

**BLACK BEAR DENSITY DEPENDENT POPULATION REGULATION,
GROWTH, AND DEN SITE SELECTION IN NORTHERN WISCONSIN**

BY

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A Thesis

**submitted in partial fulfillment of the
requirements of the degree**

MASTER OF SCIENCE

IN

**NATURAL RESOURCES
(WILDLIFE)**

College of Natural Resources

UNIVERSITY OF WISCONSIN

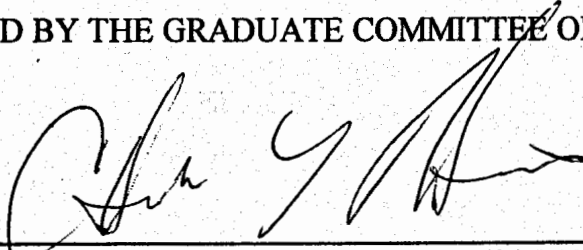
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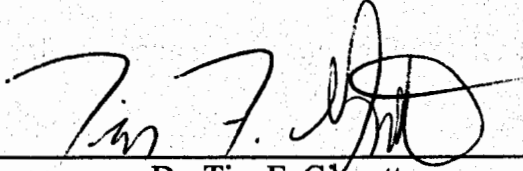
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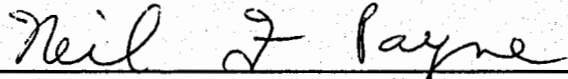
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PREFACE

The chapters of this thesis were written in the format of the Journal of Wildlife Management. Any duplication in methods or citations between chapters is intentional. Each of the three chapters is designed for easier editing before submission to a journal for publication.

ACKNOWLEDGEMENTS

This study was just part of an ongoing project begun by the late R. K. Anderson, whose foresight and dedication contributed to this project. Numerous UWSP graduate students collected the data analyzed in this thesis, and I thank them for their meticulous and detailed notes and theses.

I thank N. F. Payne and B. E. Kohn for their willingness to serve on my committee and teach and mentor me through this process. B. E. Kohn helped in field work and made me feel welcome in the northwoods. C. L. Thomas gave me the opportunity to pursue my degree and refused to let the work of Dr. Anderson die. T. F. Ginnett provided unending help throughout the entire process, including statistical guidance and frequent manuscript reviews.

The field crews that helped during winter den visits were essential to the continuity of this project, and I thank them for their willingness to volunteer their time and manpower to the project. A. Pratt and B. Prentice provided continual and invaluable help in den processing and immobilization. I thank B. Lemon and the members of the Whiskey Jack Camp for their support of this project and their gracious hospitality.

M. Ludwig's involvement was invaluable to the past successes and long term continuity of this project. Her logistical capabilities are important each winter, and she made me feel welcome from the first day I came on board.

I thank my family for their prayers and support throughout my graduate career. I thank my fellow graduate students who provided advice and support. F. Fawcett provided frequent advice and help with GIS.

Funding for this project came from: McIntire-Stennis Cooperative Research Fund, Safari Club International, Safari Club International-Madison Chapter, Safari Club International-Wisconsin Chapter, Wisconsin Bear Hunters Association, Whiskey Jack Camp, University of Wisconsin-Stevens Point, Ashland High School, and the Wisconsin Department of Natural Resources.

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INTRODUCTION AND BACKGROUND INTO BLACK BEAR BIOLOGY

Research often focuses on species of obvious social concern or harvest importance. One species that has received extensive study over the years is the black bear (*Ursus americanus*). Early studies focused mainly on the natural history or vital statistics of black bears and their populations. Some of these topics include fecundity, feeding habits, home range size, habitat selection, mortality rates/causes, litter size, population density, denning biology, diel movements, and population and individual responses to hunting pressures.

Management issues surrounding black bears are dominated by harvest potentials, population estimation, and nuisance events. Other issues include techniques for capturing, immobilizing, and tracking black bears. The most useful method of determining black bear population dynamics and demographic and natural history parameters is radio-telemetry. Many studies collar individuals for more accurate estimates of home range size, movement patterns, and habitat preferences. The monetary and time costs of telemetry studies limit both the size and scope of such an analysis. As a result, most black bear telemetry studies occur over at least 2 years, with intensive location and observation during that period. Some studies deal with a large sample size, but then only run the study for a few years. Few researchers have examined data from black bears that have been collared for a large part of their lives. Data obtained from such research could provide valuable information on long-term trends in population dynamics that would not be recognizable in a short-term study.

This thesis focuses on 3 aspects of black bear biology. The first chapter following the introduction focuses on the role of density-dependent mechanisms in regulating population size on Stockton Island, Wisconsin. The second chapter models several aspects of black bear growth and development. The third chapter identifies habitat-level factors that are important to black bears in den site selection.

The scope of knowledge regarding black bears is broad, covering numerous topics and geographical regions. Information regarding home range characteristics, reproductive biology, and population dynamics comes from across North America, covering most of the types of habitats that black bears occupy. The following section summarizes the important findings of these studies. This review of the literature covers the broad scope of these studies, comparing and contrasting regional differences and analyzing each for its applicability to a northern Wisconsin ecosystem.

Home Range and Preferred Habitat Characteristics

Home range is defined as the area used by an animal during its normal activities of foraging, breeding, traveling, and reproducing (Burt 1943). The home range size of black bears throughout their North American range is well known. Home range size differs between male and female black bears. Home range size averaged 119 km² for males and 7.5 – 19.6 km² for females in Alberta (Fuller and Keith 1980; Young and Ruff 1982). In Idaho, home range averaged 112.1 km² for adult males and 48.9 km² for adult females (Amstrup and Beecham 1976). Home range size also differs with age; yearlings have smaller ranges than subadults of the same sex (Amstrup and Beecham 1976). Kessler (1994) attributed a smaller home range for adults than subadults to the inefficient feeding behaviors of subadults.

Home range size reported for black bears in Wisconsin varies considerably. Home range sizes on Stockton Island were smaller than any other in the literature (Trauba 1996). Males averaged 32.9 km² and females 7.2 km². In northern Wisconsin, home ranges averaged 93.0 km² for males and 18.8 km² for females (Massopust 1984). Elsewhere in Wisconsin, male home ranges averaged 71.2 km²; female home ranges averaged 13.7 km² (Kohn 1982). Females have a smaller home range than males for 3 reasons. Males are larger and require larger areas for feeding. Males have large ranges during breeding season to increase their likelihood of meeting females that are in estrus (Massopust 1984). Females need to care for young that are incapable of covering large areas during their daily routines. Amstrup and Beecham (1976) hypothesized that female black bears with cubs occupy areas that are just large enough for adequate nutrition.

Factors other than sex and age determine home range size. Quality, quantity, and distribution of food affected home range size (Amstrup and Beecham 1976). The better the food quality and abundance, the smaller the home range size. On Stockton Island, smaller home ranges of black bears were attributed to high habitat quality (Trauba 1996). The beaver flowages of Stockton Island were choice habitat, and almost every bear had one as the center of its home range. Also limiting home range size on Stockton Island was the density of bears. Density there (0.76 bears/km²; Fleming 1997) was among the highest reported in the literature, but not as high as on Long Island in Willapa Bay, Washington, where density was 1.76 bears/km² (Lindzey and Meslow 1977). High density means each bear has less area available in which to feed, travel, and den.

Home Range Shape

Home range shape and overlap also vary by location. The linear nature of Stockton Island and its relatively small size (40.7 km²) defined home range shape for male black bears. The larger ranges of males tended to cover the entire island, and they were generally linear. Females, whose home ranges were not limited by the size of the island, generally had a non-linear home range shape. Home range shape is not well reported in the literature. Amount of overlap between home ranges varies by bear density, sex, and habitat quality. Females tend to be more exclusive than males, with less home range overlap with other bears (Young and Ruff 1982, Trauba 1996). Amstrup and Beecham (1976) found a 70-84% home range overlap and concluded that black bears have high intraspecific tolerance, whereas Lindzey and Meslow (1977) found a high degree of avoidance behavior in populations of high density.

Habitat Use

Habitat use by black bears can be classified into 3 general categories: transit, foraging, and resting (Massopust 1984). Transit habitats are used when moving between foraging and resting habitats, and were characterized by an open understory and good horizontal visibility. Foraging habitats naturally contained both abundant and diverse food sources, and were usually mid-successional. Resting habitat contained dense cover and cool air, like that found in conifer swamps of northern Wisconsin. Norton (1981) combined transit and resting in Wisconsin into one category: shelter-travel. Payne et al. (1998) identified monthly food availability in specific habitat types in Wisconsin. Bertagnoli (1986) compared foods eaten by Wisconsin black bears to foods available in habitat types described by Curtis (1959).

Landers et al. (1979) divided black bear habitat types in North Carolina into foraging, denning, and escape. Foraging habitats were used from den emergence until den entry, but changed from spring and summer to fall. Carolina bays were used from emergence to July, and hardwood swamps and sand ridges were chosen as foraging habitats during late fall. Denning habitats were usually in large, impenetrable bays and swamps that provided protection from disturbance. Researchers found escape cover to be the most important habitat type for black bear survival; it usually comprised hardwood swamps with dense vegetation and water.

Actual cover types that fit these categories as prime habitat vary geographically. On Stockton Island, beaver flowages provided all 3 habitat requirements and were preferred by most bears, although other forested areas were used as well (Trauba 1996). In northern Wisconsin, forest openings and aspen (*Populus* spp.)-balsam (*Abies balsamea*) mixtures provided good food production, and northern hardwoods were used for shelter and travel (Norton 1981, Bertagnoli 1986, Payne et al. 1998). Aspen, alder (*Alnus* spp.), swamp conifer, northern hardwoods, and swamp hardwoods were all used by black bears in northern Wisconsin (Kessler 1994, Payne et al. 1998). Bears in east-central Alberta seemed to prefer aspen stands, while using aspen/spruce (*Picea* spp.) and spruce areas as well. Muskegs appeared to be avoided by black bears (Young and Ruff 1982). Important cover types in the southeast United States were pocosin (year-round) and hard and soft mast-producing areas in the fall. Roads and disturbed areas also appeared important, apparently being used as travel corridors (Hellgren and Vaughan 1991), unlike in Idaho where bears avoided roads during all seasons and for all uses except

feeding (Unsworth et al. 1989). Females in their study preferred upland timber, riparian areas, and aspens while avoiding meadows, clear cuts, and sagebrush (*Tridentata* spp.).

Reproductive Biology

Many aspects of reproduction in black bears appear to point to food quality and bear density as determining factors. Age of primiparity declines as population density increases. In a relatively undisturbed population in Montana, little successful reproduction was observed before age 6 (Kasworm and Thier 1994). Average age of primiparity was 5.9 years in Alaska (Miller 1994), 5.0 years on Stockton Island (Trauba 1996), 4.6 years in the southern Appalachians (Eiler et al. 1989), and 4.0 years in North Carolina (Hellgren and Vaughan 1989).

Litter Size and Pregnancy Rate

Litter size and pregnancy rate seem to be closely related to nutritional status of the female, which in turn reflects the food abundance and quality that year (LeCount 1982, Eiler et al. 1989). Average litter sizes reported in the literature range from 3.0 (Massopust 1984), 2.4 (Kohn 1982), and 2.92 (Kessler 1994) in high quality habitat in Wisconsin, to 2.3 in Alaska (Miller 1994) and 2.6 in Montana (Eiler et al. 1989), to lows of 1.75 in northwest Montana (Kasworm and Thier 1994) and 1.9 in an unexploited black bear population in Arizona (LeCount 1982).

Another reproductive factor strongly influenced by bear density and yearly food production is pregnancy rate, i.e. the interval between successive litters. In exploited or low density populations, the average interval between litters is 2 years (McLean and Pelton 1994). In this case, females produce a litter one winter, den with

the yearlings the next winter, and then produce a new litter the next year. In a high density, stable structured population, or when food availability is low, the interval between litters can be as high as 3.2 years (Kasworm and Thier 1994), and results in a reproductive rate of 0.51 cubs/female/year.

Population Dynamics

Population dynamics refers to the changes in population level parameters as well as the regulating methods of a population; this includes survival, mortality, dispersal, age structure, intraspecific interactions, population growth, and population density. Perhaps the most important factor is density. Density is regulated by habitat quality, home range sizes and overlap, and human acceptance of the species. In an un hunted population on Stockton Island, density reached a high of 0.59 bears/km², at which point the population began to decline because of density-dependent regulating mechanisms (Trauba 1996). Young and Ruff (1982) reported data that indicate adult male abundance likely limits population density. They observed an initial density of 0.37 bears/km² and then removed some of the adult males, which resulted in an increase in density to 0.625 bears/km². Potential problems in density estimates (Garshelis 1994) led to a reanalysis of the data. Sargeant and Ruff (2001) concluded that local population density was limited by the presence of adult males, but no conclusions regarding density-dependence could be drawn. Density-dependence continues to be difficult to observe in natural populations. As a population approaches carrying capacity, 1 or more regulating mechanisms will begin to limit population growth. For black bears, these can include increased age at primiparity, decreased litter size, and decreased survival of cubs and subadults (Taylor 1994).

Numerous confounding factors often mask these mechanisms. As a result, no study has adequately demonstrated density-dependence in a black bear population (Garshelis 1994).

Survival

Black bear survival rates seem to depend strongly on local factors such as hunting pressure and population density. Trauba (1996) found adult and subadult survival rates to be near 1.0 in an un hunted population on Stockton Island. In northwest Montana the adult survival rate was 0.75 (Kasworm and Thier 1994). Most of the causes of mortality were hunting related. Based on a model incorporating litter size, age of primiparity, and interval between litters, this population could sustain an annual mortality rate of only 0.12, which means the population was declining based on model estimates (Kasworm and Thier 1994). In the southern Appalachian Mountains, the cub mortality rate of 0.379 was related most strongly to mast production, which in turn affected the mother's nutritional health (Eiler et al. 1984). In northern Wisconsin, survival rates were 0.69 for cubs and 0.33 for yearlings (Trauba 1996). The dominant mortality source for cubs and yearlings was cannibalism by mature black bears. Trauba (1996) suggested that intraspecific killings were regulating this population in a density-dependent fashion. Working with an unexploited population, LeCount (1982) observed a cub survival rate of 0.48; cannibalism was the main mortality factor. Kessler (1994) calculated a yearling survival rate of 0.89-0.94 for a population of black bears in northern Wisconsin, indicating low population stress, high nutrition, and low climatic impact. In northern Wisconsin, cub survival (0.45) was lowest in an un hunted population, mainly due to

cannibalism; subadult survival (0.29) was lowest in a hunted population, mainly due to hunting mortality (Fleming 1997). Also in Wisconsin, hunting was the major cause of death of marked bears, accounting for 94 of 100 known mortalities; harvest mortality was 16%, overall annual mortality was 27%, with male mortality greater than female mortality (Kohn 1982). Mortality rates in the Great Dismal Swamp in North Carolina of 0.87 for females older than 1.5 years and 0.59 for males older than 2.5 years reflected "unnatural" mortality causes almost exclusively, including vehicle collisions, legal and illegal harvest, and research (Hellgren and Vaughan 1989).

In general, it appears that unexploited populations experience higher cub mortality and lower adult mortality than exploited populations. The former is related to nutrition and intraspecific predation and the latter to lack of natural predators and other sources of mortality. Exploited populations tend to exhibit higher subadult and adult mortality due exclusively to legal and illegal harvest. These populations do not experience the same amount of density dependent competition and predation that are more common in high density, unexploited, stable populations.

Population Age Structure

The age structure of a black bear population has important implications for its growth and harvest rates. A stable population in Arizona was dominated by adults at least three years old, which made up 70% of the population (LeCount 1982). In the pre-removal population in Alberta, age structure was dominated (40%) by bears >6 years old. Following removal of some of the adults, the number of 2- and 3-year-olds climbed to 50%. The researchers concluded that adult males had limited the immigration of subadults, so after removal of adults, the number of subadults rose

dramatically (Young and Ruff 1982). In Wisconsin, 68% of all harvested males and 48% of harvested females were 1-3 years old (Kohn 1982). The age structure was relatively stable, with fluctuations related to increased productivity rather than increased harvest mortality (Kohn 1982).

Dispersal

Rates of dispersal by yearling and subadult bears seem to be influenced by population density (Kessler 1994). LeCount (1982) lost track of 68% of subadults from one year to the next, indicating a high dispersal rate. Dispersal among yearlings in northern Wisconsin occurred from mid-May to June, but many returned to their former ranges to den the following winter. The average dispersal distance was 36 km (Kessler 1994). Both the density of the population that is left and the density of the population being entered regulate rates of dispersal (Young and Ruff 1982).

Population Growth

Little data exist on black bear population growth. McLean and Pelton (1994) calculated an intrinsic rate of increase, r , of 0.054 for data collected over 20 years for bears in the Great Smoky Mountains National Park (GSMNP). This indicates that the population was only slightly increasing. Based on projected population estimates using model simulations, the population in GSMNP may increase exponentially (with continually good mast) or decline to near extinction (with bad mast in all years). Thus, knowing the future abundance of the food supply helps to predict future population size. In Shenandoah National Park, $r = 0.000$ (Carney 1985) and in Great Dismal Swamp, Virginia, $r = 0.0032$ (Hellgren 1988). This limited information is evidence that black bear populations grow slowly, many are at or near carrying

capacity, and many achieve a stationary population size and stable age structure, as indicated by r values at or near zero. Also, the data show the large impact of nutrition on black bear population growth and individual survival. Managing black bear habitat is more important than managing the population itself.

Individual Black Bear Characteristics

Individual growth is directly related to the amount and quality of available food, but variation exists between sexes. Norton (1981), Bertagnoli (1986), and Payne et al. (1998) found that black bears in northern Wisconsin lost weight in spring and early summer, a time when they are consuming grasses and other greens. Males lost more weight than females during this period, possibly due to the stress of breeding activity. Weight gain occurs once mast and fruit crops become available. For the first 6.5 years of life, males added 30% and females 10% to their body weight, from one spring to the next. Overwinter weight loss is more dramatic in females due to reproduction. Females lost 40% of their weight and males 25% of their weight over winter. In Wisconsin, weight gains averaged 78% for females and 36% for males from May to August (Kohn 1982).

Movement

Black bear movement patterns change by the season. Bears are most active during breeding and foraging. Black bear movement is predominantly crepuscular in spring, diurnal in summer, and nocturnal in fall (Garshelis and Pelton 1980, Kessler 1994). Activity appears to be positively related to temperature, and snow cover decreases activity (Garshelis and Pelton 1980). Females tend to be more active than

males in spring and fall as they prepare for reproduction, and all bears are less active in years when food is abundant (Amstrup and Beecham 1976).

Denning Biology

The denning biology of black bears is fairly well described in the literature. In Wisconsin, black bears enter their dens during 10-25 October. Most dens are in windblown trees and excavated holes (Massopust 1984). Kessler (1994) reported slightly earlier denning dates (15 September-16 October), with den entrance related to mean weekly temperature. He found the following chronology of den entrance related to sex and age of the bears: Pregnant females, females with cubs, yearlings, and adult males. In southern latitudes, bears den later and leave earlier. In North Carolina, bears entered their dens in late December and emerged in late March (Landers et al. 1979). Bears in Idaho denned in October and November, and emerged in mid-late April (Amstrup and Beecham 1976). Bears in southern, old growth forests appear to prefer hollow trees (Weaver and Pelton 1994), while 66% of black bear dens in an Arkansas study were in rock cavities (Hayes and Pelton 1994).

Summary

The scope of research on black bear biology is broad. Studies from around North America have focused on black bear home range size, habitat preferences, denning biology, reproductive biology, and movement. The same is true for black bears in Wisconsin, where UW-Stevens Point students have documented these parameters. The major gaps in knowledge fall in the area of population dynamics. Most studies have not lasted long enough to address questions of changing age

structure, survival, and population growth adequately. Ongoing research through UW-Stevens Point has provided the data that allow for just such analyses.

LITERATURE CITED

AMSTRUP, S. C. AND J. BEECHAM. 1976. Activity patterns of radio-collared black bears in Idaho. *Journal of Wildlife Management* 40:340-348.

BERTAGNOLI, G. G. 1986. Availability and use of foods by black bears in Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.

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

CARNEY, D. W. 1985. Population dynamics and denning ecology of black bears in Shenandoah National Park, Virginia. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

CURTIS, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, Wisconsin, USA.

DENNIS, B. AND M. L. TAPER. 1994. Density dependence in time series observations of natural populations: Estimation and testing. *Ecological Monographs* 64:205-225.

EILER, J. H., W. G. WATHEN, AND M. R. PELTON. 1989. Reproduction in black bears in the southern Appalachian Mountains. *Journal of Wildlife Management* 53:353-360.

FLEMING, K. C. 1997. A demographic comparison of a hunted and an unhunted

- population of black bears in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- FULLER, T. K. AND L. B. KEITH. 1980. Summer ranges, cover-type use, and denning of black bears near Fort McMurray, Alberta. *Canadian Field Naturalist* 94:80-83.
- GARSHELIS, D. L. AND M. R. PELTON. 1980. Activity of black bears in Great Smoky Mountains National Park. *Journal of Mammalogy* 61:8-19.
- HAYES, S. G. AND M. R. PELTON. 1994. Habitat characteristics of female black bear dens in northwestern Arkansas. *International Conference on Bear Research and Management* 9:411-418.
- HELLGREN, E. C. 1988. Ecology and physiology of a black bear (*Ursus americanus*) population in Great Dismal Swamp and reproductive physiology in the captive female black bear. Dissertation, Virginia Polytechnical Institute and State University, Blacksburg, Virginia, USA.
- HELLGREN, E. C. AND M. R. VAUGHAN. 1989. Demographic analysis of a black bear population in the Great Dismal Swamp. *Journal of Wildlife Management* 53:969-977.
- _____ and _____. 1991. Macrohabitat use by black bears in a southeastern wetland. *Journal of Wildlife Management* 55:442-448.
- KASWORM, W. F. AND T. J. THIER. 1994. Adult black bear reproduction, survival, and mortality sources in northwest Montana. *International Conference on Bear Research and Management* 9:223-230.
- KESSLER, G. P. 1994. Black bear reproductive biology, denning biology, habitat

- use, and movements in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- KOHN, B. E. 1982. Status and management of black bears in Wisconsin. Technical Bulletin Number 129. Wisconsin Department of Natural Resources, Madison, Wisconsin, USA.
- LANDERS, J. L., R. J. HAMILTON, A. S. JOHNSON, and R. L. MARCHINTON. 1979. Foods and habitat of black bear in southeastern North Carolina. *Journal of Wildlife Management* 43:143-153.
- LECOUNT, A. L. 1982. Characteristics of a central Arizona black bear population. *Journal of Wildlife Management* 46:861-868.
- MASSOPUST, J. L. 1984. Black bear homing tendencies, response to being chased by hunting dogs, reproductive biology, home range, diel movements, and habitat use in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- MCLEAN, P. K. AND M. R. PELTON. 1994. Estimates of population density and growth of black bears in the Smoky Mountains. *International Conference on Bear Research and Management* 9:253-261.
- MILLER, S. D. 1994. Black bear reproduction and cub survivorship in south-central Alaska. *International Conference on Bear Research and Management* 9:263-273.
- NORTON, N. C. 1981. Food habits, growth, and cover types used by northern Wisconsin black bears. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.

PAYNE, N. F., B. E. KOHN, N. C. NORTON, AND G. G. BERTAGNOLI. 1998.

Black bear food items in northern Wisconsin. *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters* 86:263-280.

TRAUBA, D. R. 1996. Black bear population dynamics, home range, and habitat use on an island in Lake Superior. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.

UNSWORTH, J. W., J. J. BEECHAM, AND L. R. IRBY. 1989. Female black bear habitat use in west-central Idaho. *Journal of Wildlife Management* 53:668-673.

WEAVER, K. M. AND M. R. PELTON. 1994. Denning ecology of black bears in the Tensas River Basin of Louisiana. *International Conference on Bear Research and Management* 9:427-434.

WHITE, G. C. AND K. P. BURNHAM. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46 Supplement, 120-138.

YOUNG, B. F. AND R. L. RUFF. 1982. Population dynamics and movements of black bears in east-central Alberta. *Journal of Wildlife Management* 46:845-860.

6 October 2003
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RH: Density-dependence in black bears *Gesch et al.*

**DENSITY DEPENDENCE IN A NORTHERN WISCONSIN BLACK BEAR
POPULATION**

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ABSTRACT: We tested for evidence of density dependence in a population of black bears (*Ursus americanus*) on Stockton Island, WI, using data collected from 1984 to 1997. We tested for trends in litter size and cub and yearling weights over a range of densities (0.07 bears/km² – 0.76 bears/km²). Litter size declined as density increased, but cub and yearling weights appeared unaffected by density. Applying the Ricker stock-recruitment model, we estimated that maximum recruitment occurred at 0.21 bears/km². Survival rates were constant for both sexes over all years, and recapture rates differed by sex but not by year.

Key words: black bear, density-dependence, Ricker Stock Recruitment, Stockton Island, *Ursus americanus*

Density-dependence in wild animal populations is frequently hypothesized, but infrequently observed. In order for population growth to be reduced as the population approaches carrying capacity, one or more mechanisms that regulate population growth need to take effect. Some of these self-regulating mechanisms for black bears include increased age at primiparity, decreased litter size, decreased cub and subadult survival (Taylor 1994), and skipped breeding cycles. Numerous studies have attempted to demonstrate density-dependent regulation of North American black bear populations. But none has done so adequately (Garshelis 1994). The study providing the most support for density-dependent population regulation in black bears was begun by Kemp (1972, 1976) and continued by Young and Ruff (1982). In this study, density and survival were estimated before and after the removal of 23 adult males. When both density and percentage of subadults increased following removal, the researchers concluded that adult males were regulating population density by limiting subadult recruitment into the population. Garshelis (1994) noted that density estimates were biased and the conclusions were possibly erroneous, due to violated assumptions of the Lincoln-Petersen estimator. Reanalysis of the data showed a similar increase in density. But due to an arbitrarily delimited, small study area, the researchers concluded that only *local* population density was regulated by adult males; no inferences regarding density-dependence in the population were possible (Sargeant and Ruff 2001).

Other studies with apparent density-dependent regulation were confounded by density-independent factors, such as food availability (Lindzey and Meslow 1977) or male-biased sex ratios (Clark 1991). Furthermore, most black bear populations are too stable and methods of measuring population parameters are too imprecise to detect density-dependent regulation mechanisms adequately (Garshelis 1994). Study areas are also often arbitrarily delimited, making accurate population-level density estimates impossible. Sargeant and Ruff (2001) recommended reserving population status for disjunct groupings, eliminating the confounding effects of immigration and emigration and making birth and death the only important processes of population dynamics. Differences in methods and local conditions limit the usefulness of comparing studies from different regions when testing for density-dependence. As a result, the studies most capable of determining density-dependent effects would cover a broad range of densities and consist of disjunct populations.

The study on Stockton Island, Wisconsin fits both of these criteria. Research began in 1984 with the collaring of 2 adult bears and continued until 2001. Accurate density estimates for the island are available from 1984 to 1996. Bear densities during the study ranged from 0.07 bears/km² to 0.76 bears/km². Immigration was limited to 1 or 2 bears, and 7 bears emigrated over an 11-year period, although 2 were removed due to nuisance complaints and 2 left temporarily to nearby islands (Fleming 1997).

We used previously unpublished data (Trauba 1996, Fleming 1997) to (1) model the trajectory of this population over time, (2) test for density-dependence in

black bear litter size, reproduction, and survival, and (3) model recruitment with a Ricker stock-recruitment model (Ricker 1975).

STUDY AREA

This study was conducted on Stockton Island, Wisconsin, a 40.7-km² island located 7.9 km from the Bayfield Peninsula in Lake Superior. Stockton Island is part of the Apostle Islands National Lakeshore (AINL), managed by the National Park Service (NPS). The local climate is affected by the maritime nature of the island, with warmer winters and cooler summers than the nearby mainland. Maximum daily mean temperatures range from 25.5°C in July to -4.5°C in January and annual precipitation averages 75 cm (Judziewicz and Koch 1993). The island was logged intensively in the late 1800s, and fires and logging continued to affect the vegetation until 1950. Currently, the island is covered by second-growth forest, dominated by white birch (*Betula papyrifera*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), white cedar (*Thuja occidentalis*), balsam fir (*Abies balsamea*), and quaking aspen (*Populus tremuloides*) (Judziewicz and Koch 1993). Hunting was not allowed on the island before 1994. Hunting was allowed beginning in 1994, but it is unlikely that any bears were hunted or harvested due to restrictions on baiting and difficult access to the island (Fleming 1997). Most island use was recreational, mainly camping and hiking.

METHODS

Bears were captured with foot snares, barrel traps, tranquilizer dart guns, by hand, or in dens. Trapping occurred during summer 1984, 1987-1990, and 1993-1994 (Fleming 1997). All collared bears that could be located were checked once while in

the den every year from 1984 to 2001, when all collars were removed and the study was terminated. Trapped and denned bears were immobilized with a mixture of ketamine hydrochloride and xylazine hydrochloride (1984-1996) or Telazol (1997-2001). All bears were sexed and weighed. At first capture, all non-cub bears were marked with ear tags and a permanent lip tattoo. A premolar tooth was extracted from all bears of unknown age to determine age. All captured bears of suitable weight were equipped with radiocollars.

We obtained abundance estimates, population age structure, and litter sizes from Fleming (1997). Yearly population estimates are based on the number of bears present in May. We ran 3 different analyses to test for evidence of density-dependence in fecundity as well as yearly variation in survival. We tested yearly population estimates for fit to 2 common population growth models: an exponential growth model and a logistic growth model. We determined model fit with the 2nd order Akaike Information Criterion (AIC_c) corrected for small sample size; the model of lowest AIC_c value was the best fit to the data (Burnham and Anderson 1998).

We calculated the average number of cubs for each primiparous female without yearlings for each year from 1984 to 1996. We included mature females that skipped a breeding cycle when determining average litter size for the year. This allowed us to combine actual litter size with breeding frequency to better estimate total productivity in the population. This value was regressed against estimated total abundance. We also regressed mean cub and yearling weights against total abundance to test for evidence of density-dependence in cub and yearling weight.

We obtained survival estimates with Program MARK, using a recapture only analysis (White and Burnham 1999). We ran 16 models with as few as 2 parameters (constant survival and recapture for both sexes over all years; $\Phi(.)p(.)$) and as many as 64 parameters (time and sex dependent survival and recapture probability; $\Phi(g*t)p(g*t)$). We determined model fit using the second order AIC_c scores generated by MARK.

We used a Ricker model (Ricker 1975) to test for the effect of stock size and Winter Severity Index (WSI) values on yearly recruitment:

$$R = \alpha S e^{-\beta S - cX}$$

where cub recruitment (R) is a function of stock size (S), a density independent production parameter (α), density-dependent interactions (βS), and WSI values (cX).

WSI is measured as the number of days from November to April with temperatures below -17.8°C (0°F) and more than 18 inches of snow on the ground (Kohn 1975).

We estimated model parameters (α and β) by simple linear regression using the log-transformed equation:

$$\log_e(R/S) = \log_e(\alpha) - \beta S - cX + \epsilon$$

We estimated model parameters (α , β , c) for the model containing WSI values with multiple regression by using SAS statistical software. We ran 3 model variants by using different definitions of stock: all non-cub bears, all females, and all females available for breeding. We chose the best model based on adjusted R^2 values. We

added the WSI variable to the best model, and we compared the two models by using the second order AIC_c :

$$AIC_c = n * \ln(RSS/n) + 2K + \frac{2K(K+1)}{n-K-1}$$

Where (n) is sample size (years), RSS is the sum of squared residuals, and K is the number of estimated parameters (including an error estimate). Again, the best fit model had the lowest AIC_c score.

RESULTS

Densities ranged from a low of 0.07 bears/km² in 1984 to a peak of 0.76 bears/km² in 1994 (Table 1). Population growth best fit a logistic growth curve (logistic model: $AIC_c = 22.39$, exponential model $AIC_c = 28.11$), where carrying capacity (K) is 27, initial population size (N_0) is 4, and intrinsic rate of increase (r) is 0.44 (Fig. 1).

Average litter size declined as black bear density increased ($r^2 = 0.568$, $p = 0.007$; Fig. 2). The decline in winter yearling weights as density increased was marginal and likely related to inadequate sample size ($r^2 = 0.676$, $p = 0.09$; Fig. 3), whereas winter cub weights did not appear to be affected by total abundance ($r^2 = 0.13$, $p = 0.38$; Fig. 4).

The best survival model contained a single parameter for survival for both sexes and all years, as well as 2 parameters for recapture probability, 1 for males and 1 for females (Table 2, 3).

The Ricker Stock Recruitment model of best fit did not contain a coefficient for WSI. Best fit occurred when Stock (S) included all non-cub bears in the population and predicted the following year's recruitment ($r^2 = 0.605$, $p = 0.0029$; Fig. 5). When best fit was achieved, the density-independent production parameter (α) was 1.63, and the density-dependent parameter (β) was 0.117 (S.E. 0.029). The final model looked like this:

$$R = 1.63S e^{-0.117S}$$

According to the nature of the model, recruitment (R) was maximized at 5.1 cubs/year when stock size (S) is 8.5 non-cub bears, or a density of 0.21 bears/km².

DISCUSSION

Although it is generally understood that populations at or near carrying capacity are regulated through density-dependent mechanisms, evidence that supports that position for black bear populations is weak (Taylor 1994). The main difficulties in obtaining evidence for density-dependent population regulation are density-independent, stochastic events that act as confounding factors. The data from Stockton Island clearly show a decline in fecundity (measured as average litter size) as density increased. The data also provide evidence of logistic population growth approaching the island's carrying capacity. Survival was constant for all years and both sexes based on analysis in program MARK. No model with time-dependent survival had a model likelihood greater than 0.003, whereas the third and fourth best models contained sex-dependent survival parameters. It seems likely, therefore, that

decreased survival at higher densities does not act as a regulating mechanism in the Stockton Island population. Analysis of the Ricker Stock Recruitment model shows that recruitment is maximized at an intermediate density. The data on yearling weights also suggest that perhaps competition for resources at high density limits yearling size, but the sample size is small, and other factors like female condition or food abundance may play a larger role. These factors combined provide evidence of density-dependent regulation in the Stockton Island population. Annual cub, yearling, or subadult mortality, another potential regulating mechanism at high densities (Taylor 1994), could not be estimated in this study due to inadequate sample size. Fleming (1997) observed several cases of probable cannibalism on sub-adult and yearling bears during the years of highest density, when interactions between bears would be highest.

Long-term studies are clearly important to better understand the dynamics of an animal population. But few studies are able to continue long enough to discover trends (Pelton and van Manen 1996). This project was long enough both to determine trends and to cover a wide range of densities.

Garshelis (1994) reviewed much of the research on North American black bear populations that potentially exhibit density dependence. Kemp (1972, 1976) initiated a unique study in east-central Alberta involving experimental manipulation of an un hunted black bear population. After observing the population and generating Lincoln-Petersen estimates of population size, he removed 23 adult males over 2 years. Following removal, the population was again monitored for 4 more years. Population size increased initially, and later fell to pre-removal levels. Following

adult removal, Young and Ruff (1982) observed a doubling of the proportion of subadults in the population. The researchers concluded that the population was held in check by adult male density, one of the main hypothesized density-dependent regulatory processes in black bear populations. Garshelis (1994) questioned these conclusions based on further analysis of recapture rates that indicated the Lincoln-Petersen estimates of population size were unreliable at best. On Garshelis' (1994) recommendations, Sargeant and Ruff (2001) reanalyzed the data by using Jolly-Seber open population models to estimate population size. Based on this reanalysis, they concluded that adult males influenced local bear densities on the Cold Lake Study Area. But they also cautioned that their results did not "permit inferences about density dependence or population regulation" as they defined them. They recommend that bear biologists reserve population status for disjunct or "much larger populations" to avoid confusion and minimize apparent density-dependent effects of local, small, arbitrarily defined black bear populations (Sargeant and Ruff 2001).

Other studies cited in Garshelis (1994) contained limited evidence of density-dependent population regulation. Lindzey and Meslow (1977) observed the highest reported density (176 non-cub bears/100 km²) on Long Island in Washington. Following a decline in berry production, subadult and adult bears began to disperse, and 6 cases of conspecific killings were reported. Of 2 populations of black bears in Arkansas with biased sex ratios, Clark (1991) found the population with a higher male sex ratio had a lower mean litter size and cub survival. These differences are most likely attributable to the higher number of males rather than any density-dependent effects (both populations had relatively low densities).

The main limitation of this study is the lack of data on confounding, density-independent effects. Data on food abundance and availability were not collected throughout the course of the study. It is possible that what we interpret as density-dependence could in fact be a result of low food production during certain years (Payne et al. 1998). But we believe that the trend, which spans 13 years, covers years of poor and good food production and still maintains a downward trend as density increases. Increasing density causes competition for food resources, perhaps decreasing female fitness and reducing litter size. In this instance, low food availability would be directly causing the litter size trends we observed, but these trends would be density related nonetheless.

LITERATURE CITED

- BURNHAM, K. P. AND D. R. ANDERSON. 1998. Model selection and inference: a practical information-theoretic approach. Springer, New York, New York, USA.
- CLARK, J. D. 1991. Ecology of two black bear (*Ursus americanus*) populations in the interior highlands of Arkansas. Dissertation, University of Arkansas-Fayetteville, Fayetteville, Arkansas, USA.
- FLEMING, K. C. 1997. A demographic comparison of a hunted and an unhunted population of black bears in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- GARSHELIS, D. L. 1994. Density-dependent population regulation of black bears.

- Pages 3-14 *in* M. Taylor, editor. Density-dependent population regulation in black, brown, and polar bears. International Conference on Bear Research and Management Monograph Series No. 3.
- JUDZIEWICZ, E. J. AND R. G. KOCH. 1993. Flora and vegetation of the Apostle Islands National Lakeshore and Madeline Island, Ashland and Bayfield counties, Wisconsin. *The Michigan Botanist* 32:43-193.
- KEMP, G. A. 1972. Black bear population dynamics at Cold Lake, Alberta, 1968-1970. *International Conference on Bear Research and Management* 2:26-31.
- _____. 1976. The dynamics and regulation of black bear *Ursus americanus* populations in northern Alberta. *International Conference on Black Bear Research and Management* 3:191-197.
- KOHN, B. E. 1975. Deer survey improvement. Final Report, Job 210.4 P-R Project W-141-R-10, Wisconsin Department of Natural Resources, Madison, Wisconsin, USA.
- LINDZEY, F. G. AND E. C. MESLOW. 1977. Population characteristics of black bears on an island in Washington. *Journal of Wildlife Management* 41:408-412.
- PAYNE, N. F., B. E. KOHN, N. C. NORTON, AND G. G. BERTAGNOLI. 1998. Black bear food items in northern Wisconsin. *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters* 86:263-280.
- PELTON, M. R. AND F. T. VAN MANEN. 1996. Benefits and pitfalls of long-term research: a case study of black bears in Great Smoky Mountains National Park. *Wildlife Society Bulletin* 24:443-450.

- RICKER, W. E. 1975. Recruitment and stock-recruitment relationships. Pages 265-296 in W. E. Ricker, editor. Computation and interpretation of biological statistics of fish populations, Bulletin 191 of the Fisheries Research Board of Canada.
- SARGEANT, G. A. AND R. L. RUFF. 2001. Demographic response of black bears at Cold Lake, Alberta, to the removal of adult males. *Ursus* 12:59-68.
- TAYLOR, M. 1994. Density-dependent population regulation in black, brown, and polar bears. Pages 1-2 in M. Taylor, editor. Density-dependent population regulation of black, brown, and polar bears. International Conference on Bear Research and Management Monograph Series No. 3.
- TRAUBA, D. R. 1996. Black bear population dynamics, home range, and habitat use on an island in Lake Superior. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- WHITE, G. C. AND K. P. BURNHAM. 1999. Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46 Supplement, 120-138.
- YOUNG, B. F. AND R. L. RUFF. 1982. Population dynamics and movements of black bears in east central Alberta. *Journal of Wildlife Management* 46:845-860.

Table 1. Estimated number and density of non-cub black bears on 40.7-km² Stockton Island, Wisconsin, during May 1984-1996. Data from Fleming (1997).

Year	No. males	No. females	Total	Density (bears/km ²)
1984	1	2	3	0.07
1985	1	2	3	0.07
1986	5	7	12	0.29
1987	6	7	13	0.31
1988	7	8	15	0.37
1989	8	9	17	0.42
1990	8	10	18	0.44
1991	11	12	23	0.57
1992	9	11	22	0.54
1993	12	11	23	0.57
1994	15	16	31	0.76
1995	11	15	26	0.64
1996	10	15	25	0.61

Table 2. Rank of the 5 best survival models (based on AIC_c) generated by program MARK for a population of black bears on Stockton Island, Wisconsin, 1984-2001.

Model	AIC_c	Δ_i	K^*	Model Likelihood*
$\Phi(.)p(g)^*$	292.42	0.00	3	1.00
$\Phi(.)p(t)$	292.63	0.21	18	0.90
$\Phi(g)p(t)$	294.13	1.71	19	0.43
$\Phi(g)p(g)$	294.24	1.82	4	0.40
$\Phi(.)p(.)$	297.96	5.54	2	0.06

*K = number of parameters in the model

$$\text{Model Likelihood} = \frac{QAIC_c(\text{CurrentModel})}{QAIC_c(\text{BestModel})}$$

Table 3. Parameter estimates generated by program MARK for the best survival model for a population of black bears on Stockton Island, Wisconsin, 1984-2001.

Model Parameters*	Parameter estimate	95% CI
Survival	0.808	0.749-0.856
Recapture-males	0.820	0.710-0.895
Recapture-females	0.966	0.875-0.991

*Model parameters based on model $\Phi(.)p(g)$, where Φ =survival, p =capture probability, $(.)$ indicates constant survival, and (g) indicates sex-dependent capture probability.

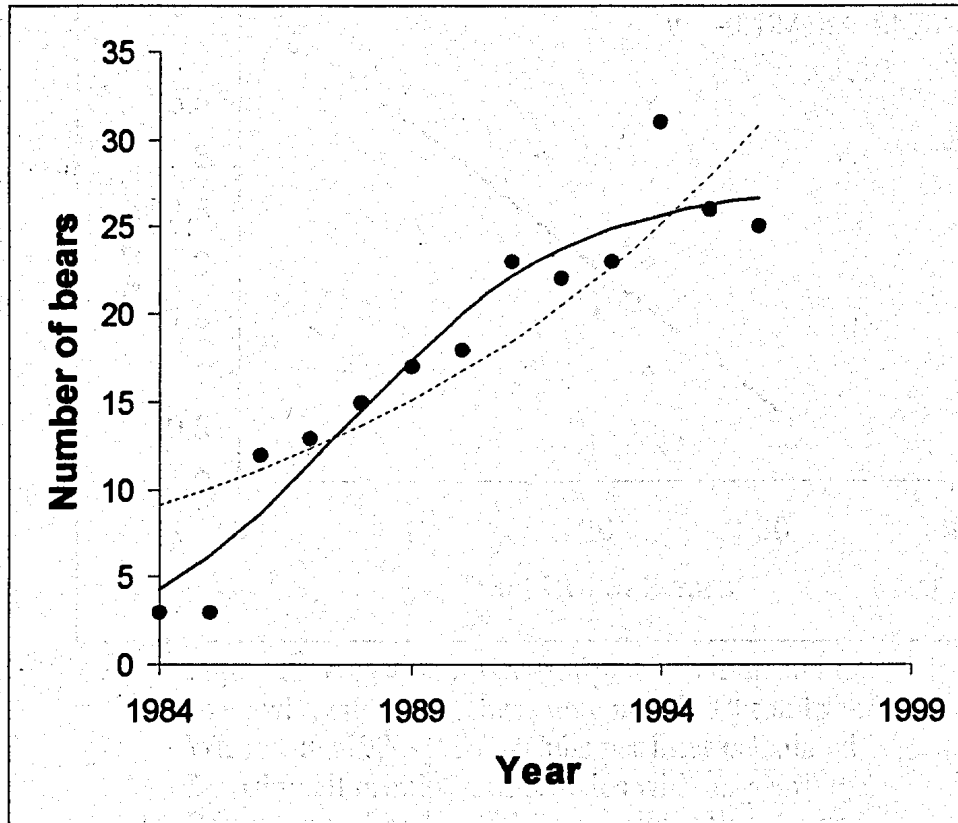


Figure 1. Population growth curves for black bears on Stockton Island, Wisconsin, 1984-1996. Data from Fleming (1997). Dashed line indicates exponential model, solid line indicates logistic model.

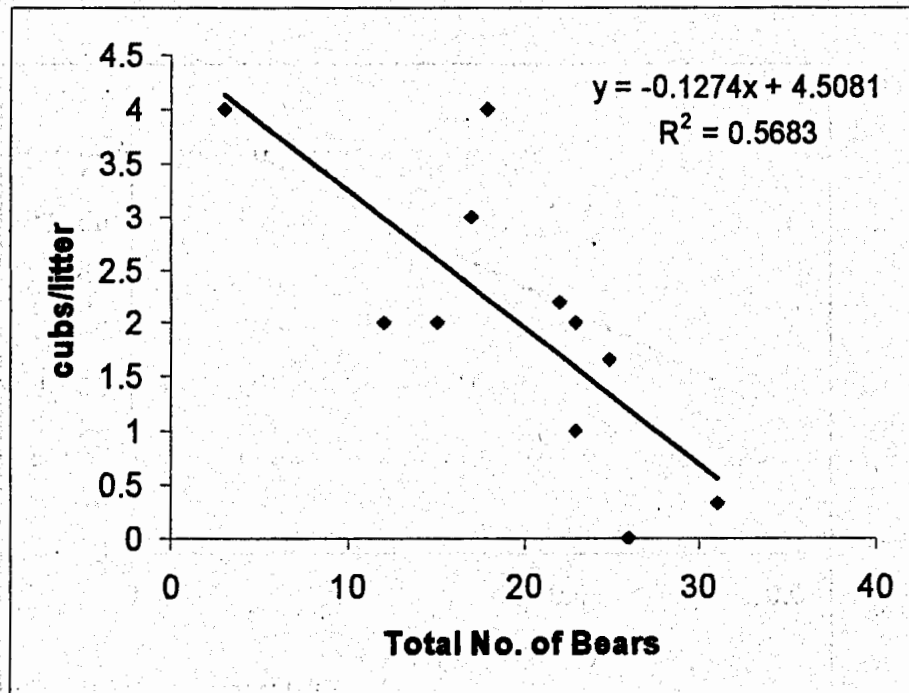


Figure 2. Negative relationship between mean litter size and total black bear abundance, Stockton Island, Wisconsin, 1984-1997. (Cubs per litter calculated By using all primiparous females without yearlings. Primiparous females without yearlings that did not produce cubs were counted as having a litter of 0).

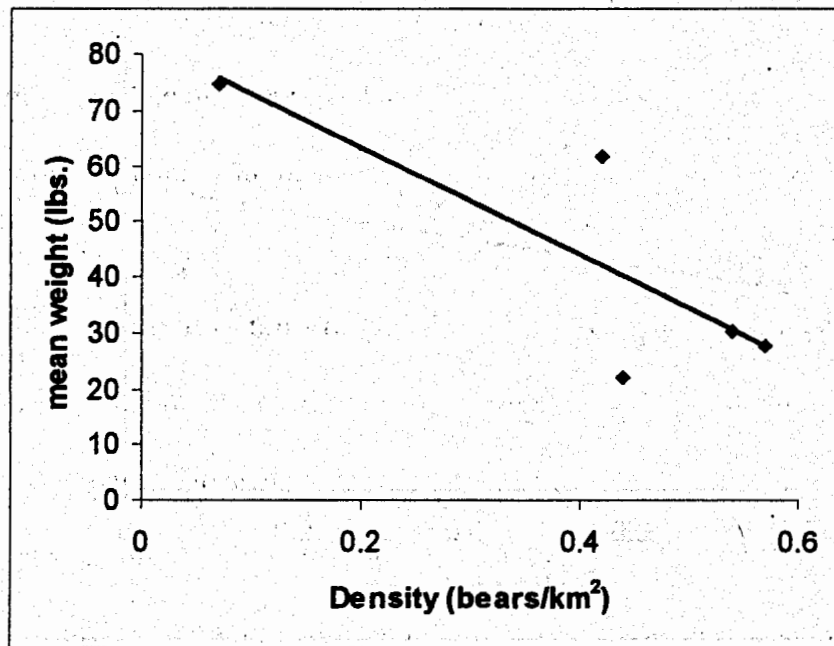


Figure 3. Mean yearling weight versus bear density, Stockton Island, Wisconsin, 1984-1996.

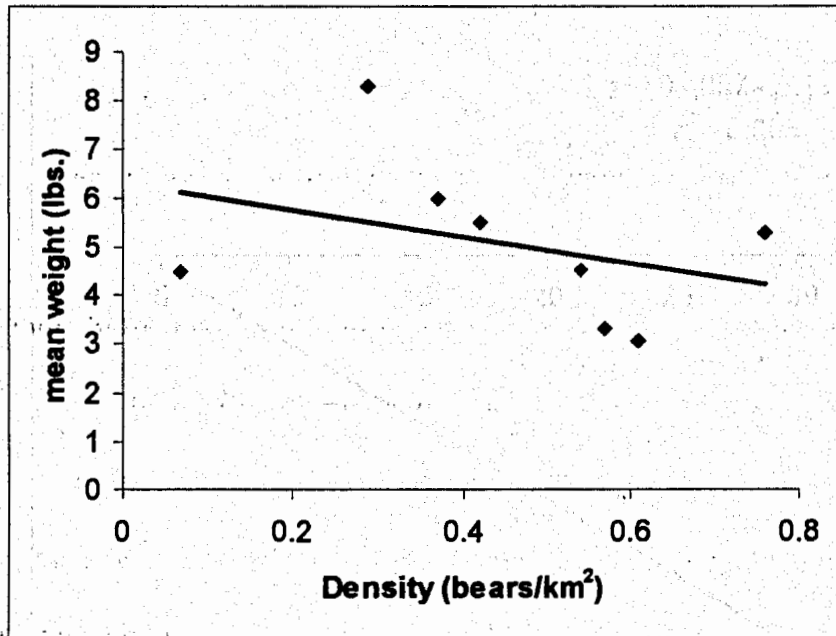


Figure 4. Mean cub weight versus bear density, Stockton Island, Wisconsin, 1984-1996.

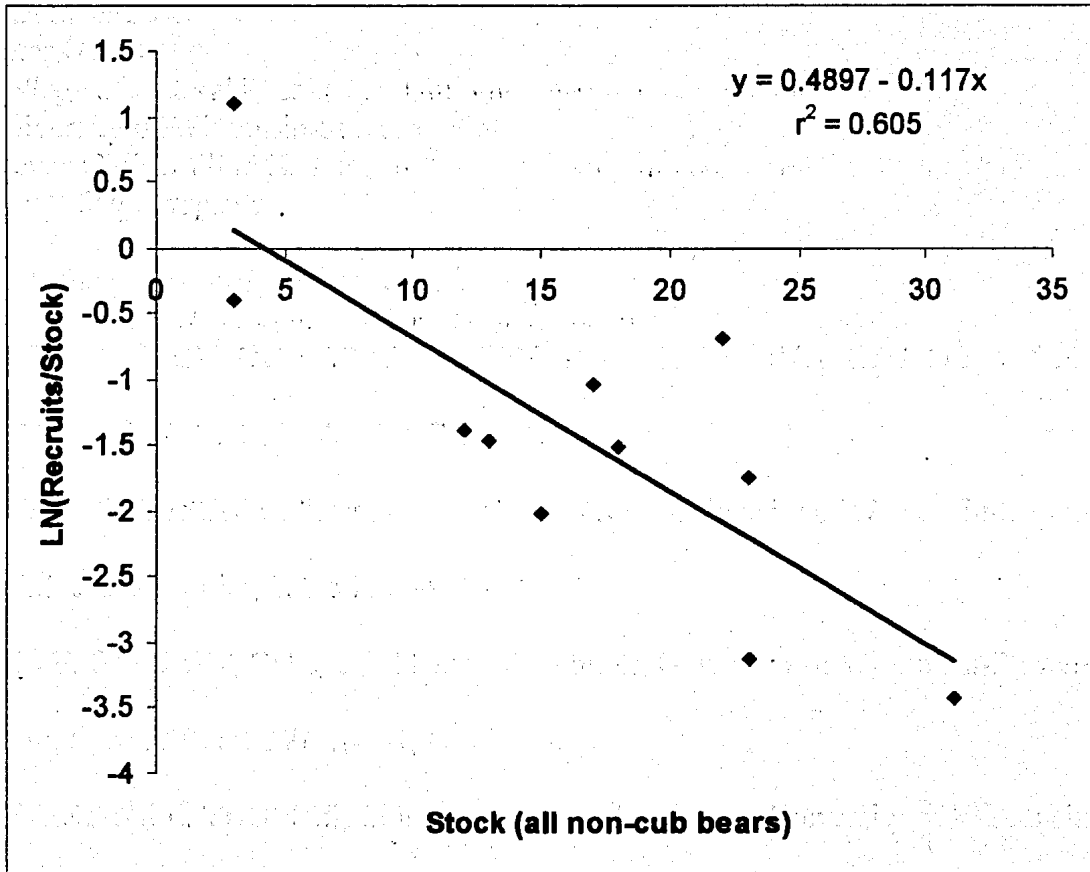


Figure 5. Linear Ricker stock recruitment model for a Wisconsin black bear population on Stockton Island, 1984-1996.

6 October 2003
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RH: Black bear growth *Gesch et al.*

**FITTING THE VON BERTALANFFY GROWTH EQUATION TO BLACK
BEAR AGE-WEIGHT AND AGE-LENGTH DATA**

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ABSTRACT: We developed two von Bertalanffy growth curves and a model predicting weight from pad measurements, girth, and length, using data collected from black bears (*Ursus americanus*) in northern Wisconsin from 1990-2002. L_{∞} from the length-age curve, was 161.6 cm, and W_{∞} from the weight-age curve was 92.299 kg. The multiple regression model predicting weight included chest girth, total length, and rear pad width, with an overall r^2 of 0.936. Both von Bertalanffy growth curves are valuable for comparisons between populations or between years within the population, and act as indicators of environmental conditions.

Key words: black bear, morphometrics, *Ursus americanus*, von Bertalanffy

Morphometrics often are recorded in animal studies to assess body condition, determine taxonomy, record growth, or predict difficult to measure variables like age and weight. Von Bertalanffy growth models have been developed for several species to assess growth rates quantitatively for comparisons between populations, sexes within a population, or years within a population. These models have been used most extensively in fisheries research but have been applied to some mammalian populations as well. Predictive equations have been developed for many species that relate a single easily measured morphometric to more difficult to measure parameters through a simple linear regression equation. Others have been developed using multiple regression to increase the predictive accuracy through the measurement of several variables. Still other models have been developed that use morphometric parameters to generate an index of health, body condition, or survival probabilities. One problem with these equations is the interpopulation variation that exists in the parameter relationships.

The most common predictive relationship for black bears (*Ursus americanus*) has been between weight and chest girth. Not only does such a model provide an easier means of assessing the weight of a heavy animal, but it also provides information on the growth and shape of the animal. Payne (1976) developed a weight-girth equation for Newfoundland black bears, and others have been developed for black bear populations in Tennessee, Montana, and Arizona (Swenson et al. 1987). Kessler (1994) developed two models for black bears in Wisconsin, using chest girth and neck circumference to predict weight. Brooks et al. (1998) developed models to

predict body length, weight, and skull width from pad width measurements for black bears in Minnesota. Kohn (1982) showed evidence of a strong relationship between both chest girth and composite pad measurements and weight, but did not provide an equation describing that relationship. He noted that some of the variation may have been caused by collecting weights throughout the summer and recommended generating predictive equations based on data collected over a short time period.

Von Bertalanffy growth equations are less common for mammal populations, but they have been fitted for a population of polar bears (Kingsley 1979). In order to understand the growth rates and development patterns of black bears better, we developed predictive equations as well as von Bertalanffy growth equations for a population of black bears in northern Wisconsin.

METHODS

Data were collected from bears in Ashland County in the Chequamegon National Forest of northern Wisconsin. Fleming (1997) described capture and handling methods. Bears were initially captured with foot snares and barrel traps between May and August. Bears were radio-collared, ear-tagged, and lip-tattooed. Year of birth was determined at first capture for bears of unknown age by counting cementum annuli on a first premolar. Bears were monitored by radio-telemetry from den emergence until den entrance. Dens were visited in late January, February, and early March. Bears were sedated with a mixture of ketamine hydrochloride and xylazine hydrochloride (1990-1996) or Telazol (1997-2002). Sedated bears were removed from the den, placed in a net, and weighed with a spring scale to the nearest pound and later converted to kilograms. Data in this study were lacking for male

bears, because only females were monitored for most of the study period. As a result, we fitted models for females only. Four pad measurements were taken: right front width (at the widest point), right front length (in a straight line down the middle of the pad), right rear width (at the widest point), and right rear length (in a straight line down the middle of the pad). Chest girth measurements were taken directly behind the front legs while the bear was lying on its side. Total body length was measured from the tip of the nose to the base of the tail along the contour of the spine. Over the course of the study (1990-2002), several people took part in taking and recording weight, girth, pad, and length measurements.

We fit von Bertalanffy weight-age, length-age, and weight-length growth equations for female bears only. For the length-age data, we used an additive error model because residuals were evenly distributed for all ages (i.e., variability in length was not an increasing function of age):

$$L_t = L_\infty (1 - e^{-K(t-t_0)})$$

where L_t is length at age t , L_∞ is maximum or asymptotic length, K is the rate at which L_t approaches L_∞ , and t_0 is length at age 0 (King 1995). We estimated parameters by using a nonlinear least-squares method in SAS (PROC NLIN; SAS Institute Inc. 1999). An additive error model was also appropriate for weight-age data:

$$W_t = W_\infty (1 - e^{-K(t-t_0)})^\beta$$

where W_t is weight at age t , W_∞ is maximum or asymptotic weight, K is the rate at which W_t approaches W_∞ , t_0 is weight at age 0, and β is a shape parameter derived

from a weight-length relationship (King 1995). Beta was estimated from the weight-length relationship; we estimated all other parameters using PROC NLIN in SAS (SAS Institute Inc. 1999). Weight-length data required a multiplicative error model, as residuals increased with increasing length (i.e., variability in weight was an increasing function of length). The basic model is

$$W = \alpha L^{\beta}$$

where W is weight, L is length, β is a parameter describing the shape, and α describes the relationship between length and weight. We \log_e transformed the model so residuals would be evenly distributed at all lengths:

$$\log_e(W) = \log_e(\alpha) + \beta \log_e(L)$$

We estimated parameters by using simple linear regression. We then used the estimate of beta in the weight-age model.

Because multiple measurements were performed on individual bears in multiple years, the lack of independence among the data might have led to biased estimates and confidence intervals. To test for bias in parameter estimates and generate unbiased confidence intervals for parameter estimates, we used a bootstrapping technique for all 3 growth models. We calculated confidence intervals by using the bias-corrected percentile bootstrap based on 1500 bootstrap samples (Dixon 1993).

We performed all multiple regression analyses with SAS software. Individual bears with missing data we eliminated from the analysis. We double \log_e transformed data to achieve linearity. All recorded measurements (4 pad measurements, total length, and chest girth) we included in regression analyses as independent variables to

predict weight. We based model selection on RSQUARE AIC in PROC REG in SAS (SAS Institute Inc. 1999). AIC is calculated as $-2LL + 2K$, where LL is the log of the likelihood of the model and K is the number of parameters included in the model (Burnham and Anderson 1998). We used AIC values to balance the inevitable result of increasing fit as more parameters are added to the model with the necessity of keeping models as simple as possible. We chose the model with the best fit based on the lowest AIC score.

RESULTS

From 1990 to 2002, 138 measurements of age, weight, total length, chest girth, and pad dimensions were taken from 61 female black bears. Sample sizes varied between analyses because not all measurements were taken on all bears. All parameter estimates were unbiased based on bootstrap results.

Results of the weight-length model were based on 134 measurements of 61 bears (Table 1). The simple regression model between weight and length was significant ($p < 0.001$; adjusted $r^2 = 0.879$; Fig. 1), yielding the following relationship:

$$W = 0.00000485L^{3.264}$$

Based on 130 measurements of 55 bears and using the beta value obtained from the weight-length relationship above, the von Bertalanffy weight-age model yielded the following relationship (Fig. 2):

$$W_t = 92.299(1 - e^{-0.349(t+1.749)})^{3.264}$$

The length-age model (Fig. 3), derived from 122 measurements of 50 bears, displayed the following relationship between length and age:

$$L_t = 161.635(1 - e^{-0.509(t+0.995)})$$

Multiple regression models were based on 131 measurements of 59 female bears. For all 63 models in the model set, r^2 ranged from 0.333 to 0.937 (Table 2). The best model based on AIC values had an adjusted r^2 of 0.936 and contained 3 parameters: girth, length, and rear pad width (Table 3).

DISCUSSION

Swenson et al. (1987) suggested that a single equation may be valid within elevational zones. They reported studies from elevations of 548 m to 3,270 m. In general, they noted an increase in the exponent of chest girth in the standard relationship $W = \alpha G^\beta$ as altitude increased, suggesting altitude affects black bear growth and body shape. The beta parameter in our single parameter equation ($W = 0.0004G^{2.6422}$) was similar to that found at a similar elevation, suggesting an elevational model might be appropriate.

While providing less biological interpretation than a simple chest girth-weight relationship, multiple measurements might provide better estimates of weight than a single parameter model. Some other measurements often taken include pad dimensions, total body length, and skull width. Swenson et al. (1987) included a body size index parameter (length x girth squared) to estimate weight more accurately. But adding more parameters will inevitably increase fit (Burnham and Anderson 1998). Using AIC to balance model performance with the principle of parsimony, we were able to find the best predictive model of weight possible for the measurements that were taken. The best 1-parameter model contained only girth, and explained 89% of the variation in weight. The best 2-parameter model included girth and length,

explaining an additional 3.6% of the variation in weight. The final parameter that increased fit enough to lower AIC was rear pad width, which explained 0.65% more variation in weight (Table 3). Three other 4-parameter models were within 2 AIC of the best model but did not increase the fit of the model (Table 2). Because chest girth is by far the best single predictor of weight, it is more practical for hunters to use, rather than taking less viable measurements.

A potentially significant additional source of variation is inter-researcher variation. During the 13 years of the study, several people were involved with handling, measuring, and recording data. This source of variation might be greater than inter-population variation (Eason et al. 1996). Eason et al. (1996) suggested ways to reduce researcher-induced variation, including using clearly defined parameters, using multiple measurements in predictive equations, limiting the number of people involved in taking morphometrics during the course of the study, and providing training and proper equipment to field researchers.

Von Bertalanffy growth models have been developed for many different animal species, and they represent a theory of organismal growth that relates length and weight to age. Such relationships allow comparisons between sexes, populations, or time periods within a population. The equations provide information on the rate at which an individual approaches maximum length or weight, as well as what the maximum weight or length is. Few weight-age or length-age models have been developed for large mammals, and none for black bears. Kohn (1982) presented average live weight-at-age data for male and female black bears in Wisconsin. He found that females reached their maximum weight after 6-7 years on average, and

males reached maximum weight at 8-9. Kingsley (1979) generated von Bertalanffy weight-age models for polar bears during 2 time periods to test for differences in growth caused by an unusually severe winter. Analysis of the curves suggested that subadult polar bears were most affected by the severe winter, perhaps due to their lack of experience and success in hunting with a reduced prey base.

Data in this study were lacking for male bears, because only females were collared for most of the study period. As a result, no comparison between sexes was possible. The curves provide a baseline on female growth during that period studied, which might be useful as a source of comparison between other populations or even in future years for the same population. Kohn (1982) suggested that black bear average weights may provide information on changing population age structure. Because bears feed at bait piles used for hunting, Wisconsin's recent (spring 2003) ban on deer baiting and feeding, if continued, might also have effects on black bear growth rates that could be detected by future weight-age relationships and analysis of von Bertalanffy growth parameters. These models provide important, indirect information on food availability and abundance, environmental stresses, and intra-population stresses including increased intra-specific competition resulting from high population densities.

LITERATURE CITED

BROOKS, R., T., R. MCROBERTS, AND L. L. ROGERS. 1998. Predictive relationships between age and size and front-food pad width of northeastern Minnesota black bears, *Ursus americanus*. *Canadian Field-Naturalist* 112:82-85.

- BURNHAM, K. P. AND D. R. ANDERSON. 1998. Model selection and inference: A practical information-theoretic approach. Springer, New York, New York, USA.
- DIXON, P. M. 1993. The bootstrap and the jackknife: Describing the precision of ecological indices. Pages 290-318 in S. M. Scheiner and J. Gurevitch, editors. Design and analysis of ecological experiments. Chapman and Hall, New York, New York, USA.
- EASON, T. H., B. H. SMITH, AND M. R. PELTON. 1996. Researcher variation in collection of morphometrics on black bears. Wildlife Society Bulletin 24:485-489.
- FLEMING, K. C. 1997. A demographic comparison of a hunted and an unhunted population of black bears in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- KESSLER, G. P. 1994. Black bear reproductive biology, denning biology, habitat use, and movements in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- KING, M. 1995. Fisheries biology, assessment and management. Blackwell Science, Oxford, England.
- KINGSLEY, M. C. S. 1979. Fitting the von Bertalanffy growth equation to polar bear age-weight data. Canadian Journal of Zoology 57:1020-1025.
- KOHN, B. E. 1982. Status and management of black bears in Wisconsin. Technical Bulletin No. 129. Department of Natural Resources, Madison, Wisconsin, USA.

PAYNE, N. F. 1976. Estimating live weight of black bears from chest girth measurements. *Journal of Wildlife Management* 40:167-169.

SAS Institute Inc. 1999. SAS/STAT user's guide, version 8. SAS Institute, Cary, North Carolina, USA.

SWENSON, J. E., W. F. KASWORM, S. T. STEWART, C. A. SIMMONS, AND K. AUNE. 1987. Interpopulation applicability of equations to predict live weight in black bears. *International Conference on Bear Research and Management* 7:359-362.

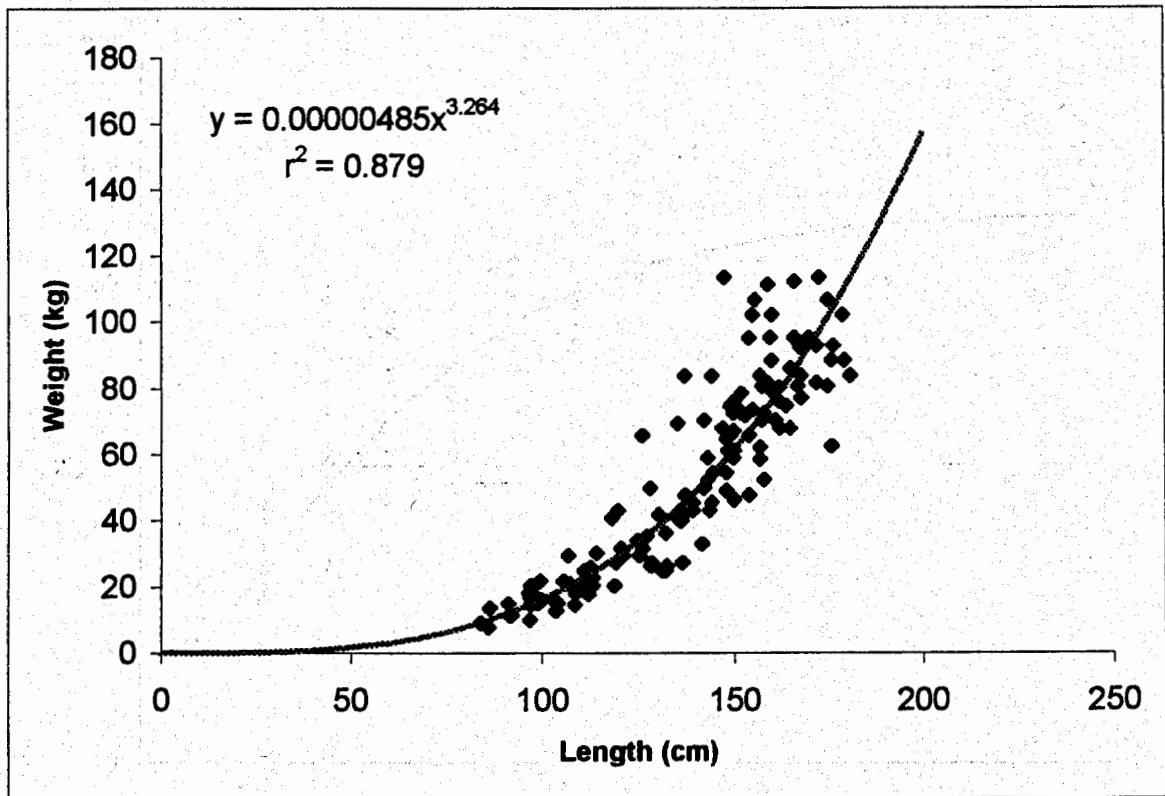


Figure 1. von Bertalanffy winter weight-length relationship for female black bears in northern Wisconsin, 1990-2002. Dots represent actual data points. ($p < 0.001$, adjusted $r^2 = 0.879$, $n = 134$ measurements of 61 bears).

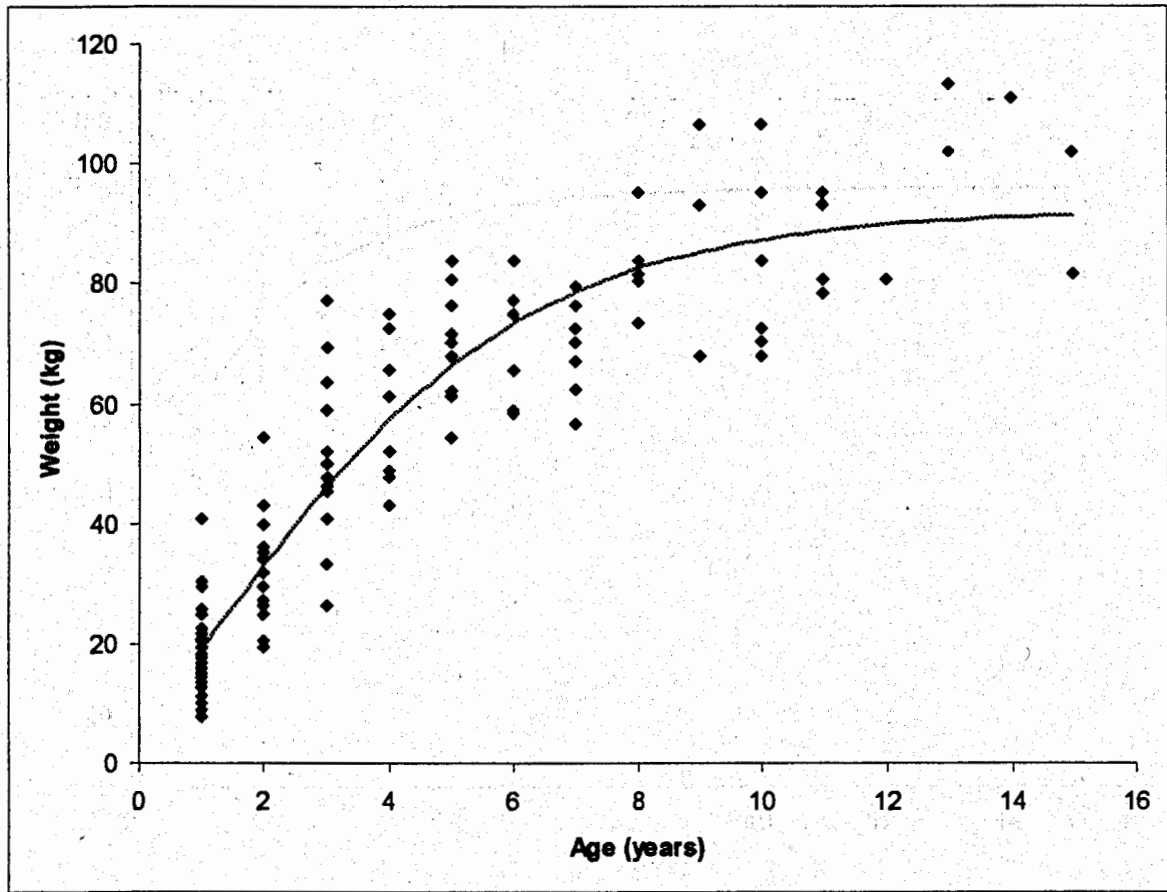


Figure 2. von Bertalanffy winter weight-age relationship for female black bears in northern Wisconsin, 1990-2002. Data points represent actual measurements. For parameter estimates see results section ($F=1304.3$, $p<0.0001$, $n=130$ measurements of 55 bears).

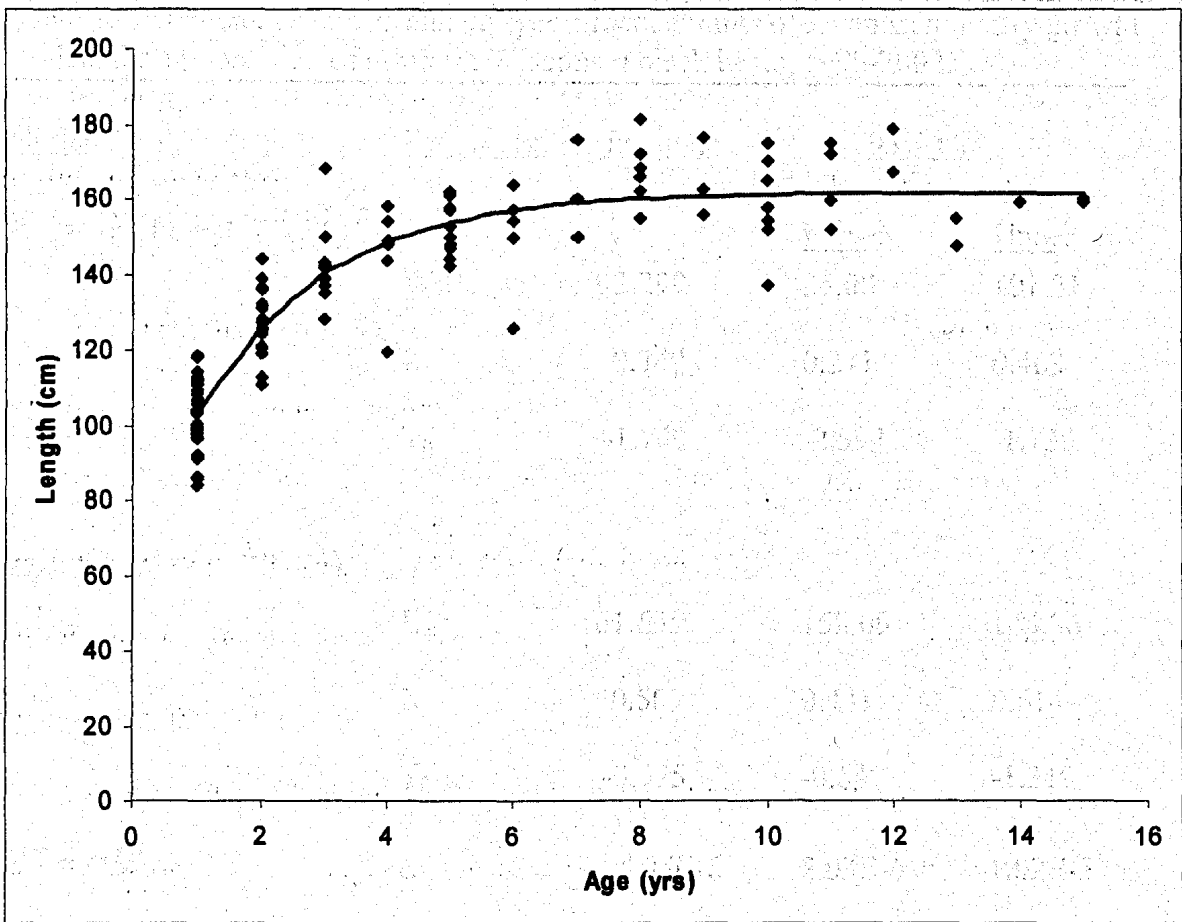


Figure 3. von Bertalanffy winter length-age relationship for female black bears in northern Wisconsin, 1990-2002. Data points represent actual measurements. For parameter estimates of the growth equation see results section ($F=334.4$, $p<0.0001$; $n=122$ measurements of 50 bears).

Table 1. Parameter estimates and 95% confidence limits of 3 von Bertalanffy growth models for a population of northern Wisconsin black bears, 1990-2002.

<u>Model</u>	<u>Parameter</u>	<u>Estimate</u>	<u>95% CI</u>	
			<u>Lower</u>	<u>Upper</u>
$W_t = W_\infty(1 - e^{-K(t-t_0)})^\beta$	W_∞^*	92.299	85.08	101.21
	K	0.349	0.271	0.463
	T_0	-1.749	-2.594	-1.138
$L_t = L_\infty(1 - e^{-K(t-t_0)})$	L_∞^*	161.635	158.09	164.86
	K	0.509	0.441	0.614
	T_0	-0.995	-0.649	-1.319
$W = \alpha L^\beta$	α	4.85E-6	2.03E-6	1.02E-5
	β	3.264	3.109	3.439

* W_∞ is in kg, L_∞ is in cm.

Table 2. Top 5 multiple regression models to predict female black bear weight from 4 pad measurements, chest girth, and total length for northern Wisconsin black bears, 1990-2002. Model selection based on AIC values.

<u>Parameters in model</u>	<u>r²</u>	<u>Δ AIC</u>
girth, length, rear w*	0.936	0
girth, length, rear w, front l	0.936	1.326
girth, length, rear w, rear l	0.936	1.702
girth, length, rear w, front l	0.936	1.968
girth, length rear w, rear l, front w	0.937	2.728

*rear w = right rear pad width, front l = front right pad length, front w = front right pad width.

n=131 measurements of 59 bears

Table 3. Parameter estimates for the best model to predict female black bear weight for northern Wisconsin black bears, 1990-2002.

<u>Variable</u>	<u>Parameter estimate</u>	<u>Partial r²</u>	<u>Model r²</u>	<u>F-value</u>	<u>P-value</u>
Intercept	-10.278 (0.428)*			575.60	<0.0001
Girth	1.336 (0.158)	0.8937	0.8937	71.86	<0.0001
Total length	1.452 (0.197)	0.0359	0.9296	54.27	<0.0001
Rear pad width	0.520 (0.145)	0.0065	0.9361	12.92	0.0005

*values in parentheses are standard errors.
n=131 measurements of 59 bears

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RH: Black bear den site selection *Gesch et al.*

**RESOURCE SELECTION FUNCTION FOR BLACK BEAR DEN SITES IN
NORTHERN WISCONSIN**

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ABSTRACT: We developed a Resource Selection Function (RSF) predicting black bear (*Ursus americanus*) den site selection in northern Wisconsin, 1993-2002.

Logistic regression analysis indicated that the 2 significant habitat conditions predicting den site selection were deciduous cover and water cover within 500 m of the den. Dens occurred in areas with higher deciduous and water cover than available in the study area. Deciduous cover and nearby water sources might provide the necessary conditions for rapid recovery from hibernation.

Key words: black bear, den site selection, Geographic Information System, logistic regression, Resource Selection Function, *Ursus americanus*

Black bear habitat use often changes from spring to summer to fall, and must fulfill 3 pre-requisites: foraging, travel, and denning. Habitat used for denning is especially important for parturition and early cub growth and development (Clark et al. 1998). Den insulation and protection from spring flooding are important factors affecting cub survival and overall female productivity (Oli et al. 1997, Clark et al. 1998, Hellgren and Vaughan 1989, White et al. 2001). Den sites and their surroundings must provide protection from disturbance by humans or predators during hibernation, be suitably dry throughout the spring and early winter to prevent drowning or premature den evacuation, provide adequate energetic efficiency through adequate insulation (Oli et al. 1997), and provide important food, water, and shelter for the critical first few weeks of physiological transition following hibernation (LeCount 1983). Den sites and types of dens used have been shown to vary by geographic location and local availability, suggesting the importance of investigating local conditions that might influence den site selection (Beecham et al. 1983). Some studies have reported den site vegetative characteristics like basal area and species dominance. To our knowledge only one study has used Geographic Information Systems to model black bear den site selection relative to large scale habitat characteristics (Clark et al. 1998). Our objective was to characterize black bear den site selection in northern Wisconsin relative to various habitat characteristics by developing a resource selection function (RSF).

METHODS

The study was conducted in Ashland County, Wisconsin on the Chequamegon National Forest. Methods and study area were described by Fleming (1997). Bears were captured with foot snares and barrel traps between May and August. All females were ear-tagged, lip-tattooed, and radio collared. Males were only monitored during the earliest years of the study, and data on their den site selection was lacking. Throughout the course of the study, female yearlings of collared adult females were collared and added to the study. Age was determined using cementum annuli analysis of a first premolar. Bears were monitored at least biweekly up to den entrance. Denning bears were located initially in December or January, and revisited in January, February, or March when they were immobilized and removed to measure and weigh adults, cubs, and yearlings, and collar new female yearlings. Den location was determined with a Garmin hand-held GPS receiver, recorded in Universal Transverse Mercator (UTM) projection, and later transformed into Wisconsin Transverse Mercator (WTM) projection.

All spatial data were manipulated by using ArcView GIS 3.3 (Environmental Systems Research Institute, Inc.). Habitat coverage of the study area was obtained from the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data (WISCLAND). Land cover data were obtained from LANDSAT Thematic Mapper satellite imagery from fly-overs in August 1991; May, July, September, and October 1992; and May 1993 (Wisconsin Department of Natural Resources 1998). We combined 42 land cover classes obtained from WISCLAND into 12 classes for the analysis. Of the 12 land cover classes, only 9 occurred within the study area:

agriculture, grassland, coniferous forest, deciduous forest, mixed deciduous/coniferous forest, open water, wetland, forested wetland, and shrubland (Table 1).

We used logistic regression to identify the variables useful in predicting if a site is used by a black bear for denning. We ran the analysis with PROC LOGISTIC in SAS statistical software (SAS Institute Inc. 1999). We entered 14 parameters into the logistic regression analysis: habitat type at den site (habitat), distance to road (distance), slope of topography (slope), aspect of topography (aspect), diversity of habitats within a 500 m radius buffer (diversity), coverage of agriculture in the buffer (ag), grassland coverage in the buffer (grass), coniferous forest coverage in the buffer (conif), deciduous forest coverage in the buffer (decid), mixed coniferous/deciduous forest coverage in the buffer (mixed), open water coverage in the buffer (water), wetland coverage in the buffer (wetland), forested wetland coverage in the buffer (forwetland), and shrubland coverage in the buffer (shrub). A 500 meter radius buffer (.79 km²) was chosen because it covers a similar area that is utilized by black bears shortly before and shortly after denning. To estimate total habitat availability, we generated 320 random points within the study area, and each of the 14 parameters listed above was calculated for the random points as well as for the den sites. To limit the model set, we compared the 5 best 1,2,3,4, and 5 parameter models (25 total models) based on AIC values. We obtained confidence intervals for parameter coefficients by using a bias-corrected bootstrap procedure based on 1500 iterations (Dixon 1993).

RESULTS AND DISCUSSION

In the winters of 1993 to 2002, 76 dens of 29 female bears were located. Of the 14 parameters included in the logistic regression analysis, the best model contained just 2 parameters: coverage of deciduous forest in the buffer and coverage of water in the buffer (Table 2). The coefficients indicate that den site selection is positively related to both parameters (Table 3). Bootstrap results indicated no bias in parameter estimates.

Black bear den site selection varies throughout their North American range. Dens vary from hollow trees and rock dens to nest bowls, excavations, and brush piles. Suitable den sites are most likely limiting where tree dens are the predominant type used. Where dens can range from brush piles to excavations to root tips to nest bowls, den availability will likely not be a limiting factor on the population. This is true of the availability and quality of dens in northern Wisconsin, where bears den on the ground or in excavations almost exclusively (Kessler 1994).

Other macro and microhabitat conditions also play varying roles in den site selection. An important characteristic of many den site locations is concealment. Beecham et al. (1980) found that low-elevation dens (<1800 m) in Idaho were in thick brush cover, whereas bears denning at higher elevations were more often in the open and dependent on the higher snow cover for concealment. Hellgren and Vaughan (1989) also observed the importance of dense vegetation in den site selection in the Great Dismal Swamp. Hayes and Pelton (1992) observed an inverse relationship between the structural security and habitat cover of den site locations.

Dens that provided high structural security (rock caves) had limited amounts of understory vegetation, whereas dens with high understory vegetation provided limited structural security. Both, however, were capable of providing the concealment and protection needed by hibernating black bears.

Aspect was not a significant predictor variable for den site selection in our model. In Arkansas more dens were on south and west facing slopes than on east and north slopes (Hayes and Pelton 1994). More dens in Alberta faced north and west than south and east (Tietje and Ruff 1980). Most dens in Idaho had aspects facing west, northwest, and north (Beecham et al. 1980). But aspect can have effect on den selection (Schwartz et al. 1986). Aspect of dens in Wisconsin did not appear to differ from random (Kessler 1994). Several theories regarding aspect have been developed. North facing slopes retain snow cover longer into spring months thus providing greater insulative effect, and they also might provide favorable soil moisture conditions for understory development (Beecham et al. 1980). Southern slopes might be preferred over northern slopes where both exist, but local topographical conditions that likely dictate den aspect and selection are most likely related to den availability (Hayes and Pelton 1992). In flat topography regions like the boreal forests, windblown trees and availability of excavation sites can be the principal determinants of both den location and entrance aspect (Tietje and Ruff 1980).

Given the relatively small topographical relief in our study area, aspect probably is not an important determining factor in den site selection in Wisconsin. Where steep slopes are available, excavation dens probably will be located on the steeper available slopes because of their better soil drainage characteristics (Beecham

et al. 1983). The slope at den site locations in our study was not significant in predicting den site selection and was not included in the model. Again, the relative lack of topographic relief likely resulted in den sites with slopes that were not different than what was available.

Several studies have looked at the land cover type that predominates in areas where black bears den. In Arizona, 91% of all dens were located in the chaparral habitat type, due to dense cover that provided protection from rain, wind, and snow in winter and reliable forage in spring (LeCount 1983). Dens in Alaska were located mainly in mature upland forests and regrowth upland forests; use only of regrowth upland forest differed from what was available, and bogs seemed to be avoided (Schwartz et al. 1987). Elsewhere in Alaska, alder (*Alnus* spp.) draws with associated spruce (*Picea* spp.) or birch (*Betula* spp.) trees appeared to be the preferred habitat type (Schwartz et al. 1987). In Ontario, 88% of dens were located in upland sites, which consisted of mixed hardwood, mixed softwood, or monotypic stands of white birch (*B. papyrifera*) and poplar (*Populus* spp.) (Kolenosky and Strathearn 1987). In the Dead Stream Swamp area of lower peninsula Michigan, Manville (1987) listed conifer swamps, upland hardwoods, and lowland shrubs and hardwoods as the preferred winter habitat types. In Alberta, young stands of aspen and birch contained 4 of 6 dens (Fuller and Keith 1980). Dens in Oregon were located mainly in late seral grand fir (*Abies grandis*) stands (Bull et al. 2000). Habitat type was not a predictor of den location in our study. But deciduous tree cover in a 500-m radius around the den site was significant. Dens were located in areas with more deciduous cover than was available throughout the study area (Table 4). Kessler (1994) identified seasonal

habitat use by black bears in Wisconsin. During the denning season (1 October until den entrance), aspen-birch had the highest importance value, followed by swamp conifer, swamp hardwoods, and northern hardwoods. Throughout the year, aspen was the most important habitat type used in northern Wisconsin. Kessler (1994) attributed this to the high number of mast producing shrub species. He observed increased aspen use as black bear age increased. This suggested that competitive exclusion occurs in this important habitat type. Our results also stress the importance of deciduous habitat, including aspen, in black bear den site selection. Our logistic regression analysis indicated that deciduous habitat was the most important variable determining den site selection.

Use of Geographic Information Systems coupled with digital land cover maps provides a relatively simple method to extract habitat data at den sites and random locations. Using this information in conjunction with a logistic regression technique can be a relatively unbiased way of selecting the habitat variables important to den site selection by black bears. Few mathematical models of den site selection have been developed for black bears. By using Mahalanobis distance values, Clark et al. (1998) developed a model to predict black bear den site selection in Arkansas relative to 7 data layers. While model performance for all dens was poor, a model including only rock den sites contained 4 significant variables. Rock dens were located at middle to high elevations, on steep slopes, near roads, and in areas with many forest types. Forest cover type, aspect, and distance to streams were not significant.

Our RSF model contained 2 significant variables: amount of deciduous cover and amount of open water within 500 m of the den. Deciduous cover is the most

abundant cover type in the study area, but dens were located in areas with more deciduous cover than available. Other studies indicated a preference for upland hardwoods and softwoods by denning black bears (Manville 1987, Kolenosky and Strathearn 1987, Schwartz et al. 1987). Deciduous habitats likely provide important food sources for bears following hibernation. Females with cubs remained in the vicinity of the den for 2-30 days in Ontario (Kolenosky and Strathearn 1987), the time when cubs are especially vulnerable to inclement weather and predation. Principal spring foods for black bears in Wisconsin include grasses, sedges, and trembling aspen leaves and catkins (Payne et al. 1998). These foods are presumably more abundant in spring in deciduous cover types. The second significant variable was open water; bears chose den sites with more open water within 500 m than randomly available, although the absolute difference between used and available sites was minimal (Table 4). Few if any studies have reported an affinity of black bears for denning near water. Possibly, the presence of nearby water is important in the days immediately following den emergence.

LITERATURE CITED

- BEECHAM, J. J., D. G. REYNOLDS, AND M. G. HORNOCKER. 1983. Black bear denning activities and den characteristics in west-central Idaho. *International Conference on Bear Research and Management* 5:79-86.
- BULL, E. L., J. J. AKENSON, AND M. G. HENJUM. 2000. Characteristics of black bear dens in trees and logs in northeastern Oregon. *Northwestern Naturalist* 81:148-153.
- CLARK, J. D., S. G. HAYES, AND J. M. PLEDGER. 1998. A female black bear

- denning habitat model using a geographic information system. *Ursus* 10:181-185.
- DIXON, P. M. 1993. The bootstrap and the jackknife: Describing the precision of ecological indices. Pages 290-318 in S. M. Scheiner and J. Gurevitch, editors. *Design and analysis of ecological experiments*. Chapman and Hall, New York, New York, USA.
- FLEMING, K. C. 1997. A demographic comparison of a hunted and an unhunted population of black bears in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- FULLER, T. K., AND L. B. KEITH. 1980. Summer ranges, cover-type use, and denning of black bears near Fort McMurray, Alberta. *Canadian Field-Naturalist* 94:80-83.
- HAYES, S. G., AND M. R. PELTON. 1994. Habitat characteristics of female black bear dens in northwestern Arkansas. *International Conference on Bear Research and Management* 9:411-418.
- HELLGREN, E. C., AND M. R. VAUGHAN. 1989. Denning ecology of black bears in a southeastern wetland. *Journal of Wildlife Management* 53:347-353.
- KESSLER, G. P. 1994. Black bear reproductive biology, denning biology, habitat use, and movements in northern Wisconsin. Thesis, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, USA.
- KOLENOSKY, G. B., AND S. M. STRATHEARN. 1987. Winter denning of black bears in east-central Ontario. *International Conference on Bear Research and Management* 7:305-316.

- LECOUNT, A. L. 1983. Denning ecology of black bears in central Arizona. International Conference on Bear Research and Management 5:71-78.
- MANVILLE, A. M. 1987. Den selection and use by black bears in Michigan's northern lower peninsula. International Conference on Bear Research and Management 7:317-322.
- OLI, M. K., H. A. JACOBSEN, AND B. D. LEOPOLD. 1997. Denning ecology of black bears in the White River National Wildlife Refuge, Arkansas. Journal of Wildlife Management 61:700-706.
- PAYNE, N. F., B. E. KOHN, N. C. NORTON, AND G. G. BERTAGNOLI. 1998. Black bear food items in northern Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 86:263-280.
- SAS Institute Inc. 1999. SAS/STAT user's guide, version 8. SAS Institute, Cary, North Carolina, USA.
- SCHWARTZ, C. C., S. D. MILLER, AND A. W. FRANZMANN. 1987. Denning ecology of three black bear populations in Alaska. International Conference on Bear Research and Management 7:281-291.
- TIETJE, W. D. AND R. L. RUFF. 1980. Denning behavior of black bears in boreal forest of Alberta. Journal of Wildlife Management 44:858-870.
- WHITE, T. H. JR., J. L. BOWMAN, H. A. JACOBSON, B. D. LEOPOLD, AND W. P. SMITH. 2001. Forest management and female black bear denning. Journal of Wildlife Management 65:34-40.
- WISCONSIN DEPARTMENT OF NATURAL RESOURCES. 1998. Land cover of

Wisconsin: User's guide to WISCLAND land cover data. Wisconsin

Department of Natural Resources, Madison, Wisconsin, USA.

Table 1. WISCLAND land cover classifications included in 9 combined classes for analysis in this study.

<u>Aggregate class</u>	<u>WISCLAND land cover classes included</u>
Agriculture	Field crops Row crops Corn (<i>Zea mays</i>) Other row crops Forage crops
Grassland	Grassland
Coniferous forest	Jack Pine (<i>Pinus banksiana</i>) Red Pine (<i>P. resinosa</i>) White Spruce (<i>Picea glauca</i>) Mixed/Other coniferous
Deciduous	Aspen (<i>Populus</i> spp.) Oak (<i>Quercus</i> spp.) Northern pin oak (<i>Q. ellipsoidalis</i>) Red oak (<i>Q. rubra</i>) Maple (<i>Acer</i> spp.) Sugar maple (<i>A. saccharum</i>) Mixed/Other broad-leaved deciduous
Mixed deciduous/coniferous forest	Mixed deciduous/coniferous
Open water	Open water
Wetland	Emergent/Wet meadow Floating aquatic herbaceous veg. Lowland shrub Broad-leaved deciduous Broad-leaved evergreen Needle-leaved
Forested wetland	Broad-leaved deciduous Coniferous Mixed deciduous/coniferous
Shrubland	Shrubland

Table 2. Top 5 logistic regression models for den site selection by female black bears in northern Wisconsin, 1993-2002 (n=76 dens of 29 bears).

<u>Parameters in model</u>	<u>ΔAIC</u>
decid water*	0
ag decid water	0.272
decid water wetland	0.831
ag decid water wetland	0.924
decid water aspect	1.645

*decid=deciduous cover in buffer, water=open water coverage in buffer,
ag=agriculture land use in buffer, wetland=wetland cover in buffer, aspect=aspect of
topography at den

Table 3. Parameter estimates and 95% confidence intervals for the best logistic regression model describing den site selection by female black bears in northern Wisconsin, 1993-2002 (n=76 dens of 29 bears).

<u>Parameter</u>	<u>Parameter estimate</u>	<u>95% CI</u>	
		<u>Lower</u>	<u>Upper</u>
Intercept	-3.8316	-5.1417	-2.9104
Decid	0.0403	0.0244	0.0597
Water	0.0652	0.0217	0.0984

Table 4. Mean deciduous and open water coverage (ha) within 500-m of female dens and random points in northern Wisconsin, 1993-2002 (n=76 dens of 29 bears).

<u>Habitat type</u>	<u>Den site</u>	<u>Random point</u>
Deciduous	58.80	48.99
Open water	3.75	2.39