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thesis entitled

GIS APPROACH TO EVALUATE A HABITAT SUITABILITY
INDEX (HSI) MODEL (BREEDING SEASON) FOR BALD
EAGLES AROUND TIPPY DAM POND, MANISTEE RIVER, MICHIGAN

presented by

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has been accepted towards fulfillment
of the requirements for

M.A. degree in Geography

David P. Lusch
Major professor

Date May 8, 1996

GIS approach to evaluate a Habitat Suitability Index (HSI) model (Breeding Season) for Bald Eagles around Tippy Dam Pond, Manistee River, Michigan

By

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A THESIS

Submitted to

Michigan State University

In partial fulfillment of the requirements

for the degree of

MASTER OF ARTS

Department of Geography

1996

ABSTRACT

GIS APPROACH TO EVALUATE A HABITAT SUITABILITY INDEX (HSI) MODEL (BREEDING SEASON) FOR BALD EAGLES AROUND TIPPY DAM POND, MANISTEE RIVER, MICHIGAN

By

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This study presents the application of geographic information systems (GIS) to habitat suitability index (HSI) modeling to assess whether the model can predict bald eagle reproduction success for the eleven bald eagle nest sites around the Tippy Dam Pond in Manistee county Michigan. This study applies the original and a modified version of the habitat suitability index (HSI) model to quarter- and half-mile buffer zones around the nest sites. Results from the analyses indicate that the original HSI model does not relate well to eaglet production. Two additional variables (Road Length Index, and White Pine Index) are included in the modified model.

It is concluded that fixed-diameter buffer zone for all factors are problematic. The foraging distance limit given in the literature was inappropriate at this site. A critically important variable, water-based human activities, needs to be included in the HSI model. The disturbance of breeding bald eagles by water-based recreation activities appears to be the most important unknown variable related to the spatial variance of eagle reproduction. Both the original and the modified HSI model fail to fully explain the spatial variance of eagle reproduction. Recommendations for future model enhancements are discussed.

To my parents who give me energy and wisdom.

ACKNOWLEDGEMENTS

The creation of any academic work is not a solitary effort, even though there are times when it feels that way. There are many people who contributed to this work in direct and indirect ways and to whom I am extremely grateful. First and foremost is Dr. David Lusch, the chair of my committee, who spent a tremendous amount of his time in helping, guiding, and teaching me research with critical reviews of my work. It is obvious why so many seek Dr. Lusch for intellectual support and scientific insight. I am deeply indebted to him for all he has done for me. I would like to thank the other members of my graduate committee: Dr. Charles Nelson who gave me insight about the recreational aspects of my research, and Dr. Edward Whitesell who contributed ecology concepts to this work.

This work would not have be possible without the research facility provided by the Entomology Spatial Analysis Lab (ESAL). Dr. Stuart Gage who created the Lab provided me an incredible opportunity to work with and learn from him. Dr. Gage provided a home for my research. He gave me unlimited use of his lab, even after I was no longer employed with him. I can not thank him enough for his generosity. Thanks must also go to Amos Ziegler (also part of ESAL) for his putting up with my continual technical questions when the computer system or ARC/INFO did not make sense.

Prior to my starting on this project there were people who set me on the path to discovery that at the time, seemed unrelated. Dr. Mike Vasievich of the U.S. Forest Service (USFS), and Dr. Daniel Stynes from the Department of Park and Recreation (MSU) gave me my first hands on experience into scientific research. Jeff Niese, who also worked at the USFS, introduced me to this project.
I met Dr. Richard Stiehl of the National Biological Service (NBS) while I attended his seminar on Habitat Suitability Index modeling in Colorado. After the seminar Dr. Stiehl kindly provided advice, over several phone calls, that later followed during the course of my work.

Thanks to Dennis Hudson who provided guidance in interpreting air photos, a skill that later became very valuable in the creation of spatial data for my thesis. Additional thanks to Marcia Larsen, and Donna Paananen at USFS, and Michael Lipsey at Geography Department (MSU) for their kindness and support. Much thank to Sharon Ruggles for all her help.

During my thesis work Mr. Rex Ennis, Mr. Chris Schumacher (Manistee National Forest, Cadillac), Mr. Kevin Stubbs, Mr. Dave Best (U.S. Fish and Wildlife Service), Mr. Michael Beaulac, Mr. Tom Wiesie, Mr. Shermam Hollander (Department of Natural Resources), Mr. Gary Dawson (Consumers Power Company), and Mr. Bill Bowerman, all helped me acquire the much needed existing data for this study.

Special thanks must go to Dr. Karen Klomparens, and the Graduate School for their help and personal support. I would not have made it through graduate school without them. Their help is deeply appreciated. Additional thanks to Dr. Julie Winkler who gave me the encouragement to start my thesis. Thanks too must go to Dr. David Horner and Dr. Joe Cousin of the International Center for moral support that was given long before this thesis started.

A lasting appreciation goes to Michigan State University which offered me a great place to learn about school, work, people and myself. The environment at this university gave me experiences, both good and bad, and opportunities that I am very grateful for.

Thanks to Bob and Carol-Lee Jones, my father and mother in law, who gave me much encouragement and advice. Most importantly, I like to thank my husband Clint Jones who gave me personal and emotional support and dedicated his time to me.

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CHAPTER 1

INTRODUCTION

1.1 Overview

This study is associated with the Tippy Dam hydroelectric project, which is owned and operated by Consumers Powers Company (CPCo), under license from the Federal Energy Regulatory Commission (FERC). The Tippy Dam Pond, which is about 1,330 acres (538 ha) in size, is situated on the lower Manistee river and is surrounded by the Manistee National, Forest in Michigan. The natural setting of the forested land and the dam pond attracts many fish, riparian, and other wildlife species. Bald eagles (*Haliaeetus leucocephalus*), a state-and federally-listed threatened species, roost, perch, and breed in the areas around this impoundment.

The hydroelectric impoundment produces an aesthetic resource that has drawn people to the surrounding river and forest areas for recreation. Today, many recreational sites and supporting infrastructure have been developed including parks, campgrounds, boat docks, vacation homes, and businesses. Seasonal home owners, commuters, and tourists contribute to the economy of the areas.

Because recreation is a major industry in this locale, there is an increasing demand for developed recreational sites. There are many recreation sites being proposed for this river/pond system; some of these may adversely affect the area's threatened bald eagle population. Bowerman and Giesey (1991) suggested that with any proposed recreational development on the river, the impact on the existing and potential bald eagle breeding areas should be analyzed.

The hydroelectric project license requires CPCo, in cooperation with state and federal resource agencies, to protect, maintain and enhance bald eagle habitats associated with the project. The federal agencies responsible for managing these areas must comply with federal environmental protection legislation by trying to estimate potential impacts of development on the threatened bald eagles. These agencies must also define the critical environmental factors which determine habitat suitability and identify areas where suitable characteristics may favor both the population maintenance and growth.

The bald eagles and their habitat in the vicinity of Tippy Dam Pond were selected for this study for three majors reasons. First, bald eagles are a threatened species in Michigan which is losing their habitat due to human activities, land development and urban sprawl. Second, bald eagles around the Great Lakes have shown a great disparity in reproductive success due to the effect of chemicals such as DDT in their food web (Bowerman, 1993). Even though the pesticide DDT was banned more than 25 years ago, these chemicals still effect bald eagle populations around the Great Lakes area today. More details about the effects of chemicals on bald eagle populations can be found in the studies of Wiemeyer et al. (1984), Gilbertson and Schnider (1991), and Bowerman (1993). The only hope to continue bald eagle populations in Michigan is to "maintain greater productivity in interior areas to compensate for lesser fecundity and greater adult mortality along the shorelines of the Great Lakes" (Bowerman, 1993). Lastly, despite a few bald eagles studies that have been done in Michigan, none of these studies have quantified the bald eagle habitat values nor analyzed the spatial relationship of bald eagles and human habitats using geographic information systems (GIS) technology. This study will introduce this concept of habitat modeling with the assistance of GIS technology to model bald eagle habitat in this part of Michigan.

1.2 Background

Bald eagle breeding areas in Michigan have been categorized into three groups: Great Lakes, Interior, and Anadromous. The Great Lakes breeding areas cover areas within 8 km of Great Lakes shoreline. The Interior breeding areas are further than 8.0 km from the Great Lakes shoreline. The Anadromous breeding areas are those Inland breeding areas that are accessible to runs of

Anadromous Great Lakes fish (Bowerman, 1993). The nesting bald eagles of this study around the Tippy dam Pond are in the Interior breeding area group.

From 1975 to 1995, there were eleven nest sites that were occupied by three breeding pairs of bald eagles around the Tippy Dam Pond. Each breeding pair had their own territory: Wellston, Red Bridge South, and Red Bridge North. Each territory consisted of a number of nest sites. Some eagles nested on the same tree for many years, but others moved around or alternated the use of several nest sites.

During the mid-1970s, a breeding pair of eagles moved into the Red Bridge South territory. This couple occupied the area for twenty-one years and produced twenty young. Within the twenty-one year period, this pair of eagles moved around five different nest sites.

The Wellston pair moved into the Tippy Dam Pond area in the late 1980s. They occupied their territory for eight years and produced eleven young while moving between four nest sites.

The Red Bridge North breeding pair moved into this region in the early 1990s. This pair produced three young in a four year period occupying two nest sites.

To determine the quality of bald eagle productivity, the average young per occupied nest is considered. The productivity is considered impaired when the average young per nest is less than 1.0. To maintain the population stability, an average of 0.7 young per nest is necessary (Bowerman, 1993). The average production of the Tippy Dam Pond eagle territories were high to moderate: 1.4 young per year in Wellston; 0.95 young per year in Red Bridge South; and 0.75 young per year in the Red Bridge North territory. The quality of bald eagle productivity around the Tippy Dam breeding area is still in good condition.

Bald eagles in the landscape around the Tippy Dam Pond produced a promising average of one young per year. The environmental variables that allow the species to have good reproductive success in this area need to be assessed and monitored in order to maintain the future population of the birds. The environmental factors that shape the suitability of the habitat for the bald eagle have not been fully mapped out and quantified. A study by Bowerman (1991) evaluated the quantity of bald eagle habitat by visually noting the abundance of supracanopy White Pines from a light aircraft survey. He also incorporated aerial photos analysis of the number of supracanopy White Pines and human disturbance features such as dwellings and roads.

Visually interpreting the environmental factors contributing to quality eagle habitat may not provide sufficient information. Each variable needs to be mapped out and calculated in some form to give values of the total contribution from each of the environmental factors in the study area.

Management of bald eagle habitat within the study area is an important component of the Manistee National Forest Land and Resource Management Plan. The managing agencies responsible for this river system desire a method that can be used to quantify the quality of the species habitat with which to judge the effects of existing conditions and proposed development upon bald eagle. To the fullest extent possible, these sites should be managed for both human recreation and eagle habitat.

1.3 Statement of Problem

This study will employ an existing habitat suitability index (HSI) model for breeding bald eagles to quantify the quality of habitat around Tippy Dam Pond. This particular HSI model has not been evaluated in Michigan since its development in 1986.

This study will evaluate the original habitat suitability index (HSI) model for the breeding bald eagle and a modified version. Results from the original and the modified HSI models will be examined to see whether the modified model can explain the habit suitability for the bald eagle more accurately than the original

HSI model. The performance of these models will be assessed in light of the spatial variance of bald eagle reproductive success at the various nest sites. To better reflect the suitability of the habitat for bald eagles, landscape attributes from field observations related to bald eagle nesting habits will be examined together with bald eagle reproductive success and the results of the original and modified HSI models.

The following research question will be investigated:

Does the original Habitat Suitability Index model for the breeding bald eagle adequately explain the spatial variance of nest-specific reproductive success?

Several subsidiary questions emanated from this principle one:

1. What additional factors which contribute to the quality of the habitat for bald eagles can be added to the HSI model to improve its ability to explain nest-specific reproductive success ?
2. What scale of landscape evaluation is most appropriate when assessing nest-specific areas regarding habitat quality for breeding bald eagles ?
3. Is it beneficial to implement the HSI model for breeding bald eagles in a GIS context ?

1.4 Description of the Study Area

The study area is located around the Tippy Dam Pond in the northwestern Lower Peninsula of Michigan (Figure 1.1). The three bald eagle territories can be found on three adjacent USGS 7.5-minute series topographic quadrangles (Marilla, Yuma, and Wellston quadrangles). These territories lie within a bounding rectangle whose corner coordinates (Michigan State Plane, 1927) are:

NW corner (Marilla quadrangle) - 1,607,823 feet, 362,081 feet

NE corner (Yuma quadrangle) - 1,565,319 feet, 362,081 feet

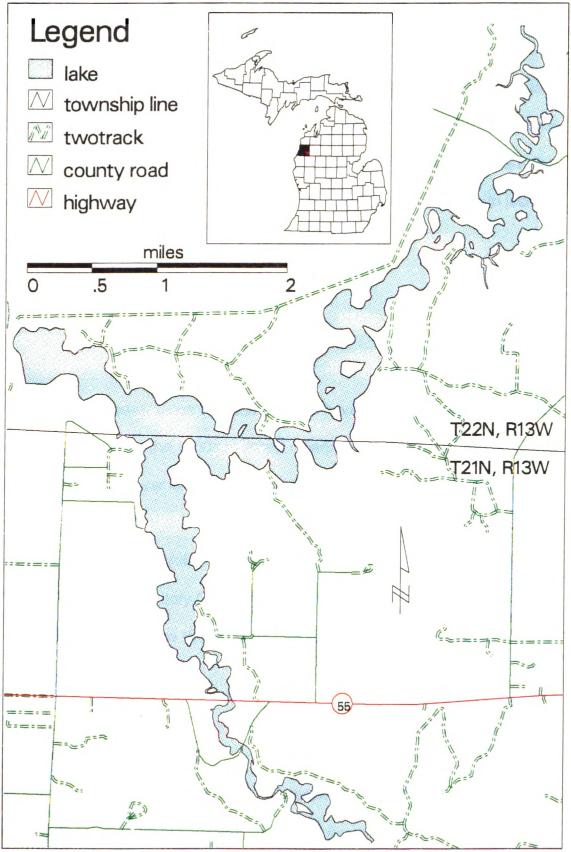
SE corner (Wellston quadrangle) - 1,607,823 feet, 328,658 feet

SW corner (Wellston quadrangle) - 1,565,319 feet, 328,658 feet

1.4.1 Physiography

The Manistee River basin is located in the northwest part of Michigan and drains to Lake Michigan. The glacial history of Michigan formed the topography of this areas. The resulting landforms from the glacial deposits include flat to rolling terrain, with occasional hills ranging from 200 to 400 m in elevation (Federal Energy Regulatory Commission, 1994).

Figure 1.1. Study area.


Legend
lake
township line
twotrack
county road
highway
miles
0
.5
1
2
T22N, R13W
T21N, R13W
55

1.4.2 Soil

Soils of this watershed were developed in a complex set of glacial sediments. These parent materials, coupled with the various landscape positions, produced several soil types. The most common characteristics among these soil are that they are coarse to sandy texture, well- to excessively well-drained, with low fertility (Federal Energy Regulatory Commission, 1994).

1.4.3 Vegetation

The basic forest cover types in the study area have been extensively modified since the later part of the 1800s by forest clearing and residential development. The current forest cover is second or third growth. Several different vegetation types are found: Jack Pine, Red Pine, White Pine, and northern hardwoods including sugar maple, white ash, basswood, hemlock, red maple and red oak (Federal Energy Regulatory Commission, 1994). One of the most important trees to bald eagles is the White Pine because it is used for nesting.

1.4.4 Climate

Michigan is in the mid-latitude portion of North America. The location determines the amount of seasonal contrast of incoming solar radiation, and the type of upper air circulation that effects the weather on a day-to-day basis. The general climate in Michigan is characterized as temperate with four seasons: Winter, Spring, Summer, and Fall. However, the Michigan climate is modified because it is surrounded by the world's largest bodies of fresh water, the Great Lakes. The Great Lakes provide a semi-marine type climate to Michigan, even though this state is located in the mid-continent (Eichenlaub et al., 1990). This climate provides an abundance of moisture to the land around the lakes, but the annual precipitation is moderate compared to other parts of the United States. Precipitation in the study area shows an annual rainfall that averages 30 inches, plus 61 inches of snowfall. Snow ground cover averages 4 months or around 120 days per year (Eichenlaub et al., 1990).

1.4.5 Fish

Fish are the most important food source for the bald eagles. The birds around the Tippy Dam Pond were observed to feed primarily on benthic-feeding fish. Fish species from the Pond that were found in bald eagle nests include Sucker, Bullhead, Bass, Northern pike, Trout, Panfish, Bowfin, an Walleye (Bowerman, 1991).

CHAPTER 2

REVIEW OF LITERATURE

2.1 Habitat Suitability Index (HSI) Models

In the early 1970s, American citizens had become increasingly aware that they were stewards of their natural resources and environment. In response to the concern of the nation about environmental quality and its increasing interest in wildlife and wildlife habitat protection, congress passed several laws that required assessment of environmental conditions and the prediction of future conditions (Jackson, 1982; Schamberger et al., 1982; Thomas, 1982). These statues include the Endangered Species Act of 1973, the National Environmental Policy Act of 1969, the Federal Water Project Recreation Act, and the Forest and Range Land Renewable Resource Planning Act of 1974 as amended by the National Forest Management Act of 1976.

The foundation of this environmental legislation was the National Environmental Policy Act (NEPA) of 1969. NEPA is "the culmination of national concern in the 1960's for natural resource conservation, and public health and welfare legislation" (U.S. Fish and Wildlife Service, 1980). NEPA applies to all programs of all federal agencies and requires these agencies to consider environmental values during assessment activities. According to the U.S. Fish and Wildlife Service (1980), NEPA stated that all federal agencies shall:

> *Utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment,*

and that they shall

> *identify and develop methods and procedures, in consultation with the Council on Environmental Quality..., which will insure that presently unquantified environment amenities and value may be given appropriate consideration in decision making along with economic and technical consideration.*

NEPA created a need for a system of habitat evaluation that allows the assessment of current environmental conditions and the prediction of future conditions under different management options. As part of meeting this need, Habitat Suitability Index (HSI) models were developed.

Numerous HSI models for specific species have been derived from biological and habitat information published in the scientific literature as well as unpublished information of field experts. These HSI models assign index values to habitat quality for selected species evaluation. The index ranges from 0.0 to 1.0; 0.0 representing unsuitable habitat, and 1.0 representing optimum habitat (U.S. Fish and Wildlife Service, 1980). This model construction is based on a logical approach. The five general steps to approach model construction are:

1. Set the model objectives: The model objectives develop a framework and a constraints-set to help guide the model development. They limit the model base to a geographic area and time period, and set the independent measurement variable that correlates with the output goal.

2. Identify model components: This step includes the identification of potential variables that can be useful in evaluating habitat suitability for a given species. The identification of model variables for the HSI is based on three criteria:

- *Variables should be closely related to the species habitat needs and the land or water development changes being studied.*
- *There should be sufficient information available such that the relationship between the variables and the specific habitat needs of the species can be described, preferably in a quantitative manner.*
- *Variables should be practical to measure, estimate, or predict given the constraints under which the model will be used.*

3. Define model relationships: The relationships between the selected variables and habitat suitability are explicitly defined in this phase. The important aspect of this step is to structure the model to define the rules by which a habitat is to be evaluated to determine an index of habitat suitability.

4. Document the model: The model needs to be documented in order to promote an understanding of the decision-rationale used during model construction. By documenting these details, the model is more likely to gain acceptance.

5. Verify and test the model. The HSI model should be verified prior to its operational use. The goal of the verification should be toward the improvement of the model to better reflect the relationships between the species and its habitat. (Stiehl, 1995:5-3 to 5-13)

More than two hundred HSI models for fish and wildlife species were developed by the U.S. Fish and Wildlife Service and published in "Blue Books." Notably, most of these models have never been fully tested. The need for model verification has been stressed in the literature (Verner et al., 1986; Morrison et al., 1992; Duncan et al., 1995), but appropriate data to support verification are frequently lacking (Schamberger and O'Neil, 1986).

2.2 Bald Eagle Protection

Bald eagles were once common birds in the forty-eight contiguous states and were abundant in Alaska during the early 1900s (King et al., 1972). Human activities since this time have greatly reduced bald eagle populations. Some destructive activities have been logging, land clearing, and housing development which destroy nesting trees and suitable habitat. Later, farmers blamed bald eagles for killing livestock so the birds were shot. Many bald eagles died from poisons that were put out by the federal or state pest and predator-control projects. Bald eagle populations declined relatively slow, but it was finally recognized and protection laws were considered. In 1940, the Bald Eagle Act was passed to prevent live or dead bald eagles, their parts, nests, or eggs from being sold, transported, exported, or imported.

After World War II, DDT and other toxic chemicals were introduced in this country for insect control. DDT was used widely to control the gypsy moth during the mid-1950s to 1960s (McCling, 1979). Bald eagle populations declined drastically during this period. Nobody knew what was causing bald eagle deaths, but the incidents were brought to the attention of the government and the National Audubon Society, and intensive action to protect the bald eagles began. The National Audubon Society's Continental Bald Eagles Project was initiated in 1960 with the cooperation of the U.S. Forest Service. This project provided survey and record keeping of the nesting status of bald eagles on the various National Forests. Bald eagle nesting status in the Huron-Manistee National Forests has been recorded ever since (Irvine, 1986). In 1966, the Department of Interior provided suitable places for bald eagles to nest by both restricting the use of and closing access to bald eagle nesting areas on public land during the breeding season. At the same time, the U.S. Fish and Wildlife Service, the U.S. Forest Service, and U.S. Bureau of Land Management (BLM) were required to include protection of bald eagles in their management plans. In 1967, bald eagles were listed as endangered in the contiguous United States except in Minnesota, Wisconsin, Michigan, Washington, and Oregon.

Michigan banned the use of DDT in 1970, the first state in the nation to do so. The United States banned the use of poisons, including DDT, on public land in 1972. Since then, eagle populations have grown slowly. The Endangered Species Act was amended in 1978 to include bald eagles in Minnesota, Wisconsin, Michigan, Washington, and Oregon on the threatened species list; bald eagles remain endangered in the rest of the contiguous states.

Each state also develops its own bald eagle laws in addition to the federal protection plans. In Michigan, bald eagles are not only protected under the Federal Endangered Species Act, but also by the Migratory Bird Treaty Act, the Bald Eagle Protection Act and the Michigan Endangered Species Act. Bald eagles will also be protected under the Bald Eagle Protection Plan of the Consumers Power Company around their hydroelectric projects on the Au Sable, Manistee, and Muskegon river systems in the near future.

2.3 Bald Eagle Nesting Habitat

Quality breeding habitat for bald eagles requires readily available food, shelter, nest sites, and isolation from human activities. These requirements for bald eagles nest site selection have been widely observed (Juenemann, 1973; Grubb, 1976; Andrew and Mosher, 1982; Bowerman, 1993).

2.3.1 Food

One of the most important components of the bald eagle breeding habitat is an adequate food supply. The availability of food is strongly associated with the location of bald eagle nesting sites. In the Greater Yellowstone Ecosystem, bald eagle breeding area selection is based on a stable food source in the nesting area (Swenson et al., 1986). In order for bald eagle young to grow and survive, a constant food supply during the nesting season is critical. Lack of adequate prey for as little as a few weeks during the breeding season can cause nest abandonment by adult bald eagles (Hansen, 1987).

Several studies across the United States have indicated that bald eagles that nest away from coastal shorelines (i.e. interior bald eagles) tend to nest close to large bodies of water in order to access their favorite food (fish). The interior bald eagles were observed to prey primarily on fish; 91.1 percent in north-central Minnesota (Dunstan and Harper, 1975); 77 percent in Maine (Todd et al., 1982), and 73 percent in Arizona (Haywood and Ohmart, 1986). The same observation also held true in Michigan. A study by Bowerman in the Upper Peninsula of Michigan (1991) demonstrated that fish comprised the highest percentage of prey items (81.5 percent). In 1993, Bowerman extended his study to the interior habitat on the Au Sable, Muskegon, and Manistee rivers in Northern Lower

Michigan. Here, 93 percent of the total observed prey of the bald eagles was fish. The majority of the fish that are foraged by bald eagles are bottom-feeder species (generally feed in shallow water) including suckers, bullhead, catfish, and northern pike.

Although fish were found to be an important diet for bald eagles, many studies demonstrated that their diet also included several other food items that have seasonal importance. Prey species taken by bald eagles in the Greater Yellowstone Ecosystem varied throughout the breeding season due to changes in prey availability (Swensen et al., 1986). Bald eagles are also known to be quite opportunistic and take prey other than fish if it is readily available (Mathisen, 1968; Dunstan and Harper, 1975; Todd et al., 1982; Haywood and Ohmart, 1986). For example, bald eagles consumed winter-starved deer and road kill during the early nesting season in interior Maine (Todd et al., 1982), and fed on carcasses of lambs on San Juan Island, Washington (Retfalvi, 1965). In another example, Alaskan sub-adult bald eagles used dump sites as an important food source all year round, and a considerable number of eagles, including adults, utilized the dump in winter, especially after snow storms (Sherrod et al., 1976). Bald eagles have been reported to feed on mammalian, avian, and reptile species. Bowerman (1991) noticed that the interior bald eagle in Michigan utilized mammalian and avian prey during the early breeding season when fish were less available. He further remarked that along river stretches of the Au Sable and Manistee river, fish were not as available and that the bald eagles that nested there preyed on reptiles.

2.3.2 Cover

Like any other creature, bald eagles need a suitable place to rest. Size and structure of trees seems to be important aspects to bald eagles when choosing roosting sites. In Oregon and California, characteristic roost trees are taller and more open-structured than the surrounding stands with one important attribute--they were close to the food source (Kiester et al., 1983). Bald eagles also need shelter, especially in winter. Wintering bald eagles look for places that can protect them from cold winter wind. Buehler et al. (1991) found that 92.9 percent of wintering bald eagles selected roosting sites in areas with small openings adjacent to the roosting trees to avoid prevailing northerly winds. The protection of the surrounding trees provides a favorable microclimate for wintering bald eagles. Consequently, energy expenditures at night are less. Reduced energy expenditure at night will also reduce food requirements during the day (Stalmaster, 1981). Spending less energy is important when winter food supplies are limited.

2.3.3 Nesting Trees *vs.* Location

Adult bald eagles tend to use the same breeding area and often the same nest each year (Gieck, 1991). Bald eagle nests can sometimes be found on cliffs (Chrest, 1964), and on the ground such as on sea stacks or on hill sides on treeless islands (Sherrod, 1976). Most of the time, bald eagle nests are found in trees, however. Tree species selection for nesting by bald eagles varies geographically with the forest type of the region. In western Washington, most nests are found on Douglas-fir and Sitka spruce (Grubb, 1976); but in Marryland Loblolly pine is preferred (Andrew and Mosher, 1982). In Michigan the overwhelming favorite nest tree is the White Pine (Bowerman, 1993).

Bald eagles prefer nesting in old-growth or mature secondary-growth forests. These old-growth and secondary-growth trees are typically dominant or co-dominant trees in the forest (Anthony et al., 1982). The height of these predominant trees has been shown to be a primary factor in eagle nest site selection (Retfalvi,1965). Juenemann (1973) stated that bald eagle nest trees in Minnesota were relatively large and prominent with heights ranging from 59 to 112 feet and diameters (d.b.h.) ranging from 20.7 to 37.3 inches. Bald eagles in the upper Midwest frequently nest on the tallest trees with the greatest d.b.h.; these range from 73.9 feet to 92.8 feet tall, and from 24.1 inches to 32.9 inches in diameter (Bowerman, 1993). In Maryland, 70 nesting trees were measured.

They averaged 73.6 feet in height and 24.2 inches in diameter (Andrew and Mosher, 1982). Finally, the mean height of nine nesting trees on San Juan Island, Washington was 100 feet (Retfalvi, 1965).

Another important factor for bald eagle nest-site selection is the presence of an open forest structure. Typically, bald eagle nesting trees are located in structurally heterogeneous forests or uneven-aged stands (Grubb, 1976) with multi-layers that vary considerably in height and diameter (Anthony et al., 1982). Andrew and Mosher (1982) agreed that open vegetation is an important characteristic of bald eagle nesting habitat. In addition to statistical testing, they found that more than 53 percent of nest sites were associated with some form of open vegetation within 100 m of the nest. In Florida, bald eagle nests were built on dominant trees along ecotones, in open fields, and in pastures (McEwan and Hirth, 1979). In Minnesota (Juenemann, 1973), 80 percent of 25 observed nest sites were associated with open land such as sedge meadows, marshes, plantations, or natural openings. Grubb (1976) found that the majority of co-dominant nest trees in western Washington were in heterogeneous stands. Open forest structure and tall nest trees provide bald eagles with an open view of the surrounding area (Juenemann, 1973; Grubb, 1976; Retfalvi, 1965) and a clear flight path for easy access to their nests (Grubb, 1976).

The distance from nest to open water is another important attribute for nest-site selection by bald eagles (Chrest, 1964; Juenemann, 1973; Nye and Suring, 1978 ; Bowerman, 1993). Observations of the distance of nests to the nearest water showed that usually nests were close to open water. Short distances from the nest to open water provide bald eagles easy access to their preferred diet of fish. Nest trees in the Columbia river estuary in Oregon and Washington were located within 1.6 km of the river (Garrett et al., 1993). Taylor and Therres (1981) found similar results, and did not consider land further than 1.6 km from water to be suitable nesting habitat in Maryland. From observing 24 out of 25 randomly selected bald eagle nest sites in Minnesota, Juennemann (1973) discovered that those nests were situated less than a half mile from open water. Bald eagle nest sites were no further than 600 feet in Washington (Grubb, 1976); no further than 240 feet in Alaska (Chrest, 1964), and averaged 312 feet in the Yellowstone Unit, 639 feet in the Snake Unit, and 1,768 feet in the Continental Unit of the Greater Yellowstone systems (Swensen et al., 1985). In 1993, Bowerman observed several nest sites in the upper Midwest with distance to open water ranging from 350 feet to 2,919 feet.

Not only is distance of bald eagle nest sites to water important but the size of the body of water is important also. Nye and Suring (1978) stated that bald eagles require open water in order to obtain their major food (fish). Peterson (1986) concluded from several studies that the optimal size of a lake suitable for bald eagle habitat was one with a surface area greater than 10 square kilometers (about 2471 acres).

2.3.4 Disturbance

Human activities have been observed to have negative influences on bald eagles in several regions (Mathisen, 1968; Grubb, 1976; Buehler et al., 1991 Bowerman, 1993; Theres et al., 1993). Retfalvi (1965) stated that human activities frequently cause reproductive failure in bald eagles. The intensity of human impact on bald eagles depends on the timing of the activities, the distance the activities are from the nest, and the view that the eagles have of the activities (Therres et al., 1993).

Human disturbance has the most critical impact on bald eagles during times of egg-laying and incubating (Mathisen, 1968). Chrest (1964) stated that the highest mortality rate of bald eagles was during the egg stage. During these periods, the birds have the least tolerance to external disturbances and may abandon their nests and leave the area. Herrick (1934) believed that bald eagles did not accidentally break the eggs that were later found in their nests. Rather, they were likely to destroy their eggs when they were frequently disturbed by human beings. He furthered suggested that during the incubation period, human activities should not be present around the nests. As the nesting period advances and the young develop, the same type of disturbance may have less effect (Mathisen, 1968). In Minnesota, human disturbance during the incubation period caused bald eagles to abandon their nest (Juenemann, 1973). Therres et al. (1993) showed a good example of human disturbances from their study in Chesapeake Bay. Housing development including land clearing, utility activities, extraction operations and road construction were responsible for the decline in available nesting habitat as well as increases in egg and nest-site abandonment by bald eagles during the breeding season.

Large lakes and rivers attract both bald eagles and people. When people choose to live or vacation near open water where bald eagles have chosen to nest, conflicts between these two arise. In north-central Minnesota, bald eagle nests were found further from shorelines in areas of high development compared to shorelines without houses (Fraser et al., 1985). In some cases, bald eagles utilized vegetation as a natural buffer strip against human disturbance (Juenemann, 1973; Therres et al., 1993). Andrew and Mosher (1982) found that nest sites located in denser forests with fewer openings that were further away from water had higher reproduction success rates than nest sites that were located closer to water with more forest openings but were also closer to human activities.

2.4 Habitat Suitability Index (HSI) Model For Bald Eagle (Breeding Season)

The HSI model for bald eagles (breeding season) was created by Allen Peterson in 1986. This model is designed to be applicable to habitat in North America located north of the 37th parallel (Peterson, 1986).

Two important elements of HSI models are the environmental variables and the associated suitability graphs. Each variable is described by a suitability index estimated from the suitability graphs. The various suitability index values are used in the HSI equation to calculate a single HSI value. The indexes range from 0.0 to 1.0; an index value of 0 for non-suitable habitat, and an index value of 1.0 for the maximum habitat suitability. For example, from the graph of Figure 2.1, an environmental variable value of 8 would yield an index value of 0.8. The HSI is designed to reflect the suitability of the habitat in relation to the population density of eagles along a shoreline.

Four environmental variables are components of the HSI model for breeding season bald eagles: 1) area covered by open water and adjacent wetlands, 2) Morphoedaphic Index (MEI), 3) the percentage of upland area covered by mature timber, and 4) the number of houses and camping sites per unit area (building density). Collectively, these variables assess the habitat suitability to provide food, shelter, and protection from human disturbance. The HSI equation uses three indexes to capture these attributes: the suitability Index for Food (SIF), the Suitability Index for Reproduction (SIR), and the Suitability Index for Human Disturbance (SIHD).

The suitability Index for Food (SIF) is composed of two variables: 1) area covered by open water and adjacent wetlands and 2) the Morphoedaphic Index (MEI).

The area covered by open water and adjacent wetlands is used to produce a suitability index value, SIV1, which is estimated from the suitability index graph specific to this environmental variable.

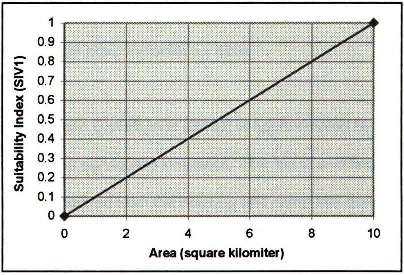


Figure 2.1. Suitability graph.

The MEI is measure of fish biomass in the water (Peterson, 1986). There is no existing data that measures the food availability for bald eagles. Since fish are the most important food source (discussed previously), MEI was used as an indirect measure of potential fish availability. This index is derived from the ratio of total dissolved solids (ppm) to the average water depth. The MEI variable generates the second suitable index score (SIV2) from the suitability graph specific to the MEI. The Suitability Index for Food (SIF) is equal to the geometric mean of SIV1 and SIV2:

$$SIF = (SIV1 \times SIV2)^{1/2} \qquad \text{...........................(Eq. 2.1)}$$

The Suitability for Reproduction (SIR) estimated from the percentage of the potential nesting area that is covered by mature timber. The percentage of mature timber produces the third suitability index value (SIV3) which is read from the graph specific to this environmental variable.

The Suitability for Human Disturbance (SIHD) is approximated by the number of housing and camp sites per square kilometer. The fourth and final suitability index value (SIV4) is derived from the housing and camp site density by means of the built-area suitability index graph.

The HSI model for breeding season bald eagles uses the food, reproduction, and human disturbance factors as shown:

$$HSI = (SIF) \times (SIR \times SIHD)^{1/2} \quad \text{................ (Eq. 2.2)}$$

or, in its final form:

$$HSI = (SIV1 \times SIV2)^{1/2} \times (SIV3 \times SIV4)^{1/2} \quad \text{.. (Eq. 2.3)}$$

2.5 The Role of Geographic Information Systems (GIS) in Wildlife Habitat Study

Geographic Information Systems (GIS) technology has obtained recognition as a set of powerful tools capable of spatial and temporal analysis with the ability to perform data base management, graphical display, and model simulation. The use of this technology has grown rapidly since it beginnings in the early 1980s. Over time, this technology has matured through the development of numerous, commercially-available GIS software systems.

The use of GIS has emerged as an important addition to the methods used on the fields of natural resource and ecological study in recent years. Johnson (1990) summarized the potential of GIS in ecological applications. She explained how others used this technology in natural resource and ecological studies. Examples included analyzing landscape alteration by beaver (Johnston and Naiman, 1990); conducting vegetation resource inventories (Stefferson, 1987); providing decision support for forest management (Herrington and Koten, 1988); assessing the spatial pattern of landscapes (O'Neill et al., 1988; Pastor and Broschart, 1990); and estimating cumulative impacts (Johnston et al., 1988). She pointed out that GIS has been applied to estimating the quality and quantity of habitat based on weighted, spatial intersection models (Davis and Delain, 1984; Donovan et al., 1987; Hodgson et al., 1987; 1988; Scepan et al, 1987; Stenback et al., 1987; Young et al., 1987). Johnson concludes that the integration of GIS with spatial models, as discussed by Wheeler (1988) and Burrough et al. (1988), is an enormously promising approach.

Studies that included wildlife habitat assessment as part of ecosystems research were well suited for GIS application. As habitat modeling was implemented, however, the limitations of the models become obvious (Farmer et al., 1982; Laymon, 1986; Schamberger, 1986). Farmer et. al. (1982) argued that many of these operational models were constructed from simplistic and easy-to-measure physical and floristic variables, and they usually lacked a number of key variables and appropriate detail. They suggested strategies for improving the development of habitat models procedures to verify the models.

Laymon and Barrett (1986) tested the Habitat Suitability Index (HSI) models (Created by the U.S. Fish and Wildlife Service) for three species (spotted owl, Marten, and Douglas' squirrel). They applied the HSI models of two species (spotted owl, and Marten) in site specific studies, and the Douglas' squirrel HSI model to a landscape scale study. Results from the models did not correlate well with independent measurements which were used for a standard of comparison for each species. Two main reasons that contributed to these poor results were that the environmental variables that formed the models did not contribute enough information to accurately reflect the actual habitat quality, and the habitat data were of questionable quality. They discouraged the use of untested models due to the lack of credibility.

Schamberger and O'Neil (1986) suggested that model testing may obtain mixed results due to the environmental variables that form the model, and the difficulty of obtaining an independent measurement. They then provided concepts of model testing that related to land use applications, and discussed the selection of appropriate standards for comparison with the result of the models.

Burley (1989) described the application of GIS incorporated with habitat suitability models designed for landscape and wildlife. He explained the application of the model to one or more species and gave selection guidance for choosing GIS software that provides the capability to handle the model.

Eng et. al. (1991), and Davis and DeLain (1986) not only utilized a GIS database for habitat modeling, but also linked the management plan with wildlife habitat to integrate forest management systems. Eng et. al. (1991) developed the Habitat Assessment and Planning (HAP) tool, and used GIS to integrate management plans to HAP. Davis and DeLain (1986) developed and applied a mathematical habitat suitability index model for spotted owls to two spatial databases. They linked the habitat suitability, and included habitat suitability maps to the timber management maps for the impact assessment and timber production analysis.

Baker and Mangus (1991) developed GIS procedures to analyze sandhill crane nest sites. They evaluated the HSI model on a-site specific basis for this specie for all nest sites and for random sites by creating a buffer zone around each site. They suggested a GIS analysis of the HSI model by calculating an HSI value for a wide range of buffer zone width. For example, 50-1000 meter zone at 50 meter intervals.

Pereira et al.(1991) developed a GIS-based habitat model using logistic multiple regression to assess habitat quality for the Mt. Graham Red Squirrel. They used a digital map database and GIS to analyze and provide inputs for two logistic multiple regression models. These models were then used to predict squirrel presence or absence. Potential habitat losses due to development were assessed using the model. A 3 percent loss of habitat was predicted. The authors noted, however, that the important of this estimated impact could not be determined. Whether a 3 percent habitat loss would cause the extinction of this endangered specie or not was uncertain.

Two comments need to be made regarding HSI modeling. First, the HSI model for the breeding bald eagles has not yet been verified. Secondly, GIS technology has not been applied to analyze this specific HSI model.
It also has been recognized that modification to the HSI model will be necessary to fit site specific areas. Modification to the model has not been reported to date in the literature.

Ecological modeling by its nature has many limitations. These limitations are from the lack of environmental data which in turn causes the model to be generalized. For example, in this study the availability of fish for breeding bald eagles is not available. Instead, the surrogate variable, MEI was used in place of the necessary data. These types of linkages make the model less and less precise. It must be understood that modeling of this type is not a precise science. Studies of this type are used for investigating and testing to determine if the model contains the correct factors and whether the factors are weighted appropriately.

CHAPTER 3

METHODOLOGY

3.1 Overview

This study will apply the original HSI model for Bald Eagles (Peterson, 1986) and a modified version of the model on the eleven bald eagle nest sites around the Tippy Dam Pond. It must be noted that the original breeding season HSI model for bald eagles (Peterson, 1986) related the index value (0.0 - 1.0) to the population density of eagles along a shoreline. In this study, the HSI model for breeding bald eagles is being related to their nest-specific reproductive outcomes (i.e. eaglet production). Areas of analysis at each nest site include both the quarter-mile and half-mile buffer zones (Figure 3.1 and Figure 3.2).

The quarter-mile buffer zone is a circular area with a radius of 1,320 feet centered on each nest. The half-mile buffer zone includes a doughnut-shaped area derived from a circular zone with a radius of 2,640 feet from the nest excluding the area of the quarter-mile buffer zone as shown in Figure 3.3. This is to prevent replication of the HSI value for the quarter-mile buffer.

The evaluation within the quarter-mile buffer zone will produce 11 values for the original HSI model and 11 values for the modified HSI model.

Figure 3.1. Quarter-mile buffer zones around the eagle nest sites at Tippy Dam Pond.

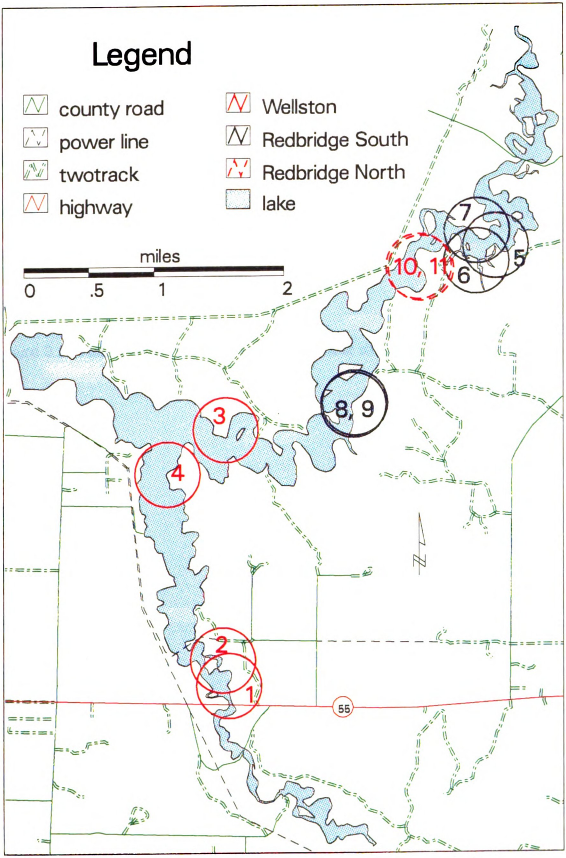

Legend
county road
power line
twotrack
highway
Wellston
Redbridge South
Redbridge North
lake
miles
0
.5
1
2
7
10, 11
6
5
8, 9
3
4
2
1
55

Figure 3.2. Half-mile buffer zones around the nest sites at Tippy Dam Pond.

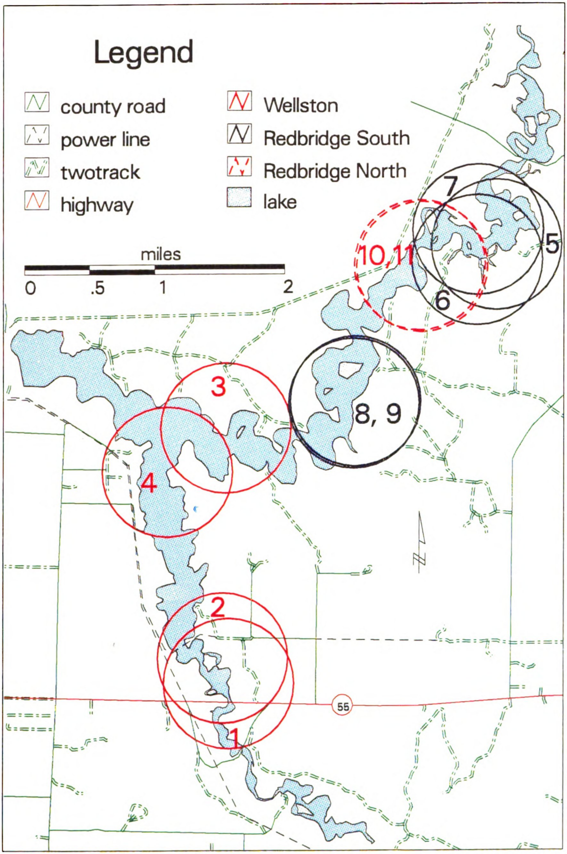
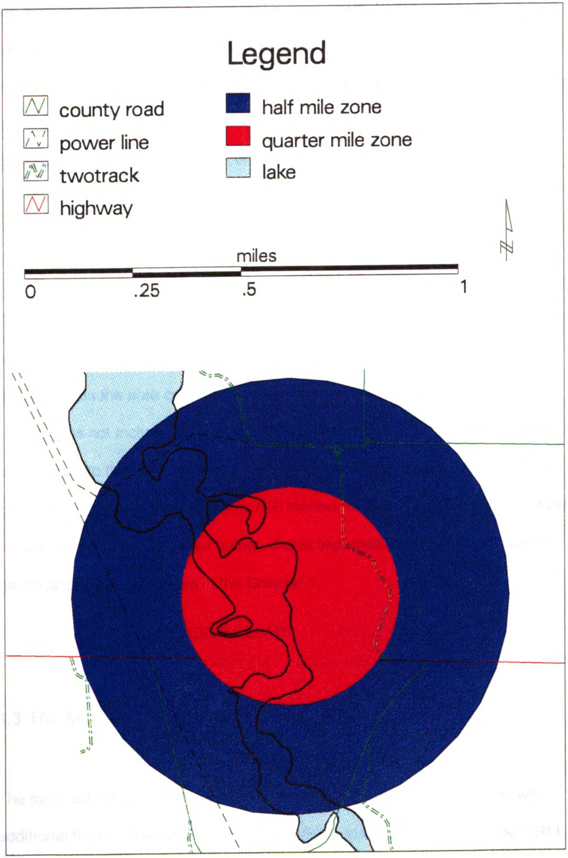

Legend
county road
power line
twotrack
highway
Wellston
Redbridge South
Redbridge North
lake
miles
0
.5
1
2
1
2
3
4
5
6
7
8, 9
10,11
55

Figure 3.3. Buffer zone analysis areas.


Legend
county road
power line
twotrack
highway
half mile zone
quarter mile zone
lake
miles
0
.25
.5
1

The evaluation within the half-mile buffer zone results in another 11 values from the original HSI model and 11 values from the modified HSI model. Both the original and the modified models of habitat suitability for the breeding bald eagle were implemented using ARC/INFO version 7.03 on a SUN10 workstation that operates in SUN OS 413, a UNIX environment.

3.2 The Original HSI Model

The original HSI model that was used in this study consist of variables that were suggested by Peterson (1986) except for one variable, SIV1. SIV1 is an index that measures the area covered by open water and adjacent wetlands. This variable was not included in my study since all eleven bald eagle nest locations are proximal to the same reservoir. If applied, the SIV1 value will hold constant in both the original and the modified HSI models for the 11 nest sites. This study will use the equation 3.1 listed below. Detail explanation of other variables in the equation were explained in the Chapter 1.

$$HSI = SIV2 \times (SIV3 \times SIV4)^{\frac{1}{2}} \qquad \text{.......... (Eq. 3.1)}$$

3.3 The Modified HSI Model

The modified model contains all the factors from the original model plus two additional factors: the White Pine Index (WPI) and the Road Length Index (RLI).

The WPI is based on the number of supracanopy White Pines within the buffer zones. This index was used to modified the original SIV3. The new factor, called SIV3p, is derived from the arithmetic mean of SIV3 and the WPI as shown in Eq. 3.2.

$$SIV3p = (SIV3 + WPI)^{\frac{1}{2}} \quad \text{.......... (Eq. 3.2)}$$

The RLI was determined by measuring the length of the highways, county roads, two-tracks, and power lines within the buffer zones. This index was used to modify the original SIV4 to give SIV4p defined as the geometric mean of SIV4 and the RLI as shown in Eq. 3.3.

$$SIV4p = (SIV4 \times RLI)^{\frac{1}{2}} \quad \text{........... (Eq. 3.3)}$$

So the modified HSI is computed from the following equation:

HSIp is used to represent the modified HSI.

$$HSIp = SIV2 \times (SIV3p \times SIV4p)^{\frac{1}{2}} \quad \text{.......... (Eq. 3.4)}$$

3.4 GIS Data Input

The data required for both the original and the modified Habitat Suitability Index (HSI) Model for breeding bald eagles were gathered, or generated within a GIS including both the spatial data (point, line, and area) and their respective attribute databases.

All of the spatial data were referenced to the Michigan State Plane Coordinate System (1927), central zone with the units in feet. The newly created digital data were digitized using ARC/INFO version 7.03 and a CALCOMP digitizer. Each digital file was cleaned and built to generate topology.

3.4.1 Original HSI

The original HSI required the spatial locations of the nest sites and the three other variables: SIV2, SIV3, and SIV4. The nest locations, SIV3 and SIV4 were unavailable as digital spatial data and had to be developed. Digital data relevant to SIV2 did exist, but were not in the right format for analysis. Several steps were performed to convert this digital file to a useable form.

3.4.1.1 Existing Digital Data

The data needed for SIV2 was the average water depth of the Tippy Dam Pond. SIV2 is a factor scaled by the Morphoedaphic Index (MEI). As described in the previous chapter, the MEI is derived from total dissolved solids (ppm) divided by average water depth (feet). The average water depth within quarter-mile and half-mile buffer zones for each nest site was calculated using an area weighted technique which will be discussed in the data analysis section of this chapter.

Water depths of the whole Tippy Dam Pond were taken from a bathymetry map that was provided by the Consumers Power Company. It was stored in a CAD format as an DXF file in an unknown coordinate system.

The technique that was used to generate a coordinate system and map units for this CAD file was to scale and orient the CAD file to overlay on a reference that contains a State Plane Coordinate System in unit of feet.

To generate a usable coordinate system with known map units for this CAD file, the Lakes file for Manistee county, an existing digital file from the Michigan Resource Information System (MIRIS), was used as a reference file. The Lakes file contained all the lakes in Manistee County including Tippy Dam Pond. All other lakes in the file were deleted except for Tippy Dam Pond.

Intergraph software was used to visually overlay the CAD file on the Tippy Dam Pond vector file. Before the overlaying, the map units were set to feet and the CAD file was converted into an Intergraph format design file. The bathymetry map and the reference file were displayed together on the same computer screen to show the location of each map. The bathymetry map was interactively scaled and oriented to match the reference map which was planimetrically correct and georeferenced to the Michigan State Plane Coordinate System with units in feet. The newly georeferenced bathymetry map (in Intergraph format) was converted into an ASCII file using C-MAP software (Center For Remote Sensing, Michigan State University). The ASCII file was imported into ARC/INFO using the GENERATE command to create a bathymetry map coverage.

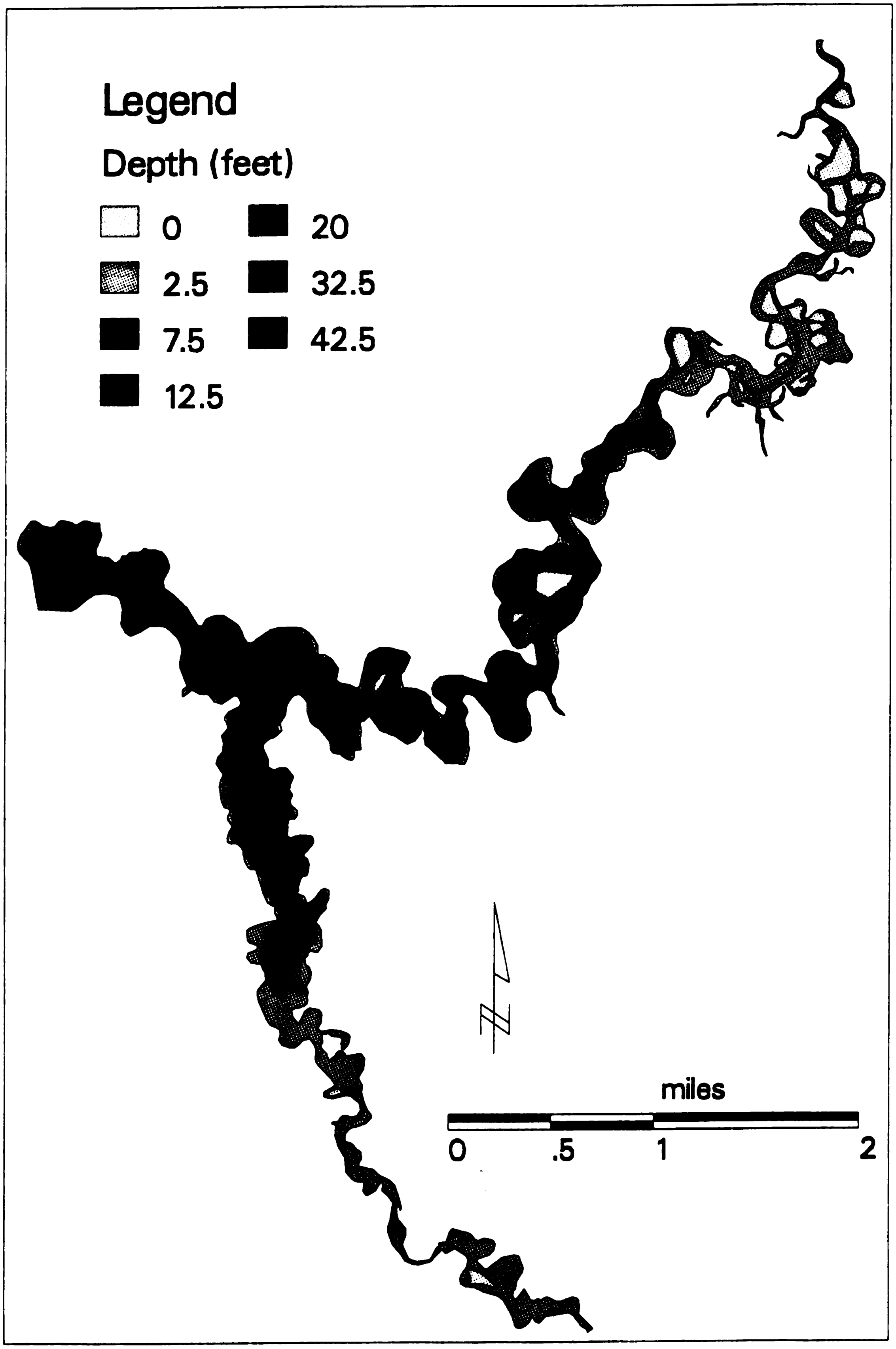
The isobaths on the bathymetry coverage used for the analysis were 0, 5, 10, 15, 25, 40, and 50 feet. This coverage was cleaned and built to obtain a polygon topology. The area bounded by adjacent contour lines was assigned a depth attribute derived as follows:

The mean depth of the polygons created from adjacent isobaths was calculated by adding the value of the two bounding isobaths and dividing by 2. For example:

$$\text{Average water depth} = \frac{10 + 15}{2} = 12.5$$

The mean value was assigned, in this example, to the area between the adjacent 10 feet and 15 feet isobaths. These calculated mean values were treated as the mean depth of each polygon. As a result, the following depths were calculated: 2.5, 7.5, 12.5, 20, 32.5, and 42.5 respectively. The bathymetry map is shown in Figure 3.4.

Figure 3.4. Bathymetry of Tippy Dam Pond.


Legend
Depth (feet)
0
2.5
7.5
12.5
20
32.5
42.5
miles
0
.5
1
2

3.4.1.2 Creating the Unavailable Digital Data

The required digital data which were unavailable included the bald eagle nest locations, the percentage of mature trees, and the location of housing and camping sites. These data were complied from written reports, aerial photo interpretation, and USGS topographic maps, respectively.

The U.S. Fish and Wildlife Service, the U.S. Forest Service, and the Wildlife Division, Michigan Department of Natural Resource (MDNR) provided the information for Bald eagle nest locations and their attributes. This information was stored in many formats: spreadsheet, reports, and maps. The digital map of the nest locations was created from bald eagle nests occupied anytime during the period 1975 to 1995.

Some bald eagle breeding pairs nested on the same tree for many years but some moved around or alternated the use of several nest sites. The location of each nest site on the spreadsheet was recorded in Tier, Range, Section, and subsection, for example 21N, 13W, 8, NE, SE. These written descriptions were used to plot locations on the base map (7.5-minute quadrangle, 1:24,000 scale). The nest format does not describe the exact nest site, instead it locates within quarter-quarter sections (40 acres). Data from reports, and maps were used for comparison purposes to corroborate the spreadsheet data. Eleven nest locations were digitized using the 40-acre quarter-quarter section centroids to generate a point coverage. Each nest was stored as a coverage by itself; there are eleven coverages for the eleven nest sites.

The first four nest locations represent the Wellston territory of a single breeding pair of Bald Eagles. The Red Bridge South territory (a second breeding pair) contains nest locations 5 to 9. Finally, the last two nests, ten and eleven, represent the territory of a third eagle pair, the Red Bridge North couple. The attribute database for each nest site was created using the INFO database manager.

Mature trees in this study are defined as any tree taller than 20 meters. Percent of mature trees were derived from visual interpretation of Color Infrared (CIR) aerial photographs. These aerial photographs from 1978 (scale 1: 24,000) are the most recent CIR transparencies that are available from the Land and Water Management Division, MDNR. A one-mile-wide buffer zone was drawn around the Tippy Dam Pond. Within this analysis area, polygons were drawn on acetate overlays on the air photos around homogeneous stands that contained the same amount of mature trees. These cover types were then updated using the most recent black and white infrared aerial photographs which were taken in 1987 at a scale of 1:15,840. These two were provided by Land and Water Management

Division, MDNR. Percent of mature trees in each polygon was assigned by visual comparison with a standard crown density scale.

Percent of mature trees in the study area was categorized as 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, and 90 percent. Areas with immature trees (less than 20 meter tall), non-forested land, and water were assigned a value of 0 percent. The polygons of percent mature trees on the acetate overlays were transferred using a Kargl magnifying rear projector onto a base map with a scale of 1:24,000 for digitizing. The base map contains objects such as roads, rivers, and lakes that were used for georeferencing. The percent mature trees map is shown in Figure 3.5.

USGS topographic maps (1985) at a scale of 1:24,000 were used to generate a point coverage of houses. These paper maps were referenced to the Michigan State Plane Coordinate System, during the set-up phase of the digitizing process. Maps of camping sites were provided by the U.S. Forest Service, Manistee National Forest in Cadillac, Michigan (no date). These sites were transferred using a Kargl magnifying rear projector to the USGS 7.5-minute base maps (1:24,000). These point features were digitized to generate a point coverage for the camping sites. The map of housing and camping sites is shown in Figure 3.6.

Figure 3.5. Percent mature trees in the vicinity of Tippy Dam Pond.

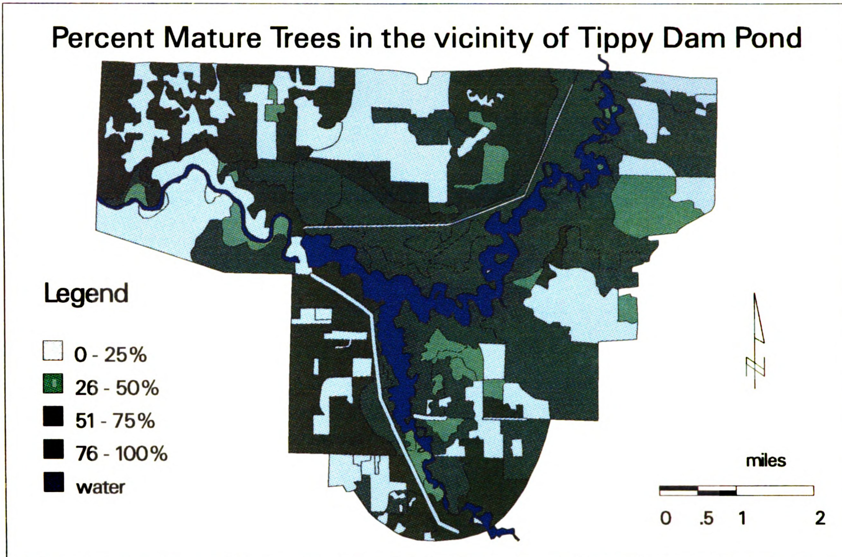
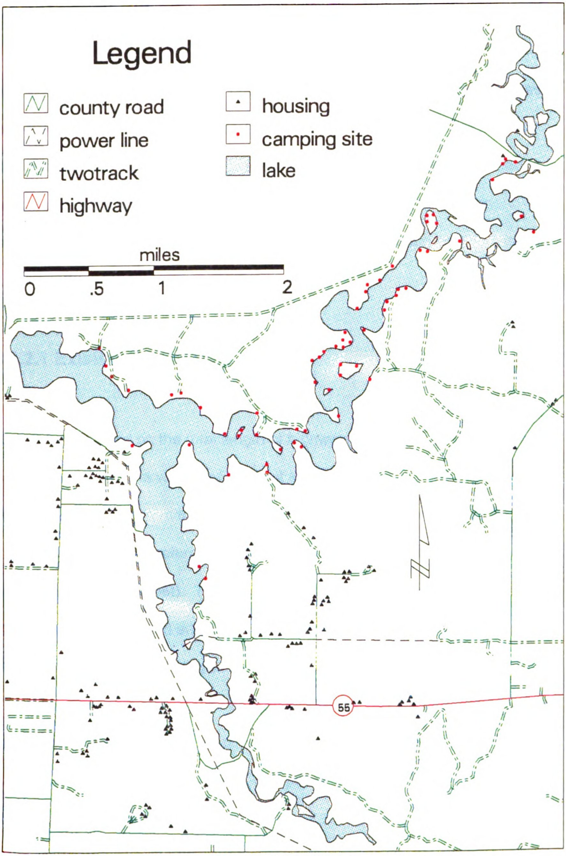

Percent Mature Trees in the vicinity of Tippy Dam Pond
Legend
0 - 25%
26 - 50%
51 - 75%
76 - 100%
water
miles
0
.5
1
2

Figure 3.6. Housing and camping sites and linear disturbance features.


Legend
county road
power line
twotrack
highway
housing
camping site
lake
miles
0
.5
1
2
55

3.4.2 Modified HSI

Two variables were added to the original HSI to create a modified HSI. These variables are the White Pine Index (WPI) which accounts for the number of supracanopy White Pine trees in the vicinity of the nest site, and the Road Length Index (RLI) which accounts for the intensity of potential human disturbances as a function of the total length of transportation corridors in the vicinity of the nest site.

3.4.2.1 Existing Digital Data

The RLI was based on the total length of highways, county roads, two tracks, and power lines in the vicinity of the nest sites. These linear features were stored in digital files from the Michigan Resource Information System (MIRIS). All MIRIS data are georeferenced to the Michigan State Plane Coordinate System (map units in feet). They are stored in Intergraph design file format. MIRIS data were created and made available by the Land and Water Management Division, Michigan Department of Natural Resources (MDNR). The process of converting these design files to ARC/INFO coverages was the same as the process described previously for the bathymetry map. The highways, county roads, two-tracks, and power lines within the study areas are depicted in Figure 3.6.

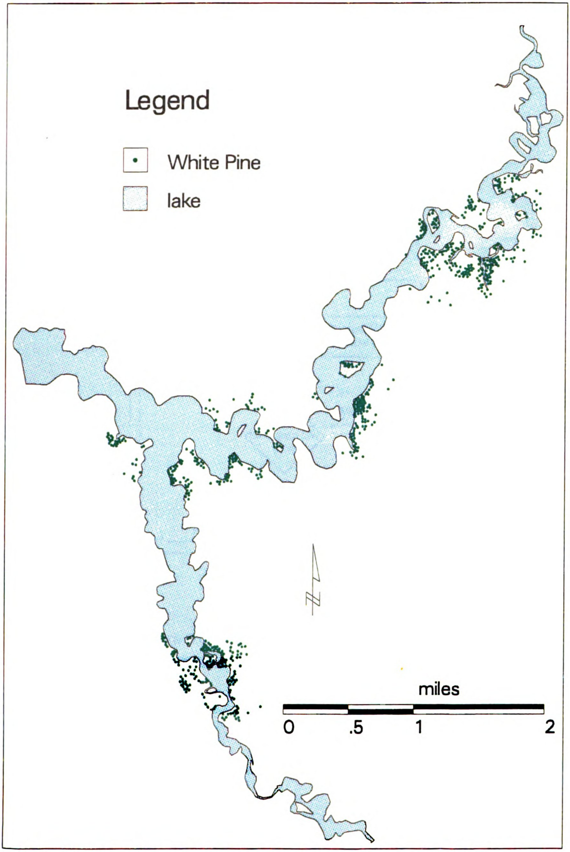
3.4.2.2 Creating the Unavailable Digital Data

The WPI is a function of the number of supracanopy White Pine trees proximal to the nest. The 1985 CIR air photos at a scale of 1:12,000 (provided by the U.S. Forest Service, Huron-Manistee National Forest, Michigan) were inspected in stereo in order to map all of the obvious supracanopy White Pine trees occurring within a half-mile around each nest location. The supracanopy White Pines were mapped as individual point features onto an acetate overlays on the air photos. These points were subsequently transferred using a Kargl projector onto a USGS 7.5-minute base map (1:24,000) for digitizing. The supracanopy White Pine map is shown in Figure 3.7.

3.5 GIS Data Processing

Data processing for both the original HSI and the modified HSI within the quarter-mile and half-mile buffer zones were performed using similar procedures. The general steps in the process are shown in the flowchart Figure 3.8.

Figure 3.7. Supracanopy White Pines within one half-mile of the various eagle nests.


Legend
White Pine
lake
miles
0
.5
1
2

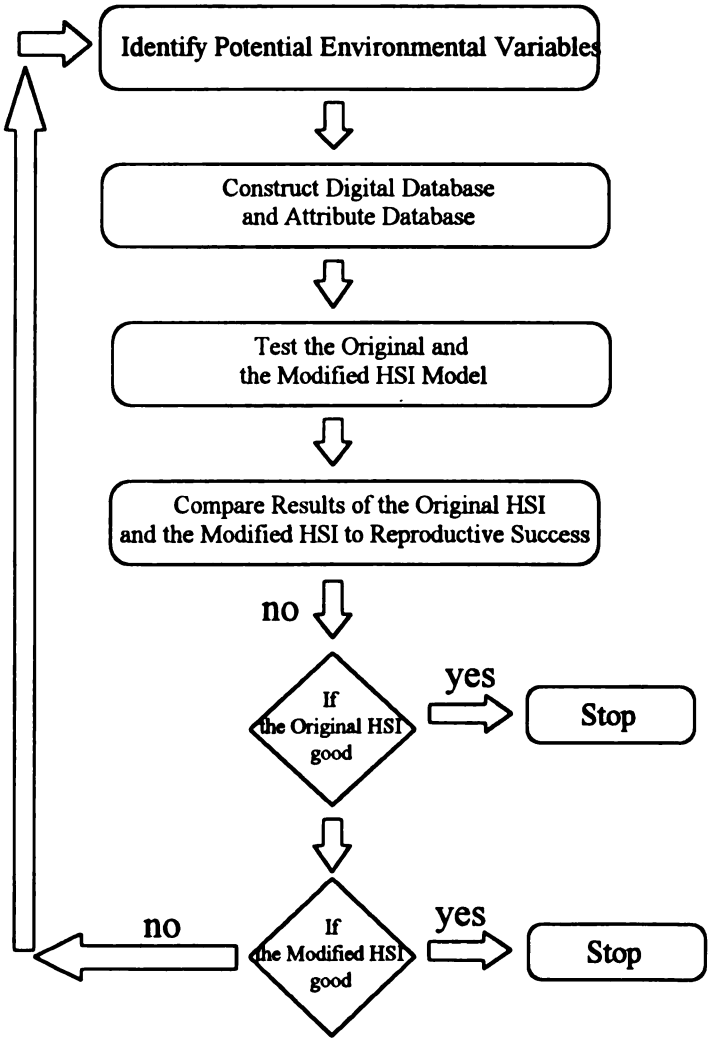


Figure 3.8. Model development flowchart.

3.5.1 Coverage Preparation

The GIS input data discussed earlier contained features that covered the whole landscape around the Tippy Dam Pond. This study evaluated only a portion of this landscape, focused on the individual nest sites. To be able to perform the site-specific studies, all the digital files needed to be constrained to the quarter-mile, and half-mile buffer zones of the eleven nest sites. The quarter-mile buffer zone was created by using a nest location as a center and building a buffer with a radius of 1,320 ft. around the nest. The half-mile buffer zone used a similar process but the area of interest in the half-mile buffer zone is the annulus between the half-mile radius and the quarter-mile radius. To generate an area with this doughnut shape, the quarter-mile buffer was used to eliminate the central area in the half-mile buffer using the ERASE command in ARC/INFO.

Following their construction, the quarter-mile and half-mile buffer zones were used as “cookie cutters” to “clip” all the input digital data (bathymetry, percent mature trees, number of houses, camping sites, number of white pine, highways, county roads, two-tracks, and electric lines). The INTERSECT command in ARC/INFO performs this task. For the purpose of clarity, these nine input files within both the quarter-mile and the half-mile buffer zones were uniquely named for each of the nest sites.

3.5.2 Data Analysis

The analysis procedures used for the quarter-mile buffer zones for both the original and the modified HSI will be explained in detail. The analysis for the half-mile buffer zones follow the same procedure. Nest 1 will be used to demonstrate the analyses, but all eleven nest sites were evaluated using the same method.

3.5.2.1 Original HSI Model

SIV2

The food availability factor of the model uses the morphoedaphic index (MEI) as an estimator of fish biomass productivity (Peterson, 1986). The MEI is calculated from the total dissolved solids contents of the water divided by its mean depth. The mean water depths within the buffer zones for the eleven nest sites are not equal and must be individually calculated.

An area-weighted mean depth was calculated for each nest site buffer zone in order to account for the steep bathymetric gradients found in some areas. The area-weighted mean depth of any of the buffer zones is equal to the sum of products of each depth polygon area times its mean depth divided by the total area of water within the zone. The calculation is demonstrated by using the attributes from nest location 1 (Table 3.1) below.

Table 3.1. Example mean-depth calculation.

	Area (square feet)	mean-depth (feet)	area x mean-depth
polygon 1	90337.141372.5	2.5	225842.85
polygon 2	1283418.37277	2.5	3208545.8
Total	1373755.51		3434388.65

$$\text{The area weighted mean} = \frac{(\text{area x mean-depth})}{\text{Total area}}$$

$$= \frac{3434388.65}{1373755.51} = 2.5$$

The area weighted mean of depth of nest 1 = 2.5

Total dissolved solids (TDS) content in Tippy Dam Pond (Table 3.2) was acquired from the quarterly water quality sampling conducted by Consumers Power Company from June to February during 1990 - 1991 (Environmental report p. E2-5).

Table 3.2. Tippy Pond water quality data (1990 - 1991).

	June	September	November	February
Total dissolved solids (ppm)	192	184	138	246

The average value of 190 was used for this study since it is close to the TDS value in June (192) which is the only month sampled during the breeding season (March - July).

The measurement of MEI can be done by using the total dissolved solids (TDS) in relation to water mean depth of the lake as following:

$$MEI = \frac{\text{total dissolved solids (ppm)}}{\text{water mean depth (feet)}} \quad \text{..... Eq. 3.5}$$

$$\text{For this example, the MEI} = \frac{190}{2.5} = 76$$

MEI of nest 1 = 76

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Table 3

The MEI of nest 1 (76) is related to an SIV2 value of 0.96. The food factor of habitat suitability (SIV2) is positively related to the MEI via a curvilinear function given by Peterson (1986) and shown in Figure 3.9.

SIV3

SIV3, the suitability index for bald eagle reproduction, is estimated by the percent of potential nesting area cover which is measured by the percent of mature trees in each nest's buffer zones.

To derive an average percent of mature trees for each nest site, an area weighted mean technique was used.

Figure 3.10 shows the polygons of percent mature trees within one-quarter mile around nest 1. Table 3.3 shows the area and percent mature trees for each of these polygons. The area weighted mean is calculated and shown below Table 3.3.

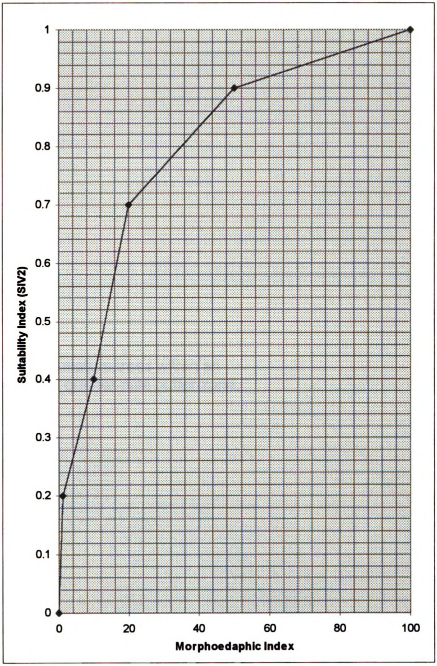

Figure 3.9. Suitability graph for Morphoedaphic Index (MEI).

Figure 3.10. Percent mature trees within an example quarter-mile buffer zone.

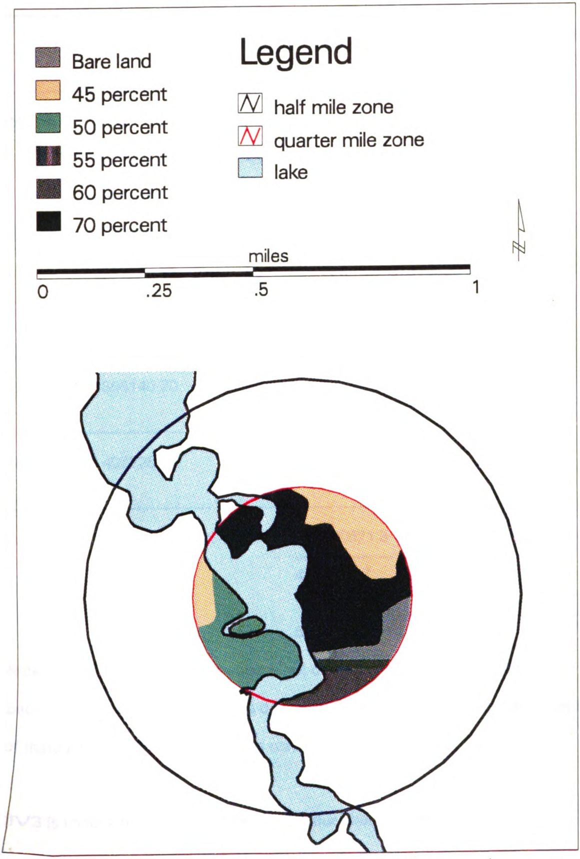
Legend
Bare land
45 percent
50 percent
55 percent
60 percent
70 percent
half mile zone
quarter mile zone
lake
miles
0
.25
.5
1
N

Table 3.3. Area and percentage of mature trees around nest 1.

Record	Area(square feet)	Percent	percent x area
1	662862.68	45	29828820.6
2	1763412.53	70	123438877.1
3	178000.09	45	8010004.05
4	756321.81	50	37816090.5
5	294089.58	0	0
6	61424.31	55	3378337.05
7	356140.70	60	21368442.00
Total	4072251.7		223840571.3

$$\text{Weighted area mean for nest 1} = \frac{223840571.3 \text{ (square feet x percent)}}{4072251.7 \text{ (square feet)}}$$

$$= 54.96 \text{ percent}$$

Note that the area covered by water is not considered for this calculation because the potential nesting area does not include the water. Only the percent of mature trees in the land area was considered.

SIV3 is linearly related to the percent of mature trees as shown in Figure 3.11.

The value of weighted percent mature trees of nest location 1 = 54.85. This value gave the value for SIV3 for nest location 1 = .72.

SIV4

The suitability index for human disturbance is estimated from an inverse, linear function housing density. The housing density in this study is defined as number of houses and camping sites divided by total land area within the study zone.

Number of houses and camping sites ,for example nest location 1 is equal to the number of records from the clipped housing coverage plus the number of record from the clipped campsite coverage:

Number of record in Housing1 = 9

Number of record in Camping-site1 = 0

So, there are 9 houses, and 0 camping sites in the quarter-mile buffer zone of nest 1. The total number of human disturbance points is equal to number of records in Housing1 added to the number of records in the Camping1 coverage.

Number of disturbance locations = 9 + 0 = 9

The total land area of nest location 1 is obtained from the Mature-trees1 coverage.

Total land area = 4072251.7 square feet = 0.38 square kilometers

$$\text{Housing density for nest location 1} = \frac{\text{Number of human disturbance points}}{\text{Total land area (square kilometer)}}$$

$$= 24$$

The housing density value (24) is plotted on the suitability graph of human disturbance (Figure 3.12) to produce an SIV4 of 0.

<u>**HSI**</u>

The three required variables for the original HSI model for nest sites are:

SIV2 = .96

SIV3 = .72

SIV4 = 0

From Eq. 3.1 the original $HSI = SIV2 \times (SIV3 \times SIV4)^{\frac{1}{2}}$

Nest 1 HSI value = $.96 \times (.72 \times 0)^{1/2} = 0$

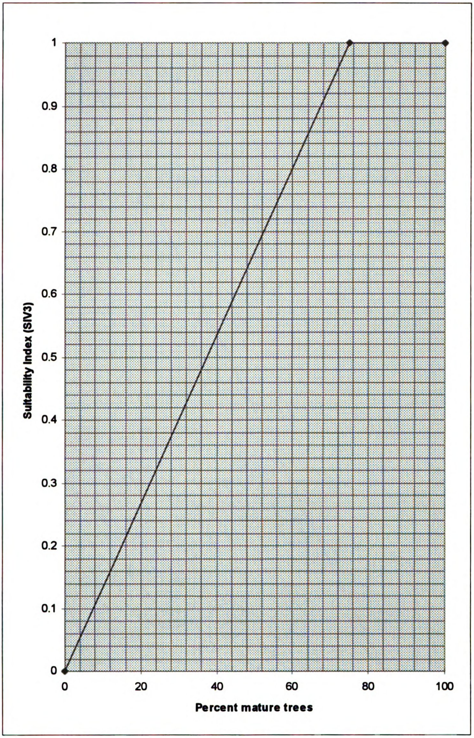

Figure 3.11. Suitability Index graph for percent mature trees.

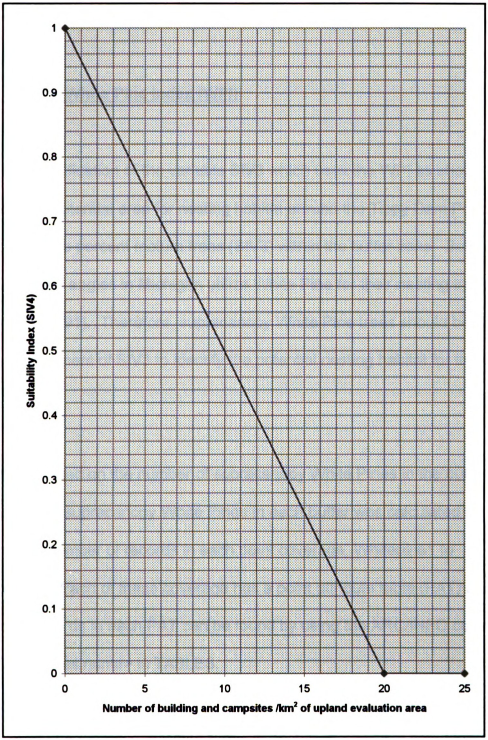

Figure 3.12. Suitability index graph for housing density of upland evaluation.

3.5.2.2 Modified model

SIV3p and the White Pine Index (WPI)

SIV3p is a modification of the variable SIV3 which uses the WPI as shown in Eq. 3.2. The potential area for nesting habitat around the Tippy Dam Pond was assessed by the percent mature trees (SIV3) within the buffer zone. But the majority of bald eagles in Michigan utilize White Pine for their nesting trees (Bowerman, 1991). Therefore, supracanopy White Pine trees should be used as another component of SIV3 to identify the potential nesting habitat for the bald eagle.

The WPI is based on the number of supracanopy White Pines in the buffer zone. The number of supracanopy White Pines in each buffer was calculated by counting the number of records in each point coverage, Whitepine1 to Whitepine11. Each of these coverage has a point attribute table (PAT) and the number of records in each PAT can be found by using the ARC/INFO command SELECT < tables name> in TABLES.

The number of supracanopy White Pines in each buffer zone is listed in Appendix A, Table 3 and Table 4. The highest number of White Pine in a quarter-mile buffer zone was 106 on nest 6. This number was used as the maximum number of white pine that result in a WPI value of .05 in the suitability graph. The highest value of the White Pine Index was set to .05 in order to add sensitivity to the presence of supracanopy White Pines into the percent mature trees factor (SIV3) without overly bias this factors. According to Bowerman (1991) " a potential breeding area includes 1 or more areas of 50.6 ha (125 acres) or greater located near forest or riparian edges, with at least 8 supracanopy White Pines of a 60.96 cm (24 inch) diameter at breast height (DBH) minimum.", was suggested by the Hiawatha National Forest (1986). With this suggestion the lowest number of supracanopy White Pines was set to 8. Sites containing eight or fewer supracanopy White Pines are assigned a WPI value of 0.01. Since the nesting tree is a point feature within a landscape habitat which is assessed by SIV3, allowing the additive WPI to spatially vary between 1 percent and 5 percent seem appropriate at this time. The White Pine Suitability Index is shown in Figure 3.13.

The quarter-mile buffer zone around nest site 1 contain 86 supracanopy White Pines. Using the relationship shows in Figure 3.11 the derived value of the White Pine Index for this site is .042. SIV3p is calculated from Eq. 3.2 as shown below:

$$SIV3p = (.72 + .042)^{1/2}$$
$$= 0.87$$

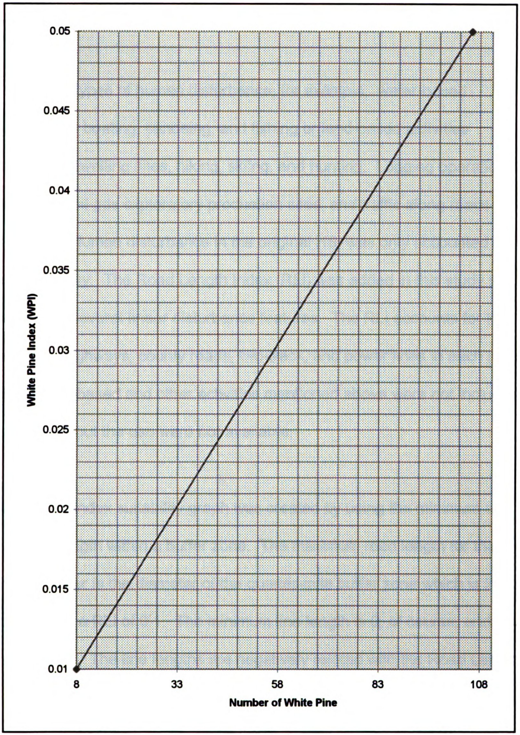

Figure 3.13. White Pine Index (WPI) graph based on the number of White Pines.

SIV4p and the Road Length Index (RLI)

There are many types of human disturbance, for example, water-based activities such as boating, canoeing, and fishing or land-based activities associated with dwelling sites, hiking, skiing, and hunting. Logging operation, extractive sites, oil gas exploratory production sites, and traffic along roads also disturb eagles. Human disturbance in the original HSI was only accounted for by housing density. The Road Length Index (RLI) was added in this study to compensate for several linear disturbance features. The RLI accounts for the total length of highways, county roads, two-track, and power lines in each buffer zone. The water-based and other activities mentioned above were not included because data about the use were not available.

The road length index suitability graph was created by using the minimum and maximum line length within a buffer zone. The maximum road length for the quarter-mile buffer is the diameter of the quarter-mile buffer zone which is 2,640 feet and is set to a RLI of 0.1. The minimum line length is 0, of course, and yields a RLI of 1. The line lengths are negatively related with the Road Length Index; the longer the summed lengths the lower the RLI.

The RLI was not set to 0 when the line lengths equal or exceed the maximum; instead the lowest RLI was set to 0.1 because its multiplicative against SIV4. If

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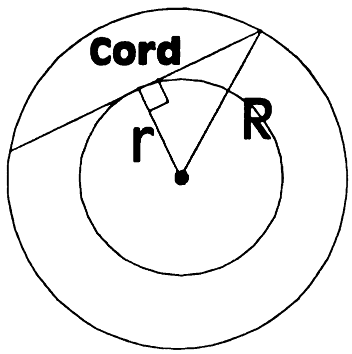
RLI was allowed to go to zero, it could completely null out the spatial variance of SIV4. It was decided that linear disturbance features should be able to lower SIV4 by no more than 90 percent (i.e. RLI = 0.1). The suitability graph of the Road Length is shown in Figure 3.14.

The RLI suitability graph for the half-mile buffer zone was created in the similar fashion. The only different was that the maximum value of the line length is equal to the cord of the circular doughnut shape in the half-mile zone as demonstrated in Figure 3.15.

Figure 3.15. Cord tangent to a quarter-mile buffer zone.



$\text{Cord} = 2\,(R^2 - r^2)^{1/2}$ .... (Eq. 3.6)

R = radius of the half-mile buffer zone (2640 feet)

r = radius of the quarter-mile buffer zone (1320 feet)

$\text{Cord} = 2\,(6969600 - 1742400)^{1/2} = 4573$ feet

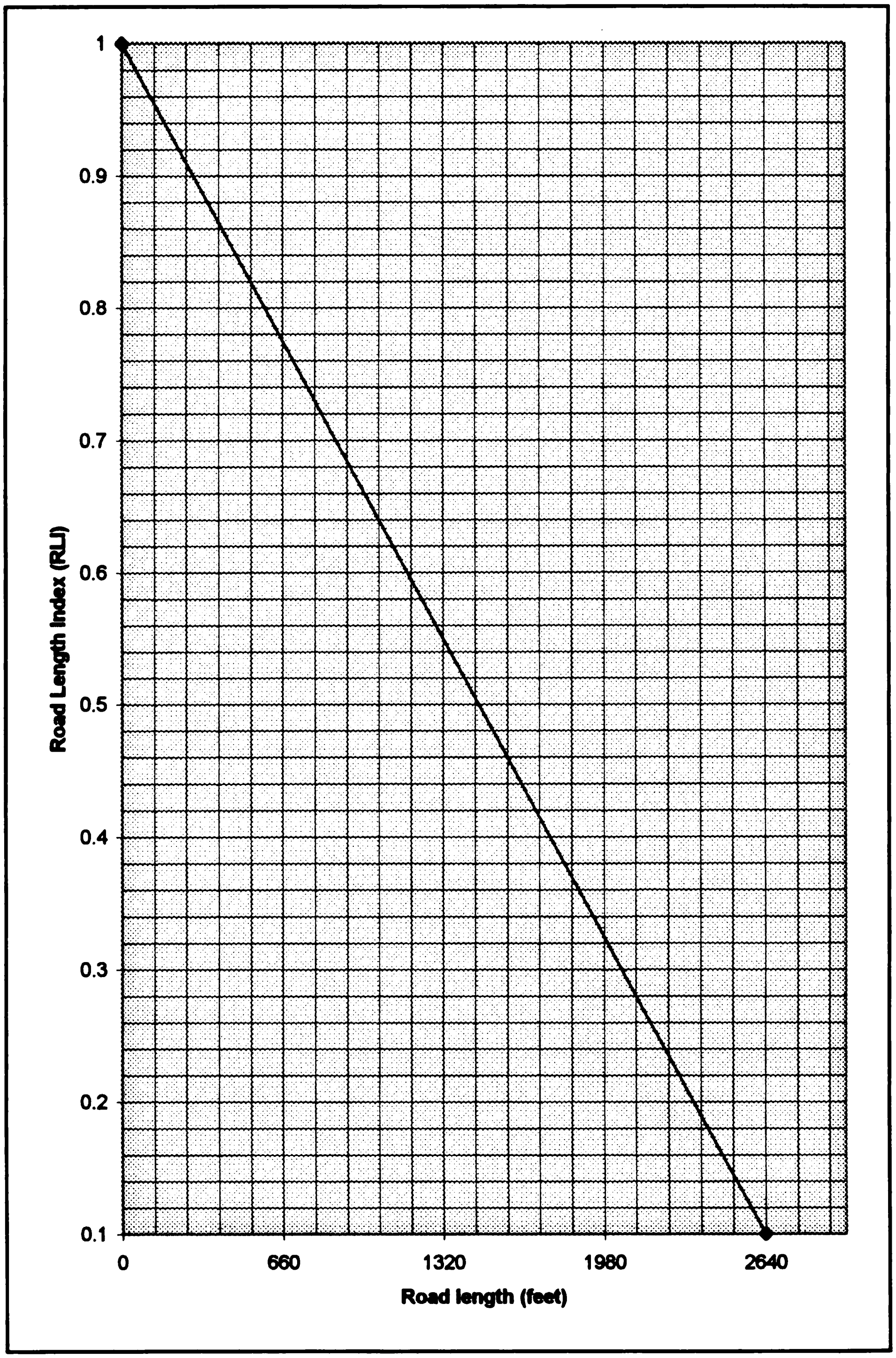


Figure 3.14. Road Length Index graph based on total road length within the quarter-mile buffer zone.

Therefore, the upper threshold value for the line length in the half-mile buffer zone = 4,573 feet which is assigned a value of the RLI = 0.1. The minimum of line disturbance length remains 0 which is set to a value of RLI 1. Figure 3.16. shows the suitability graph of RLI for the half-mile buffer zones.

To find the overall value of RLI for a buffer zone, the length of each linear disturbance feature was measured and multiplied times its weighting factor. The summed score of all the linear features was compared with the appropriate RLI suitability graph to derive the RLI value. The RLI feature weights are as follow (Table 3.4).

Table 3.4. Score for each linear feature.

feature	weight
highways	x 1.6
county roads	x 1.4
two-tracks	x 1.2
power lines	x 1.0

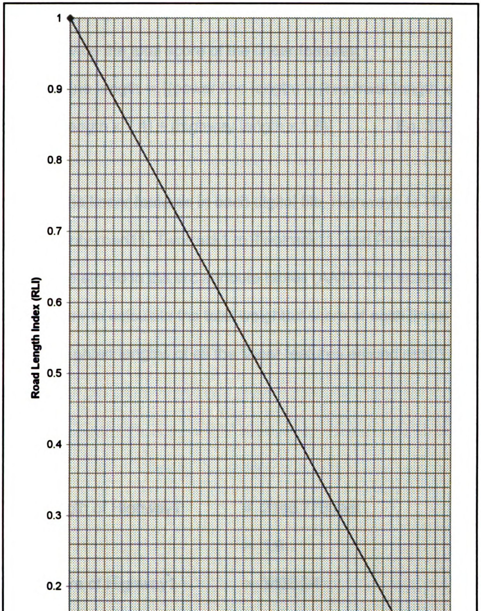


Figure 3.16. Road Length Index graph based on total road length within the half-mile buffer zone.

The weight for each line type was multiplied by its summed length in the buffer zone. The total weighted line length for all road types and power lines were added up to provide the total score of the linear features.

Total weighted line length = [(power line length) + (two-track length x 1.2) + (county road length x 1.4) + (highway length x 1.6)] .... Eq. 3.7

The lengths of the linear features in each digital file, Highway1 to Highway11, Cnty-road1 to Cnty-road11, Twotrack1 to Twotrack11, and Powerline1 to Powerline11, are stored in the arc attribute tables (AAT). The example below demonstrates how to calculate the total weighted score of each linear feature and the total weighted lengths of all the linear features around nest 1 to derive the RLI.

Highway1.AAT

Total length of Highway1	= 2145.776 feet
Score	= 1.6
Total score of Highway1	= 3433.24

Cnty-road1.AAT

Total length of Cnty-road1	= 0 feet
Score	= 1.4
Total score of Cnty-road1	= 0

Twotrack1.AAT

Total length of Twotrack1	=	2192.53 feet
Score	=	1.2
Total score of Twotrack1	=	2631.03

Powerline1.AAT

Total length of Powerline1	=	0
Score	=	1
Total score of Powerline1	=	0

Total score of the linear features = 3433.24 + 0 + 2631.03 + 0 = 6064.27

The total score of the linear features is greater than 2640 feet which equates on in the suitability graph to an RLI = 0.1. This value is used in Eq. 3.3

$$SIV4p = (SIV4 \times RLI)^{1/2}$$

$$SIV4p = (0 \times 0.1)^{1/2} = 0$$

In summary, the modified HSI model for nest site 1 = $SIV2 \times (SIV3p \times SIV4p)^{1/2}$

$$= 0.96 \times (0.87 \times 0)^{1/2}$$

$$= 0$$

In this case, the impact of the zero value from SIV4 is obvious.

CHAPTER 4

RESULTS

4.1 Introduction

The evaluation results of the original and the modified HSI of the eleven nest sites within the quarter-mile and the half-mile buffer zone will be presented. Charts and Tables will be used to visualize the results of all nest sites.

Explanation of the results will be based on the three bald eagle territories which subdivide the study area: Wellston, Red Bridge North, and Red Bridge South. Each territory was occupied by a nesting pair of eagles. Usually, several nests can be located in one territory and the eagle pair may occupy or build a different nest from one year to the next. These nests were use by the eagles over the period from 1975 to 1995.

The Wellston territory consists of nests 1, 2, 3, and 4. The second territory, Red Bridge South, comprises nests 5, 6, 7, 8, and 9. The last two nests, 10 and 11, make up the Red Bridge North territory.

4.2 Original Habitat Suitability Index Model (Original HSI)

The results of the original HSI model in the quarter-mile and the half-mile buffer zones, and the bald eagle reproductive outcomes are shown in Table 4.1 and Table 4.2, respectively, at the end of this chapter.

4.2.1 SIV2

The area-weighted average water depth around each nest determined the values of SIV2. Figure 4.1 shows the average water depth within the quarter-mile and half-mile buffer zones. More detail can be found in Appendix A, Table 1 and Table 2.

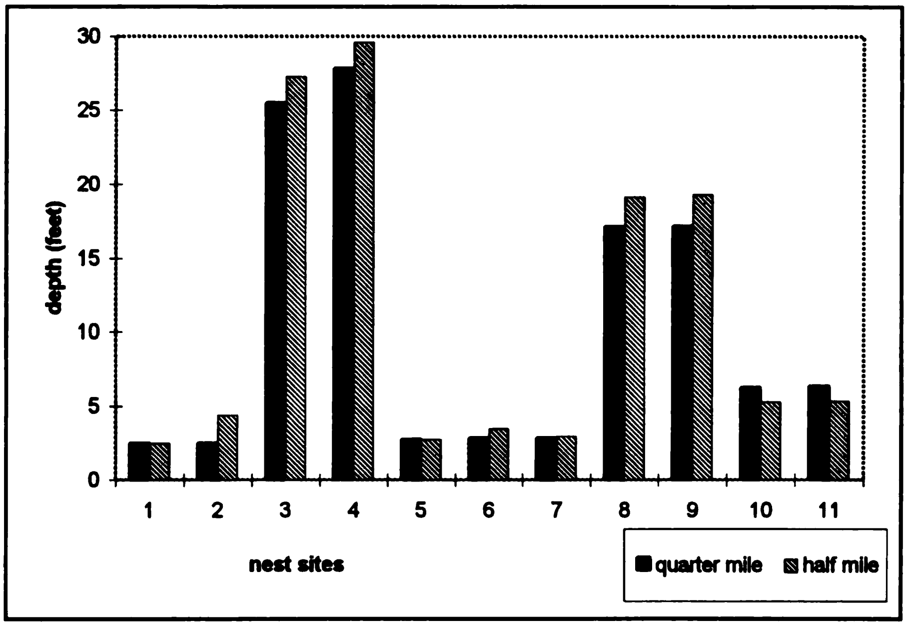


Figure 4.1. Mean water depth within the quarter-mile and half-mile buffer zones.

4.2.1.1 Wellston Territory

Nest 1 and nest 2 are located by shallow water (less than 5 feet deep) within the quarter-mile and the half-mile buffer zone. As shown in Appendix A, Table 1 and Table 2, the shallow water proximal to nest 1 and nest 2 in the quarter-mile zone gave high SIV2 values of 0.96 for both nest sites. The SIV2 values of nest 1 and nest 2 in the half-mile zone were 0.96 and 0.85, respectively.

The same eagles also occupied nest 3 and nest 4, however, where the deepest water was located (deeper than 25 feet). The average water depth around these two nests yielded very low values of SIV2; 0.35 and 0.33 in the quarter-mile, and 0.34, and 0.32 in the half-mile buffer zone, respectively.

4.2.1.2 Red Bridge South Territory

Three nests (5, 6 and 7) were located next to shallow water (less than 5 feet deep). The average water depth of nests 5, 6, and 7 yield very high SIV2 values of 0.94 in the quarter-mile buffer zone and 0.94, 0.91, and 0.93 in the half-mile zone.

The last two nests in this territory , 8 and 9, were located adjacent to rather deep water (deeper than 15 feet). The SIV2 was as low as 0.45 for both nests in the quarter-mile buffer zone , and 0.40 for both nests in the half-mile buffer zone.

4.2.1.3 Red Bridge North Territory

This territory contains nests 10 and 11. These two nests were located near moderately shallow water (less than 10 feet) in the quarter-mile and the half-mile buffer zone. The SIV2 values yielded from these water depths were 0 .77 in the quarter-mile, and 0.88 in the half-mile for both nests.

4.2.2 SIV3

The percentage of mature trees in the immediate area provides the value of SIV3. Figures 4.3 and 4.4 present the percentage of mature trees within the quarter-mile and the half-mile buffer zone, respectively.

The majority of mature trees in the quarter-mile buffer zone fell within the 51 - 75 percent range except for nest 1 and nest 2. Nests 1 and 2 contained mixed areas of tree growth where the percentage of mature trees ranged from 0 to 75 percent (see figure 4.3).

The percentage of mature trees in the half-mile buffer zone was somewhat different and can be put into 3 groups. The first group, nests 1 to 4, contains a mixed range of mature trees from 1-25 %, 26-50 %, 51-75%, and >75%. The percentage of mature trees in the second group, nest 5 to nest 9, were in 51- 75 range. The last group, nests 10 and 11, are dominated by well-stocked, mature forests (percent mature trees mostly 51-77% or higher than 75 percent).

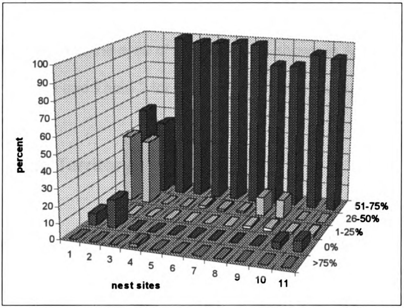


Figure 4.3. Percent mature trees within the quarter-mile buffer zone.

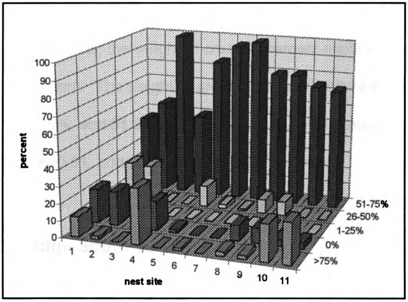


Figure 4.4. Percent mature trees within the half-mile buffer zone.

The weighted area of percent mature trees that was used to calculated the percent mature trees and the area of each group is shown in Appendix A, Table 1 for the quarter-mile and Table 2 for the half-mile buffer zone.

4.2.2.1 Wellston Territory

The weighted areas of percent mature trees in the quarter-mile buffer zone were not homogeneous, 54.89%, 48.67%, 65.56% , and 68.5% around nests 1, 2, 3, and 4, respectively. As a result, the SIV3 figures were 0.72, 0.65, 0.86, and 0.91 for the corresponding nest sites.

In the half-mile buffer zone, the weighted areas of percent mature trees also showed a similar pattern. The weighted areas of percent mature trees were 49.4%, 49.14%, 67.9%, and 61.22% for nests 1, 2, 3, and 4, and yielded SIV3 values of 0.66, 0.66, 0.91, and 0.81, respectively.

4.2.2.2 Red Bridge South Territory

The quarter-mile buffer zone produced quite homogeneous values for the weighted areas of percent mature trees in this territory: 68.28%, 69.36%, 65.97%, 60.55%, and 60.44%. The consequence of these percentages yielded

SIV3 values of 0.91, 0.92, 0.86, 0.8, and 0.8 to the corresponding nest sites (5, 6, 7, 8, and 9).

The weighted areas of percent mature trees of nests 5, 6, 7, 8, and 9 in the half-mile buffer were 62.5%, 67.95%, 66.95%, 56.51%, and 56.32%. The SIV3 figures were 0.83, 0.91, 0.9, 0.75, and 0.75 corresponding to each nest site.

4.2.2.3 Red Bridge North Territory

In the quarter-mile buffer zone, the SIV3 of nests 10 and 11, 0.88 and 0.86, were produced by the weighted area of percent mature trees of 66% and 64.48%, respectively.

The half-mile buffer zone consists of higher values for the weighted area of percent mature trees (71% and 71.79%) than the quarter-mile buffer zone. The corresponding values of SIV3 for nests 10 and 11 were also higher (0.94, and 0.96).

4.2.3 SIV4

Housing density, the total number of houses and the number of camping sites per square kilometer, were used to estimate the SIV4 within the quarter-mile and the half-mile buffer zones. Figure 4.5 shows the housing density around each nest site within the quarter-mile and the half-mile buffer zone. Appendix A, Table 1 and Table 2 show the actual number of housing and camping sites around each buffer zone.

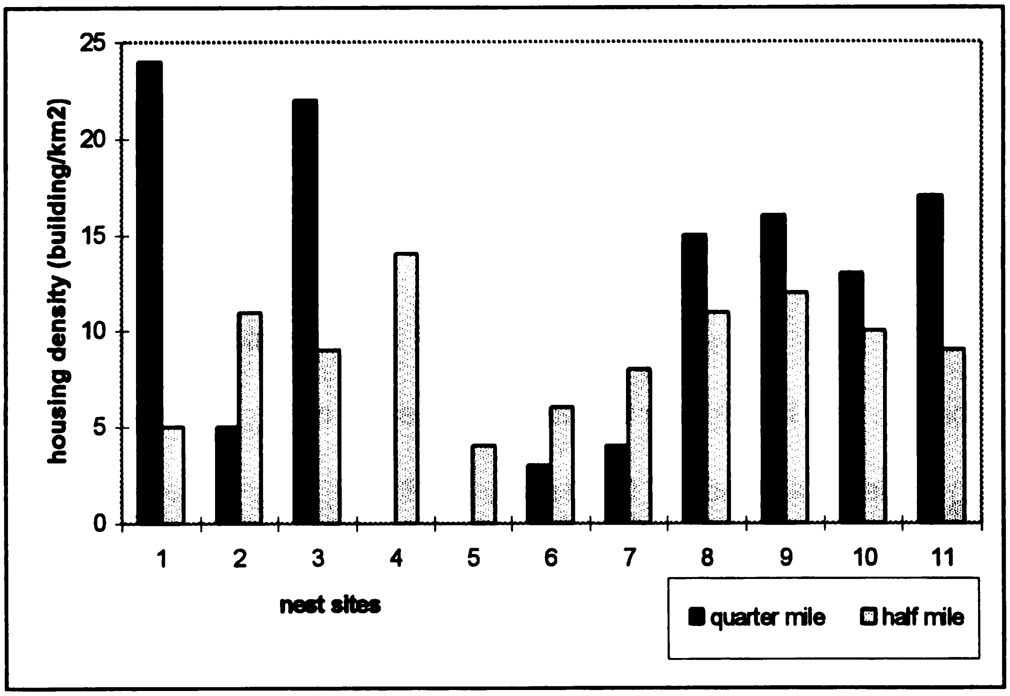


Figure 4.5. Housing density within the quarter-mile and half-mile buffer zones.

4.2.3.1 Wellston Territory

Notice in the quarter-mile buffer zone that the only nest that contained zero housing and camping sites was nest 4. Since there was no housing or camping site disturbance, the highest value of SIV4, 1.0, was produced.
For all the nests in this territory, nests 1 and 2 were the only two nesting areas that contained only houses; there were no camping sites around these two nests. Nest 1 was in a more populated area, having 9 houses, while the area surrounding nest 2 contained 2 homes. So, houses were the only component that accounted for the zero value of SIV4 for nest 1, and 0.75 for nest 2. Campsites were the only component that was responsible for the SIV4 of 0 for nest 3.

In the half-mile buffer zone, nests 1 and 2 were the only two nests that had houses and no camping sites. The number of houses around nest 1, and nest 2 were 7 and 14, respectively. The SIV4 values of 0.75, and 0.45 were produced, respectively, for the houses around the two nests. The area around nest 3 contained 9 camping sites but no houses. The SIV4 for nest 3 was 0.55. The only nest in this territory that was disturbed by both housing and camping sites (7 and 3, respectively) was nest 4. These housing and camping sites brought the value of the SIV4 down to 0.3.

4.2.3.2 Red Bridge South Territory

There were no housing sites in the quarter-mile buffer zones around any of the nest sites in this territory. Camping sites were the only component that accounted for the value of SIV4. Nest 5 had no camping sites nearby so the SIV4 was equal to 1.0. Nests 6 and 7, each contained 1 camping site that yielded the SIV4 value of 0.85 and 0.8, respectively. The quarter-mile buffers around the last two nests, 8 and 9, contained 4 camping sites each. These nests received SIV4 values of 0.25 and 0.2, respectively.

There was no housing sites within the half-mile buffer zones of any nest site within this territory. All five nest sites (5, 6, 7, 8, and 9) were within a half-mile of camping sites (5, 7, 9, 12, and 12 , respectively), yielding corresponding SIV4 values of 0.8, 0.7, 0.6, 0.45, and 0.4.

4.2.3.3 Red Bridge North Territory

Both nests in this territory (10 and 11) had quarter-mile buffer zones that contained of camping sites, (4 and 5, respectively) yielding SIV4 values of 0.35 and 0.15.

Nests 10 and 11 in the half-mile buffer zone had no housing disturbance. However, twelve camping sites were located around nest 10 and eleven campsites were nearby nest 11 producing SIV4 values of 0.5 and 0.55, respectively.

4.2.4 HSI

4.2.4.1 Wellston Territory

HSI values in the quarter-mile buffer zone were 0.0 for nests 1 and 3. Nests 2 and 4 produced HSI values of 0.67 and 0.315, respectively.

In the half-mile buffer zone, the HSI value of the four nests were varied. The highest HSI value of the four nests was 0.675 from nest 1. Nest 2 produced a moderate HSI value of 0.463. The HSI values of 0.24, and 0.158 were produced by nests 3 and 4, respectively.

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4.2.4.2 Red Bridge South Territory

Nests 5, 6, and 7 in the quarter-mile buffer zone produced rather high HSI values of 0.897, 0.832, and 0.78, respectively. The last two nests in this territory, 8 and 9, yielded quite low HSI values of 0.201 and 0.18, respectively.

In the half-mile buffer zones, nests 5, 6, and 7, produced rather high HSI values of 0.766, 0.726, and 0.683, respectively. An HSI value of 0.232 was produced by nest 8, and 0.219 by nest 9.

4.2.4.3 Red Bridge North Territory

In the quarter-mile buffer zones, the HSI values of the two nests were moderate to low. An HSI value of 0.427 was produced from nest 10, and a value of 0.277 from nest 11. The HSI value from the half-mile zone for nest 10 and nest 11 are quite similar; 0.548 and 0.581.

4.3 Modified Habitat Suitability Index Model (Modified HSI)

Results of the modified HSI model in the quarter-mile and the half-mile buffer zone including the bald eagle reproduction outcome are shown in Tables 4.3 and 4.4 respectively, at the end of this chapter.

4.3.1 SIV3p

The number of supracanopy white pines around each nest was used to estimate the SIV3p factor. The spatial variance of white pines in the vicinity of each nest will be examined using Figure 4.6. The values of SIV3p will be explained using Table 3 and Table 4 in Appendix A.

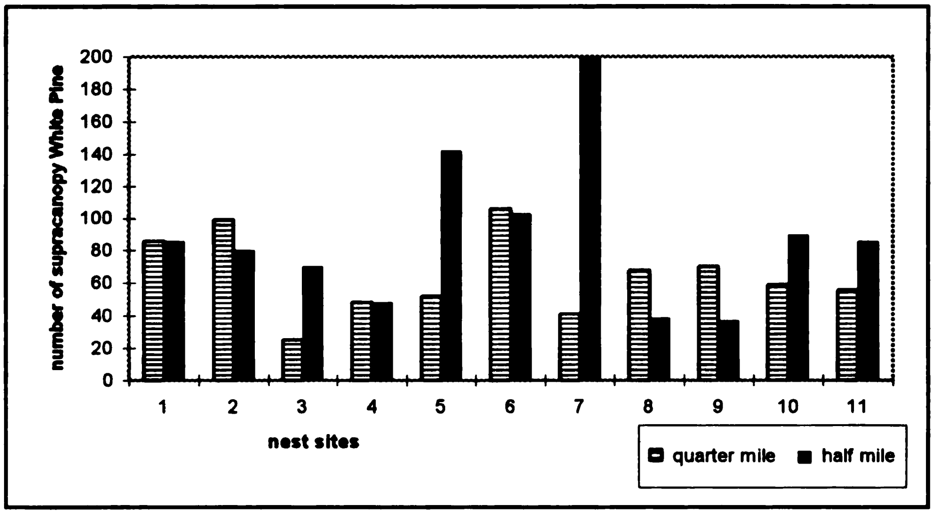

Figure 4.6. Number of supracanopy White Pine within the quarter-mile and half-mile buffer zones.

4.3.1.1 Wellston Territory

In the quarter-mile zones, nests 1 and 2 contain significantly more white pines than nests 3 and 4 (see figure 4.6). Nest site 3 has the fewest supracanopy white pines of any of the eleven nest locations. All of the sites have well over the minimum suggested number of white pines (eight).The results of the SIV3p calculations for all the nests in the quarter-mile zone were high. Nests 1, 2, 3, and 4 generated SIV3p values of 0.87, 0.83, 0.94, and 0.97, respectively.

A similar pattern exist among the half-mile zones: the number of white pines for nest 1 and nest 2 is greater than that for nest 3 and nest 4. The disparity in numbers of white pines between nests 1 and 2 and nest 3 and 4 is much less within the half-mile buffer zones. The half-mile SIV3p values for all the nests were high: nest 1 = 0.84, nest 2 = 0.84, nest 3 = 0.97, and nest 4 = 0.91.

4.3.1.2 Red Bridge South Territory

Supracanopy white pines in the quarter-mile buffer zones of nests 5, 7, 8, and 9 are nearly the same. Nest 6, on the other hand, had a significantly higher number of white pines. In fact, this location had the greatest concentration of white pines within the quarter-mile buffer of any of the eleven sites. The SIV3p values for all the nests were high; 0.97, 0.98, 0.94, 0.91, and 0.91 for nests 5, 6, 7, 8, and 9, respectively.

The half-mile buffer zones of, nests 5, 6, and 7 contain high to extremely high numbers of white pines, with the highest in the vicinity of nest 7. The lowest number of white pines appear around nests 8 and 9. The values of the SIV3p in nests 5, 6 and 7 (0.94, 0.98, 0.97) were higher than nests 8 and 9 (0.88 and 0.88).

4.3.1.3 Red Bridge North Territory

White pines for nest 10 and nest 11 were similar to one another in both the quarter-mile and the half-mile zones. The quarter-mile values of the SIV3p were 0.95 and 0.94. The proximity of these two nests accounts for their similarity. In the half-mile zones the SIV3p values were very high (nest 10 = 0.99, nest 11 = 1.0).

4.3.2 SIV4p

SIV4p values were the result of modifying the SIV4 factor of the original HSI model with the Road Length Index (RLI) as described in the methodology. Figure 4.7 explains the absolute road length. The details of RLI are portrayed in Tables 3 and 4 in Appendix A.

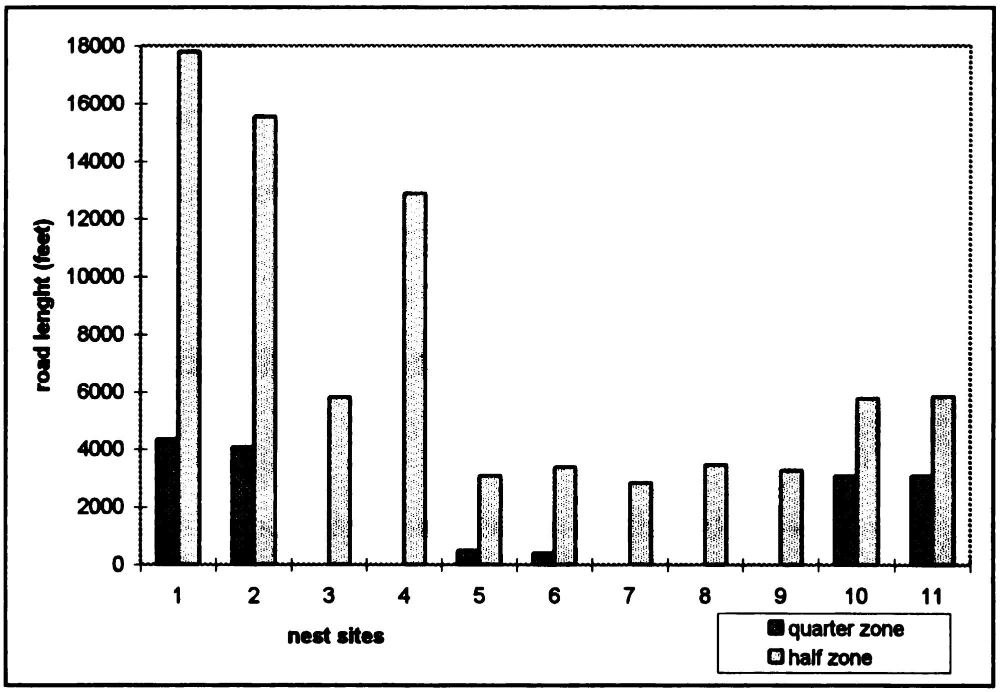

Figure 4.7. Road length within the quarter-mile and half-mile buffer zones.

4.3.2.1 Wellston Territory

In the quarter mile zones, nests 1 and 2 showed high disturbance from linear, cultural features (road length greater than 4,000 feet). On the other hand, there was no linear disturbance nearby nest 3 and nest 4. The RLI of nests 1, 2, 3, and 4 were 0.1, 0.1, 1.0 and 1.0, respectively.

The linear, cultural disturbance in the half-mile zones of nest 1, nest 2, and nest 4 was very high (greater than 12,000 feet). Nest 3 also showed a high value of road length (greater than 5,000 feet). Since the linear disturbance was so high, a low RLI value of 0.1 was determined for all nest sites.

4.3.2.2 Red Bridge South Territory

Linear disturbances in the quarter-mile zones of this territory were very low. Nests 7, 8, and 9 showed no linear disturbance features at all. These three nests were assigned the highest value of RLI = 1.0. There were small disturbances (less than 500 feet) in the quarter-mile zones of nest 5 and nest 6. The RLI around these two nests was, therefore, moderately high (0.79 and 0.8).

In the half-mile buffer zones, all the linear disturbances were somewhat high and distributed quite equally among all the nest sites. The RLI of 0.26, 0.19, 0.325, 0.17, and 0.22 were assigned to nests 5, 6, 7, 8, and 9, respectively.

4.3.2.3 Red Bridge North Territory

Nests 10 and 11 are proximal to high linear disturbances in the quarter-mile zones. The RLI for both nest sites was accordingly very low (0.1). The disturbance in the half-mile buffer zones for these two nests was also very high, yielding a minimum value of RLI = 0.1 for both nest sites.

4.3.3 HSI

Results of the modified HSI model in the quarter-mile and the half-mile buffer zones are shown in Tables 4.3 and 4.4.

4.3.3.1 Wellston Territory

The HSI values of nest 1 and nest 3 were 0 in the quarter-mile zone. Nest 2 and nest 3 produced moderate HSI values of 0.459 and 0.325, respectively.

In the half-mile buffer zones, HSI values of 0.459 and 0.358 were produced for nest 1 and nest 2. Nests 3 and 4 produced lower HSI values of 0.162, and 0.127, respectively.

4.3.3.2 Red Bridge South Territory

In the quarter-mile zones, nests 5, 6, and 7 produced high HSI values of 0.872, 0.847 and 0.862 respectively. The HSI values of nest 8 and nest 9 were lower (0.304 and 0.288) than the other three nests in this territory. Following a similar pattern, in the half-mile buffer zones, the HSI values of nests 5, 6, and 7 were moderate (0.614, 0.54, and 0.61) while the HSI values of nest 8 and nest 9 were low (0.197 and 0.204, respectively).

4.3.3.3 Red Bridge North Territory

Nest 10 and nest 11 in the quarter-mile zones produced HSI values of 0.325 and 0.262, respectively. In the half-mile zones, HSI values of 0.377 was produced from nest 10, and 0.388 from nest 11.

Table 4.1. Results of the original HSI model within the quarter-mile buffer zones.

SITE	SIV3	SIV4	sqrt(SIV3xSIV4)	SIV2	HSI	# Young	Year	Young/yr
1	0.72	0	0	0.96	0	0	1	0
2	0.65	0.75	0.689	0.96	0.67	2	1	2
3	0.86	0	0	0.35	0	2	1	2
4	0.91	1	0.954	0.33	0.315	7	5	1.4
5	0.91	1	0.954	0.94	0.897	4	10	0.4
6	0.92	0.85	0.884	0.94	0.832	0	1	0
7	0.86	0.8	0.829	0.94	0.78	1	1	1
8	0.8	0.25	0.447	0.45	0.201	9	6	1.5
9	0.8	0.2	0.4	0.45	0.18	6	3	2
10	0.88	0.35	0.555	0.77	0.427	0	1	0
11	0.86	0.15	0.359	0.77	0.277	3	3	1

Table 4.2. Results of the original HSI model within the half-mile buffer zones.

SITE	SIV3	SIV4	sqrt(SIV3xSIV4)	SIV2	HSI	# Young	Year	Young/yr
1	0.66	0.75	0.703	0.96	0.675	0	1	0
2	0.66	0.45	0.545	0.85	0.463	2	1	2
3	0.91	0.55	0.707	0.34	0.24	2	1	2
4	0.81	0.3	0.493	0.32	0.158	7	5	1.4
5	0.83	0.8	0.815	0.94	0.766	4	10	0.4
6	0.91	0.7	0.798	0.91	0.726	0	1	0
7	0.9	0.6	0.735	0.93	0.683	1	1	1
8	0.75	0.45	0.581	0.4	0.232	9	6	1.5
9	0.75	0.4	0.548	0.4	0.219	6	3	2
10	0.94	0.5	0.685	0.8	0.548	0	1	0
11	0.96	0.55	0.727	0.8	0.581	3	3	1

Table 4.3. Results of the modified HSI model within the quarter-miles buffer zones.

SITE	SIV3	WPI	SIV3p	SIV4	RLI	SIV4p	sqrt(SIV3pxSIV4p)	SIV2	HSI	# Young	Year	Young/yr
1	0.72	0.042	0.87	0	0.1	0	0	0.96	0	0	1	0
2	0.65	0.047	0.83	0.75	0.1	0.27	0.478	0.96	0.459	2	1	2
3	0.86	0.017	0.94	0	1	0	0	0.35	0	2	1	2
4	0.91	0.0265	0.97	1	1	1	0.984	0.33	0.325	7	5	1.4
5	0.91	0.028	0.97	1	0.79	0.889	0.928	0.94	0.872	4	10	0.4
6	0.92	0.05	0.98	0.85	0.8	0.825	0.901	0.94	0.847	0	1	0
7	0.86	0.024	0.94	0.8	1	0.894	0.917	0.94	0.862	1	1	1
8	0.8	0.0348	0.91	0.25	1	0.5	0.676	0.45	0.304	9	6	1.5
9	0.8	0.0351	0.91	0.2	1	0.447	0.639	0.45	0.288	6	3	2
10	0.88	0.031	0.95	0.35	0.1	0.187	0.422	0.77	0.325	0	1	0
11	0.86	0.03	0.94	0.15	0.1	0.122	0.34	0.77	0.262	3	3	1

Table 4.4. Results of the modified HSI model within the half-mile buffer zone.

SITE	SIV3	WPI	sqrt(WPI+SIV3) SIV3p	SIV4	RLI	sqrt(SIV4xRLI) SIV4p	sqrt(SIV3pxSIV4p)	SIV2	HSI	# Young	Year	Young/yr
1	0.66	0.042	0.84	0.75	0.1	0.27	0.48	0.96	0.459	0	1	0
2	0.66	0.0395	0.84	0.45	0.1	0.21	0.42	0.85	0.358	2	1	2
3	0.91	0.0351	0.97	0.55	0.1	0.23	0.48	0.34	0.162	2	1	2
4	0.81	0.0265	0.91	0.3	0.1	0.173	0.398	0.32	0.127	7	5	1.4
5	0.83	0.05	0.94	0.8	0.26	0.46	0.65	0.94	0.614	4	10	0.4
6	0.91	0.049	0.98	0.7	0.19	0.36	0.6	0.91	0.54	0	1	0
7	0.9	0.05	0.97	0.6	0.325	0.44	0.66	0.93	0.61	1	1	1
8	0.75	0.023	0.88	0.45	0.17	0.28	0.49	0.4	0.197	9	6	1.5
9	0.75	0.022	0.88	0.4	0.22	0.3	0.51	0.4	0.204	6	3	2
10	0.94	0.043	0.99	0.5	0.1	0.22	0.47	0.8	0.377	0	1	0
11	0.96	0.042	1	0.55	0.1	0.23	0.48	0.8	0.388	3	3	1

CHAPTER 5

DISCUSSION

5.1 Introduction

The original HSI model was designed to apply to a broad area across the country. It was not designed to fit problems in a specific area. In detailed site specific analysis, problems and associated factors can better be identified. To accommodate this need, the original model needs to be modified to handle specific problems in particular areas.

There are two drawbacks to the original HSI model. The first is human disturbance factor. Housing density is the only variable that accounts for this disturbance factor in the original model. In addition, the suitability graph for housing density is too general. It assumes that all the buildings (housing and camping sites) have the same intensity of disturbance to nesting eagles. This assumption may not be accurate. The type of activity and distance of the activity from the bald eagles had a big role to play in how disturbing the activity was to the bald eagles. Bowerman (1991) observed bald eagles behavior response to different type of human activities, and stated that ground-related human activities had the most impact follow by water and air borne activities. Distance determine the level of response to the activity by the bald eagles. As an example, human activities within 500 meter caused a 75 percent alert response in bald eagles (Bowerman, 1991). The suitability graph should be fine tuned to represent the intensity of common activities around each type of building structure. This study did not modify the suitability graph for housing density because no disturbance intensity data were available.

Other types of human disturbance are not addressed in the original HSI model. Road activities are not accounted for nor is disturbance due to power lines. The power lines themselves are not particularly detrimental to eagles. Rather, the use of power line clearance zone by humans (hiking, ORV, traffic, etc.) can be disturbing to nesting eagles. Both the disturbances from road or trail use and power lines clearance use are assigned quantified values of disturbance magnitude in the modified HSI model. Water-based human disturbances (swimming, fishing, and boating, etc.) were not accounted for in the original or the modified models.

Secondly, the suitability factor for bald eagle reproduction does not include an inventory of specific nesting trees (supracanopy White Pines in the Tippy Dam Pond landscape) except for the percentage of mature trees.

5.2 The Original HSI and the Modified HSI

The modified HSI model shows some improvements over the original HSI model. One obvious improvement is in the human disturbance factor. The changes to this factor allows the modified HSI model to assess the linear disturbance (highway, county roads, two tracks, and power lines) in the quarter-mile and half-mile buffer zones around each nest. The disturbance intensity of each linear type was also identified by assigning different scoring to each linear feature. The improvement of the human disturbance factor can be demonstrated by an example from nest 2.

The original HSI value of nest 2 (Table 4.1) was 0.67 with a housing disturbance (SIV4) score of 0.75. The addition of the linear disturbance score (RLI = 0.1) to the housing disturbance score (0.75), provided a new human disturbance (SIV4p)score of 0.27 (Table 4.3). With the SIV4p, the modified HSI produced a score of 0.459. The human disturbance score was adjusted by the RLI. Roads activities had shown a negative influence on the nesting bald eagle at nest 2.

Another improvement was the addition of the White Pine Index (WPI) to the suitability for reproduction index (SIV3). In Michigan, the majority of bald eagles nest on supracanopy White Pines (Bowerman 1993). Clusters of White Pines were observed from air photos interpretation around all nest sites. White Pines should be another key variable to indicate the habitat suitability for bald eagle reproduction. Since all nest sites consisted of clusters of White Pines, the adjusted original SIV3p was higher than the original SIV3 for all nest sites.

The modified HSI model appears to be more accurate in modeling the breeding bald eagle habitat than the original HSI model. Therefore, all of the following discussion will be specific to the modified HSI model.

5.3 General Observation

The value of SIV2 (determined by average water depth) varies across the landscape from nest 1 to nest 11. The implication of these values suggests that bald eagle nest locations were not based on the average water depth across the Tippy Dam Pond.

This can be demonstrated by the average water depth of each nest in the three territories (Appendix A, Table 1, and Table 3). In the Wellston territory, nest 1 and nest 2 were located adjacent to very shallow water, around 2.5 feet, while nest 3 and 4 are proximal to the deepest water (greater than 25 feet). The Red Bridge South territory contains five nests. The first three sites (5,6,7) are located along shallow water (less than 3 feet deep), while the other two nests (8,9) are next to deeper water (greater than 17 feet). Finally, in the Red Bridge North territory, the two nest sites (10, 11) are located along moderately shallow water (around 6 feet).

Even though the average water depth of all nest sites varied, each territory had at least one neighborhood that contained shallow water. As an example, although the average water depth of nest sites 10 and 11 (Red Bridge North territory) was moderate, these nests were close (about half mile) to the shallowest part of the Tippy Dam Pond. Thus shallow water areas were part of all nesting territories.

5.4 The Modified HSI and the Fledgling Production

Bald eagle reproduction is the only available independent measurement for this study. The reproduction success of each nest site for each territory will be compared with the HSI scores. The comparisons will also examine the landscape attributes around the nest and the territory. The discussion will be based on the results of Table 4.3 and Table 4.4, and APPENDIX A Table 3 and Table 4. The discussion will focus on the quarter-mile buffer zone since it is an exclusive zone for bald eagle management plans.

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5.4.1 Wellston Territory

A pair of breeding eagles started utilizing the area during the 1980s. This territory was occupied for 8 years, and a total of 11 young were produced. Nest 4 was the most productive and was occupied the longest (5 years), with an average production of 1.4 young per year.

Nest 1, 2, and 3, each were occupied for only 1 year. Nest 2 and 3 produced a rather high yearly average number of two fledglings per year. Nest site 1 produced no young. However, from a wildlife biologist perspective (Ennis pers. comm.), a one-year occupancy is not sufficient for determining the relationship of the nest site and the habitat suitability around the nest.

5.4.1.1 The Quarter-Mile Buffer zone

The HSI values for the quarter-mile buffer zone for each nest site were different except for nests 1 and 3. These nests generated HSI scores of 0 while nests 2 and 4 produced HSI scores of 0.459, and 0.325 respectively.

The HSI scores of nests 1 and 3 were influenced by the SIV4 value. The housing around nest 1 was the only factor that gave the SIV4 value of 0 while the density of camping sites determined the SIV4 value of 0 for nest 3 (Table 3, Appendix A).

It is not appropriate to say that these two nests contained 0 or no habitat suitable for nesting eagles. As mentioned earlier in the discussion of the drawbacks of the suitability graph for housing disturbance, the intensity of the activity around different building structures is not accounted for. The suitability graph for housing density assumes that all building structures produce the same amount of disturbance intensity. The HSI scores of nest 1 and nest 3 show the consequences of that assumption. Since these two nests were occupied for only 1 year in different time periods, there was not enough information to justify the 0 values of the HSI.

In looking at nest 2 and nest 4, it can be seen that the HSI score of nest 2 was higher (0.459) than nest 4 (0.325). While both sites had high reproduction success (2 young per year for nest 2 and 1.4 young per year for nest 2), nest 4 was occupied for a longer period of time (5 years) compared to nest 2 (1 year). This raises the question of why nest 4 produced a lower HSI value than nest 2. Since nest 4 was located near deeper water than nest 2, the SIV2 for nest 4 would be lower (0.33) than the SIV2 for nest 2 (0.96). The contribution of the average water depth to the HSI model results in the lower HSI value of nest 4.

Further investigation was carried out to determine whether the SIV2 (determined by the average water depth) around each nest provided enough information to judge the food supply for each nest. Wildlife biologist Rex Ennis, at the Huron-Manistee National Forest, observed that bald eagles in Wellston territory foraged around the delta where the Pine River enters the Tippy Dam pond. This delta is located in the vicinity of the quarter-mile buffer zone of nest 1 and nest 2. The average water depth of nests 1 and 2 is shallow (2.5 feet) which produced an SIV2 value of 0.96. From field observations, the food source for the eagles occupying nest 4 was provided by the areas around nest 1 and nest 2 (which have a high value of SIV2 of 0.96). Accordingly, the HSI value of nest 4 should be recalculated by substituting the SIV2 value of nest 4 (0.33) with the SIV2 of nest 2 (0.96). The adjusted HSI value of nest 4 should be:

$$HSIp = (SIV3p \times SIV4p)^{1/2} \times SIV2 = (0.97 \times 1)^{1/2} \times (0.96) = 0.945$$

The SIV2 value calculated within a quarter-mile radius of a nest site did not adequately assess the actual food supply for each nest site.

5.4.1.2 The Half-Mile Buffer Zone

Looking beyond the quarter-mile to the half-mile buffer zone around nest 4, there was high disturbance potential from housing and camping sites, and from linear disturbance features that brought the HSI value in the half-mile zone down to 0.381 by the calculation below (note: SIV2 = 0.96 will be used for the same reason give above)

$$HSIp = (0.91 \times 0.173)^{1/2} \times 0.96 = 0.381$$

The intensity of human impact on bald eagles depends on the timing of the activities, the distance the activities are from the nest, and the visual view that eagles have of the activities (Therres et al., 1993). Bald eagles seem to avoid areas of high human disturbance. On occasions, when the disturbances around the nests were high, bald eagles utilized vegetation as a buffer to avoid viewing human activities (Juenemann, 1973; Therres et al., 1993). This may explain the situation of bald eagles utilizing nest 4 in the Wellston territory.

5.4.2 Red Bridge South Territory

Nesting eagles have occupied this territory for 21 years and produced 20 young. Overall five different locations have been used for nesting. Two nests (6 and 7) were occupied for only one year. Nest 5 was utilized for the greatest number of years, (10 years), though not continuously for this period of time. The birds moved among three nest sites (5, 6, and 7), starting with nest 5 for two years, then to nest 6 for 1 year, back to nest 5 for 7 years, then to nest 7 for 1 year.

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They moved to other nests (8,9) for 5 years and then back to nest 5 for one year.

This nesting pair of eagles seems to favor nest 5. The reasons that the Red Bridge South pair moved around the area are uncertain. However, some activities around the site may explain their behavior. Nest 5, 6, and 7 are located near the boat launch (west bank, immediately downstream from Red Bridge). Boats traveling downstream from the boat launch Nests (moving toward Tippy Dam Pond) enter the Red Bridge South territory. As a result, recreation activities such as boating and fishing may occur very close to these nest sites. These human activities may have disturbed the nesting birds causing them to move around the area in subsequent years in an attempt to find a peaceful nest site.

5.4.2.1 The Quarter-Mile Buffer Zone

Nests 5, 6, and 7 are located very close to each other. The reluctance of the birds to move away from these sites entirely, could indicate that the area provides good environmental factors for nesting and foraging despite the human disturbances. In the quarter-mile buffer zone, the HSI values for nests 5, 6, and 7 were high (0.872, 0.847, and 0.862) as expected. The suitability index for reproduction (SIV3p) was 0.97, 0.98, and 0.94 for nest 5, nest 6, and nest 7, respectively.

There was no housing and very few camping sites in the area: 0 for nest 5, and only 1 for nest 6 and nest 7. So building disturbance was low and thus yielded high SIV4p values (1, 0.85, and 0.8). The linear disturbance potential from roads and power lines was also low. Together, these environmental factors provided high HSI values for nests 5, 6, and 7.

Nest 5 produced the highest HSI value (0.872) of all the nest sites around the Tippy Dam Pond. The reproduction average of nest 5 over the 10 years it has been occupied, however, was only 0.4 young per year. Nest 6, which was occupied for only one year, had no production. Nest 7, which was also occupied for only 1 year produced one eaglet.

It is necessary to examine why the rate of bald eagle reproduction from these three nests was low when their HSI values were so high. The suitability index for reproduction (SIV3p) was high, and the land-based human disturbances were low which yields high SIV4p values. It is important to note, however, that neither the original HSI model nor the modified HSI model accounted for water-based human disturbances (the intensity of boating, canoeing, swimming, and fishing activities). If included in the analysis, water-based human disturbances would un

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undoubtedly lower the HSI values of nests 5, 6, and 7. Lower HSI values for these sites would agree more favorably with the eagle reproduction data.

Ironically, the HSI values of nests 8 and 9 were lower than the three previous nests, but the productivity was higher. Nest 8 was occupied for 6 years and produced 9 young; an average production of 1.5 young per year. The eagles occupied nest 9 for 3 years producing 6 young, an average of 2 offspring per year. Two factors could be responsible for these results.

Nests 8 and 9 are located adjacent to moderately shallow water. The problems of the SIV4 factor (human disturbance) were from the suitability graph discussed earlier (place-based rather than activity-intensity-based). The average water depth of these two sites was moderate, resulting in an SIV2 value of 0.45 for both nests. There were no data existing on the foraging habitat of this breeding pair. No reason to believe that they would not forage as far away from their nest as the breeding pair at nest 4 did. Under these conditions an adjustment of the suitability index may be appropriate. An adjustment of the suitability index for food (SIV2) can be substituted in a similar manner to that of the Wellston territory. If the SIV2 values of nests 8 and 9 are replaced by the SIV2 value of 0.94 from the three other nests (5, 6, and 7), the new HSI would be:

$$\text{HSIp for nest 8} = (\text{SIV3p} \times \text{SIV4p})^{1/2} \times \text{SIV2}$$

$$= (0.91 \times 0.5)^{1/2} \times 0.94 = 0.634$$

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HSIp for nest 9 = $(0.91 \times 0.447)^{1/2} \times 0.94$

= 0.60

These adjusted HSI values for nests 8 and 9 (0.634 vs. 0.304; 0.60 vs. 0.288, respectively) are more in concert with the reproduction data, but in comparison with similar relationships from nest 4 (adjusted HSIp = 0.945 vs. average reproduction of 1.4 young per year) these indicate that the amount of unexplained variance is still some what high.

5.4.2.2 The Half-Mile Buffer Zone

The results of the HSI and the factors that control it within the half-mile buffer zones are very similar to those from the quarter-mile zones. The half-mile HSI scores of all nest sites were lower than the quarter-mile HSI scores due to the larger linear disturbances from two-tracks and the increase point disturbances from camping sites. This spatial relationship suggests two things. First, suitable eagle breeding habitat in the Tippy Dam Pond area is very insular. Much of the landscape is fragmented or disturbed. Second, the spatial density of two tracks and camping areas, or at least the timing of their use, is a problem that can be mitigated by management planning.

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5.4.3 Red Bridge North Territory

Breeding eagles moved into this territory in the early 1990s. It has been occupied for 4 years and 3 young were produced . This pair of eagles occupied nest 10 for 1 year and produced no young. They have used nest 11 for 3 years and have produced 3 young at this site.

5.4.3.1 The Quarter-Mile Buffer Zone

In the quarter-mile buffer zone, the HSI values of these two nests are low: 0.325 for nest 10 and 0.262 for nest 11. Camping sites were the only point disturbance that influenced the value of the SIV4. Linear disturbances of these two sites were due to two-tracks. The disturbance of two-tracks reached the maximum-value threshold and pulled the value of the RLI down to its minimum (i.e. 0.1).

Two variables for these sites could be adjusted based on field observations and the assumption: the linear disturbance factor and the SIV2 (food/foraging factor). Around the two nest sites, the RLI was influenced by the presence of two tracks. However, the two-track on the east side of the Pond were closed to the public during the breeding season (Ennis pers. comm.) but it is not certain if two-tracks within the quarter-miles zone at the west side of the Pond were closed to public during the breeding season (Schumacher pers. comm.). The total length of two track

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track at the west side was measured to be 879.38 feet long around nest 10, and 1265.69 feet around nest 11. If the disturbance on the west side of the river is only considered, the RLI values of nests 10 and 11 that were measured from the total two-track length would be around 0.71, and 0.57 respectively.

The foraging habitat data of the Red Bridge North territory did not exist. The same assumption about the foraging area previously applied to the Red Bridge South territory could apply to this area. Nest 10 and 11 were located about half mile away from the shallow water where nest 5 was located. So the SIV2 of nest 5 (a Red Bridge South Territory site) could be used to substitute for the SIV2 of nests 10 and 11. The adjusted HSI values of nests 10 and 11 after modifying the SIV2 and the RLI can be seen below:

RLI = 0.71 for nest 10

RLI = 0.57 for nest 11

SIV2 = 0.94 for both nest sites (10, 11)

Nest 10

$$SIV4p = (SIV4 \times RLI)^{1/2}$$

$$SIV4p = (0.35 \times 0.71)^{1/2} = 0.498$$

$$HSIp = (SIV4p \times SIV3p)^{1/2} \times SIV2$$

$$= (0.498 \times 0.95)^{1/2} \times 0.94$$

$$= .647$$

Nest 11 $SIV4p = (0.15 \times 0.57)^{1/2} = 0.292$

$HSIp = (0.292 \times .94)^{1/2} \times 0.94$

$= 0.492$

5.4.3.2 The Half-Mile Buffer Zone

The HSI values in the half-mile buffer zone of nest 10 and 11 are a little bit higher then the HSI in the quarter-mile zone (0.377 vs. 0.325 and 0.388 vs. 0.262 for nest 10 and 11, respectively) from three reasons: SIV3p, SIV4p and SIV2. The half-mile buffer zone comprised a little bit higher values of SIV3p (0.99 and 1 for nest 10 and 11), and SIV2 of 0.8 for both nests. The housing disturbance in the half-mile zones were a little bit lower than the quarter-mile zones but the linear disturbance remained the same. Thus, the values of SIV4p for nest 10 and 11 in the half-mile buffer zone (0.22 and 0.23 respectively) were a little bit higher than the values of SIV4p in the quarter-mile buffer zone (0.187 and 0.122 for nest 10 and 11 respectively). Notice that human disturbance factors were controlled by camping sites and two-tracks. The same discussion of the half-mile buffer zone of Red Bridge South can also be applied in the Red Bridge North territory.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Conclusions

The central focus of this thesis was the adequacy of the original HSI model for the breeding bald eagle to explain spatial variance of nest-specific reproductive success. The original HSI model is not sufficient to evaluate the habitat suitability for the bald eagle around the Tippy Dam Pond. Many human disturbance activities around the landscape were not accounted for by the original HSI model. The human disturbance factor of the model only addressed point disturbances: housing and camping sites. In addition to the lack of variables that explain the human disturbance component, the suitability graph that was used to measure the suitability index for the housing and camping sites assumed that these two features generated the same intensity of disturbance to bald eagles. The suitability index for food, represented by factor SIV2 was not sufficient to measure the food supply of the bald eagles. There were not enough data about available food sources around the Tippy Dam Pond to adequately adjust the SIV2. As an example, nest site 4 has a very low SIV2 factor score, but in reality the eagle occupants of this site forage several miles away in an area with an outstanding SIV2 characteristic.

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The first subsidiary question of the thesis was what additional factors that contribute to the quality of the habitat for bald eagle might be added to the HSI model to improve its ability to explain nest-specific reproductive success. The modified model was created to adjust the HSI values to account for some of the missing attributes in the original model. It was obvious that the human disturbance factors of the HSI model needed to be refined. The land-based activities that were included in the modified HSI model cover human disturbances associated with housing and camping sites, various classes of roads and trails, and power line clearances. It was not feasible for this study to identify the disturbance intensity from either housing or camping sites. The suitability graph of the building disturbance from the original HSI model was used in the modified HSI model. The intensity of linear disturbance from highways, county roads, two tracks, and power lines were weighted by multiplying an assumed, relative value of disturbance magnitude to each linear feature type. The values of the magnitude that were assigned to these various linear disturbance features were estimated from field observations made by Bowerman (1991).

Even though the modified HSI model has two additional variables, it does not adequately predict the habitat suitability for the nesting bald eagles as measured by their reproductive success. Suggested additional habitat details that are needed to more completely define the model will be reviewed in the next section.

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The second subsidiary research question dealt with the appropriate scale of landscape evaluation when assessing nest-specific areas regarding habitat quality for breeding bald eagles. As shown in the differences in factor scores between the quarter-mile and the half-mile buffer zones, suitable bald eagle habitat in the Tippy Dam area is very insular and the landscape is highly fragmented in terms of disturbance and resources. The two fixed-distance buffer zones that were used for all factors were not adequate to explain how bald eagles use their habitat. The food factor that was calculated within the buffer zones was totally wrong since many of the birds foraged outside these buffer zones.

The third and final subsidiary question is the benefit of implementing HSI model in a GIS. ARC/INFO provides the Arc Macro Language (AML) to collect all the necessary commands to process the analysis for the HSI model. Using macros in a GIS allows the analysis to be quickly modified. This saves a great deal of time over manual operation methods and makes it possible to conduct iterative trials, or "what if" scenario investigations. This approach is critical to support the need to modify the HSI model to account for site-specific conditions.

GIS did provide the ability to easily calculate and analyze the HSI values for each nest site. However, the values of HSI from the computer analysis of standard environmental variables are not enough to accurately interpret actual habitat suitability. Field observations need to be incorporated into the GIS analysis. Field data are the key factor to understanding bald eagle behavior, the portions of the landscape they use, their response to various disturbances, and to accurately interpret the HSI values of each nest sites relative to their reproductive success.

The modified HSI model is an improvement, but it still is not an optimum model. Further research needs to be done to make the model more accurately correlate with the fledgling production. The modified model should be applied to other FERC regulated impoundments in northern Lower Michigan since the same data are likely to be available. The importance of this work is that there are many FERC relicensing activities under way both in Michigan and the Upper Great Lakes. The approach investigated in this study should be tried in several of these other areas as a means of at least promoting discussion, although it is probable that new eagle management insights will be gained. Federal and state agencies are under statutory mandate to manage bald eagle habitat. The fact that the quantitative model is at present not perfect is of lesser importance; it is far better than nothing at all. The model will provide some information although it must be recognizing that it is imperfect information. The spatial nature of the model and the ability to rapidly modify it make possible the identification of the next important factors to be assessed.

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This thesis has made a contribution not only to professional wildlife managers but also to the discipline of geography. This study falls into the realm of method development under the spatial analysis tradition of the discipline and it certainly falls under the human-environmental interaction portion of the discipline. Its connections with biogeography, both flora and fauna, are obvious.

6.2 Suggestions For Future Research

It is suggested that a Geographic Information System (GIS) be used for further evaluation of the modified HSI model. The federal and state agencies responsible for bald eagle management plans should structure the data they collect so that they can be readily used in a GIS (e.g. easily extracted from field records for later analysis). Importantly, bald eagle nest locations and foraging areas (keyed to specific eagle individuals) should be located on USGS topographical maps for reference. The quantitative data related to the bald eagles should be recorded in a database format. Bald eagle field observations need to be documented for each time period that the eagles are utilizing the locations.

Recreational data is another key, missing component to answering several questions for this study. Potential recreation data that may be helpful for future modifications of the HSI model is the magnitude, range, and temporal distribution of water-based recreation, the frequency of housing and camping area use, and the disturbance intensity of camping and housing during the nesting season, especially in the incubation period. Human disturbance has the most critical impact on bald eagles during the egg-laying and incubating period (Mathisen, 1969), and the highest mortality rate of bald eagles was at the egg stage (Chrest, 1964). During these periods the nesting birds have the least tolerance to external disturbances and may abandon their nests and leave the area. Chrest (1964) recommended that during the incubation period human activities should not be present around the nests.

Data regarding water-based recreation including boating, jet skiing, fishing, canoeing, and swimming are critically needed, especially in the Red Bridge South and Red Bridge North territories. The response of the eagles to each of these water-based activities, and the number and type of activity needs to be inventoried and assessed. For example, the type of boat and the responses of the eagles to each boat type, number of boats, and the activity from the boats in the nesting area should be studied. In addition, the boat launch just downstream from Red Bridge appears to promote the frequency and intensity of human disturbances affecting the eagles of this area. These impacts must be more fully studied.

The intensity and type of activity related to the response of bald eagles around residential housing and the camping sites also needs to be addressed. The focus of such an activity intensity study is to verify or modify the suitability graph for human disturbance from housing and camping sites. SIV4 could be stored as either area or point data as long as intensity of disturbance is the attribute. A proximity analysis (distance weighting scheme) should be incorporated into the disturbance intensity evaluation. Proximity captures the sense that the closer the features are to the nesting eagles the greater the influence the feature has on the eagles. The concept of proximity analysis is only practical using GIS technology. All new variables should be considered as candidates for such proximity weighting schemes. The interaction and intensity of human activities (fishing, boating, and swimming etc.) in the bald eagle foraging areas also should be investigated.

More information is needed to indicate the food factor for the bald eagles. This factor should include the amount and the location of fish in the reservoir, and other important food sources for the breeding eagle when a fish source is not available. The new food factors can be used to replace or to adjust the value of SIV2. The SIV2 was estimated from the morphoedaphic index (MEI). The MEI is the relation of the total dissolved solids (TDS units in ppm) to the average mean depth of water. The total dissolved solids (TDS) data around each nest in the Tippy Dam Pond does not exist. The TDS data that was used for this study was from the quarterly water quality sample conducted during 1990 - 1991 by Consumers Power Company. Water samples for the analysis of TDS were gathered from mid-depth at the deepest portion of Tippy Pond in front of the power house. The MEI was used according to Peterson (1986) from the study of Ryder (1965) and Jenkins (1982) that fish biomass density were assumed to increase with the MEI. A study of the actual fish biomass density should be done to verify the relationship between MEI around each nest sites and the potential feeding areas.

Most especially, it is clear that improved methods of spatial analysis of HSI are required. In hindsight, the use of fixed buffer zone widths/shapes for all factors is inappropriate. Especially regarding the food factor, sites may be better evaluated by using simple distance measures to known foraging areas. Again, the requirement for field observations is a limiting factor, but seems to be absolutely necessary none the less.

APPENDIX

APPENDIX A

Table 1. Detail results of the original HSI model in the quarter-mile buffer zones. (part 1 of 2)

					Percent mature trees						
SITE	TDS	mDEPTH	MEI	SIV2	0%	>0,<=25%	>25,<=50%	>50,<=75%	>75%	weighted%	SIV3
1	190	2.5	76	0.96	7.22	0	40.73	52.05	0	54.89	0.72
2	190	2.5	76	0.96	16.83	0	38.66	44.51	0	48.67	0.65
3	190	25.47	7.46	0.35	0	0	0	100	0	65.56	0.86
4	190	27.85	6.82	0.33	0	0	0	98.11	1.89	68.5	0.91
5	190	2.78	68.32	0.94	0	0	1.8	98.2	0	68.28	0.91
6	190	2.84	66.99	0.94	0	0	0.91	99.09	0	69.36	0.92
7	190	2.84	66.98	0.94	0	0	1.39	98.6	0	65.97	0.86
8	190	17.13	11.09	0.45	0	1.68	11.43	86.88	0	60.55	0.8
9	190	17.19	11.06	0.45	0	1.85	11	87.14	0	60.44	0.8
10	190	6.26	30.34	0.77	3.96	0.91	0	95.13	0	66	0.88
11	190	6.33	30.01	0.77	5.92	0.97	0	93.11	0	64.48	0.86

Table 1. Detail results of the original HSI model in the quarter-mile buffer zones. (part 2 of 2)

SITE	#house	#camp	land(sqft)	land(sqkm)	Housing Density	SIV4	sqrt(SIV3xSIV4)
1	9	0	4072251.7	0.38	24	0	0
2	2	0	4029708.2	0.37	5	0.75	0.689
3	0	4	1963650.4	0.18	22	0	0
4	0	0	1996944.5	0.18	0	1	0.954
5	0	0	2878253.7	0.27	0	1	0.954
6	0	1	3822347.5	0.35	3	0.85	0.884
7	0	1	2497261.4	0.23	4	0.8	0.829
8	0	4	2783338.2	0.26	15	0.25	0.447
9	0	4	2680689.6	0.25	16	0.2	0.4
10	0	4	3234350.7	0.3	13	0.35	0.555
11	0	5	3185001.2	0.29	17	0.15	0.359

Table 2. Detail results of the original HSI model within the half-mile buffer zones. (part 1 of 2)

					Percent mature trees						
SITE	TDS	mDEPTH	MEI	SIV2	0%	>0,<=25	>25,<=50	>50,<=75	>75	weighted%	SIV3
1	190	2.5	76	0.96	20.48	0	22.46	45.1	11.96	49.4	0.66
2	190	4.4	42.99	0.85	20.34	0	21.62	56.16	1.88	49.14	0.66
3	190	27.26	6.97	0.34	0	0	0.37	99.63	0	67.9	0.91
4	190	29.61	6.41	0.32	17.51	0	0	49.4	33.09	61.22	0.81
5	190	2.78	68.37	0.94	1.9	0.25	12.86	84.98	0	62.5	0.83
6	190	3.49	54.39	0.91	0	0.27	2.63	95.61	1.49	67.95	0.91
7	190	2.96	64.2	0.93	0.11	0.26	1.03	98.6	0	66.99	0.9
8	190	19.13	9.93	0.4	9.13	0.03	8.36	79.76	2.72	56.51	0.75
9	190	19.29	9.85	0.4	9.05	0	8.45	80.29	2.21	56.32	0.75
10	190	5.3	35.78	0.8	3.82	0.02	0.27	74.18	21.71	71	0.94
11	190	5.34	35.55	0.8	3.52	0.01	0.27	72.01	24.19	71.79	0.96

Table 2. Detail results of the original HSI model within the half-mile buffer zones. (part 2 of 2)

SITE	#house	#camp	land(sqft)	land(sqkm)	Housig Density	SIV4
1	7	0	14664754.6	1.36	5	0.75
2	14	0	13725509.3	1.28	11	0.45
3	0	9	10473453	0.97	9	0.55
4	7	3	7828326.5	0.71	14	0.3
5	0	5	12882414.7	1.19	4	0.8
6	0	7	12014792.4	1.1	6	0.7
7	0	9	12378331.5	1.15	8	0.6
8	0	12	11277871.8	1.05	11	0.45
9	0	12	11226577.8	1.04	12	0.4
10	0	12	12967265.8	1.2	10	0.5
11	0	11	13072827.9	1.21	9	0.55

Table 3. Detail results of the modified HSI model within the quarter-miles buffer zones. (part 1 of 4)

					Percent mature trees						
SITE	TDS	mDEPTH	MEI	SIV2	0%	>0,<=25%	>25,<=50%	>50,<=75%	>75%	weighted%	SIV3
1	190	2.5	76	0.96	7.22	0	40.73	52.05	0	54.89	0.72
2	190	2.5	76	0.96	16.83	0	38.66	44.51	0	48.67	0.65
3	190	25.47	7.46	0.35	0	0	0	100	0	65.56	0.86
4	190	27.85	6.82	0.33	0	0	0	98.11	1.89	68.5	0.91
5	190	2.78	68.32	0.94	0	0	1.8	98.2	0	68.29	0.91
6	190	2.84	66.99	0.94	0	0	0.91	99.09	0	69.37	0.92
7	190	2.84	66.98	0.94	0	0	1.39	98.6	0	65.97	0.86
8	190	17.13	11.09	0.45	0	1.68	11.43	86.88	0	60.55	0.8
9	190	17.19	11.06	0.45	0	1.85	11	87.14	0	60.44	0.8
10	190	6.26	30.34	0.77	3.96	0.91	0	95.13	0	66	0.88
11	190	6.33	30.01	0.77	5.92	0.97	0	93.11	0	64.49	0.86

Table 3. Detail results of the modified HSI model within the quarter-miles buffer zones. (part 2 of 4)

SITE	#wp	WPI	sqrt (WPI+SIV3) SIV3p	#house	#camp	land(sqft)	land(sqkm)	Housing Denisty	SIV4
1	86	0.042	0.87	9	0	4072251.7	0.38	24	0
2	99	0.047	0.83	2	0	4029708.2	0.37	5	0.75
3	25	0.017	0.94	0	4	1963650.4	0.18	22	0
4	48	0.0265	0.97	0	0	1996944.5	0.18	0	1
5	52	0.028	0.97	0	0	2878253.7	0.27	0	1
6	106	0.05	0.98	0	1	3822347.5	0.35	3	0.85
7	41	0.024	0.94	0	1	2497261.4	0.23	4	0.8
8	68	0.0348	0.91	0	4	2783338.2	0.26	15	0.25
9	70	0.0351	0.91	0	4	2680689.6	0.25	16	0.2
10	59	0.031	0.95	0	4	3234350.7	0.3	13	0.35
11	56	0.03	0.94	0	5	3185001.2	0.29	17	0.15

Table 3. Detail results of the modified HSI model within the quarter-miles buffer zones. (part 3 of 4)

SITE	hiRL	cntyRL	twotrackRL	electricRL	Sum RL	hiRLx1.6	cntyRLx1.4	twotrackRLx1.2	electricRLx1
1	2145.77	0	2192.53	0	4338.3	3433.24	0	2631.03	0
2	0	0	3408.75	675.8	4084.55	0	0	4090.49	675.8
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	499.12	0	499.12	0	0	598.94	0
6	0	0	441.76	0	411.76	0	0	530.11	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	3082.39	0	3082.39	0	0	3698.87	0
11	0	0	3088.49	0	3088.49	0	0	3706.19	0

Table 3. Detail results of the modified HSI model within the quarter-miles buffer zones. (part 4 of 4)

SITE	SumRLscore	RLI	sqrt(SIV4xRLI) SIV4p	sqrt(SIV3pxSIV4p)
1	6040	0.1	0	0
2	4766	0.1	0.27	0.478
3	0	1	0	0
4	0	1	1	0.984
5	599	0.79	0.889	0.928
6	530	0.8	0.825	0.901
7	0	1	0.894	0.917
8	0	1	0.5	0.676
9	0	1	0.447	0.639
10	3699	0.1	0.187	0.422
11	3706	0.1	0.122	0.34

Table 4. Detail results of the modified HSI model within the half-mile buffer zones. (part 1 of 4)

					Percent mature trees						
SITE	TDS	mDEPTH	MEI	SIV2	0%	>0,<=25	>25,<=50	>50,<=75	>75	weight %	SIV3
1	190	2.5	76	0.96	20.48	0	22.46	45.1	11.96	49.4	0.66
2	190	4.4	42.99	0.85	20.34	0	21.62	56.16	1.88	49.14	0.66
3	190	27.26	6.97	0.34	0	0	0.37	99.63	0	67.9	0.91
4	190	29.61	6.41	0.32	17.51	0	0	49.4	33.09	61.22	0.81
5	190	2.78	68.37	0.94	1.9	0.25	12.86	84.98	0	62.5	0.83
6	190	3.49	54.39	0.91	0	0.27	2.63	95.61	1.49	67.95	0.91
7	190	2.96	64.2	0.93	0.11	0.26	1.03	98.6	0	66.99	0.9
8	190	19.13	9.93	0.4	9.13	0.03	8.36	79.76	2.72	56.51	0.75
9	190	19.29	9.85	0.4	9.05	0	8.45	80.29	2.21	56.32	0.75
10	190	5.3	35.78	0.8	3.82	0.02	0.27	74.18	21.71	71	0.94
11	190	5.34	35.55	0.8	3.52	0.01	0.27	72.01	24.19	71.79	0.96

Table 4. Detail results of the modified HSI model within the half-mile buffer zones. (part 2 of 4)

SITE	#wp	WPI	sqrt(WPI+SIV3) SIV3p	#house	#camp	land(sqft)	land(sqkm)	Housing Density	SIV4
1	86	0.042	0.84	7	0	14664754.6	1.36	5	0.75
2	80	0.0395	0.84	14	0	13725509.3	1.28	11	0.45
3	70	0.0351	0.97	0	9	10473453	0.97	9	0.55
4	48	0.0265	0.91	7	3	7828326.5	0.71	14	0.3
5	142	0.05	0.94	0	5	12882414.7	1.19	4	0.8
6	103	0.049	0.98	0	7	12014792.4	1.1	6	0.7
7	199	0.05	0.97	0	9	12378331.5	1.15	8	0.6
8	39	0.023	0.88	0	12	11277871.8	1.05	11	0.45
9	37	0.022	0.88	0	12	11226577.8	1.04	12	0.4
10	90	0.043	0.99	0	12	12967265.8	1.2	10	0.5
11	86	0.042	1	0	11	13072827.9	1.21	9	0.55

Table 4. Detail results of the modified HSI model within the half-mile buffer zones. (part 3 of 4)

SITE	hiRL	cntyRL	twotrackRL	electricRL	SUM LR	hiRLx1.6	cntyRLx1.4	twotrackRLx1.2	electricRLx1
1	2891	5251.1	3835.5	5824	17801.3	4625.1	7351.5	4602.6	5824
2	3867	3408.2	2930.1	5337.6	15542.6	6186.6	4771.5	3516.1	5337.6
3	0	0	5821.4	0	5821.4	0	0	6985.6	0
4	0	2586.6	3202.1	7091.6	12880.3	0	3621.2	3842.5	7091.6
5	0	0	3087.5	0	3087.5	0	0	3705	0
6	0	0	3381.7	0	3381.7	0	0	4058	0
7	0	0	2841.5	0	2841.5	0	0	3409.8	0
8	0	0	3469	0	3469	0	0	4162.8	0
9	0	0	3266.8	0	3266.8	0	0	3920.2	0
10	0	0	5767.8	0	5767.8	0	0	6921.3	0
11	0	0	5828.3	0	5828.3	0	0	6994	0

Table 4. Detail results of the modified HSI model within the half-mile buffer zones. (part 4 of 4)

SITE	SumRLscore	RLI	sqrt(SIV4xRLI) SIV4p	sqrt(SIV3pxSIV4p)
1	22403	0.1	0.27	0.48
2	19812	0.1	0.21	0.42
3	6986	0.1	0.23	0.48
4	14555	0.1	0.173	0.398
5	3705	0.26	0.46	0.65
6	4058	0.19	0.36	0.6
7	3410	0.325	0.44	0.66
8	4163	0.17	0.28	0.49
9	3920	0.22	0.3	0.51
10	6921	0.1	0.22	0.47
11	6994	0.1	0.23	0.48

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