CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

A Test of a Habitat Suitability Index for Black Bears In Northeastern Minnesota

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Arts in Geography

By

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May 2018

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Acknowledgement

I would like to thank Dr. Lynn Rogers, Dr. Roger Powell and Sue Mansfield. Without whom this unique study would have never occurred.

Dedication

This paper is dedicated to bear researchers everywhere

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Abstract

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This study takes a habitat suitability index (HSI) for Black Bears (*Ursus americanus)* designed for the Appalachian Mountains region of North Carolina and applies it to the Eagles Nest area in Northeastern Minnesota. The Minnesota HSI was tested using 36 home ranges and 239,756 GPS points taken from 13 GPS-collared female black bears between - 2010 and 2013. HSI predicted habitat selection by the bears at both the population and, individual home range levels and the distribution of collared bears was positively correlated with HSI values. Further, it was found that Northeastern Minnesota offers poor habitat in terms fall foods owing to the deficiency of mature hard mast producing species. Additionally, although the HSI characterizes lowland / poorly drained areas as poor habitat for food, escape cover, and denning, this study identified an attractance to cedar, spruce and balsam fir swamps for bedding--a variable not considered in previous models data. Also, the extent to which bears are attracted to and avoiding sources of anthropogenic food are addressed herein. Lastly, HSI components are

evaluated *a posteriori* using literature and in situ observations as to their applicability to this study area and either modified or eliminated from the analysis.

1.0 Introduction

Habitat suitability index (HSI) models were originally developed as part of the Habitat Evaluation Procedures to quantify effects of land management alternatives on wildlife habitat (United States Fish and Wildlife Service 1981). The HSI evaluates an organism's life requisites using the structure, composition, and spatial components of habitat. As HSI development gained popularity in the 1980's, researchers attempted to create models for many different species including, but not limited to, muskrat (*Ondatra zibethicus*), bobcat (*Lynx rufus),* pileated woodpecker (*Dryocopus* pileatus), pronghorn (*Antilocapra* americanus), ruffed grouse (*Bonasa* umbrellus), spotted owl (*strix* occidentalis), North American beaver (*Castor canadensis*), and the American black bear (*Ursus americanus*).

1.1 Literature Review

The first HSI for black bears was created by Dr. Lynn Rogers and Arthur W. Allen in 1987 for the Upper Great Lakes Region of the United States. This model contains four main components, herein referred to as Life Requisite Values (LRVs): spring food, summer food, fall food and human intolerance. These four LRVs are further broken into eight variables: percentage of area in wetland cover types, percentage canopy cover of soft mast producing species, number of soft mast producing species, percentage of area in non-forested cover types ≤ 250 meters from forest cover types, basal area of hard mast producing species > 40 years of age, number of hard mast producing species, percent of area in cover types that have ≥ 1% canopy cover of hard mast producing species, and percent of area that is inside the zone of influence around human use and habitation sites.

McLaughlin (1989) proposes an HSI for black bears which includes the same spring (herbaceous vegetation), summer (soft mast) and fall (hard mast) LRVs as Rogers and Allen which shows that bear biologists from different organizations held similar understanding of black bear food requirements. Further, McLaughlin includes colonial insects, apples, corn, garbage and vertebrates as food variables in addition to offering a food interspersion variable which address the spatial relationship between food sources. Escape cover over is also addressed in this HSI as the percent area in forest and juxtaposition of forest and non-forest lands.

Zimmerman (1992) created an HSI for his doctorate at North Carolina State University. His model was created *a priori* from literature and was composed of the two previous LRVs: food and escape cover, as well as a new LRV--denning. The Zimmerman model consists of 24 individual variables required to construct the final HSI. Mitchell et al. (2002) then tested his model using range and location telemetry data from a 12 year long black bear study in the Pisgah Bear Sanctuary in North Carolina. The results showed a positive correlation between the Zimmerman HSI values and habitat selection by the Pisgah bears which means that the model accurately predicted habitat selection such that the bears avoided poor habitat and were attracted to good habitat.

Starting in 2009 Dr. Lynn Rogers, on behalf of the Wildlife Research Institute in Eagles Nest, MN, began collaring female black bears with GPS units for the purpose of collecting location data as well as field observations. Since researchers were using GPS collars equipped to transmit once every ten minutes new batteries were required every 8 to 10 days, thus females were chosen over males because of their smaller and more stable home ranges. Over five years the study amassed what is to date the largest assemblage of location data (over 250,000 GPS points) collected in a black bear study.

1.2 Statement of Purpose

This study serves two purposes: The first purpose seeks to identify if HSI values predict habitat selection by bears; If the ultimate rationale of HSI development is to construct a model which can be applied on a global scale, then components then HSI components need to be tested across differing regions and differing populations. If the Zimmerman HSI shows a positive correlation between HSI values and habitat selection by bears in northeastern Minnesota, then its credibility may be supported, thus warranting further research. To determine whether habitat selection is positively correlated with HSI values this study follows the methodology presented in Mitchell et al (2002). If Zimmerman's HSI is applicable to Eagles Nest, Minnesota then there should be a positive correlation between HSI values and habitat selection.

The second purpose of this study is to examine each LRV independently to determine applicability to the study area. Since the Zimmerman HSI was developed using habitat characteristics in the Appalachian Mountains some of the variables may not apply to the forests of northeastern Minnesota.

2.0 Study Area

2.1 Location

The study area is 399.45 km^2 in the northeastern Minnesota commonly referred to as the North Woods. (Figure 1). The study area in St. Louis County is bordered on the east by the City of Ely (pop. 3,460), and Tower (pop. 500) on the west. Within the study area are the townships of Eagles Nest (pop. 204) and Breitung (pop. 605). There are only three paved roads: U.S. Route 169 which runs approximately east-west through the study area, and Grant McMahan Blvd. which encompasses Shagawa Lake and Echo Trail on the far eastern border. All other roads are dirt or gravel.

2.2 Land Cover

The study area consists of 22 different land cover types based on the NatureServe Ecological Classification System (NatureServe 2009). The three largest land cover types in the study area are Boreal White Spruce-Fir-Hardwood Forest (38%), Boreal-Laurentian Conifer Acidic Swamp and Treed Poor Fen (21%), and Open Fresh Water (15%). Only 1% of the study area,\(4.18 km^2)is considered developed. Table 1 details land cover type for the study area.

2.3 Food sources and types

Important spring foods include grass, especially blue-joint grass (*Calamagrostis canadensis*) in ash swamps, aspen leaves (*Populus spp.*), large-leafed aster leaves (*Eurybia macrophylla*), interrupted fern stems (*Osmunda claytoniana*), peavine leaves (*Lathyrus spp.*), skunk cabbage (*Symplocarpus foetidus*), dandelion leaves and flowers

(*Taraxacum spp*.), clover (*Trifolium spp*.), red maple seeds (*Acer rubrum*), and wild calla leaves (*Calla palustris*) (Rogers 2016).

Soft mast bear foods in the study area, also referred to as summer foods for the purpose of LRV Fsu[1], include juneberry (*Amelanchier spp*.), wild sarsaparilla and spikenard (*Aralia spp*.), dogwood berry (*Cornus spp*.), plum, pincherry and chokecherry (*Prunus spp*.), currant and gooseberry (*Ribes spp*.), blackberry and raspberry (*Rubus spp*.), cranberry and arrowwood (*Viburnum spp*.), and blueberry (*Vaccinium spp*.) (Garshelis 1988). Hard mast bear food in is limited to hazelnuts (*Corylus americana*) owing to a lack of other hard mast producing species in northeastern Minnesota such as northern red oak (*Q. rubra*) and pin oak (*Q. ellipsoidalis*) which comprise < .05% of area within Superior National Forest surrounding the study area (Rogers and Lindquist 1991).

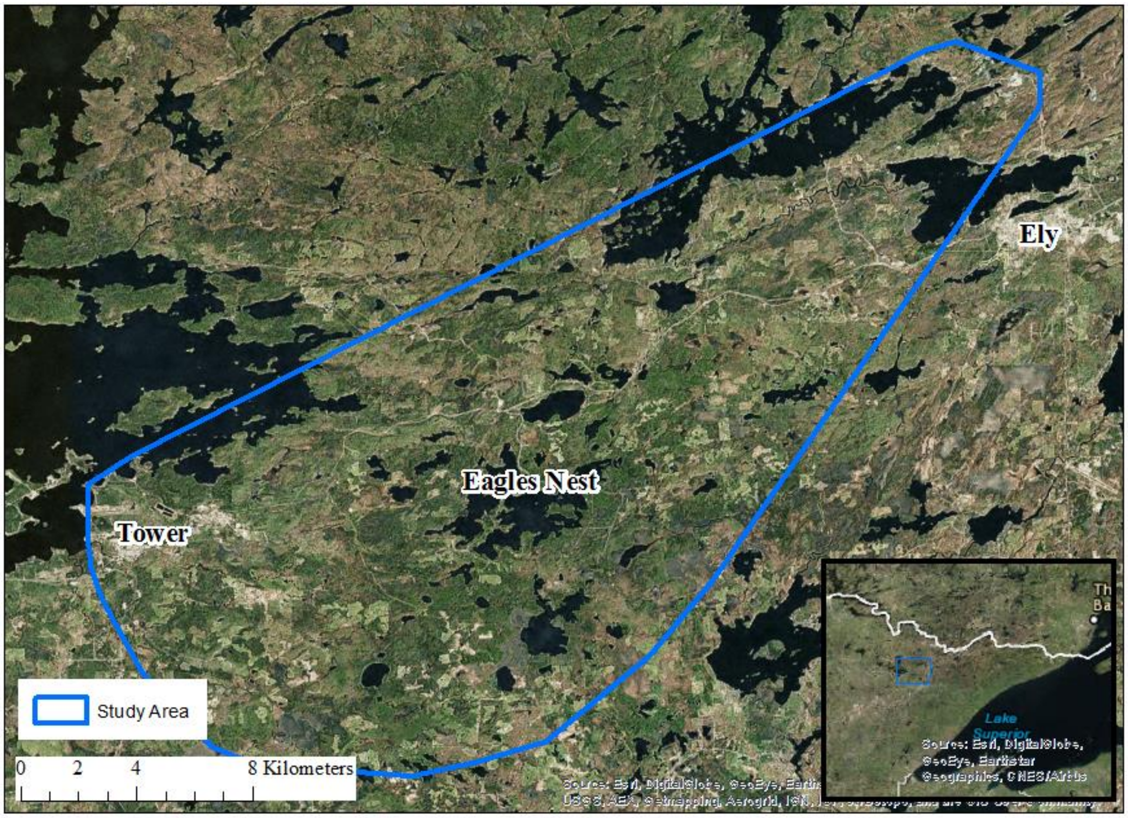

Figure 2-1: Study Area

Land Cover Type	Percent of Land Cover
Managed Tree Plantation	0.01%
Laurentian-Acadian Northern Hardwoods Forest	4.47%
Laurentian-Acadian Northern Pine-(Oak) Forest	3.47%
Laurentian Pine-Oak Barrens	1.29%
Central Interior and Appalachian Floodplain Systems	< 0.01%
Laurentian-Acadian Floodplain Systems	0.71%
Laurentian-Acadian Swamp Systems	1.88%
Boreal Aspen-Birch Forest	10.62%
Boreal Jack Pine-Black Spruce Forest	1.28%
Boreal White Spruce-Fir-Hardwood Forest	38.42%
Boreal-Laurentian Conifer Acidic Swamp and Treed Poor Fen	21.21%
Eastern Boreal Floodplain	0.17%
Cultivated Cropland	0.01%
Pasture/Hay	0.09%
Introduced Upland Vegetation - Perennial Grassland and Forbland	< 0.01%
Disturbed, Non-specific	0.02%
Harvested Forest - Grass/Forb Regeneration	0.34%
Open Water (Fresh)	14.96%
Developed, Open Space	0.67%
Developed, Low Intensity	0.29%
Developed, Medium Intensity	0.07%
Developed, High Intensity	0.02%

Table 2-1: Land Cover Types within Study Area from GAP Land Cover Minnesota

3.0 Methodology

The methodology used to construct HSI components is based upon (Zimmerman (1992) and Mitchell et. al. (2002) and deviations are explained.

3.1 Fy1: Abundance of Colonial Insects

Colonial insects found in dead wood; ants, wasps, and bees, as well as detritus-eating beetles are available as food from emergence to denning and may compose up to half of the bears' diet from spring until early summer when berries begin to ripen (Zimmerman 1992; Rogers and Allen 1987). A downed log is defined as a piece of wood with a base diameter ≥ 15cm and a maximum density of logs is set at 1 per $9m^2$ (Zimmerman 1992). Unfortunately, as of this writing there is no method of estimating downed woody debris except for an extensive ground survey. Therefore, for this LRV I applied a value of 1 to all forest cover types found on the GAP land cover raster under the assumption that a forest is where downed logs are likely to be found. All non-forest land cover types were assigned a value of 0 reflected a presumed lack of downed logs

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fy1	Abundance of Colonial Insects	NA	Fy1 = 0.00082(x) + 0.1, for (x) ≤ 1100; Fy1 = 1.0, for (x) > 1100, where: (x) = the number of fallen logs / ha	Zimmerman (1992)

Table 3-1: Fy1: Abundance of Colonial Insects

3.2 Fy2a: Quality of Anthropogenic Food Source

Humans provide food for bears both intentionally and unintentionally throughout spring, summer and fall. This HSI addresses the quality of the anthropogenic food, the seasonal availability of the anthropogenic food as well as the danger associated with bears going to residences for food. Garbage, campers' food, and crops tend to provide bears with year round sustenance especially in times of shortage. These zones of anthropogenic food also act as sinks as humans tend to kill bears at an unsustainable rate (Rogers and Allen 1987).

Interviews with WRI researchers determined that 17 residences within the study area were found to provide high quality food for the bears during spring, summer, and fall without any threat of harm. One residence was determined to both provide high quality food for three seasons in the form of multiple bird feeders and was deemed high risk of reprisal to bears because he had a bear killed which frequented the feeders. The remaining residences, commercial buildings and camp grounds were determined to have unintentionally provided low quality food for at least one season at high risk of reprisal to the bears.

The locations of the 2358 residences, commercial buildings and campgrounds within the study area was digitized from aerial imagery with the help of the St. Louis County parcel shapefile. Where the exact location of a structure was hidden by forest canopy the Minnesota State 2013 LiDAR classified dataset was employed.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fy2a	Quality of Anthropogenic Food Source	Ground Survey (Qualitative)	Fy2a = [(A+R) / 2]S, where: A = food availability (high=1.0, medium=0.6, low=0.1), R = risk of reprisal (high=0.1, medium=0.5, low=1.0), S = number of seasons available (0 to 3)/3	Zimmerman (1992)

Table 3-2: Fy2a: Quality of Anthropogenic Food Source

3.3 Fy2b: Costs of Traveling to Anthropogenic Food Source

Working in Great Smoky Mountains National Park, Garshelis et al. (1981) showed that females with cubs exhibit the least amount of daily movement with a mean maximum daily movement of 1.5 km while Beeman (1975) reported that the maximum movement of female bears with cubs to be 3km. Therefore, this component assumes a linear relationship between cell value and distance from anthropogenic food source such that the highest value is given to cells 1.5 km and a zero value to cells > 3km (Zimmerman 1992). This study employed a least cost distance (the measured distance from the destination to the source) instead of Euclidian distance (the measured distance from every cell to the nearest source) to account for bears going around lakes.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fy2b	Costs of Traveling to Anthropogenic Food Source	GIS (Cost Distance)	Fy2b = 1.0, for $x \leq 1.5$; Fy2b = $-0.667x + 2$, for $1.5 < x \leq 3.0$; Fy2b = 0, for $x > 3.0$, where: x = distance(km) to anthropogenic food source	Beeman (1975) Garshelis et al. (1983)

Table 3-3: Fy2b: Costs of Traveling to Anthropogenic Food Source

3.4 Fy2c: Access to Escape Cover ≥ 400 ha from Anthropogenic Food Source:

The U.S. Fish and Wildlife (1982) states that for escape cover to be useful to black bears it must contain at least 400 ha of conterminous forest cover not bisected by roads. Additionally, further research shows a decrease in use by bears of cleared areas located 183 meters from forest cover. Therefore, Zimmerman (1992) has weighed this component such that the cell value decreases as the distance between the anthropogenic food source and escape cover ≥ 400 ha of conterminous forest increases. Zimmerman 1992 estimated cover using the green shaded portion of 7.5-minute quadrangle topographic maps.

Using the 2011 edition of the National Land Cover Dataset, NCLD 2011, this study defined escape cover as cells representing Conifer, Deciduous, Mixed Forest, Woody Wetland, and Scrub/Shrub. Road location was identified using the St. Louis County Roads shapefile.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fy2c	Access to Escape Cover ≤ 400 ha from Anthropogenic Food Source	GIS (NLCD 2011, Cost Distance)	Fy2c = 1.0 for $x < 25$; Fy2c = -.0017x + 1.0425, for $25 \leq x \leq 200$; Fy2c = -.0015x + 0.6, for $200 < x < 400$; Fy2c = 0, for $x > 400$, where: x = distance(m) between anthropogenic food source and escape cover	McCollum (1973) US Fish and Wildlife Service (1982) Rogers and Allen (1987)

Table 3-4: Fy2c: Access to Escape Cover ≥ 400 ha from Anthropogenic Food Source

3.5 Fsp1: Productivity of Vegetation Associated with Moist Habitats and Availability of Water after Denning

The primary source of spring food for black bears is succulent green vegetation and much of the spring food is associated with moist habitats (Rogers 1987). Therefore, Zimmerman (1992) indexes Fsp1 as a function of distance from perennial water. Perennial water includes lakes, streams, and rivers identified in the National Hydrography Dataset. Additional sources of perennial water include poorly drained soils identified by the SSURGO soil database and wetland cover types identified by the National Land Cover Dataset and GAP Land Cover Dataset. Once identified, a Euclidean distance raster to the sources of perennial water was developed for this study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fsp1	Productivity of vegetation associated with moist habitats and availability after denning	GIS (Euclidian Distance)	Fsp1 = 1.0, for $x \leq 0.64$; Fsp1 = $-1.167x + 1.75$, for $.064 < x < 1.5$; Fsp1 = 0, for $x \geq 1.5$; where: x = distance (km) to perennial water	Beeman and Pelton (1980) Carlock et al. (1983) Rogers and Allen (1987)

Table 3-5: Fsp1: Productivity of Vegetation Associated with Moist Habitats and Availability of Water after Denning

3.6 Fsp2: Productivity of Spring Vegetation

Another segment of spring foods includes young plants sprouting from the forest floor. The relationship between ground cover of spring vegetation is complex but generally there is a decrease in ground vegetation as canopy increases (Zimmerman 1992). Zimmerman sets the value of Fsp2 as a function of percent tree canopy cover and forest type. By contrast, this study uses the 2011 NLCD Percent Tree Canopy raster and the 2011 NCLD land cover raster to define forest type and percent tree canopy.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fsp2	Productivity of Spring Vegetation	GIS (NCLD 2011, Percent Canopy Cover)	Fsp2 = 1.0, for $0.07 \leq x \leq 0.5$; Fsp2 = $0.01x + 1.5$, for $x > 0.5$ Fsp2 = $-0.22959x^2 + 0.875x + 0.5$, for $x < 7$; where: x = (herbaceous area + woody wetland area + scrub area + wetland area) / study area Fsp2 = 1.0, for ≤ 25; Fsp2 = $-0.16x + 1.4$, for $25 < x < 75$; Fsp2 = 0.2 for $x \geq 75$;	Zimmerman (1992) Rogers and Allen (1987)

			where: x = % percent canopy cover in deciduous forest Fsp2 = 1.0, for $x \leq 25$; Fsp2 = -0.02x + 1.5, for $25 < x < 75$; Fsp2 = 0, for $x \geq 75$; where: x = % canopy cover in conifer forest Fsp2 = 1.0, for $x \leq 25$; Fsp2 = [(-0.016x +1.4) + (-0.02x + 1.5)] / 2, for $25 < x < 75$; Fsp2 = 0.1, for $x \geq 75$; where: x = % canopy cover in mixed forest	

Table 3-6: Fsp2: Productivity of Spring Vegetation

3.7 Fsu1: Productivity of Berry Species

Wild berries are an important food for bears in the summer time. To create Fsu1 Zimmerman 1992 requires two values to be known; number of berry genera present and percent ground cover of berry species. Noyce and Coy (1990) presents an estimate of berry genera present and percent ground cover based on forest type and soil drainage in my study area (Figure 3). Using the 2011 GAP land cover raster to define forest type and the SSURGO soil database to differentiate between well drained and poorly drained soils, this study improves on the detail necessary to identify critical, short-lived understory food sources.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fsu1	Productivity of Spring Berries	2011 GAP Land Cover/(Noyce and Coy 1990)	Fsu1 = (0.027 + 0.005n)x, for (0.027 + 0.005n)x < 1.0; Fsu1 = 1.0, for (0.027 + n)x ≥ 1.0, where: n = number of berry genera present , x = % percent cover in berry plants	Rogers and Allen (1987)

Table 3-7: Fsu1: Productivity of Berry Species

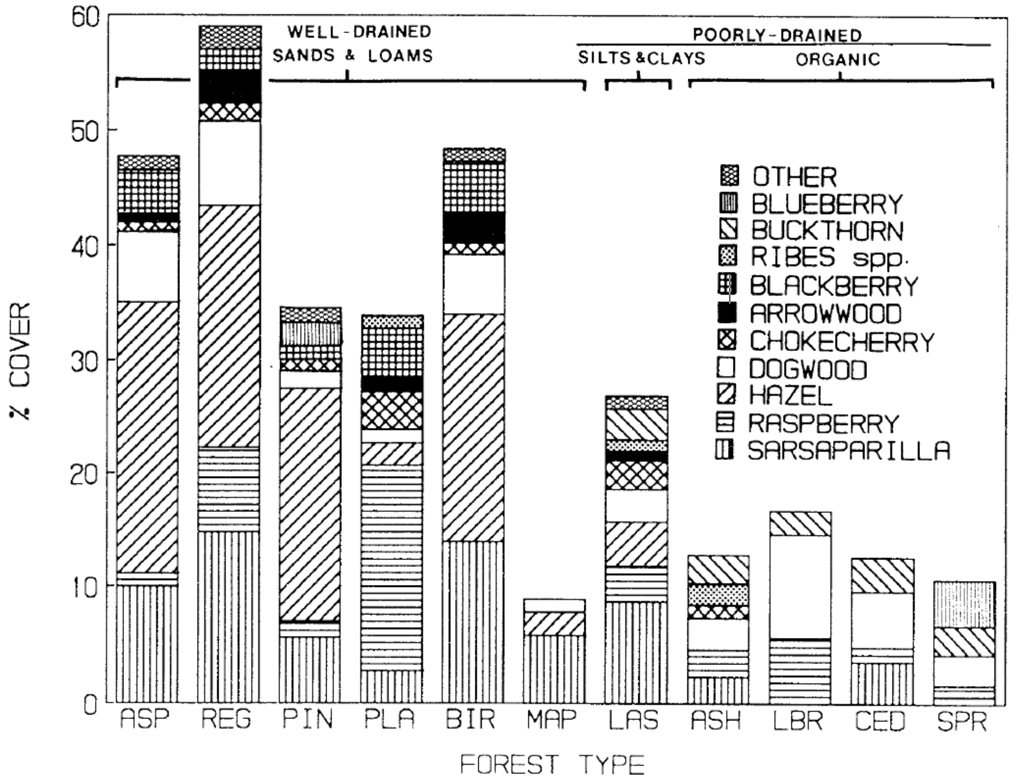

Figure 3-1: Berry Genera Abundance

3.8 Fsu2: Productivity of Squaw Root

Powell and Seaman (1990) found that squaw root (*Conopholis americana*) is an important summer food for black bears in the Appalachian Mountains however, it does not exist in Minnesota forests. Therefore, this component is excluded from this study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Fsu2	Productivity of Squaw root	Does not apply to study area	0.0 to 0.1, See Powell et al. (1997)	Baird and Riopel (1986) Zimmerman (1992)

Table 3-8: Fsu2: Productivity of Squaw Root

3.9 Ff1: Age of Stand

Hard mast, acorns and other nuts, are the preferred source of food for bears in the fall owing to their abundance and high fat content (Rogers and Lindquist 1991). Goodrum et al (1971) found that acorn yield is dependent on tree age where maximum acorn production occurs between 60 and 100 years. Acorn yield drops off prior to 60 years and after 100 years.

Since this component is based upon the presence of acorns and *Quercus spp*. is scarce in northeastern Minnesota (Rogers et.al. 1991 and NatureServe. 2009), this component was excluded from this study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Ff1	Age of Stand	MN DNR and SNF Stand Age Data Set.	Ff1b = 0, for $x < 20$; Ff1b = 0.025x – 0.5, for $20 \leq x \leq 60$; Ff1b = 1.0, for $60 \leq x \leq 100$; Ff1b = -0.004x + 1.4, for $100 < x < 125$; Ff1b = 0.9, for $x \geq 125$; where: x = age of stand (years)	Goodrum et al. (1971) Brody (1984)

Table 3-9: Ff1: Age of Stand

3.10 Ff2: Productivity of Grapes

Eiler et al (1989) found that wild grapes are an important fall food for bears when acorn crops fail. However, MN TAXA (2016) states that wild grapes do not exist in northeastern Minnesota therefore, this component is excluded from this study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Ff2	Productivity of Grapes	Does not apply to study area	Ff2 = 0.005x, for $x \leq 200$; Ff2 = 1.0, for $x > 200$; where: x = number of grape vines / ha	Collins (1983) Eiler et al. (1989) Zimmerman (1992)

Table 3-10: Ff2: Productivity of Grapes

3.11 Ff3: Effects of Roads on Access to Hard Mast

Zimmerman (1992) states that in North Carolina, bears avoid areas within 200 meters of roads and 75 % of bear harvests occur <1.6 km from roads, thus he placed a decreasing value on forests as the distance toward a road increased. By contrast, this study used the St. Louis County Roads shapefile to define roads and Euclidian distance to define distance to roads.

LRV	Habitat Feature	Survey Method	Function	Source(s)
Ff3	Effects of Roads on Access to Hard Mast	GIS (cost distance)	Ff3 = 0.50, for $x \leq 0.2$; Ff3 = $0.357x + 0.429$, for $0.2 < x \leq 1.6$; Ff3 = 1.0, for $x > 1.6$; where x = distance to nearest temporary road (km) Ff3 = 0.44, for $x \leq 0.2$; Ff3 = $0.40x + 0.36$, for $0.2 < x \leq 1.6$; Ff3 = 1.0, for $x > 1.6$; where x = distance to nearest improved dirt road (km) Ff3 = 0.33, for $x \leq 0.2$; Ff3 = $0.454x + 0.273$, for $0.2 < x \leq 1.6$; Ff3 = 1.0, for $x > 1.6$; where x = distance to nearest paved road (km)	Quigley (1992) Vallarubia (1982) Collins (1983)

Table 3-11: Ff3: Effects of Roads on Access to Hard Mast

3.12 If: Interspersion for Food Resources

Zimmerman (1992) created the interspersion value to account for the spatial distribution of food. If a food value for any one seasonal food is 0 then the value of that cell is decreased based on the distance to the nearest food source for that same LRV. To create my interspersion raster I located the 0 raster cell values in LRV's Fsp, Fsu and Ff. I then calculated the linear distance to the nearest non zero cell value.

LRV	Habitat Feature	Survey Method	Function	Source(s)
If	Interspersion of Food Resources	GIS	If = 1, for x ≤ 5; If = -0.07x + 1.35, for 5 < x ≤ 19; If = 0, for x > 19; where: x = distance (km) between food resources	Beeman (1975) Eubanks (1976) Garshelis and Pelton (1981)

Table 3-12: If: Interspersion for Food Resources

3.13 E1: Accessibility via Roads

To function as escape cover for bears, the U.S. Fish and Wildlife Service (1982) suggests that a minimum of 400 ha of conterminous forest not bisected by roads is required. By contrast, Zimmerman (1992) suggests that 32 ha not bisected by roads is optimal area of conterminous forest for escape cover. This study defined forest using all forest classifications found in the 2011 GAP land cover raster with roads defined using the St. Louis County roads shapefile.

LRV	Habitat Feature	Survey Method	Function	Source(s)
E1	Accessibility via Roads	GIS	E1 = 0, for x ≤ 4; E1 = 1.11[log10 (x X 100)] – 2.89, for 4 < x < 32; E1 = 1.0, for x ≥32; where: x = area(ha) of conterminous forest not bisected by roads	USDA Forest Service (1982)

Table 3-13: E1: Accessibility via Roads

3.14 E2: Density of Understory

A closed understory provides low visibility, travel lanes, and cool areas for resting (Zimmerman 1992). This component requires knowing the percent canopy cover for understory ≤ 3 meters. After identifying all non-ground returns ≤ 3 meters, I processed the 2011 Minnesota LiDAR dataset using the percent canopy cover tutorial published by University of Minnesota (2012).

LRV	Habitat Feature	Survey Method	Function	Source(s)
E2	Density of Understory	MN LiDAR dataset 2013	$E2 = 0$, for $x \leq 20$; $E2 = -0.007x + (2.38 \times 10^{-4})x^2 + 0.06$, for $20 < x < 80$; where: x = % closure of understory	Zimmerman (1992)

Table 3-14: E2: Density of Understory

3.15 E3: Steepness of Terrain

Zimmerman (1992) states that slopes <15° are traversable by humans but slopes >15° are not and therefore can be considered potential escape routes for bears. This study used a 3-meter x 3-meter DEM raster dataset and the ArcMap slope tool to determine slope in the study area.

LRV	Habitat Feature	Survey Method	Function	Source(s)
E3	Steepness of Terrain	GIS (slope)	E3 = 0, for $x < 15$; E3 = $0.0333x - 0.5$, for $15 \leq x \leq 45$; E3 = 1.0, for $x > 45$; where: x = slope(degrees) of terrain	Zimmerman (1992)

Table 3-15: E3: Steepness of Terrain

3.16 E4: Distance from Roads

Collins (1983) reports that 50% of black bears are killed within 0.8 km of a road and 73% are killed within 1.6 km of a road. Therefore, Zimmerman (1992) placed a decreasing value upon escape cover as the distance to roads increases. This study defined roads using the St. Louis County roads shapefile and distance to roads using the Euclidian distance tool in ArcMap.

LRV	Habitat Feature	Survey Method	Function	Source(s)
E4	Distance from Roads	GIS	E4 = 0, for $x = 0$; E4 = $0.156x + 0.195x^2 + 0.25$, for $0 < x < 1.6$; E4 = 1.0, for $x \geq 1.6$; where: x = distance (km) to nearest road	Collins (1983)

Table 3-16: E4: Distance from Roads

3.17 E5: Availability of Lowland Day Bed Sites

LRV	Habitat Feature	Survey Method	Function	Source(s)
E5	Availability of Lowland Bed Sites	Gap Land Cover	E5 = 1 for cover types Black Ash, Lowland Northern White-Cedar, and Balsam Fir mix E5 = 0 for all other cover types	Elowe (1984) Elowe and Dodge(1989) Rogers (1993) Mansfield, Powell and Rogers (unpublished data)

Table 3-17

Mother bears with cubs seek out furrowed trees in wet land cover types for protection and thermal cover (Rogers 1993), (Elowe and Dodge 1989) and (Elowe 1984). In the study area point clusters in the GPS data identified locations where the study bears bedded multiple times for periods exceeding four hours. A survey of 100 of these bed sites revealed an attraction by the study bears to low land cover types associated with Northern White Cedar, Black Ash and Balsam Fir. Solitary old growth White Pine trees were also identified with these bed sites (Mansfield, Powell and Rogers unpublished data 2016). I created this new component, E5, to address bed sites. Cover types where bedding conditions found by Mansfield, Powell and Rogers (unpublished data 2016) are likely to exist are assigned a value of 1. All other cover types are assigned a value of 0.

3.18 D1: Accessibility via Roads

Johnson and Pelton (1981) suggest that bears choose a denning location where they are unlikely to be disturbed. Zimmerman (1992) choose 200 ha of conterminous forest not bisected by roads as the minimum area bears require for seclusion.

Unfortunately, two of the four denning components required for this LRV do not apply to the study area so the denning component was excluded from this study all together.

LRV	Habitat Feature	Survey Method	Function	Source(s)
D1	Accessibility via Roads	GIS	D1 = 0, for $x \leq 2$; D1 = $(9.8 \times 10^{-2})x - 0.20$, for $2 < x < 12.25$; D1 = 1.0, for $x \geq 12.25$; where: x = area(ha) of conterminous forest not bisected by roads	Beeman (1975) Eubanks (1976) Garshelis and Pelton (1981) Warburton (1984) Zimmerman (1992)

Table 3-18: D1: Accessibility via Roads

3.19 D2: Availability of Dense Stands of Rhododendron or Mountain Laurel for Ground Dens

Some bear dens are dug into the ground. In Tennessee these ground dens were usually associated with dense stands of Rhododendron (*Rhododendron spp.*) and Mountain Laurel (*Kalmia latifolia*) (Tennessee Wildlife Resource Agency 1983). Neither of these two plant species exists in my study area (MNTAXA 2016) and even though Minnesota specific species such as hazel and alder would stand as substitutes, the LiDAR data and procedure for determining the density of ground cover would be duplicative of component E2. Therefore, this component was excluded from the study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
D2	Availability of Dense Stands of Rhododendron (Rhododendron sp). or Mountain Laurel (Kalmia latifolia) for Ground Dens	Does not apply to study area	D2 = 0.0333x, for x < 30; D2 = 1.0, for x ≥ 30; where: x = area(ha) in Rhododendron or Mountain Laurel	Zimmerman (1992)

Table 3-19: D2: Availability of Dense Stands of Rhododendron or Mountain Laurel for Ground Dens

3.20 D3: Availability of Cave and Rock Dens

Wathen et al (1986) states that ground dens were located on steeper slopes than tree dens and cave and rock crevices are assumed to be positively correlated with slope. Zimmerman (1992) places a greater value on raster cells located on an increasing slope. I defined slope using the same methodology I used in LRV E3: Steepness of Terrain. Unfortunately, two of the four denning components required for this LRV do not apply to the study area so the denning component was excluded from this study all together.

LRV	Habitat Feature	Survey Method	Function	Source(s)
D3	Availability of Cave or Rock Dens	GIS (Slope)	D3 = tan(x), for x ≤ 45; D3 = 1.0, for x > 45; where: x = slope (degrees) of terrain	Zimmerman (1992)

Table 3-20: D3: Availability of Cave and Rock Dens

3.21 D4: Availability of Tree Cavity Dens

Johnson and Pelton (1981) reported that tree dens are considered the best dens sites because they offer extra seclusion and superior insulation. Zimmerman (1992) suggests that in order for an area to provide tree dens the trees must have a diameter at breast height of at least 90cm. In my study area there are only three trees which can potentially achieve a DBH ≥ 90 cm: Red Pine (*Pinus resinosa*), Eastern White Pine (*Pinus strobus*), and Northern White Cedar (*Thuja occidentalis*) (MNDNR 2016).

To determine DBH I relied upon the Minnesota Department of Natural Resources forest inventory shapefile, the Superior National Forest Inventory shapefile, and ground survey. My ground survey consisted of sampling 200 randomly selected 20 meter circumference plots within my study area. Also, since accessing my sample plots required a substantial amount of walking through my study area, any and all trees which I came into contact with which appeared to have a large DBH were measured. No trees were found to possess a DBH ≥ 90 cm therefore, this component was excluded from the study.

LRV	Habitat Feature	Survey Method	Function	Source(s)
D4	Availability of Tree Cavity Dens	MN DNR and SNF Stand Age Data Set / ground survey	D4 = 0.564(log10^x) – 0.352, for x ≤ 250; D4 = 1.0, for x > 250; where: x = number of trees ≥ 90 cm DBH / ha	Zimmerman (1992)

Table 3-21: D4: Availability of Tree Cavity Dens

3.22 Interspersion of all Resources

This LRV was constructed in the same manner as LRVIf: Interspersion for Food Resources, except 0 values for each LRV; food, escape cover, and denning, were applied.

LRV	Habitat Feature	Survey Method	Function	Source(s)
ILRV	Interspersion of All Resources	GIS	ILRV = 1.0, for $x \leq 5$; ILRV = $-0.07x + 1.35$, for $5 < x \leq 19$; ILRV = 0, for $x > 19$; where: x = distance (km) between resources	NA

Table 3-22: Interspersion of all Resources

3.23 HSI Component Functions

Model	Index	LRV	Habitat Feature	Function	Source(s)
HSI				HSI = [(LRVF + LRVE + LRVD) / 3] X ILRV	Mitchell (2002)
LRV			Life Requisite Variable for Food Resources	LRVF = (Fy + Fsp + Fsu + Ff)/4 X If, for (Fy + Fsp + Fsu + Ff)/4 X If < 1.0; LRVF = 1.0 for (Fy + Fsp + Fsu + Ff)/4 X If ≥ 1.0	Mitchell (2002)
	Fy		Year – Round Foods	Fy = Fy1 + Fy2, for Fy1 + Fy2 ≤ 1.0; Fy = 1.0, for Fy1 + Fy2 > 1.0	Mitchell (2002)
	Fsp		Spring Foods	Fsp = (2Fsp1 + Fsp2) / 3	Mitchell (2002)
	Fsu		Summer Foods	Fsu = Fsu1 + Fsu2, for Fsu1 + Fsu2 ≤ 1.0; Fsu = 1.0, for Fsu1 + Fsu2 > 1.0	Mitchell (2002)
	Ff		Fall Foods	Ff = [(2Ff1 + Ff2) / 3] X Ff3	
LRVE			Life Requisite Variable for Escape Resources	LRVE = (E1 + E2 + E3 + E4 + E5)/5 for (E1 + E2 + E3 + E4 + E5)/5 < 1.0; LRVE = 1.0, for (E1 + E2 + E3 + E4 + E5)/5 ≥ 1.0	
LRVD			Life Requisite Variable for Denning Resources	LRVD= {[(D1 + D2) / 2] (D3 + D4)}^0.5, for = {[(D1 + D2) / 2] (D3 + D4)} ^0.5 < 1.0; LRVD = 1.0, for = {[(D1 + D2) / 2] (D3 + D4)} ^0.5 ≥ 1.0	This component was excluded from the analysis

Table 3-23: HSI Component Functions

3.24 Home Range Estimation

All methods of estimating and quantifying animal home range have problems and no method will be best for all research. Early methods of determining home range included creating a circle or ellipse around the observations (Powell et al. 1997). Later methods included the use of the bivariate Fourier series (Anderson 1982) and time sequential polar coordinates (Powell et al. 1997). Mitchell et al (2002) employed 95% kernel density estimation using least squares cross validation test to determine home ranges for the purpose of testing Zimmerman (1992) therefore, I employed 95% kernel density estimation using least squares cross validation test to determine home ranges for the purpose of testing this HSI.

3.25 Testing the Habitat Suitability Index

I created one 60 meter HSI raster to test all 36 individual home ranges and 4 population home ranges. Since HSI raster cell values were in float format between 0 – 1, I classified the values into 20 classes in increments of .5. I then created a model in ArcMap (Figure 4) based on Ivlev's electivity index to determine habitat selection by the bears (Ivlev 1961). Ivlev's electivity index determines the extent to which the bears are either attracted to or avoiding an HSI value by looking at the availability of that class within the HSI and the amount of GPS observations found within the class (use of class – availability of class / use of class + availability of class). An index value of -1 shows strong avoidance while an index value of 1 shows strong attraction. I also performed the test for the entire population for each year.

The HSI was tested both at the individual level and population level. At the individual level each of the 36 home range point assemblages was tested independently,
At the population level all GPS points for all bears for a given year were treated as one home range.

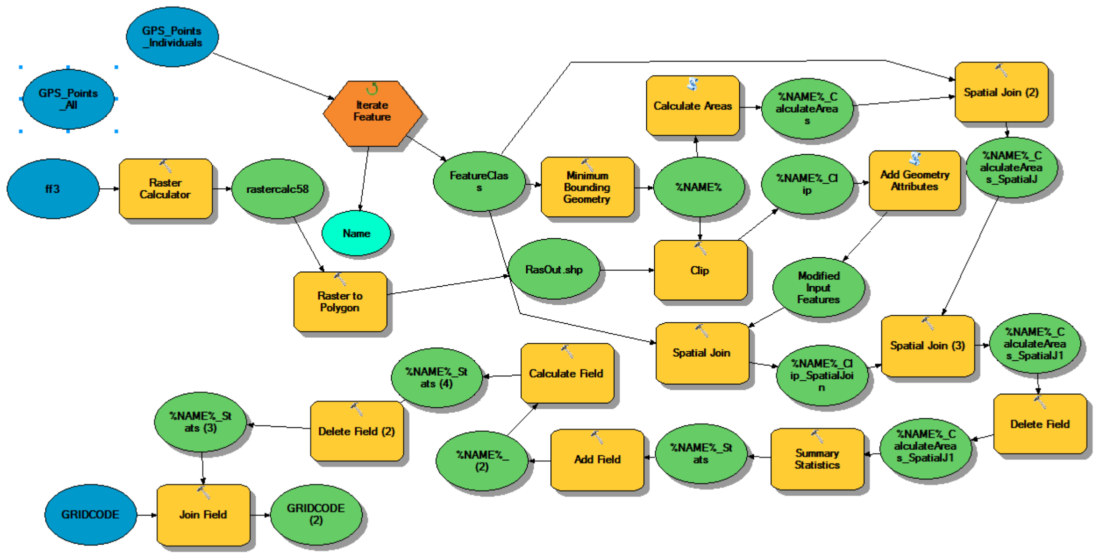

Figure 3-2: ArcMap Model for Testing HIS

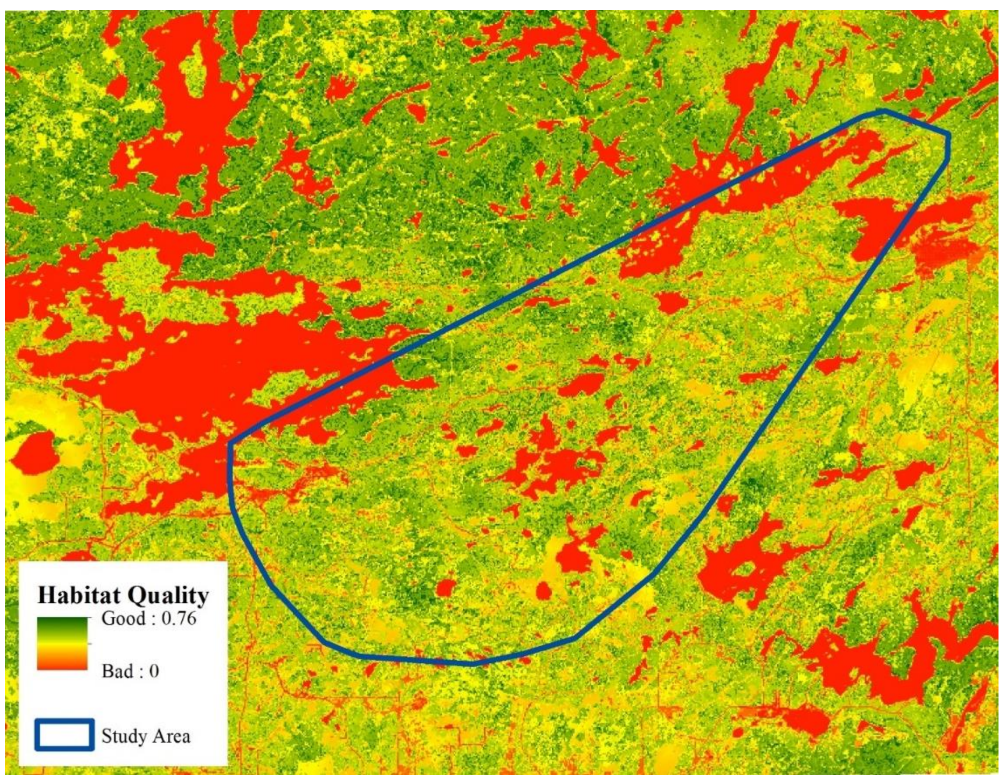

Figure 3-3: HSI Raster

4.0 Results

The results for both individual and population level tests show a positive correlation between HSI values and GPS point location. The bars depict the range of values within the class while the dashed line represents the average. At the individual level the positive correlation is slightly greater than at the population level (R^2 = .32 and .10 respectively).

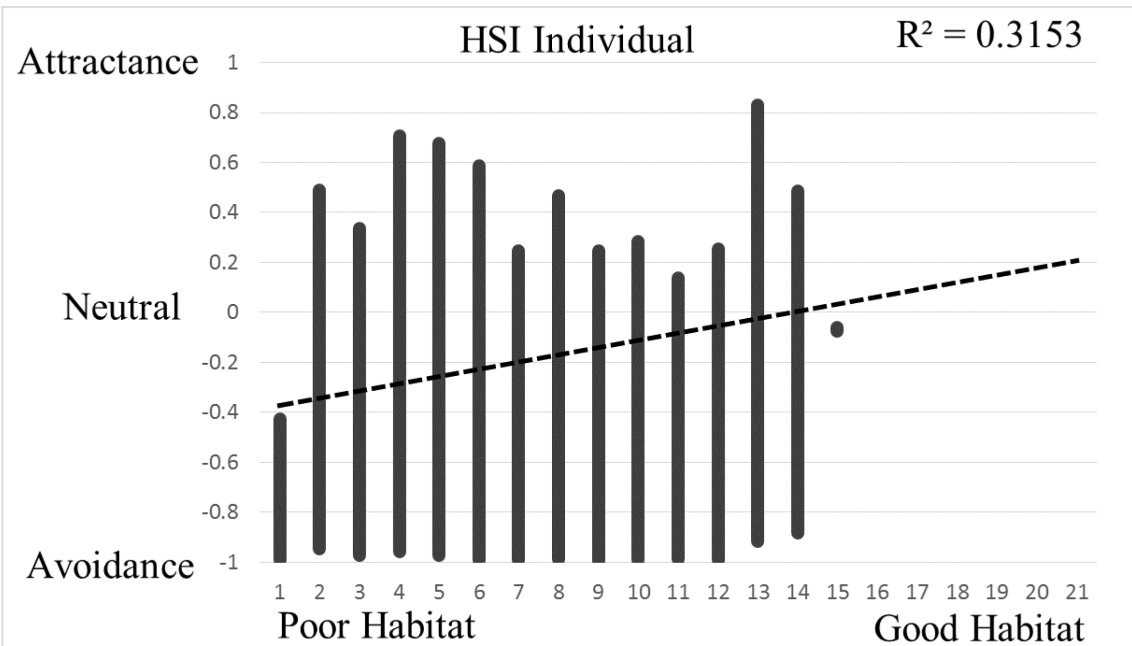

Figure 4-1: Results of HSI Test at Individual Level

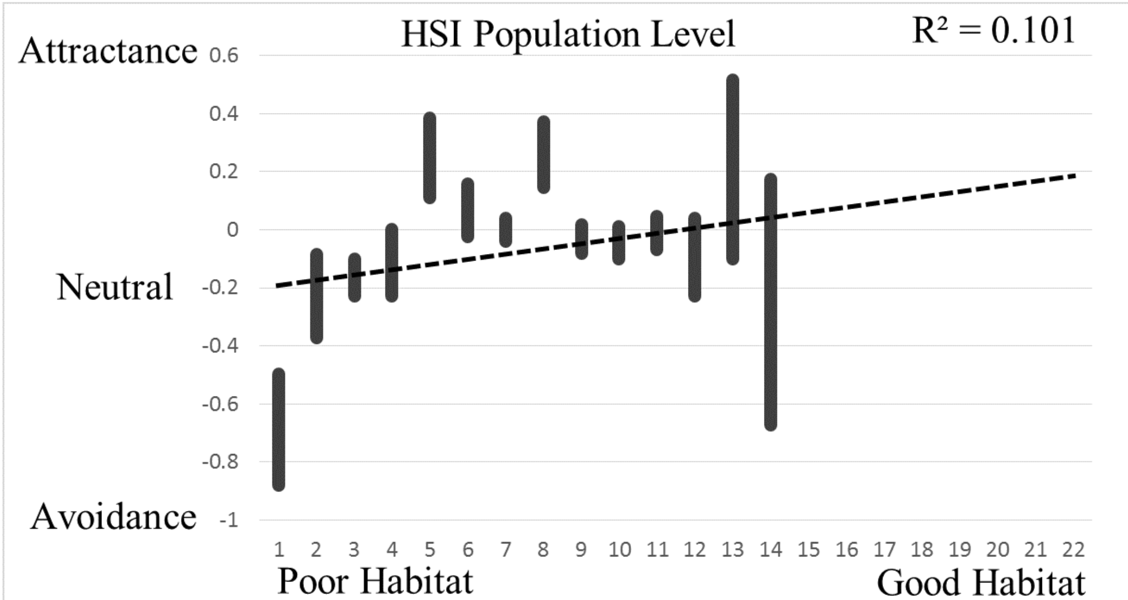

Figure 4-2: Results of HSI Test at Population Level

5.0 Discussion

5.1 Low HSI Values

Since HSI values reflect habitat quality low values are associated with poor habitat while higher values are associated with better habitat. Unlike Mitchell (2002) who had maximum HSI values of 0.85 for the Pisgah bear sanctuary study in the southern Appalachians, this study area shows lower values with a maximum HSI value of .74 (class 14). The HSI class with the greatest number of cells, 27% of study area, is class 8 which reflects HSI values between 0.35 and 0.40. 13% percent of this can be attributed to open perennial water and developed areas. The second largest HSI class, 14% of the study area, is class 9 which represents HSI values between 0.40 and 0.45. Low HSI values might suggest that the study area is poor habitat for black bears or it might suggest that there are additional life Life Requisite Values (LRV) in the study area which the Zimmerman HSI does not account for. Variables required to fulfill LRV's which are present in Pisgah but not this study area include: squaw root, rhododendron, mountain laurel, trees with Diameter at Breast Height (DBH) values≥ 90 cm's and grapes. Additionally, steep slopes are deemed important for to LRVs and found throughout the Appalachian Mountains but the terrain in this study area consists of flat, glacially scoured bedrock.

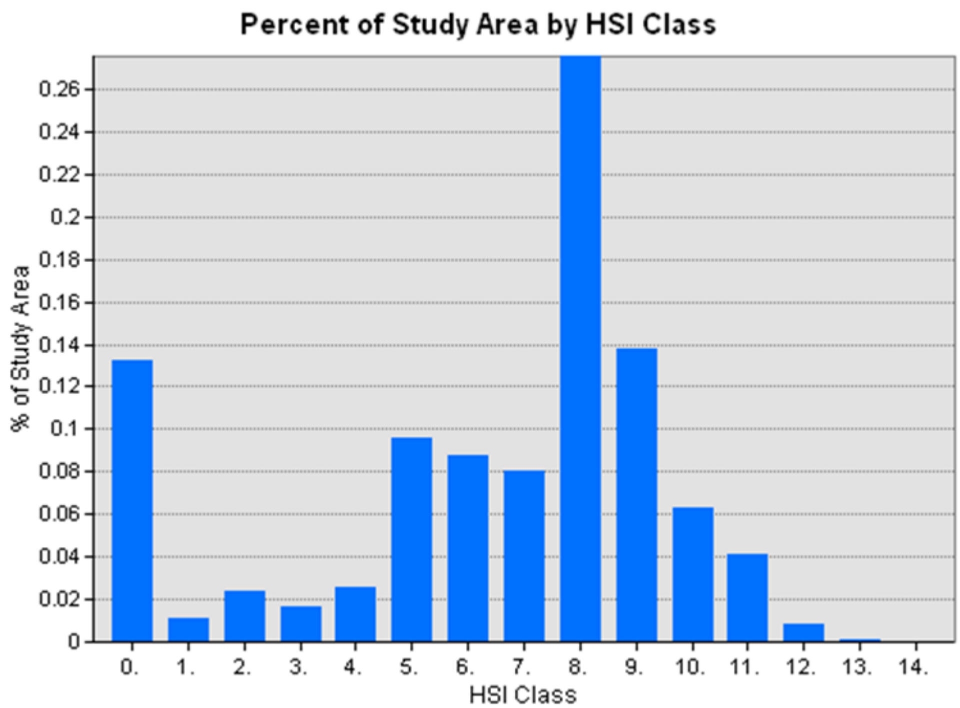

Figure 5-1: Percent of Study Area by HSI Class

5.2 Quantifying Down Woody Debris

Many methods to estimate woody debris were attempted. First, using Forest Inventory Analysis data I attempted to correlate the quantity of downed woody debris by stand age and stand type. The result of the correlation showed no significant relationship between stand age and stand type. I then conducted a ground survey where I surveyed 200 locations within my study area and tried to correlate down woody debris by stand type but was unable find a significant relationship. Lastly, I contacted Grant Domke, a leading Down Woody Debris specialist at the USFS field station in St. Paul, MN. No method for calculating this LRV was established.

5.3 Hard Mast Fall Foods

Hard mast fall foods other than hazelnuts are extremely rare owing to a deficiency of stands containing *Quercus spp.* which comprises < 5% of the study area. Furthermore, the oak stands that do exist within the study area have been reported by the research team to be too young to produce substantial hard mast and therefore, any mast which may exist, would provide an insignificant food benefit for the entire bear population.

Being that there are few mature hard mast producing species within the study area it could be suggested that the North Woods area of Minnesota is very poor habitat for black bears in the fall. This is an important factor because an abundance of fall food is required for the bears to gain the weight required for winter denning and embryo implantation.

5.4 Anthropogenic Foods

The anthropogenic food component of this model has the strongest positive correlation with and R^2 of .82 at the individual level and .92 at the population level. This shows that the bears in this study area are behaving the same toward anthropogenic food as the bears in Zimmerman (1992). The research team identified 16 locations within the study area where high quality food was made available to the bears throughout the year without the risk of reprisal. One residence was identified as having numerous bird feeders which the study bears frequented at a high risk of reprisal. This residence is identified in Figure 9 as class 11. Conventional wildlife management dogma claims that if bears are fed at houses then bears will associate all houses as sources of food. If true then this anthropogenic food component should not show a positive correlation because bears would frequent all houses instead of just those which provide food. Instead, the strong positive correlation suggests that the bears only frequent houses where high quality, consistent food exists without risk of reprisal while avoiding less desirable residences. Also, the strong positive correlation suggests that, with respect to anthropogenic food, the study bears in Minnesota behave the same toward anthropogenic food as the bears in Pisgah.

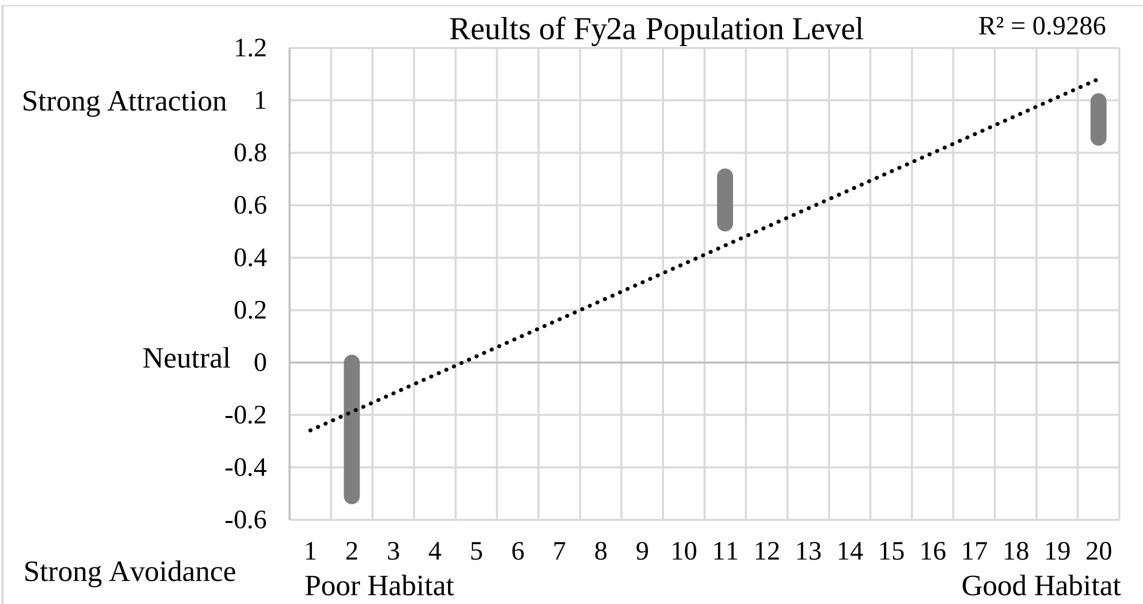

Figure 5-1: Results of Component Fy2a at Population Level

5.5 Squaw Root

Zimmerman (1992) deemed squaw root an important summer food for bears in the Appalachian Mountains but this food source does not exist in Minnesota. The research team has been unable to recommend an alternate summer food source in

Minnesota therefore, in order to make this model applicable to the study area this component was excluded.

5.6 Grapes

Zimmerman (1992) deemed grapes an important fall food in the Appalachian Mountains yet grapes do not exist in northeastern Minnesota which further suggests that my study offers poor fall food black bear habitat. The grape component should be was in an HSI for black bears in northeastern Minnesota.

5.7 Rhododendron or Mountain Laurel for Ground Dens

Rhododendron and Mountain Laurel do not exist in northeastern Minnesota however, since ground dens do exist in the study area it would suffice to substitute alder and hazel in their place. Unfortunately, the process of quantifying the density of low lying ground cover was already employed in E2 and duplicating the component might result in undo weighting for this LRV. Therefore, I chose to exclude this component.

5.8 Tree Cavity Dens

In the Appalachian Mountains tree cavities are used as dens by black bears but in northeastern Minnesota no trees were found to exist which have a DBH ≥ 90 cm as required by Zimmerman (1992). According to MNDNR (2016) the Red Pine, Eastern White Pine and Northern White Cedar are capable of attaining DBHs of 90 cm and tree stumps were found in the study area proving that at one time old extensive groves of white pines with DBHs > 90 cm once existed but logging practices in 18th and 19th centuries removed all trees old growth trees suitable for denning. Therefore, this LRV was removed from this model.

5.9 Availability of Cave and Rock Dens

The testing of this individual component shows a positive correlation between slope and habitat selection however, the methodology employed in creating this component was duplicative of E3, steepness of terrain. Therefore, to avoid double weighting of slope and because two of the other components related to denning do not apply to the study area, I excluded D3 from the analysis.

5.10 Accessibility via Roads for Denning

This component was excluded from the analysis due to reasons stated above.

5.11 Bed Sites and Lowland Swamps

A survey of 100 bed sites in the study area identified an attraction to lowland cover types associated with Northern White Cedar, Balsam Fir and Black Ash for the purpose of bedding and old growth White Pines were identified as bed trees at many of the site (Mansfield, Powell and Rogers unpublished data 2016). Although it is possible to predict where these cover types exist using the GAP land cover and SSURGO soil datasets, finding the locations of isolated old growth White Pine trees requires finer scale survey methods not available at this time.

5.12 Perennial Water Associated with Component Fsp1

The Pisgah National Forest is upland mountainous well drained terrain and perennial water is limited to streams and reservoirs. My study area is relatively flat with a substantial amount of poorly drained lowlands thus water is abundant throughout and the entire area. Based on the criteria set forth by Zimmerman (1992) all portions within the study are assigned a value of 1 because the entire study area is <.64 km from water.

6.0 Conclusion

When tested independently, each component in this HSI, with the exception of E4, distance from roads, showed a positive correlation between habitat quality and habitat selection by the study bears. This suggests that the bears in this study exhibit similar behavior as the study bears in Pisgah as well as the bears in the literature employed to construct Zimmerman (1992). It also demonstrates the feasibility of constructing habitat suitability indexes with globally applicable components. Further testing of the HSI components found herein should be performed using black bear collar data from black bear studies in differing habitats and geographic locations. Conversely, the collar data in this study should be tested using components derived from black bear studies in differing habitats and geographic locations.

As remote sensing and GIS technology continues evolve at an incredible pace the ability to accurately model habitat variables is increasingly achievable but, to validate HSI models on a global scale requires cooperation between black bear researchers and sharing of data.

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