PREDICTING ECOLOGICAL AND SOCIAL SUITABILITY OF BLACK BEAR HABITAT IN MICHIGAN'S LOWER PENINSULA

by

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Abstract

Black bear (Ursus americanus) populations in Michigan's Northern Lower Peninsula (NLP) are observed to be increasing and expanding their geographic extent, as indicated by trends in bear nuisance reports, harvest reports, and sightings. I modeled bear habitat selection in the NLP using observed telemetry locations and 12 environmental variables. I used bear telemetry locations from 20 males and 35 females that were collected by the Michigan Department of Natural Resources throughout the NLP from 1992 to 2000. I chose Bayesian discrete choice hierarchical models to model bear selection of grid cells at three different spatial resolutions – 3 km, 2 km, and 1 km. I used separate models for males and females because of their different habitat requirements and behavior. The male 3km model and female 2km model best fit the data and were used to identify existing suitable habitat in the NLP and also used to predict the suitability of areas in the entire Lower Peninsula for potential bear range expansion. The results of applying the models illustrate a paucity of suitable bear habitat in the Southern Lower Peninsula (SLP). However, the results also indicate the potential for wildlife management agencies to develop a bear habitat network in the LP. In addition, I integrated survey information from the Social Carrying Capacity (SCC) project with the GIS-based habitat prediction models to illuminate the relationships between human behavior and attitudes regarding bears and suitable bear habitat in Michigan's Lower Peninsula. This analysis was conducted within two bear-density regions identified by researchers at Michigan's Department of Natural Resources (Zone B and Zone C) where bear populations and human development have recently been expanding. Overall, the variables I chose to evaluate describe respondent demography as well as attitudes toward bear presence *and* bear-management policies. Using these variables, I identified potential conflict regions as places with more intolerant people and

suitable bear habitat. The results indicated no significant relationship between variables that represented attitudes towards bears and bear management policies with suitable bear habitat. However, the conflict region maps indicated that Zone C had approximately more than twice as much area where potential bear/human conflict can occur than in Zone B. Furthermore, there is no denying that the landscape is considerably different between the two zones and thus residents in Zone C may respond more unpredictably than residents in Zone B to current methods the MDNR employs to handle nuisance bears. The results from this research will enable the Michigan Department of Natural Resources to refine their future bear harvest strategies and develop regionally specific bear management plans.

Chapter 1: Ecological Model

1.1. Introduction

Wild animals select habitat and food resources that improve their fitness for survival and reproduction. They likely select habitat and food resources non-randomly; that is, a particular habitat or resource may be selected more than others even if it is very rare. Modeling wildlife resource selection can provide useful information regarding the distribution and dynamics of wildlife populations. Wildlife ecologists have been analyzing and modeling wildlife resource-selection criteria for some time (Neu et al. 1974, Johnson 1980, Byers et al. 1984, Heisey 1985, Dunn and Braun 1986, Thomasma et al. 1991, Aebischer et al. 1993). A number of approaches have been developed for and applied to the resource-selection problem, and the choice of resource-selection modeling approach for a given situation is determined by study design, data available, and the assumptions made therein (Alldredge and Ratti 1986, 1992).

Studies about a species' habitat and resource selection improve the scientific community's knowledge of wild animal populations, but also have important implications for wildlife management (Van Manen and Pelton 1997, Thogmartin et al. 2004, McDonald et al. 2006). This is especially the case for large mammals that have a history of conflict with human populations (Hilton-Taylor 2000, Woodroffe 2000, Schwartz et al. 2003), where information about habitat selection by animals can be used to guide resources and management to reduce conflicts. Black bears in North America are a good example of the tenuous relationship between wildlife and human populations (Beckman 2003, Breck et al. 2006). Since European settlement, bear habitat in the United States has been significantly reduced. The current range of bears is a fraction of their past distribution because of human-induced habitat fragmentation and degradation (B.W.

Conley 1978, R.H. Conley 1978). Despite this reduction in habitat, black bear populations in the United States are healthy, for the most part, and many states indicate that black bear populations are growing and expanding their ranges. As a result, the extent and magnitude of the interface between humans and bears is growing, which has led to more conflicts between the two species (Servheen et al. 1999, Carr 2003). For instance, human activity can displace or disturb bears in their use of habitat. Bears may also be indiscriminately persecuted because of human intolerance. Likewise, bears may become habituated to anthropogenic food sources making them more likely to damage row crops, apiaries, and fruit trees. Bears in human dominated areas may even pose a threat to human safety.

Bear populations in Michigan's Northern Lower Peninsula (NLP) are observed to be increasing and expanding their geographic extent, as indicated by trends in bear nuisance reports, harvest reports, and sightings (Etter 2002). Additionally, urban sprawl continues to characterize Michigan's land development patterns; planners expect developed areas in Michigan to increase by 178% by 2040 (PSC 2001). Consequently, the potential for bear-human conflict is likely to increase over time in Michigan's Lower Peninsula if comprehensive management initiatives are not in place to pre-empt these unnecessary clashes. Thus, the Michigan Department of Natural Resources (MDNR) is pursuing information on bear populations so that they can design a more comprehensive bear management plan. A more informed plan may not only help reduce human-bear conflict, but also foster sustainable *co-existence* between bears and humans (see CDFG 1998, Carr 2003, Spiker and Bittner 2004).

The primary objective of my research was to create and apply a model that identified how various environmental attributes influence the distribution of black bears in the NLP. The quantitative model of these influences was then used to calculate and map the suitability of habitat to black bears (Clark et al. 1993, Rudis and Tansey 1995, Van Manen and Pelton 1997, Mitchell et al. 2002). Bear radio-telemetry location data were collected by the MDNR from 1992-2000. In addition, data on environmental and habitat attributes in Michigan that may be potentially important to bear populations were collected or, in some cases, derived. Bayesian discrete choice hierarchical models were used to model bear selection of grid cells at three different spatial resolutions – 3 km, 2 km, and 1 km. Different resolutions were used to evaluate model results for sensitivity to scale. The model that best fit the data was used to identify existing suitable habitat and to predict the suitability of areas in the Lower Peninsula for potential bear range expansion. The GIS model predictions also indicated spatial relationships (i.e., proximity and dispersion) between suitable habitats across the landscape. This information can be used to support bear habitat conservation recommendations (i.e., continuous tracts of land and travel corridors). The results from the model can assist additional black bear research projects as well as help management institutions understand bear distribution dynamics important for bear management plans (see CDFG 1998, Carr 2003, Spiker and Bittner 2004, Ternent 2005).

1.1.1. Discrete Choice Models

Resource selection stipulates that an individual animal selects resources non-randomly. In this context, the question is whether or not an individual bear selects a particular area of land non-randomly given the opportunity to choose from a much larger area. However, no two bears are exactly alike in their selection criteria. Furthermore, bear locations from radio-telemetry are inherently imprecise and the spatial pattern of bear captures was probably not perfectly random. Therefore, given ecological realities and data uncertainties, it is reasonable to frame the selection process as being statistical by nature. It is not reasonable to try to predict the selection criteria for each bear at each location but rather to focus on the aggregate statistical properties of the bear population over larger spatial extents (Wikle 2003).

Johnson (1980) described four orders of hierarchical selection by wildlife. The first order of selection refers to the geographical range of the species. The second order refers to the home range of an individual or social group. The third order refers to the use of particular habitat elements within the home range. The fourth order refers to the actual food items that an animal chooses at a feeding site (Johnson 1980). My aim was to identify which environmental attributes are influential in the selection process by bears within the NLP bear population home range. This is defined as third order selection. Discrete choice models are well adapted to model this type of selection and are commonly used in wildlife studies of resource selection (Cooper and Millspaugh 1999). The underlying theory is derived from economic theory that suggests consumers choose some product over others to maximize their satisfaction. This is analogous to saying that an individual bear will choose an area non-randomly based on the higher “utility” of that area relative to all other areas (Cooper and Millspaugh 1999). Spatial independence of the bear locations is an important assumption built into many discrete choice models (McCracken et al. 1998, Manly et al. 2002). Another assumption is that all of the study area is equally available to each bear (McCracken et al. 1998, Manly et al. 2002). This focuses the model variables and selection criteria to only the environmental attributes within specific areas of land. The preferred selection of a particular area of land by a bear is defined as the probability of selection being greater than the probability of selection of some other area. Selection then should be represented as a likelihood of that area being chosen if the entire area were equally available.

1.1.2. Bayesian Inference

A deterministic model, discrete choice in this case, is chosen because it models a certain ecological process. However, the results from these models are fixed and do not reflect the statistical qualities of complex ecological processes. Bayesian inference can enable researchers to incorporate a deterministic model into a stochastic framework. Ecologists are increasingly using Bayesian statistical inference to estimate ecologically meaningful parameters (Ellison 2004). The fundamental difference between Bayesian inference and more traditional frequentist methods is how these techniques represent the parameter values. Frequentist methods assume that each parameter has a fixed value whereas Bayesian inference represents parameters as random variables with probability distributions (Ellison 1996, Link 2002). This method accounts for bias in data collection and acknowledges that a true, fixed value for a parameter is highly unlikely in a natural experiment where no two organisms are exactly alike. In addition, the p-value typically used in frequentist methods does not tell the researcher how probable the null hypothesis is or how probable the alternative hypothesis is (Ellison 1996). Bayesian inference uses probability calculus to determine the likelihood of a specific hypothesis given observed data (McCullagh and Nelder 1991).

Bayesian inference can describe the probability distributions of the environmental attribute parameters using the statistical fact that the joint distribution of two events equals the product of the probability of one of the events and the conditional probability of the second event given the first one.

$$P(Y) \cdot P(H|Y) = P(HY) = P(H) \cdot P(Y|H) \tag{1}$$

From this the terms can be rearranged such that two probability distribution functions, called prior and posterior distributions, can be used to make inference on the parameter values.

$$P(H|Y) = \frac{f(Y|H) \cdot \pi(H)}{P(Y)} \tag{2}$$

This expression is known as Bayes' theorem (Bayes 1763). The prior distribution (or just prior) represents the expected probability of observing a parameter value, which is determined a-priori by the researcher. In effect, the prior summarizes what is already known about the parameter. The information in the prior distribution $\pi(H)$ acts to modify the posterior distribution $P(H|Y)$ (Link 2002). The function in the numerator is Fisher's likelihood function (Edwards 1992). It is the likelihood function that modifies the prior information into posterior expectations (Box and Tiao 1973, Reckhow 1990). The denominator is the expected value of the likelihood function that acts as a normalizing constant.

$$P(Y) = \int f(Y|H) \cdot \pi(H) dH \tag{3}$$

The normalizing constant, equal to the integral of the conditional probabilities of the likelihood function weighted by their prior probabilities, scales the posterior so that the area under the posterior probability distribution is equal to one. In other words, the posterior distribution becomes proportional to the prior (since they are distributions for the same random variable) by normalizing the numerator to get a probability measure (Ellison 1996). The posterior distribution describes the range of possible values for the parameter of interest and their probabilities (Link 2002).

Through an iterative process, the posterior distribution will converge to what is called the Bayes estimate. The Bayes estimate is the mean value of the parameter of interest (Link 2002). Bayesian inference allows for a researcher to add new data that may change the probability distribution of a given parameter thus enabling the application of adaptive management techniques. In other words, wildlife managers can evaluate the effectiveness of decisions and make appropriate changes.

1.2. Bear Physical Description and Range

The Black Bear is a large, heavily boned mammal with a long snout, small eyes, rounded ears, small tail, and powerful limbs (Servheen et al. 1999, Obbard 2003). Adult males are approximately 130 to 190 cm (4-6 feet) long from tip of the nose to the tip of the tail and vary in weight from 60 to 140kg. Adult females are approximately 110 to 170 cm (3.5 – 5.5 feet) long and vary in weight from 40 to 70kg. Black bear fur is shaggy and usually black although coat color can also range from dark brown to light brown with some bears having a white patch on their chest (Servheen et al. 1999). They have powerful front legs with large curved, non-retractable claws on each foot enabling them to bend branches, turn over rocks, and tear apart logs to retrieve food (Rogers and Allen 1987, Servheen et al. 1999)

Figure 1: Current Distribution (1994) of Black Bear in the United States (Pelton and van Manen 1997).

Black bear are the only bears inhabiting the Eastern United States (Figure 1), and range from the Sierras, Idaho and Montana, south through the Rockies into Mexico, Northern Great Lakes area, Ozarks, Gulf Coast, Florida, and New England south through the Appalachians to northern Georgia (Pelton 1982).

1.3. Study Area

There are approximately 20,000 bears in Michigan occupying 90,650 sq. km in the NLP and the Upper Peninsula (UP; MDNR unpublished data). Approximately 90% of Michigan's bears reside in the UP, which has excellent bear habitat and consists of large tracts of federal, state, and privately owned commercial forest lands. Despite the small percentage of bears in the NLP, current trend information indicates that their numbers are increasing and that their population will likely expand to the southern portion of the Lower Peninsula (SLP) in the future (Etter 2002). The SLP is dominated by human influenced land uses. Traditionally, it is habitat disturbance and human-induced mortality that has limited bear numbers and distribution in Michigan (MDNR unpublished report).

From 1991 to 2000, bears were trapped and radio-collared in the Baldwin and Red Oak Bear Management Units (BMU) in the NLP of Michigan. The Baldwin BMU is located in the northwest one third of the Lower Peninsula and Red Oak BMU is located in the northeast two thirds of the Lower Peninsula (Figure 2). For my purposes, the Northern Lower Peninsula encompasses an area of 47,120 sq. km and includes 33 counties (Figure 2). This region is dominated by forest and is in the Northern Lacustrine-Influenced Region of Lower Michigan (Albert 1995). The land cover in this region comprises 15% agriculture, 16% upland non-forested, 17% northern hardwood and mixed forest, 9% oak, 10% aspen, 9% pine, 11% forested wetland, 6% non-forested wetland, and 7% other (which includes developed and major water bodies).

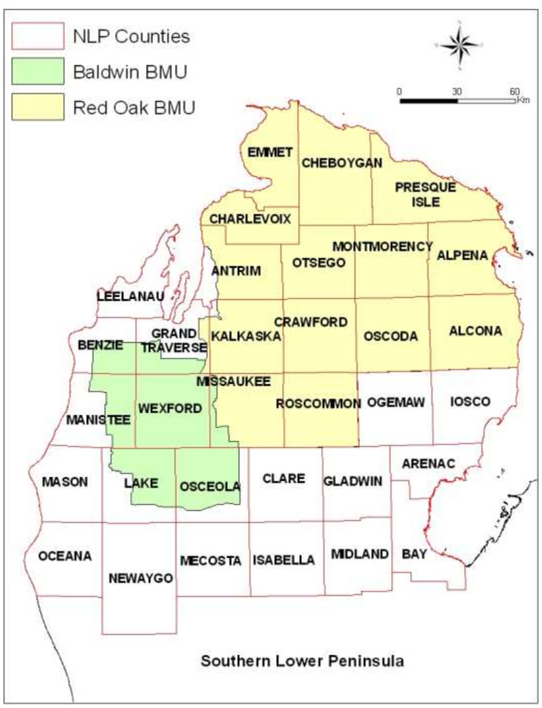


Figure 2: Northern Lower Peninsula Counties with locations of Red Oak and Baldwin Bear Management Units.

The Great Lakes surrounding Michigan create unique temperature and precipitation gradients across the state relative to the rest of the continent. The NLP is distinguished from the SLP by having cooler temperatures throughout the year and a shorter and more variable growing season. The average annual temperature in the NLP is approximately 7 degrees C but the extreme minimum temperature ranges from -40 to -45 degree C (Barnes and Wagner 2004). The average length of the growing season in the NLP is 126 days

(Albert et al. 1986). The interior of the region is dominated by sandy, high plains that tend to have greater temperature extremes than the rest of the region and a shorter growing season of about 115 days (Barnes and Wagner 2004). The elevation in the NLP ranges from about 259 to 526m (Leatherberry and Spencer 1996). Precipitation is more uniform across the state compared to temperature. In general, precipitation decreases from southwest to northeast across the entire state (Barnes and Wagner 2004). In the NLP, the annual precipitation is approximately 71 to 81 cm and annual snowfall ranges from 102 to 356 cm (Leatherberry and Spencer 1996).

The underlying bedrock in the NLP includes sandstone, shale, limestone and dolomite (Dorr and Eschman 1970). The most common landforms include glacial moraines, till plains, outwash and lake plains, ice-contact terrain, sand dunes, and beach ridges (Barnes and Wagner 2004). The soils in the region are sands, loamy sands and sandy loams (USDA 1981, Albert 1990).

The land cover of the region has changed considerably since the middle of the 19th century, through intensive logging for white pine, hemlock and northern hardwoods. Following this intensive logging were catastrophic fires that additionally altered the land cover. For this reason, early successional forest types including aspen and birch forests are more prevalent today than in the past (Barnes and Wagner 2004).

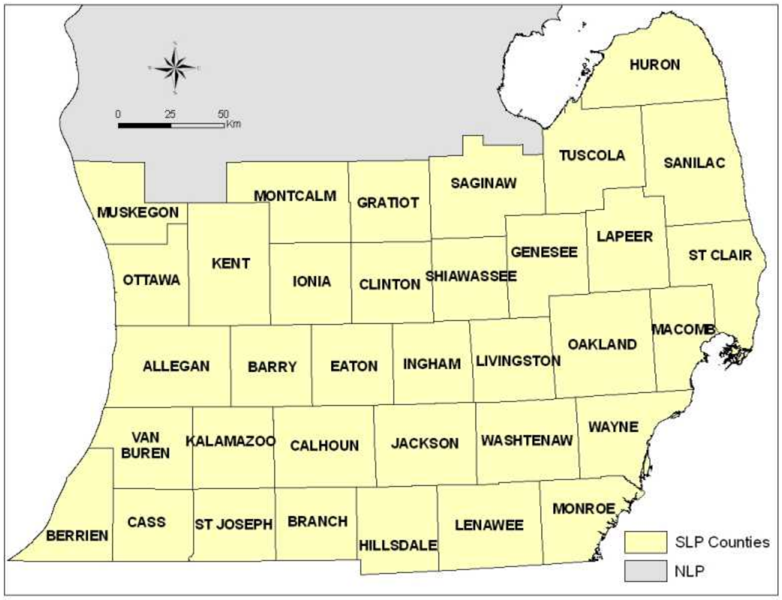


Figure 3: Michigan Southern Lower Peninsula Counties.

I made model estimations of bear habitat suitability for the SLP counties (Figure 3). This region comprises 51% agriculture, 8% upland non-forested, 11% northern hardwood and mixed forest, 3% oak, 1% aspen, 2% pine, 5% forested wetland, and 6% non-forested wetland, and 12% other (i.e., developed or water).

1.4. Materials and Methods

I chose to use a Bayesian discrete choice hierarchical model because of the high-dimensionality of the model, the error in the telemetry location data, and concerns about the different numbers of telemetry locations for individual bears. Bayesian inference provides a framework through which variance and error terms can be calculated for the parameter values. Discrete choice models enabled me to analyze the suitability of a user-defined piece of land (e.g., a grid cell) instead of whole land-cover types. It is possible with a large enough error in the telemetry data that a location may be incorrectly associated with a certain land-cover category. To avoid misclassifications due to potential positional errors, I chose to analyze pieces of land defined by grids with 3 km, 2 km, and 1 km squared cells. These grids intersected the home ranges of male and female bears. These grid resolutions are much larger than the maximum telemetry error accepted (16 ha) in a bear location, so even if the location was not exactly in a land-cover category it should still fall within grid cells defined at any of the three scales of analysis. Furthermore, the results from the three scales may provide additional information on bear selection criteria as well as model limitations. Hierarchical models provided a means by which I could weight relocations and individual bears, thereby yielding inference about the population level selection characteristics. The results from the models that performed the best were used to estimate bear habitat suitability across the entire Lower Peninsula.

1.4.1. Telemetry and Home Range Estimation

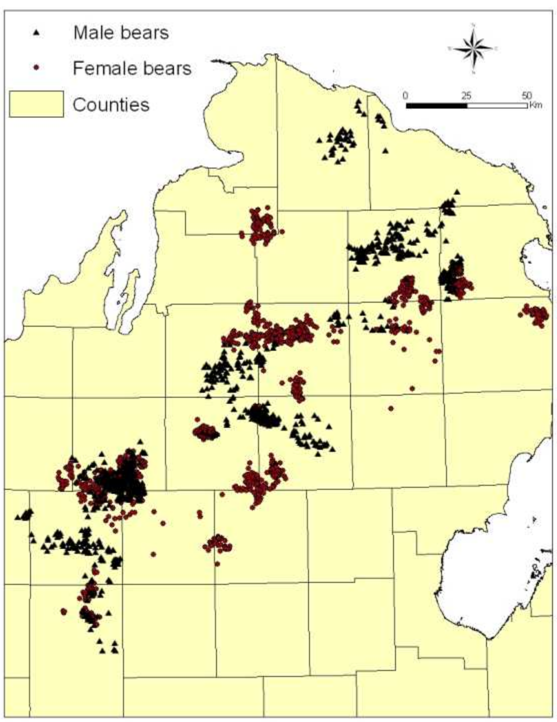


Figure 4: Telemetry Locations of Black Bears in Northern Lower Peninsula, Michigan.

Bear telemetry locations were collected from captured bears throughout the Northern Lower Peninsula. My analyses were based on 2,670 telemetry locations from 35 female and 1,408 telemetry locations from 20 male bears (Figure 4). Bears were captured by the Michigan Department of Natural Resources in barrel traps or in dens (Kohn 1982). All bears were equipped with radio-collars with a time-delayed mortality switch. Bears were located to the nearest quarter-quarter section using a GPS unit from a fixed-winged aircraft. Bears were also ground triangulated using a hand-held yagi antennae. Triangulated locations were determined using a minimum of two radio bearings in the maximum likelihood estimator in LOCATE II (Nams 1990). Locations with greater than a 16 hectare error (equivalent to 1 quarter, quarter section) were removed from analysis. Bears were located a minimum of once every other week when they were out of their dens from April to November. Telemetry locations were collected from 1992 to 2000 (Etter 2002). The collection of bear telemetry data was originally conceived by the MDNR as a long-term process. As a result, most locations for an individual bear were collected at least several days apart and so these locations are assumed to be spatially independent. I only included bears in analysis that were at least two years of age and older because yearling bear locations were likely correlated with the locations of their mother, and therefore, did not fulfill the model assumption of independent locations. In addition, females greater than 2 years old represent the population segment most crucial to productivity (Clark et al. 1993). I used separate models for males and females because of their different habitat requirements and behavior (Clark et al. 1993).

Home ranges are best defined as "…that area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range" (Burt 1943). The kernel home range estimation technique has become very popular in the ecological literature because it considers the density of the telemetry locations when creating home ranges (Schenk 1998, Dickson 2002, Koehler 2003). In general, the density at any location on the ground is an estimate of the amount of telemetry locations in that area (Seaman and Powell 1996). In this case, however, it is the geographic extent of the home ranges created by the kernels that defines available habitat to each bear.

I created 30m resolution home range estimates for each bear using the kernel density estimator tool from the HawthsTools extension within ESRI's ArcGIS software program (ESRI 2002b). I used a fixed kernel with a least squares cross validation smoothing parameter because it gives area estimates with very little bias (Horne and Garton 2006). In addition, I only included bears with at least 30 locations for precise kernel home range estimation (Horne and Garton 2006). The average kernel home range for the 35 female bears was 227 sq. km. and the average kernel home range for the 20 male bears was 606 sq. km. The home ranges for the individual bears of each sex were combined to create two aggregate-level home ranges. The aggregate home ranges for males and females represent the total available habitat to all bears of each sex (Figure 5 and Figure 6).

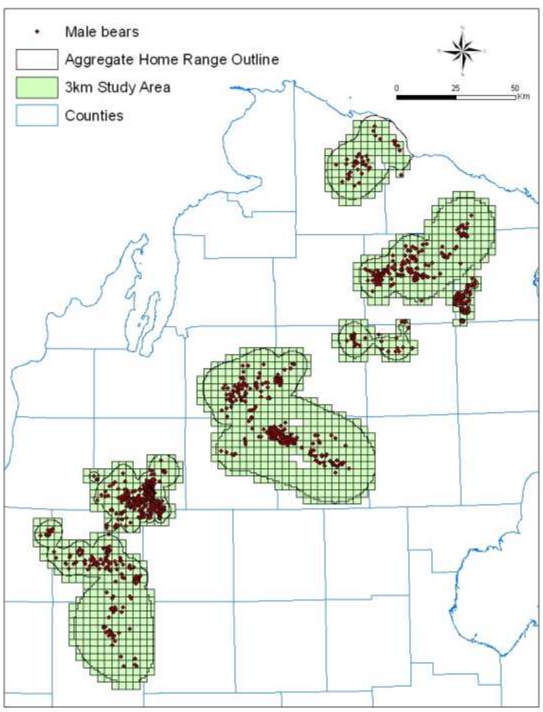


Figure 5: Aggregate home ranges and telemetry locations for male bears. Three different resolution study areas were delineated from the home range outlines. This figure only shows the 3km resolution study area.

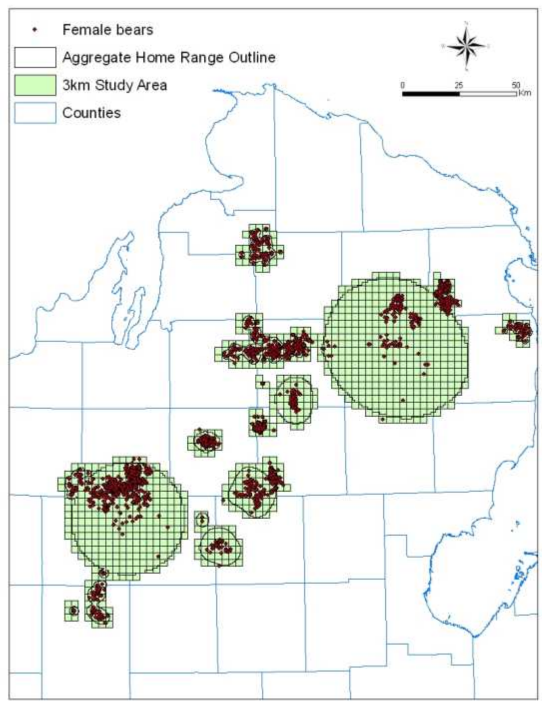


Figure 6: Aggregate home ranges and telemetry locations for female bears. Three different resolution study areas were delineated from the home range outlines. This figure only shows the 3km resolution study area.

1.4.2. Environmental Variable Selection and Data Preparation

Description of habitat selection patterns requires measurements of environmental characteristics that can serve as inputs to a habitat-selection model. I compiled 12 variables that can theoretically relate to habitat use by bears (Table 1).

Table 1: List of model variables calculated at three different raster resolutions, 3km, 2km, and 1km.

	Variable	Variable Type	Details	Source
Z-transformed for each grid cell	Hydrological Features Area	Continuous	Meters	GIS manipulation of MDNR lake and stream rasters
	Slope Deviation	Continuous	Degrees	GIS manipulation of IFR DEM
	Road Length	Continuous	Meters	GIS manipulation of MDNR CGI road shapefile
	Human Population Density	Continuous	per 30 meter raster cell	GIS manipulation of MDNR census shapefile and landcover raster
	Number of Patches (NUMP)	Continuous	Total number of patches	Patch Analyst
	Mean Patch Size (MPS)	Continuous	Average patch size	Patch Analyst
	Patch Size Coefficient of variation (PSCOV)	Continuous	Coefficient of variation of patches	Patch Analyst
	Edge Density (ED)	Continuous	Amount of edge relative to the landscape area	Patch Analyst
	Average Weighted Mean Shape index (AWMSI)	Continuous	Shape Complexity	Patch Analyst
	Shannon's Diversity Index (SDI)	Continuous	Measure of relative patch diversity	Patch Analyst
	Shannon's Evenness Index (SEI)	Continuous	Measure of patch distribution and abundance	Patch Analyst
Identified dominant type for each grid cell	Landcover	Categorical	Meters 1. Human Development 2. Agriculture 3. Upland Non-Forested 4. Northern Hardwood and Mixed 5. Oak 6. Aspen 7. Pine 8. Forested Wetland 9. Non-forested Wetland	Reclassified from landcover raster

Land cover:

A substantial amount of literature indicates that land cover is a crucial determinant of bear presence because of its association with food abundance and den selection (Rogers and Allen 1987, Clark et al. 1993, Rudis and Tansey 1995, Van Manen and Pelton 1997, Mitchell et al. 2002). Bears emerge from their dens in spring, after which they have 5-8 months to fulfill their nutritional needs for the entire year (Beeman and Pelton 1980). The availability of food influences bear survival and reproduction by directly affecting growth rates, female ages of first reproduction, and cub survival. For instance, fertilized eggs will not implant to form cubs unless the female bear reaches about 70 kg (Obbard 2003). As a result, bears prefer to occupy forests with diverse vegetation types that provide for their nutritional needs (Herrero 1979, Hugie 1979).

Although bears use dense forest as security and escape cover, they tend to prefer habitat that is interspersed with forest clearings because soft mast is more abundant in these clearings than in the understory (Hugie 1979). Black bears also prefer large tracts of undisturbed land with a variety of cover types (Manville 1987). Manville (1983) noted that bears in the Lower Peninsula of Michigan commonly use wetlands dominated by white cedar (Thuja occidentalis), balsam fir (Abies balsamea), black spruce (Picea mariana), and tamarack (Larix laricina) year round. He also noted that in order to meet the bear habitat requirements for food and cover, large tracts of lowland brush, alder (Alnus spp.), hardwood communities, and upland hardwoods including aspen (Populus spp.) must be available (Manville 1983). Manville (1983) also found that 68% of bear dens occurred in conifer-dominated wetlands.

I used land-cover data that had been created as part of the IFMAP project from triple date multi-seasonal Landsat imagery with a 30 m spatial resolution and obtained from the MDNR. Based on knowledge of bear ecology (Larry Visser, Wildlife Management Unit Supervisor, MDNR) the land-cover codes in this dataset were categorized into 9 cover classes from a land-use/land-cover layer available from the Michigan Center for Geographic Information (MCGI; Appendix B, http://www.michigan.gov/cgi). These 9 categories were agriculture, upland non-forested, northern hardwood and mixed, oak, aspen, pine, forested wetlands, non-forested wetlands, and a class that combined development land with major water bodies (i.e. land uninhabitable by bear). Land cover proportions were summarized within grid cells at each of the target resolutions.

Hydrological Features:

Black bears can overheat easily in the summer months and frequently use water bodies to cool off. In fact, bears may be unable to fully utilize forest clearings because of heat stress (Jonkel and Cowan 1971, Rogers 1980). Water must be accessible throughout the year because bears drink frequently when feeding on vegetation, nuts, or insects (Rogers and Allen 1987).

I obtained lakes and streams data with a resolution of 30 meters for the Lower Peninsula (LP) from the MDNR. I combined lakes and streams to create a simple raster dataset with hydrological features at a resolution of 30m. This raster layer was reclassified so that each raster cell represented either no water (0) or water (1). I then tabulated the area of water (1) for each of the model grid cells at all three resolutions.

Roads:

Road density can have both positive and negative influences on bear presence. Bears sometimes use logging, service, unpaved, and infrequently used roads as travel routes (Manville 1983, Young 1984). Roadsides may also provide good food sources (e.g., soft mast and green vegetation; Jonkel and Cowan 1971, Manville 1983). Frequently traveled roads, however, result in high numbers of bear/vehicle related deaths. As of 1987, highways accounted for almost 100 bear road kills each year in the Great Lakes Region (Rogers and Allen 1987). Bear mortality due to vehicle collisions is of particular concern in areas with dense human populations. A 1990 petition to list the Florida black bear as a federally threatened species cited road mortality as one of the primary reasons necessitating federal protection (Dobey 2005). In addition, if these roads are impassable, they may block access to important habitat for bears. Dixon (2006) indicated that the functionality of habitat corridors for black bears in Florida was compromised by road networks.

I obtained the vector layer of named roads for the State of Michigan (Version 6) from MCGI. The layer contained only one category of roads, maintained paved roads. I converted this layer into a 5m resolution raster dataset. I then calculated the total amount of road length within each model grid cell for all three target resolutions.

I also obtained a vector layer of unnamed roads (from the older Version 3) for the state of Michigan from MCGI that included many various road types (i.e., unpaved and smaller unnamed residential streets). I combined the layer of unnamed roads with the layer of named roads and used the Feature Class Code (FCC) field to categorize all state roads into three categories based on approximate size and traffic volume (see Appendix C). As before, I converted the reclassified road layer into a 5m resolution raster dataset. I calculated the total amount of road length from each road category within each grid cell for the target resolution that performed best in the male and female model. I ran the best-fit male and female models again with roads represented as three separate covariates to determine if road size and traffic volume influence bear selection.

Slope Variation:

A large proportion of black bear habitat is characterized by mountain ranges and drastic changes in slope. Various models of black bear habitat have included slope as a model variable (Clark et al. 1993, Van Manen and Pelton 1997, Mitchell et al. 2002). Slope is associated with soil composition and, in turn, with vegetation types which are important determinants of bear presence (Herrero 1979, Hugie 1979, Zimmerman et al. 1999). In addition, the topographic characteristics of the landscape are different when characterized at different target resolutions. The way in which bears perceive the slope of their environment may also change at various scales which may influence habitat selection. For these reasons, I chose to use the variation in slope as a model variable.

Slope data were derived from a 30 m digital elevation model (DEM) for the State of Michigan. This DEM was compiled by and obtained from the Institute of Fisheries Research at the University of Michigan. I calculated the standard deviation of 30 m slope values for each model grid cell for all three target resolutions.

It is important to note that a relationship between slope and bear selection may indicate association, but not necessarily causation because of the correlation between human presence and less steep slopes. Habitat fragmentation associated with heavy human populations has relegated bears to the steeper slopes of the mountainous regions in the northeast and southeast United States (Leopold 1959, Rogers and Allen 1987, Williamson 2002). It is possible that in other regions of the U.S. where bears are present, human settlement has also relegated them to higher elevations with steeper slopes.

Human Population Density:

Larger human populations lead to higher conflict rates and thus higher mortality rates of bears (Rogers and Allen 1987). In some cases, however, bears are lured to camping areas, dumps, or other unnatural food sources including backyards (CDFG 1998, D. Etter, MDNR, Pers. Comm.). Several other black bear habitat models have used human population or development as model variables (Clark et al. 1993, Van Manen and Pelton 1997, Mitchell et al. 2002).

The grid of human population density was calculated using dasymetric mapping (James et al. 2004). This method has been shown to produce accurate population density distributions (Eicher 2001). The original population layer downloaded from MCGI was indexed by census block. Census block population density estimates are very coarse and not the optimal method of depicting human population densities relative to bear presence. The dasymetric method recognizes the fact that certain areas within a census block are populated while others are not (Wright 1936). However, dasymetric mapping enables a user to divide the population density of the census block enumeration unit into the much smaller spatial scales of a raster cell (James et al. 2004, Eicher 2001). Thus, a dasymetric map can be at a much finer scale, appearing continuous, with each raster cell having a population density value.

The census block population values in the LP were redistributed to 30 m raster grid cells via the land-use/land-cover raster layer. I reclassified this dataset into 4 categories: urban development, agriculture, forested, open, and water. I calculated the population densities of these 5 categories to be 0.90, 0.07, 0.02, 0.01, and 0.0, respectively. I used areal interpolation (James et al. 2004, Eicher 2001) with the population densities to transfer the population density data from the census block unit to a 30m unit. I then calculated the sum of human populations within each model grid cell for all three target resolutions.

Landscape Metrics:

I calculated several landscape pattern metrics for each grid cell to describe the spatial arrangements of land covers (Table 1). These spatial arrangements provide information on patch diversity and structure that may influence the ways in which bears travel and select various areas over the landscape. The metrics used included number of patches (NUMP), mean patch size (MPS), patch size coefficient of variation (PSCOV), edge density (ED), area weighted mean shape index (AWMSI), Shannon's diversity index (SDI), and Shannon's evenness index (SEI). The variable NUMP measures patch frequency. The variable MPS measures the mean size of the patches across all land cover types. The variable PSCOV describes the variability in patch sizes. The variable ED is the amount of edge relative to the landscape area. The variable AWMSI is the sum of each patch's perimeter divided by the square root of patch area for all patches divided by the number of patches. This variable is also adjusted for shape size. The variable SDI is a relative measure of the diversity of patch types. The variable SEI measures how evenly the different patch types are distributed across the land area (McGarigal and Marks 1994). I used only the area in the cell to define the landscapes for use as input to the calculation of the landscape metrics. The landscape metrics were calculated within ESRI's ArcView 3.3 (ESRI 2002a) using the Patch Analyst extension (http://flash.lakeheadu.ca/~rrempel/patch). These metrics were chosen because they cover a wide array of patch information including edge, shape, and interspersion. These metrics have been shown to contain the majority of patch information (Riitters et al. 1995).

1.4.3. Model Specification

Utility to a bear of a piece of land is defined by a linear function

$$U = \beta X + e = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + e\,, \qquad (4)$$

where X is a vector, length k, of the attributes within the piece of land. β is a vector, length k, of estimable parameters describing the contribution of each attribute within the piece of land. Since no two animals are exactly alike in their habitat requirements or behavior, an error term e must be included in the utility function. If the error terms in the utility functions are independent and identically distributed extreme-value errors, then the probability of selecting a piece of land will have a multinomial logit form (McCracken et al. 1998). A discrete choice model is applied in the form of a multinomial logit where the probability of use of grid cell s by animal i is described by

$$P_i(s) = \frac{\exp(\beta_{i1}x_{s1} + \beta_{i2}x_{s2} + \ldots + \beta_{ik}x_{sk})}{\sum_{r \in S} \exp(\beta_{i1}x_{r1} + \beta_{i2}x_{r2} + \ldots + \beta_{ik}x_{rk})}\,. \qquad (5)$$

The collection of all grid cells S within the study area is described by a vector of length r. The probability that the jth independent relocation of bear i occurs in grid cell s_{ij} is $p_i(s_{ij})$. For grid cell s_{ij} the likelihood for all observed relocations is

$$\prod_{i=1}^{m}\prod_{j=1}^{n_i} p_i(s_{ij}), \qquad (6)$$

where m represents all bears and n_i represents all independent relocations for bear i.

1.4.4. Hierarchical modeling

One aim of my analysis was to determine habitat selection by bears at the population level. However, it is individual bear selection that will provide inference about selection at the population level (Thomas et al. 2006). It is common in resource selection analyses for individual heterogeneity to be overlooked when determining population level selection criteria. Some analyses average individual parameters while others only use equally sized subsets of the observational data in the analysis (see Miller et al. 2000, Glenn et al. 2004). These methods do not account for variability in covariate selection or appropriately weight individual bears with differing numbers of relocations (see Thomas et al. 2006).

A hierarchical model is preferred in this case because it can produce individual bear models that in turn describe the population-level model of habitat selection. Hierarchical models provide a mechanism by which to weight relocations and individual bears that yield inference about the population-level selection characteristics (Thomas et al. 2006). Normally, the complexity and high dimensionality of hierarchical models would make direct computation of the posterior probabilities infeasible. For example, defining the joint distribution of the stochastic process of habitat selection for each bear is nearly impossible. Recently, however, software packages like WinBUGS have been developed to use Markov Chain Monte Carlo (MCMC) simulations that can overcome these limitations and estimate the posterior distributions (http://www.mrc-bsu.cam.ac.uk/bugs). This is accomplished by specifying the distributions of the conditional models for each bear. MCMC simulations, using a Metropolis-Hastings-Gibbs sampling approach, breaks down a very complex joint distribution of a collection of random variables (individual models) into a much simpler series of conditional models. The product of the conditional models yields the sought after joint distribution. The framework necessary to accomplish this is composed of three separate modeling stages (Wikle 2003): data model, parameter model, and hyper-parameter model (Thomas et al. 2006). The data model specifies the distribution of the data given the individual selection parameters. This distribution represents a likelihood commonly used in maximum-likelihood analysis. The second stage describes the probability models of the selection parameters for each bear conditional on population level selection parameters. These individual parameters are considered to be a statistically random selection from the whole population. The third stage is the hyper-parameter model which accounts for the uncertainty in the parameter model and describes the population-level selection parameters (Wikle 2003, Thomas et al. 2006). The parameter models are a-priori defined by independent normal distributions with zero mean and unit variance. Since I have no information on the parameter estimates, I chose to express my ignorance of the prior distribution by giving the parameter priors a 'non-informative' uniform distribution wherein all values are equally likely (Jeffreys 1961). The final posterior estimation of the mean and variance across all animals provides inference about the population level selection and variability in selection for each environmental attribute. The individual parameter models are looped into the population level model (hyper-parameter) and thus each bear is treated equally while treating the number of relocations differently. In this way, different weights are applied to differing numbers of relocations per animal while producing valid error terms (Thomas et al. 2006).

1.4.5. WinBUGS

I ran all models in WinBUGS using 24,100 iterations in a single chain with a 4,100 iteration 'burn-in' (see Appendix A). Parameter estimates, posterior distributions, and validation values were calculated from the last 20,000 iterations. The number of 'burn-in' iterations and parameter convergence was determined using the suggestions from Raftery and Lewis (1992).

1.4.6. Model Validation

I assessed individual model goodness of fit with a Bayesian p-value that estimates the deviance between a dataset, replicated during the MCMC samplings, to the observed dataset. The deviance was calculated by

$$D(s_r, s_o) = 2 \cdot \sum_{i=1}^{n} L(s_o|\theta) - L(s_r|\theta), \qquad (7)$$

where s_r is the replicated data, s_o is the observed data, L( ) is the log-likelihood for the discrete choice model, and θ is the vector of parameters. WinBUGS uses the observed data to create a 'known' likelihood of bear presence within each grid cell. Similarly, WinBUGS can create a 'predicted' likelihood of bear presence within each grid cell derived from a replicate dataset produced from within the program. WinBUGS generates the 'predicted' likelihood based on the current parameter values at each iteration of the MCMC algorithm and compares that likelihood to the 'known' likelihood. The Bayesian p-value is created by estimating the frequency at which the fit of the observed data exceeds the fit of the replicate data. A good fit model has values close to 0.5 whereas a poorly fit model has values less than 0.05 or greater than 0.95 (see Thogmartin et al., 2004).

I ran two sets of models for all three target resolutions; one set with all of the covariates (full models) and one set with only the significant covariates (significant-only models). Covariate parameter significance was evaluated by examining the 95% Bayesian Credibility Intervals produced by WinBUGS. Bayesian Credibility Intervals are interpreted as being a bounded distribution within which 95% of the potential parameter values will fall (Ellison 1996). If those distributions cross zero (0) then the covariate parameter values are interpreted as not being significant. I used the deviance information criterion (DIC), a Bayesian alternative to Akaike's information criterion, to select the best model from the two sets of models at all three target resolutions. The best fitting and most parsimonious model has the smallest DIC value.

$$DIC = \overline{D}(\theta) + P_D, \tag{8}$$

where $\overline{D}(\theta) = E_{\theta|Y}[D(\theta)]$ measures model 'adequacy' and is the posterior expectation of the Bayesian deviance $D(\theta) = -2\log p(y|\theta)$ and $P_D = \overline{D}(\theta) - D(\overline{\theta})$ measures model 'complexity' (Speigelhalter et al. 2002).

I used two other datasets to verify the bear habitat suitability maps in the LP that were estimated from the model results. I first used the GAP land-stewardship data obtained from the MCGI website to perform visual verification. The land-stewardship data was developed as part of the Michigan GAP analysis project
(http://www.dnr.state.mi.us/spatialdatalibrary/metadata/gap_stewardship_lp.htm), and identifies

state (e.g., game areas and parks), federal (e.g., nature reserves and parks) and trust (e.g., The Nature Conservancy) land boundaries that are managed to maintain plant and animal biodiversity. I expected that suitable bear habitat and the land-stewardship data would correspond.

I also used data on harvested bears from 2002 – 2004 as another means of verifying the results of the bear habitat suitability maps of the LP. Surveys of Michigan bear hunters indicate that 70% of hunters choose a hunting location based on their impression of a high bear density in that area (Frawley 2006). Therefore, the grid cells that have harvest locations can act as a surrogate for grid cells that are suitable bear habitat. I used a chi-square goodness-of-fit statistic to test if the relationship between grid cells with harvest locations and suitable habitat grid cells estimated from the model deviated from a random relationship.

1.5. Results

The full models of the males and females for all three resolutions better fit the data (smaller DIC values) than the significant-only models (Table 2).

Table 2: DIC values for the full models and significant-only models.

	Female 1km	Female 2km	Female 3km	Male 1km	Male 2km	Male 3km
Full Model	33866	25636	20583	19205	16272	14385
Significant-only Model	35655	29335	22811	20109	18167	17081

The 3km, 2km, and 1km full male models had p-values of 0.55, 0.66, and 0.71, respectively (Table 3). Thus, the observed data from the 3km male model best fit the replicate data. The

3km, 2km, and 1km full female models had p-values of 0.61, 0.56, and 0.65, respectively (Table 3). Thus, the replicate data from the 2km female model best fit the observation data.

Table 3: P-values of the full models.

	1km	2km	3km
Males	0.71	0.66	0.55
female	0.65	0.56	0.61

The autocorrelation function in WinBUGS displays MCMC posterior sample dependence over time, i.e., across model iterations as a measure of convergence towards a model solution. The autocorrelation plots for all other parameters in the best fit 3km male model and best fit 2km female model (see Appendix D) indicated that the sample dependence decreased rapidly with increasing lag, indicating a relatively high degree of independence of solutions across iterations and a robust search of the solution space. The history plot function within WinBUGS displaying model deviance across iterations confirmed parameter convergence for those two models (see Appendix E).

Bayesian credibility intervals indicated that water, human population, MPS, PSCOV, ED, SDI, northern hardwood and mixed, and aspen were significant covariates in all of the female models. Water, human population, MPS, PSCOV, ED had negative relationships with bear selection whereas SDI, northern hardwood and mixed, and aspen had a positive influence on selection. The upland non-forested, oak, and pine covariates were insignificant at all resolutions for females (Tables 4, 5, and 6). After running the best-fit female 2km model again with the reclassified road covariates, the results indicated an insignificant negative relationship with the first road category (large size and high traffic volume) and significant negative relationships with the second two road categories (medium and small sizes and traffic volumes; Table 7).

Bayesian credibility intervals indicated that water, MPS, PSCOV, ED, developed, and forested wetland were significant covariates for all of the male models. Water, MPS, PSCOV, ED, and developed habitat had negative relationships for male selection whereas forested wetland had a positive influence on selection. The human population, NUMP, northern hardwood and mixed, and pine covariates had insignificant distributions at all scales for males (Tables 4, 5, and 6). After running the best-fit male 3km model again with the reclassified road covariates, the results indicated an insignificant negative relationship with the first road category (large size and traffic volume) and significant negative relationships with the second two road categories (medium and small sizes and traffic volumes; Table 7).

Table 4: Mean, s.d., median, lower, and upper credibility intervals for all covariates of the female and male 1km models.

	Female 1KM					Male 1KM				
Variables	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**
Water	-0.4808	0.113	-0.4783	-0.7106	-0.2637	-0.294	0.08955	-0.2904	-0.477	-0.1241
Slope	-0.4163	0.1602	-0.4153	-0.7322	-0.1039	-0.0694	0.1095	-0.06924	-0.2864	0.1468
Road	-0.2602	0.09969	-0.2592	-0.4594	-0.06906	-0.1579	0.1067	-0.1546	-0.3791	0.04739
Human Population	-3.175	0.7719	-3.155	-4.766	-1.717	-0.8352	0.4915	-0.8313	-1.824	0.1206
NUMP	-0.3681	0.1676	-0.367	-0.6993	-0.04429	0.2489	0.149	0.2568	-0.05796	0.5292
MPS	-2.369	0.539	-2.358	-3.478	-1.342	-2.056	0.4852	-2.033	-3.071	-1.154
PSCOV	-0.4922	0.09643	-0.4921	-0.68	-0.303	-0.4754	0.08289	-0.4745	-0.6422	-0.3137
ED	-1.117	0.2229	-1.115	-1.554	-0.6813	-0.8433	0.1761	-0.8455	-1.177	-0.4774
AWMSI	0.2391	0.08808	0.2386	0.06737	0.4129	0.1922	0.09576	0.1929	0.001434	0.3791
SDI	0.8305	0.2078	0.8262	0.4317	1.25	-0.2166	0.0974	-0.2157	-0.404	-0.02371
SEI	-0.7928	0.2137	-0.7898	-1.222	-0.384	-0.06164	0.08909	-0.05912	-0.2437	0.1065
Developed	0.01382	0.3293	0.01504	-0.64	0.6315	-0.882	0.3752	-0.8615	-1.592	-0.2113
Agriculture	-0.8362	0.5562	-0.7836	-2.071	0.114	-1.368	0.6985	-1.256	-3.023	-0.3658
Upland Non-Forested	-0.4282	0.3211	-0.4202	-1.087	0.1777	-0.3906	0.2841	-0.3825	-0.9857	0.1535
Northern Hardwood and Mixed	0.8371	0.2964	0.8367	0.2579	1.424	0.4018	0.3007	0.4106	-0.2148	0.9716
Oak	-0.9834	0.562	-0.9425	-2.198	0.02083	-0.8916	0.4666	-0.8486	-1.928	-0.08946
Aspen	0.8528	0.3295	0.8531	0.192	1.496	0.3994	0.2105	0.4007	-0.02003	0.8096
Pine	-0.632	0.3728	-0.611	-1.402	0.06109	0.3038	0.1985	0.3076	-0.09132	0.6838
Forested Wetland	1.46	0.2667	1.461	0.9341	1.981	1.574	0.1834	1.568	1.227	1.953
Non-forested Wetland	-0.2841	0.5733	-0.2206	-1.585	0.6711	0.8531	0.3307	0.8694	0.1488	1.467

Table 5: Mean, s.d., median, lower, and upper credibility intervals for all covariates of the female and male 2km models.

	Female 2KM					Male 2KM				
Variables	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**
Water	-1.239	0.3424	-1.236	-1.931	-0.5567	-0.6309	0.1733	-0.6266	-0.9839	-0.3005
Slope	-0.3157	0.1976	-0.3142	-0.7089	0.07402	-0.121	0.1288	-0.1218	-0.3784	0.1343
Road	-0.2482	0.1437	-0.2476	-0.5313	0.03502	-0.2292	0.1835	-0.2263	-0.6005	0.1252
Human Population	-1.166	0.4524	-1.154	-2.099	-0.322	-0.5341	0.4582	-0.5259	-1.47	0.3468
NUMP	-0.6917	0.4345	-0.6903	-1.545	0.1673	0.3151	0.2906	0.3173	-0.2732	0.8808
MPS	-3.183	0.5244	-3.159	-4.29	-2.22	-1.644	0.4487	-1.635	-2.559	-0.7845
PSCOV	-0.9459	0.2077	-0.9446	-1.361	-0.543	-0.7647	0.1978	-0.7652	-1.147	-0.3717
ED	-2.13	0.4388	-2.128	-2.993	-1.263	-1.457	0.3799	-1.458	-2.198	-0.7014
AWMSI	0.6585	0.1482	0.658	0.3675	0.9491	0.5009	0.1417	0.5015	0.2188	0.7811
SDI	1.001	0.3984	0.9939	0.2307	1.801	-0.08255	0.1367	-0.0777	-0.3589	0.1865
SEI	-0.5437	0.3813	-0.5383	-1.314	0.1915	-0.2324	0.2014	-0.2293	-0.6372	0.1581
Developed	-7.12	1.339	-7.159	-9.71	-4.237	-2.374	0.4612	-2.39	-3.24	-1.422
Agriculture	-3.218	3.149	-2.879	-10.39	1.992	-2.1	2.136	-1.837	-7.066	1.372
Upland Non-Forested	1.724	1.719	1.762	-1.881	4.987	-1.725	0.7668	-1.677	-3.38	-0.3452
Northern Hardwood and Mixed	4.3	1.7	4.323	0.8764	7.587	1.571	1.013	1.555	-0.4065	3.633
Oak	0.005634	2.242	0.1631	-4.842	3.994	-0.3986	0.4952	-0.3949	-1.403	0.5639
Aspen	4.439	1.628	4.443	1.16	7.665	1.874	0.8324	1.854	0.2777	3.57
Pine	2.068	2.06	2.156	-2.216	5.88	1.239	1.035	1.244	-0.8121	3.298
Forested Wetland	6.927	1.725	6.919	3.532	10.34	3.438	0.9877	3.416	1.526	5.466
Non-forested Wetland	-9.127	4.737	-8.491	-20.06	-1.668	-1.524	1.247	-1.312	-4.56	0.1645

Table 6: Mean, s.d., median, lower, and upper credibility intervals for all covariates of the female and male 3km models.

	Female 3KM					Male 3KM				
Variables	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**
Water	-1.127	0.2658	-1.125	-1.661	-0.6149	-0.8379	0.2159	-0.8336	-1.277	-0.4258
Slope	-0.7072	0.3012	-0.7083	-1.307	-0.1063	-0.3274	0.1832	-0.3272	-0.6909	0.03215
Road	-0.3268	0.1972	-0.329	-0.7143	0.06364	-0.5579	0.207	-0.5589	-0.9778	-0.1472
Human Population	-1.919	0.6511	-1.898	-3.26	-0.6909	-0.3637	0.5942	-0.3546	-1.581	0.7957
NUMP	-2.647	0.7355	-2.638	-4.129	-1.235	0.3937	0.4309	0.3937	-0.4563	1.238
MPS	-7.329	1.572	-7.32	-10.46	-4.259	-1.661	0.4514	-1.65	-2.586	-0.7919
PSCOV	-0.9913	0.3419	-0.9884	-1.67	-0.3193	-0.8015	0.2737	-0.7987	-1.345	-0.2622
ED	-2.288	0.7579	-2.289	-3.801	-0.8157	-1.817	0.5708	-1.821	-2.943	-0.6825
AWMSI	0.1945	0.2774	0.1923	-0.352	0.7424	0.3626	0.2106	0.3613	-0.04793	0.7805
SDI	1.261	0.6345	1.247	0.03164	2.537	1.257	0.4924	1.244	0.3386	2.261
SEI	-1.227	0.6356	-1.212	-2.524	-0.01921	-1.344	0.5758	-1.331	-2.52	-0.2568
Developed	0.299	1.022	0.2623	-1.586	2.412	-7.909	1.648	-8.001	-10.97	-4.566
Agriculture	-8.964	4.688	-8.534	-19.28	-1.148	-7.218	5.595	-6.696	-19.38	2.324
Upland Non-Forested	0.3675	2.485	0.4965	-4.984	4.931	-1.847	4.049	-1.559	-10.71	5.447
Northern Hardwood and Mixed	4.393	2.055	4.407	0.2596	8.338	6.31	3.787	6.326	-1.285	13.69
Oak	1.866	1.443	1.887	-1.089	4.646	0.3612	3.45	0.451	-6.833	6.912
Aspen	4.845	1.596	4.807	1.807	8.067	6.913	3.321	6.886	0.4993	13.46
Pine	1.982	1.552	2.006	-1.173	4.987	4.103	3.981	4.219	-4.243	11.6
Forested Wetland	3.608	2.172	3.627	-0.8746	7.795	8.299	3.395	8.298	1.656	14.97
Non-forested Wetland	-8.397	4.156	-7.803	-18.19	-1.98	-9.013	4.405	-8.381	-19.62	-2.334

Table 7: Mean, s.d., median, lower, and upper credibility intervals for reclassified road covariates of the 2km female and 3km male models. Model was run with all other covariates, but inclusion of the road categories did not result in any significant changes in those parameters. Therefore, they are left out of the table for simplicity.

	Female 2KM					Male 3KM				
Road variables	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**	**mean**	**s.d.**	**median**	**2.50%**	**97.50%**
Large	-0.324	0.1742	-0.3233	-0.6741	0.0195	-0.03589	0.1508	-0.03434	-0.3409	0.2576
Medium	-0.253	0.1106	-0.2523	-0.4741	-0.03741	-0.3505	0.1494	-0.3489	-0.6478	-0.06221
Small	-1.303	0.4463	-1.295	-2.213	-0.441	-0.7282	0.2957	-0.7222	-1.325	-0.1518

In general, the variance in selection of all of the attributes among the individual bears from both males and females got smaller as the model was run at finer resolutions. In the female 1km model, the variance was highest for human population, MPS, and oak. In the female 2km model, the variance was highest for human population, MPS, agriculture, and non-forested wetland. In the female 3km model, the variance was highest for MPS and agriculture. In the male 1km model, the variance was highest for MPS and oak. In the male 2km model, the variance was highest for human population, agriculture, and upland non-forested. In the male 3km model, the variance was highest for human population, ED, agriculture, and non-forested wetland. Of note, the male 3km model and female 2km model share the same highly variable covariates for individual bears *and* best fit the observation data (Figure 7).

There were individual bears for each model that often had extreme parameter values compared with the others. In the female 1km model, bear 17 had an outlying selection parameter for MPS and PSCOV. In the female 2km model, bear 23 had an outlying selection parameter for developed and non-forested wetland and bear 27 was an outlier for MPS and forested wetland. In the female 3km model, there were several bears with outlying selection parameters but bear 29 and bear 33 were systematic outliers for most of the land cover categories. In the male 1km model, bear 5 had outlying selection parameters for roads, human population, and aspen. In the male 2km model, several bears had outlying selection parameters with bear 8 and bear 9 being an outlier for several land cover categories. In the male 3km model, there did not appear to be any systematic outliers (Figure 7).

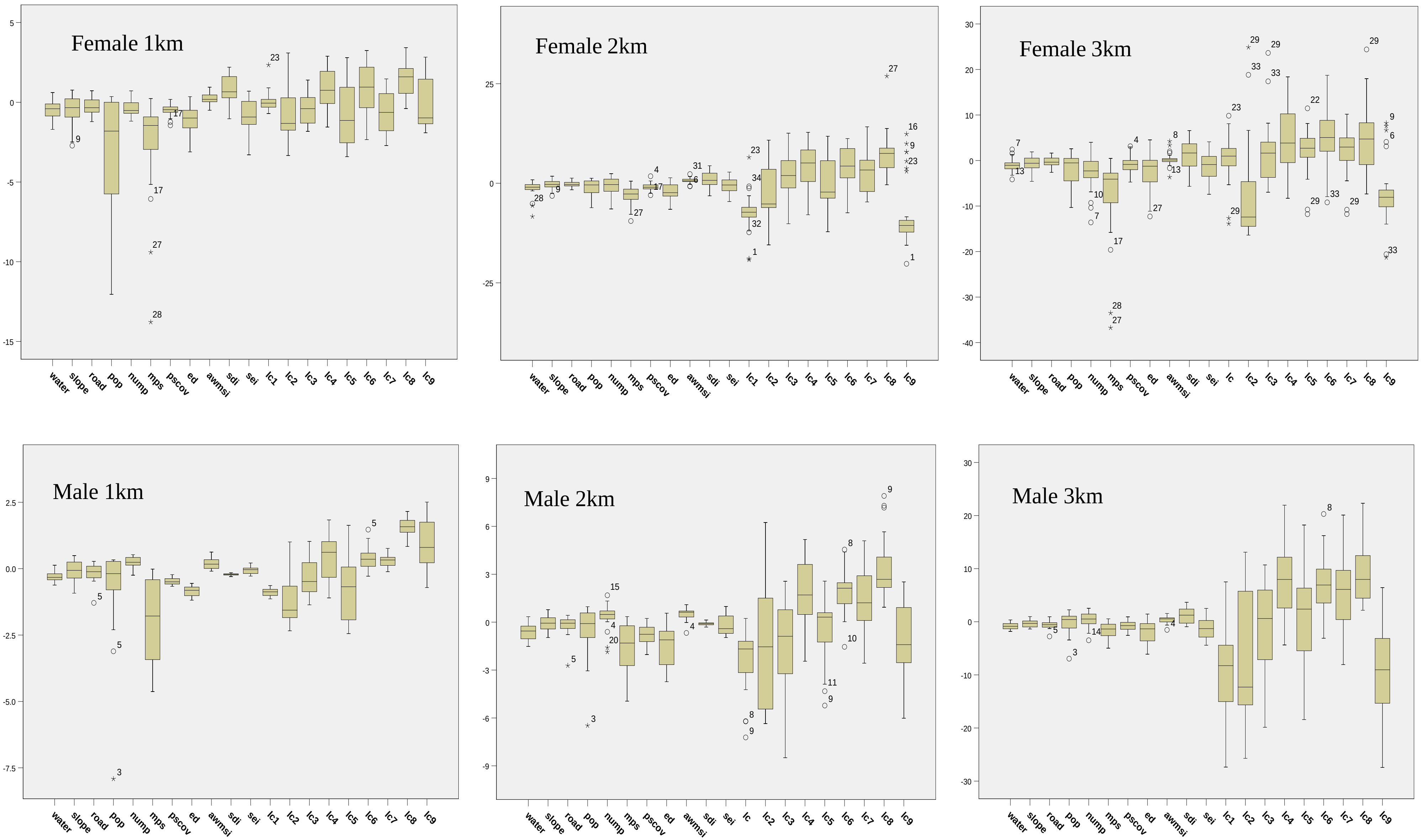


Figure 7: Variation in selection of the environmental attributes by individual bears at all three scales. Covariates listed from left to right are in the same order as those listed top down in Tables 4, 5, and 6. Top row: Female 1km, 2km, 3km. Bottom row: Male 1km, 2km, 3km.

Mapping the results from the models required some ad hoc decisions. Because the full models fit the data better than the significant-only models, I entered the median values of the parameters from the full models into the discrete choice equation, thus, calculating a probability of use for each grid cell. The calculated grid cell probabilities using the median parameter values are equivalent to the median posterior values that would have been calculated within WinBUGS. Furthermore, the density function within WinBUGS shows that the posterior distributions of all the parameters for all models closely approximates a normal distribution making the median value very similar to the mean.

The probability that a bear would randomly select a grid cell is the probability of selecting one grid cell over all of the grid cells in the study area. For the female 3km, 2km, and 1km models, random probability would be 0.001 (1/990), 0.00068 (1/1467), and 0.00035 (1/2856), respectively. For the male 3km, 2km, and 1km models, random probability would be 0.0009 (1/1088), 0.00077 (1/1290), and 0.00049 (1/2040), respectively. After entering the parameter values from the models into the discrete choice equation to calculate cell selection probabilities, I calculated how many grid cells had selection probabilities greater than random. The probability that males would select a grid cell within the study area more frequently than random occurred in 20% of the 3km grid cells, 24% of the 2km grid cells, and 35% of the 1km grid cells. The probability that females would select a grid cell within the study area more frequently than random occurred in 20% of the 3km grid cells, 14% of the 2km grid cells, and 29% of the 1km grid cells (Figure 8 and Figure 9).

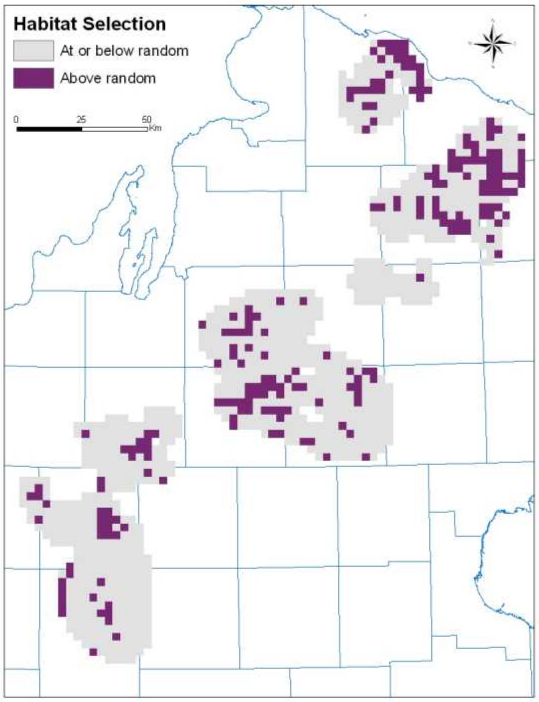


Figure 8: Locations where selection by males is greater than random in 3km study area.

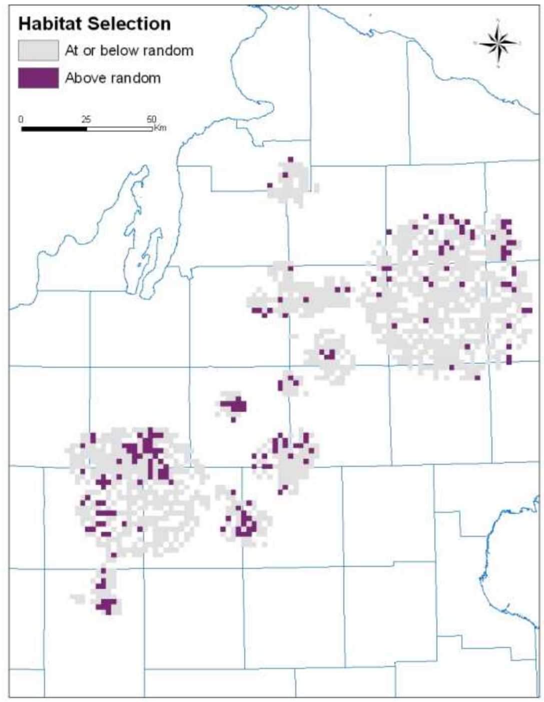


Figure 9: Locations where selection by females is greater than random in 2km study area.

To apply the results obtained from within the study area to the entire Lower Peninsula, I calculated grid cell selection likelihoods. To calculate the selection likelihoods, I first calculated the "utility" of each grid cell just using the equation in the numerator of the discrete choice model. Instead of normalizing the selection probabilities to the entire study area by dividing by the sum of the "utility" values, I divided the "utility" value for each grid cell by a reference grid cell "utility" value. I chose to use the average grid cell "utility" value from across Michigan. Thus, after dividing each grid cell by the average "utility" value, those grid cells with values less than '1' have suitability less than the average and values greater than '1' have increasingly greater suitability than the average. In other words, each grid cell value should be interpreted as the likelihood of a bear selecting it over the average condition within the Lower Peninsula of Michigan. I, somewhat arbitrarily, describe suitability values of less than 1 as unsuitable, 1-5 as low, 5-10 as medium, and >10 as high. The maximum suitability attainable for a grid cell was different for each model. The maximum suitability for females in the 3km, 2km, and 1km models was 142, 168, and 69, respectively. The maximum suitability for males in the 3km, 2km, and 1km models was 50, 50, and 86 respectively (Figure 10 and Figure 11).

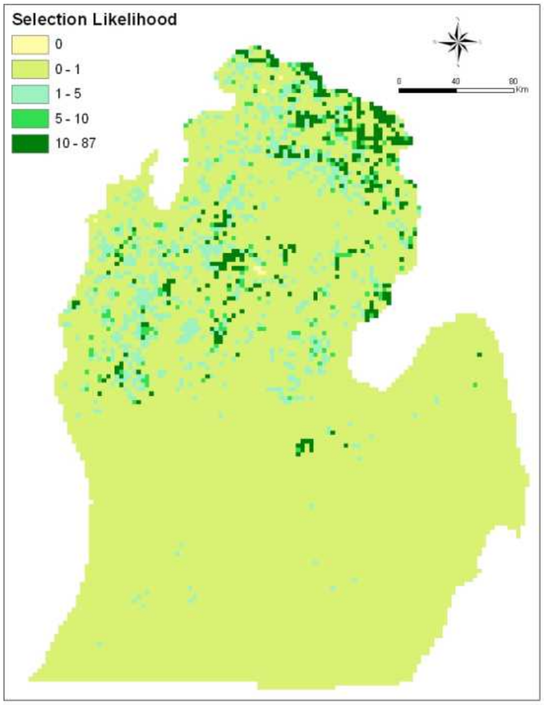


Figure 10: Predicted habitat selection in Lower Peninsula for Males at 3km resolution.

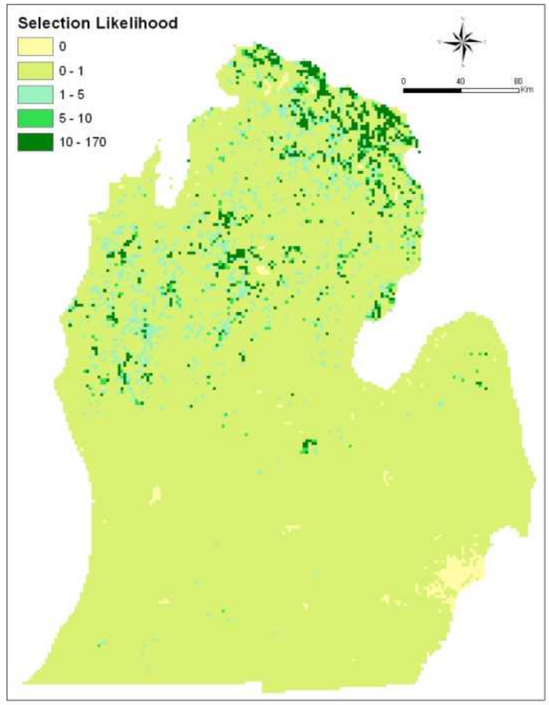


Figure 11: Predicted habitat selection in Lower Peninsula for females at 2km resolution.

A large portion of the NLP, reaching as far south as Midland and Newaygo counties, was indicated for all target resolutions as being suitable to males and females (Table 8).

The Southern Lower Peninsula (SLP) had considerably less suitable area for males and females.

Table 8: Percentages of suitable habitat to males and females in the Southern Lower Peninsula, Northern Lower Peninsula, and the entire Lower Peninsula of Michigan.

		1km			2km			3km		
		SLP	NLP	LOWER	SLP	NLP	LOWER	SLP	NLP	LOWER
Female	Low	2.5	28	13.7	0.2	9.1	4.1	0.2	14.4	6.4
	Medium	0.14	6	2.7	0.12	2.1	1	0.06	5.3	2.3
	High	0.06	4.5	2	0.08	5.9	2.6	0.02	5.9	2.6
	TOTAL	2.7	38.5	18.4	0.4	17.1	7.7	0.28	25.6	11.3
Male	Low	2.2	31	14.9	0.8	24	11	0.4	15	6.8
	Medium	0.27	7.1	3.3	0.14	3.9	1.8	0.03	3.5	1.5
	High	0.06	4	1.8	0.15	6.7	3	0.18	6.8	3.1
	TOTAL	2.53	42.1	20	1.09	34.6	15.8	0.61	25.3	11.4

The 3km combined map resulted in 16.7% of the Lower Peninsula being suitable, the 2km combined map resulted in 18.7% being suitable, and the 1km combined map resulted in 24.6% being suitable (Figure 12 and Figure 13).

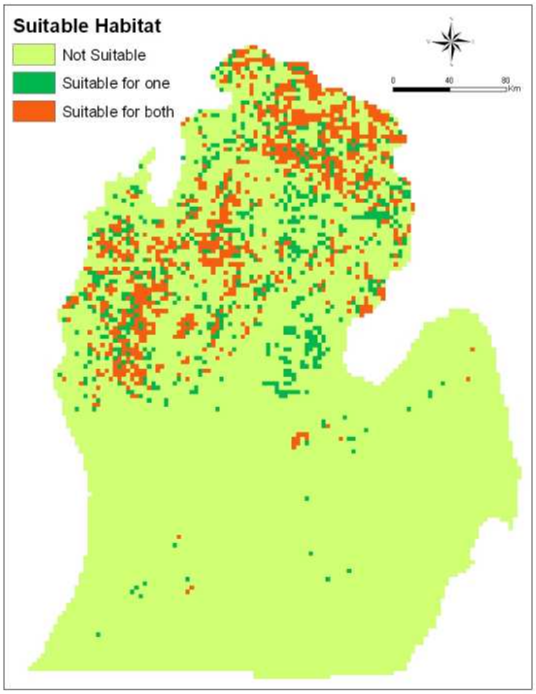


Figure 12: Suitable habitat in Lower Peninsula for bears at 3km resolution.

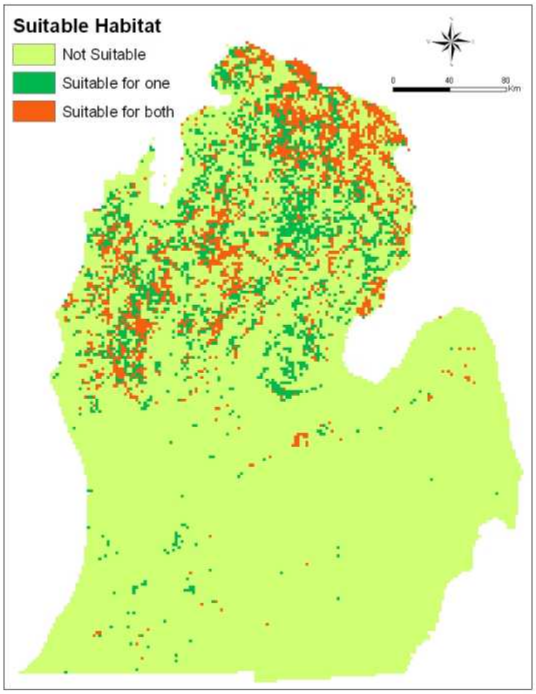


Figure 13: Suitable habitat in Lower Peninsula for bears at 2km resolution.

The pattern of GAP land-stewardship data clearly corresponds with the spatial patterns of suitable bear habitat (Figure 14). Additionally, the chi-square statistic indicated that there was a significantly positive relationship between the percentage of grid cells with harvested bear locations and suitable habitat grid cells in the 3km and 2km maps (Table 9). Moreover, the locations that were not directly within a suitable grid cell were still in very close proximity to a suitable grid cell as indicated by the map (Figure 15).

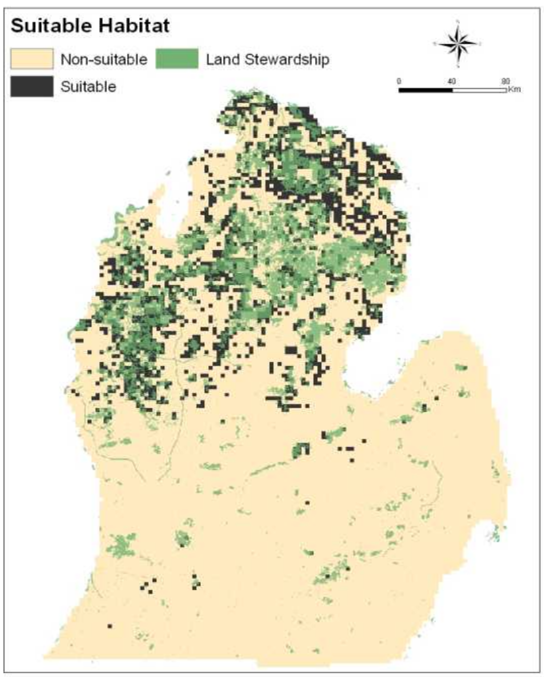


Figure 14: GAP land-stewardship data overlaid the 3km suitability map.

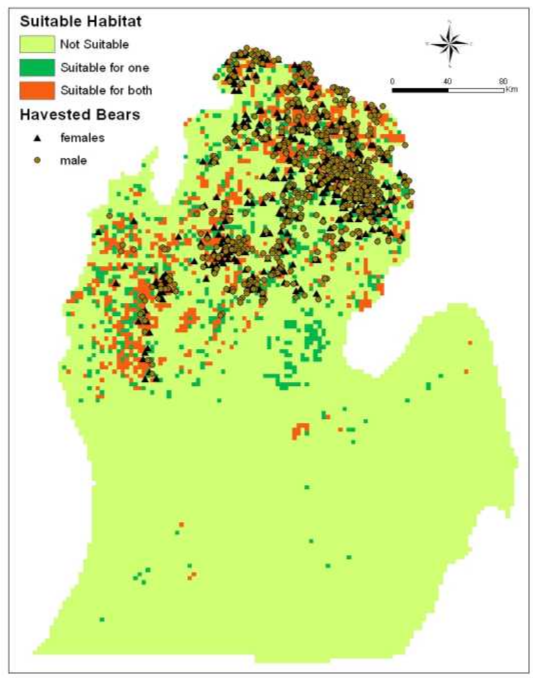


Figure 15: Male and female harvested bears from 2002-2004 overlaid the 3km suitability map.

Table 9: Percentages and chi-square tests of harvested bears from 2002 – 2004 that fell within suitable habitat at the 2km and 3km resolutions.

	2km	3km
Female	60% (n=266)	60% (n=265)
χ^2	18.8	18.0
P value	<0.05	<0.05
Male	65% (n=340)	60% (n=319)
χ^2	46.4	24.8
P value	<0.05	<0.05

1.6. Discussion and Conclusions

All of the significant-only models had DIC values substantially larger than those in the full models. DIC measures model ‘adequacy’ and penalizes for model ‘complexity’. Selecting models based on information criteria, such as DIC, concentrates on the maximization of predictive ability. The strength of dependence between the covariates and the response in the full models was much greater than those in the significant-only models while the penalization for more variables was considerably smaller. This may be the case because the full hierarchical model produces a correlation structure between the covariates and the individual bear models. This structure is optimally designed to predict the response and as a result may widen the Bayesian credibility intervals for some of the parameter estimates (D. Johnson, Pers. Comm.). The correlation structure may result in an influential parameter appearing insignificant. Therefore, it is not advisable with hierarchical models to test hypotheses regarding the influence of parameter estimates based entirely from their Bayesian credibility intervals.

I hypothesized that the 1km models would perform the best for both males and females. However, the male 3km model had the best p-value while the female 2km model had the best p-value. The lower p-values at different resolutions may reflect the difference in male and female bear behavior. Males typically travel much larger distances for mating opportunities than females (Rogers 1987). Thus, they tend to have much larger home ranges that overlap several females and may perceive their environment at larger scales (Alt 1977, Alt 1978). In other words, when males establish home-ranges their scope is larger than that of females and the selection parameters would pick up those patterns. Female behavior and area selection is dictated more by the necessity of rearing cubs (Garris and Pelton 1984, Rogers 1987). Females must have sufficient fat deposits prior to denning so that they can support the cubs after they are born. Furthermore, finding adequate feeding sites, after den emergence, that are closer to the den site reduces energy expenditure and promotes cub growth (Lindzey and Meslow 1977). These characteristics may explain the better performance of the female model at a smaller resolution than the male model.

The home-ranges of bears in Michigan are larger than those reported for other studies from the Midwest and Eastern United States. This has been attributed to large amounts of habitat fragmentation (Etter 2002). Therefore, bears must frequently travel over undesirable patches to reach desirable patches. Thus, the way male and female bears perceive their environment may necessarily be coarser than a 1km scale. Additionally, bears frequently select areas with an interface of heavily forested land cover and open field (Rogers and Allen. 1987). A 1km scale may not pick up these crucial interfaces and patch dynamics. For instance, the diversity of patches was significantly positive in the male 3km model, corresponding with the selection of areas with diverse types of vegetation. However, the male 2km model indicated an insignificant negative relationship while the male 1km model indicated a significant negative relationship. It is important to note that I summarized all of the environmental variables only for the area within each grid cell. Thus, the probability of selection is only dependent on the environmental variable values within the grid cell and does not account for the landscape surrounding each grid cell. It is possible to summarize some variables within areas that are larger than the output spatial grid cells. Doing so may maintain the finer 1km resolution while acknowledging spatial characteristics that are of a larger size.

The male 3km model indicated that water had a negative relationship with bear selection. This is somewhat counterintuitive, but may be because water bodies present obstacles to dispersal that require energy to circumvent in the search for food. The negative relationship may also exist because large water bodies have comparatively large human populations with more development and road networks (http://www.michigan.gov/dnr/0,1607,7-153-10366_11865_28193-83100--,00.html). Although, human food availability at low human population densities does sometimes attract bears, they normally avoid dense human populations (Rogers and Allen 1987). Bears experience higher mortality rates in areas with dense road networks because of vehicular accidents and human disturbance. Road networks also fragment bear habitat (Brody and Pelton 1989, Kasworm and Thier 1994). The initial male 3km model indicated no significant relationship with the one aggregate road covariate. The addition of the unnamed roads increased road density dramatically in the NLP. Thus the second run of the male 3km model and female 2km model indicated that the prevalence of the medium and smaller roads in the NLP do negatively influence bear selection. The density of large roads (i.e., freeways) was comparatively much lower than the other two categories and may not have been dense enough to result in a significant negative relationship like those of the smaller categories. The negative relationship between road density and bear selection is similar to Minnesota and the Upper Peninsula of Michigan where bear density has been shown to have negative correlations with road densities and human populations (Rogers and Allen 1987).

Aside from SDI, the male 3km model indicated negative relationships between bear selection and MPS, PSCOV, ED, and SEI covariates. The negative relationships with MPS, which suggest a preference for smaller patches, and PSCOV, which suggest a preference for equally sized patches, are difficult to interpret because bears typically prefer unbroken tracts of habitat (Landers et al. 1979, Pelton 1982). Bears may be selecting grid cells with similar sized patches of various land-cover types that provide for bear habitat requirements. Similarly, larger amounts of forest edge at small scales are usually associated with bear presence because of their unique habitat and food requirements. However, edge density at the broad scale, as illustrated in these models, likely corresponds with human-induced habitat fragmentation thus explaining the negative relationship with ED. One way, not explored in my analyses, to determine the MPS and PSCOV of just the forest land-cover types is to examine just those class-level patch metrics instead of the overall landscape patch metrics. The negative relationship with SEI indicates a behavioral inclination of bears to find patches clumped together with abundant food sources. It conserves search energy and travel time to utilize areas with clumps of suitable land-cover types (Rogers 1987).

The male 3km model also indicated that aspen had a positive influence on selection. Bears often consume aspen catkins and aspen leaves during the spring (Rogers and Allen 1987). Manville (1983) had previously indicated that bears in the NLP require large tracts of aspen for population viability. The male 3km model also indicated that forested wetland had a strong positive influence on selection. Wetlands and riparian areas provide cooling, water, and seasonal foods (Landers et al. 1979, Alt et al. 1980, Kellyhouse 1980, Reynolds and Beecham 1980, Elowe 1984, Manville 1983, 1987). Forested wetlands frequently contain lowland grass and herbaceous vegetation that are essential spring foods in places like Northeast Minnesota and Massachusetts (Elowe 1984, 1987, Rogers 1987). Forested wetlands and riparian areas provide succulents and also serve as travel corridors during summer. Finally, the male 3km model indicated that developed land cover had a strong negative influence on selection. Human occupation removes usable bear habitat through habitat fragmentation and conversion to agriculture and urban land uses. Also, broad scale development is largely related to growing human populations that, in turn, correspond to more human disturbance of bears. Bears will more likely encounter humans in comparatively denser areas when they are attracted to limited seasonal resources such as meadows or berry patches (CDFG 1998). Historically, these phenomena have resulted in the decline of the overall bear populations, particularly in the eastern portion of their range (Cowan 1972, Cardoza 1976, Pelton and Burghardt 1976, Collins 1978, Raybourne 1978, Willey 1978, Hugie 1979, Lentz et al. 1980, Manville 1983). The male 3km model also indicated a strong negative relationship of non-forested wetland with bear selection. The non-forested wetland category includes floating aquatic areas and places like fens, bogs, wet prairies, and wet meadows. This negative relationship is contrary to research in Colorado (Hoover and Wills 1987), California (Grenfell and Brody 1986), and Washington (Lyons et al. 2003) where black bears have demonstrated a high degree of selection of wet meadows, as these areas provide herbaceous vegetation in the spring for bears. During collection of radio-telemetry data used to construct my model, bears were sometimes observed using the edges of non-forested wetlands (D. Etter, MDNR, Pers. Comm.). Due to the large error that could be associated with telemetry locations (16 ha) detecting use at this finer scale was not possible. Also, telemetry locations were collected only during the day when bears likely were not as apt to travel into the exposed regions of a non-forested wetland to forage.

The female 2km models indicated that a negative relationship exists between water and females, similar to the males in the male 3km model. The female 2km model also indicated that human population had a negative relationship with female presence. Females are much less likely to travel the same distances as males to forage and their movements are often constrained by cubs of the year; thus they have smaller home ranges than males (Alt et al. 1976, Alt 1977, Alt 1980, Alt et al. 1980). Both sexes generally select den sites away from possible disturbance (Tietje and Ruff 1980) and will apparently become more nocturnal in response to human disturbance (Ayres et al. 1986). Since sub-adult males travel larger extents than females in their search for areas with few dominant males and abundant foods, they are more likely to confront human-disturbed areas. In addition, sub-adult males are more likely to panhandle for food in human-dominated areas (Rogers 1987, McLean and Pelton 1989). Females may abandon their dens and newborn cubs if disturbed by humans or domestic dogs (Lindzey and Meslow 1977, Hamilton and Marchington 1980, LeCount 1983, Manville 1983). The female 2km model indicated similar significant relationships between the landscape metrics and bear selection as the male 3km model. Females also had a slightly positive relationship with AWMSI. AWMSI measures how much shape complexity a land-cover patch has relative to a circle. Shape complexity may indicate potential for escape and refuge cover in the landscape within the complex configurations of the different patches. Escape and refuge cover has been shown to be directly related to habitat preference by black bear (Hugie 1979). Females in the 2km model also indicated similar relationships with land cover types as males in the 3km models. Females had significant positive relationships with northern hardwood and mixed hardwood communities. Bear presence is associated with northern hardwood and mixed hardwood communities across most of their range in North America (Landers et al. 1979, Pelton et al. 1980, Johnson and Pelton 1981, Maehr and Brady 1984, Smith 1985)**.** This is because these communities are important in the production of hard mast and late ripening berries essential in bear's fall diets. Additionally, Manville (1983) has suggested that large tracts of these communities are important in sustaining bear populations in the NLP.

There were some individual bears that had extreme selection parameter values compared to those of the other bears. Almost all these "outlier" bears used a region directly west and southwest of Lake Mitchell. This region had a preponderance of telemetry locations from many of the females and males collected for the entirety of the study period. The concentration of these points in a small area created very specific parameter values that usually fell outside the range of parameter values found from bears selecting from much larger areas. The area near Lake Mitchell is dominated by wetlands but is also highly interspersed with every other land-cover type except human development. This high land-cover diversity likely supports the food and cover requirements of bears. The female bears with outlying selection parameters all had the majority of their locations in this region and were all rearing cubs at some point over the study period. In addition, all of the bears with outlying selection parameters had relatively smaller home ranges that overlapped this region near Lake Mitchell. This supports the contention that this region supported bear habitat and food requirement to such a degree that when bears discovered it they stayed very close to it. Another interesting spatial feature of this area is that large patches of agriculture land cover exist directly to the south and west. The coarse temporal and spatial resolution in the telemetry data may not reflect the specific utilization patterns of the small and fragmented agriculture land covers in the NLP. Further research, incorporating telemetry data with finer temporal and spatial resolutions, should be dedicated to this region because it may indicate that bears are utilizing the agriculture land cover more frequently than the negative selection parameter indicates. Moreover, additional research should examine the impact that the bears with outlying selection parameters had on parameter mean and standard error estimations by removing them from analyses in future models.

The visual relationship between the GAP land-stewardship data (i.e., land-ownership layer) and suitable bear habitat in the NLP indicates that lands managed for biodiversity may serve as good habitats for bear populations. For instance, several large areas of estimated suitable habitat for females and males that exist in the Northeastern section of the LP also correspond with the GAP land-stewardship data. However, a large portion of estimated suitable bear habitat in the NLP is conspicuously not covered by any GAP data. These suitable portions lie primarily in the Presque Isle, Alpena, and Alcona counties and are mostly in private ownership. Large concentrations of bears harvested from this area are taken from these private lands (Figure 13). Portions of these lands are on the fringes of large dairy operations as well as smatterings of agricultural land on private hunting clubs which consist mostly of food plots to attract deer (D. Etter, MDNR, Pers.

Comm.). The hunting clubs are explicitly managed for several wildlife species (e.g., deer and turkeys) which explains why bear harvest and bear density remains high in this region. Since these clubs are privately owned, though, they do not appear on the GAP data layer.

The results of applying the models to the entire Lower Peninsula illustrate a paucity of suitable bear habitat in the SLP. This is not surprising given predominant land covers, road and human densities, and current land-management methods in the SLP compared to those in the NLP. The female 2km and male 3km suitability maps, however, did indicate a possible corridor of bear habitat in the Southern Lower Peninsula. The corridor closely corresponds to Michigan State Game Areas designated in the GAP analysis data for Michigan. The suitable habitat corridor has a Southwestern orientation and ranges from Michigan's "thumb" in Huron County with suitable patches in Verona, Minden City, and Sanilac State Game Areas. Then it follows Cass River with patches in the Cass City, Deford, and Tuscola State Game Areas. A substantial portion of suitable habitat exists in the Shiawassee National Wildlife Refuge/State Game Area and Gratiot-Saginaw State Game Area. The corridor then follows the Maple River State Game Area with several patches in the Southwest region of the state including portions of the Middleville, Barry, Allegan, and Fort Custer State Game Area. In all, this corridor spans from Huron County through Tuscola, Saginaw, Gratiot, Clinton, Ionia, Barry, Allegan Counties and culminating in several suitable areas in Calhoun, Van Buren, Kalamazoo, Cass, and St. Joseph Counties.

The MDNR maintains a database of reported bear road kills, complaints, and sightings throughout the state. This database is not a complete record of bear activity in the state, but it can provide insights into the distribution of bear, particularly in areas of low bear density.

Reports from the Southwest LP are becoming more frequent. A map of reported bear complaints and sightings collected from 1999 – 2006 is helpful in identifying the paths bears may take in traveling south (Figure 16).

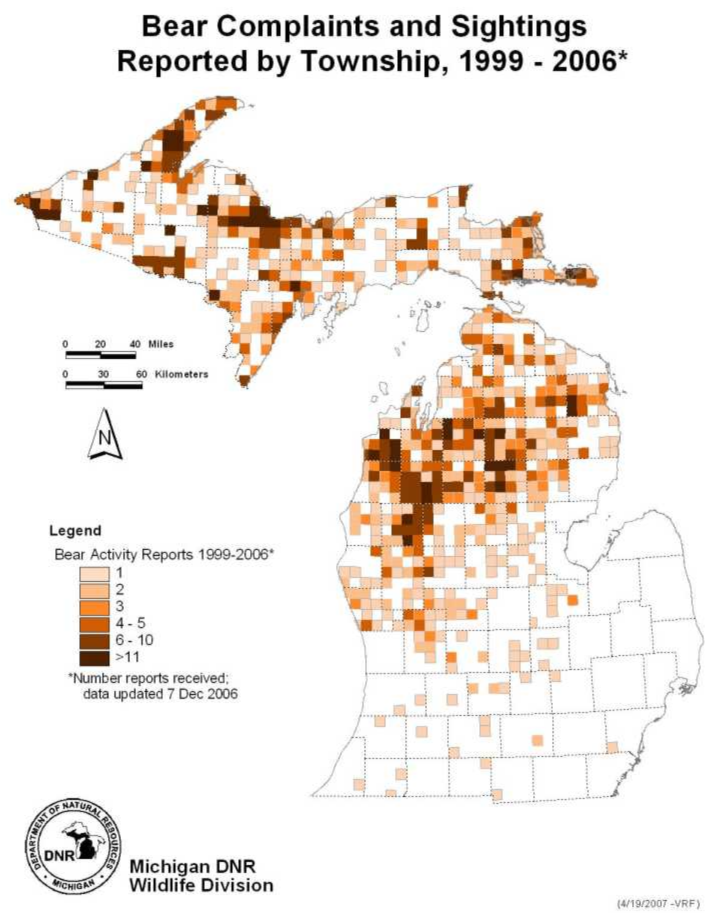


Figure 16: Sightings and complaints of bear from 1999-2006 (MDNR).

The Au Sable state forest has considerable suitable habitat for male bears, however, large tracts of agriculture exist between this area and suitable habitat in Huron County. The potential for bears to travel through Au Sable State Forest and across large areas of agricultural land cover is verified by the bear complaints and sightings map. These data show several bear complaints or sightings at intermediate areas between Au Sable and the Shiawassee National Wildlife Refuge, with a few complaints or sightings directly in the National Wildlife Refuge. Another path bears may take when traveling south is through a smattering of suitable habitat in Mecosta, Isabella, and Montcalm counties. The entire Manistee National Forest is suitable habitat to bears but large unbroken tracts of agricultural land cover also separate the National Forest from the suitable habitat in the Southwest region of the state. Even if the threshold for suitability is lowered from '1' to '0.9' in the female 2km map and the male 3km map only a few isolated grid cells become suitable. These isolated grid cells do not bridge any of the suitable habitats in the SLP. Once again, though, the complaints and sightings data indicate that bear are capable of traveling through agriculture land covers. There are complaints or sightings in many counties throughout the Southwestern region of the state.

The increased frequency of bear sightings in the Southwestern region of the state attests to the adaptability of bears to navigate fragmented or marginal habitats (Bauer 1996, Obbard 2003). The model results are limited in their applicability to the SLP because the model was specified to the unique environmental characteristics of the NLP and the model results merely describe which variables influence local bear selection. Thus, bear may select fragmented habitat in the SLP more frequently than expected and in unpredictable ways. For instance, bears may shift to the plant and forest land-cover compositions that exist at agriculturally maintained edges where there is typically higher plant species richness (Gysel 1951, Bruner 1977, Ranney et al. 1981, Brothers and Spingard 1992) and a higher abundance of exotic plant species (Ranney et al. 1981, Ambrose and Bratton 1990, Brothers and Spingard 1992). Bears in the heavily fragmented landscape of New Jersey persist by frequently venturing onto farms to consume corn (McConnell et al. 1997). Bears in the San Gabriel Mountains of Southern California have adapted to the growing human population and urban development in the foothills by incorporating city habitats in their home ranges and using them late at night when human activity is minimal (Lyons 2004).

Future efforts to evaluate potential for a SLP bear population should focus on evaluating bear utilization of the predominant agricultural land-cover type. The landscape in the SLP transforms dramatically from spring through fall as row crops develop and are ultimately harvested. Knowledge of how bears use this changing landscape seasonally may provide additional insight into bear movements in this highly fragmented landscape. Acquiring this information could be accomplished by applying the Bayesian models I used for the NLP to the SLP using bear radio-telemetry data collected with a much finer temporal and spatial resolution.

Future research into bear population expansion must also acknowledge the comparatively higher road and human population densities in the SLP compared to the NLP. Future model simulations of bear habitat in the LP should consider traffic volume on roads as separate variables. Bears traveling southward will more likely be exposed to human activity and dangerous road networks. A higher exposure rate of bears to humans in the SLP may negatively alter public sentiment resulting in increased bear/human conflicts. For example, change to personal property and structures were the reasons cited for 40% of the depredation permits issued in California between 1987 and 1997 which is a sharp increase from 10% in the early 1980's (CDFG 1998).

The model results indicate that there is habitat potential for a LP bear metapopulation to exist. The establishment of a metapopulation may contribute to the long-term survival of bears across the LP by increasing genetic diversity and maintaining population size via source/sink dynamics (Levins 1969, Hanski 1999). A metapopulation in the LP may have distinctly unique habitat requirements as well as genetic characteristics. Recent genetic research indicates substantial genetic differentiation between LP and UP bears (Lopez 2004). This is expected due to the large expanses of Lakes Michigan and Huron that separate the two peninsulas. In addition, Lopez (2004) indicated that there may be small scale spatial genetic structure in the NLP bear populations. Future research should explore the relationship between habitat availability and genetic structure within the NLP bear population. Investigating this relationship may help identify the spatial patterns of bear dispersal from the NLP into the SLP.

A potential metapopulation could utilize a network of habitats throughout the NLP extending to limited portions of the southwestern LP. The conservation and maintenance of large tracts of hardwood communities as well as aspen stands will be important in sustaining ‘source’ populations of bears. The USFWS biological report prepared by Rogers and Allen (1987) acknowledged the importance of aspen by suggesting that livestock grazing be eliminated in aspen stands to enhance availability of black bear foods. Furthermore, forested wetland travel corridors can provide habitat for foraging and refuge while also serving as genetic linkages between ‘source’ populations as bears travel through them in search of mates (Rogers and Allen 1987, Harris and Scheck 1991, Rosenberg et al. 1997). Conservation of forested wetlands as travel corridors should be considered when developing a bear management plan for Michigan.

Another consideration is whether a stable and healthy bear population can persist in the NLP despite the forecasted expansion of the human enterprise in the near future. The fragmentation of bear habitat through unchecked parcelization, i.e., the splitting of property into a profusion of small (5 – 10 acre) lots, that has defined settlement in the SLP (MDNR Terrestrial Summary B), should be avoided in the NLP. Furthermore, the massive conversion of forested habitats into industrial, residential and recreational complexes (MDNR Terrestrial Summary A and B) will also be detrimental to the bear population in the NLP. Approximately 33% of land in the NLP is in public ownership (MDNR, unpublished data) and the model results indicate that these areas are primary habitat for bear. Habitat fragmentation, particularly around water bodies which demand high prices for vacation property, and the construction of roads will further constrain and disconnect suitable bear habitat in the NLP.

Public agencies should continue to conserve and maintain forested lands in order to continue supporting a viable bear population. Furthermore, purchasing additional lands identified as suitable habitat for bear in the Northeast LP could also provide a buffer between new residential developments and a robust population of bears. This buffer will reduce the conflict that arises when bears inhabit areas directly adjacent to human development. This problem is evident in New Jersey where newer developments border important wetland areas heavily used by black bear. Residents frequently complain about bears consuming garbage and using bird feeders when bears cross residential properties to move between habitat fragments (McConnell et al. 1997).

Suitable habitats in the SLP provide valuable information for future considerations by the State of Michigan to purchase land for the establishment of a LP network of connected habitat. If bear perennially use forest edge in the SLP then these areas may contribute to the LP network. These networks could provide more viewing, recreational, and hunting opportunities to the public in the LP. Habitat networks that extend into the heavily human-impacted SLP could be a means of exposing the multiple benefits of wildlife to an uninitiated portion of the public. This exposure may be essential in developing positive attitudes towards wildlife species, thus, preemptively reducing human/bear conflicts. Additionally, the development of positive attitudes would remove a significant onus from wildlife management agencies by reducing the monetary expenditure and man-power requirements necessary to respond to human/bear conflicts. Managing and maintaining a bear-habitat network while fostering positive human/bear interactions is imperative in creating the conditions necessary for the coexistence of a robust bear population amongst the human population in the Lower Peninsula of Michigan.

Chapter 2: Social Carrying Capacity

2.1. Introduction

Since European settlement, black bear habitat in the United States has undergone substantial fragmentation due to a growing human population and clearing of forested land (Bauer 1996). During this time black bears have been persecuted as pests and hunted as trophies (USDI 1995, Whitcomb et al. 2001). This has resulted in a vast contraction in the range and distribution of black bears in the United States (B.W. Conley 1978, R.H. Conley 1978). More recently, however, due to various forms of legal protection and the process of reforestation, bear numbers have rebounded (Williamson 2002).

This is the case for black bears in Michigan, where at one time they inhabited the entire state but during the mid 18th century were extirpated from the Southern Lower Peninsula (MDNR unpublished). Currently, bear numbers in Michigan are increasing and are presenting a unique challenge to state management agencies like Michigan’s Department of Natural Resources. In Michigan’s Northern Lower Peninsula bear populations are growing and are expanding their geographic extent southward. This has been reflected in trends in bear nuisance reports, harvest reports, and sightings. Additionally, the area of urban development is increasing in Michigan and planners project a 178% expansion of developed areas by 2040 (Etter 2002). Clearly, the potential for bear/human conflict is likely to increase over time, and various means to manage this conflict have become pressing concerns for wildlife management agencies within the state.

Achieving co-existence between bears and humans in the near future will depend on a synthesis of knowledgeable management initiatives *and* favorable public sentiment towards both bears and wildlife management agencies (McConnell et al. 1997, Peyton et al. 2001, Siemer and Decker 2003, RMNO 2004, Spiker and Bittner 2004, Ternent 2005). Knowledgeable management initiatives may be achieved by integrating the ecological and human dimensions. The ecological dimension involves wildlife researcher's and manager's knowledge about bear ecological requirements and habitat suitability (Clark et al. 1993, Rudis and Tansey 1995, Van Manen and Pelton 1997, Mitchell et al. 2002). The human dimension involves a wide array of interest groups or stakeholders and their behaviors in the presence of bears and attitudes to various bear management policies (Peyton et al. 2001, Siemer and Decker 2003, RMNO 2004). By integrating these dimensions, I hope to determine what relationships exist between bear habitat suitability and human attitudes to bear presence and bear management policies. Information that integrates these dimensions will describe the likely future of bear populations and the associated human responses in the Lower Peninsula of Michigan, enabling the development of an informed management framework for formulating policy.

In the previous chapter, I provided information on the ecological dimension of bears in the form of results from several habitat suitability models in Michigan's Lower Peninsula. The model results inform management agencies about environmental attributes that may influence the selection of habitat by bears. Furthermore, the model estimates potential habitat for male and female bears in Michigan's Lower Peninsula.

In this chapter, I briefly discuss some historical and current human attitudes towards bears. In addition, I briefly discuss the various methods the Michigan Department of Natural Resources has employed to manage bears. Finally, I discuss the results of an analysis that incorporated information gathered from the Social Carrying Capacity (SCC) project and the bear habitat spatial models into an integrated assessment.

The Social Carrying Capacity (SCC) project for bears, completed in 2002, aimed to better understand human attitudes regarding Black Bears in the NLP (Peyton et al. 2001). I integrated the survey data from the SCC with the GIS-based habitat prediction models to illuminate the correlation between human behavior and attitudes regarding bears and suitable bear habitat. Understanding human behavior and attitudes regarding bears has important implications for the conservation of bear habitat (see Peyton et al. 2001, Siemer and Decker 2003, RMNO 2004, Siemer and Otto 2005). The synthesis of geolocated SCC data with the habitat-prediction models was used to identify potential conflict areas. Exploring the synthesized results using data on bear harvest, complaints, and sightings helped predict the interaction dynamics at the bear/human interface *and* will allow an examination of the conditions that would facilitate co-existence. This examination will enable the DNR and appropriate management institutions to refine their future bear harvest strategies in Michigan. The results will also allow the development of regionally specific bear-management policies, including education initiatives that might alleviate potential future bear/human conflict. This will enable the DNR to allocate resources and utilize adaptive management techniques essential in human-environment systems.

2.2. Study Area

My habitat models were created for all of Michigan's Lower Peninsula at 3km, 2km, and 1km resolutions. The Lower Peninsula is usually characterized as two separate ecosystems – the Northern Lower Peninsula (NLP) and Southern Lower Peninsula (SLP) (Figure 17). The NLP is in the Northern Lacustrine-Influenced Region of Lower Michigan characterized by diverse topography with extensive outwash plains and large moraines (Albert 1995). Land cover of the region is dominated by forest (67%). The other major land-cover types are wetlands (20%) agricultural (4%), and urban (2%; Figure 18, http://www.michigan.gov/dnr/0,1607,7-153-10370_30909_31053-153466--,00.html). The land covers were changed considerably during the latter half of the 19th century through intensive logging for white pine, hemlock and northern hardwoods. This intensive logging was followed by catastrophic fires that additionally altered the land cover. The result is that early successional forest types, including aspen and birch forests, now are more prevalent in the NLP today than in the past (Barnes and Wagner 2004).

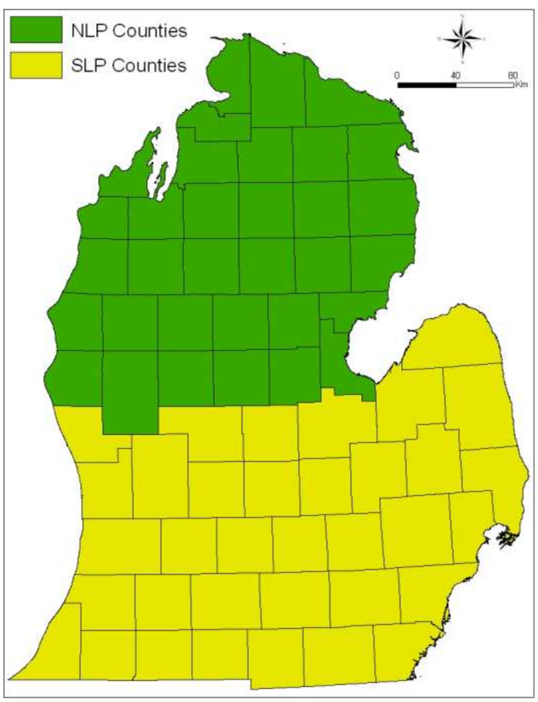
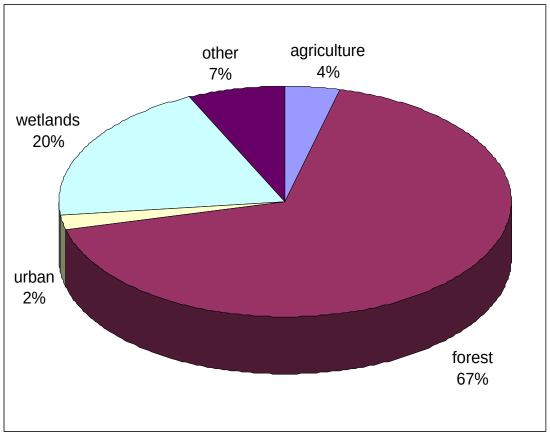


Figure 17: Map of Northern and Southern Lower Peninsula Counties of Michigan.



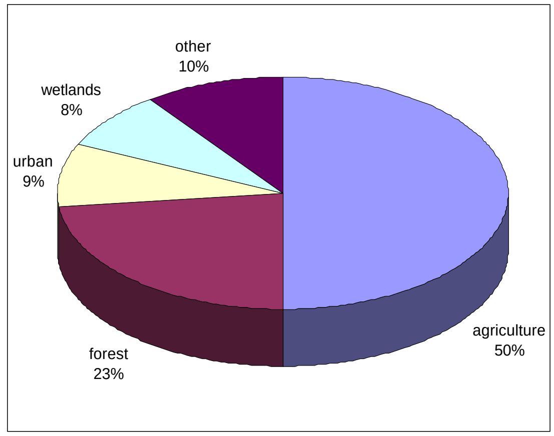


Figure 18: Land-cover proportions in the NLP (MDNR website).

Figure 19: Land-cover proportions in the SLP (MDNR website).

The SLP is characterized by rolling hills and flat lake plains. The land cover of the region is dominated by agriculture (50%). The other major land-cover types are forest (23%), urban (9%), and wetlands (8%; Figure 19, http://www.michigan.gov/dnr/0,1607,7-153-10370_30909_31053-153463--,00.html). The habitat in the SLP has been highly fragmented due to a great deal of agricultural and urban development. In addition, the areas of oak savanna and prairie have largely converted to closed-canopy oak forests (Albert 1995). Vast areas of forest have become fragmented and now support row crops, making this region the most heavily farmed region in Michigan.

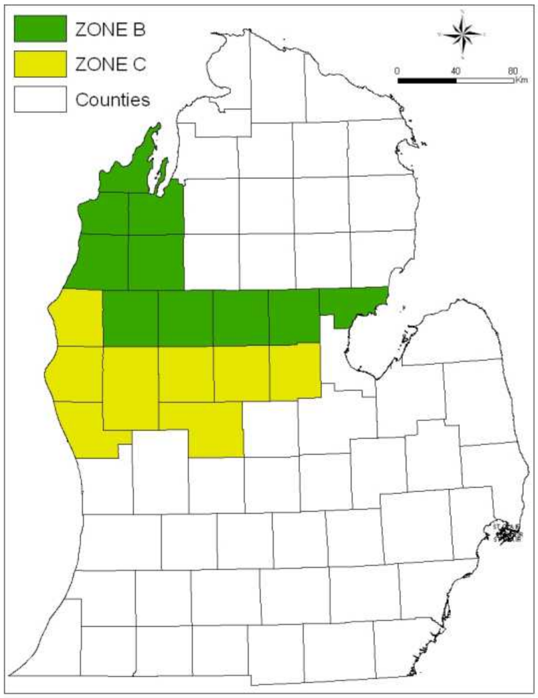


Figure 20: Map of Zone B and Zone C in the Lower Peninsula of Michigan.

The survey data I used for this study were analyzed using four zones that segmented the NLP from North to South – A, B, C, and D (Peyton et al. 2001). These zones were delineated based on differences in approximate bear densities as suggested by Tim Reis (Wildlife Management Unit Supervisor, MDNR) and Larry Visser (Wildlife Management Unit Supervisor, MDNR). I chose to focus on Zones B and C (Figure 20). Zone B was defined as having been occupied by bears as long as humans have been present albeit at a low density. This zone consists of Leelanau, Benzie, Grand Traverse, Manistee, Wexford, Lake, Osceola, Clare, Gladwin, and Arenac counties. Zone C is a transition zone between the NLP and SLP and is a region that will likely see increasing numbers of bears in the future (Peyton et al. 2001). Zone C is defined in the SCC as being recently occupied by a low density of bears. This zone consists of Mason, Oceana, Muskegon, Newaygo, Mecosta, Montcalm, Isabella, and Midland counties.

2.3. Background

2.3.1. Bear Population and Range

From the latest survey conducted in 1996 by TRAFFIC North America, a joint wildlife trade monitoring organization program of the World Wildlife Fund (WWF) and the World Conservation Union (IUCN), the bear population in the United States and Canada was estimated to be 735,000 to 941,000. In 1996, The United States alone had 339,000-465,000 (Figure 21).

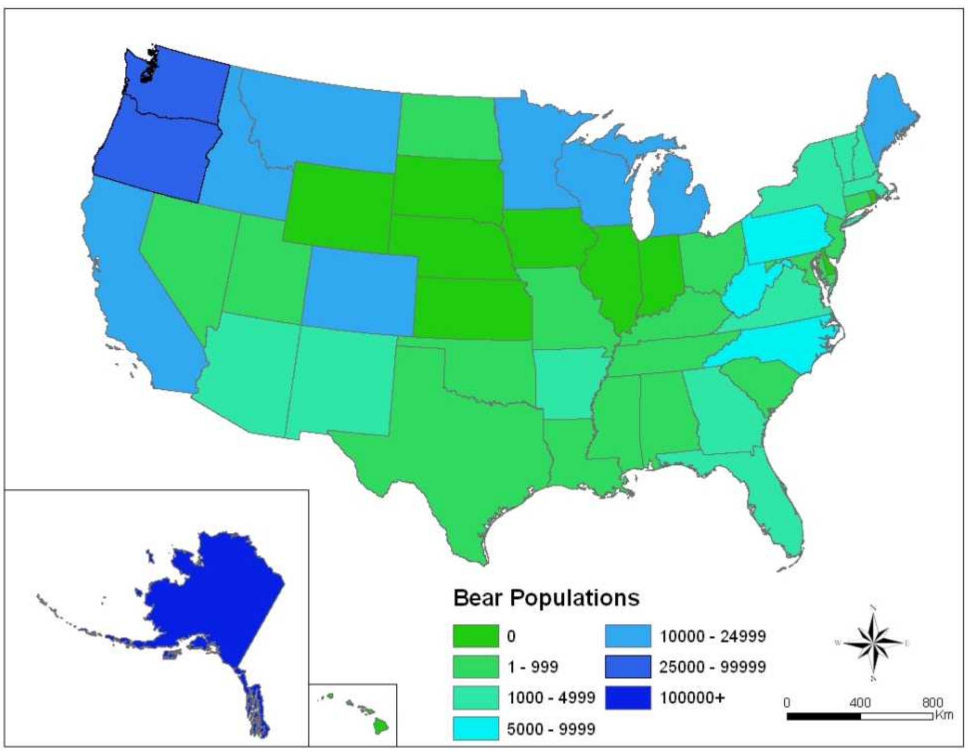


Figure 21: Bear Populations in the United States

The survey indicated that all of the states surveyed had bear populations that were stable or increasing. In fact, since the 1980's the bear population has been steadily increasing (Figure 22; Williamson 2002).

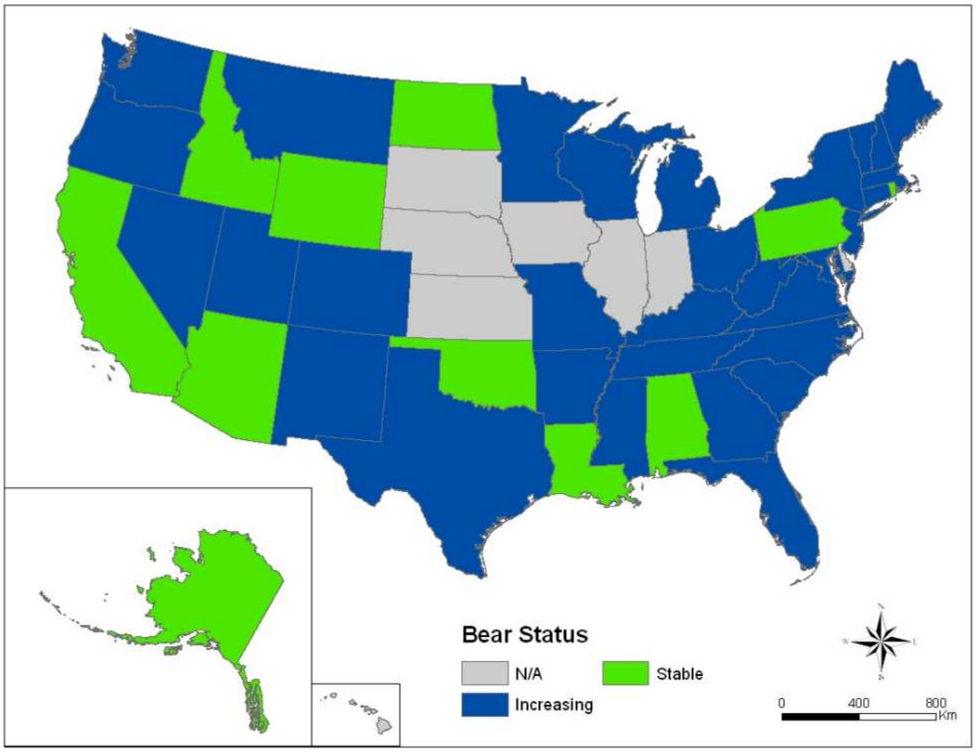


Figure 22: Bear status in the United States.

Figure 23: Current Distribution (1994) of Black Bears in the United States (Pelton and van Manen, 1997).

Historically, bears occupied all of the United States excluding Hawaii. Currently, bears occupy roughly 20% of their historical range. Although 41 states indicated having a bear population, most of the United States bear population is concentrated in only several states – Alaska, Washington, Oregon, Idaho, California, Maine, Montana, and Minnesota. Approximately 251,000 to 371,000 (74 to 80 percent) of the estimated U.S. bear population reside in these eight states (Williamson 2002). Black bears are the only bears in the eastern forests of the United States (Figure 23; Pelton 1982).

There are approximately 20,000 bears in Michigan, occupying 90,650 sq. km in the Northern Lower Peninsula and the Upper Peninsula. The Upper Peninsula (UP) contains an estimated 90% of Michigan's bears. The bears in the UP occupy optimal habitat on federal, state, and privately owned commercial forest lands. Despite the small percentage of bears in the NLP, current trend information indicates that their numbers are increasing and that their population will likely expand into the southern portion of the Lower Peninsula (LP) in the future. The southern half of the LP is strongly influenced by human settlement and land use. Traditionally, habitat disturbance and human-induced mortality that have limited bear numbers and distribution in Michigan (Whitcomb et al. 2001, Etter 2002, MDNR unpublished).

2.3.2. Historical Human Attitudes

The Europeans that colonized North America brought their old world culture with them that included a view of wilderness as "something alien to man – an insecure and uncomfortable environment against which civilization had waged an unceasing struggle" (Nash 1982). The people that spread west across North America viewed predators much like nomadic shepherds – as a threat to important resources (Boitani 1995). This meant that predators, including black bears, were viewed as an economic threat. The pervasive attitude of the time can be summed up by an early director of the U.S. Biological Society, E.A. Goldman, who wrote, "Large predatory animals destructive of livestock and game, no longer have a place in our advancing civilization" (Dunlap 1988).

As European people began to settle and started farming the New World, bears came to represent a threat (USDI 1995, Whitcomb et al. 2001). While bears are often portrayed as vicious carnivores in the popular imagination, bears are actually opportunistic mammals that are just as capable of destroying valuable orchards and favorable crops as eating other animals (Rogers and Allen 1987, Schwartz et al. 2003). Consequently, due to their preference for valuable crops and the occasional livestock, black bears began to be seen as pests – an obstacle to societal advancement (USDI 1995, Bauer 1996). This sentiment led many states to pay bounties for bears, encouraging uncontrolled harvests in most of the east coast states. Once bears were perceived as a pest, bear populations underwent precipitous declines due in large part to widespread poisonings and bounty-related killings (USDI 1995, Schwartz et al. 2003). In addition to these active programs of bear extermination, the growth of North American human populations caused widespread fragmentation and degradation of bear habitat through timber harvesting and burning, clearing land for crops and grazing. By the early 1900's, the black bear that was once numerous in the Eastern U.S. could only be found in remote mountainous areas of Georgia Kentucky, Maryland, North Carolina, Pennsylvania, Tennessee, Virginia, and West Virginia (USDI 1995). The framing of bears as "pests" formed a substantial part of the United States' early bear management philosophy and continues to linger in the views of some members of the public and wildlife management employees (Bauer 1996, Schwartz et al. 2003).

In the early 1900's, wildlife agencies managed bears indirectly by focusing on the species impact as predators of game ungulates. The over-riding goal of wildlife management in the United States was to maximize wild ungulate populations and hunting harvests. Aldo Leopold, a pioneer in the field of wildlife management, defined game management as "the art of making land produce sustained annual crops of wildlife for recreation use" (Leopold 1933). The major stakeholder group exerting political clout over management goals and decisions was a powerful and vocal hunting contingent. This anthropocentric utilitarian philosophy of game management established and dominated the direction of wildlife management for the next half-century (Schwartz et al. 2003).

While originating in debates between John Muir and Gifford Pinchot at the turn of the 20th century, preservation philosophy only began to take shape in the environmental movement of the 1970's, when preservationist concerns become increasingly popular. The environmental movement emerged as a social force during the 1970's and became a significant part of the political scene during the 1980's (Peek 1986). It is clear that the public shift toward preservationist values affected wildlife agencies in the last half of the 20th century. In addition, social values had shifted from an emphasis on predator control towards large carnivore conservation and management. Consequently, the utilitarian attitudes towards bears and wildlife in general gradually declined in North America as significant and influential numbers of people began to recognize the intrinsic value of wildlife, including large predators such as black bears (Schwartz et al. 2003). The MDNR presently has the difficult task of balancing the complexities that arise when bears are simultaneously adored as charismatic mega-fauna, trophies for sports hunters, and the bane of predator-fearing suburbanites.

2.3.3. Bear Management in Michigan

The Bear Specialist Group of the World Conservation Union (IUCN) sent out a survey in 1993 to 40 states requesting information about bear legal status and management policies. They received responses from 39 states. The Black bear is classified as a game species in 33 states, though only 28 of these states, including Michigan, have a bear hunting season. Seven states classify black bears as rare, threatened, or endangered. This is particularly the case in the Southeastern United States where rapid habitat fragmentation and unregulated hunting has severely reduced bear numbers (Pelton et al. 1998).

Bears have few natural predators. Humans are the primary cause of bear mortality (Rogers and Allen 1987, MDNR unpublished). In the NLP, hunting accounts for 60% of annual bear mortality (Whitcomb et al. 2001, Etter 2002).

The large demand for bear hunting in Michigan was demonstrated in 2001 when 48,831 applicants applied for 7,920 available bear tags – a significant increase from 1991 when 9,450 applicants applied for 5,519 available tags. These hunters provide a significant source of revenue for the state. For example, in 1998, a total of 7,196 bear hunters spent an estimated $3.4 million during the bear hunting season (Etter 2002). Furthermore, funding for black bear management in Michigan is generated in part from the sale of hunting licenses and federal taxes on the sale of firearms, ammunition and other hunting supplies. These funds are generated from an excise tax through the Federal Aid in Wildlife Restoration Act (Pittman-Robertson Act). Private donations to the MDNR by a variety of special interest groups also help to support bear research and management in Michigan (D. Etter, MDNR, Pers. Comm.).

In the State of Michigan, regulations regarding black bears have changed over time to reflect changes in public attitudes toward bears. This transformation started from views of bears as vermin, then as trophy animals, and more recently as charismatic megafauna. Black bear became a game animal in 1925, before which they could be killed at any time and by any means. After 1925, bears could only be hunted during the deer season. The bag limit was and still is only one bear per year. Statewide protection was altered in 1939 when the Conservation Commission, now the Natural Resource Commission (NRC), was authorized by state legislature to grant protection to bears for only those counties that requested it. At this period, most counties in Michigan opted to not have any bear regulations and allowed bear hunting with dogs and traps at any time. In the 1940's, many counties dropped or added various levels of protection for bears. In 1948 bear cubs were legally protected and have remained so ever since. In 1952, the state legislature permanently outlawed bear trapping except under special permit and granted the Conservation Commission authorization to set statewide regulations on bear hunting and methods of take. After 1952, various regions in Michigan experimented with hunting bears under a small game license, hunting bears during the deer season, and special fall bear seasons. In 1965, bear hunting was closed in the entire Lower Peninsula because of concerns of a declining bear population. The closure was lifted in 1969 with limited hunting opportunities to those with a permit acquired from a lottery. In 1973, new regulations required that a hunter seal or tag a bear within 48 hours and register it at a DNR office. Information collected during registrations is invaluable for monitoring the bear population and hunter activity. A bear license and permits for dogs became required for all seasons in 1982. In 1990, the state began a permit and quota system following nine bear management units. Seven units were in the Upper

Peninsula and one in the Lower Peninsula. In 1996, two more bear management units were added to the Lower Peninsula for a total of eleven bear management units in the State. This system and the number of units has remained in place ever since, with the exception of expanding the area of several units (Figure 24; Whitcomb et al. 2001).

In these units, the MDNR requires licensed hunters to provide information on the location and the physiological conditions of the bears harvested. The harvest information combined with various population indices and estimators enables the MDNR to model bear populations and estimate an appropriate bear harvest level for the following year (Etter 2002, MDNR unpublished).

Figure 24: Map showing Bear Management Units and hunting seasons in Michigan as of 2007 (MDNR).

2.3.4. Bear-Management Techniques

Managing human-bear conflicts is complex and involves the application of various methods for different scenarios. In the past, North American national parks had to respond to the increased frequency of negative interactions between humans and bears. Negative incidents and injury rates were on the rise until garbage and human food-management techniques were improved (Ream 1979, Mattson et al. 1996, McLellan et al. 1999). Currently, all national parks with bears have management plans that incorporate techniques for handling bears through removal, relocations, or aversive conditioning (Rancourt 1998, Clark et al. 2002). Additionally, national parks attempt to influence human behavior by closing potentially dangerous areas to human use, requiring minimum group sizes when hiking in bear country, and enforcing campsite cleanliness (Albert and Bowyer 1991, Sherwonit 1996, White et al. 1999).

State management agencies have an added complication because they must approach bear management while carefully considering the environment and policies that exist within or around human settlements. Across the northeast, many wildlife management agencies have prepared or are in the process of preparing comprehensive bear management plans to respond to the increased levels of human-bear conflicts in the last decade (IAFWA 2004). In New York, for example, where there is a concern about residential development expanding into bear habitat and bear populations expanding into human dominated areas (NYSDEC 2003). This expanding urban-rural interface has resulted in an increase in complaints that encompass a range of negative economic, psychological, and physiological effects (Schusler and Siemer 2004). Wildlife managers in these regions indicate that there is an association between the increased availability of human food sources, including garbage, bird seed, pet food, gardens, and crop fields, and the level of negative human-bear conflicts. It is expensive for management agencies to respond to these problems draining the level of funding available for other management activities. More importantly, negative encounters with bear may engender a lower tolerance by the public and exacerbate the problem (McConnell et al. 1997, Siemer and Otto. 2005, Ternent 2005). Therefore, these conflicts involve a network of proximate and ultimate causes born from the complex interactions of bear behavioral and human attitudinal and behavioral responses. Understanding the complex system of cause and effect that instigates human-bear conflict can inform management agencies about how to approach other concerns at the urban-rural interface, including those between people and coyotes, white-tailed deer, and mountain lion (Siemer and Otto. 2005).

Typically, managers respond to human-bear conflict caused by an abundance of bears by introducing regulated bear hunting. There is a great deal of uncertainty and controversy that surrounds these policies and they have yet to be rigorously evaluated in terms of their efficacy (Siemer and Otto 2005). Additionally, a regulated bear hunt does not remove specific "nuisance" bears. This is especially the case if a nuisance bear occurs in areas closed to hunting such as safety zones or private communities (McConnell et al. 1997, Ternent 2005). Alternative approaches to reducing bear nuisance behavior may be necessary in areas surrounding residential development closed to hunting.

There are several methods available to reduce human-bear conflict. A common method employed is bear translocation. Translocation involves capturing the nuisance bear and moving it to a habitat some distance away from the capture site. However, bears have an excellent ability to return to a particular site. The inclination of bears to be recidivists instigates problems as they frequently come back to human populated areas to find food (Rogers 1986, McConnell et al. 1997, Spiker and Bittner 2004, Ternent 2005). The effectiveness of translocation is determined by the sex and age of the bear, and distance from the problem site. All bears are capable of ‘homing’ back to a site outside of their home range, but adult males are best at it (Rogers 1984b, Ternent 2005). In general, bears tend to return less often if moved more than 64 kilometers from the problem site and will return only rarely if relocated greater than 161 kilometers or across physiographic barriers (Sauer and Free 1969, Alt et al. 1977, Alt et al. 1982, Massopust and Anderson 1984, Rogers 1986, Shull et al. 1994). In Michigan, the protocol for establishing release site distance is that it be at least 80 km from the capture location (MDNR 1995).

Translocation is advantageous for several reasons. Translocation focuses on the nuisance bear specifically while avoiding the less publicly accepted practice of euthanasia (Ternent 2005). Euthanasia is primarily used in cases where a bear is an immediate threat to human safety or repeatedly causes problems (Warburton and Maddrey 1994). Several statewide surveys indicate that people would rather avoid using lethal methods of bear removal (Peyton et al. 2001, Siemer and Decker 2003, RMNO 2004). Another advantage is that a translocated adult female can still contribute to a bear population with additional reproductive cycles (Rogers 1986). Moreover, a translocated bear is a better use of the resource because it can still be legally harvested instead of destroyed (Rogers 1986, Ternent 2005). Translocation also has disadvantages. A translocated bear may experience higher levels of aggression from bears resident in the new location, decreasing survivability and the short-term reproductive capacity of females (Rogers 1986). From a management standpoint, translocation is relatively expensive (McConnell et al. 1997, Ternent 2005). The equipment and labor costs of translocating a bear in Virginia were estimated at $349 (Comly 1993) and $2,000 in New Jersey (Ternent 2005). Additionally, hunters sometimes oppose translocation because it removes a harvestable bear from their region. Furthermore, finding an adequate site to translocate a bear is becoming increasingly difficult. In many states, there are fewer areas outside a reasonable distance from the conflict site that have sufficient habitat or lack extensive human development. More importantly, this method as an ultimate solution tends to take the focus off the root of the problem, that is, modifying human behavior by cleaning up potential attractants like food and garbage or by addressing urban planning issues (McConnell et al. 1997, Ternent 2005).

Another suite of methods utilized to reduce human-bear conflicts involves aversive conditioning techniques. Pennsylvania, New Jersey, and Michigan all have incorporated aversive conditioning protocols in their management policies (Carr and Burguess 2003, Etter et al. 2003, Ternent 2005). The aim of aversive conditioning is to expose a bear to uncomfortable stimuli when engaging in an unwanted activity thereby creating a negative association with that specific activity (Ternent 2005). Several methods include various olfactory repellents (Hunt 1984, Rogers 1984a, Hyngstrom 1994), rubber bullets (Gillin et al. 1994, Schirokauer and Boyd 1998), emetic compounds (Colvin 1975, Ternent and Garshelis 1999), and electric shock (Storer et al. 1938, McAtee 1939, Robinson 1963, Brady and Maehr 1982). Aversive conditioning may be preferable to translocation in human dominated areas with no suitable release sites because it does not require moving the bear. The effectiveness of aversive conditioning has been called into question, however. Bears treated with aversive conditioning tend to avoid a particular site and not the negative behavior (Ternent 2005). In fact, recent research has indicated that aversive conditioning may be ineffective at altering bear long-term behavior (Beckman et al. 2004, Lyons 2004). In addition, it does not appear to alter behavior of bears that are highly habituated to human presence (McCullough 1982). Finally, aversive conditioning only temporarily addresses bear behavior and not the underlying cause of the conflict – food availability (McConnell et al. 1997, Spiker and Bittner 2004, Ternent 2005).

Management agencies also use preventative educational programs as tools in reducing conflicts. Some educational measures have included television and radio programs, brochures, bookmarks, coloring books, and signs designed to provide information to a broad array of people on how to behave in bear country. These materials include information about bear ecology that can help people avoid unnecessary confrontations. These methods tackle an underlying cause of human-bear conflict by providing information to people on how to remove the temptation for bears to feed on human food sources by taking several simple precautions. Educational campaigns also commonly include training programs to teach public service agencies how to manage nuisance bear situations (Carr and Burguess 2003, Spiker and Bittner 2004, McConnell et al. 1997, Ternent 2005). The effectiveness of these programs is uncertain and seldom evaluated (Gore 2004, Lackey and Ham 2003). Some of the uncertainty pertains to the willingness of individuals to alter behaviors associated with removing food attractants including bird feeding, garbage disposal, and the proper cleaning of barbeque grills (Siemer and Otto 2005). In addition, the efficacy of these educational programs is not comprehensively evaluated. Program effectiveness is generally measured by the levels of bear-related complaints. However, bear-related complaints can be confounded by other variables and thus other indices should be used to measure educational program success. For instance, these indices could incorporate variables that reflect changes in human behavior, perceptions, and knowledge. Furthermore, most educational programs are designed and instituted by various stakeholders, thus, indicators of program efficacy should also provide a means of informing decisions about the allocation of scarce resources (Gore et al. 2006).

2.4. Methods and Materials

In order to understand the potential for bear-human conflict in Northern Lower Michigan, I analyzed survey data collected as part of the Social Carrying Capacity (SCC) study (Peyton et al. 2001). I obtained the respondent survey data in a spreadsheet form. All respondents were indexed with an ID number and address. I geocoded the addresses into point locations initially using the geocoding service provided within ArcGIS 9.1. For those addresses that were not matched, I used an online geocoding service from the following website (http://geocoder.us). All of the addresses were located successfully. Once the locations were geocoded, I joined the survey table data to those spatial locations.

I used 3km and 2km resolution bear habitat suitability maps for the LP in this analysis. This is because these resolutions of the habitat models (discussed in chapter one) produced the best estimates of male and female bear habitat in the LP, respectively. These suitability maps are represented as three categories of bear habitat: not suitable to bear (0), suitable to male or female bear (1), and suitable to both sexes (2).

I analyzed the spatial relationships between the survey locations and the suitability maps using the focal statistics functions within ArcGIS 9.1 toolbox. I calculated the sum of habitat suitability scores within a 3x3 window for each grid cell using the 3km and 2km suitability maps. I extracted these data for each survey location. Thus, an individual respondent was considered to be proximal to suitable bear habitat if the sum value calculated by the focal statistics function was greater than zero.

Overall, the variables from the Social Carrying Capacity (SCC) survey I chose to evaluate describe respondent demography as well as attitudes toward bear presence *and* bear-management policies (Table 10). Some of the responses were compiled into two general variables because the content of the questions was related. The first group measured a respondent's overall 'concern' for the risks/costs associated with bear presence (Table 11). The second group is the Bear Sensitivity Index that I discuss in more detail below. For two variables (i.e., q_19_2 and intol_tol), I compared their levels between individuals with high levels of proximal habitat suitability and those individuals with low levels using a chi-squared statistic. I compared their levels within Zone B and Zone C separately to describe attitudinal characteristics in those regions. I also compared their levels between Zone B and Zone C to describe attitudinal characteristics as a function of location within the state. For the rest of the variables, I compared individuals with high levels of proximal habitat suitability between Zone B and Zone C using the Mann-Whitney U statistic. Finally, for the 'intol_tol' and 'concern' variables, I performed a regression analysis with the sum of habitat suitability around the respondent.

Table 10: Categorical variables used in analysis of Social Carrying Capacity.

	Variable	Details	Category	Value
Demographic	q_2_cat	Number of years living in bear country	no years 1-10 years 11-20 years 21-30 years 31-40 years >40 years	0 1 2 3 4 5
	exp_cat	Percent of life spent in bear area	no years 1-25% 26-50% 51-75% 76-100%	0 1 2 3 4
	q_19_2	Hunter or nonhunter	hunter non-hunter	1 2
Attitudes to Bear Presence	q_7	How would knowing that a black bear lived 5-10 miles of your home affect your enjoyment of living there?	Would increase my enjoyment would not affect my enjoyment would decrease my enjoyment not sure	1 2 3 4
	q_8	How would knowing that a black bear lived within 1 mile of your home affect your enjoyment of living there?	Would increase my enjoyment would not affect my enjoyment would decrease my enjoyment not sure	1 2 3 4
	q_11a	How important to you is the role that black bear play in nature if black bear lived in you zone of residence?	Very important to me somewhat important to me slightly important to me not important to me not sure	1 2 3 4 5
	q_11b	How important to you is it just knowing that black bears exist in your zone if black bear lived in your zone of residence?	Very important to me somewhat important to me slightly important to me not important to me not sure	1 2 3 4 5
	q_11c	How important to you is recreational opportunities for viewing black bear if black bear lived in your zone of residence?	Very important to me somewhat important to me slightly important to me not important to me not sure	1 2 3 4 5

	q_11d	How important to you is recreational opportunities for hunting black bear if black bear lived in your zone of residence?	Very important to me somewhat important to me slightly important to me not important to me not sure	1 2 3 4 5
	BSI	Bear Sensitivity Index (see BSI table for additional details)	tolerable personal threat frequent events occasional events presence	1 2 3 4 5
	Intol_tol	Intolerance Level (based on tolerance scenarios)	Intolerant of no scenarios Intolerant at scenario A Intolerant at scenario B Intolerant at scenario C Intolerant at scenario D Intolerant at scenario E Intolerant at scenario F Intolerant at scenario G Intolerant at scenario H	0 1 2 3 4 5 6 7 8
	concern	Combined concern category (see 'concern' table for additional details)	very concerned to not concerned at all	4 -16
Attitudes to bear management policies	q_10	Which of the following management goals would you like the Department of Natural Resources to adopt for Zone D, given that Zone D has more people than other zones in Michigan, and forest habitat is limited in Zone D?	ensure that no bears live in the zone let a few bear exist only in remote areas of the zone let their numbers increase to whatever the habitat will allow actively work to increase habitat and encourage more bears not sure	1 2 3 4 5
	q_15a	How strongly would you support/oppose the option to leave the bear alone as long as no one is injured?	Strongly support somewhat support undecided somewhat oppose strongly oppose	1 2 3 4 5
	q_15b	How strongly would you support/oppose the option to trap and relocate bears which repeatedly cause problems for people to another part of the Lower Peninsula of Michigan?	Strongly support somewhat support undecided somewhat oppose strongly oppose	1 2 3 4 5

q_15c	How strongly would you support/oppose the option to destroy bears which repeatedly cause problems for people?	Strongly support somewhat support undecided somewhat oppose strongly oppose	1 2 3 4 5
q_15d	How strongly would you support/oppose the option to increase the use of carefully regulated hunts to lower bear numbers?	Strongly support somewhat support undecided somewhat oppose strongly oppose	1 2 3 4 5
q_17a	I would tolerate more problems caused by a black bear if I knew that the only option available to authorities was to trap and destroy the bear	strongly agree agree not sure disagree strongly disagree	1 2 3 4 5
q_17b	If the Department of Natural Resources determined that a recreational hunt was necessary to achieve the number of black bear I desire in my zone, I would support a hunt which harvested a limited number of bears	strongly agree agree not sure disagree strongly disagree	1 2 3 4 5
comb_prf	The number of black bear you think would be a reasonable goal for your Zone	no bears 75% as many bears half as many bears 25% as many bears current number of bears 25% more bears 50% more bears 75% more bears at least twice as many bears	0 1 2 3 4 5 6 7 8

Table 11: Details for 'Concern' variable

Variables	Details	Category	Value
q_12a	How concerned are you about threats to public safety associated with having black bears in your zone of residence?	Extremely concerned somewhat concerned slightly concerned not concerned not sure	1 2 3 4 5
q_12b	How concerned are you about agricultural damage (e.g. crops, livestock, beehives) associated with having black bears in your zone of residence?	Extremely concerned somewhat concerned slightly concerned not concerned not sure	1 2 3 4 5
q_12c	How concerned are you about threats to pets associated with having black bears in your zone of residence?	Extremely concerned somewhat concerned slightly concerned not concerned not sure	1 2 3 4 5
q_12d	How concerned are you about damage to personal property associated with having black bears in your zone of residence?	Extremely concerned somewhat concerned slightly concerned not concerned not sure	1 2 3 4 5

One product of the Social Carrying Capacity study was a score describing the intolerance of respondents to bears. This score was calculated for an individual by their responses to 8 scenarios (Table 12). The scenarios represented various forms of bear/human interactions that were designed to reflect four dimensions: 1) the intensity of the interaction, 2) social proximity of the interaction, 3) spatial proximity to self, and 4) the temporal nature of the interaction. Responses provided to these scenarios were "I would not contact any authorities," "I would inform the authorities about the bear and ask what I should do" and "I would ask/tell someone to do something about the bear." An individual was defined as intolerant to a particular scenario if they requested that authorities intervene. The responses to each of the eight scenarios were re-classified to create a Bear Sensitivity Index (BSI). The BSI uses the four dimensions of bear/human interactions to classify individuals into 5 categories from completely tolerant to intolerant of bear presence (Table 13). The BSI was further reclassified into those individuals that were tolerant to bear presence (combination of first three BSI categories) and intolerant (combination of last two BSI categories).

Table 12: Scenarios given to respondents

Scenarios:	Details
A	you see or hear a bear attempting to enter some part of your home
B	a bear repeatedly threatens and charges pets near your home
C	a bear damages several bird-feeders and barbecues over a week near your home
D	you see a bear near your home more than once in one week
E	a local farmer tells you of bear damage to livestock/ crops
F	a bear, unprovoked, chases a neighbor's pet once
G	a bear damages a bird-feeder or barbecue near your home once
H	you see a bear near your home one morning

Table 13: Bear Sensitivity Index derived from scenarios

BSI Values	Details
Tolerant of all	a tolerance of all 8 of the scenarios presented
Intolerant of Personal Threat	a tolerance of all interactions except a clear personal threat (intolerant of items a and/or b)
Intolerant of Frequent Events	tolerant of occasional, but not frequent interactions with black bear (intolerant of items c, d and/or e)
Intolerant of Occasional Events	tolerant of the presence of bear, but intolerant of any actual interactions (intolerant of items f and/or g)
Intolerant of Presence	intolerant of even the presence of a bear (intolerant of item h)

The best ecological habitat models for males and females were obtained at the 3km and 2km resolutions, respectively. Thus, I identified conflict areas at these two levels of resolution by overlaying regions of intolerance and suitable bear habitat defined by the models. I first identified individuals as tolerant or intolerant to bear presence based on categories designated by the BSI of the SCC. I created raster maps of the density of tolerant and intolerant individuals 2km and 3km resolutions in Zones B and C. I subtracted the values in the tolerant datasets from the intolerant datasets in both zones and reclassified the resultant datasets to identify regions where the intolerance value was greater than the tolerance value. Finally, I multiplied the reclassified datasets with the suitability maps of the corresponding resolution. The results were raster datasets that identified potential conflict regions as the overlap of intolerance and suitable bear habitat.

2.5. Results

Within both zones at both resolutions, the chi-square test statistics indicated no significant difference in the levels of tolerance between individuals living near areas of high bear-habitat suitability compared to those living near areas of low bear habitat suitability (Table 14, 16). For both resolutions, there was also no significant difference in tolerance levels of individuals living near suitable habitat or individuals living near non-suitable habitat *between* Zone B and Zone C (Table 15, 17). *Within* both zones at the 3km resolution, there was no significant difference in the hunting lifestyle between individuals living near bear habitat to individuals living near non-suitable habitat (Table 20). *Within* Zone B at the 2km resolution, there was also no significant difference in the hunting lifestyle between individuals living near bear habitat to individuals living near non-suitable habitat (Table 18). However, *within* Zone C at the 2km resolution, there was a significantly higher proportion of non-hunters living near bear habitat than living near non-suitable habitat (Table 18). For both resolutions, there was no significant difference in the hunting lifestyle of individuals living near bear habitat or individuals living near non-suitable habitat *between* Zone B and Zone C (Table 19, 21).

For both resolutions, the amount of time spent in bear country for those individuals living near bear habitat in Zone B was significantly greater than in Zone C (Table 22, 23). At the 2km resolution, the percent of life spent in bear country for those individuals living near bear habitat between Zone B was also significantly greater than in C (Table 23). All of the other variables did not appear to show any significant differences for those individuals living near bear habitat between Zone B and Zone C.

Table 14: Chi-square test for differences in tolerance levels between individuals living near suitable habitat and individuals living near non-suitable habitat in Zone B and Zone C at 2km resolution.

	Zone B		Zone C	
	suitable	non-suitable	suitable	non-suitable
Tolerant	50.20%	31.73%	22.29%	56.29%
Intolerant	12.05%	6.02%	6.29%	15.14%
χ^2	*0.46*		*0.03*	
P value	*0.50*		*0.87*	

Table 15: Chi-square test for differences in tolerance levels of individuals living near suitable habitat as well as individuals living near non-suitable habitat between Zone B and Zone C at 2km resolution.

	Zone B and C		Zone B and C	
Zone B and C	**B suitable**	**C suitable**	**B non-suitable**	**C non-suitable**
Tolerant	49.02%	30.59%	22.97%	57.27%
Intolerant	11.76%	8.63%	4.36%	15.41%
χ^2	*0.26*		*1.18*	
P value	*0.61*		*0.28*	

Table 16: Chi-square test for differences in tolerance levels between individuals living near suitable habitat and individuals living near non-suitable habitat in Zone B and Zone C at 3km resolution.

	Zone B		Zone C	
	suitable	Non-suitable	suitable	non-suitable
Tolerant	54.69%	26.94%	26.86%	51.71%
Intolerant	12.24%	6.12%	5.43%	16.00%
χ^2	*0.00*		*2.11*	
P value	*0.97*		*0.15*	

Table 17: Chi-square test for differences in tolerance levels of individuals living near suitable habitat as well as individuals living near non-suitable habitat between Zone B and Zone C at 3km resolution.

	Zone B and C		Zone B and C	
	B suitable	**C suitable**	**B non-suitable**	**C non-suitable**
Tolerant	48.38%	33.94%	20.75%	56.92%
Intolerant	10.83%	6.86%	4.72%	17.61%
χ^2	*0.10*		*0.91*	
P value	*0.75*		*0.34*	

Table 18: Chi-square test for differences in hunter lifestyle between individuals living near suitable habitat and individuals living near non-suitable habitat in Zone B and Zone C at 2km resolution.

	Zone B		Zone C	
	suitable	non-suitable	suitable	non-suitable
hunter	27.71%	17.75%	15.02%	27.33%
non hunter	31.60%	22.94%	14.41%	43.24%
χ^2	*0.22*		*4.28*	
P value	*0.64*		*0.04*	

Table 19: Chi-square test for differences in hunter lifestyle of individuals living near suitable habitat as well as individuals living near non-suitable habitat between Zone B and Zone C at 2km resolution.

	Zone B and C		Zone B and C	
	B suitable	C suitable	B non-suitable	C non-suitable
hunter	27.23%	21.28%	12.46%	27.66%
non hunter	31.06%	20.43%	16.11%	43.77%
χ^2	*0.42*		*0.67*	
P value	*0.51*		*0.41*	

Table 20: Chi-square test for differences in hunter lifestyle between individuals living near suitable habitat and individuals living near non-suitable habitat in Zone B and Zone C at 3km resolution.

	Zone B		Zone C	
	suitable	Non-suitable	suitable	non-suitable
Hunter	30.84%	14.98%	16.22%	26.13%
non hunter	34.36%	19.82%	16.82%	40.84%
χ^2	*0.38*		*3.06*	
P value	*0.54*		*0.08*	

Table 21: Chi-square test for differences in hunter lifestyle of individuals living near suitable habitat as well as individuals living near nonsuitable habitat between Zone B and Zone C at 3km resolution.

	Zone B and C		Zone B and C	
	B suitable	C suitable	B non-suitable	C non-suitable
Hunter	27.13%	20.93%	11.26%	28.81%
non hunter	30.23%	21.71%	14.90%	45.03%
χ^2	*0.08*		*0.39*	
P value	*0.78*		*0.53*	

Table 22: Results of Mann-Whitney U tests with associated Wilcoxon W, Z, and p-values. These results show the difference in responses by individuals near suitable habitat between Zone B and Zone C at the 3km resolution.

Variable	Mann-Whitney U	Wilcoxon W	Z	p-value (2-tailed)
Q_7	6,529.500	17,407.500	-1.142	0.253
Q_8	5,488.500	14,804.500	-0.849	0.396
Q_10	5,403.000	9,868.000	-1.864	0.062
Q_11A	7,294.500	18,025.500	-0.284	0.776
Q_11B	7,744.000	20,147.000	-1.261	0.207
Q_11C	7,324.500	19,414.500	-1.665	0.096
Q_11D	7,741.500	19,676.500	-1.081	0.280
Q_15_A	8,085.000	20,488.000	-1.175	0.240
Q_15_B	8,510.500	21,071.500	-0.550	0.583
Q_15_C	8,630.000	21,350.000	-0.440	0.660
Q_15_D	8,811.500	21,531.500	-0.153	0.879
Q_17_A	8,748.000	14,853.000	-0.084	0.933
Q_17_B	8,312.500	14,528.500	-0.969	0.333
EXP_CAT	8,351.000	14,792.000	-1.477	0.140
Q2_ctg	8,008.000	14,449.000	-2.032	*0.042*
INTL_SCR	8,767.000	22,297.000	-0.776	0.437
COMB_CAT	3,502.000	6,583.000	-1.696	0.090
BSI	8,762.000	22,292.000	-0.799	0.424
CCRN_GRP	7,299.000	19,234.000	-1.001	0.317

Table 23: Results of Mann-Whitney U tests with associated Wilcoxon W, Z, and p-values. These results show the difference in responses by individuals near suitable habitat between Zone B and Zone C at the 2km resolution.

Variable	Mann-Whitney U	Wilcoxon W	Z	p-value (2-tailed)
Q_7	5,436.500	15,166.500	-0.836	0.403
Q_8	4,543.000	12,544.000	-0.673	0.501
Q_10	4,817.500	8,220.500	-0.691	0.490
Q_11A	5,797.500	14,977.500	-0.463	0.643
Q_11B	6,002.500	17,177.500	-1.559	0.119
Q_11C	6,140.000	17,018.000	-1.100	0.271
Q_11D	6,428.500	16,868.500	-0.890	0.374
Q_15_A	6,482.500	17,360.500	-1.256	0.209
Q_15_B	6,985.000	17,863.000	-0.277	0.782
Q_15_C	7,129.000	11,882.000	-0.183	0.855
Q_15_D	7,065.500	11,818.500	-0.216	0.829
Q_17_A	7,269.000	18,444.000	-0.060	0.952
Q_17_B	6,834.500	11,784.500	-1.052	0.293
EXP CAT	6,321.000	11,371.000	-2.566	*0.010*
Q2_ctg	6,140.000	11,190.000	-2.898	*0.004*
INTL_SCR	7,334.500	19,424.500	-0.736	0.462
COMB_CAT	3,126.500	5,541.500	-1.006	0.314
BSI	7,508.000	19,598.000	-0.436	0.663
CCRN_GRP	6,295.500	17,026.500	-0.562	0.574

The density maps of respondent tolerance and intolerance to bear presence did not indicate any specific patterns but did indicate that a much larger spatial extent is represented as tolerant rather than intolerant in both zones (Figure 25 and Figure 26). These maps do not represent ratios but rather direct estimates of tolerance and intolerance densities based on 254 points in Zone B and 355 points in Zone C.

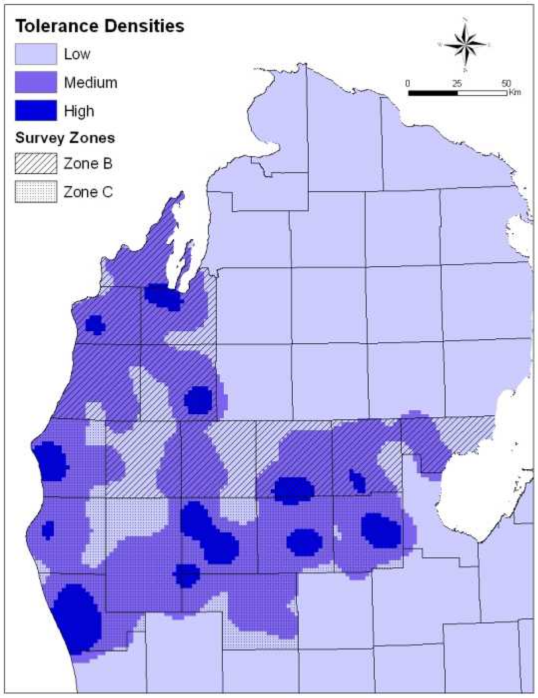


Figure 25: Tolerance density at 2km resolution.

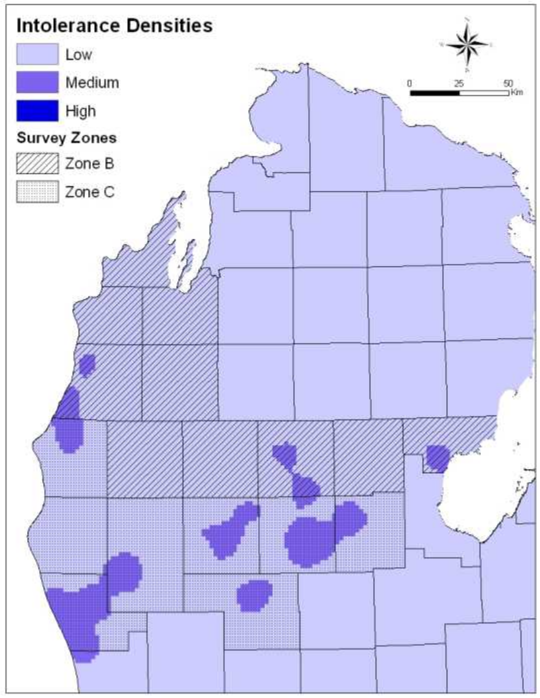


Figure 26: Intolerance density at 2km resolution.

The conflict region maps are based on the ratio of intolerance to tolerance, combined with areas of suitable habitat, and indicate that Zone C had approximately more than twice as much area where potential bear/human conflict can occur than in Zone B (Table 24, Figure 27, and Figure 28).

Table 24: Percentages of conflict regions in each Zone

	Zone C (2km)	Zone C (3km)	Zone B (2km)	Zone B (3km)
Conflict Region	5.80%	6.20%	2.80%	2.90%

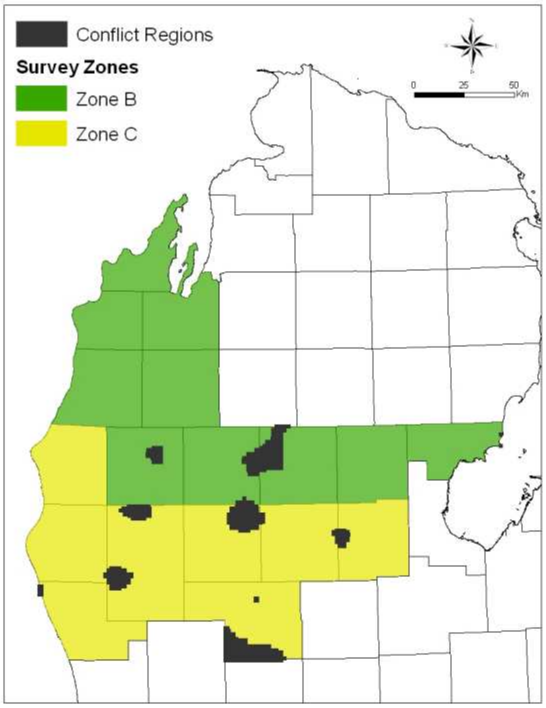


Figure 27: Conflict regions at 2km resolution.

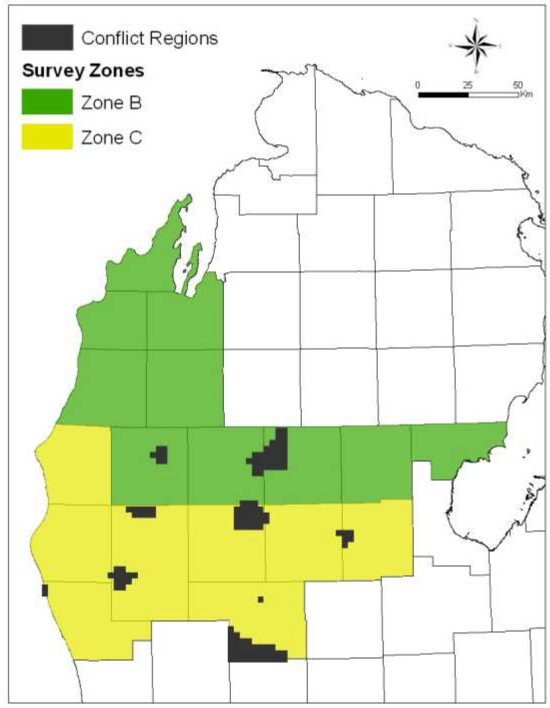


Figure 28: Conflict regions at 3km resolution.

The regression analyses at both resolutions between intolerance and the sum of bear habitat suitability within a 3x3 window of an individual respondent indicated no significant relationships. The regression analyses at both resolutions between concern levels and the sum of suitable bear habitat within a 3x3 window of an individual respondent also indicated no significant relationship. However, there was very nearly a positive relationship between intolerance and concern level with the sum of suitable bear habitat within Zone C at the 3km resolution (Table 25).

Table 25: Results of regression analyses between the intolerance score and concern level to the sum of suitable bear habitat within a 3x3 window of an individual respondent.

	Variable	R Square	P Value
ZoneB (2km)	intolerance	0.006	0.340
	concern	0.008	0.265
Zone C (2km)	intolerance	0.001	0.712
	concern	0.002	0.667
Zone B (3km)	intolerance	0.000	0.785
	concern	0.009	0.223
Zone C (3km)	intolerance	0.029	0.073
	concern	0.032	0.059

2.6. Discussion and Conclusions

Using the results from my habitat models, I hypothesized that there would be significant differences in the responses from those individuals living near bear habitat between Zone B and Zone C for all of the SCC variables. It is encouraging that there are high levels of tolerance in both zones and the results indicate, contrary to my hypothesis, that there are no dramatic differences in tolerance levels to bear presence and bear management policies within each zone as well as between Zone B and Zone C. Despite the similarities in general attitudes towards bear presence and management policies, however, there is no denying that the landscape is considerably different between the two zones. These differences include an increased human population and urban/suburban development in Zone C. Moreover, the two zones have different histories in regards to bear presence and management. It is important to note that the responses in Zone C are based on the bear population at the time the survey was conducted and may not represent future attitudes as the bear population continues to grow. All of these differences will likely lead to an increased probability of human-bear conflict in Zone C. The current methods the MDNR employs to handle nuisance bears may not be as effective or publicly accepted in Zone C as they are in Zone B.

Hunting is the primary tool used by MDNR to remove the potential of human-bear conflict caused by an abundance of bears. This may be a perfectly acceptable solution to residents in Zone B where the hunting lifestyle of individuals living near or not living near suitable bear habitat was not significantly different. However, there was a significantly higher proportion of non-hunters living near suitable bear habitat in Zone C than in Zone B. Furthermore, the higher density of urban and residential developments in the SLP may further preclude the application of regulated bear hunts. Not using regulated hunts as a means of bear management will put additional pressures on the MDNR staff to respond to human-bear conflicts.

The MDNR currently puts nuisance bears into 4 categories. Category I bears are considered to be a direct threat to public safety. These scenarios include a bear that has attacked a human. Category II bears are considered to be a potential threat to public safety. These scenarios include a bear located in an urban area or being physically confined in a public area. Category III bears are considered to be a threat to personal property. Category IV bears are not a threat to public safety or personal property at that time. The DNR has protocols to handle each of these categories. All of the responses, except for category I scenarios, involve efforts by DNR personnel to remove the attractants thus removing future potential for nuisance activity. The first category always elicits an immediate response and involves euthanizing the bear. Responses to the second category are also immediate and involve the discretionary use of aversive conditioning, relocation, or euthanasia. The DNR uses discretion when responding to the third category and will typically use aversive conditioning or relocation. The fourth category elicits no immediate response and, while the DNR may provide some technical advice, it is the responsibility of the people in the vicinity of the bear to remove attractants.

In the future, the residents in Zone C may respond more unpredictably to MDNR nuisance bear protocols than would be expected based on the attitudes to bear presence and management policies found in residents of Zone B. Fortunately, category I and category II bears are very rare in Michigan and although bear numbers may increase in the future that does not necessarily translate into more category I or II bears. Bears in the Western United States exhibited more nuisance activity as a result of mast failure from severe drought. This trend is not as severe in Michigan because the state has many more alternative natural foods than in the west (D. Etter, MDNR, Pers. Comm.). However, if category I and category II bear events become more frequent then the ebb of tolerance may shift to intolerance in Zone C where residents are not as familiar to living in bear country. Furthermore, the most intolerant individuals to bear presence preferred the extreme measure of euthanasia to be used more often for nuisance bears (Peyton et al. 2001). Thus, if intolerant individuals become a vocal minority in Zone C or even further south then euthanasia may be more frequently expected, which in turn may elicit more public disapproval from those individuals opposed to euthanasia.

Careful attention should be paid to the conflict regions in Zones C. There is already twice the density of conflict regions in Zone C than in Zone B. Those individuals most sensitive to bear presence may be the most vocal in requesting that action be taken by the MDNR. These actions may be unwarranted and will put additional pressure on the staff and use up financial resources.

The presentation and evaluation of educational materials will likely be paramount in these regions to prepare residents for potential human-bear conflicts. The MDNR currently uses a variety of educational methods including “written material, audiovisual presentations, media interviews, and web-based information.”

The SCC study stated that although < 20% of the respondents in Zone C preferred no bears in their zone, there was a clear indication that the majority of individuals preferred only a very limited presence of bears. Furthermore, nearly half of the respondents indicated they would be less likely to call the MDNR regarding a nuisance bear if it meant the bear would be killed. Therefore, to avoid public backlash to a perceived overabundance of bear or to euthanasia of individual problem bear, I agree with the suggestion in the SCC study for the MDNR to initiate a ‘repeat offender’ policy in their bear management protocols for category II and category III bears. This protocol may increase the tolerance of the diverse group of stakeholders in Zone C to bear presence and bear management strategies. Moreover, the conservation of bear habitat and wildlife corridors may habituate residents to bear presence in Zone C by providing several forms of positive human-bear interaction.

References

Aebischer, N.J., P.A. Robertson, and R.E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

Albert, D.A. 1990. A regional landscape ecosystem classification of Michigan stressing physiographic, geologic, and soil factors. Ann Arbor, MI: University of Michigan. 384 p. Ph.D. dissertation.

Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: a working map and classification. Gen Tech. Rep. NC-178. St. Paul, MN: U.S. department of Agriculture, Forest Service, North Central Forest Experiment Station.

Albert, D.A., Denton, S.R., and Barnes, B.V. 1986. Regional landscape ecosystems of Michigan. School of Natural Resources, University of Michigan, Ann Arbor, MI.

Albert, D.M. and R.T. Bowyer. 1991. Factors related to grizzly bear-human interactions in Denali National Park. Wildlife Society Bulletin 19(3):339-349.

Alldredge, J.R., and J.T. Ratti. 1986. Comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management 50:157-165.

Alt, G.L. 1977. Home range, annual activity patterns, and movements of black bears in northeastern Pennsylvania. M.S. Thesis, Pennsylvania State University, University Park, Pennsylvania. 67pp.

Alt, G.L. 1978. Dispersal patterns of black bears in northeastern Pennsylvania: a preliminary report. Proceedings of the Eastern Black Bear Workshop on Bear Research and Management 4:186–199.

Alt, G.L. 1980. Home range and movements of Pennsylvania black bear. Pennsylvania Game News 51(11):10–15.

Alt, G.L., and J.S. Lindzey. 1980. Management of Pennsylvania's black bear: past, present, and future. Transactions of the Northeastern Fish and Wildlife Conference 37:58–70.

Alt, G.L., F.W. Alt, and J.S. Lindzey. 1976. Home range and activity patterns of black bears in northeastern Pennsylvania. Transactions of the Northeastern Fish and Wildlife Conference 33:45–56.

Alt, G.L., G.J. Matula, Jr., F.W. Alt, and J.S. Lindzey. 1977. Movements of translocated nuisance black bears of northeastern Pennsylvania. Transactions of the Northeastern Fish and Wildlife Conference 34:119–126.

Alt, G.L., G.J. Matula, Jr., F.W. Alt, and J.E. Lindzey. 1980. Dynamics of home range and movements of adult black bears in northeastern Pennsylvania. Bear Biology Association Conference Series 3:131-136.

Alt, G.L., R.J. Askey, D.E. Jones, and D.C. Madl. 1982 (abstract only). Movements and mortality of black bears relocated 100+ air-miles in Pennsylvania. Transactions of the Northeastern Fish and Wildlife Conference 39:16. Abstract only.

Ambrose, J.P., and S.P. Bratton. 1990. Trends in landscape heterogeneity along the borders of Great Smokey Mountains National Park. Conservation Biology 4:135-143.

Ayres, L. A., L.S. Chow, and D.M. Graber. 1986. Black bear activity patterns and human induced modifications in Sequoia National Park. International Conference on Bear Research and Management 6:151-154.

Barnes, B.V, and W.H. Wagner, Jr. 2004. Michigan Trees. The University of Michigan Press, Ann Arbor, Michigan.

Bauer, E. 1996. Bears: Ecology, Behavior, Conservation. Voyageur Press, Stillwater, MN.

Beeman, L.E., and M.R. Pelton. 1980. Seasonal foods and feeding ecology of black bears in the Smoky Mountains. Bear Biology Association Conference Series 3:141-148.

Beckmann, J. P., and J. Berger. 2003. Rapid ecological and behavioural changes in carnivores: The responses of black bears (Ursus americanus) to altered food. Journal of Zoology 261:207-212.

Beckmann, J. P., Lackey, C. W., Berger, J. 2004. Evaluation of deterrent techniques on altering behavior of ‘nuisance’ black bears. Wildlife Society Bulletin 32:1141-1146.

Beier, P., and R. F. Noss. 1998. Do habitat corridors provide connectivity? Conservation Biology 12:1241–1252.

Boitani, L. 1995. Ecological and cultural diversities in the evolution of wolf-human relationships. Pages 3-11 in L.N. Carbyn, S.H. Fritts, and D.R. Seip, editors. Ecology and Conservation of Wolves in a Changing World. Canadian Circumpolar Institute, Occasional Publication No. 35, University of Alberta, Edmonton, Alberta, Canada.

Box, G.E.P., and G.C. Tiao. 1973. Bayesian inference in statistical analysis. Addison-Wesley, Reading, Massachusetts, USA.

Brady, J. R., and D. S. Maehr. 1982. A new method for dealing with apiary-raiding black bears. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 36:571–577.

Breck, S.W., N. Lance, and P. Callahan. 2006. A shocking device for protection of concentrated food sources from black bears. Wildlife Society Bulletin 34:23-26

Brody, A.J., and M.R. Pelton. 1989. Effects of roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17:5–10.

Brothers, T.S., and A. Spingard. 1992. forest fragmentation and alien plant invasion of central Indiana old-growth forests. Conservation Biology 6:91-100.

Bruner, M.C. 1977. Vegetation of forest island edges. M.S. thesis. University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346-352.

Byers, C.R., R.K. Steinhorst, and P.R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. Journal of Wildlife Management 48:1050-1053.

California Department of Fish and Game. 1998. Black bear management plan. *On-line:* http://www.dfg.ca.gov/hunting/bearplan.pdf

Cardoza, J.E. 1976. The history and status of the black bear in Massachusetts and adjacent New England states. Massachusetts Division of Fisheries and Wildlife Research Bulletin 18. 173 pp.

Carr, P.C. and K. Burguess. 2003. New Jersey Status Report. Proceedings of the 17th Eastern Black Bear Workshop. New Jersey, USA. 11pp.

Clark, J.D., J.E. Dunn, and K.G. Smith. 1993. A multivariate model of female black bear habitat use for a Geographic Information System. Journal of Wildlife Management 57(3):519-526.

Clark, J.E., F.T. van Manen, and M.R. Pelton. 2002. Correlates of success for on-site releases of nuisance black bears in Great Smoky Mountains National Park. Wildlife Society Bulletin 30(1):104-111.

Collins, J.M. 1978. Status report, North Carolina. Proceedings of the Eastern Black Bear Workshop 4:43-45.

Colvin, T. R. 1975. Aversive conditioning black bear to honey utilizing lithium chloride. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 29:450–453.

Comly, L. M. 1993. Survival, reproduction, and movements of translocated nuisance black bears in Virginia. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Conley, B.W. 1978. Status report, Arkansas. Proceedings of the Eastern Black Bear Workshop 4:1-4.

Conley, R.H. 1978. Status report, Tennessee. Proceedings of the Eastern Black Bear Workshop 4:70-73.

Cooper, A.B., and J.J. Millspaugh. 1999. The application of discrete choice models to wildlife resource selection studies. Ecology 80:566-575.

Cowan, I. McT. 1972. The status and conservation of bears (Ursidae) of the world-1970. International Conference on Bear Research and Management 2:243-367.

Dickson, B.G., and P. Beier. 2002. Home-range and habitat selection by adult cougars in southern California. Journal of Wildlife Management 66:1235-1245.

Dixon, J.D., M.K. Oli, M.C. Wooten, T.H. Eason, J.W. McCown, and D. Paetkau. 2006. Effectiveness of a regional corridor in connecting two Florida black bear populations. Conservation Biology 20:155-162.

Dobey S., D.V. Masters, B.K. Scheick, J.D. Clark, M.R. Pelton, M. Sunquist. 2005. Ecology of Florida black bears in the Okefenokee–Osceola ecosystem. Wildlife Monographs 158.

Dorr, J.A. and Eschman, D.F. 1970, Geology of Michigan: The Universtiy of Michigan Press, Ann Arbor.

Dunlap, T. 1988. Saving America's Wildlife. Princeton University Press, Princeton, new Jersey, USA.

Dunn, P.O., and C.E. Braun. 1986. Summer habitat use by adult female and juvenile sage grouse. Journal of Wildlife Management 50:228-235.

Eicher, C.L., and C.A. Brewer. 2001. Dasymetric mapping and areal interpolation: Implementation and evaluation. Cartography and Geographic Information Science 28:125-138.

Ellison, A.M. 1996. An introduction to Bayesian inference for ecological research and environmental decision-making. Ecological Applications 6:1036-1046.

Ellison, A.M. 2004. Bayesian inference in ecology. Ecology Letters 7:509-520.

Elowe, K.D. 1984. Home range, movements, and habitat preferences of black bear (Ursus americanus), in western Massachusetts. M.S. Thesis. University of Massachusetts, Amherst. 112 pp

Erickson, A.W., 3. Nellor, and G.A. Petrides. 1964. The black bear in Michigan. Michigan State University. Agriculture Experimental Station Research Bulletin. No. 4. East Lansing. 102 pp

ESRI (Environmental Systems Research, Inc.). 2002a. ArcView 3.3. ESRI, Redlands, California, USA.

ESRI (Environmental Systems Research, Inc.). 2002b. ArcView 9.1. ESRI, Redlands, California, USA.

Etter, D.R. 2002. Black bear population management techniques. Final Report. Federal Aid in Wildlife Restoration Project. W-127-R-20. Michigan Department of Natural Resources and U.S. Fish and Wildlife Service. Project No:127-R-20. Study No:127-109

Etter, D. R., T. F. Reis, and L. G. Visser. 2003. Michigan Status Report. Proceedings of the 17th Eastern Black Bear Workshop. New Jersey, USA. 9pp.

Frawley, B.J. 2006. 2005 Michigan black bear hunter survey. Michigan Department of Natural Resources. Wildlife Division Report No. 3458.

Garris, R.S., and M.R. Pelton. 1984. Activities of black bears in Cherokee National Forest, Tennessee. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 38:51-60, Lansing, MI. 27 pp.

Gillin, C.M., F.M. Hammond, and C.M. Peterson. 1994. Evaluation of an aversive conditioning technique used on female grizzly bears in the Yellowstone Ecosystem. International Conference on Bear Research and Management 9(1):503–512.

Gore, M.L., Knuth, B.A., Curtis, P.D., and J.E. Shanahan. (2006). Education programs for reducing human-bear conflict: indicators of success? Ursus 17: 75 - 80.

Grenfell, W.E. and A.J. Brody. 1986. Black bear habitat use in Tahoe National Forest, California. Proceedings International Conference on Bear Research and Management 6, pp. 65–72.

Glenn, E.M., M.C. Hansen, and R.G. Anthony.2004. Spotted owl home-range and habitat use in young forests of western Oregon. Journal of Wildlife Management. 68:33-50.

Gore ML. 2004. Comparison of intervention programs designed to reduce human black bear conflict: a review of literature. HDRU Series Publication No. 04-4. Department of Natural Resources, Cornell University: Ithaca: New York.

Gysel, W.L. 1951. Borders and openings of beech-maple woodlands in southern Michigan. Journal of Forestry 49:13-19.

Hamilton R. J. and R. L. Marchington. 1980. Denning and related activities of black bears in the coastal plain of North Carolina. International Conference on Bear Research and Management 4:121-126.

Hanski, I. 1999. Metapopulation Ecology. Oxford University Press.

Harris, L. D. 1984. The fragmented forest: island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago.

Harris, L. D., and J. Scheck. 1991. From implications to applications: the dispersal corridor principle applied to the conservation of biological diversity. Pages 189–220 in D. A. Saunders and R. J. Hobbs, editors. Nature conservation 2: the role of corridors. Surrey Beatty & Sons, Chipping Norton, New South Wales, Australia.

Heisey, D. M. 1985. Analyzing selection experiments with log-linear models. Ecology 66:1744-1748.

Herrero, S.M. 1979. Black bears: the grizzly's replacement? Pages 179-195 in D. Burk, ed. The black bear in modern North America. Boone and Crockett nub. Amwell Press, Clinton, NJ.

Hilton-Taylor, C. G (Switzerland): IUCN Species Survival Commission. 2000. 2000 IUCN Red List of Threatened Species; 61 pp.

Hoover, R.L., and D.L. Wills, Editors. 1987. Managing Forested Lands for Wildlife, Colorado Division of Wildlife, Denver, CO.

Horne, J.S., and E.O. Garton. 2006. Likelihood cross-validation vs. least squares cross-validation for choosing the smoothing parameter in kernel home range analysis. Journal of Wildlife Management 70:641-648.

Hugie, R.D. 1979. Working group report: Central and Northeast Canada and United States. Pages 250-271 in D. Burk, ed. The black bear in modern North America. Boone and Crockett Club. Amwell Press, Clinton, NJ.

Hunt, C.L. 1984. Behavioral responses of bears to tests of repellents, deterrents, and aversive conditioning. M.S. Thesis, University of Montana, Missoula, Montana.

Hyngstrom, S.E. 1994. Black bears. Pages c5–c15 in S.E. Hygnstrom, R. M. Timm, and G. E. Larson, editors. Prevention and control of wildlife damage. University of Nebraska Press, Lincoln, Nebraska.

International Association of Fish and Wildlife Agencies (IAFWA). 2004. Potential costs of losing hunting and trapping as wildlife management tools. Animal Use Issues Committee, IAFWA: Washington DC.

James, B.H., C.P. Lo, and T.W. Hodler. 2004. Dasymetric estimation of population density and areal interpolation of census data. Cartography and Geographic Information Science 31:103-121.

Jeffreys, H. 1961. Theory of probability. Third edition. Oxford University Press, Oxford, UK.

Johnson D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, K.G., and M.R. Pelton. 1980. Environmental relationships and the denning period of black bears in Tennessee. Journal of Mammalogy 61(4):653-660.

Johnson, K.G., and M.R. Pelton. 1981. Selection and availability of dens for black bears in Tennessee. Journal of Wildlife Management 45(1):111-119.

Johnson, K.G., D.O. Johnson, and M.R. Pelton. 1978. Simulation of winter heat loss for a black bear in a closed tree den. Proceedings of the Eastern Workshop on Black Bear Research and Management 4:155-166.

Jonkel, C.J., and I. McT. Cowan. 1971. The black bear in the spruce-fir forest. Wildlife Monographs 27:1-57.

Kasworm, W.T. and T.J. Thier. 1994. Adult black bear reproduction, survival, and mortality sources in northwest Montana. Proceedings International Conference on Bear Research and Management 9:223–230.

Kellyhouse, D.G. 1980. Habitat utilization by black bears in northern California. Bear Biology Association Conference Series 3:221-228.

Koehler G.M., D.J. Pierce. 2003. Black bear home-range sizes in Washington: climatic, vegetative, and social influences. Journal of Mammalogy 84:81–91.

Kohn, B.E. 1982. Status and management of black bear in Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin 129.

Lackey B.K, and S.H. Ham. 2003. Contextual analysis of interpretation focused on human-black bear conflict in Yosemite National Park. Applied Environmental Education and Communication 2:11-21.

Lamb, G.R. 1983. Home range and habitat use of female black bears in northern Maine. M.S. Thesis. University of Maine, Orono. 26 pp.

Landers, J.L., R.J. Hamilton, A.S. Johnson, and R.L. Marchington. 1979. Foods and habitat of black bears in southeastern North Carolina. Journal of Wildlife Management 43(1):143-153.

Leatherberry, E.C. and J.S. Spencer, Jr. 1996. Michigan forest statistics, 1993. Resource Bulletin NC-170. St Paul, MN: U.S. Department of Agriculture, Forest Service. North Central Forest Experiment Station.

LeCount, A.L. 1980. Some aspects of black bear ecology in the Arizona chaparral. Bear Biology Association Conference Series 3:175-179.

LeCount, A. L. 1983. Evidence of wild black bears breeding while raising cubs. Journal of Wildlife Management 41:408-412.

Lentz, W.M. 1980. Aspects of habitat and denning requirements of black bears in northeastern Georgia. M.S. Thesis. University of Georgia, Athens. 82 pp.

Lentz, W.M., R.L. Marchington, and D.M. Carlock. 1980. Black bear habitat in north Georgia: some implications of wilderness designation. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 34:550-556.

Leopold, A. 1933. Game Management. University of Wisconsin Press, Madison, Wisconsin, USA.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin of the Entomology Society of America 71:237-240

Lindzey, F.G., and E.C. Meslow. 1977. Home range and habitat use by black bears in southwestern Washington. Journal of Wildlife Management 41(3):413-425.

Link, W.A., E. Cam, J.D. Nichols, and E.G. Cooch. 2002. Of BUGS and birds: Markov chain Monte Carlo for hierarchical modeling in wildlife research. Journal of Wildlife Management 66:277–291.

Lopez, V. 2004. Project Report. Spatial genetic structure and the assumption of geographic closure in a mark-recapture study of black bear (*Ursus americanus*) in Michigan. Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI.

Lyons, A.L., W.L. Gaines, and C. Servheen. 2003. Black bear resource selection in the northeast Cascades, Washington. Biological Conservation 113: 55-62.

Lyons, A.J. 2004. Activity patterns of an urban black bear population in the San Gabriel Mountains of southern California. Proceedings of the 15th International Conference on Bear Research and Management.

Maehr, D.S., and J.R. Brady. 1984. Food habits of Florida black bears. Journal of Wildlife Management 48(1):230-235.

Manly B.F.J., McDonald L.L., Thomas D.L., McDonald T.L., Erickson W.P. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Chapman and Hall, London, United Kingdom.

Manville, A.M. 1983. Human impact on the black bear in Michigan's Lower Peninsula. International Conference of Bear Research and Management 5:20-33.

Manville, A.M. 1987. Den selection and use by black bears in Michigan's Northern Lower Peninsula. International Conference of Bear Research and Management 7:317:322.

Massopust, J.L., and R.K. Anderson. 1984. The response of black bears to being chased by hunting dogs. Proceedings of the Eastern Black Bear Workshop on Bear Research and Management 7:59–65.

Mattson, D.J., S. Herrero, R.G. Wright, and C.M. Pease. 1996. Science and management of Rocky Mountain grizzly bears. Conservation Biology 10(4):1013-1025.

McAtee, W. L. 1939. The electric fence in wildlife management. Journal of Wildlife Management 31:928–929.

McConnell P.A., J.R. Garris, E. Pehek, and J.L. Powers. 1997. State of New Jersey, Department of Environmental Protection, Division of Fish, Game and Wildlife. Black Bear Management Plan.

McCracken, M.L., B.F.J. Manly, and M.V. Heyden. 1998. The Use of Discrete-Choice Models for Evaluating Resource Selection. Journal of Agricultural, Biological, and Environmental Statistics 3:268-279.

McCullagh, P., and J.A. Nelder. 1991. Generalized linear models. Second edition. Chapman and Hall, London, UK.

McCullough, D. R. 1982. Behavior, bears, and humans. Wildlife Society Bulletin 10:27–33.

McDonald, T.L., B.F.J. Manly, R.M. Nielson, and L.V. Diller. 2006. Discrete-Choice modeling in wildlife studies exemplified by northern spotted owl nighttime habitat selection. Journal of Wildlife Management 70(2):375-383.

McGarigal and Marks. 1994. Fragstats: Spatial pattern analysis program for quantifying landscape structure. Reference manual. Forestry Science Department. Oregon State University. Corvallis Oregon 62 p.+ Append.

McLean, P.K. and M.R. Pelton. 1989. Some demographic comparisons of wild and panhandler bears in the Smokey Mountains. International Conference on Bear Research and Management 8:105-112.

McLellan, B.N., F. Hovey, R.D. Mace, J.G. Woods, D.C. Carney, M.L. Gibeau, W.L. Wakkinen, and W.K. Kasworm. 1999. Rates and causes of grizzly bear mortality in the interior mountains of British Columbia, Alberta, Montana, and Idaho. Journal of Wildlife Management 63:901-920.

Michigan Department of Natural Resources. Northern Lower Peninsula Resources. *On-line:* http://www.michigan.gov/dnr/0,1607,7-153-10366_11865_28193-83100--,00.html

Michigan Department of Natural Resources. Michigan's Wildlife Action Plan Terrestrial Summary A. SLP Suburban/small town. *On-line:* http://www.michigandnr.com/publications/pdfs/HuntingWildlifeHabitat/WCS/LF/SLP_Suburban.pdf

Michigan Department of Natural Resources. Michigan's Wildlife Action Plan Terrestrial Summary B. SLP Large contiguous unfragmented landscape. *On-line:* http://www.michigandnr.com/publications/pdfs/HuntingWildlifeHabitat/WCS/LF/SLP_Large_contiguous.pdf

Michigan Department of Natural Resources. Population Status and Range of Michigan Black Bears. Unpublished.

Michigan Department of Natural Resource. 2005. Michigan Problem Bear Management Guidelines.

Miller, D.A., B.D. Leopold, G.A. Hurst, and P.D. Gerald. 2000. Habitat selection models for eastern wild turkeys in central Mississippi. Journal of Wildlife Management 64:765-776.

Mitchell, M.S., J.W. Zimmerman, and R.A. Powell. 2002. Test of a habitat suitability index for black bears in the southern Appalachians. Wildlife Society Bulletin 30(3):794-808.

Nams, V.O. 1990. Locate II user's guide. Pacer, Truro, Nova Scotia.

Nash, R. 1982. Wilderness and the American Mind. Yale University Press, New Haven, Connecticut, USA.

Noss, R.F., and L.D. Harris. 1986. Nodes, networks, and mums—preserving diversity at all scales. Environmental Management 10:299–309.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 42:172-174.

NYSDEC. 2003. Black bears in New York: natural history, range, and interactions with people. New York State Department of Environmental Conservation: Albany, New York.

Obbard, M.E. 2003. Nuisance Bear Review Committee Report and Recommendations:

Appendix 5, Black bear ecology. Wildlife Research and Development Section, Ontario Ministry of Natural Resources.

Ozoga, J.J., and L.J. Verme. 1982. Predation by black bears on newborn white-tailed deer. Journal of Mammalogy 63(4):695-696.

Peek, J.M. 1986. A Review of Wildlife Management. Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Pelton, M.R. 1982. Black bear. Pages 504-514 in J.A. Chapman and G.A. Feldhamer, eds. Wild mammals of North America:-biology, management, and economics. Johns Hopkins University Press, Baltimore, MD.

Pelton, M.R., and G.M. Burghardt. 1976. Black bears of the Smokies. Natural History 85(1):55-63.

Pelton, M. R., and van Manen, F. T. 1997. Status of black bears in the southeastern United States. In Proceedings of the Second International Symposium on the Trade of Bear Parts, March 21-23 1997, Seattle, Washington, D. Williamson and A. L. Gaski (eds.). TRAFFIC USA/World Wildlife Fund, Washington, D.C. p. 31-44.

Pelton, M.R., L.E. Beeman, and D.C. Eager. 1980. Den selection by black bears in the Great Smoky Mountains National Park. Bear Biology Association Conference Series 3:149-151.

Pelton, M.R., A.B. Coley, T.H. Eason, D.L. Doan Martinez, J.A. Pederson, F.T. van Manen, and K.M. Weaver. 1998. Chapter 8: American Black Bear Conservation Action Plan *in* Status Survey and Conservation Action Plan: Bears. IUCN/SCC Bear Specialist Group. IUCN, Gland, Switzerland, and Cambridge, UK.

Peyton, B., P. Bull, T. Reis, and L. Visser. 2001. An Assessment of the Social Carrying Capacity of Black Bears in the Lower Peninsula of Michigan. Submitted to: Wildlife Division, Michigan Department of Natural Resources.

Public Sector Consultants. 2001. Michigan land resource project. *On line*: www.pscin.com/Documents/lbilu/index.htm.

Raftery, A.E., and S. Lewis. 1992. How many iterations in the Gibbs sampler? Pages 763–773 in Bayesian Statistics 5. J. M. Bernando, J. O. Berger, A. P. Dawid, and A. F. M. Smith, ed. Oxford University Press, New York.

Rancourt, L.M. 1998. Barking dogs repel hungry park bears. National Parks 72(11-12):13-14.

Ranney, J.W., M.C. Bruner, and J.B. Levenson. 1981. The importance of edge in the structure and dynamics of forest islands. Pages 67-95 in R.L. Burgess and D.M. Sharp, editors. Forest island dynamics in a man-dominated landscape. Springer-Verlag, New York.

Raybourne, J.W. 1978. Status report for Virginia. Proceedings of the Eastern Workshop on Black Bear Research and Management 4:79-80.

Ream, C. 1979. Human-wildlife conflicts in back-country: Possible solution. Pages 153-163 in Proceedings: Recreational impact on wildland. USDA Forest Service. Pacific Northwest Region. Report No. R-6-001-1979. Seattle, WA.

Reckhow, K.H. 1990. Bayesian inference in non-replicated ecological studies. Ecology 71:2053-2059

Responsive Management National Office. 2004. Public Attitudes toward Black Bear Management in Maryland. Conducted for the Maryland Department of Natural Resources by Responsive Management.

Reynolds, D.G., and J.J. Beecham. 1980. Home range activities and reproduction of black bears in west-central Idaho. Bear Biology Association Conference Series 3:181-190.

Riitters, K.H., R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones and B.L. Jackson. 1995. A Factor Analysis of Landscape Pattern and Structure Metrics. Landscape Ecology 10:23–39.

Robinson, F.A. 1963. Beekeeping among the bears. American Bee Journal 103:454– 456.

Roehl, E. 1984. Food facts. Apollo Books. Winuna, Minnesota. 212 pp.

Rogers, L.L. 1980. Inheritance of coat color and changes in pelage coloration in black bears in northeastern Minnesota. Journal of Mammalogy 61:324-327.

Rogers, L.L. 1984a. Reactions of free-ranging black bears to capsaicin spray repellent. Wildlife Society Bulletin. 12:59-61.

Rogers, L.L. 1984b. Homing by black bears and other large mammals. Proceedings of the Eastern Workshop on Black Bear Research and Management 7:76-77.

Rogers, L.L. 1986. Effects of translocation distance on frequency of returns by black bears. Wildlife Society Bulletin 14(1):76-80.

Rogers, L.L. 1987. Effects of food supply and kinship on social behavior, movements, and population growth of black bears in northeastern Minnesota. Wildlife Monographs 97. 72 pp.

Rogers, L.L and A.W. Allen. U.S. Fish and Wildlife Service. 1987. Habitat suitability index models: Black bear, upper Great Lakes region. Biological report 82(10.144).

Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological corridors: form, function, and efficacy. BioScience 47:677–687.

Rudis, V.A., and J.B. Tansey. 1995. Regional assessment of remote forests and black bear habitat from forest resource surveys. Journal of Wildlife Management 59(1):170-180

Sauer, P.R., and S. Free. 1969. Movements of tagged bears in the Adirondacks. New York Fish and Game Journal 16:205–223.

Schenk, A., M.E. Obbard, and K.M. Kovacs. 1998. Genetic relatedness and home-range overlap among female black bears (Ursus americanus) in northern Ontario, Canada. Canadian Journal of Zoology 76: 1511-1519.

Schirokauer, D.W., and H.M. Boyd. 1998. Bear-human conflict management in Denali National Park and Preserve 1982–94. Ursus 10:395–403.

Schusler, T., and W.F. Siemer. 2004. Report on stakeholder input groups for black bear impact management in the Lower Catskills, Upper Catskills, and Western New York. Cornell Cooperative Extension of Tompkins County: Ithaca, New York.

Schwartz, C.C, J.E. Swenson, and S.D. Miller. 2003. Large carnivores, moose, and humans: a changing paradigm of predator management in the 21st century. Alces 39:41-63

Seaman, D.E. and R.A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075 85.

Servheen C., H. Herrero and B. Peyton and the IUCN/SSC Bear and Polar Bear Specialist Groups. 1999. IUCN. *On-line:* http://www.iucn.org/themes/ssc/publications/actionplans.htm

Sherwonit, W. 1996. Katmai at a crossroads. National Parks 70 (5-6):28-33.

Shull, S.D., M.R. Vaughan, and L. Comly. 1994. Use of nuisance bears for restoration purposes. Proceedings of the Eastern Black Bear Workshop on Bear Research and Management 12:107–114.

Siemer, W.F., and D.J. Decker. 2003. Cornell University, Department of Natural Resources, Human Dimensions Research Unit. 2002 New York State Black Bear Management Survey: Study Overview and Findings Highlights. HDRU Series No. 03-6.

Siemer, W.F. and P. Otto. 2005. A group model building intervention designed to inform wildlife management decisions. In J.D. Sterman, N.P. Repenning, R. S. Langer, J.I. Rowe, and J.M. Yanni, eds. Proceedings 23rd International Conference of the System Dynamics

Society. System Dynamics Society: Albany,NY. *On-line*: http://www.dnr.cornell.edu/hdru/PUBS/SiemerOtto.pdf.

Smith, T.R. 1985. Ecology of black bears in a bottomland hardwood forest in Arkansas. Ph.D. Dissertation. University of Tennessee, Knoxville. 209 pp.

Spiegelhalter, D.J., N.G. Best, B.P. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society B 64:583–639.

Spiker Jr., H.A. and S. L. Bittner. 2004. Wildlife and Heritage Service: Black Bear Management Plan 2004-2013. Maryland Department of Natural Resources.

Storer, T. I., G. H. Vansell, and B. D. Moses. 1938. Protection of mountain apiaries from bears by the use of electric fences. Journal of Wildlife Management 2:172–178.

Ternent, M.A. 2005. Bureau of Wildlife Management, Pennsylvania Game Commission. Management Plan for Black Bear in Pennsylvania (2005-2015).

Ternent, M.A., and D. L. Garshelis. 1999. Taste-aversion conditioning to reduce nuisance activity by black bears in a Minnesota military reservation. Wildlife Society Bulletin 27:720–728.

Tietje, W.D., B.O. Pelchat and R.L. Ruff. 1986. Cannibalism of denned black bears. Journal of Mammalogy 67(4):762-766.

Thogmartin, W. E., J. R. Sauer, and M. G. Knutson. 2004. A hierarchical spatial model of avian abundance with application to Cerulean Warblers. Ecological Applications 14:1766–1779.

Thomas, D.L., D. Johnson, and B. Griffith. 2006. A Bayesian random effects discrete-choice model for resource selection: Population-level selection inference. Journal of Wildlife Management 70(2):404- 412

Thomasma, L.E., T.D. Drummer, and R.O. Peterson. 1991. Testing the habitat suitability index for the fisher. Wildlife Society Bulletin 19:291-297.

U.S. Department of Agriculture, Soil Conservation Service. 1981. Soil association map of Michigan. Ext. Bull. E-1550. East Lansing, MI: Michigan State University, Agriculture Experiment Station, Cooperative Extension Service. 1 map (1:1,000,000).

U.S. Department of the Interior. 1995. Wildlife Biologue, American Black Bear (Ursus americanus. *On-line:* http://library.fws.gov/Pubs/ambear.pdf

Van Manen F.T., and M.R. Pelton. 1997. A GIS model to predict Black bear habitat use. Journal of Forestry 95(8):6-12.

Warburton, G.S., and R.C. Maddrey. 1994. Survey of nuisance bear programs in eastern North America. Proceedings of the Eastern Black Bear Workshop on Bear Research and Management 12:115–123.

Whitcomb S., M. Strong, and T. Reis. 2001. A history of Bear Regulations in Michigan. Michigan Department of Natural Resources. Unpublished.

White, D., Jr., K.C. Kendall, and H.D. Picton. 1999. Potential energetic effects of mountain climbers on foraging grizzly bears. Wildlife Society Bulletin 27(1):146-151.

Wikle, C.K. 2003. Hierarchical Bayesian models for predicting the spread of ecological processes. Ecology 84:1382-1394

Willey, C.H. 1978. The Vermont black bear. Vermont Fish and Game Dept. Montpelier. 73 pp.

Williamson, D.F. 2002. In the Black: Status, Management and Trade of the American Black Bear (Ursus americanus) in North America. TRAFFIC North America, World Wildlife Fund.

Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. Animal Conservation 3:165-173.

Wright, J.K. 1936. A method of mapping densities of population: With Cape Cod as an example. The Geographical Review 26:103-110.

Young, O.D. 1984. Black bear habitat use at Priest Lake, Idaho. M.S. Thesis. University of Montana, Missoula. 66 pp.

Zimmerman J.C., L.E. DeWald, and P.G. Rowlands. 1999. Vegetation diversity in an interconnected ephemeral riparian system of north-central Arizona, USA. Biological Conservation 90:217-228

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Websites:

ESRI's ArcGIS software and documentation online:
http://www.esri.com

Patch Analyst software and documentation online:
http://flash.lakeheadu.ca/~rrempel/patch/

WinBUGS software and documentation online:
http://www.mrc-bsu.cam.ac.uk/bugs/

Appendix A: WinBUGS Model

```
model
{

   for(j in 1:N){
      x[j,2]~dcat(p[x[j,1],1:Ns])
        x.rep[j]~dcat(p[x[j,1],1:Ns])
         Dj[j] <- 2*log(p[x[j,1],x.rep[j]]) – 2*log(p[x[j,1],x[j,2]])
   }
   D <- sum(Dj[1:N])
   pVal <- step(D)

   for(I in 1:Na){
      for(s in 1:Ns){
         log(eprod[I,s])<-(inprod2(z.c[s,],abeta.c[I,])+inprod2(z.d[s,],abeta.d[I,]))
         p[I,s]<-eprod[I,s]/sumeprod[i]
      }
      sumeprod[i]<-sum(eprod[I,])
   }

   for(I in 1:Na){
      for(k in 1:K.c){
                    abeta.c[I,k]~dnorm(beta.c[k],tau.c[k])
                    }
      for(k in 2:K.d){
       abeta.d[I,k]~dnorm(beta.d[k],tau.d[k])
        abeta.d.alt[I,k]<-abeta.d[I,k]- mean(abeta.d[I,])
      }
      abeta.d[I,1]<-0
      abeta.d.alt[I,1]<- -mean(abeta.d[I,])
   }
   for (k in 1:K.c){
    beta.c[k]~dnorm(0.0,0.01)
    sd.c[k]~dunif(0,100)
    tau.c[k]<-1/pow(sd.c[k],2)
   }
   for (k in 2:K.d){
    beta.d[k]~dnorm(0.0,0.01)
    sd.d[k]~dunif(0,100)
    tau.d[k]<-1/pow(sd.d[k],2)
    beta.d.alt[k]<-beta.d[k]-mean(beta.d[])
   }
   beta.d[1]<-0
   beta.d.alt[1]<- -mean(beta.d[])
}
```

Appendix B: Land cover categorization scheme

Major Classes - first number is Level 1, second number is Level 2, third number is Level 3, and fourth number is Level 4. We have a Grass type that is level 5. Classes to be identified statewide (primarily Level 3) with Landsat satellite imagery classification are underlined. Number in parentheses following classification name is the grid value.

Group1 – Developed

1 Urban
- 11 <u>**Low Intensity Urban**</u> **(1)**
- 12 High Intensity Urban
  - **121** <u>**Airports**</u> **(3)**
  - **122** <u>**Road/Parking Lot**</u> **(4)**
  - **123** <u>**High Intensity Urban**</u> **(2)**
  - **350** <u>**Parks/Golf Courses**</u> **(13)**

Group 2 - Agriculture

2 Agricultural
- 21 Herbaceous Agriculture
  - 211 Cropland
    - **2111** <u>**Non-vegetated Farmland**</u> **(5)**
    - **2112** <u>**Row crops**</u> **(6)**
    - **2113** <u>**Forage crops**</u> **(7)**
    - 2114 Other Cropland
  - 212 Non-tilled Herbaceous Agriculture
- 22 Non-Herbaceous Agriculture
  - **222** <u>**Orchards/Vineyards/Nursery**</u> **(9)**

7 Bare/Sparsely Vegetated
- **710** <u>**Sand/Soil**</u> **(31)**
- **720** <u>**Exposed Rock**</u> **(32)**
- **730** <u>**Mud Flats**</u> **(33)**
- **790** <u>**Other Bare/Sparsely Vegetated**</u> **(35)**

Group 3 – Upland Nonforested

3 Upland Openland
- **330** <u>**Low Density Trees**</u> **(12)**
  - 3301 Low Density Deciduous Trees

3302 Low Density Conifer Trees
3303 Mixed Low Density Trees

320 **<u>Upland Shrub</u> (12)**

3201 Sweet Fern
3202 Autumn Olive/Honeysuckle
3203 Upland Blueberry
3204 Mast Producing Shrub
3205 Mixed Upland Shrub

310 **<u>Herbaceous Openland</u> (10)**

3101 Poverty Grass, Cladonia
3102 Grass
- 31021 Warm Season Grass
- 31022 Cool Season Grass

3103 Rubus-Fern
3104 Degraded
3105 Mixed Upland Herbaceous

4 Upland Forest
- 41 Upland Deciduous Forest

Group 4 – Northern Hwd and Mixed

411 **<u>Northern Hardwood</u> (14)**

4110 Sugar Maple Association
4111 S. Maple, Hard Mast Association
4112 Maple, Beech, Cherry Association
4113 R. Maple, Conifer
4114 Beech, Hemlock
4115 Y. Birch, Hemlock NH
4116 Mixed N. Hardwood – Aspen
4117 Mixed N. Hardwood - Pine
4119 Mixed Northern Hardwoods

414 **<u>Other Upland Deciduous</u> (17)**

4141,2,… Single Species e.g. Birch

419 **<u>Mixed Upland Deciduous</u> (18)**

4190 Mixed Upland Deciduous with Cedar
4191 Mixed Upland Deciduous w/ Conifer
4192 Mixed Southern Upland Deciduous
4193 Birch, Aspen
4199 Other Mixed Upland Deciduous

43 **<u>Upland Mixed Forest</u> (22)**

4310 Pine, Oak Mix
4311 Pine, Aspen Mix
4312 Hemlock, Mixed Deciduous
4319 Mixed Upland Forest

Group 5 – Oak

412 **<u>Oak Types</u> (15)**

4120 Oak, Hickory
4121 Oak, Aspen
4122 Oak, Pine
4123 Red Oak
4124 Red with White Oak
4125 Black, N. Pin Oak
4126 White, Black, N. Pin Oak
4129 Mixed Oak

Group 6 - Aspen

413 **<u>Aspen Types</u> (16)**

4130 Aspen
4131 Aspen, Oak
4132 Aspen, Jack Pine
4133 Aspen, Mixed Pine
4134 Aspen, Spruce/Fir
4135 Aspen, Cedar
4136 Aspen, Mixed Conifer
4137 Aspen, Birch
4139 Aspen, Mixed Deciduous

Group 7 - Pine

42 Upland Coniferous Forest

42(1,2) **<u>Pine Types</u> (19)**

* Planted vs. Natural Pines will NOT be distinguished statewide at level 3;
separate 3 digit numbering for each is for convenience NOT classification

421 Planted Pines*

42100 Planted White Pine
42101 Planted White Pine, Mixed Deciduous
42110 Planted Red Pine
42111 Planted Red Pine, Mixed Deciduous
42120 Planted Jack Pine
42121 Planted Jack Pine, Mixed Deciduous
42130 Planted Scotch Pine
42140 Planted Mixed Pine
42141 Planted Mixed Pine, Mixed Deciduous
42150 Strip Planted Pine

422 Natural Pines*

42200 Natural White Pine
42201 Natural White Pine, Mixed Deciduous
42210 Natural Red Pine
42211 Natural Red Pine, Mixed Deciduous
42220 Natural Jack Pine
42221 Natural Jack Pine, Mixed Deciduous
42250 Pine, Oak
42260 Natural Pine, Mixed Deciduous
42290 Natural Mixed Pine

423 **Other Upland Conifers (20)**

42300 Planted Larch
42301 Planted Larch, Mixed Deciduous
42310 Planted Spruce
42311 Planted Spruce, Mixed Deciduous
42320 Upland Spruce
42330 Upland Fir
42340 Upland Spruce/Fir
42350 Upland Hemlock
42360 Upland Cedar
42370 Upland Cedar, Aspen
42380 Non Pine Upland Conifer, Mixed Deciduous
42390 Mixed Non-Pine Upland Conifers

429 **Mixed Upland Conifers (21)**

Group 8 – Forested Wetland

61 Lowland Forest

611 **Lowland Deciduous Forest (24)**

6110 Cottonwood
6111 Lowland Balsam Poplar
6112 Lowland Aspen
6113 Lowland Maple
6114 Lowland Oak
6115 Lowland Ash
6116 Lowland Birch
6117 Lowland Deciduous, Mixed Coniferous
6118 Lowland Deciduous with Cedar
6119 Mixed Lowland Deciduous Forest

612 **Lowland Coniferous Forest (25)**

6120 Lowland Cedar
6121 Tamarack
6122 Black Spruce
6123 Lowland Fir
6124 Lowland Spruce-Fir
6125 Lowland Black Spruce, Jack Pine
6126 Lowland Jack Pine

6127 Lowland Pine
6128 Lowland Coniferous, Mixed Deciduous
6129 Mixed Coniferous Lowland Forest

613 **Lowland Mixed Forest (26)**

6130 Fir, Aspen, Maple
6131 Hemlock, White Pine, Maple, Birch
6132 Mixed Lowland Forest with Cedar
6139 Mixed Lowland Forest

Group 9 - Nonforested Wetland

62 Nonforested Wetlands

621 **Floating Aquatic (27)**

622 **Lowland Shrub (28)**

6220 Alder/Willow
6221 Fen
6222 Shrub-Carr
6223 Inundated Shrub Swamp
6224 Treed Bog
6225 Bog
6229 Mixed Lowland Shrub

623 **Emergent Wetland (29)**

6230 Cattail
6231 Phragmites
6232 Wet Prairie
6233 Wet Meadow
6239 Mixed Emergent Wetland

629 **Mixed Non-forest Wetland (30)**

Appendix C: FCC Michigan road classification scheme

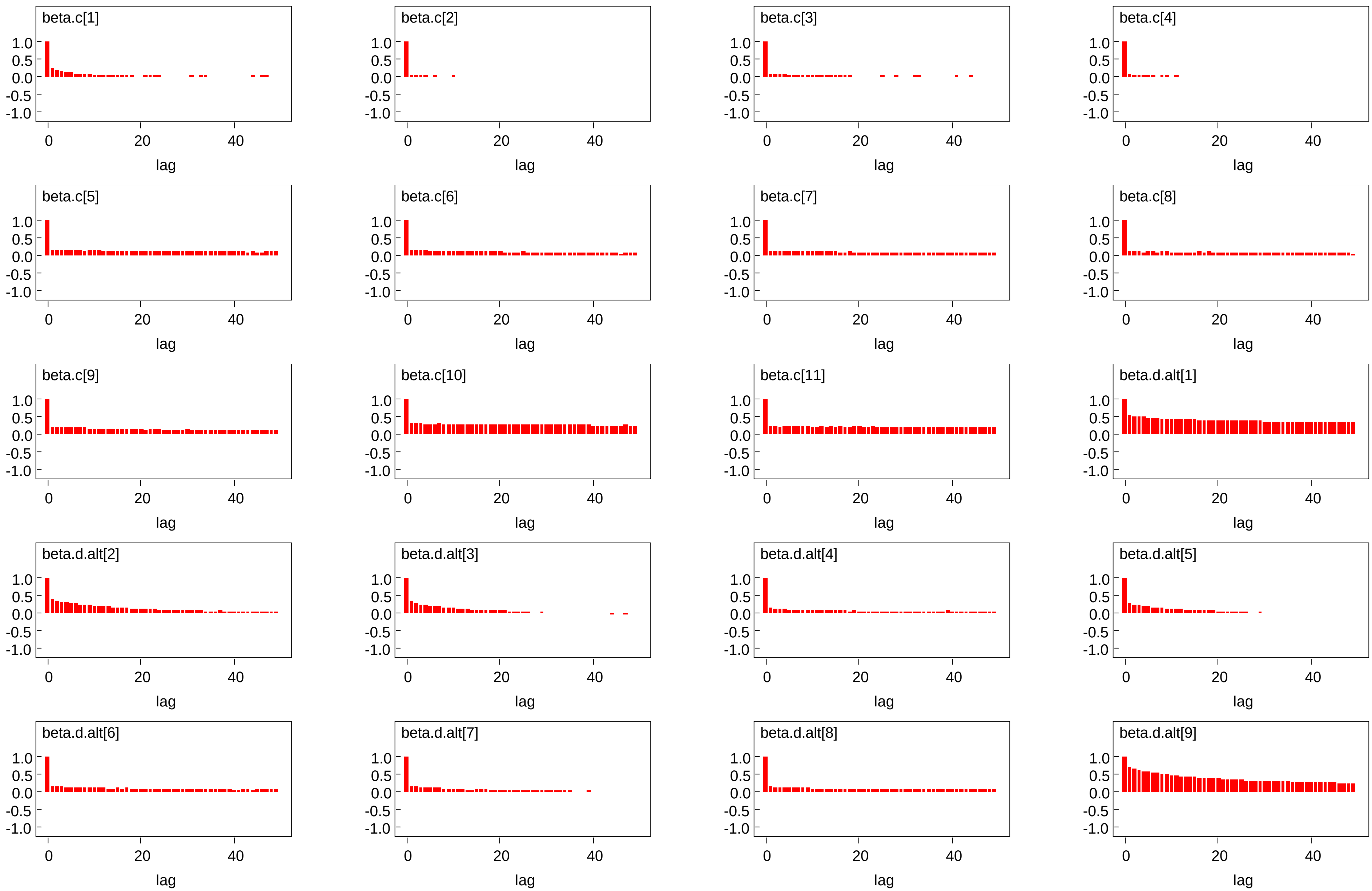
Class 1:
A1* – all limited access hwys
A2* – truckline not limited access
A31 – Primary Arterial roads

Class 2:
A32 – Minor Arterial roads
A33 – Local roads
A4* – Non-Certified roads
A61 – Unnamed, non PR (Physical Road Number) roads within Cemeteries
A62 – Unnamed, non PR internal drives around malls, commercial sites, retail sites, industrial sites, office sites, schools, colleges, and universities
A63 – Unnamed, non PR driveways. A driveway is defined as a road that serves only one residence
A65 – Unnamed, non PR roads in residential areas. IE: apartment complexes, mobile home communities, and new developments.

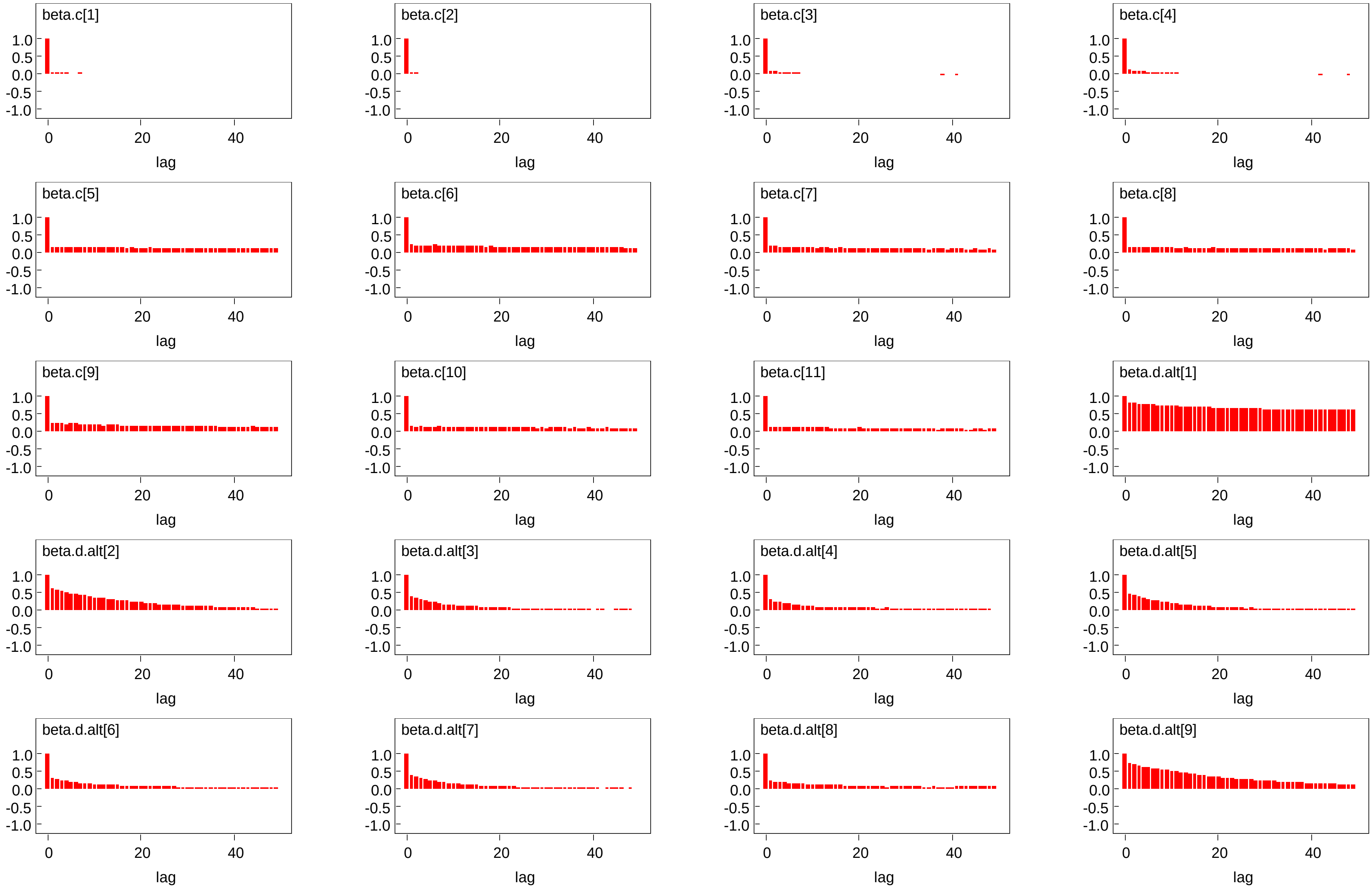
Class 3:
A45 – Forest roads within federal jurisdiction
A64 – Internal roads of Federal, State and Local parks and campgrounds.
A66 – Unnamed, non PR two-track roads or vehicular trails.
A69 – All other features that were originally classified as a road feature in TIGER or MIRIS but do not match any of the criteria used to classify framework roads. More research is needed to better classify these roads
A71 – General Trails or Paths
A72 – Rail-to-trail
A90 – Certified road right-of-ways. These roads are owned by a local jurisdiction (Act 51 certified), but are not drivable
A91 – Road whose existence is strongly questioned, but have not been confirmed as not existing by a local jurisdiction

Appendix D: Covariate autocorrelations

Male 3km: All covariate plots are in the same order as they are in tables 4, 5, and 6.

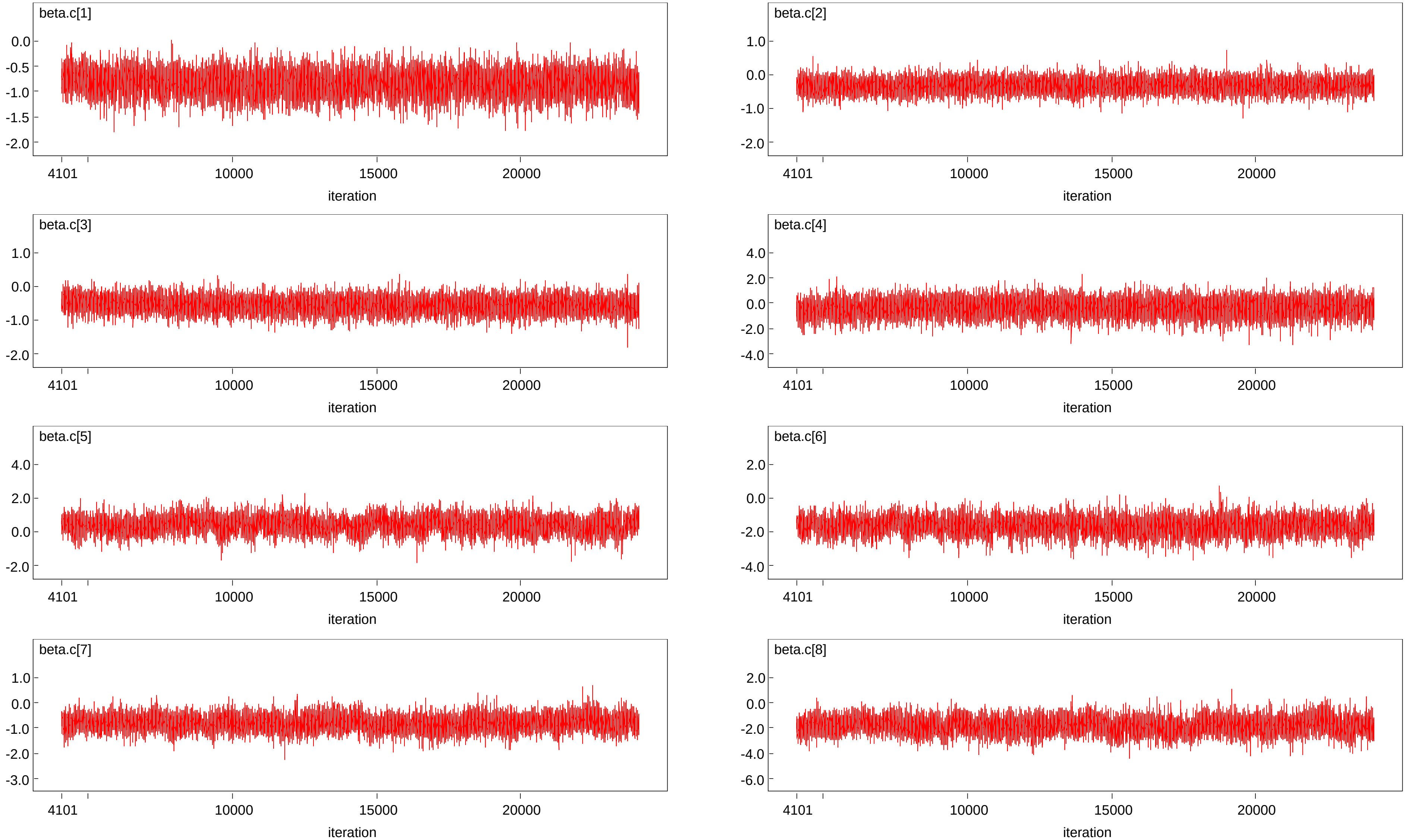


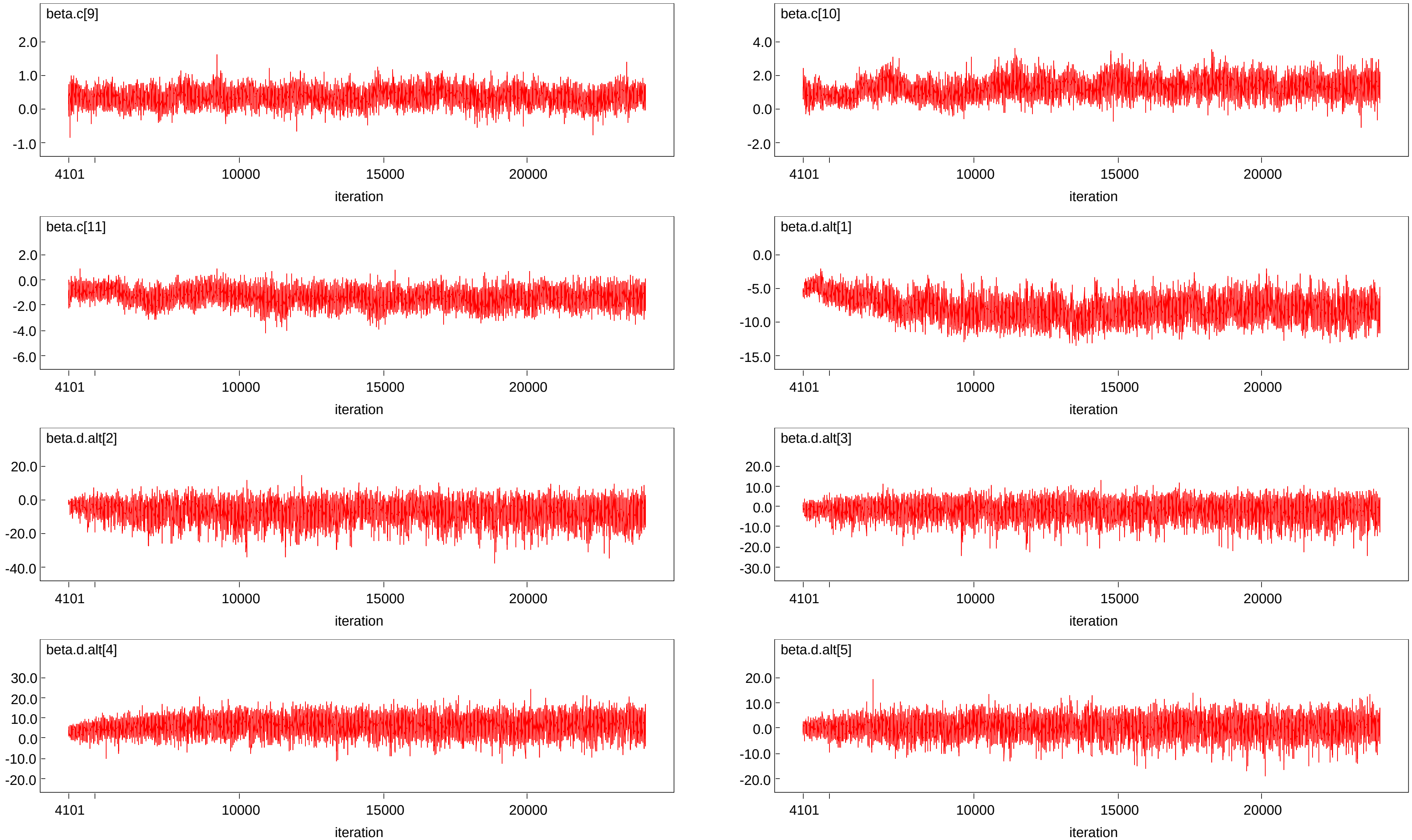
Female 2km: All covariate plots are in the same order as they are in tables 4, 5, and 6.



Appendix E: Covariate history plots

Male 3km: All covariate plots are in the same order as they are in tables 4, 5, and 6.

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1.0
0.0
-1.0
4101
10000
15000
20000
iteration
beta.c[10]
4.0
2.0
0.0
-2.0
4101
10000
15000
20000
iteration
beta.c[11]
2.0
0.0
-2.0
-4.0
-6.0
4101
10000
15000
20000
iteration
beta.d.alt[1]
0.0
-5.0
-10.0
-15.0
4101
10000
15000
20000
iteration
beta.d.alt[2]
20.0
0.0
-20.0
-40.0
4101
10000
15000
20000
iteration
beta.d.alt[3]
20.0
10.0
0.0
-10.0
-20.0
-30.0
4101
10000
15000
20000
iteration
beta.d.alt[4]
30.0
20.0
10.0
0.0
-10.0
-20.0
4101
10000
15000
20000
iteration
beta.d.alt[5]
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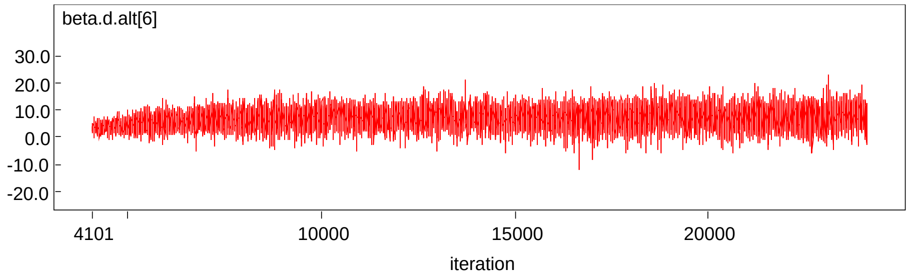
10.0
0.0
-10.0
-20.0
4101
10000
15000
20000
iteration


beta.d.alt[6]
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10.0
0.0
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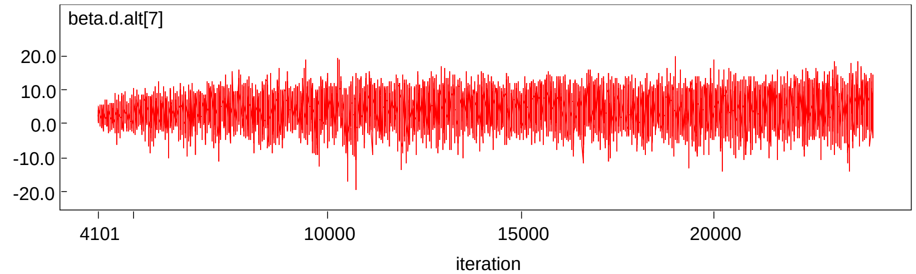
-20.0
4101
10000
15000
20000
iteration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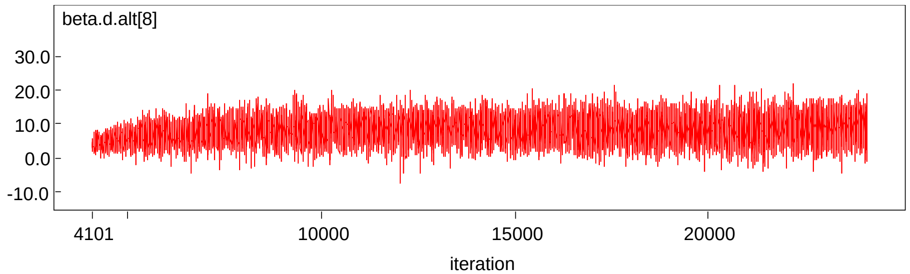
-20.0
4101
10000
15000
20000
iteration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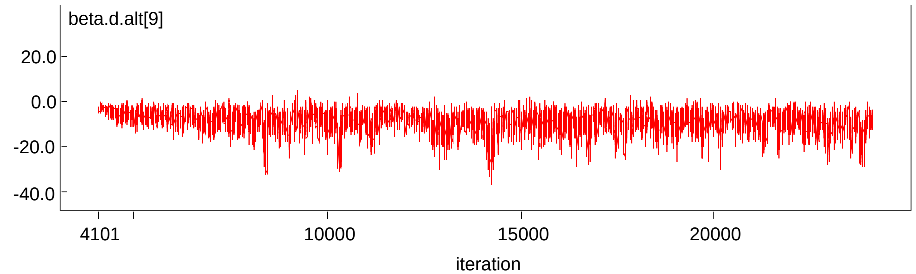
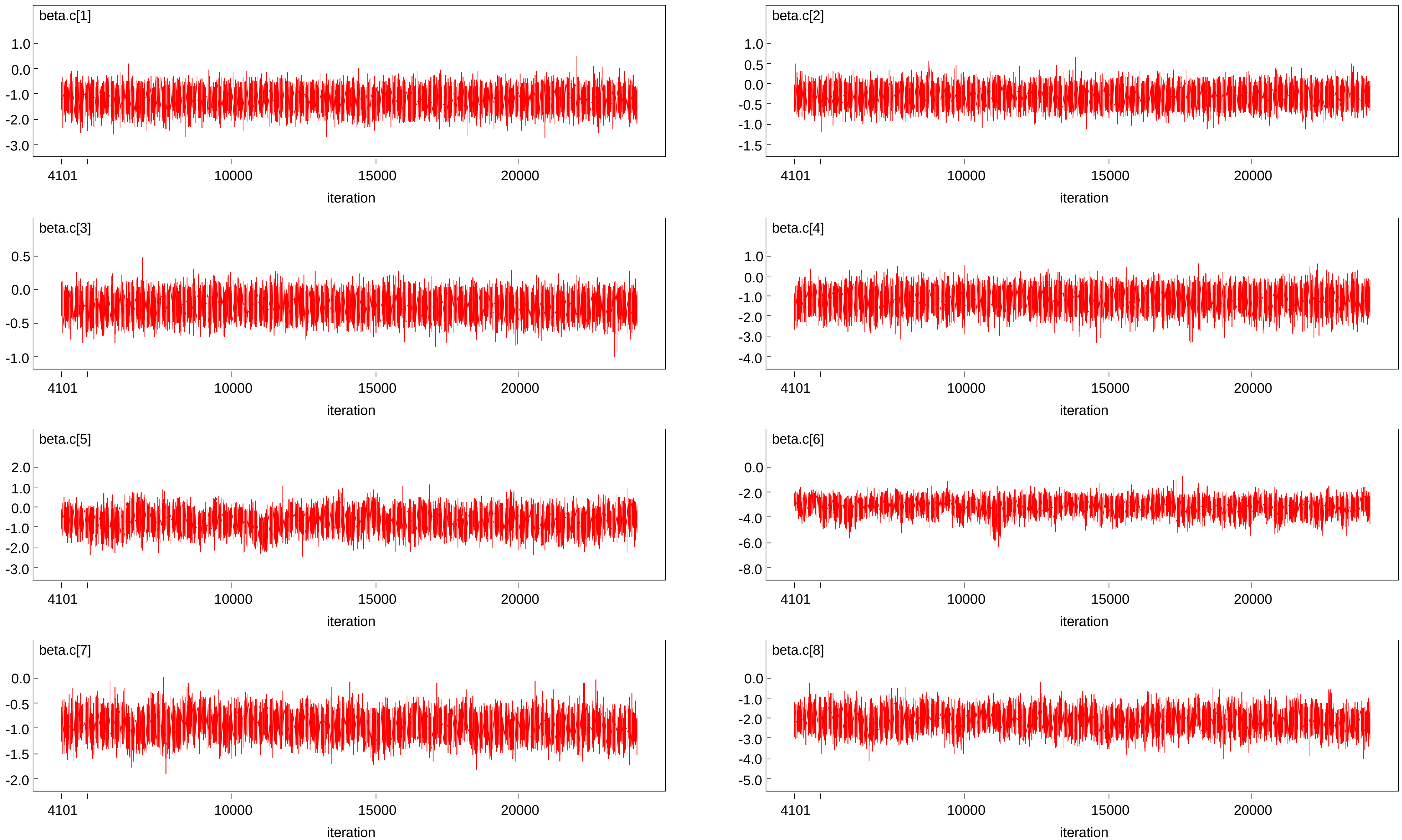
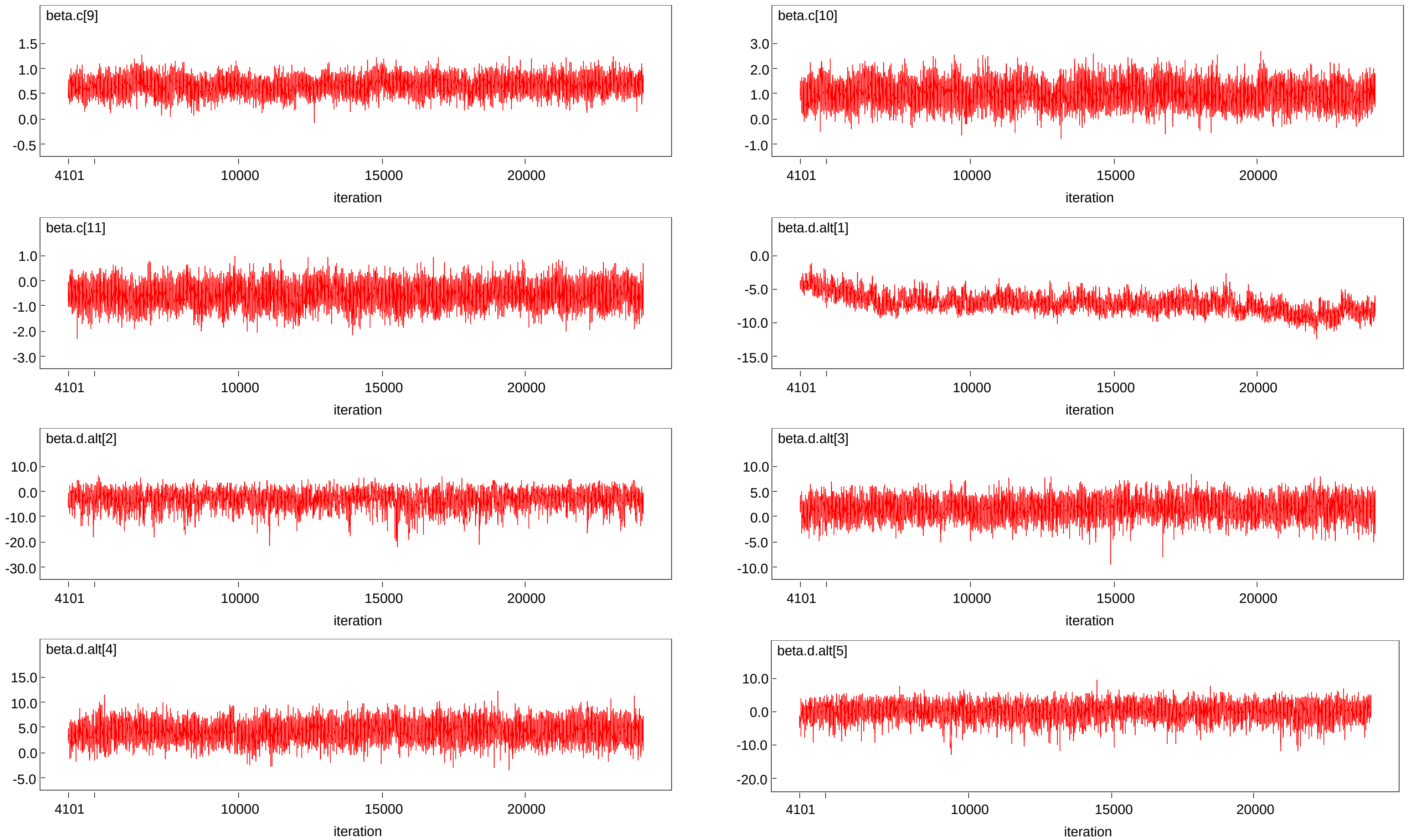
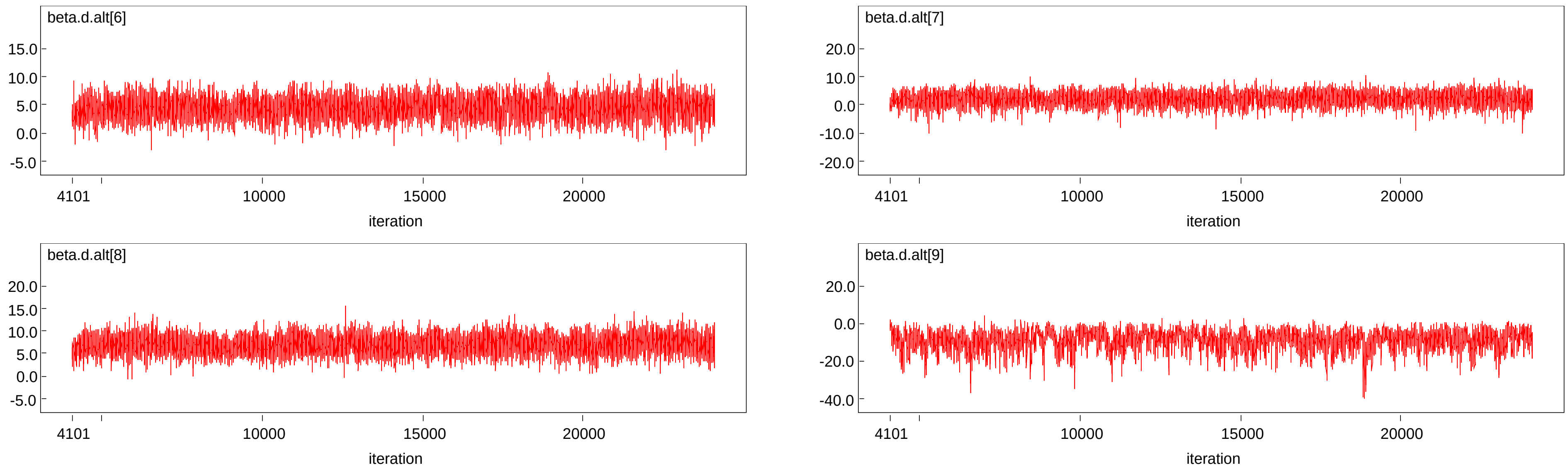
10000
15000
20000
iteration


beta.d.alt[9]
20.0
0.0
-20.0
-40.0
4101
10000
15000
20000
iteration

Female 2km: All covariate plots are in the same order as they are in tables 4, 5, and 6.




beta.c[9]
1.5
1.0
0.5
0.0
-0.5
4101
10000
15000
20000
iteration
beta.c[10]
3.0
2.0
1.0
0.0
-1.0
4101
10000
15000
20000
iteration
beta.c[11]
1.0
0.0
-1.0
-2.0
-3.0
4101
10000
15000
20000
iteration
beta.d.alt[1]
0.0
-5.0
-10.0
-15.0
4101
10000
15000
20000
iteration
beta.d.alt[2]
10.0
0.0
-10.0
-20.0
-30.0
4101
10000
15000
20000
iteration
beta.d.alt[3]
10.0
5.0
0.0
-5.0
-10.0
4101
10000
15000
20000
iteration
beta.d.alt[4]
15.0
10.0
5.0
0.0
-5.0
4101
10000
15000
20000
iteration
beta.d.alt[5]
10.0
0.0
-10.0
-20.0
4101
10000
15000
20000
iteration


beta.d.alt[6]
15.0
10.0
5.0
0.0
-5.0
4101
10000
15000
20000
iteration
beta.d.alt[7]
20.0
10.0
0.0
-10.0
-20.0
4101
10000
15000
20000
iteration
beta.d.alt[8]
20.0
15.0
10.0
5.0
0.0
-5.0
4101
10000
15000
20000
iteration
beta.d.alt[9]
20.0
0.0
-20.0
-40.0
4101
10000
15000
20000
iteration