This is to certify that the

thesis entitled

An Aerial Censusing Procedure for
Elk in Michigan

presented by

Mark R. M. Otten

has been accepted towards fulfillment
of the requirements for

M.S. degree in Fisheries and Wildlife

Jonathan B. Haufler
Major professor

Date November 7, 1989

AN AERIAL CENSUSING PROCEDURE FOR ELK IN MICHIGAN

By

Mark R. M. Otten

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1989

ABSTRACT

AN AERIAL CENSUSING PROCEDURE FOR ELK IN MICHIGAN

By

Mark R. M. Otten

This project developed an aerial census procedure, using stratified random sampling, for the estimation of the number of elk (*Cervus elaphus*) in Michigan. Sampling units were delineated in 3 elk density strata based on visible ground features. Standard flight conditions and search procedures were defined and used to determine optimal allocation of sampling effort. Sightability of elk was determined through use of radio-collared animals.

Logistic regression analysis indicated that, of 5 visibility bias sources tested, only conifer cover and group size significantly ($P < 0.10$) affected observability. Simulated census data indicated that a prediction procedure, based only on conifer cover, consistently produced the best results, and an optimal sightability model was produced. Sampling units were evaluated for variance. Low density units need to be sampled more intensively than medium or high density units to decrease variance and confidence interval estimates during future elk surveys.

ACKNOWLEDGEMENTS

This project was supported by the Federal Aid in Wildlife Restoration Act under Pittman-Robertson project W-127-R, and the Michigan Department of Natural Resources.

I would like to express my deep appreciation to Dr. Jonathan B. Haufler for acting as my major professor, being available whenever he was needed, for kicking me when I needed it, and for being a friend. I would like to thank Dr. Scott R. Winterstein, not only for serving on my graduate committee, but also for providing an enormous amount of assistance with the Horvitz-Thompson variance estimates. Thanks also to Dr. Donald O. Straney for finding time in his busy schedule to serve on my graduate committee.

Special thanks to Lou "elk hunter" Bender, Jim "thick understory" Hirsch, and Gina Ballard for all of their help in collecting data, and making the field work interesting, if not exciting.

I would also like to acknowledge all of the other graduate students in the Department of Fisheries and Wildlife for eagerly sharing their expertise, knowledge, experience, and friendship with me. In particular I would like to thank Jim Hirsch, Lou Bender, Jerome Leonard, Paul Padding, Rique Campa, and Chen Jian for good times on and off campus.

I cannot fully express my sincere appreciation for all of the patient help given me by Jane Thompson -- thanks Jane.

Without the help of many persons in the Michigan Department of Natural Resources, this project would have been impossible to carry out. I am deeply indebted to Doug Whitcomb, Tom Carlson, Frank Bennett, Nels Johnson, Rick McKinnon, and Ed Langeneau for their participation in the execution of the aerial counts. I also thank helicopter pilots Sgt. John Kenny and Sgt. Lew Vassilakos for their enthusiasm and interest in this project.

Thanks to Dr. Michael Samuel for providing me with important and timely correspondence.

I extend my wholehearted gratitude to my Mom, my brothers, and my friends. I cannot possible thank them often enough or sincere enough to repay the lifetime of encouragement, understanding, support, and love that they have given me.

Finally, I would like thank Dianne Moning for being trusting and patient during our time apart, for sharing in my fears and my joys, for accepting me without conditions, and for believing in me when I did not believe in myself.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Wildlife populations have been surveyed and censused with fixed-wing aircraft and helicopters since at least 1935 (Cahalane 1938). Initially, survey flights were made to count animals occupying remote areas or areas not accessible by land vehicles (Cahalane 1938, Dice 1941). Since the late 1950's, however, aerial censusing techniques have been used to survey entire populations over extended areas, instead of just isolated animal groups. Most recently, complex census techniques and mathematical models have been developed to maximize census accuracy and to minimize flight time and man-power usage (Floyd et al. 1979, Kufeld et al. 1980, Crete et al. 1986, Houston et al. 1986, Samuel et al. 1987).

Aerial censusing is probably the only feasible and economical way to census many big game species (Anderson et al. 1980:294). To date, partial or complete aerial surveys have been used to count moose (*Alces alces*) (Gasaway et al. 1985), Alaskan brown bear (*Ursus arctos*) (Erickson and Siniff 1963), bison (*Bison bison*) (Wolfe and Kimball 1989), caribou/reindeer (*Rangifer tarandus*) (Klein and Kuzyakin 1982), elk (*Cervus elaphus*) (Buechner et al. 1951, Robel 1960), pronghorn antelope (*Antilocapra americana*) (Springer 1950), mountain goat (*Oreamnos americanus*) (Houston et al. 1986), mule deer (*Odocoileus hemionus*) (Kufeld et al. 1980), and white-tailed deer (*Odocoileus* *virginianus*) (Petrides 1953, Leon et al. 1987). Conditions under which successful aerial censuses should take place, however, can be very rigorous (Davis and Winstead 1980:225). Survey flights must be timed to optimize the probability of sighting the largest number of animals. As such, base-line information on species behavior, range, habitat usage, and response to weather must be strongly considered.

Aerial surveys, designed to produce measures of population size or density, will consistently underestimate true population size (Caughley 1974), particularly when animals occur in dense cover (Beasom 1979). Routledge (1981) cautioned that total counts based solely on a series of incomplete or partial aerial surveys cannot produce reliable population estimates. Under-estimations are primarily the result of the incomplete visibility of animals from the air. Even under optimal conditions and under stringently planned and executed procedures, aerial counts have missed 11-71% of the animals known to be present (Caughley 1977:34). In general, the visibility of an animal, or group, will decrease with decreases in group size, animal body size, movement or activity level, and observer experience; and with increases in vegetative cover, search speed and altitude, and time spent observing (Shupe and Beasom 1987). Aerial survey procedures can also be problematic due to acceptable weather conditions, short maximum flight times (fuel loading limits), and restrictions associated with animal distribution and terrain.

Improvements in aerial censusing techniques have taken 3 forms: refinements in survey methodology, calculation and application of correction factors, and a combination of both of these. Refinements in survey technique increase census efficiency to some degree, but are normally employed to maximize the probability of sighting an animal (or animal group). Many forms of technique modification have been implemented, with varying degrees of success. Before 1964, most census technique refinements were based on changes in flight characteristics, while the actual methodology remained relatively unchanged. These studies invariably used some form of line-transect flight scheme in an attempt to cover the entire study area and to count all animals present (Cahalane 1938, Saugstad 1942, Riordan 1948, Buechner et al. 1951). Improvements to this methodology have included the use of stratified random sampling with optimal allocation (Siniff and Skoog 1964), stratified random sampling with proportional allocation (Evans et al. 1966), simultaneous use of fixed-wing aircraft and helicopters (Lovaas et al. 1966), increasing search intensity (LeResche and Rausch 1974), visual recapture of marked animals (Rice and Harder 1977), stratification of the study area based on animal density (Floyd et al. 1979, Kufeld et al. 1980, Houston et al. 1986), the use of belt transects (DeYoung 1985), and the use of aerial photography (Myers and Bowen 1989). Although these and other studies utilized methods best suited to meet specific objectives, more traditional techniques may still be appropriate for some research. Current studies, for instance, often rely on stratified quadrat sampling, but Beasom et al. (1986) and White et al. (1989) contend that in many cases line-transects may still be the most efficient and effective method available.

In recent years, attempts at minimizing visibility biases have focused more on the development and application of correction factors than on further refinements in technique. Correction factors are derived from sightability functions obtained through ground-truthing procedures. Sightability functions are mathematical probabilities calculated to account for individuals missed during census fly-overs (Caughley 1974). Sighting probabilities can be developed in a variety of ways, and are usually specific for a particular animal species in an identified area. Caughley (1974) suggested calculating the partial regression of variables affecting sightability in defined density strata. Cook and Jacobson (1979) developed a method of estimating visibility bias by comparing the independent counts of 2 observers. Samuel and Pollock (1981) developed correction factors specifically for animals that occur in groups by estimating sightability through the extrapolation of an asymptotic regression function. Crete et al. (1986) corrected helicopter quadrat counts of moose by simultaneously conducting a fixed-wing count (assumed to be accurate) of the sampled quadrats. Houston et al. (1986) corrected for missed animals by applying a fixed sighting probability over the entire study area, using Caughley's (1977:47) index-manipulation-index technique. Samuel et al. (1987) used a logistic regression procedure, based on factors significantly affecting sightability, to build sighting probabilities and produce a prediction equation. Visibility bias can be a severe problem, and any accurate aerial censusing procedure must include correction factors to account for missed animals (Pollock and Kendall 1987).

The native Michigan elk herd was extirpated from the lower peninsula by 1877 (Murie 1951:28). In 1918, 7 elk were released along the Sturgeon River 6.4 km south of Wolverine (Stephenson 1942), became established, and eventually gave rise to the present elk herd in Michigan's northern lower peninsula. Since it's establishment, the elk herd has experienced periods of rapid growth and periods of severe decline (Moran 1973, Beyer 1987). The Michigan Department of Natural Resources (MDNR) has used a combined air and ground census in an attempt to count every elk within the range (T. Carlson, pers. commun.). This technique was first used in 1975, producing a herd estimate of 200 animals (Ruhl 1984). Through implementation of the Elk Management Plan (MDNR 1984) the elk herd has increased steadily from 850 in 1984 to 940 in 1985, 950 in 1986, 1000 in 1987 (Beyer 1987:123), and 1020 in 1988 (E. E. Langeneau, pers. commun.).

The census method used by the MDNR provided an approximation of elk numbers and constituted a considerable investment of time, money and manpower. This paper describes a new censusing technique that was developed to increase accuracy and reduce expenditures of future elk surveys. This methodology utilizes standard search procedures and sightability correction factors to produce a statistically-based herd estimate (with confidence intervals) solely from helicopter counts. This technique will allow MDNR managers to accurately survey the entire elk herd in a more efficient manner.

OBJECTIVES

The primary objective of this study was to develop an accurate, stratified random, aerial censusing technique that would provide a statistically based estimate of the size of the Michigan elk herd. In addition, several other objectives were identified.

1. To identify those factors that significantly ($P < 0.10$) affect the visibility of elk from the air.

2. To divide the elk range into strata of high, medium, and low elk density and develop a standard systematic sampling procedure for the random survey of those strata. This included the standardization of helicopter flight speed, altitude, and pattern, and the standardization of acceptable weather conditions.

3. To develop a standard correction factor calculation and application procedure from data collected during aerial surveys.

4. To calculate population size and variance estimates for the Michigan elk herd, and 95% and 90% confidence intervals around the population estimate.

5. To develop an overall elk censusing procedure that is relatively inexpensive and can be carried out with helicopter flights alone.

STUDY SITE DESCRIPTION

The present elk range encompasses approximately 1,000 km^2 of semi-wild land in Michigan's northern lower peninsula. The area spans portions of Cheboygan, Montmorency, Otsego, and Presque Isle counties, and is centered on the 33,500 ha Pigeon River Country State Forest (PRCSF) (Fig. 1). Approximately one-half of the area is in private ownership, primarily in the western and southwestern portions of the range. Private hunting clubs, each covering 259 to 5466 ha, presently make up about 20% of privately-owned land, and nearly 25% of the central elk range (Moran 1973:4).

The Michigan elk range exists on the Presque Isle Rolling Plain, Emmet-Alcona Hill Land, and Huron Lake-Border physiographic region (Sommers 1977). The podzol soils, ranging from low fertility dry sands on outwash plains to medium-high fertility sandy loams on till plains (Moran 1973:4), are of Pleistocene origin (Sommers 1977). The area is within the Lake Huron super-watershed and is drained by the north-flowing Black, Sturgeon, and Pigeon Rivers.

The Michigan elk range is characterized by relatively mild summers and fairly cold winters (Sommers 1977). The mean annual temperature on the elk range is 5.6°C (Strommen 1974), with yearly lows occurring in January and yearly highs occurring in July (NOAA 1988). Like most years, 1987 and 1988 showed little variation in mean monthly

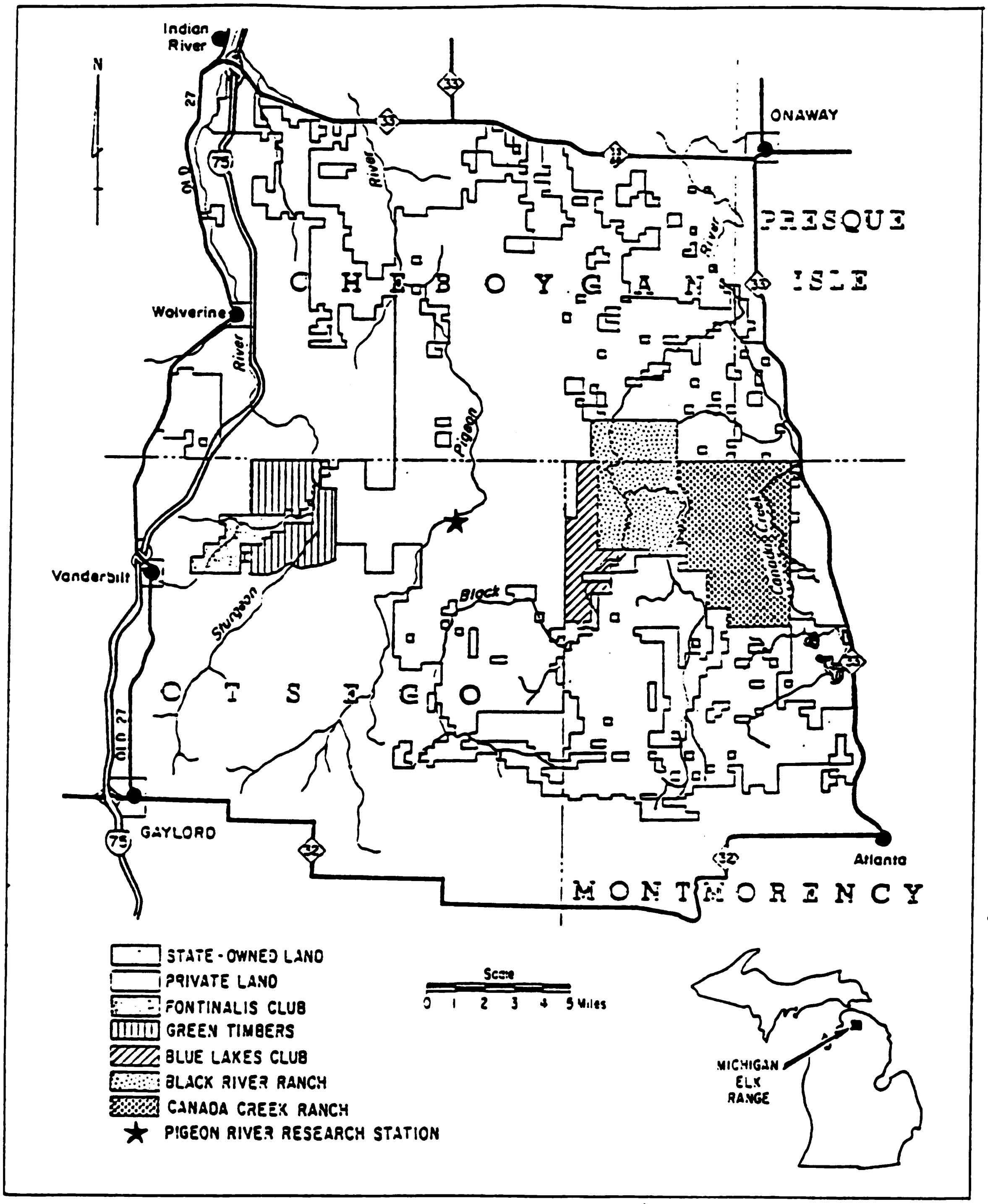

Fig. 1. Location and principle land ownerships of the Michigan elk range (Moran 1973).

temperatures from the 1922-1988 long-term average (Fig. 2). Freezing temperatures may occur as late in the spring as the end of May, and as early in the fall as mid-September (NOAA 1987). Mean annual rainfall is 74.9 cm, with 95% occurring between May and October (Strommen 1974). There can be large variations in total monthly precipitation from year to year, but September, on average, was the wettest month for the period 1922-1988 (Fig. 3) (NOAA 1988). Mean annual snowfall is 246.6 cm, with an average ground cover of 15 cm by the end of December (Michigan Weather Service 1974).

Vegetation types are generally well mixed due to rapid variations in moisture level, soil fertility, and management intensity. Lowland areas are dominated by white cedar (Thuja occidentalis), black spruce (Picea mariana), alder (Alnus glutinosa), balsam fir (Abies balsamea), and dogwood (Cornus spp.) (Moran 1973). Upland areas are characterized by well mixed stands of jack pine (Pinus banksiana), red maple (Acer rubrum), aspens (Populus spp.), white pine (Pinus strobus), sugar maple (Acer saccharum), and red pine (Pinus resinosa) (Moran 1973). Transitional areas are dominated by willows (Salix spp.), poor quality red maple, poor quality aspens, and white birch (Betula papyrifera) (Moran 1973). Moran (1973:7) broke the physiography of the elk range into 6 general classes: sandy outwash plains, outwash plain-morainic ecotones, steep morainic slopes, morainic uplands, riverbanks and bottomlands, and coniferous swamps.

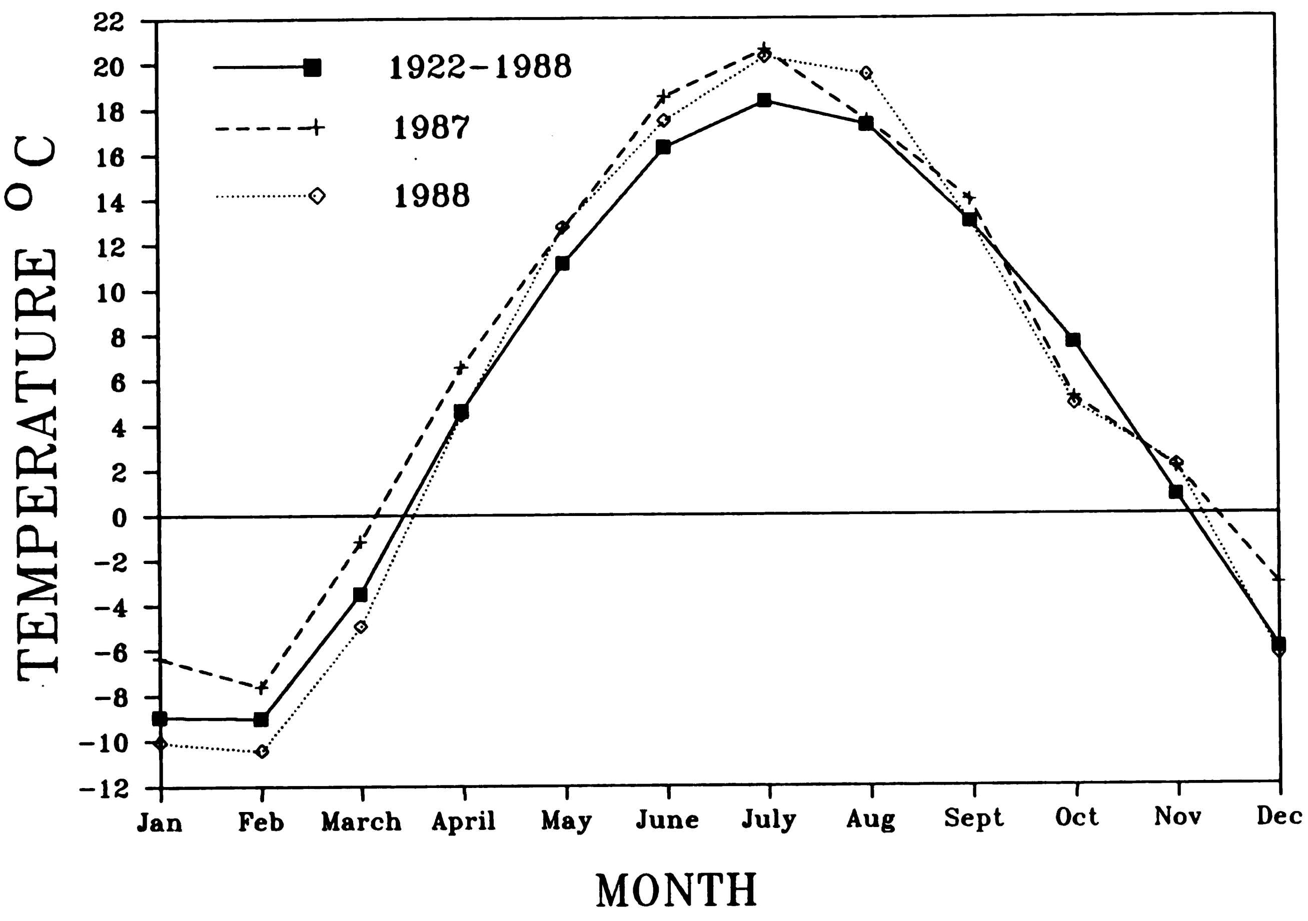

Fig. 2. Mean monthly temperatures recorded at Vanderbilt, Michigan for the long-term period 1922-1988, and for the years 1987 and 1988.

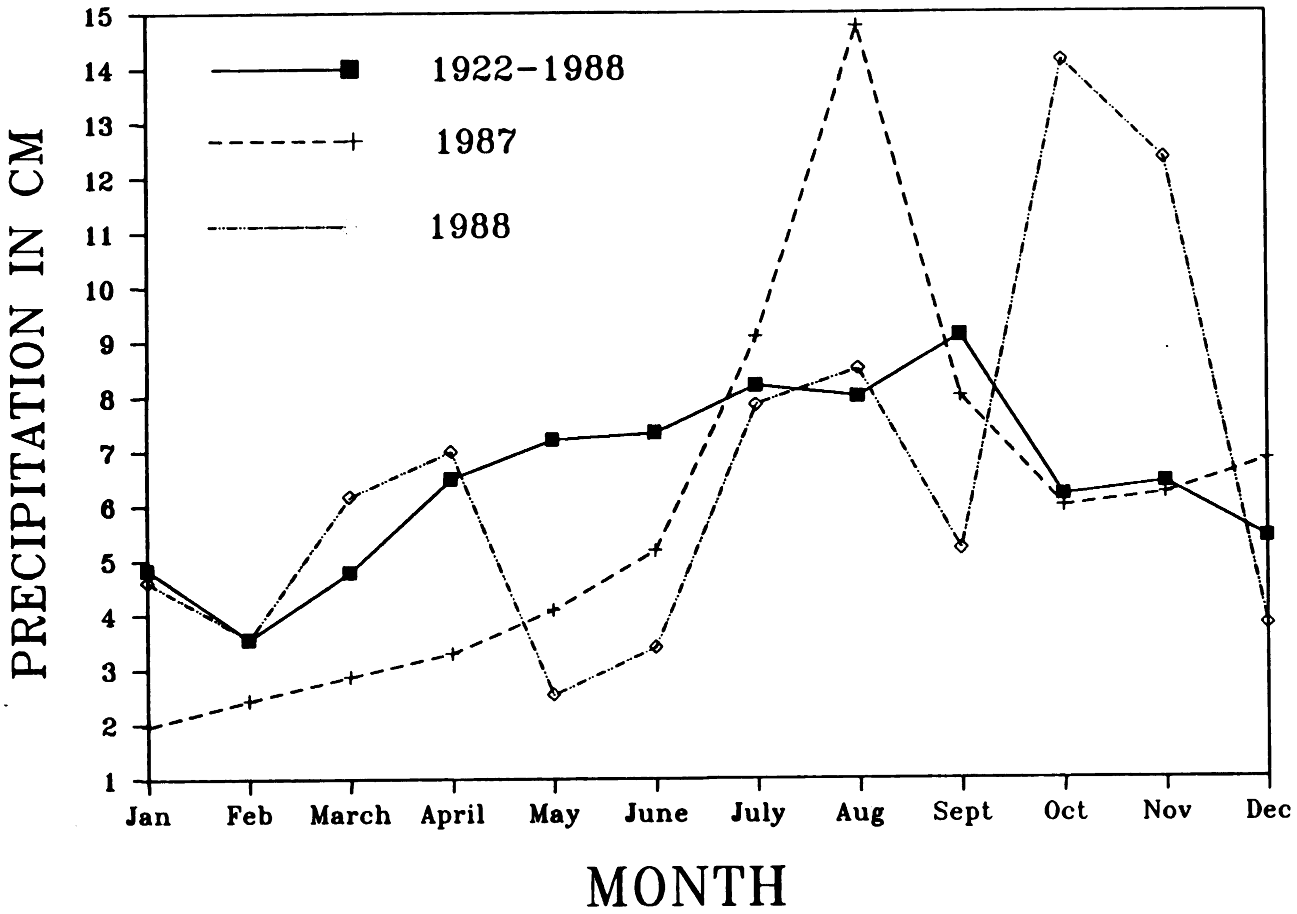

Fig. 3. Total monthly precipitation recorded at Vanderbilt, Michigan for the long-term period 1922-1988, and for the years 1987 and 1988.

METHODS

Improvements in the aerial censusing of elk in Michigan involved both an improvement in survey technique, and the use of correction factors to account for visibility bias. Technique improvements included a standardization of flight/weather conditions, a standardization of helicopter flight characteristics, the construction of sampling unit boundaries to facilitate the stratification of the survey area, and the calculation of variance estimates for the optimal allocation of sampling effort. Correction factors, designed to account for animals missed during censusing, were developed through sightability modelling procedures, and judged for accuracy through computer simulations.

Sampling Unit Boundaries

The present elk range encompasses a large area in Michigan's northern lower peninsula, spanning portions of Cheboygan, Montmorency, Otsego, and Presque Isle counties. Since an area this size could not be totally surveyed in a relatively short period of time, it was necessary to exclude portions of the range with occasional occurrences of small numbers of elk, stratify the remaining area, and construct sampling units within each stratum. Locations of elk groups sighted during the previous 5 MDNR elk counts (1984 to 1988) were plotted on a 1:84,480 map to determine elk distributions and densities throughout the range.

Areas where density was below 1 elk per 10 km^2 were excluded from sampling and flight considerations. As a result, the area to be surveyed encompassed 1,015.5 km^2 of the primary elk range lying east of U.S. Interstate 75, north of the Wilkinson Road/M-32 network, west of the Hall Road/Voyer Lake Road/Upper Rainey River (west branch) network, and south of the Rondo Road/Afton Road/Pigeon River Road/M-33/Hacket Lake Road network (Fig. 4, Fig. 5).

The survey area was then divided into strata of observed low, medium, and high elk density, as developed by Siniff and Skoog (1964) and modified by Houston et al. (1986). Stratification is a technique used to improve sampling precision, but requires some knowledge of animal distribution so that sampling units can be grouped into homogenous strata. Knowledge of elk distribution and densities was provided by the Michigan Department of Natural Resources through previous elk count data. Each of the 3 density strata were further broken down into individual sampling units, averaging 10.8 km^2 in area (Table 1, Appendix Table A1). Boundaries between density strata and individual sampling units were constructed using natural and man-made surface features easily visible from the air during winter (Fig. 4, Fig. 5). Major roads, creeks, and rivers were used primarily, but some boundaries included hilltops, swamp conifer stands, and ridges. Density strata and sampling unit boundaries were marked on a 1:84,480 map of the entire Michigan elk range. The area of each sampling unit was determined using the Bryant dot-grid method (Bryant 1943).

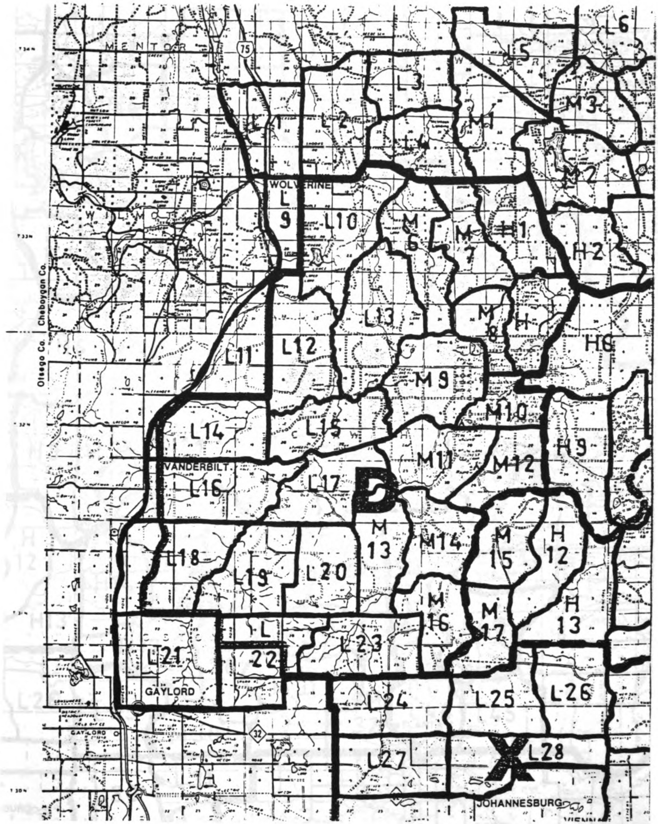

Fig. 4. Western sampling units of low, medium, and high elk density constructed for the aerial censusing of elk in Michigan.

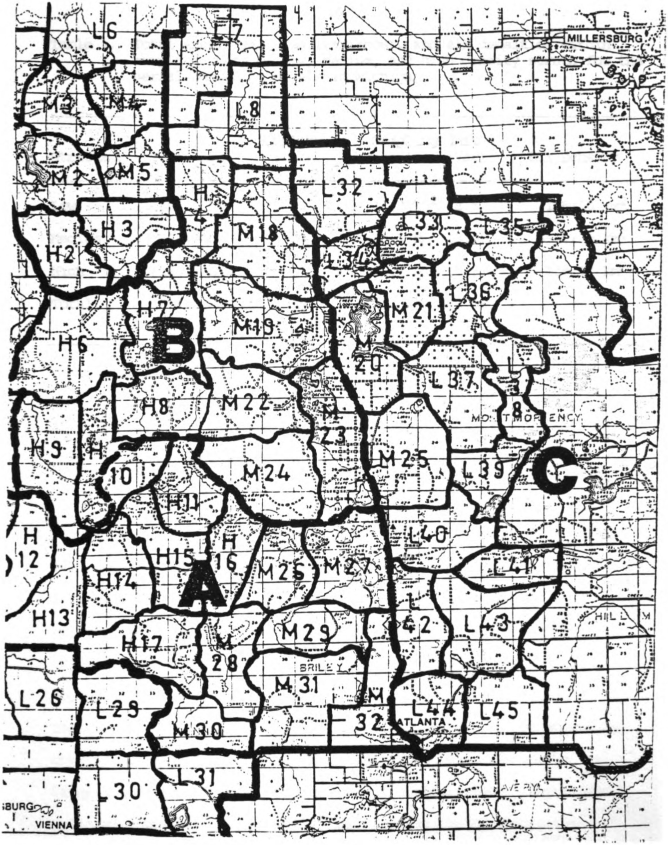

Fig. 5. Eastern sampling units of low, medium, and high elk density constructed for the aerial censusing of elk in Michigan.

Table 1. Total area, mean area (variance), and elk densities within sampling units of low, medium, and high density strata for the aerial censusing of elk in Michigan.

Stratum	Total Area	Sampling Units	Sampling Unit Mean Area (Var)	Elk Density
Low	506.1 km^2	45	11.2 km^2 (8.6)	1-5/10 km^2
Medium	328.5 km^2	32	10.3 km^2 (8.6)	6-10/10 km^2
High	180.9 km^2	17	10.6 km^2 (5.2)	11+/10 km^2
Total	1015.5 km^2	94	10.8 km^2 (8.0)	-----

Flight Conditions and Characteristics

Helicopter flights over the primary elk range were made to determine the sightability of elk (for correction factor development) and to gain estimates of between sampling unit variance for the optimal allocation of sampling effort throughout the low, medium, and high density strata. All flights were made in a Bell Jet Ranger 206-A helicopter (Bell Aviation, Ft. Worth, TX), with counts and observations performed by the aircraft pilot and a Michigan DNR biologist.

Wyoming Game and Fish Department (1982:56) suggested surveying elk only when a standard set of weather conditions could be met. Optimally, survey flights should be made when ground temperatures are at or above -12°C (10°F), immediately after a fresh snowfall, with snow depths of less than 60 cm, under clear skies (high, thin clouds permitted), and with little or no air turbulence. Because of time restraints, this set of standard weather conditions could not be strictly followed during this project. All helicopter flights were made when ground temperatures were at or above -23°C (-10°F) (at Gaylord airport), under clear skies, and when wind speed was less than 27 km/hr. Recommended minimum ground temperature, maximum snow depth conditions, and fresh snow cover conditions could not be precisely followed. Wyoming Game and Fish Department (1982) allows for winter elk surveys anytime between 1 December and 15 March. Optimally, elk censuses in Michigan should be carried out as close to 1 December as possible, when elk groups are large and make minimal use of dense swamp conifer stands (Beyer 1987). Helicopter availability, however, only allowed for flights between 7 January and 2 March.

Helicopter flights were made during 9 days between 7 January and 9 February, 1988 and 9 days between 7 February and 2 March, 1989. All flights made during 1988 focused on sightability model development, while flights made in 1989 focused on sightability modelling, variance estimation, and sampling intensity determination. All helicopter surveys were carried out between 9:30 and 15:30 and generally consisted of one 3-hour morning session and one 3-hour afternoon session. A 1-hour break was taken between sessions to allow for aircraft refueling and observer relaxation.

To insure consistency during the sampling of density units, a standardized search procedure was developed. Sampling units were surveyed using consecutive parallel transects across the entire unit, along search lines 250 m apart (Fig. 6) Spacing of search lines produced a band 1/4 km in width, allowing observers to search each band completely and with similar intensities. The direction of search varied per sampling unit based on unit shape, wind speed and direction, sun position, and location of the next unit to be sampled. The final decision as to flight direction was delegated to the pilot, based on his ability to keep a constant, standardized ground speed of 97-113 km/hr (60-70 miles/hr) and an altitude of 46-61 m (150-200 ft).

Sightability Model Data Collection

One of the major problems with any aerial censusing procedure is the inability of observers to count every animal during survey flyovers (Caughley 1977:36). This form of visibility bias usually leads to an under-estimation of true animal abundance or density. Several

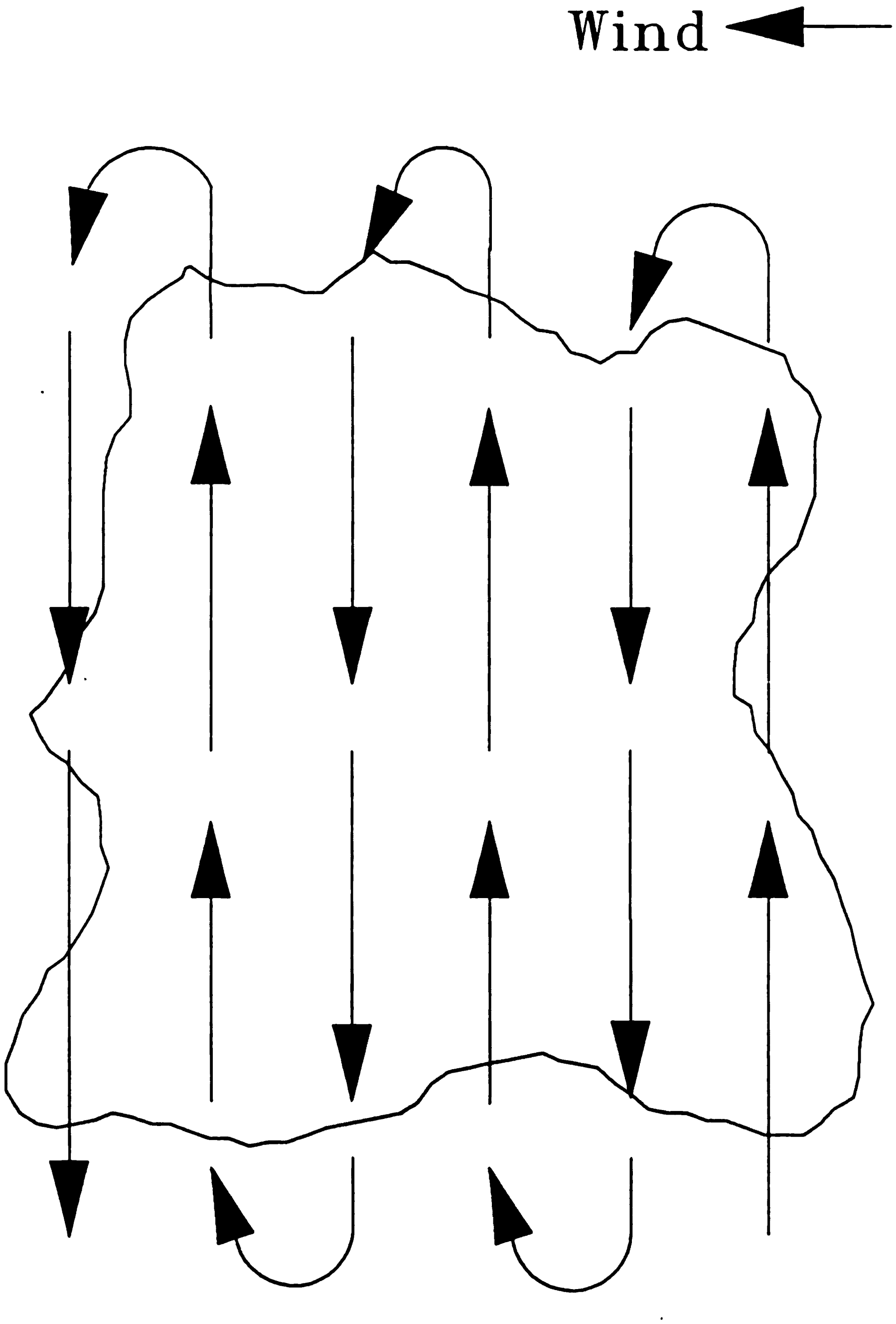

Fig. 6. An example of 1/4 km interval helicopter search transects over a hypothetical sampling unit for the aerial censusing of elk in Michigan.

procedures have been developed to account for those animals missed during a census. Most of these procedures involve the determination of correction factors that are applied directly to visual counts (Cook and Jacobson 1979, Crete et al. 1986, Houston et al. 1986, Samuel et al. 1987). The development of correction factors or visibility bias adjustments, however, require an independent accurate count of surveyed animals for comparison with counts obtained from the air. Sightability models developed for the aerial censusing of elk in Michigan were based on this type of procedure.

Michigan State University has been conducting telemetry studies of elk within and around the Pigeon River Country State Forest since 1981 (Beyer 1987:14-16). Between 1 January, 1988 and 10 March, 1989, 32 individually collared elk were available for use in sightability model development. During this period, collared elk were located at least every 3 weeks, with intervals between locations kept to 1 week or less prior to aerial surveys, and to 3 days during surveys. Close monitoring of all collared elk allowed ground crews to more easily find individual animals, and helped determine the sampling units to be surveyed for visibility bias estimation.

Data for the development of sightability models was collected using the standard helicopter search pattern and under the weather conditions already described. Flights were made during 9 days between 7 January and 9 February, 1988 and during 9 days between 7 February and 2 March, 1989. Sampling units to be surveyed during these periods were chosen based on the current location of collared elk. Only units containing at least 1 radio-collared animal were surveyed. The specific sampling units chosen for censusing were based on unit location, unit size, and estimated flight time between units, in an attempt to maximize data collection efficiency. In general, 3 to 4 closely spaced sampling units were surveyed during each of two 3-hour daily flight sessions. Individual sampling units were not surveyed on consecutive days, and all units containing collared elk were surveyed at least twice.

The development of elk sightability models was based on data gathered on the accuracy of aerial counts of collared animals (and their associated groups) as compared to ground or aerial counts of the same groups. Helicopter crews consisted of 3 members: a Michigan Department of Natural Resources observer, a pilot/observer, and a locator/radioman. The helicopter was equipped with a 2-element yagi antenna and a TR-2 portable receiver matched with a TS-1 scanner (Telonics, Mesa, AZ) to allow the helicopter locator to closely monitor all collared elk in each designated sampling unit. This crew member was in constant direct communication with ground crew members using hand-held two-way radios, but did not participate in searching for elk, and did not communicate collared elk locations to aerial search crews. Ground crew members were also outfitted with 2-element antennas and TR-2 portable receivers to closely monitor elk in selected units.

Once units to be sampled were chosen and ground crew members were in position actively monitoring elk in those units, helicopter counts were made. Surveys followed standard flight procedures until an elk group was sighted by helicopter observers. At this point, an attempt was made to count all elk by deviating from the standard pattern, reducing altitude, and circling the observed group. Air crews recorded elk group size, bull/cow/calf composition, time of day, parameters on vegetation stands occupied by the group, location (legal description), and behavior class of sighted groups, where 1 = bedded, 2 = standing, and 3 = moving. Vegetation stand parameters recorded included an estimation of the percentage of conifer cover, based on 4 conifer cover classes, where, 1 = 0-25%, 2 = 26-50%, 3 = 51-75%, and 4 = 75%+. Overall stand age class, where 1 = sapling, 2 = pole, and 3 = mature, and conifer age class (1 = sapling, 2 = pole, and 3 = mature) were also recorded as vegetation stand parameters. The presence or absence of a collared in an observed group was determined by the helicopter locator and communicated to helicopter observers after the group had been completely counted. Sighted elk groups were carefully observed from the air to assure that all animals were counted. Once pertinent data on each elk group was recorded, helicopter crews resumed the standard flying pattern at the point where it was initially broken off.

If an elk group containing a radio-collared elk was not observed from the air, as determined by the helicopter locator, the flight pattern was not interrupted. Upon completing the search of a sampling unit, collared elk not observed were located from the helicopter or by ground crews, and data gathered on it. Ground crew members recorded elk group size, time of day, stand vegetation parameters, location, and behavior for groups not observed from the air.

This procedure was repeated for all units sampled during each day. Upon locating groups missed during aerial surveys, ground crews immediately proceeded to locate and monitor collared elk in other designated sampling units. In general, each ground crew member was able

to monitor elk in 1 unit during morning flights, and 1 unit during afternoon flights, utilizing aircraft refueling breaks to move between chosen units.

Sightability Model Development

Correction factors designed to account for animals missed during the aerial censusing of elk in Michigan, were developed in 3 distinct stages. In stage 1, data collected on the aerial sightability of elk was analyzed by forward stepwise logistic regression (Judge et al. 1980). In stage 2, factors found to significantly affect observability were used to build sightability models as described by Samuel et al. (1987). In stage 3, constructed sightability models were used to generate correction factors, again following the procedures developed by Samuel et al. (1987).

Logistic regression analysis was performed on collected sightability data using the S.A.S. statistical package (Helwig and Council 1979) on the Michigan State University I.B.M. mainframe computer. Logistic regression analysis performs 2 important tasks. First, it judges, at a defined level of significance, which of the independent variables tested, significantly affects the dependent variable. Second, it produces regression coefficients associated with those significant independent variables that can be used to construct prediction functions. Initially, the entire data set collected was analyzed to reveal which variables significantly ($P < 0.10$) influence elk sightability. Conifer cover class, group size, conifer age class, and stand age class were defined as independent variables, while the classification of elk groups as "seen" or "not seen" was defined as the dependent variable. Prior to regression analysis, elk behavior was eliminated from consideration as an independent variable.

In order to determine the effects different model conditions had on resultant coefficients, 6 additional logistic regression analyses were performed. In subsequent analyses, portions of the data set were omitted, specific independent variables were not considered, and the level of significance was redefined. Each analysis included 1 or more of the model conditions listed above, but retained the classification of elk groups as "seen" or "not seen" as the dependent variable. The data set conditions and regression parameters used for each analysis are presented in Table 2.

An elk sightability model was developed from the results of each logistic regression analysis performed. For instance, the results of analysis 1 were used to build sightability model 1. In this way 7 distinct sightability models were constructed. Only those independent variables determined to significantly influence elk visibility were used to build each specific model. Development of all sightability models was patterned after the work of Samuel et al. (1987). If regression analysis found group size and conifer cover class to be the only factors significantly influencing sightability, the model would take the form:

$$u = C + Cg(\text{group size}) - Cc(\text{conifer cover class})$$

where,

u = the predicted sightability value
C = the regression constant
Cg = the regression coefficient for group size
Cc = the regression coefficient for conifer cover class.

Table 2. Composition of data sets, and independent variables included in 7 logistic regression analyses for the aerial censusing of elk in Michigan. An "X" indicates conifer classes included in data sets.

Analysis	Conifer Class 1	2	3	4	Other Independent Variables: Groups Size	Conifer Age	Stand Age	Alpha
Model 1	X	X	X	X	Included	Included	Included	0.10
Model 2	X	X	X	X	Included	Omitted	Omitted	0.25
Model 3	X	X	(X	)	Included	Included	Included	0.10
Model 4	X	X	(X	)	Omitted	Omitted	Omitted	0.10
Model 5	X	X	X	---	Included	Included	Omitted	0.10
Model 6	---	X	X	X	Included	Included	Included	0.25
Model 7	---	---	X	X	Included	Included	Included	0.10

The conifer cover class coefficient is a negative number since increases in vegetative cover decrease sightability (Cook and Jacobson 1979). Conversely, the group size coefficient is positive since an increase in animal group size increases the probability of sighting that group from the air (Samuel et al. 1987) If the logistic regression procedure determined that stand age class also had a significant influence on sightability, the model would take the form:

u = C + Cg(group size) - Cc(conifer cover class) - Cs(stand age class).

where,

u, C, Cg, and Cc are defined as above
Cs = the regression coefficient for stand age class

Here the stand age class coefficient is also negative since an increase in the age of the dominant vegetation decreases the sighting probability (Caughley 1974). The sightability value (u) is determined by inserting observed group size, conifer cover class, and stand age class into their respective places and carrying out the arithmetic. In addition, the derived model could be expanded to include visibility differences caused by conifer age. For this variable, the resultant regression coefficient would also be negative since increases in vegetation age decrease animal visibility.

Conversion of all 7 elk sightability models to correction factors was accomplished using the procedure given by Samuel et al. (1987). In each case, a sighting probability function was first derived through the formula:

$$y = \frac{\exp^{u}}{1 + \exp^{u}}$$

where,

y = the sighting probability
u = the sightability value

From these functions then, correction factors were calculated by inverting each sighting probability (1/y). Correction factors were then applied to actual visual counts to arrive at an estimation of elk abundance in the units sampled.

Computer Simulations

Judgement of models, based on accuracy and stability, was accomplished through prediction calculations and through computer simulation. Initially, models were judged based solely on how accurately they predicted the total number of elk in each of the 4 conifer cover classes. Predicted elk numbers were calculated by applying correction factors, determined for all 7 models, to counts of elk groups actually seen by helicopter crews. Since the data set used to build model 5 omitted elk observations in conifer class 4, a mathematical probability calculation was used to predict elk numbers in that class (Appendix II). Each prediction was then compared to the total number of elk in groups (seen and not seen) containing a collared animal, for each of the 4 conifer cover class. In this manner, models that accurately and consistently predicted known elk totals from observed elk totals, could be separated from those models that did not.

Accurate and consistent models, model parts, and mathematical probability calculations were used to construct 4 elk prediction procedures of varying complexity. Procedure I utilized a single model to predict elk numbers, procedures III and IV utilized parts of 2 models to predict elk numbers, while procedures II utilized parts of 3 models to predict elk numbers, as described below.

Procedure I: All cover classes predicted with model 1.

Procedure II: Cover classes 1, 2, and 3 predicted with model 5; cover class IV predicted mathematically (Appendix II).

Procedure III: Cover class 1 predicted with model 4; cover classes 2 and 3 predicted with model 6; cover class 4 predicted mathematically.

Procedure IV: Cover class 1 predicted with model 4; cover classes 2 and 3 predicted with model 3 (in this procedure cover class 4 is combined with class 3).

All procedures were then tested for accuracy and consistency with simulated elk censusing data. The purpose of these simulations was threefold: to determine which procedure was most accurate and unbiased, to determine whether single model or multiple-model procedures handled elk census data better, and to assess the ease with which complex procedures could be used.

All simulations were performed with the Lotus 1-2-3 personal computer software package, version 2.0 (LeBlond and Cobb 1985). One hundred groups of elk were placed within all conifer classes, using 8 ratio schemes (Table 3). This was done to test model performance under various elk group distributions that were either observed in the field, judged probable to occur, judged possible to occur, judged too extreme to occur, or judged too uniform to occur (Table 3). Elk group sizes were randomly generated, within specified boundaries, for each conifer cover class. Conifer cover class 1 (0-25% conifer) contained groups from 1 to 50 animals in size, cover class 2 (26-50% conifer) contained groups 1 to 30 animals in size, cover class 3 (51-75% conifer) contained groups from 1 to 20 animals in size, and cover class 4 (>75% conifer) contained groups from 1 to 15 animals in size. Once the number and size of groups present in each conifer cover class were determined, each group was randomly designated as "seen" or "not seen". Simulations were constructed such that from 70-95% of groups in cover class 1 were "seen", from 65-90% of groups in cover class 2 were "seen", from 30-60% of groups in cover class 3 were "seen", and from 0-20% of groups in cover class 4 were "seen". These ranges reflect the percentage of groups actually seen during data collection, and agree with ranges given by T. Carlson (pers. commun.). Procedures I-IV were then used to predict elk numbers in each conifer cover class solely from the sizes of elk groups designated as "seen". Total elk predicted by each procedure for the 4 conifer cover classes was then compared to the total number of elk known to be present in each class. The number of elk predicted in all classes by each procedure and the number of elk known to be present in all classes was also compared.

Table 3. Distribution of 100 elk groups within 4 conifer cover classes of 8 simulations designed to test prediction procedures developed for the aerial censusing of elk in Michigan.

Simulation (Distribution)	Conifer Cover Class (% Conifer Cover)			
	1 (0-25%)	2 (26-50%)	3 (51-75%)	4 (75%+)
Simulation 1 (Extreme)	31	32	32	5
Simulation 2 (Even)	25	25	25	25
Simulation 3 (Observed)	46	20	14	20
Simualtion 4 (Probable)	50	18	18	14
Simulation 5 (Possible)	60	14	13	13
Simulation 6 (Extreme)	61	25	10	4
Simulation 7 (Even)	31	23	23	23
Simulation 8 (Possible)	40	20	20	20

Results of computer simulations were analyzed to evaluate the performance of all procedures based on average bias, number of estimates within 50 of the known total, range of estimates (distance between the minimum and maximum estimate), and overall bias. A chi-square test of significance was performed to test whether models were biased under each simulation. Bias tendencies were given the most consideration when judging prediction procedures, followed by average bias, and range.

Population and Variance Estimation

During flights made between 23 February and 2 March, 1989, units of low, medium, and high elk densities were surveyed to estimate variances for the optimal allocation of sampling effort, and to estimate Michigan elk herd size. Units to be surveyed were chosen, by strata, using a random number generator. Ten low density, 14 medium density, and 14 high density units were surveyed using the standardized search procedures described above. A Michigan DNR observer, and a pilot/observer counted and recorded all animals seen during helicopter flyovers. Elk counts were not corrected for visibility bias until all units had been surveyed.

An estimate of the total elk population was made from the data collected from 23 February through 2 March, 1989. Since the sampling units used in this census were of unequal size, the expanded population estimate was based on the ratio of area sampled to total area (Caughley 1977). The number of elk seen within a particular conifer class of each stratum were summed and the total corrected using the prediction procedure found to be most appropriate, based on sightability data collected in 1988-89. As such, 12 distinct counts were corrected, 1 for each of the 4 conifer classes within each of the 3 density strata (i.e. conifer class 1 of the low stratum, conifer class 2 of the medium stratum, and conifer class 3 of the high stratum). The corrected counts for each conifer class within a particular stratum were summed to arrive at a total corrected count for that stratum. Corrected elk counts were multiplied by the inverse percentage of area actually flown within each stratum, providing an estimate of the number of elk present within each stratum. Summing the individual stratum estimates provided an estimate for total elk numbers over the entire range.

A modified non-response Horvitz-Thompson estimator, as presented by Steinhorst and Samuel (1989), was used to estimate variance from population helicopter surveys. The estimator partitions total variance into components of survey error, sightability error, and model error. The survey component estimates error due to survey methodology and sampling effort allocation. The sightability component estimates error due to visibility bias, that is, the inability of aerial counters to sight all animals present. The model component estimates error associated with the sightability model used to correct elk counts.

Variance estimates were calculated for each of the 3 density strata and then summed as an estimate of overall unit variance. Total variance was then used to construct 95% and 90% confidence intervals at 60 degrees of freedom. A coefficient of variability (Steel and Torrie 1980:27) was calculated from population and variance estimates for comparison with similar estimates from other aerial wildlife census research.

Census Costs

Total costs were estimated for both the current Michigan DNR elk censusing technique and the stratified aerial sampling method used in this study. A direct comparison was made between these two estimates using the following parameters:

Helicopter rental -- $150.00/hr

Helicopter fuel -- $1.85/gallon

Pilot lodging -- $65.00/day

MDNR personnel salary -- $25.00/hour/man

Snowmobile rental -- $78/machine/day

Michigan DNR census cost estimates include helicopter rental for 17-31 hours, fuel costs for 2-4 days (75 gallons/day) of flight, pilot lodging for 1-3 nights, 20 MDNR personnel salaries for 2-4 days (9 hours/day), and rental of 7 snowmobiles for 2-4 days. Stratified aerial census cost estimates include helicopter rental for 31-45 hours, helicopter fuel costs for 4-6 days (150 gallons/day) of flight, pilot lodging for 3-5 nights, and 2 MDNR personnel salaries for 4-6 days (9 hours/day). Since the stratified aerial method requires no snowmobile rental, this additional expense need not be included. Due to difficulties in ascertaining the cost of operating wheeled vehicles this expenditure has not been included for the MDNR census method cost estimate.

RESULTS

Data Collection

Fifty-five sampling units (17 different) were flown on 18 days in 1988 and 1989 for sightability model development. A total of 775 elk in 79 groups were observed from the air, the ground, or both. A total of 638 elk in 52 groups (12.3 elk/group) were seen by aerial crews, while 137 elk in 27 groups (5.1 elk/group) were not seen during flyovers. Of the elk groups seen, 32 (61.5%) were in vegetation where conifer cover was not more than 25% (cover class 1), 13 (25%) were in stands of 26-50% conifer cover (cover class 2), 5 (9.6%) were in stands of 51-75% conifer cover (cover class 3), and 2 (3.8%) were in stands where conifer cover was more than 75% (cover class 4). Of the elk groups not seen by aerial crews, 4 (14.8%) were in conifer cover class 1, 3 (11.1%) were in conifer cover class 2, 6 (22.2%) were in conifer cover class 3, and 14 (51.9%) were in conifer cover class 4. Appendix Table A2 summarizes the data collected for sightability model development.

Helicopter survey flights were made to estimate between sampling unit variance, and to determine the optimal allocation of sampling effort through low, medium, and high density strata. Fourteen of 17 high density units, totalling 150.4 km^2 (83.1% of total strata area, 82.4% of strata units), were surveyed, counting 252 elk in 25 groups. Fourteen of 32 medium density units, totalling 139.8 km^2 (42.6% of strata area, 43.75% of strata units), were surveyed, counting 101 elk in 13 groups. Ten of 45 low density units, totalling 97 km^2 (19.2% of strata area, 22.2% of strata units) were surveyed, counting 74 elk in 10 groups. Appendix Table A3 summarizes the data collected for the estimation of population size and variance.

Sightability Models

A sightability model was developed based on logistic regression analysis and included the calculated coefficients for factors found to significantly ($P < 0.10$) influence elk visibility from the air. Five possible sources of visibility bias were recorded during data collection and used as independent variables during regression: conifer cover class, group size, conifer age class, dominant vegetation (stand) age class, and animal behavior class. The dependent variable for regression analysis was the dichotomous classification of elk groups as "seen" or "not seen". Before sightability modelling was initiated, animal behavior data was judged to be incompatible with the rest of the data set and was not included in the logistic regression analysis.

The initial step of the logistic regression analysis indicated that only conifer cover class ($P < 0.001$) significantly influenced elk visibility. Elk group size, conifer age class, and stand age class showed no significant influence on sightability. Final coefficients, thus, included the regression constant (3.698) and the conifer cover class coefficient (-1.333). Model 1 was constructed using these coefficients and took the form:

$$u = 3.698 - (1.333)(\text{conifer cover class})$$

The final coefficient for conifer cover classes was negative due to the inverse relationship between conifer cover and animal visibility from the air (Caughley 1974).

Correction factors specific for each conifer cover class were then calculated as described by Samuel et al. (1987). The correction for elk groups seen in conifer cover class 1 was: (1.094)(ES), where ES = the total number of elk seen in that cover class. The correction for elk groups seen in cover classes 2, 3, and 4 were: (1.355)(ES), (2.353)(ES), and (6.135)(ES), respectively. Corrected elk counts for each conifer cover class are presented in Appendix Table A4.

Six additional models were developed using logistic regression analysis by eliminating specific independent variables, or by eliminating portions of the data set before analysis. All models were constructed using some or all of the defined conifer cover class, except models 3 and 4, which combined data from classes 3 and 4 into a single class representing conifer cover of 50% or more.

Table 2 summarizes the conditions imposed on the data set prior to regression analysis. Table 4 summarizes the final coefficients of factors significantly influencing elk visibility, as determined with 7 logistic regression analyses. Models 2 through 6 were built using significant variable coefficients in the same manner as model 1, and as described in the methods.

Since cover class 4 was omitted from the data set used to build model 5, elk predictions for this class were made with a mathematical probability calculation (Appendix II). All models were judged for accuracy by comparing the total number of elk known to be present in

Table 4. Significant logistic regression coefficients of 7 sightability models developed for the aerial censusing of elk in Michigan.

Model	Constant	Cover Class	Group Size
1	3.698	-1.333 ($P < 0.001$)	———
2	2.481	-1.168 ($P < 0.001$)	0.119 ($P < 0.125$)
3	4.207	-2.374 ($P < 0.007$)	0.344 ($P < 0.037$)
4	4.041	-1.634 ($P < 0.001$)	———
5	3.338	-1.115 ($P < 0.007$)	———
6	2.847	-1.664 ($P < 0.003$)	0.345 ($P < 0.036$)
7	5.108	-1.764 ($P < 0.069$)	———

each conifer cover class with elk numbers predicted by each model. Only those elk groups that were actually seen by aerial crews were used in each model to predict elk numbers (Table 5).

<u>Computer Simulations</u>

The results in Table 5 were used to construct 4 elk prediction procedures, based on logistic regression derived sightability models. These procedures included whole models, portions of models, combinations of models, and mathematical probabilities. Procedures utilizing several different models were constructed to determine if an elk prediction methodology based on multiple models, though more complex to use, would more accurately and consistently account for missed animals. The constitution of each prediction procedure, based on the 4 conifer cover classes, is given below.

Procedure I: All cover classes predicted with model 1.

Procedure II: Cover classes 1, 2, and 3 predicted with model 5; cover class 4 predicted mathematically (Appendix II).

Procedure III: Cover class 1 predicted with model 4; cover classes 2 and 3 predicted with model 6; cover class 4 predicted mathematically.

Procedure IV: Cover class 1 predicted with model 4; cover classes 2 and 3 predicted with model 3 (in this procedure cover class 4 is combined with class 3).

These 4 procedures were tested for accuracy and stability with 8 computer simulations. Each simulation was comprised of 100 elk groups, distributed in varying proportions among the 4 conifer cover classes, and randomly assigned as "seen" or "not seen". Procedures I and II were

Table 5. Known elk totals for 4 conifer cover classes and predicted totals for 7 sightability models for the aerial censusing of elk in Michigan, 1988-1989.

	Conifer Class			
	1	2	3	4
Total Elk in Groups with Collared Elk	483.0	157.0	58.0	77.0
			135.0 (Class 3 + 4)	
Model Predictions				
Model 1	489.9	204.8	77.7	42.9
Model 2	465.6	178.8	71.5	48.0
Model 3	449.4	162.2	136.9 (Class 3 + 4)	
Model 4	487.2	220.5	111.1 (Class 3 + 4)	
Model 5	495.6	200.8	66.2	62.5*
Model 6	---	153.5	60.3	100.5
Model 7	---	---	72.7	56.1

* Prediction produced through mathematical probability calculations

judged to be the most accurate, stable, and least biased (Table 6, Fig. 7). Procedure I was unbiased more often than Procedure II, except when the distribution of elk in conifer cover classes approached evenness. Procedure II tended to have a slight positive bias, particularly when large percentages of elk occurred in conifer cover class 1. Although Procedure I produced the widest range from minimum value to maximum value, it's unbiasedness and simplicity make it the most desireable procedure of the 4 tested.

Population and Variance Estimates

Most elk observed from the air during those flights conducted specifically for population sampling were seen in less than 25% conifer cover, with no elk groups seen in any areas where conifer cover exceeded 75% (Table 7).

Using the sightability model equation u = 3.689 - (1.333)(conifer cover class), an elk population was estimated, based on the percentage of total area surveyed, to be 1,236 animals (Table 8).

Variance estimations using a modified non-response Horvitz-Thompson estimator (Steinhorst and Samuel 1989) are given in Table 9. Analysis of the variance components showed that survey error accounted for 54.6% of the total variance, sightability error accounted for 42.7%, and model error accounted for only 2.7%. Low density stratum variance was found to account for 84% of the total variance, while medium density variance and high density variance accounted for only 11% and 5% of the total variance, respectively. Individual stratum variance was summed to provide an estimate of total variance of 53,023.3. At 60 degrees of

Table 6. Biases, average bias, range, and number of points within 50 animals of true population size for 4 prediction procedures under 8 simulated aerial censuses of elk in Michgan. The series under each simulation reflects the number of elk groups assigned to conifer cover classes 1-2-3-4.

Simulation	Procedure	Bias	Avg. Bias	Range	Within 50
	I	None	21.7	413	51
1	II	Pos	48.1	314	46
31-32-32-5	III	None	-22.6	266	48
	IV	None	1.4	364	42
	I	None	-11.7	430	46
2	II	Neg	-49.7	309	48
25-25-25-25	III	Pos	97.9	307	22
	IV	Neg	-55.1	395	39
	I	None	-11.6	466	47
3	II	None	-2.4	342	66
46-20-14-20	III	Neg	-46.4	355	51
	IV	Neg	-62.7	324	39
	I	None	-21.8	422	53
4	II	None	19.3	277	60
50-18-18-14	III	None	-21.9	355	55
	IV	Neg	-43.0	314	40
	I	None	-16.5	375	46
5	II	Pos	34.9	321	49
60-14-13-13	III	None	-2.2	283	53
	IV	Neg	-43.2	306	49
	I	Pos	88.8	371	57
6	II	Pos	103.9	279	20
61-25-10-4	III	Pos	49.8	297	42
	IV	Neg	-30.5	300	55
	I	Neg	-34.6	463	37
7	II	Neg	-47.3	312	51
31-23-23-23	III	Neg	-91.2	269	24
	IV	Neg	-64.2	388	38
	I	None	-11.1	517	34
8	II	None	-15.0	362	49
40-20-20-20	III	Neg	-65.2	283	42
	IV	Neg	-55.5	336	42

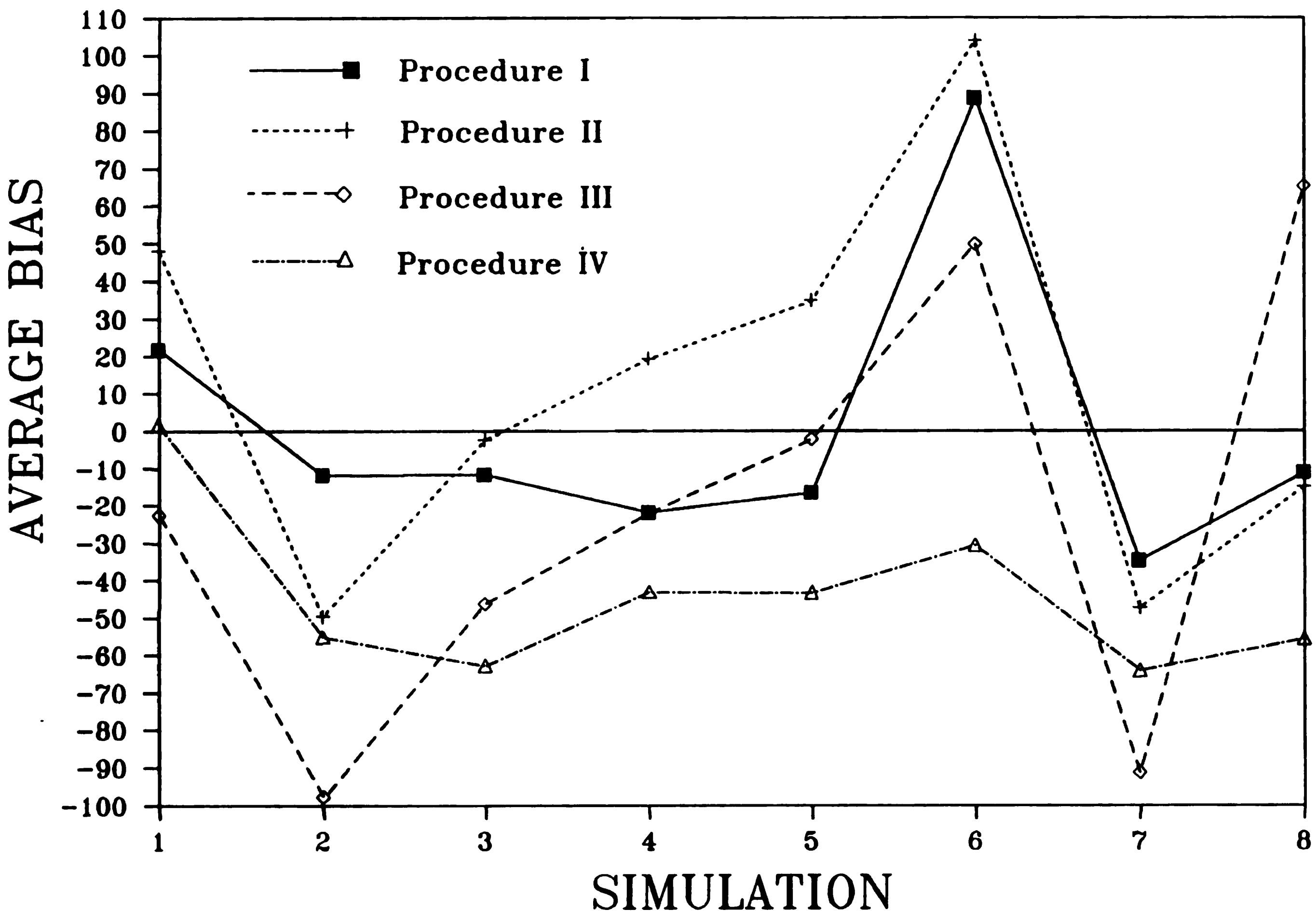

Fig. 7. Average biases for 4 elk population prediction procedures under simulated aerial censusing data for elk in Michigan.

Table 7. Distribution of elk within conifer age and cover classes for groups seen during Michgan elk population/variance helicopter surveys, 1989.

Conifer Cover Class Conifer Age	Density Stratum High	 Medium	 Low	 Total
Class 1				
No Conifer	7 (15%)	2 (4%)	6 (13%)	15 (31%)
Sapling Conifer	5 (10%)	2 (4%)	0	7 (15%)
Pole Conifer	0	2 (4%)	0	2 (4%)
Mature Conifer	4 (8%)	0	0	4 (8%)
Total	16 (33%)	6 (13%)	6 (13%)	28 (58%)
Class 2				
Sapling Conifer	1 (2%)	1 (2%)	1 (2%)	3 (6%)
Pole Conifer	1 (2%)	3 (6%)	0	4 (8%)
Mature Conifer	4 (8%)	1 (2%)	2 (4%)	7 (15%)
Total	6 (13%)	5 (10%)	3 (6%)	14 (29%)
Class 3				
Sapling Conifer	0	0	0	0
Pole Conifer	0	0	0	0
Mature Conifer	3 (6%)	2 (4%)	1 (2%)	6 (13%)
Total	3 (6%)	2 (4%)	1 (2%)	6 (13%)
Class 4				
All Conifer	0	0	0	0
Totals	25 (52%)	13 (27%)	10 (21%)	48

Table 8. Estimates of total elk population size derived from Michigan elk population/variance helicopter surveys, 1989.

Parameter	Density Stratum Low	Medium	High	Total
Total Units	45	32	17	94
Units Sampled	10	14	14	38
Total Area (km^2)	506.1	328.5	180.9	1,015.5
Area Sampled (km^2)	97.2	139.9	150.3	387.4
Ratio Sampled (A_k)@	0.19	0.43	0.83	0.38
Area Estimator ($1/A_k$)	5.26	2.33	1.20	----
Observed Elk Count				
Conifer Class 1	40	46	198	284
Conifer Class 2	19	44	37	100
Conifer Class 3	15	11	17	43
Conifer Class 4	0	0	0	0
Corrected Elk Count				
Conifer Class 1	43.76	50.32	216.60	310.68
Conifer Class 2	25.77	59.67	50.18	135.62
Conifer Class 3	35.26	25.86	39.96	101.08
Conifer Class 4	0.00	0.00	0.00	0.00
Total (T_c)	104.79	135.85	306.74	547.38
N_1 (T_c * $1/A_k$)	551.20	316.53	368.09	1235.82

Note: @A_k = Area sampled/Total area

Table 9. Estimates of variance components in low, medium, and high density strata from Michigan elk population/variance helicopter surveys, 1989.

Error Component	Density Stratum Low	Medium	High	Total
Sampling Error	37,982.48	6,221.52	2,769.65	46,973.65
Covariance	-12,484.17	-3,397.35	-2,140.09	-18,021.61
Survey Error	25,498.31	2,824.17	629.57	28,952.05
Survey Error	25,498.31	2,824.17	629.57	28,952.05
Sightability	17,925.64	2,692.27	2,039.57	22,657.48
Model Error	976.08	248.75	188.96	1,413.79
Stratum Total	44,400.04	5,765.19	2,858.09	
Variance Total				53,023.32

Coefficient of Variability = 18.6%

freedom, the 95% confidence interval is N $\pm$ 451, and the 90% confidence interval is N $\pm$ 378. Based on a population estimate of 1,236, the 95% confidence interval for estimated Michigan elk herd size is 785-1,687 animals, while the 90% confidence interval is 858-1,614 animals. The calculated coefficient of variability (CV) associated with the calculated population and variance estimates is 18.6%

Census Costs

In 1988 the Michigan DNR utilized around 20 personnel and numerous volunteers to act as ground counters during the annual 3-day elk census (E. E. Langeneau pers. commun.). Although volunteer workers were not accounted for in cost analysis, the MDNR personnel salary component still represents the major expenditure incurred by the state agency (Table 10). Even if a stratified random aerial census was executed over 6 days, the monetary savings in personnel would still make it less expensive than the current DNR method. Based on a fuel usage rate of 25 gallons per hour (150 gallons/day), use of a stratified random census would cost approximately $7,755 for 4 days, $9,598 for 5 days, and $11,440 for 6 days. Complete elk counts from the air and ground would cost approximately $13,262 for 2 days, $19,701 for 3 days, and $26,139 for 4 days (Table 10). Even if a conventional census could be executed in 2 days, a 6 day stratified aerial count could still cost nearly $2,000 less. The estimated cost of a 3 day complete count, $19,071 agrees well with the true cost, $20,000 to $24,000, calculated by the Michigan DNR (E. E. Langeneau pers. commun.).

Table 10. Cost analysis for 2 methods of censusing elk in Michigan: a 2-4 day complete air and ground census, and a 4-6 day statified random aerial census.

Cost Component	Complete			Random		
	2 days	3 days	4 days	4 days	5 days	6 days
Helicopter Rental	$2550	$3600	$4650	$4650	$5700	$6750
Helicopter Fuel@	$555	$833	$1110	$1110	$1388	$1665
Pilot Lodging	$65	$130	$195	$195	$260	$325
Personnel Salary#	$9000	$13500	$18000	$1800	$2250	$2700
Snow Mobile Rental*	$1092	$1638	$2184	----	----	----
Total	$13262	$19701	$26139	$7755	$9598	$11440

@150 gallons/day at $1.85/gallon
#$25/9 hours/man/day
*7 machines at $78/machine/day

DISCUSSION

Collected Data

The primary constraints to the collection of data for sightability modelling, and for population/variance estimation were helicopter availability and weather. The Bell Jet Ranger helicopter used for all flights was rented from the Michigan State Police Air Unit, and as such, was not always available upon demand. Although arrangements for research were made in advance, police use, maintenance, scheduling conflicts, and available funds limited helicopter availability. Within this constraint, weather conditions and availability of observers and ground crews further reduced the number of suitable flying days.

Recommended standard weather conditions are carefully designed to increase the probability of sighting a large number of elk (Wyoming Game and Fish Department 1982). In Michigan elk should be censused as soon after 1 December as possible. Census timing is important, since this is the period when elk are congregated in large groups, temperatures are fairly high, and snow fall is frequent enough to produce a clean background but is not very deep. Since elk tend to retreat into dense conifer swamps as the ambient air temperature drops (Beyer 1987), survey flights should not be executed when ground temperatures are lower than -12°C (10°F). Kelsall (1969) determined that ungulate mobility was severely restricted when snow depths exceeded 2/3 of adult chest height.

Considering figures published by Flook (1970:130) and Telfer and Kelsall (1979), movement should not be hampered in snow depths of less than 70 cm; agreeing well with the depth Sweeney and Sweeney (1984) reported as a hinderance to elk movement. To insure good elk mobility, survey flights should not be executed if snow depths exceeded 60 cm. Caughley (1974) indicated that observer fatigue and cloud cover could significantly affect aerial wildlife counts. As such, flight sessions should be kept to a maximum of 3 hours, and only made when little or no cloud cover is present over the study area. Strict adherence to these and other flight limitations will insure that the majority of elk in sampling units will not be in conifer swamps, will be in large congregations, and will be highly visible.

The conditions under which data was collected did not always follow those recommended. Time restrictions caused by helicopter and ground crew availability resulted in helicopter survey flights in temperatures as low as -23°C (-10°F) and in snow depths exceeding 60 cm. Further, no flights were made in December of any year, with population/variance surveys pushed back to late February and early March. The overall result was that a fair number of elk may have been in dense swamp conifer stands during some of the survey flights, and large elk groups had probably begun to break up. To avoid these problems, future elk surveys should be carried out as close to 1 December as possible, under the standard weather conditions recommended above.

During 14 days of sightability data collection, 79 observations (5.6/day) were recorded. Samuel et al. (1987) built 2 logistic regression prediction models based on the observation of 111 elk groups, but found that regression coefficients did not change significantly after 65 observations (M.D. Samuel pers. commun.). Though a data set of 100 to 120 observations would have been desirable, the 79 actually recorded is probably sufficient for the development of an accurate sightability model for Michigan elk. The only potential problem with the sightability data is the uneven distribution of observations throughout the density strata. This problem will be discussed later.

Data collection for population/variance estimation took place over 4 days and covered units in all density strata. Calculated variance estimates indicated that sampling was probably too heavy in the high density stratum, adequate in the medium density stratum, and probably too light in the low density stratum. As such, the data collected for population/variance estimates may have been inadequate, while sampling effort was certainly not optimally allocated. Optimal allocation of sampling effort will be discussed more fully below.

Of 17 different sampling units sampled for sightability modelling, only 5 (29.4%) were not high density units. The preponderance of high density units in the data set may be problematic in a number of circumstances. Prior to censusing, it was assumed that elk group size, elk behavior, and elk use of conifer cover classes was independent of the density stratum occupied. If this assumption is not valid, regression models constructed to predict sightability over the entire elk range may not be accurate. The gathering of elk sightability data was totally dependent on the detection of animals equipped with radio transmitting collars, as is recommended by Steinhorst and Samuel (1989). As a result, the number and location of units actually available for censusing was limited by the number and distribution of collared elk. It has been assumed that sightability factors act independent of density strata, so the uneven distribution of collared animals is of no real concern. If this assumption is found to be invalid, an effort to place collared animals evenly throughout the entire range would have to be made.

Results show that, for groups seen, the average number of elk per group is more that twice that for groups not seen. This would seem to indicate that elk group size does significantly influence elk visibility. The resultant logistic regression model, however, leaves it out. Table A2 shows that, for groups seen, the median group size and the group size mode are both 7, quite a bit below the average of 12.3 elk/group. For groups not seen, the median group size and the group size mode are 5, agreeing well with the average of 5.1 elk/group. Several very large elk groups, I believe, have produced a misleading comparison by inflating the average group size for groups seen. If the 7 largest groups are removed from the data set for groups seen, the average drops to 8.4 elk/group. In addition, whereas the average group size for groups not seen is only 41% of that for groups seen, the median and mode for groups not seen is more than 71% of that for groups seen. These figures further indicate that average group size for groups seen has probably been inflated by the sighting of several very large groups. It is easy, then, to see why group size was not included in the logistic regression model at the 90% level.

Most of the elk groups (86.6%) that were seen from the air were located in areas where conifer cover was less than 50% Of the elk groups that were not seen by helicopter crews, 74% inhabited dense conifer cover, while less than 26% were in moderate to sparse conifer. Not surprisingly, all models generated, except 1, determined that conifer cover had a highly significant ($P < 0.007$) effect on elk visibility from the air (Table 4). To minimize the effect of conifer cover, future aerial censuses in Michigan should be carried out in early December when elk make infrequent use of dense conifer stands.

Sightability Models

Many forms of aerial census correction methodologies have been developed over the past 20 years. If sightability of an animal is constant, mark-recapture or change-in-ratio procedures can be used successfully (Rice and Harder 1977, Eberhardt 1978). Several recent studies indicated, however, that sightabilities can change over a study area due to a number of factors (Samuel and Pollock 1981, Gasaway et al. 1985). Under these circumstances, aerial counts corrected with a constant sighting function can produce an under-estimation of population size (Seber 1982:322) and other methods are required. The method for evaluating the sightability of elk in Michigan used a logistic regression analysis (Samuel et al. 1987) to construct correction models based on factors that significantly affect aerial animal visibility.

The initial sightability model for winter helicopter counts of elk in Michigan indicated that percent conifer cover alone was the primary factor influencing observability. Many other researchers have also indicated that vegetation cover was an important factor to consider when making aerial counts on ungulates (Floyd et al. 1979, Gasaway et al. 1986, Samuel et al. 1987). Many researchers have also stressed the importance of animal group size to sightability (Cook and Martin 1974, Cook and Jacobson 1979, Samuel and Pollock 1981, Crete et al. 1986), although it was not included in the initial sightability model determined for Michigan elk. In order to gauge the effect it would have on the resultant sightability models, group size was introduced into 3 regression analyses. Since analysis of the original data set determined that groups size was not a significant factor (at $P < 0.10$), the data set had to be reconstructed, or the level of significance dropped in order to include it. Of 3 regression models built to include group size, the accuracy of 2 indicated that it may be appropriate to include group size into sightability models (Table 5). As such, models that utilized elk group size were included in 2 of 4 prediction procedures tested for accuracy and consistency.

Three additional sightability models were also built by restructuring the data set or redefining the level of significance necessary to include independent variables. This was done to determine how logistic regression analysis behaved under different circumstances. Precise knowledge of model behavior could then serve to indicate how best to record and structure future sightability or census data. Results showed that models built with restricted data were slightly more accurate than models built with the original data set intact (Table 5). Restricting the data necessitated restricting the conditions under which that model can be used. Since the model is constructed using only the data from the conifer cover classes to which it's use is restricted, the resultant predictions are very good. For instance, model 7 was built only using data from conifer cover classes 3 and 4. Since the resultant regression model could only be applied to those classes, the predictions generated by the model are fairly accurate. Model 6 was constructed using conifer cover classes 2, 3, and 4, and can only be applied to elk seen in them. As a result, the predictions generated are good, particularly for cover classes 2 and 3. These results indicated that an analysis limited to a single cover class should produce highly accurate predictions for elk in that class.

The tendency for models to become less accurate as they encompass more conifer cover classes is due primarily to differences in elk sightability among classes. While 86.5% of the elk groups in sparse conifer (classes 1 and 2) were seen, less than 50% were seen in cover class 3, and only 12.5% were seen in dense conifer cover (class 4). When a single model is used for all classes of conifer cover, it takes into account such sightability differences, and accuracy suffers. Models produced with restricted data, however, are freed from this problem, and have to take into account only 1 or 2 different sightabilities, and can produce more accurate predictions.

Despite increased accuracy over those that encompass several conifer cover classes, models built from only 1 or 2 classes may not be the most desirable. Any advantages gained through increases in precision, may be undermined by increases in method complexity. To determine whether single model or multiple model methods provide the most accurate, consistent, and unbiased elk population predictions, 8 simulations were performed. The results of these simulations were analyzed to reveal trends and biases and will be discussed in the following section.

Gasaway et al. (1985) found that bedded moose were more likely to be missed during flyovers than were standing or moving moose. Samuel et al. (1987) also found that animal behavior was significantly related to sightability, but that it was strongly correlated with group size and vegetation cover characteristics. As a result, the actual effect that animal behavior had on aerial sightability could not be determined. Initially, elk behavior was included for consideration as a significant influence on Michigan elk sightability. Prior to data analysis, however, this factor was removed from consideration. Determination of the behavior of missed elk required visual contact and verification by ground crew members. Since the elapsed time from flyover to ground visual contact could be as great as 45 minutes, it was deemed unreasonable to assume that elk behavior had not changed. In order to include this factor in analysis, it would have been necessary for ground crews to make contact with each elk group prior to or during helicopter surveys. Limitations on man-power and time prevented ground crew members from immediately verifying behavior with this adjustment.

<u>Computer Simulations</u>

The performance of 4 elk prediction procedures under simulation indicated that a model constructed from the full data set, though probably less accurate within individual conifer cover classes, is more consistent and unbiased than are multiple model procedures (Table 6).

The inaccuracy of single model procedures is manifested in the range of bias values produced. Bias values were calculated by taking the difference between known total elk numbers and predicted total elk numbers. Procedure I had a greater spread from minimum bias to maximum bias than any other procedure for all 8 simulations. The most important characteristics of these procedures, however, are their average biases. Procedure I is biased in 2 simulations, procedure II is biased in 5, procedure III is biased in 5, and procedure IV is biased in 7. The lack of bias in most simulations, and the relative ease with which it can be calculated and applied to field observations, makes procedure I the best choice for predicting elk populations in Michigan.

Underlying the design and construction of each of the 8 simulations are several parameters and characteristics that should be discussed. Within each simulation a percentage of 100 elk groups are assigned to each of the 4 conifer cover classes. Elk group sizes appearing within a particular class were randomly generated, but fell within a specified range. This range was determined from information gathered during sightability model data collection and from personal observations. In addition, the distribution of group sizes was mathematically dictated to produce average group sizes of 5 to 12 elk/group. It was assumed that the size and distribution of groups within each cover class accurately reflected true group size and distribution parameters. Specifying the size of elk groups within each cover class also relied on the assumption that elk group size was not independent of vegetation cover. It is difficult to fully test or analyze the effect of vegetation cover on group size, but indications are that there may be a relationship.

The effects weather and season have on the group sizes of herding animals have been well documented for many species (Bergerud 1978, Boyd 1978, Houston 1982). Contrarily, the relationship between animal group size and vegetation density has not been researched to a large extent. Jeppesen (1987), however, found that groups of red deer (Cervus elaphus) averaged 3.7 animals/group when in forests, and 9.7 animals/group when in open lands. Moran (1973) and Bergerud (1978:87) also indicated that vegetation cover and density may affect observed group sizes in elk and caribou, respectively. Within a particular season, then, variations in group size are not unusual for animals observed in different densities of vegetation. These findings support the use of different ranges of group size in each conifer cover class during simulation design and construction.

Fig. 6 illustrates the erratic behavior of the prediction procedures. Procedure I is fairly consistent under most conditions, except when conifer cover class use ratios approach equality or become extremely unequal. It's behavior suggested that inaccuracies or inconsistencies may occur when an unusually large number of elk groups inhabit areas of dense conifer cover (class 4), or when very few groups make use of stands of moderate conifer cover (classes 2 and 3). If future elk surveys are flown in early winter, as recommended, few elk will be in dense conifer, but some will be in moderate conifer cover. Under these conditions, this procedure will work well.

Procedure II behaves much the same way as procedure I, but tends to become positively biased more quickly. At extreme distribution proportions, procedure II tends to explode, and drops precipitously when elk distributions throughout conifer cover classes approach equality. Procedure III follows the trends established by procedures I and II, but in an exaggerated fashion. It is possible that procedures II and III suffer inconsistencies due to the use of several class-specific models. Procedures II and III predict elk populations in 4 cover classes with 3 distinct models, removing the tendency of a single model to temper extremes in a particular cover class. For this reason procedure I tends to be more consistent and less affected by drastic inequalities in elk group distribution.

Procedure IV was constructed with 2 different models, but restricts the number of conifer cover classes from 4 to 3. For this reason, it also tends to be more consistent, though still rather undesirable because of it's strong negative biases. It is interesting to note that procedure IV performs best when the number of elk groups in dense conifer cover is very small; while the other procedures perform rather poorly under these conditions.

Assuming that future elk censuses will be carried out in early winter when few groups use dense conifer, but many use moderate conifer, procedures I and II are the most appropriate. Procedure I, however, has several advantages that make it more useful for predicting elk populations in Michigan. Primary among these is simplicity. Designing computer programs to make population and variance estimate calculations is much less complex with a single model procedure than with a multiple model procedure. Procedure I also tends to be more unbiased, and less severe when biased. This allows for some variation in the distribution of elk groups within conifer cover classes, without suffering a large decrease in accuracy. The only real drawback to procedure I is the wide range of predictions it can produce. This characteristic, though important, is secondary to the overall bias and consistency characteristics. Procedure I, overall, performs the best under simulated elk census information analysis.

Population and Variance Estimates

Helicopter survey flights for the estimation of Michigan elk herd population parameters was hindered only by available time and funds. It would have been advantageous, however, to have 5 or 6 days, instead of 4, available for censusing, particularly for variance estimation. Although sampling units were randomly chosen for censusing, proper sequencing and routing allowed air crews to survey between 4 and 6 units during each 3 hour flight session. Limitations imposed by helicopter fuel capacity, observer fatigue, and optimal observing conditions, restricted the number of units that could realistically be sampled to a maximum of 6. Factors that could have acted to reduce the number of units sampled, such as sampling very large units, airsickness, and widely spaced units, were rarely encountered. As such, air crews were able to completely survey 38 sampling units in 4 days.

Many factors contributed to the ability of air crews to census a nearly maximum number of units. The 2 most important of which were unit boundary delineation and observer experience. Sampling unit boundaries were, in most cases, constructed using permanent natural and man-made landmarks easily detected from the air in winter conditions. The survey of units during the winter of 1988 allowed air crews to determine the appropriateness of proposed boundaries before an actual census was carried out. Sampling unit boundaries that proved to be unusable were redefined using more identifiable land features. Retaining cryptic, arbitrary, or temporary boundary lines would undoubtedly have reduced the number of units surveyed per session. Flights were always made using a primary observer who had intimate knowledge of the study area and who had previous flight experience. In this way, little or no time was lost during censusing due to observer disorientation, non-recognition of boundary lines, or airsickness.

Several other factors contributed to the large number of sampling units that were successfully surveyed. Included among these were: enthusiasm and experience of pilots, adherence to standard flight patterns, adequate pre-flight preparation, and short refueling and rest periods. A conscious effort was made on this project to organize thoroughly so that survey flights could be done as smoothly and as quickly as possible. Even so, the amount of data collected in 4 days of flying was inadequate to produce a population estimate with a smaller confidence interval. The timing of census flights also probably increased the variance estimate. Better allocation of sampling effort, however, should reduce future confidence intervals, even if surveys are made on only 4 days.

The Wyoming Game and Fish Department (1982:56) recommended that aerial surveys be carried out between 1 December and 15 March, while elk are concentrated on winter ranges. The aerial censusing of elk in Michigan, however, should be made as soon as snow conditions permit. It is during this period that Michigan elk form large groups, but usually make little use of dense conifer stands due to shallow snow and above-zero (^{o}F) temperatures (Moran 1973). Elk herd population estimate surveys in this study were carried out in late February and early March, more than a month after the optimal censusing period. Since no reliable, independent estimate of elk herd size is available, however, it is impossible to judge how survey timing may have affected the accuracy of the population estimate produced in this study. Further, the estimation of elk population size was a secondary goal to the estimation of variance for subsequent sampling effort allocation, and should be viewed as such.

A major problem in survey methodology, correction factor determination, and population/variance estimation occurs when no elk are seen in a stratum, or conifer cover class within that stratum. Theoretically, the absence of sightings should act to depress the overall population estimate. This, however, is not the case. As an example, population estimate flights over the Michigan elk range located no elk in cover class 4. If a single elk group of 4 individuals would have been sighted in conifer cover class 4 of a medium density unit, an additional 24.68 animals would have been included in the population estimate, pushing it to 1,293. Overestimation, as a result, are most likely if there is a significant shift in the sightability of elk from the air. To guard against this, future elk censuses should be carried out within the strict weather, time of year, and flight pattern parameters recommended from this study.

Steinhorst and Samuel (1989) used a modified Horvitz-Thompson estimator to analyze moose data collected and presented by Jacobson (1976). An analysis of the variance components revealed that survey sampling error was the source of most variation (73%), followed by response or sightability error (21%), and model error (6%). An analysis of the variance components for this study revealed that survey error, due to sampling effort allocation, was also the major contributor (55%), followed by sightability error (43%) and model error (3%). This analysis indicated that the survey procedure and unit allocation used may have to be refined, but that the regression prediction model itself is sound. Steinhorst and Samuel (1989) cautioned other researchers that variance and it's components can vary widely due to differences in survey design, visibility bias, and number of surveys or trials. These 3 factors may have caused the observed differences in percentage of variance attributable to each component between the study by Jacobson (1976) and this one.

The variance associated with the estimation of the Michigan elk population is fairly large. This is clearly indicated by the relatively wide confidence intervals produced. Since it is difficult to directly compare variance estimates from different aerial censusing results, coefficients of variation (CV) will be compared. The CV obtained in this study, 18.6%, agrees well with that reported by Steinhorst and Samuel (1989) -- 18%, and is lower than those reported by Cook and Jacobson (1979) -- 21.4%, and Beasom et al. (1986) -- 29%. Siniff and Skoog (1964), developed stratified aerial sampling with optimal allocation and reported a CV of 11.1%.

When dealing with field studies, it is not uncommon to encounter large variances. As such, coefficients of variation lower than 15% may be very difficult to achieve. While a 95% confidence interval of ± 100 animals may be highly desirable for the Michigan elk herd, the associated CV shows that this is an unrealistic goal (Table 11). Although adjustments in sampling effort allocation, and increases in total survey time may reduce the variance enough to produce a CV of 12.4%, the resultant 95% CI associated with this CV (± 300) is still fairly wide. Even so, a CV below 13% and a confidence interval below ± 300 is probably not realistic, unless 80% or more of the elk range can be sampled.

Although the variance associated with the elk population estimates is rather large, it is not prohibitively so. Some adjustments to the allocation of sampling effort, however, could reduce the variance to a more reasonable level. Since the variance components associated with the low density stratum accounted for nearly 84% of the total variance, it is apparent that not enough low density units were sampled. Contrarily, probably too many high density units than necessary were sampled, while the number of medium density units sampled was probably about right. During future aerial censuses, the allocation of sampling effort within each density stratum will depend on the number of survey days available. If only 4 flying days are to be used, no more than 40 units could realistically be sampled. Within this limitation, 19 low density units should be surveyed, with the remainder alloted to the medium and high density stratum. A minimum of 50 total units may have to be censused in order to significantly reduce the final variance

Table 11. Theoretic coefficients of variability, when N = 1,236 and df = 60, for 95% and 90% CI's based on data from Michigan elk population/variance helicopter surveys, 1989.

95% CI	CV	90% CI	CV
N $\pm$ 100	0.041	N $\pm$ 100	0.049
N $\pm$ 150	0.062	N $\pm$ 150	0.074
N $\pm$ 200	0.083	N $\pm$ 200	0.099
N $\pm$ 250	0.103	N $\pm$ 250	0.123
N $\pm$ 300	0.124	N $\pm$ 300	0.148
N $\pm$ 350	0.144	N $\pm$ 350	0.173
N $\pm$ 400	0.165	N $\pm$ 400	0.197
N $\pm$ 450	0.186	N $\pm$ 450	0.222
N $\pm$ 500	0.206	N $\pm$ 500	0.247

estimate, but may not be possible. Refinements in the allocation of sampling effort throughout density strata, however, may reduce the number of units needed to produce a smaller variance, removing the need to survey 50 or more units. Recommended sampling allotment for a variety of available flight days are presented in Table 12.

The total effect of increasing the number of low density units included in aerial surveys is not restricted to a reduction in variance, CV, and confidence intervals. Estimations of total elk numbers can be easily affected by censusing more low density units. This is so because of the high probability of flying units that contain few, if any, elk. In addition, the sampling of 2 or 3 more low density units could provide more precise information on elk distributions and densities throughout the stratum.

Census Costs

One of the objectives of this study was to develop a censusing method that would eliminate the need for ground counters, thus reducing the total expenditure needed to carry out an elk herd census. The stratified random aerial census developed and tested in this study, does just that. The Michigan Department of Natural Resources can save thousands of dollars each year by using this method instead of the total count method now being employed. In addition to reduced expenditures from the elimination of ground counters, monetary savings will be made on vehicle depreciation, snowmobile rental, and fuel costs. Compared to a 3 day complete air and ground count, a 4 day stratified random census could save the MDNR $11,946 every year.

Table 12. Recommended number of units to be surveyed in each elk density strata, when the total number of units to be surveyed is known, for the aerial censusing of elk in Michigan.

Total Units	Density Stratum			Days Required
	High	Medium	Low	
20	4	6	10	2
25	5	8	12	2-3
30	7	8	15	3
35	8	10	17	3-4
40	9	12	19	4
45	10	13	22	4-5
50	11	15	24	5
55	11	17	27	5-6
60	12	18	30	6
65	13	20	32	6-7

The major limitations to an all aerial census are the strict standardized weather conditions and flight patterns necessary for a successful survey, and the extra investment of flight time and costs. A 5 or 6 day stratified aerial census may represent an extra investment of 2 or 3 days of helicopter costs and weather considerations, but represents the saving of 3 days of ground crew and land vehicle use. The stratified random aerial census used in this study is, without a doubt, a much more efficient technique. Further refinements in sightability factor evaluation, sampling effort allocations, and variance estimations can increase the effectiveness of the technique. I believe that this methodology represents an efficient and effective step forward in the statistical estimation of Michigan elk herd population parameters.

CONCLUSION AND CENSUS RECOMMENDATIONS

1. Helicopter and ground crew availability resulted in helicopter survey flights when temperatures dropped below -23°C (-10°F) and snow depths exceeded 60 cm. These conditions did not follow recommended weather guidelines. Future aerial elk surveys should be carried out under these conditions:

A. As soon as sufficient snow cover permits. Because large elk groups begin to break up, temperatures may drop below -12°C, and snow depths may become excessive, surveys should not be carried out later than the second week in January.

B. As soon after a fresh snowfall as possible, as long as snow depths do not exceed 60 cm (at which point elk foraging and movement may be impaired).

C. Under clear skies, no earlier than 9:00, and no later than 16:00. If ground temperatures drop below -12°C (10°F), large numbers of elk may move into dense swamp conifer stands for thermal cover. Conducting a survey under these conditions should be avoided.

D. Flight sessions should not exceed 3 hours as observer fatigue may result in an unusually high number of animals missed.

E. Helicopter surveys should be made at an altitude of 46-61 m above ground level and at an air speed of 97-113 km/hr. Searches over sampling units should be as parallel transects, at 1/4 km intervals.

2. Logistic regression analysis indicated that only conifer cover class (percent conifer cover) significantly affected elk sightability from the air. The accuracy of 7 regression models and the performance of 4 elk prediction procedures under simulation indicated that a single-model prediction procedure including only conifer cover class (as a significant independent variable) most consistently accounted for animals missed during censusing. Subsequently, the proper sightability model is:

$$u = 3.698 - 1.333 \text{ (Conifer Cover Class)}.$$

The specific correction factors, then, are:

Cover Class 1: (1.094)(Elk Seen)

Cover Class 2: (1.355)(Elk Seen)

Cover Class 3: (2.353)(Elk Seen)

Cover Class 4: (6.135)(Elk Seen)

These values should be used in future elk counts to correct for animals missed in a specific conifer cover class unless additional information on elk sightability is developed to further refine these factors.

3. The Michigan elk herd was estimated at 1,236 animals. It is impossible to evaluate the accuracy of this estimate since no reliable independent estimate exists. The variance estimate of 53,023 produces a 95% CI of $\pm$ 451 animals. The 18.6% CV is a little high, but not unusual for field studies. Allocation of sampling effort to include more low density units, and conducting aerial surveys early in the year, should increase population and variance estimate accuracy and reliability.

4. Survey error accounted for most of the estimated variance, indicating that sampling effort was not optimally allocated. Model error accounted for only 2.7% of the total variance, indicating that the recommended model is a good one. Variance components in the low density stratum were higher than in either the medium or high strata, indicating that not enough low density units were surveyed during population and variance estimation.

In future elk counts, a considerably larger proportion of low density units should be sampled. Ideally a total of 50-60 units should be surveyed, with 24-30 of these being low density units.

5. Stratified random aerial surveys are less expensive to conduct than are total air and ground counts. Elimination of ground crew can save the Michigan DNR from $7,000 to $12,576 each year.

6. Future elk counts should be carried out solely from the air, using the following procedure.

A. Select the total number of units that can be surveyed based on the number of days available for censusing.

B. Allocation of sampling effort should be determined from Table 11, based on the total number of units to be surveyed.

C. Specific units to be surveyed should be randomly selected and then sampled in an order and direction that maximizes the number of units surveyed during each flight session.

D. For each elk group seen, the following data should be recorded: the density unit the group was seen in, total size of the group, and the conifer class occupied by the group.

E. After all units have been surveyed, the total number of elk seen in each conifer class within each density stratum should be corrected using the appropriate correction factor. Estimates of population size can then be made based on the total area surveyed, as in Table 8.

F. Variance should be estimated using the modified Horvitz-Thompson estimator presented by Steinhorst and Samuel (1989). Confidence intervals, at the 90 or 95% level, can then be developed and placed around the population estimate.

LITERATURE CITED

Anderson, W.H., W.A. Wentz, and B.D. Treadwell. 1980. A guide to remote censusing for wildlife biologists. Pages 291-303 in S.D. Schemnitz ed., Wildlife management techniques manual. 4th ed. The Wildlife Society, Washington, D.C. 868pp.

Beasom, S.L. 1979. Precision in helicopter censusing of white-tailed deer. J. Wildl. Manage. 43:777-780.

____________, F.G. Leon III, and D.R. Synatzske. 1986. Accuracy and precision of counting white-tailed deer with helicopters at different sampling intensities. Wildl. Soc. Bull. 14:364-368.

Bergerud, A.T. 1978. Caribou. Pages 83-100 in J.L. Schmidt, and D.L. Gilbert eds., Big game of North America. Stackpole Books, Harrisburg, PA. 494pp.

Beyer, D.E., Jr. 1987. Population and habitat management of elk in Michigan. Ph.D. Thesis, Michigan State University, East Lansing, Michigan. 148pp.

Boyd, R.J. 1978. American elk. Pages 11-29 in J.L. Schmidt, and D.L. Gilbert eds., Big game of North America. Stackpole Books, Harrisburg, PA. 494pp.

Bryant, M.M. 1943. Area determination with the modified acreage grid. J. For. 41:764-766.

Buechner, H.K., I.O. Buss, and H.F. Bryan. 1951. Censusing elk by airplane in the Blue Mountains of Washington. J. Wildl. Manage. 15:81-88.

Cahalane, V.H. 1938. The annual northern Yellowstone elk herd count. Trans. North Am. Wildl. Conf. 3:388-389.

Caughley, G. 1974. Bias in aerial survey. J. Wildl. Manage. 38:921-933.

___________. 1977. Analysis of vertebrate populations. Wiley and Sons Publ., New York. 232pp.

Cook, R.D., and F.B. Martin. 1974. A model for quadrat sampling with "visibility bias." J. Amer. Stat. Assoc. 69:345-349.

_________, and J.O. Jacobson. 1979. A design for estimating visibility bias in aerial surveys. Biometrics. 35:735-742.

Crete, M., L.P. Rivert, H. Jolicoeus, J.M. Brassard, and F. Messier. 1986. Predicting and correcting helicopter counts of moose with observations made from fixed-wing aircraft in southern Quebec. J. Appl. Ecol. 23:751-761.

Davis, D.E., and R.L. Winstead. 1980. Estimating the numbers of wildlife populations. Pages 221-245 in S.D. Schemnitz ed., Wildlife management techniques manual. 4th ed. The Wildlife Society, Washington, D.C. 868pp.

DeYoung, C.A. 1985. Accuracy of helicopter surveys of deer in south Texas. Wildl. Soc. Bull. 13:146-149.

Dice, L.R. 1941. Methods for estimating populations of mammals. J. Wildl. Manage. 5:396-407.

Eberhardt, L.L. 1978. Appraising variability in population studies. J. Wildl. Manage. 42:207-238.

Elk Management Plan. 1984. Mimeograph on file, Michigan Department of Natural Resources, Lansing, Michigan. 46pp.

Erickson, A.W., and D.B. Siniff. 1963. A statistical evaluation of factors influencing aerial survey results on brown bears. Trans. North Am. Wildl. Conf. 28:391-409.

Evans, C.D., W.A. Troyer, and C.J. Lensink. 1966. Aerial census of moose by quadrat sampling. J. Wildl. Manage. 30:767-776.

Flook, D.R. 1970. Causes and implications of an observed sex differential in the survival of wapiti. Can. Wildl. Serv. Bull. Rep. Ser. 11. Ottawa: Canadian Wildl. Serv. 59pp. (Cited in: Thomas, J.W. and D.E. Toweill. 1982. Elk of North America: ecology and management. Stackpole Books, Harrisburg, PA. 698pp.)

Floyd, T.J., L.D. Mech, and M.E. Nelson. 1979. An improved method for censusing deer in deciduous-conifer forests. J. Wildl. Manage. 43: 258-261.

Gasaway, W.C., S.D. Dubois, and S.J. Harbo. 1985. Biases in aerial transect surveys for moose during May and June. J. Wildl. Manage. 49:777-784.

____________,___________, D.J. Reed, and S.J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biol. Pap. Univ. Alaska, No. 22. U.S. Govt. Printing Office, Denver, Colorado. 85pp.

Helwig, J.T., and K.A. Council eds. 1979. S.A.S. users guide. S.A.S. Inst., Cary, N.C. 494pp.

Houston, D.B. 1982. The northern Yellowstone elk. MacMillan Publ. Co., Inc., New York. 474pp.

____________, B.B. Moorhead, and R.W. Olson. 1986. An aerial census of mountain goats in the Olympic Mountain range, Washington. Northwest Sci. 60:131-136.

Jeppesen, J.L. 1987. Seasonal variation in group size, and sex and age composition in a Danish red deer (Cervus elaphus) population under heavy hunting pressure. Vildlbiologisk Station Comm. #212, Kalo, Denmark. 19pp.

Judge, G.G., W.E. Griffiths, R.C. Hill, and T. Lee. 1980. The theory and practice of econometrics. John Wiley and Sons, Publ. 793pp.

Kelsall, J.P. 1969. Structural adaptations for moose and deer in snow. J. Mamm. 50:302-310.

Klein, D.R., and V. Kuzyakin. 1982. Distribution and status of wild reindeer in the Soviet Union. J. Wildl. Manage. 46:728-733.

Kufeld, R.C., J.H. Ottherman, and D.C. Bowden. 1980. A helicopter census for mule deer on Uncompahgre Plateau, Colorado. J. Wildl. Manage. 44:632-639.

LeBlond, G.T., and D.F. Cobb. 1985. Using 1-2-3. 2nd ed. Que Corporation, Indianapolis, IN. 534pp.

Leon, F.G. III, C.A. DeYoung, and S.L. Beasom. 1987. Bias in age and sex composition of white-tailed deer observed from helicopters. Wildl. Soc. Bull. 15:426-429.

LeResche, R.E., and R.A. Rausch. 1974. Accuracy and precision of aerial moose censusing. J. Wildl. Manage. 38:174-182.

Lovaas, A.L., J.L. Egan, and R.R. Knight. 1966. Aerial counting of two Montana elk herds. J. Wildl. Manage. 30:364-369.

Michigan Weather Service. 1974. Climate of Michigan by stations. Michigan Dept. of Agriculture with National Oceanic and Atmospheric Administration--National Weather Service, U.S. Dept. of Commerce. East Lansing, Michigan.

Moran, R.J. 1973. The rocky mountain elk in Michigan. Michigan Project W-95-R and W-117-R. Research and Development Report No. 267. Michigan Department of Natural Resources, Lansing, Michigan. 93pp.

Murie, O.J. 1951. The elk of North America. Stackpole Books, Harrisburg, PA. 376pp.

Myers R.A., and W.D. Bowen. 1989. Estimating bias in aerial surveys of harp seal pup production. J. Wildl. Manage. 53:361-372.

National Oceanic and Atmospheric Administration (NOAA). 1987. Climatological data, annual summary, Michigan. Vol. 102:1-17.

____. 1988. Climatological data annual summary, Michigan. Vol. 103:1-22.

Petrides, G.A. 1953. Aerial deer counts. J. Wildl. Manage. 17:97-98.

Pollock, K.H., and W.L. Kendall. 1987. Visibility bias in aerial surveys: a review of estimation procedures. J. Wildl. Manage. 51:502-510.

Rice, W.R., and J.D. Harder. 1977. Application of multiple aerial sampling to mark-recapture census of white-tailed deer. J. Wildl. Manage. 41:197-206.

Riordan, L.E. 1948. The sexing of deer and elk by airplane in Colorado. Trans North Am. Wildl. Conf. 13:409-430.

Robel, R.J. 1960. Determining elk movement through periodic aerial counts. J. Wildl. Manage. 24:103-10.

Routledge, R.D. 1981. The unreliability of population estimates from repeated incomplete aerial surveys. J. Wildl. Manage. 45:997-1000.

Ruhl, J.D. 1984. Elk movements and habitat utilization in northern Michigan. M.S. Thesis, Michigan State University, East Lansing, Michigan. 44pp.

Samuel, M.D., and K.H. Pollock. 1981. Correction of visibility bias in aerial surveys were animals occur in groups. J. Wildl. Manage. 45: 993-997.

_____________, E.O. Garton, M.W. Schlegel, and R.G. Carson. 1987. Visibility bias during aerial surveys of elk in north-central Idaho. J. Wildl. Manage. 51:622-630.

Saugstad, S. 1942. Aerial census of big game in North Dakota. Trans. North Am. Wildl. Conf. 7:343-356.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. 2nd ed. MacMillan Publ. Co. Inc., New York, N.Y. 653pp.

Shupe, T.E., and S.L. Beasom. 1987. Speed and altitude influences on helicopter surveys of mammals in brushland. Wildl. Soc. Bull. 15: 552-555.

Siniff, D.B., and R.O. Skoog. 1964. Aerial censusing of caribou using stratified random sampling. J. Wildl. Manage. 28:391-401.

Sommers, L.M. ed. 1977. Atlas of Michigan. Michigan State University Press, East Lansing, Michigan. 242pp.

Springer, L.M. 1950. Aerial census of interstate antelope herds of California, Idaho, Nevada, and Oregon. J. Wildl. Manage. 14: 295-298.

Steel, R.G., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill Book Co., New York, New York. 633pp.

Steinhorst, R.K., and M.D. Samuel. 1989. Sightability adjustment methods for aerial surveys of wildlife populations. Biometrics 45:415-425.

Stephenson, J.H. 1942. Michigan elk. Mich. Conservation 21:8-9.

Strommen, N.D. 1974. Climatological summary of Vanderbilt, Michigan. U.S. Department of Commerce, National Oceanic and Atmospheric Administration Environmental Data Service, with the Michigan Weather Service. 1pp.

Sweeney, J.M., and J.R. Sweeney. 1984. Snow depths influencing winter movements of elk. J. Mamm. 65:524-526.

Telfer, E.S., and J.P. Kelsall. 1979. Studies of morphological parameters affecting ungulate locomotion in snow. Can J. Zool. 57:2153-2159.

White, G.C., R.M. Bartmann, L.H. Carpenter, and R.A. Garrott. 1989. Evaluation of aerial line transects for estimating mule deer densities. J. Wildl. Manage. 53:625-635.

Wolfe, M.L., and J.F. Kimball. 1989. Comparison of bison population estimates with a total count. J. Wildl. Manage. 53:593-596.

Wyoming Game and Fish Department. 1982. Elk. Pages 57-67 in Handbook of Biological Techniques. 2nd ed. 442pp.

APPENDIX I: TABLES

Table A1. Areas of sampling units constructed in 3 density strata for the aerial censusing of elk in Michigan.

Unit	Area (km^2)	Unit	Area (km^2)	Unit	Area (km^2)
H1	9.93	M1	12.03	L1	10.37
H2	9.26	M2	12.40	L2	13.01
H3	10.01	M3	8.40	L3	8.23
H4	12.48	M4	7.87	L4	9.93
H5	8.90	M5	6.97	L5	13.96
H6	17.23	M6	9.61	L6	15.39
H7	9.93	M7	9.31	L7	15.83
H8	9.08	M8	6.57	L8	14.44
H9	11.90	M9	13.06	L9	4.65
H10	13.73	M10	6.34	L10	15.17
H11	8.63	M11	10.24	L11	8.28
H12	9.03	M12	7.57	L12	13.81
H13	10.42	M13	9.53	L13	15.57
H14	10.92	M14	9.39	L14	12.56
H15	9.98	M15	9.53	L15	10.56
H16	7.74	M16	8.18	L16	14.04
H17	11.62	M17	7.25	L17	10.29
		M18	16.45	L18	15.02
		M19	17.81	L19	11.27
		M20	10.56	L20	10.24
		M21	8.05	L21	17.00
		M22	10.92	L22	14.01
		M23	12.48	L23	11.45
		M24	13.73	L24	12.12
		M25	13.60	L25	10.87
		M26	8.15	L26	10.34
		M27	12.43	L27	11.98
		M28	9.21	L28	11.09
		M29	8.45	L29	11.04
		M30	7.42	L30	10.42
		M31	15.52	L31	11.14
		M32	9.39	L32	14.14
				L33	11.01
				L34	5.54
				L35	7.92
				L36	9.21
				L37	12.75
				L38	7.12
				L39	6.75
				L40	10.92
				L41	6.34
				L42	8.98
				L43	13.91
				L44	8.23
				L45	9.18

Table A2. Summarization of data collected for sightability modelling of elk in Michigan, 1988-1989. GS = Group Size, CC = Conifer Cover Class, CA = Conifer Age, SA = Stand Age, AB = Animal Behavior, S/NS = Seen or Not Seen.

Date	Unit	G S	C C	C A	S A	A B	S/NS
1/7/88	H10	9	1	1	3	-	NS
1/7/88	H5	3	4	3	3	-	NS
1/8/88	H6	5	4	3	3	-	NS
1/8/88	H6	7	4	3	3	-	NS
1/14/88	H11	6	3	3	3	-	NS
1/14/88	H1	7	1	1	2	S	S
1/14/88	M13	7	1	1	2	M	S
1/14/88	H11	7	2	1	1	B	S
1/14/88	H17	24	1	1	1	M	S
1/14/88	H17	2	1	1	3	S	S
1/14/88	H5	4	2	3	3	M	S
1/15/88	H14	7	1	1	3	B	S
1/15/88	H11	8	3	3	3	S	S
1/25/88	M12	5	4	3	3	-	NS
1/25/88	H6	3	4	3	3	-	NS
1/25/88	H2	4	2	3	3	M	S
1/25/88	H15	8	1	1	3	B	S
1/26/88	H17	5	4	3	3	-	NS
1/26/88	H11	12	2	1	3	S	S
1/26/88	H11	7	1	1	2	M	S
1/26/88	H17	8	1	1	1	S	S
1/26/88	H15	10	2	2	3	B	S
1/26/88	H15	5	1	1	3	M	S
1/27/88	M12	1	1	1	3	S	S
1/27/88	H8	3	1	1	3	S	S
1/27/88	H7	6	1	3	3	M	S
1/27/88	H10	5	1	1	3	B	S
2/8/88	H6	31	2	3	3	S	S
2/8/88	H2	4	4	3	3	-	NS
2/8/88	H6	5	4	3	3	-	NS
2/8/88	H2	12	4	3	3	-	NS
2/8/88	H2	16	1	1	1	-	NS
2/8/88	H10	14	1	2	2	S	S
2/8/88	H15	18	1	1	1	B	S
2/8/88	H11	2	3	2	2	M	S
2/8/88	H17	19	1	1	3	S	S

Table A2 (Cont'd)

Date	Unit	G S	C C	C A	S A	A B	S/NS
2/9/88	H1	8	4	3	3	-	NS
2/9/88	H6	4	4	3	3	S	S
2/9/88	H10	9	1	1	3	B	S
2/9/88	H6	7	2	3	3	B	S
2/9/88	H2	19	1	1	1	M	S
2/9/88	H8	26	1	3	3	S	S
2/7/89	H11	10	2	2	3	B	S
2/7/89	H11	21	2	2	3	M	S
2/7/89	H11	28	2	2	3	S	S
2/16/89	H11	1	2	3	3	-	NS
2/16/89	H10	6	3	2	2	-	NS
2/16/89	H11	10	1	1	1	-	NS
2/17/89	H9	1	1	1	1	-	NS
2/17/89	M7	5	1	1	1	B	S
2/17/89	H5	1	3	3	3	-	NS
2/21/89	H6	3	4	3	3	B	S
2/22/89	M12	4	3	3	3	-	NS
2/22/89	H5	7	3	3	3	S	S
2/22/89	H5	7	1	1	1	M	S
2/22/89	H5	3	2	3	3	-	NS
2/22/89	H5	2	2	3	3	-	NS
2/22/89	H8	5	2	1	3	M	S
2/22/89	H6	1	4	3	3	-	NS
2/22/89	H10	19	1	1	3	M	S
2/23/89	H11	57	1	2	2	B	S
2/23/89	H11	8	1	2	2	S	S
2/23/89	H11	2	4	3	3	-	NS
2/23/89	H17	23	1	1	1	S	S
2/23/89	H8	5	2	2	3	M	S
2/23/89	H8	36	1	1	3	S	S
2/23/89	H10	25	1	1	3	B	S
2/23/89	H10	2	1	1	3	S	S
2/24/89	H11	8	1	1	2	S	S
2/24/89	H11	55	1	1	2	M	S
2/24/89	H11	3	3	3	3	-	NS
2/24/89	H7	9	3	3	3	B	S
2/24/89	H7	4	4	3	3	-	NS
2/24/89	H9	3	1	3	3	S	S
2/24/89	H5	6	4	3	3	-	NS
2/24/89	H5	5	3	3	3	-	NS
2/24/89	H8	7	2	3	3	S	S
3/1/89	M10	7	3	3	3	S	S
3/2/89	L8	4	1	1	3	M	S

Table A3. Summary of data collected for Michigan elk herd population/variance estimation, 1989. GS = Group Size, CC = Conifer Cover Class, CA = Conifer Age, SA = Stand Age, and B/C/C = Bull/Cow/Calf ratio.

Unit	G S	C C	C A	S A	B/C/C
H2	0	—	—	—	—
H4	8	2	1	3	1/5/2
H5	7	3	3	3	0/7/0
H5	7	1	1	1	0/5/2
H5	5	2	3	3	0/5/0
H6	7	2	3	3	N/A
H6	8	2	3	3	N/A
H7	9	3	3	3	0/6/3
H8	2	1	3	3	2/0/0
H8	6	1	1	1	0/4/2
H8	5	2	2	3	0/4/1
H9	3	1	—	1	3/0/0
H9	6	1	—	1	6/0/0
H9	1	1	—	1	1/0/0
H10	25	1	1	3	2/15/8
H10	5	1	—	3	5/0/0
H11	1	3	3	3	1/0/0
H11	8	1	—	2	0/6/2
H11	57	1	—	2	N/A
H12	17	1	3	3	N/A
H12	6	1	—	1	N/A
H12	18	1	1	3	N/A
H14	4	2	3	3	4/0/0
H15	0	—	—	—	—
H16	1	1	3	3	1/0/0
H16	13	1	3	3	2/7/4
H17	23	1	1	1	3/12/8
M2	6	2	2	3	0/4/2
M4	0	—	—	—	—
M7	8	1	2	2	0/6/2
M7	14	2	2	3	3/8/3
M7	9	1	2	3	N/A
M9	1	1	—	1	1/0/0
M10	13	2	3	3	3/7/3
M10	7	3	3	3	0/5/2
M12	4	3	3	3	4/0/0
M14	0	—	—	—	—
M18	0	—	—	—	—
M21	4	1	—	3	4/0/0
M22	20	1	1	3	1/14/5

Table A3 (Cont'd)

Unit	G S	C C	C A	S A	B/C/C
M23	0	—	—	—	—
M26	4	1	1	3	0/2/2
M26	2	2	1	2	2/0/0
M29	9	2	2	3	2/6/1
M32	0	—	—	—	—
L1	0	—	—	—	—
L8	4	2	1	3	4/0/0
L9	0	—	—	—	—
L11	6	2	3	3	6/0/0
L11	9	2	3	3	N/A
L11	15	3	3	3	N/A
L15	0	—	—	—	—
L20	4	1	—	3	4/0/0
L20	4	1	—	3	4/0/0
L20	2	1	—	3	0/2/0
L30	8	1	—	3	4/4/0
L37	1	1	—	3	1/0/0
L41	0	—	—	—	—
L42	21	1	—	2	3/11/7

Table A4. Corrected group size counts for the aerial censusing of elk in Michigan. Corrected counts are based on the number of elk seen and the conifer cover class occupied at sighting.

Elk Observed	Number of Elk Predicted by Cover Class			
	1	2	3	4
1	1.094	1.355	2.353	6.135
2	2.188	2.71	4.706	12.27
3	3.282	4.065	7.059	18.405
4	4.376	5.42	9.412	24.54
5	5.47	6.775	11.765	30.675
6	6.564	8.13	14.118	36.81
7	7.658	9.485	16.471	42.945
8	8.752	10.84	18.824	49.08
9	9.846	12.195	21.177	55.215
10	10.94	13.55	23.53	61.35
11	12.034	14.905	25.883	67.485
12	13.128	16.26	28.236	73.62
13	14.222	17.615	30.589	79.755
14	15.316	18.97	32.942	85.89
15	16.41	20.325	35.295	92.025
16	17.504	21.68	37.648	98.16
17	18.598	23.035	40.001	104.295
18	19.692	24.39	42.354	110.43
19	20.786	25.745	44.707	116.565
20	21.88	27.1	47.06	122.7
21	22.974	28.455	49.413	128.835
22	24.068	29.81	51.766	134.97
23	25.162	31.165	54.119	141.105
24	26.256	32.52	56.472	147.24
25	27.35	33.875	58.825	153.375
26	28.444	35.23	61.178	159.51
27	29.538	36.585	63.531	165.645
28	30.632	37.94	65.884	171.78
29	31.726	39.295	68.237	177.915
30	32.82	40.65	70.59	184.05
31	33.914	42.005	72.943	190.185
32	35.008	43.36	75.296	196.32
33	36.102	44.715	77.649	202.455
34	37.196	46.07	80.002	208.59
35	38.29	47.425	82.355	214.725
36	39.384	48.78	84.708	220.86
37	40.478	50.135	87.061	226.995
38	41.572	51.49	89.414	233.13
39	42.666	52.845	91.767	239.265
40	43.76	54.2	94.12	245.4

Table A4 (Cont'd)

Elk Observed	Number of Elk Predicted by Cover Class 1	2	3	4
41	44.854	55.555	96.473	251.535
42	45.948	56.91	98.826	257.67
43	47.042	58.265	101.179	263.805
44	48.136	59.62	103.532	269.94
45	49.23	60.975	105.885	276.075
46	50.324	62.33	108.238	282.21
47	51.418	63.685	110.591	288.345
48	52.512	65.04	112.944	294.48
49	53.606	66.395	115.297	300.615
50	54.7	67.75	117.65	306.75
51	55.794	69.105	120.003	312.885
52	56.888	70.46	122.356	319.02
53	57.982	71.815	124.709	325.155
54	59.076	73.17	127.062	331.29
55	60.17	74.525	129.415	337.425
56	61.264	75.88	131.768	343.56
57	62.358	77.235	134.121	349.695
58	63.452	78.59	136.474	355.83
59	64.546	79.945	138.827	361.965
60	65.64	81.3	141.18	368.1
61	66.734	82.655	143.533	374.235
62	67.828	84.01	145.886	380.37
63	68.922	85.365	148.239	386.505
64	70.016	86.72	150.592	392.64
65	71.11	88.075	152.945	398.775
66	72.204	89.43	155.298	404.91
67	73.298	90.785	157.651	411.045
68	74.392	92.14	160.004	417.18
69	75.486	93.495	162.357	423.315
70	76.58	94.85	164.71	429.45
71	77.674	96.205	167.063	435.585
72	78.768	97.56	169.416	441.72
73	79.862	98.915	171.769	447.855
74	80.956	100.27	174.122	453.99
75	82.05	101.625	176.475	460.125
76	83.144	102.98	178.828	466.26
77	84.238	104.335	181.181	472.395
78	85.332	105.69	183.534	478.53
79	86.426	107.045	185.887	484.665
80	87.52	108.4	188.24	490.8
81	88.614	109.755	190.593	496.935
82	89.708	111.11	192.946	503.07
83	90.802	112.465	195.299	509.205

Table A4 (Cont'd)

Elk Observed	Number of Elk Predicted by Cover Class 1	2	3	4
84	91.896	113.82	197.652	515.34
85	92.99	115.175	200.005	521.475
86	94.084	116.53	202.358	527.61
87	95.178	117.885	204.711	533.745
88	96.272	119.24	207.064	539.88
89	97.366	120.595	209.417	546.015
90	98.46	121.95	211.77	522.15
91	99.554	123.305	214.123	558.285
92	100.648	124.66	216.476	564.42
93	101.742	126.015	218.829	570.555
94	102.836	127.37	221.182	576.69
95	103.93	128.725	223.535	582.825
96	105.024	130.08	225.888	588.96
97	106.118	131.435	228.241	595.095
98	107.212	132.79	230.594	601.23
99	108.306	134.145	232.947	607.365
100	109.4	135.5	235.3	613.5

APPENDIX II: CALCULATIONS

Calculation 1. Summary of mathematical probability calculations used to predict elk numbers in conifer class 4 for logistic regression sightability model #5.

Step 1: Sum the number of elk groups actually seen in conifer cover classes 1, 2, and 3.

Step 2: Divide the total groups seen in classes 1, 2, and 3 by 0.8. This is the estimated total number of groups that are present in conifer cover classes 1, 2, and 3. Collected data indicates that 80% of all groups in classes 1-3 will be seen from the air.

Step 3: Multiply the total in step 2 by 0.2. This is the estimated number of groups present in conifer cover class 4. Since 80% of all groups will be in classes 1-3, 20% will be in class 4.

Step 4: Multiply the number of groups in class 4 (from step 3) by 5. This is the number of elk estimated to be in conifer cover class 4. Elk groups size data indicates that the average size for elk groups in class 4 is 5.

Applying actual data obtained from sightability model development, the estimated number of elk in class 4 is 62.5.

Step 1: Groups seen: class 1 = 32, class 2 = 13, class 3 = 5. Total groups seen = 50.

Step 2: 50/0.8 = 62.5 (total groups in all classes)

Step 3: 62.5 * 0.2 = 12.5 (elk groups in class 4)

Step 4: 12.5 * 5 = 62.5 (total elk in conifer cover class 4)