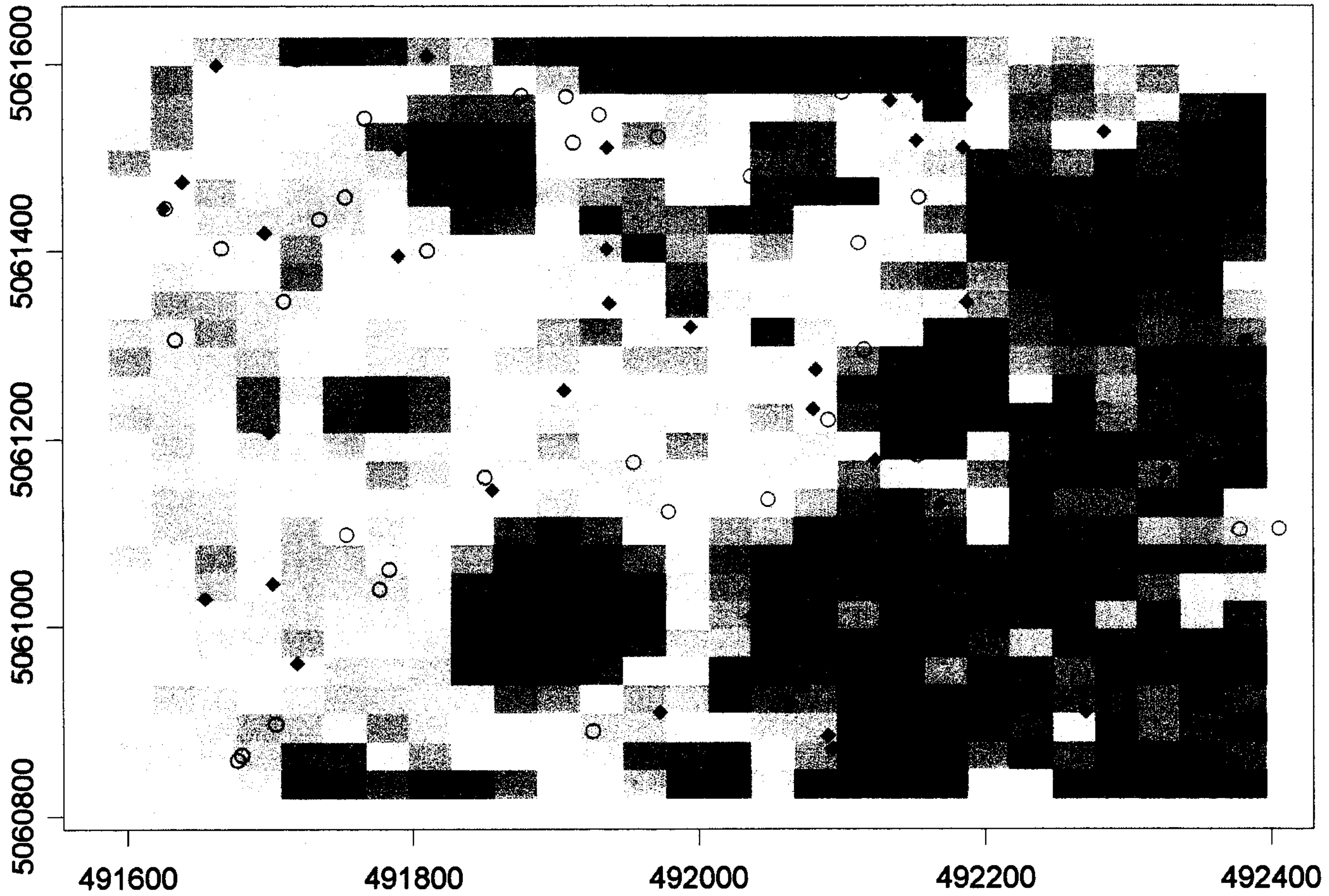


Figure 20 Nest Site 3 Probability Surface with Observed Nests (circles) and Modeled Nests (diamonds). Magenta is low and cyan is high probability.

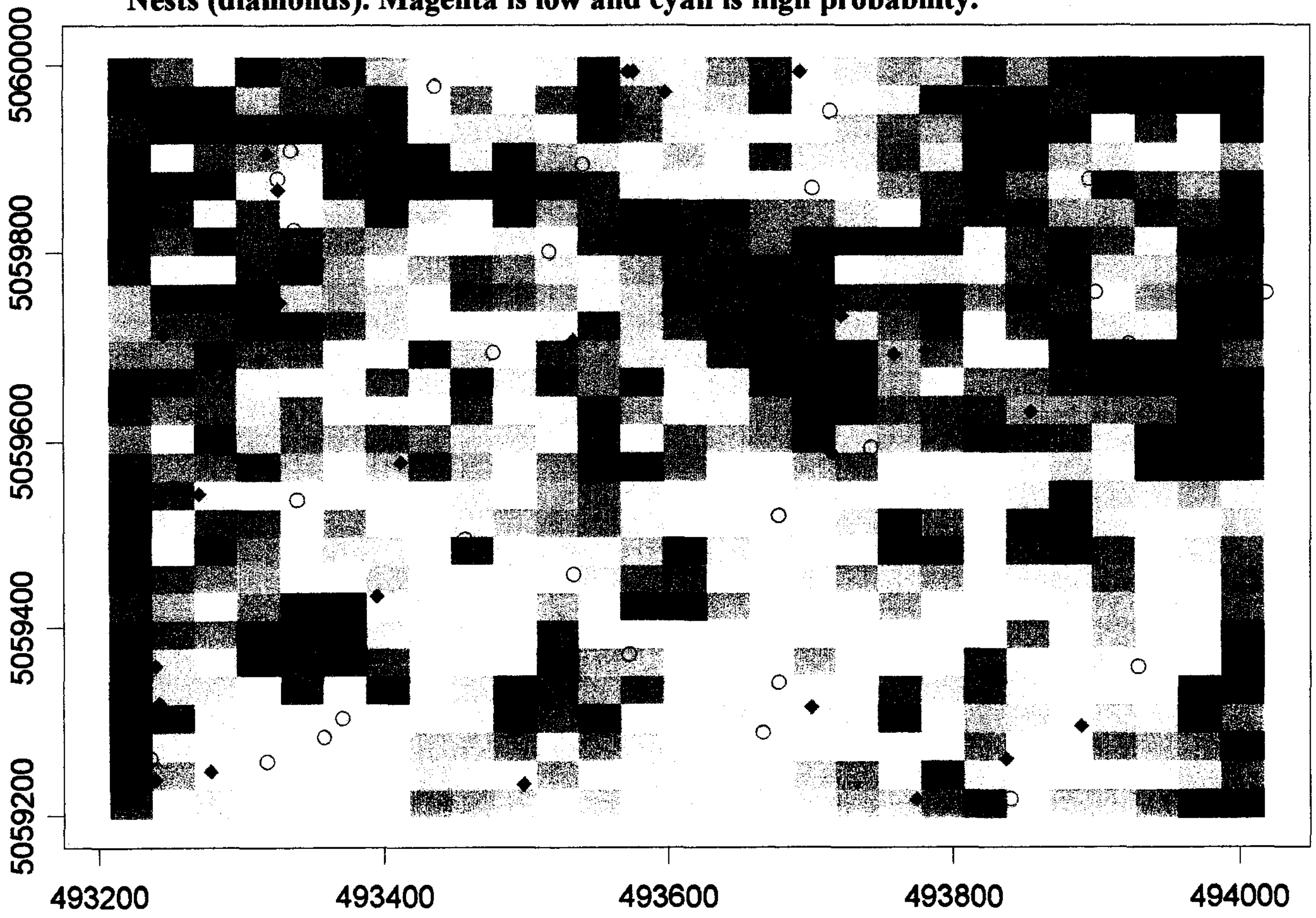


Figure 21 Nest Site 4 Probability Surface with Observed Nests (circles) and Modeled Nests (diamonds). Magenta is low and cyan is high probability.

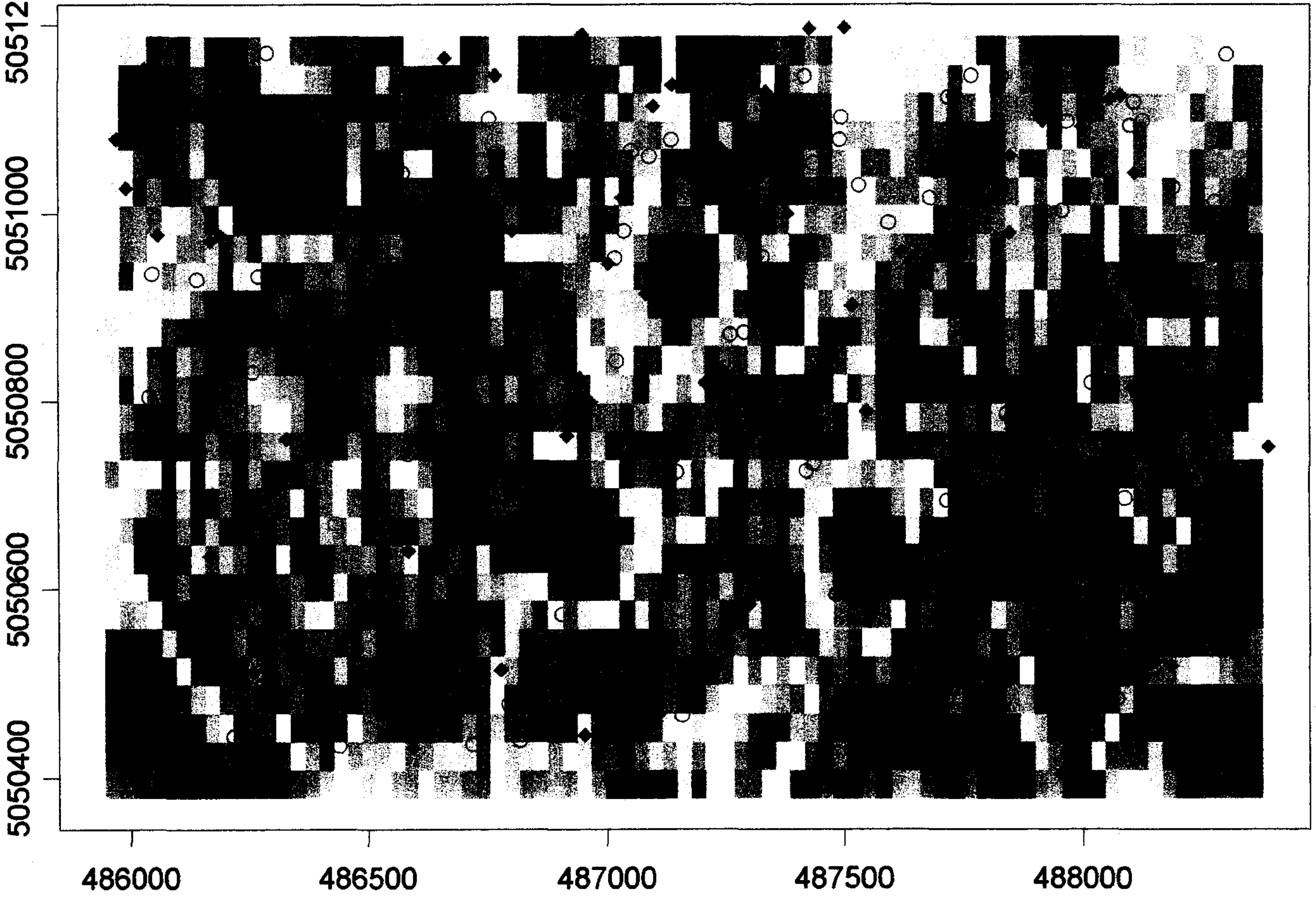


Figure 22 Nest Site 5 Probability Surface with Observed Nests (circles) and Modeled Nests (diamonds). Magenta is low and cyan is high probability.

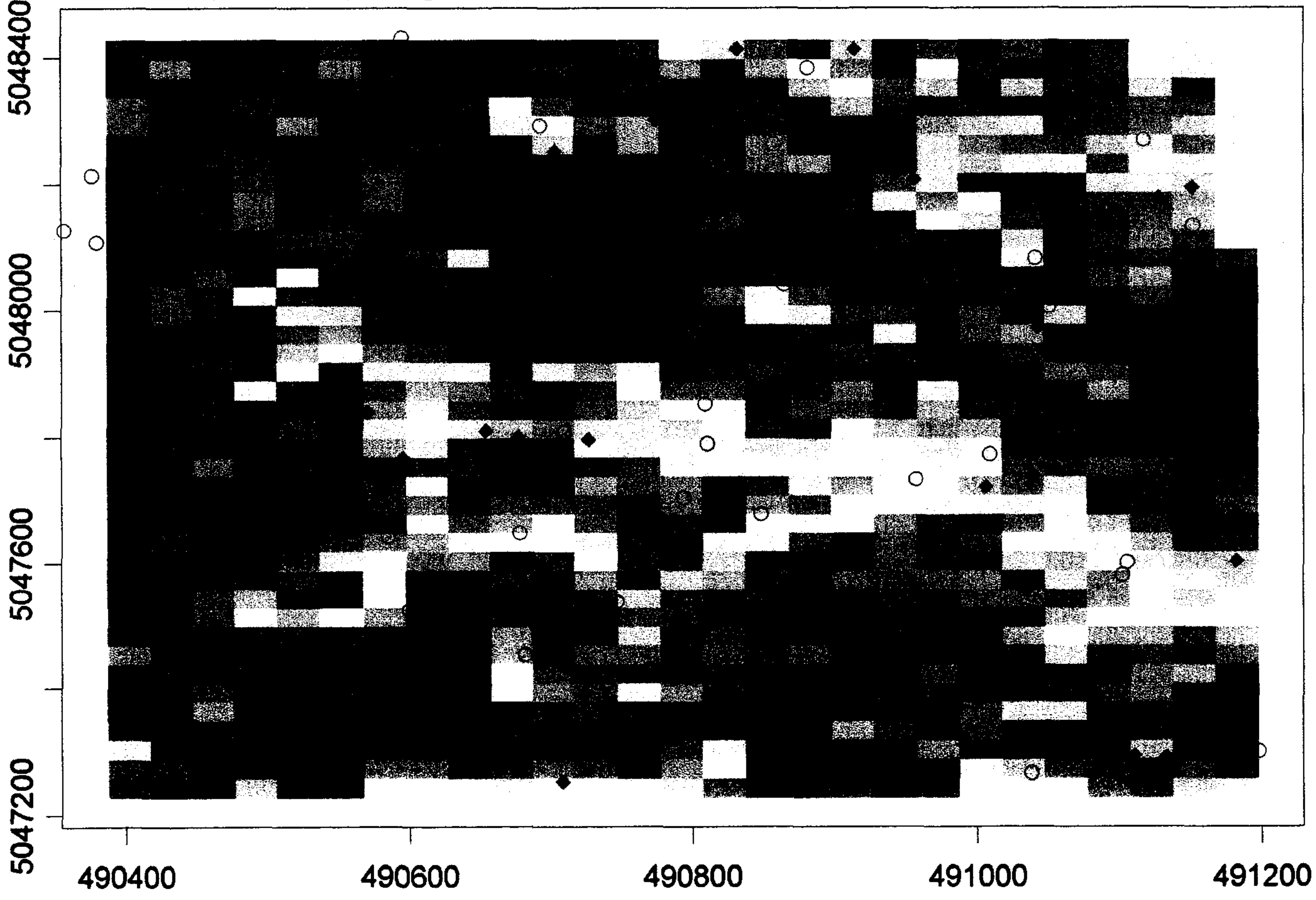


Figure 23. Nest Site 1. Transformed K- function L(t) for observed nests over distance t. Envelope boundaries and smooth mean are derived from 200 simulations of the point process model. Bounds represent 99.5% confidence envelope for the point process model.

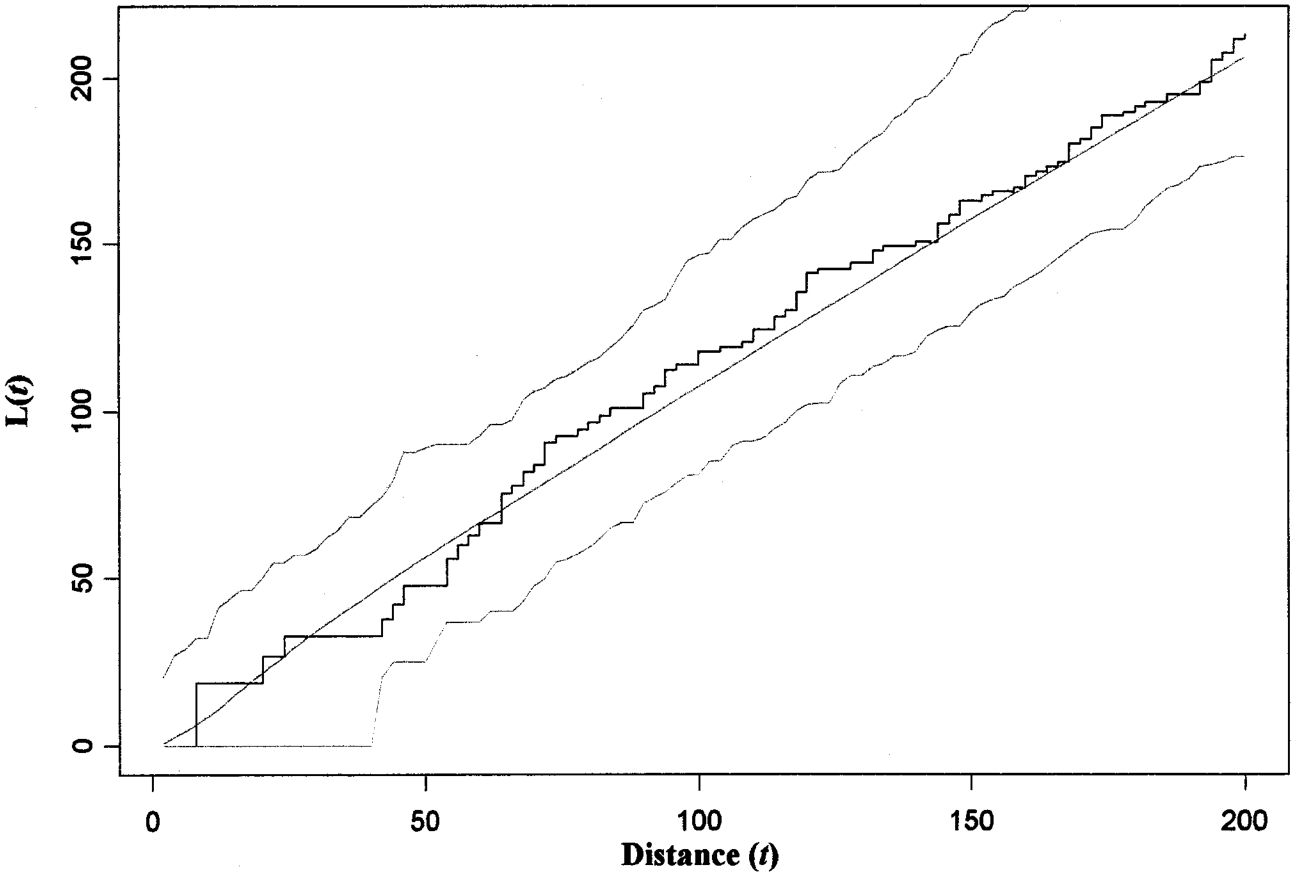


Figure 24. Nest Site 2. Transformed K- function L(t) for observed nests over distance t. Envelope boundaries and smooth mean are derived from 200 simulations of the point process model. Bounds represent 99.5% confidence envelope for the point process model.

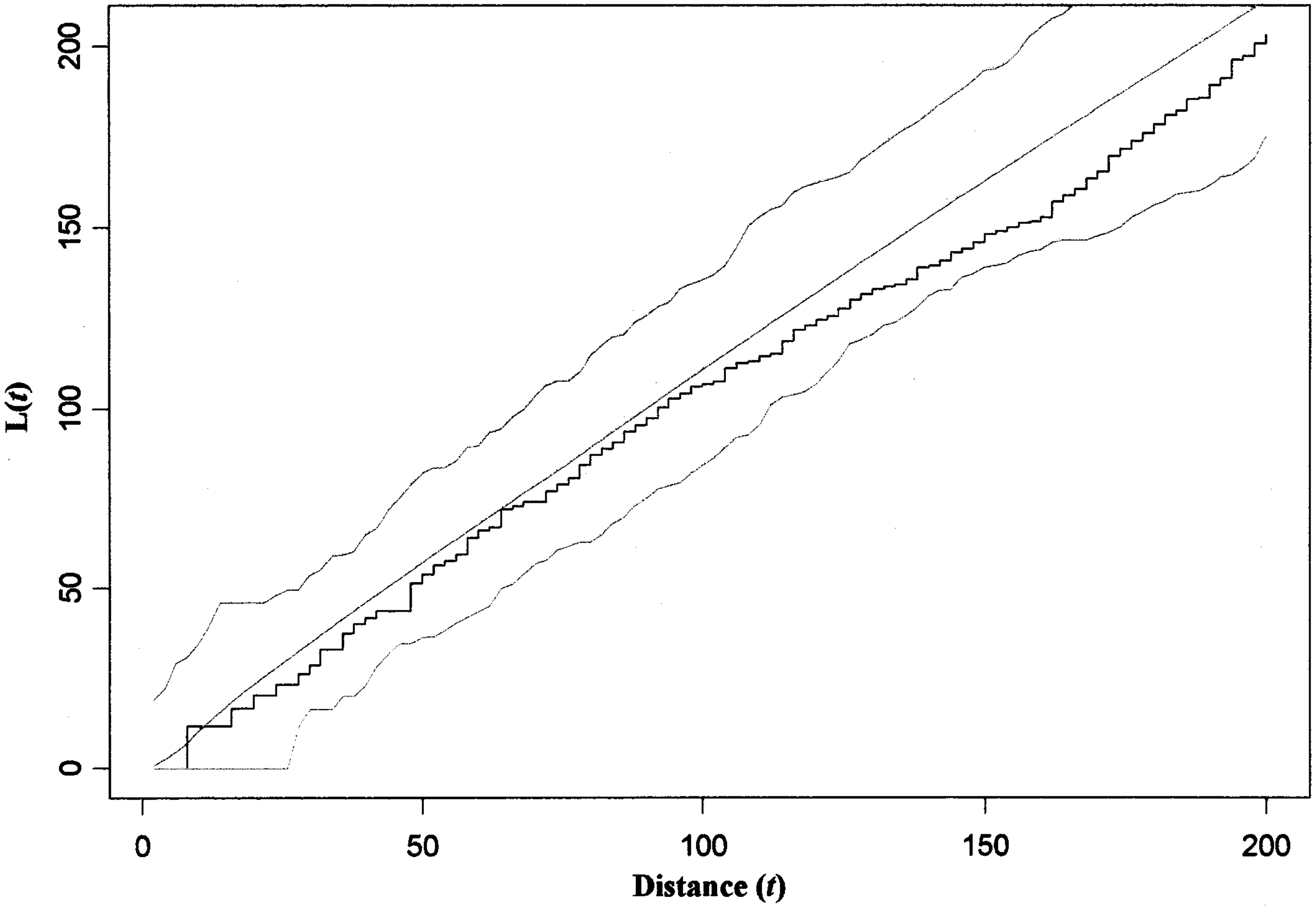


Figure 25. Nest Site 3. Transformed K- function L(t) for observed nests over distance t. Envelope boundaries and smooth mean are derived from 200 simulations of the point process model. Bounds represent 99.5% confidence envelope for the point process model.

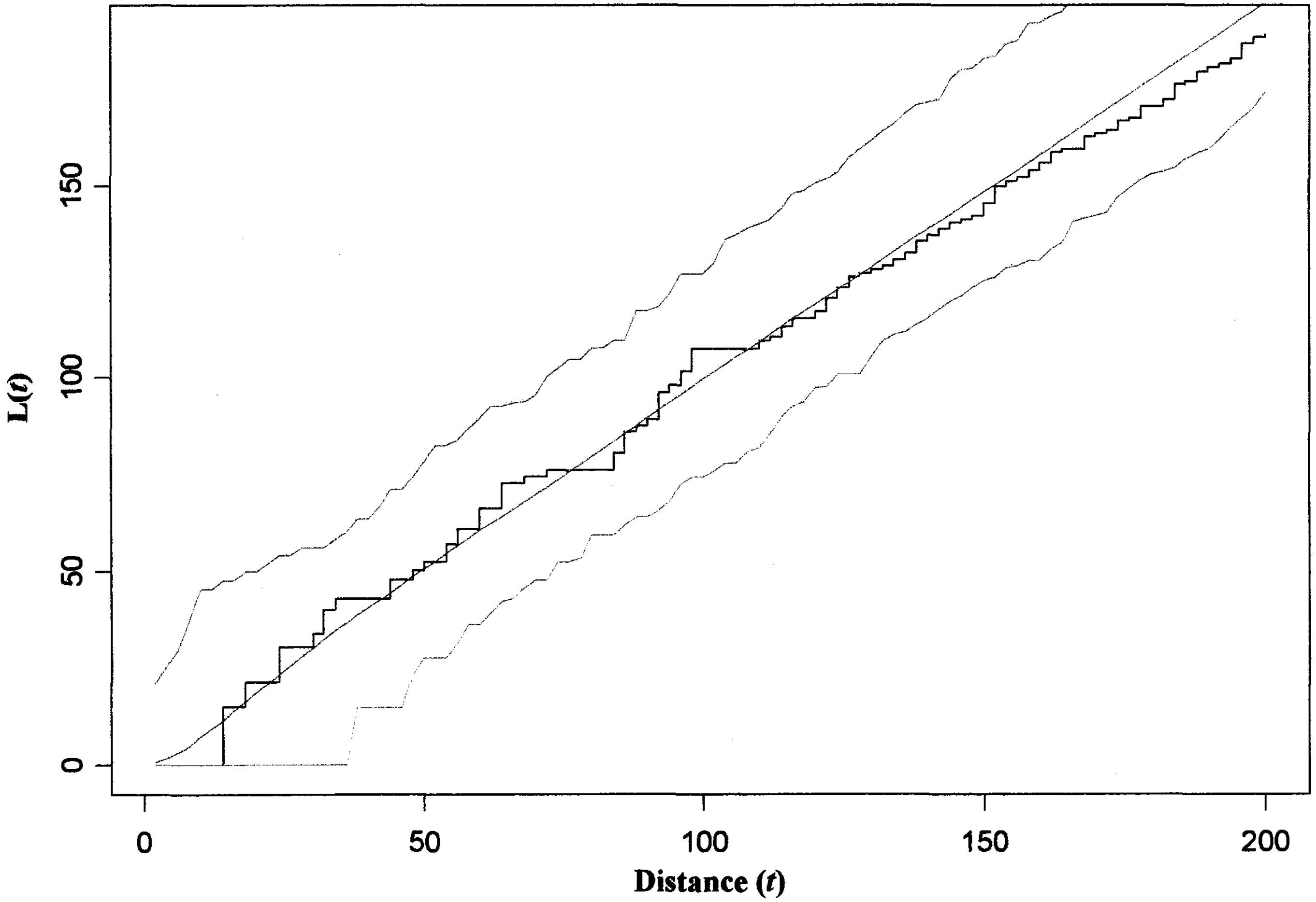


Figure 26. Nest Site 4. Transformed K- function L(t) for observed nests over distance t. Envelope boundaries and smooth mean are derived from 200 simulations of the point process model. Bounds represent 99.5% confidence envelope for the point process model.

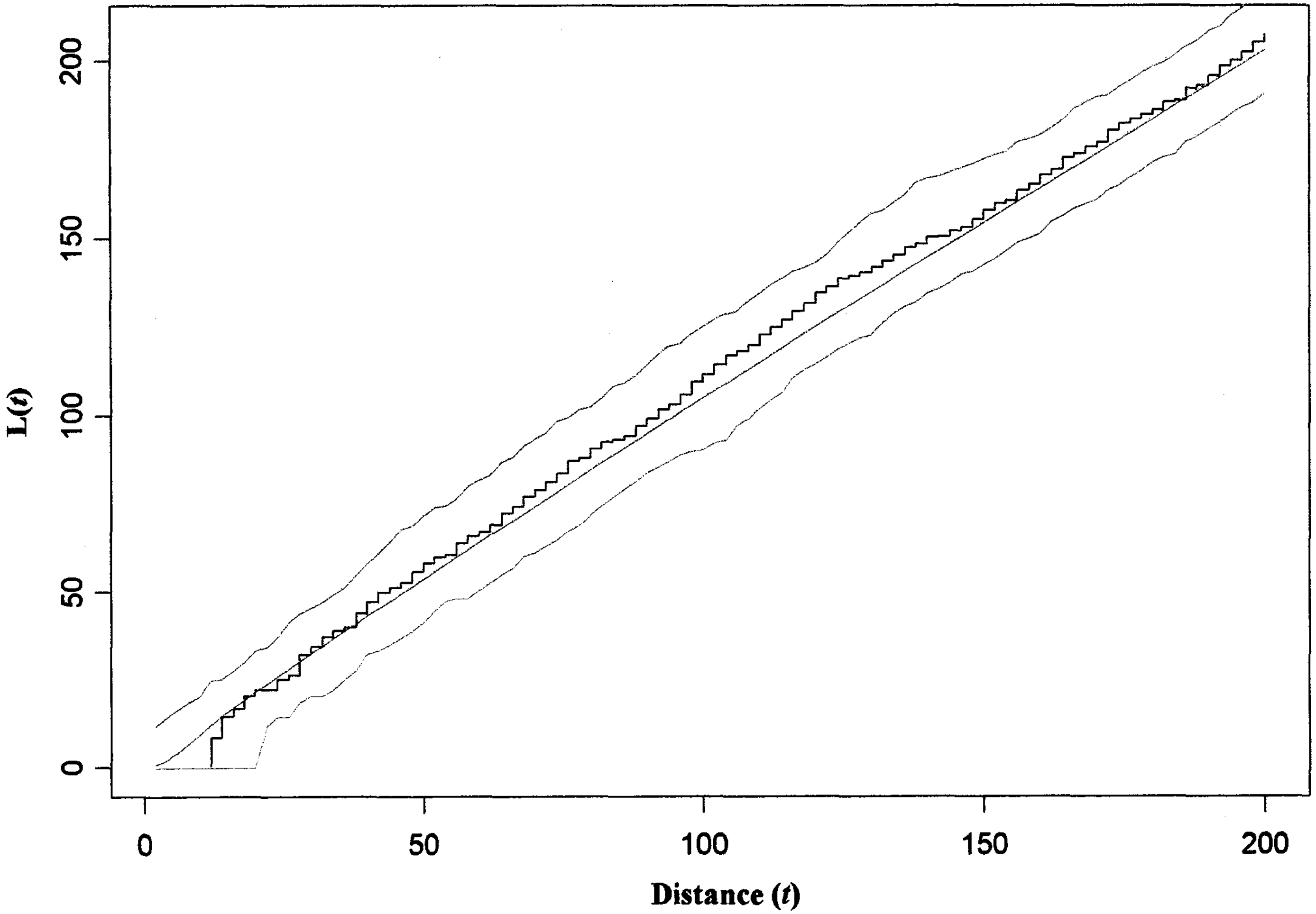


Figure 27. Nest Site 5. Transformed K- function L(t) for observed nests over distance t. Envelope boundaries and smooth mean are derived from 200 simulations of the point process model. Bounds represent 99.5% confidence envelope for the point process model.

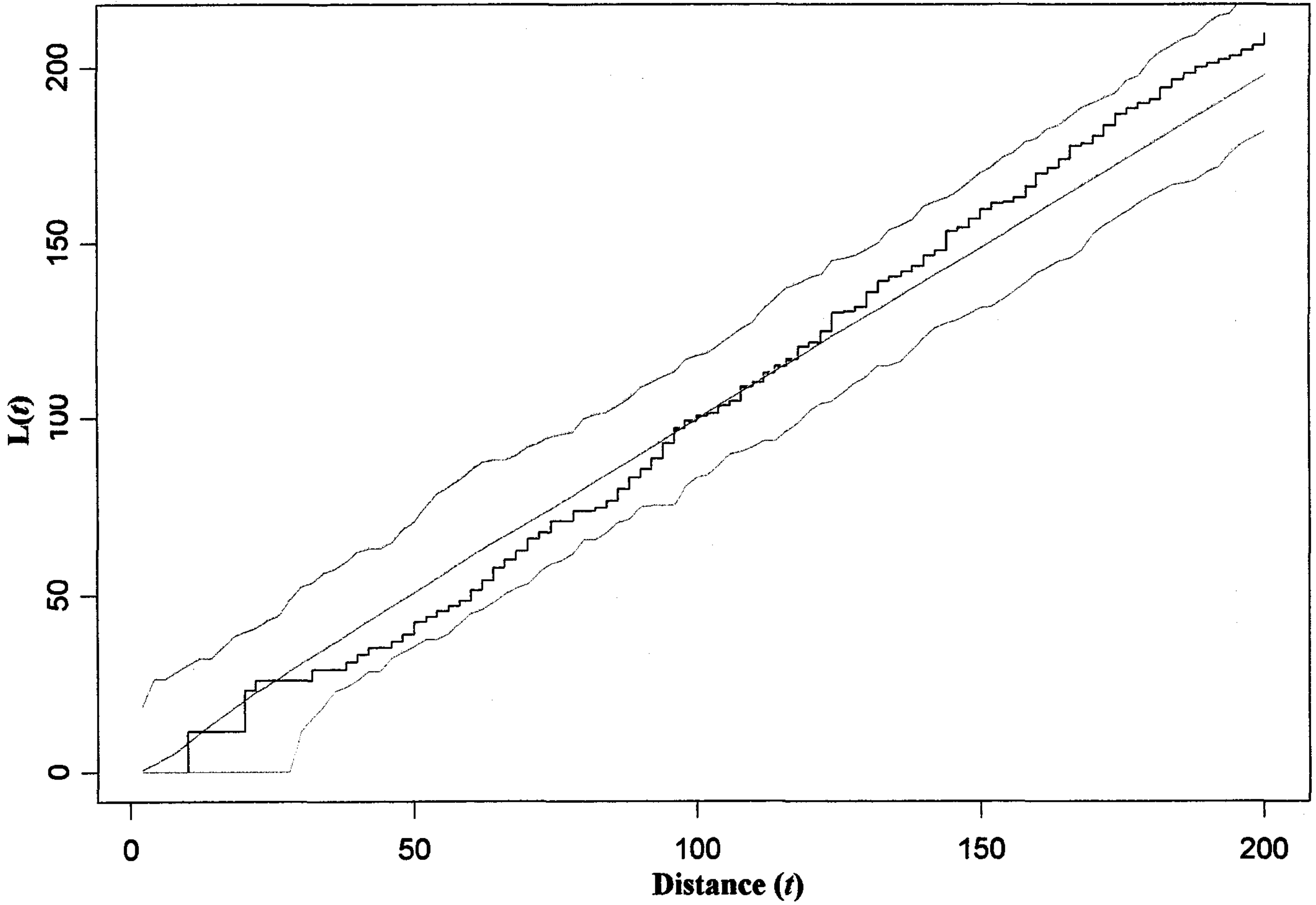


Figure 28. Site 1 Modeled and Observed Nest Locations.

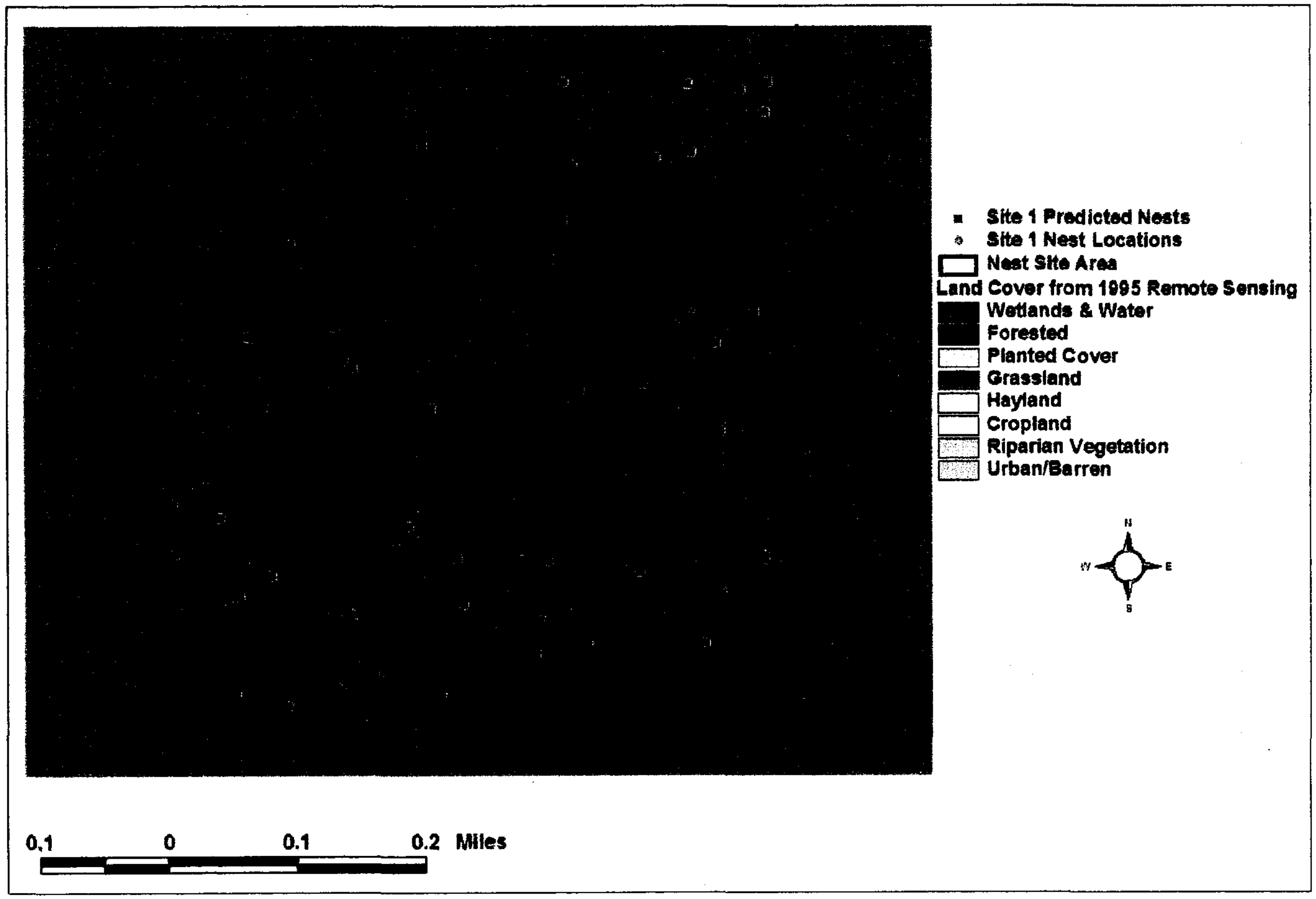


Figure 29. Site 2 Modeled and Observed Nest Locations.

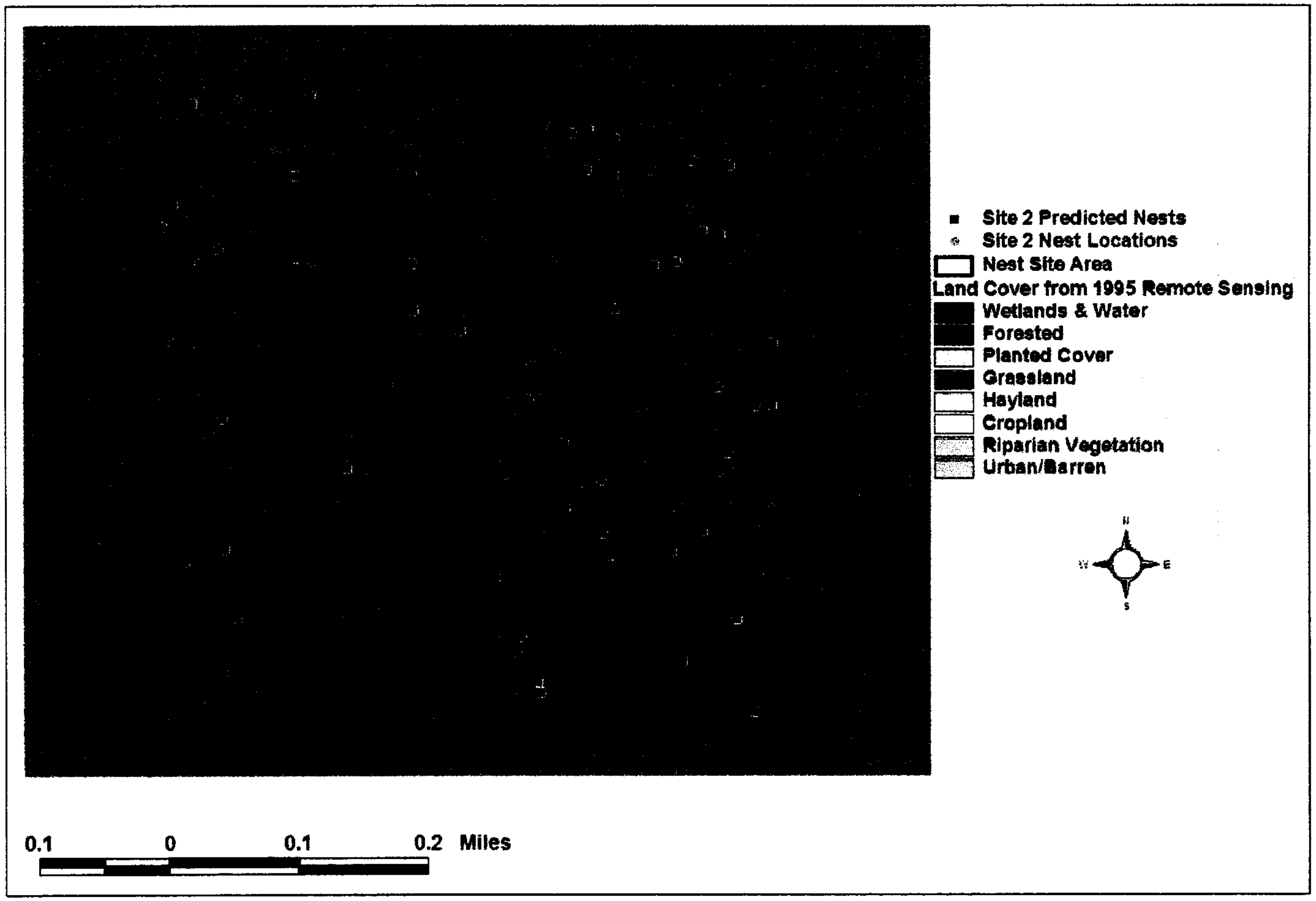


Figure 30. Site 3 Modeled and Observed Nest Locations.

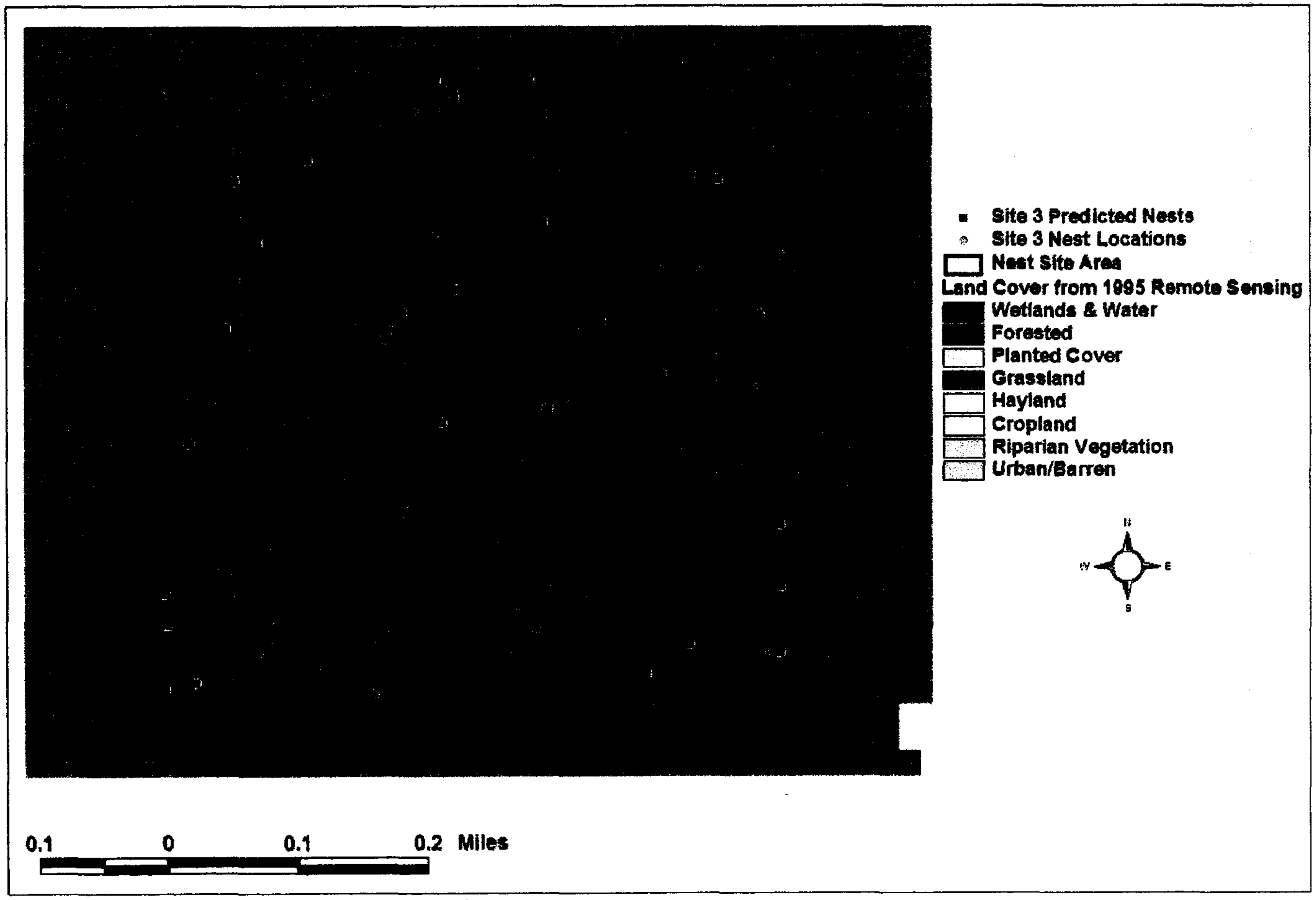


Figure 31. Site 4 Modeled and Observed Nest Locations.

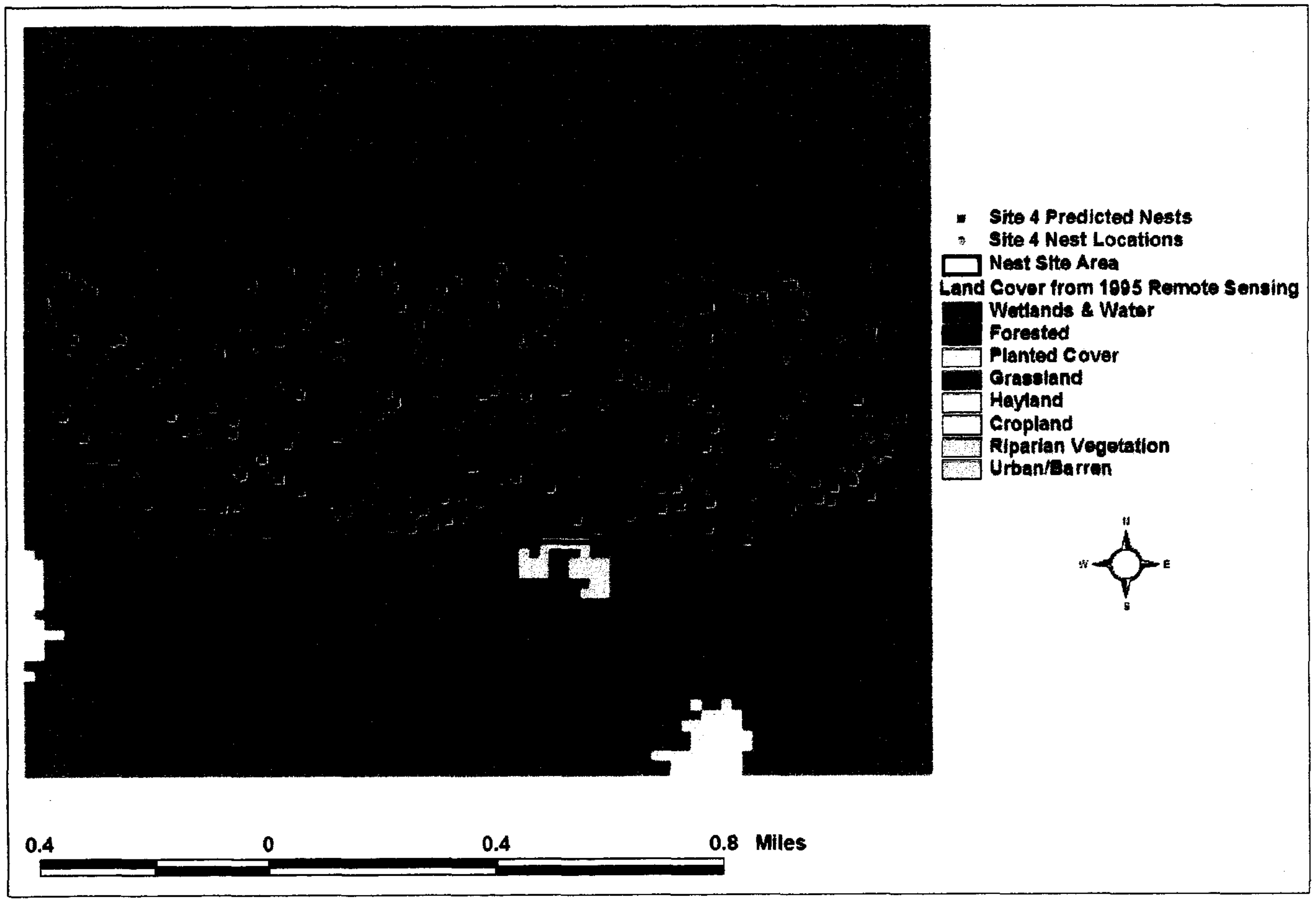
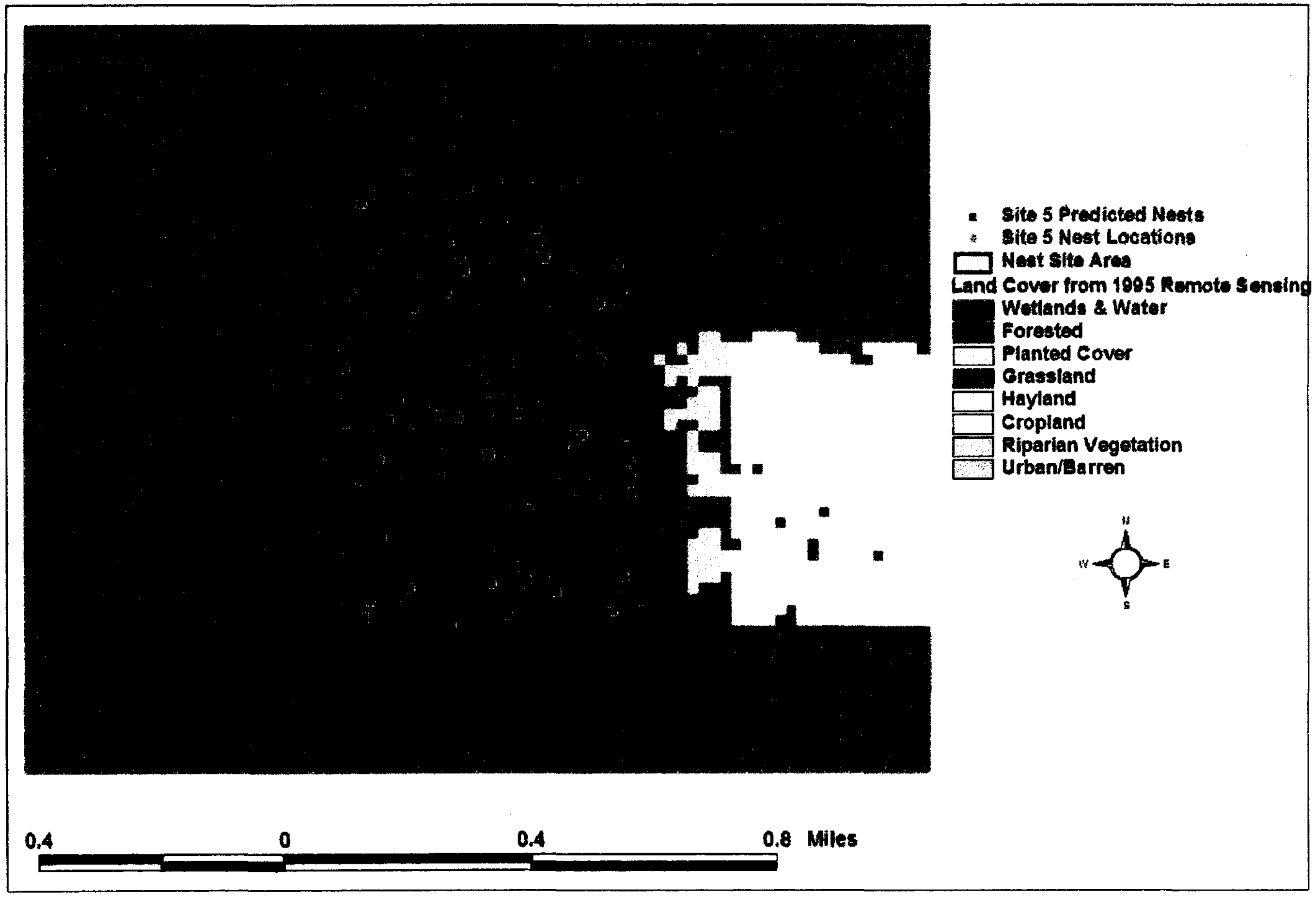


Figure 32. Site 5 Modeled and Observed Nest Locations.



5 DISCUSSION, CONCLUSIONS AND SUMMARY

5.1 Discussion and Conclusions

The results of this study highlight the differences between sites. Site 4 failed to conform to the constraints of a Poisson point process. The other sites were not significantly different from CSR. These sites also show no significant difference from the point process model developed from the site 4 data. Several of the other sites show some divergence from the Poisson process but never enough to reject the null hypothesis of CSR. In order to observe spatial interactions in waterfowl nesting behavior it may be necessary to collect data at higher nest densities or over a larger geographic area. Data collection at higher densities may give insight into greater differentiation between nests within a grassland habitat. Would collecting data over a larger geographic area better represent scale-level associations of the nest site selection process? Evidence from the k-function suggests that deviations from CSR in site 4 are at a scale within the evaluation region for the other sites (clustered at 80 to 140 m). The difference between site 4 and the other sites is then the number of observations at each distance. This conclusion can be validated with further design improvements.

A more interesting result is the weak evidence of negative spatial association for successful and unsuccessful nests on site 2. This weak association is consistent with results from other habitat studies (Clark and Shutler 1999). These associations may be an indication that, where successful habitats are preferred over time, a process of natural selection may be present (Southwood 1977, Clark and Shutler 1999). The weak correlation indicates the need to track nesting activities and demographics over time as well as tracking specific birds. Tracking sites over time would enable analysis of the use of areas as a function of nest success differences. A site with higher success would be expected to be selected more often over time and nest densities on these sites would correspondingly be expected to increase. The temporal increase, either within or between years, would be evidence of a process of natural selection (Klopfer 1963), whereby either within year adaptations or between year adaptations to "good" habitats would be revealed by nest densities and higher nest success.

Marking and tracking individual birds and their re-nesting attempts as well as philopatry is also a mechanism for assessing process in nest site selection (Clark and Shutler 1999). Philopatry would be a measure of consistency of use and a baseline from which to measure new birds identifying the safer habitat. Future studies should also incorporate information on predators that may be the influence of spatial pattern use (Sonerud 1985). Predator foraging patterns and behavior account for the majority of between site nest success variation and search patterns. The predator community may also account for within site variations in nest success (Phillps et al. 2003). There may not be real habitat differences between successful and unsuccessful nests. Instead, differences may be a result of predators being successful in an area and adapting their foraging behavior to concentrate in these past successful areas. Thus predator behavior may account for within site variation and needs to be addressed before inferences are made based on results from this study.

There was evidence of marginally significant negative spatial association between Blue Winged Teal and Gadwall on sites 4 and 5 of the Goebel Ranch. The relationship was evident only on sites dominated by introduced grasses. The sites on the Ordway Prairie that were dominated by warm season native vegetation showed no indication of spatial association between species. The differences in the spatial juxtaposition of habitat between these two ranches may account for the differences (Scott Mcleod, pers. comm., 2003). The habitat at the Goebel Ranch appears segregated in terms of rank cover versus shorter cover and the rank cover at the Ordway Prairie is more interspersed with the other vegetation. Nest records and conversations with biological crew leaders suggest that Gadwall showed a preference for the rank cover and Blue Winged Teal tend to choose somewhat shorter vegetation. The indication from the MRPP statistic are likely valid and can be explained as a combination of habitat selection bias and the difference in distribution of those habitat elements between the two ranch landscapes. This assumption can be tested with additional demographic and field data collection.

Nest demographic studies primarily focus on collection of data in grassland habitats (James Ringelman, pers. comm., 2000). This exclusion limits the ability of this research to make inferences over large geographic landforms such as the Missouri Coteau. To make broader geographic inferences it must be assumed that the data collected represents enough of the nesting population in a landscape. The accepted assumption among waterfowl experts is that nest densities in other habitat types are low enough that neglecting them has little or no effect on predicted results across these larger areas. Cowardin et al. (1985) showed the relative preference for nesting mallards as: Grassland 40.1%, Wetland 16.2%, Hayland 12.0% and all other areas 31.7% of which 2.2% is cropland, which was 90% of the remaining area. If however, wetland type and number dictates waterfowl densities (Cowardin 1985) and upland habitat is for nesting and not part of home range selection, then the densities of nesting waterfowl in grassland habitats surrounded by crop should be higher than that of a "sea of grass" with an equivalent wetland community. This should be addressed in the sampling design of future research or the analysis of existing nesting data from other studies.

Most of the nest site selection literature has focused on choosing a habitat type or on the influence of landscape metrics in relation to the nest or the surrounding landscape (Blakesley et al. 1992; Peake and Ritchison, 1998; Clark and Shutler, 1999; Orth and Kennedy 2001). The context of these models between habitats or between site variations, can be used to build a framework for the type and amount of habitat required to provide for a particular species of waterfowl (Howerter 2003). The modeling of within site variation has application to the habitat itself. The results of this study, though not yet conclusive, and the spatial modeling techniques used in it are intended to assist land stewards with managing the habitat for waterfowl production.

These models are well suited for prediction and simulation at a landscape scale. Previously mentioned assumptions regarding habitat use relative to availability for nesting by waterfowl will need to be addressed before the application of the model with confidence. The models developed as a part of this research are compatible with the work of researchers on the Canadian Prairie Habitat Joint Venture Assessment Sites (PHJV). The Canadian research is focused on vital rates as a function of patch and nest metrics. The models of waterfowl vital rates being developed by these researchers are well suited for simulations, and these models will require a nest site selection sub-model. When the models are refined and combined, the strength of the combined models will be in their ability to estimate productivity under changing habitat conditions. The "what if" scenarios will be useful because they will provide a new level of information to waterfowl managers and planners.

5.2 Summary

This study is a step toward understanding patch level behavior of waterfowl. The model has shown some promise, but changes in the study are required. Density and scale of the point patterns have not been adequately addressed. The analysis of subsequent year's data on higher density sites may address some of the sample size issues.

The spatial patterns of waterfowl nest locations are captured using the theoretical approaches of using presence data and minimum thresholds. A spatial statistical point process model was developed using these techniques and remotely sensed data. The analyses reported in this study are from data collected in the 2001 field season. These analyses were validated using concurrent years data for nest locations. Ducks Unlimited, Inc. has continued to collect nest location and demographic information on the subject properties.

Temporal variation needs to be addressed and additional sites for broader spatial application need to be included in future research. Whether these results are a "snapshot in time", or whether inferences made here can be applied to subsequent years, will be addressed in future research. As additional data become available, the spatial statistical modeling techniques applied in this dissertation will be used to extend the model and, hopefully, account for both spatial and temporal variation. DU waterfowl management strategies will continue to adapt based on the information provided in this and other waterfowl studies.

The findings from this and other supporting research will help guide the waterfowl conservation communities strategic planning and tactical delivery process. The breeding grounds are the most critical area on the continent from a population dynamics perspective (Belrose 1980). Adaptive management based on sound science for program evaluation is paramount to the continued success of waterfowl resource managers. This and other research are focused on addressing the key uncertainties that currently limit our ability to quantify our habitat goals. Without quantifiable program evaluation and feedback, waterfowl managers will be constrained by anecdotal and subjective planning. Applications based on spatial statistical research are a necessary step forward to begin to quantify waterfowl responses to habitat management and optimizing DU and other conservation investments in the Prairie Pothole landscape.

6 LITERATURE CITED

Akaike, H. 1977. On entropy maximization principle. In Applications of Statistics, P. R. Krishnarah (ed.), 27-41. Amsterdam, North-Holland.

Aspinall, R. and N. Veitch. 1993. Habitat mapping from satellite imagery and wildlife survey data using Bayesian modeling procedure in a GIS. Photogrametric Engineering and Remote Sensing, 59:537-543.

Austin, Jane E., Thomas K. Buhl, Glenn R. Guntenspergen, Wayne Norling, and H. Thomas Sklebar. 2001. Duck populations as indicators of landscape condition in the prairie pothole region. Environmental Monitoring and Assessment 69:29-47.

Bellrose, F.C., Jr. 1980. The ducks, geese and swans of North America. Stackpole, Harrisburg, Pennsylvania.

Berry, K.J., and P.W. Mielke. 1983. Computation of finite population parameters and approximate probability values for multi-response permutation procedures (MRPP). Communications in Statistics-Simulation and Computation, 12:83-107.

Blakesley, J.A., a. Franklin, R. Gutierrez. 1992. Spotted owl roost and nest site selection in northwestern California. Journal of Wildlife Management. 56:388-392.

Clark, R.G., and D. Shutler. 1999. Avian habitat selection: Pattern from process in nest-site use by ducks. Ecology, 80:272-287

Cowardin, L. M., D. S. Glimmer, C.W. Shaiffer. 1985. Mallard recruitment in the agricultural environment of North Dakota. Wildl. Monogr. 92. 37pp.

Cox, R., R. Reynolds, C. Loesch and T. Shaffer. 2001. Waterfowl accessibility maps for the Prairie Pothole Region. Unpublished.

Dahl, T.E., 2000, Status and trends of wetlands in the conterminous United States 1986 to 1997. Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service.

Devries, J.H. 1998. Haying, grazing, and burning effects on waterfowl nest cover and waterfowl nesting. Ducks Unlimited Canada. Unpublished Report.

Diggle, P. J. 1979. On parametric estimation and goodness-of-fit testing for spatial point patterns. Biometrics. 35:87-101.

Duebbert, H. F. and H. A. Kantrud. 1974. Upland duck nesting related to land use and predator reduction. J. Wildl. Manage. 38: 257-265.

Dunnings, J. B.; D. J. Stewart; B. J. Danielson; B. R. Noon; R. Root; R. H. Lamgertson; and E. E. Stevens. 1995. Spatially explicit population models: Current forms and future uses. Ecological Applications, 5:3-11.

Environmental Systems Research Institute (ESRI). 2001. ArcGIS Software. Redlands. CA.

Erdas Corporation. 2001. Imagine Software. Atlanta, GA.

Getis, A., and J. Franklin. 1987. Second-order neighborhood analysis of mapped point patterns. Ecology 68:473-477.

Greenwood, R.J., A.B. Sargeant, D.H. Johnson, L.M. Cowardin, and T.L. Shaffer. 1995. Factors associated with duck nest success in the Prairie Pothole Region of Canada. Wildlife Monographs no. 128.

Herr, A. M. and L. D. Queen. 1993. Crane habitat evaluation using GIS and remote sensing. Photogrammetric Engineering and Remote Sensing. 59:1531-1538.

Higgins, K.F., L.M. Kirsch, and I.J. Ball, Jr. 1969. A cable-chain device for locating duck nests. Journal of Wildlife Management 33:1009-1011.

Higgins, K.F. 1977. Duck nesting in intensively farmed areas of North Dakota. Journal of Wildlife Management. 41:232-242.

Higgins, K.F., D.E. Naugle, and K.J. Forman. Feb. 22-25, 2001. Recent changes in Northern Great Plains farming practices and demographics: new threats to wetlands and grasslands. 6th Prairie Conservation and Endangered Species Conference, Winnipeg, Manitoba, Canada.

Howerter, D.W. 2003. Factors affecting duck nesting in the aspen parklands: a spatial analysis. Ph.D. Dissertation. Montana State University. Bozeman, MT. 135 pp.

Ingegritsen, S.E. and R.J.P. Lyon. 1985. Principal components analysis of multitemporal image pairs. International Journal of Remote Sensing 6(5):687-696.

Insightful Corporation. 2001. S-PLUS Statistical Software. Seattle. WA.

Isaaks, E. H. and R. M. Srivastava. 1989. An introduction to applied geostatistics. Oxford University Press, New York.

Jensen, J.R. 1996. Image enhancement. Ch. 7 (or Pp. 139-195) In: Introductory Digital Image Processing. Prentice Hall Series In Geographic Information Science, K.C. Clarke (series ed). Prentice Hall, Upper Saddle River, New Jersey.

Johnson, D.H., D.W. Sparling, and L.M. Cowardin, 1987. A model of the productivity of the mallard duck. Ecol. Model., 38:257-275.

Johnson, D.H., J.D. Nichols, and M.D. Schwartz. 1992. Population dynamics of breeding waterfowl. Pages 446-485 *in* B.D.J. Batt, A.D. Afton, M.G. Anderson, C.D. Ankney, D.H. Johnson, J.A. Kadlec, and G.L. Krapu, editors. Ecology and Management of Breeding Waterfowl, University of Minnesota Press, Minneapolis.

Johnson, R.R., K.F. Higgins, M.L. Kjellsen, and C.R. Elliott. 1997. Eastern South Dakota wetlands. Brookings: South Dakota State University. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/1998/eastwet/eastwet.htm (Version 02JUL98).

Kaminski, R. M. and M. W. Weller. 1992. Breeding habits of nearctic waterfowl. Batt, B. D. J. et al. Editors. Ecology and management of breeding waterfowl, University of Minnesota, MN. p. 568-589

Kirsch, L. M., H. F. Duebbert, and A. D. Kruse. 1978. Grazing and haying effects on habitats of upland nesting birds. Trans. North Am. Wildl. Nat. Resour. Conf. 43:486-497.

Klett, A.T., H.F. Duebbert, C.A. Fannes, and K.F. Higgins. 1986. Techniques for studying nest success of ducks in upland habitats in the Prairie Pothole Region. U.S. Fish and Wildlife Service Resource Publication 158.

Klopfer, P.H. 1963. Behavioral aspects of habitat selection: the role of early experience. Wilson Bulletin 75:15-22.

Krapu and Rieneke 1992 Foraging Ecology and Nutrition. Pages 1-29 *in* B.D.J. Batt, A.D. Afton, M.G. Anderson, C.D. Ankney, D.H. Johnson, J.A. Kadlec, and G.L.

Krapu, editors. Ecology and Management of Breeding Waterfowl, University of Minnesota Press, Minneapolis.

Mardia, K.V., J.T. Kent and J.M. Bibby, 1979, Multivariate Analysis. New York: Academic Press. 407 p.

Maxwell, S.K., R.M. Hoffer, and C.D. Bonham. 1997. Principle Components Analysis Applied to Multitemporal Landsat Imagery. 1997 ACSM/ASPRS Annual Convention and Exposition Technical Papers, Volume 3 Remote Sensing and Photogrammetry, pp 28 – 39.

Mielke, P.W. (1986). Non-metric statistical analyses: Some metric alternatives. Journal of Statistical Planning and Inference. 13:377-387.

Mielke, P.W. (1991). The application of multivariate permutation methods based on distance functions in the earth sciences. Earth-Science Reviews. 31:55-71.

Miller, M.R., and T.D. Nudds. 1996. Prairie landscape change and flooding in the Mississippi River Valley. Conservation Biology 10:847-853.

Miller, M.R., and D.C. Duncan. 1999. The northern pintail in North America: Status and conservation needs of a struggling population. Wildlife Society Bulletin 27:788-800.

Miller, M.R., D.C. Duncan, K. Guyn, P. Flint and J. Austin. 2001. The Northern Pintail in North America: The Problem and a Prescription for Recovery. Proceedings of the Northern Pintail Workshop, 23-25 March 2001. Sacramento, CA.

Neter, J., W. Wasserman, and M.H. Kutner. 1985. Applied Linear Statistical Models. Irwin. Homewood, IL.

Nelson, Jeffery W., 2000. Director of Operation Ducks Unlimited Great Plains Regional Office. personal communications.

Ord, J. K. 1990. Statistical methods for point pattern data. P. A. Griffith (editor). Spatial Statistics: Past, Present, and Future. Institute of Mathematical Geography, Syracuse University, New York. p.31-53.

Ormsby, J. P. and R. S. Lunetta. 1987. Whitetail deer food availability maps from thematic mapper data. Photogrammetric Engineering and Remote Sensing. 39:1081-1083.

Orth, P.B. and P. Kennedy. 2001. Do land-use patterns influence nest-site selection by burrowing owl (*Athene cunicularia hypugaea*) in northeastern Colorado? Canadian Journal of Zoology. 79:1038-1045.

Peak, D.R. and G. Richardson. 1998. Nest site selection and nest success in White-eyed Vireos. Kentucky Warbler 74:64-67.

Pereira, J. M. and R. M. Itama. 1991. GIS-based habitat modeling using logistic multiple regression: A study of the Mt. Graham red squirrel. American Society of Photogrammetry and Remote Sensing. 57:1475-1486.

Pielou, E.C., 1977. Mathematical Ecology. John Wiley & Sons, Inc. New York.

Phillips, M.L., W.R. Clark, M.A. Sovada, D.J. Horn, R.R. Koford, and R.J. Greenwood. 2003. Predator selection of prairie landscape features and its relation to duck nest success. Journal of Wildlife Management 67:104-114.

Phillips, M.L. 2001. Landscape ecology of mammalian predators and its relationship to waterfowl nest success in the Prairie Pothole Region of North Dakota. Dissertation. Iowa State University, Ames, IA.

Reich, R.M., P.W. Mielke, Jr., and F.G. Hawksworth. 1990. Application of permutation techniques in analyzing spatial patterns. In: State-of-the-art methodology of forest inventory: A symposia proceedings; 1989 July 30-August 5; Syracuse, NY: Gen. Tech. Rep. PNW-263. Portland, OR: U.S. Department of Agriculture, Forset Service: 384-389.

Reich, R.M., and R. Davis. 1998. Quantitative Spatial Analysis. Colorado State University. Fort Collins, Colorado.

Reich, R.M., J. Lundquist, and V. Bravo. 2000. Spatial relationship of resident and migratory birds and canopy openings in diseased ponderosa pine forests. Environmental Modelling & Software 15:189-197.

Reich, R.M., 2003. Biometrician. Colorado State University. Personal communications.

Reynolds, R.E., T.L. Shaffer, J.R. Saur, and B.G. Peterjohn. 1994. Conservation reserve program: Benefits for grassland birds in the northern plains. Transactions of the North American Wildlife and Natural Resources Conference 59:328-336.

Reynolds, R.E., and D.R. Cohan. 1996. Using landscape information approaches to increase duck recruitment in the prairie pothole region. Transactions of the North American Wildlife and Natural Resources Conference 61:86-93.

Reynolds, R.E., and C. Loesch. 1996. Waterfowl accessibility and attractiveness maps for North and South Dakota. Unpublished.

Ringelman, J.K., 1996. The life cycle of waterfowl. Presentation. Institute for Wetlands and Waterfowl Research Symposia. Oak Hammock Marsh, Canada.

Ringelman, J.K., 2000. Factors affecting waterfowl populations and breeding ground mortality. Presentation. Institute for Wetlands and Waterfowl Research Symposia. Oak Hammock Marsh, Canada.

Ripley, B.D. 1976. The second-order analysis of stationary point processes. Journal of Applied Probability. 13:255-266

Robel, R.J., J.N. Briggs, A.D. Dayton, and L.C. Hulbert. 1970. Relationships between visual obstruction measurements and weights of grassland vegetation. Journal of Range Management 23:295-298.

Seargent, A.B., and D.G.Raveling. 1992. Mortality During the Breeding Season. Pages 396-422 *in* B.D.J. Batt, A.D. Afton, M.G. Anderson, C.D. Ankney, D.H. Johnson, J.A. Kadlec, and G.L. Krapu, editors. Ecology and Management of Breeding Waterfowl, University of Minnesota Press, Minneapolis.

Sargeant, A.B., Greenwood, R.G., Sovada, M.A. and Shaffer, T.L., 1993. Distribution and abundance of predators that affect duck production -- prairie pothole region. Resour. Publ. 194, US Fish and Wildlife Service, Washington, DC, 96 pp.

Sonerud, G.A. 1985. Nest hole shift in Tengmalm's owl *Aegolius funereus* as defense against nest predation involving long term memory of the predator. Journal of Animal Ecology 54:179-192.

South Dakota Agricultural Statistics Service (SDASS), 1999, South Dakota Agricultural Statistics, Sioux Falls, SD

Southwood, T.R.E. 1977. Habitat,the templet for ecological strategies? Journal of Animal Ecology 46:337-366.

Stephens, S. A. 2003. The Influence of Landscape Characteristics on Duck Nesting Success in the Missouri Coteau Region of North Dakota. Draft of Dissertation. Unpublished.

Thomas, I.L., V.M. Benning, and N.P. Ching. 1987. Introduction to image enhancement and analysis. Ch. 6 (or pgs. 29-55) In: Classification of Remotely Sensed Images. Adam Hilger, Bristol, England.

USFWS. 2001. Waterfowl population status, 2001. United States Fish and Wildlife Service, Office of Migratory Bird Management, Laurel, Maryland.

Venebles, W.N., and B.D. Ripley. 1997. Modern Applied Statistics with S-PLUS. Springer-Verlag, New York.

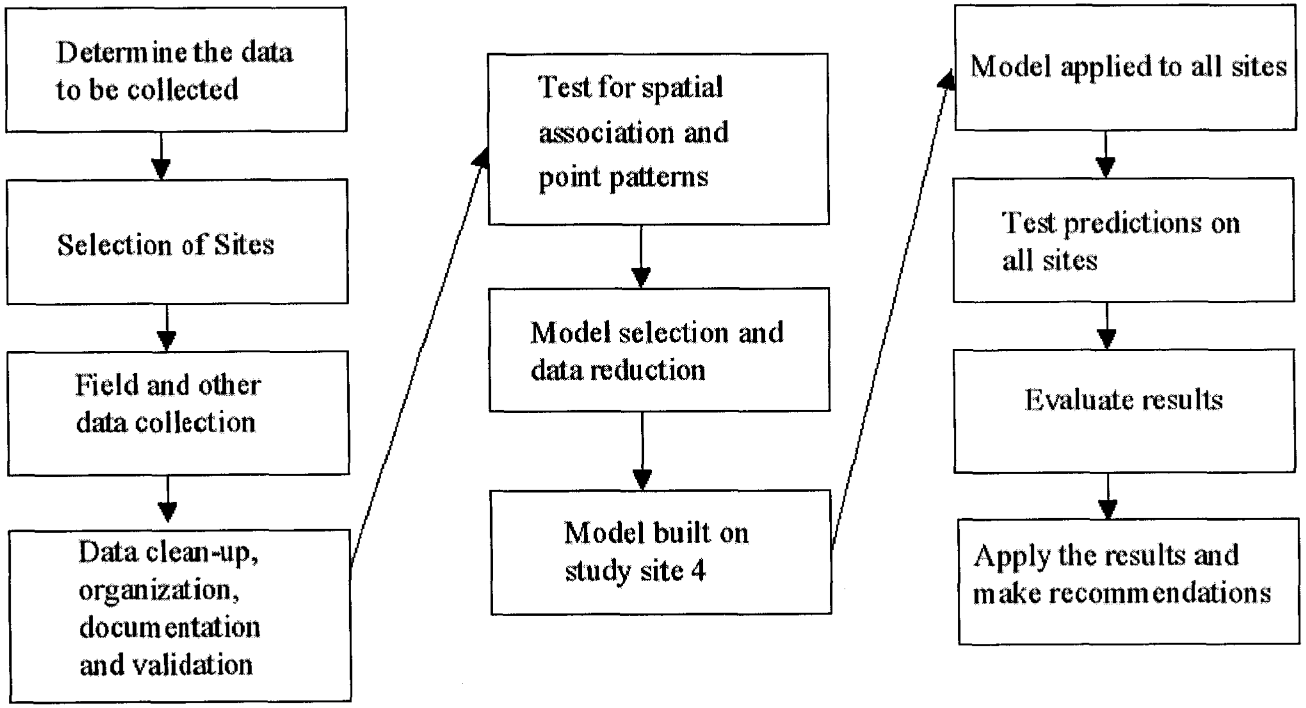
Walters, CJ, and R Hilborn. 1978. Ecological optimization and adaptive management. Annual Review of Ecology and Systematics 9:157-88.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71:2060-2068.

Weller, M.W. 1956. A simple field candeler for waterfowl eggs. Journal of Wildlife Management 20:111-113.

APPENDIX A

Table 8. Flowchart of the research process



APPENDIX B

Table 9. List of common and scientific names of species cited.

	Common Name	Scientific Name
Plant	Kentucky bluegrass	*Poa pratensis* L.
	Smooth brome	*Bromopsis inermis* (Leyss)
	Canada thistle	*Circium arvense* (L.) Scop.
Animal	Blue-winged teal	*Anas discors*
	Gadwall	*Anas strepera*
	Mallard	*Anas platyrhynchos*
	Eurasian Curlew	*Numenius arquata*
	Red Squirrel	*Tamiasciurus hudsonicus*