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POPULATION DYNAMICS OF THE MICHIGAN BOBCAT (*Lynx rufus*) WITH REFERENCE TO AGE STRUCTURE AND REPRODUCTION

By

Richard Thomas Hoppe

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ABSTRACT

POPULATION DYNAMICS OF THE MICHIGAN BOBCAT (Lynx rufus) WITH REFERENCE TO AGE STRUCTURE AND REPRODUCTION

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Growing concern toward the management of bobcats (Lynx rufus) has prompted wildlife researchers to study the population dynamics of this species.

Seventy-five bobcat specimens were collected by field station personnel in the Michigan Department of Natural Resources between October 25, 1978, and March 31, 1979. Age frequency was determined through cementum annuli. Reproductive tracts were examined from 35 carcasses, showing 18 females to 17 males. There was no indication of pregnancy in females. Ovulation occurred in 5 animals prior to breeding season, suggesting early cycling. Follicle counts ranged from 1-9 per set, having a mean of 3.4. Corpora lutea ranged from 1-7 per set, having a mean of 4.6. Corpora rubra ranged from 5-17 per set, having a mean of 9.7. A new ageing technique was developed using cranial and post-cranial measurements. A discriminant function analysis was used whereby independent measured variables are selected for entry into the analysis. Age structure of samples shows 64% young of the year, possibly suggesting a good reproductive potential or that inexperienced young are more vulnerable to being trapped and hunted.

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I am deeply indebted to John Stuht, Paul Friedrich, and Carl Bennett, of the Rose Lake Wildlife Research Station for their support and supply of needed materials. Special thanks go to Doug Reeves whose advice and knowledge were deeply appreciated.

Funding for this project was provided by the Earth-Forest Environmental Society, whose former president Bruce Bunting was willing to believe in my study.

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INTRODUCTION

Growing concern toward the management of bobcats (*Lynx rufus*) has prompted wildlife researchers to study the population dynamics of this species. Although the bobcat exists in the 48 contiguous states, little has been reported on age structure and reproductive parameters in the upper Great Lakes region (Erickson 1955). Reproductive parameters have been studied in the northeast (Pollack 1950). Provost *et al.* (1973) provided a very extensive discussion on population dynamics in the southeast. Age structure and reproductive biology have been investigated in the south-central United States (Fritts and Sealander 1978) and the Rock Mountain states (Duke 1949, 1954, Gashwiler *et al.* 1961, Bailey 1972, Crowe 1975*a*, 1975*b*).

Extensive data collection to facilitate management for the Michigan bobcat has come about only since 1976. In the Upper Peninsula (DNR Region I) (Figure 1), a five-dollar bounty system was in effect from 1935 until 1965, and afterwards an open season remained on this species until 1976 when a compulsory registration was initiated. Hunters and trappers were then required to take their bobcats to the nearest Michigan Department of Natural Resources field station for tagging and ageing. The average number of cats taken between 1935 and 1975 in the Upper Peninsula was 592 (Table 1) with a range of 1,247 in 1935 to a low of 4 in 1940. Between 1976-1979 the average harvest was 289 animals. In 1961 the upper Lower Peninsula (Region II) (Figure 2) initiated a random

Figure 1. Map of Michigan, showing the three regions.

Table 1. Michigan (Region I) bobcat bounties paid out between years 1935-1965.

Year	Number	Amount
1935	1,247	5,675
1936	816	4,890
1937	408	2,480
1938		
1939		
1940	4	20
1941	309	1,545
1942	290	1,450
1943	362	1,810
1944	582	2,910
1945	682	3,410
1946	611	3,055
1947	460	2,300
1948	513	2,565
1949	454	2,270
1950	642	3,210
1951	690	3,450
1952	838	4,190
1953	58	290
1954	696	3,480
1955	847	4,235
1956	763	3,815
1957	762	3,810
1958	784	3,920
1959	775	3,875
1960	1,016	5,080
1961	771	3,855
1962	591	2,955
1963	588	2,940
1964	494	2,470
1965	**116	580
1966		
1967		
1968		
1969		
1970		
Total	17,169	$86,535

**Repealed - Payments through July 21 only.

bobcat mail survey and between 1961-1970 an average of 63 bobcats were taken per year. No data were available between the years 1971-1973. A permit system was started in 1974, with permitees receiving mail surveys. Between 1974 and 1977 average take on bobcats was 47. In 1977 compulsory registration went into effect for all of Region II and since then the average harvest has been 63 bobcats.

Presently, hunting and trapping of bobcats is allowed in Michigan. In the Upper Peninsula bobcats can be hunted and trapped from October 25 through March 31, while in the upper Lower Peninsula hunting is allowed only from January 1 through February 28. There is no quota on the number of bobcats taken in either region, but it is compulsory that all bobcats be registered with the Michigan Department of Natural Resources (MDNR). Table 2 shows county and number of bobcats harvested during the past three years.

Due to lack of information on Michigan bobcats, there is a strong need for knowledge on the population dynamics of this species. Results from this study will provide baseline data to facilitate sound management in the near future. Data herein have been compiled from a one-year study (October 1978 through October 1979). The objectives in this study were: 1) to determine age structure and reproductive parameters of the Michigan bobcat, 2) to compare my findings with those of Erickson (1955), and 3) to determine methods for ageing through cranial and post-cranial measurements.

Table 2. Three-year summary (1977-1979) of Michigan bobcat harvest from registration data, including hunting and trapping kill plus miscellaneous (car, train, other).

County	KILL 1977	1978	1979	Total
	Region 1 October 25 - March 31			
Alger	14	8	19	41
Baraga	16	7	11	34
Chippewa	28	45	47	120
Delta	16	22	55	93
Dickinson	29	7	21	57
Gogebic	11	16	8	35
Houghton	3	8	8	19
Iron	17	13	13	43
Keweenaw	0	2	1	3
Luce	9	9	8	26
Mackinac	24	24	43	91
Marquette	25	18	17	60
Menominee	37	34	26	97
Ontonagon	16	22	12	50
Schoolcraft	24	24	30	78
Undetermined	19	-	-	19
TOTALS	288	259	319	866
	Region 2 January 1 - February 28			
Alpena	21	22	15	58
Alcona	0	0	1	1
Cheboygan	9	11	14	34
Emmet	-	-	1	1
Iosco	-	-	1	1
Midland	-	-	1	1
Montmorency	8	4	9	21
Ogemaw	-	-	1	1
Otsego	2	8	4	14
Presque Isle	11	26	20	57
Undetermined	2	-	-	2
TOTALS	53	71	67	191

Total Summary, Region I and II

1977	1978	1979	Total	Average
341	330	386	1,057	353

MATERIALS AND METHODS

Data Acquisition

Samples utilized in this investigation were provided through a system developed through cooperation of the MDNR field personnel and private hunters and trappers. Figure 2 shows a diagrammatic illustration of how the system worked. Basically, each hunter and trapper received a letter describing the procedures (Figures A1, A2). A monetary reward was given to those who cooperated in this study. Four dollars were given to the hunters and trappers from Region I due to greater harvest of bobcats in this region and longer distances to travel for registration. Two dollars were given to the hunters from Region II because of shorter traveling distance for registration and greater willingness to cooperate in the study. Specimens were taken by field station personnel who kept them in cold storage. When space became a limiting factor, samples were sent to the Rose Lake Wildlife Research Center, Shiawassee County, Michigan, where laboratory and autopsy rooms were provided. Reproductive tracts were removed with scalpels, scissors, and bone shears. Cats without reproductive tracts were listed as males. As tracts were removed from the bobcats, they were immediately placed in Mossman's AFA fixative (Provost 1962) and later stored in 70% ethanol. AFA was chosen as a fixative to emphasize formation of scars in the reproductive organs. Hearts, kidneys, livers, and intestines were preserved in 10% formalin for future use. Skulls and carcasses were cleaned by dermestid beetles (*Dermestes vulpinus*) at

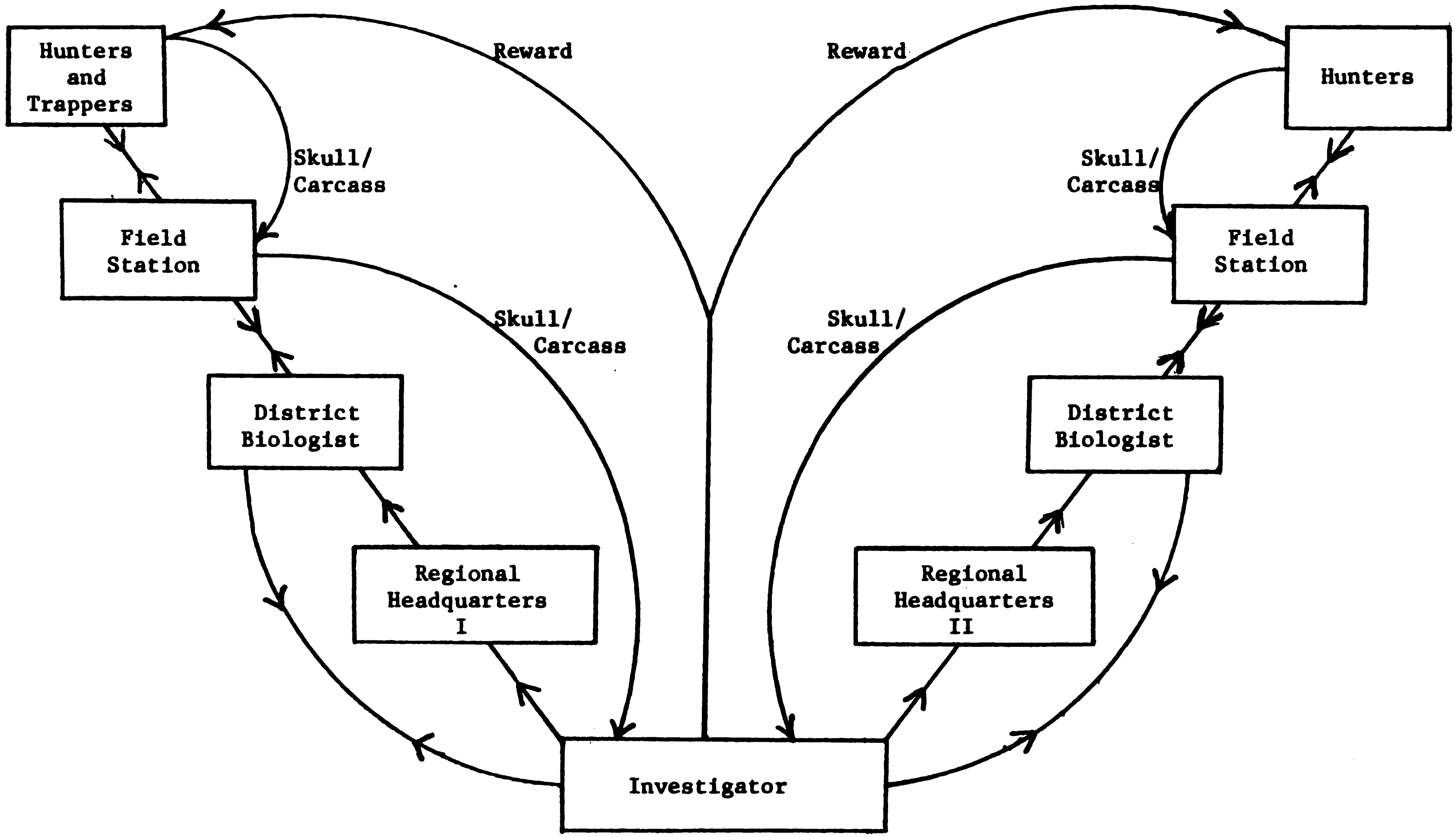

Figure 2. System of communication and delivery of bobcats. Arrows signify direction of communication.

the Michigan State University Museum. Depending on weather conditions, carcass material took anywhere from two to eight weeks in the bug house for cleaning. Due to reaction of yellow identification tags with decaying remains, museum identification tags had to be used. Each specimen was placed in the bug house in its own separate container, thus minimizing any separation of bones.

Life Table Construction

Age determination through cementum annuli is a well established procedure. Jonkel (1966), Linhart and Knowlton (1967), Craighead et al. (1970), Grau et al. (1970) and Grue et al. (1973) have all shown that incremental layers are present in the cementum layers of many carnivores. Crowe (1972) also showed these layers to be present in the cementum of the bobcat, indicating that cementum layers may be used to provide quantitative measure of the age. An open root apical foramen in the canines of the bobcat allows the one year old age class to be established (Crowe 1975a). The first annulus is laid down late in the second winter of the cat's life, after the foramen has closed (20-23 months). Older bobcats, therefore, can be aged by counting the number of annuli (designating one less than the number of winters survived) and adding one.

Age was established through the counting of cementum annuli from longitudinally sectioned teeth (Crowe 1972) and all sectioning and ageing of teeth were done by Gary Matson, Millstown, Montana. Difficulties in ageing through cementum annuli may sometimes exist. Age analysis is complicated by species and geographical differences which have a tendency to cause variation in cementum deposition patterns (Matson 1979). A life table was constructed and smoothed (Caughley 1977).

Reproductive Parameters

Provost (1962) suggested that ovaries and reproductive tracts could be fixed in Mossman's AFA. He also warned that possible bleaching and discoloration may accompany fixation. It seemed the advantages as discussed by Provost outweighed possible disadvantages. During examination of reproductive tracts, ovaries did show a prominent difference between corpora lutea (CL) and corpora rubra (albicantia) (CR). The uteri of females showed no prominent placental scar marks. It was brought to my attention by communicating with bobcat researchers, (1979, Bobcat Research Conference) that freezing the uterus rather then fixing it enables tracts and scars to be easily handled and observed, however, there was no way to verify this method.

Reproductive organs were used to determine litter size. In addition, corpora lutea, corpora rubra, and volumetric displacement of ovaries were related to age. A direct relationship was found between age and volume of the ovary (Crowe 1975a). Anestrus females were used in determining volume relationships. A method was developed to estimate actual volume displacement (AVD) in the field by linear measurements of the ovary correlated to a measured volume displacement (MVD). Vernier calipers were used to measure length, width, and height of each ovary and testis and volume was later calculated. However, since the shape of the ovary will vary considerably due to CL and follicle formation (Figure 3), dimensions of the ovary must be standardized to utilize this technique.

Figure 3. Three ovaries, showing different stages of maturity.

The length was defined as the largest distance between the ligament connected to each end of the ovary (line AB in Figure 4). This ligament was observed as a dark line where the ovary connected to the tract. Height is then that distance perpendicular to the center of line AB (Figure 5) and width is defined as that distance through the center of the ovary perpendicular to line AB (Figure 6). Doing this each time enabled the three measurements to be consistent.

Testis was also measured for length, width, and height. The side showing the epididymis was used for reference point AB. Measurements were taken similar to ovary, making sure when testis is placed down it remains in that position for length and height. Width was taken by slowly turning testis approximately one-quarter turn, then measuring.

Actual volumetric displacement was determined for each ovary and testis. Finely incremented graduated cylinders were used to determine displacement. When determining volume displacement with a liquid it is essential that reading be taken from only one reference point, such as the meniscus. Doing this allows for consistancy. Measured volume displacement (MVD) was regressed with the actual volumetric displacement (AVD).

Ovaries were later cut into four evenly spaced sections. Cut was performed by scalpel. Sections were then examined under dissecting microscope for CL, CR, and follicle formation for later use in reproductive analysis.

Cranial and Post-Cranial Measurements

Cleaned skulls and carcasses were used for obtaining data for developing a simplified ageing technique. Nine cranial and eight post-

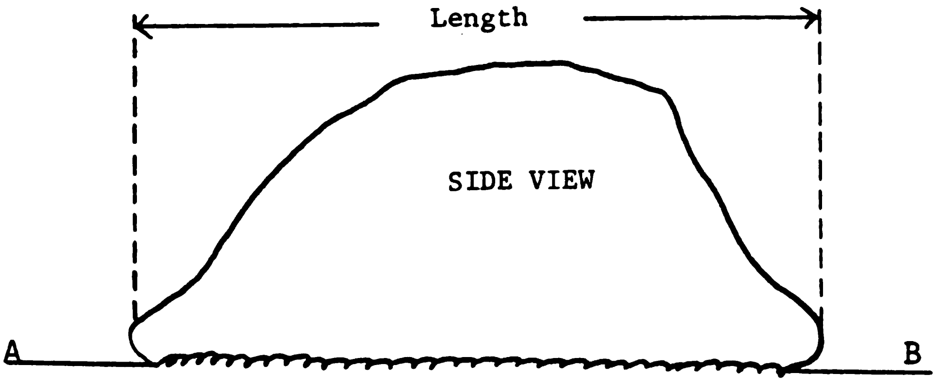

Figure 4. Measurement of ovary length.

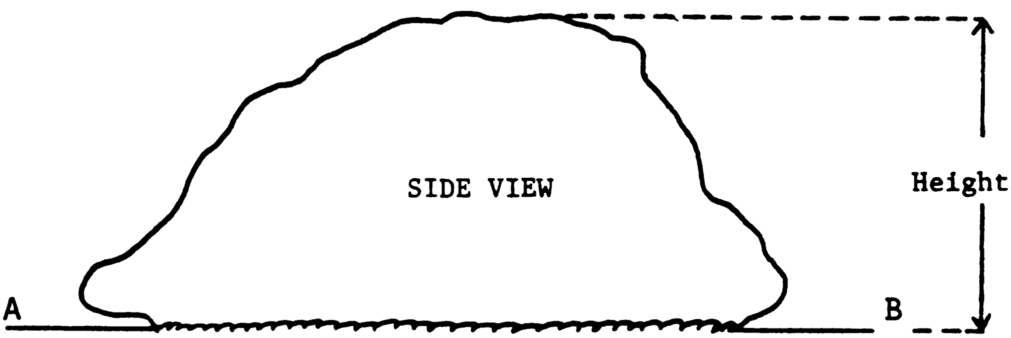

Figure 5. Measurement of ovary height.

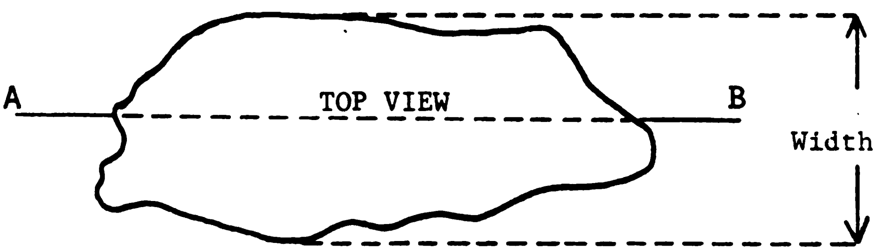

Figure 6. Measurement of ovary width.

cranial measurements were taken (Hall 1946) (Table 3). Vernier calipers were used to measure all cranial and post-cranial parts to the nearest tenth of a millimeter. Of the eight different post-cranial measurements taken, not all were used on the seven bones chosen (Von Den Driesch 1976) (Table 4). A total of 20 measurements were taken on the radius, tibia, scapula, humerus, ulna, femur, and fibula.

Table 3. Definitions for cranial measurements.

CL (Condyolbasal Length) -- Least distance on skull from a line connecting the posteriormost projections of the exoccipital condyles to a line connecting the anteriormost projections of the premaxillary bones.

ZB (Zygomatic Breadth) -- Greatest distance across zygomatic arches of cranium perpendicular to long axis of skull.

MB (Mastoidal Breadth) -- Greatest distance across mastoid bones perpendicular to long axis of skull.

IC (Interorbital Constriction) -- The least distance across the top of the skull between the orbits.

PL (Palatal Length) -- Distance on the skull from anteriormost point on the posterior border of the palate to a line connecting the anteriormost parts of the pre-maxillary bones.

TR (Length of Tooth Row) -- Measurement parallel to long axis of cranium. Over-all length of upper teeth.

WRT (Width of Tooth Row) -- Width of tooth row from outer most portion across canine where pre-maxillary bone meets canine.

TL (Total Length) -- Line from lambdoidal crest to anteriormost projection of the pre-maxillary bones.

WTRD (Width Temporal Ridge) -- Width of temporal ridge, where frontal meets parietal.

Table 4. Definitions for post-cranial measurements

GL (Greatest Length)

RGL -- Radius, greatest length
TGL -- Tibia, greatest length
HGL -- Humerus, greatest length
UGL -- Ulna, greatest length
FGL -- Femur, greatest length
FIGL -- Fibula, greatest length

BP (Greatest breadth of the proximal end)

RBP -- Radius, greatest breadth of the proximal end
TBP -- Tibia, greatest breadth of the proximal end
FBP -- Femur, greatest breadth of the proximal end

BD (Greatest breadth of the distal end)

RBD -- Radius, greatest breadth of the distal end
TBD -- Tibia, greatest breadth of the distal end
FBD -- Femur, greatest breadth of the distal end

SD (Smallest breadth of diaphysis)

RSD -- Radius, smallest breadth of diaphysis
TSD -- Tibia, smallest breadth of diaphysis
HSD -- Humerus, smallest breadth of diaphysis
FSD -- Femur, smallest breadth of diaphysis

GLP (Greatest length of the glenoid process)

SGLP -- Scapula, greatest length of the glenoid process

HS (Height along spine)

SHS -- Scapula, height along spine

SCL (Smallest length of the neck)

SSLC -- Scapula, smallest length of the neck

BPC (Greatest breadth across the coronoid process)

UBPC -- Ulna, greatest breadth across the coronoid process

STATISTICAL METHODS

The age distribution data was utilized in a life table analysis and transformed by several methods in order to determine the best linear fit. The log-log transformation was the most suitable. A Leslie matrix computer model was used for projecting the population of female bobcats through time and estimating the rate in increase (r_s) for use in the life table.

A discriminant analysis was used in developing a new ageing technique. The Wilks method was used which selects independent variables for entry into the analysis based on their discriminating power. A one-way analysis of variance was used to determine the most significant cranial and post-cranial measurements.

The Statistical Package for the Social Sciences (SPSS) was used for the linear regression and discriminant analysis (Nie et al. 1975). All computations were performed on the Cyber 750 computer at Michigan State University

RESULTS

Hunters and trappers supplied skulls and/or carcasses from 75 animals collected between October 25, 1978 and March 31, 1979 (35 were complete carcasses and 40 were skulls). Sex was determined by autopsy immediately after carcass collection. Reproductive tracts were removed from 18 females and 7 males. The remaining 10 were recorded as males, because even though they lacked testes due to removal by trappers and hunters during skinning, no female reproductive tracts were observed during autopsy. Region I provided 93% of the specimens, while Region II supplied only 7%. The sex ratio was 18 females to 17 males (51.4%). Many of the skulls received from hunters were shot in the head, thus resulting in fragmentation of skull parts. Those parts unable to be measured were voided from data analysis. Results of cranial and post-cranial measurements showing mean, variance, and range are found in Tables 5 and 6.

Life Table

The age structure data show that 64% (46) of the 72 aged bobcats were young of the year, 5% (4) were two-year olds, 20% (14) were three and four-year olds, 4% (3) were five-year olds, and 7% (5) were six to eleven years old (Figure 7). Since the majority of specimens were the young of the year, bias on the age distribution may be due to the small sample size and large number of specimens from Region I.

Table 5. Post-cranial measurements (mm) for three age groups, showing mean, variance, minimum, and maximum.

measured variables	valid cases (n)	mean	variance	minimum	maximum
		AGE 1 N=18			
RGL	11	122.18	360.56	81.0	148.0
RBP	11	12.59	2.05	9.9	14.2
RBD	16	19.80	3.88	14.2	22.5
RSD	18	4.26	0.29	3.5	5.7
TGL	15	149.26	390.78	104.0	180.0
TBP	17	28.48	6.66	22.1	33.2
TBD	16	21.48	6.35	18.5	27.3
TSD	18	8.64	0.81	6.9	10.0
SGLT	18	20.13	3.79	14.3	22.5
SHS	18	91.11	172.45	59.0	114.0
SSLC	18	17.62	2.42	14.2	19.7
HGL	18	130.38	260.13	94.0	158.0
HSD	18	9.19	1.24	6.9	11.5
UGL	12	149.75	222.93	132.0	179.0
UBPC	18	14.54	1.64	12.2	16.5
FGL	18	147.55	372.96	105.0	179.0
FBP	13	28.13	7.93	22.6	33.7
FBD	18	26.46	7.29	19.9	30.9
FSD	18	9.37	1.04	7.3	11.5
FIGL	6	149.16	225.36	127.0	171.0
		AGE 2-3 N=5			
RGL	4	136.50	95.00	128.0	150.0
RBP	5	12.68	1.34	11.5	14.1
RBD	4	19.45	2.27	18.6	21.7
RSD	4	4.75	0.20	4.4	5.4
TGL	5	162.60	287.30	141.0	188.0
TBP	5	29.42	3.49	28.0	32.6
TBD	5	20.20	1.21	19.0	21.5
TSD	5	9.00	0.55	8.3	10.2
SGLP	5	20.62	2.48	19.5	23.4
SHS	5	101.60	129.80	85.0	117.0
SSLC	5	17.84	2.46	16.1	20.1
HGL	5	142.20	215.70	124.0	165.0
HSD	5	9.60	0.95	8.7	11.3
UGL	3	155.33	37.33	150.0	162.0
UBPC	5	14.76	3.43	12.7	17.1
FGL	5	163.60	273.80	141.0	186.0
FBP	4	29.50	9.65	27.3	34.1

Table 5. (cont'd.)

measured variables	valid cases (n)	mean	variance	minimum	maximum
FBD	5	26.98	5.23	23.9	29.9
FSD	5	9.64	1.44	8.8	11.7
FIGL	4	155.25	103.58	148.0	170.0
		AGE 4-11 N=6			
RGL	5	132.40	191.30	109.0	143.0
RBP	6	12.28	1.24	10.5	14.0
RBD	5	19.74	2.39	17.9	22.1
RSD	5	4.65	0.32	3.6	5.2
TGL	6	156.16	194.16	137.0	170.0
TBP	6	29.00	5.02	25.1	32.0
TBD	6	20.48	2.79	18.2	23.4
TSD	6	9.08	0.64	7.7	9.9
SGLP	6	20.65	2.93	18.0	22.8
SHS	6	100.16	193.76	81.0	114.0
SSLC	6	18.33	2.35	16.1	20.4
HGL	6	138.16	224.56	119.0	154.0
HSD	6	10.00	1.39	8.3	11.6
UGL	5	157.00	244.00	131.0	170.0
UBPC	6	14.66	1.17	13.5	16.1
FGL	6	178.16	248.10	142.0	246.0
FBP	5	29.04	10.50	24.1	32.5
FBD	6	24.83	41.97	11.9	30.0
FSD	6	9.95	0.91	8.3	10.9
FIGL	4	155.25	24.25	151.0	160.0

Table 6. Cranial measurements (mm) for three age groups showing mean, variance, minimum, and maximum.

measured variables	valid cases (n)	mean	variance	minimum	maximum
		AGE 1 = 43			
CL	34	107.89	75.46	94.4	127.8
ZB	36	79.82	47.52	69.4	96.4
MB	32	52.42	10.67	46.1	59.7
IC	40	20.98	6.60	16.3	27.4
PL	43	46.34	17.39	38.0	56.0
LTR	43	41.99	10.60	33.3	50.4
WTR	41	31.68	7.70	24.5	38.5
TL	34	117.08	107.79	101.6	139.1
WTRD	29	22.92	32.09	11.7	29.8
		AGE 2-3 N=13			
CL	11	117.90	111.50	99.0	134.1
ZB	12	88.60	42.78	75.3	97.7
MB	10	55.55	13.78	49.4	61.1
IC	12	24.22	3.20	20.3	26.8
PL	13	50.70	18.50	43.1	57.7
LTR	13	44.90	11.50	39.8	51.3
WTR	13	33.70	5.87	30.2	37.7
TL	12	128.12	117.40	108.6	147.6
WTRD	10	12.23	55.09	1.8	21.8
		AGE 4-11 N=16			
CL	15	115.86	61.46	101.4	127.5
ZB	14	91.42	46.39	78.7	102.7
MB	12	55.34	7.61	51.1	60.9
IC	16	25.13	3.92	20.6	28.5
PL	16	50.63	9.34	46.1	56.7
LTR	16	44.49	6.46	40.8	49.2
WTR	16	34.53	5.20	30.7	38.0
TL	14	125.57	83.60	110.3	140.0
WTRD	12	15.78	51.22	3.9	26.2

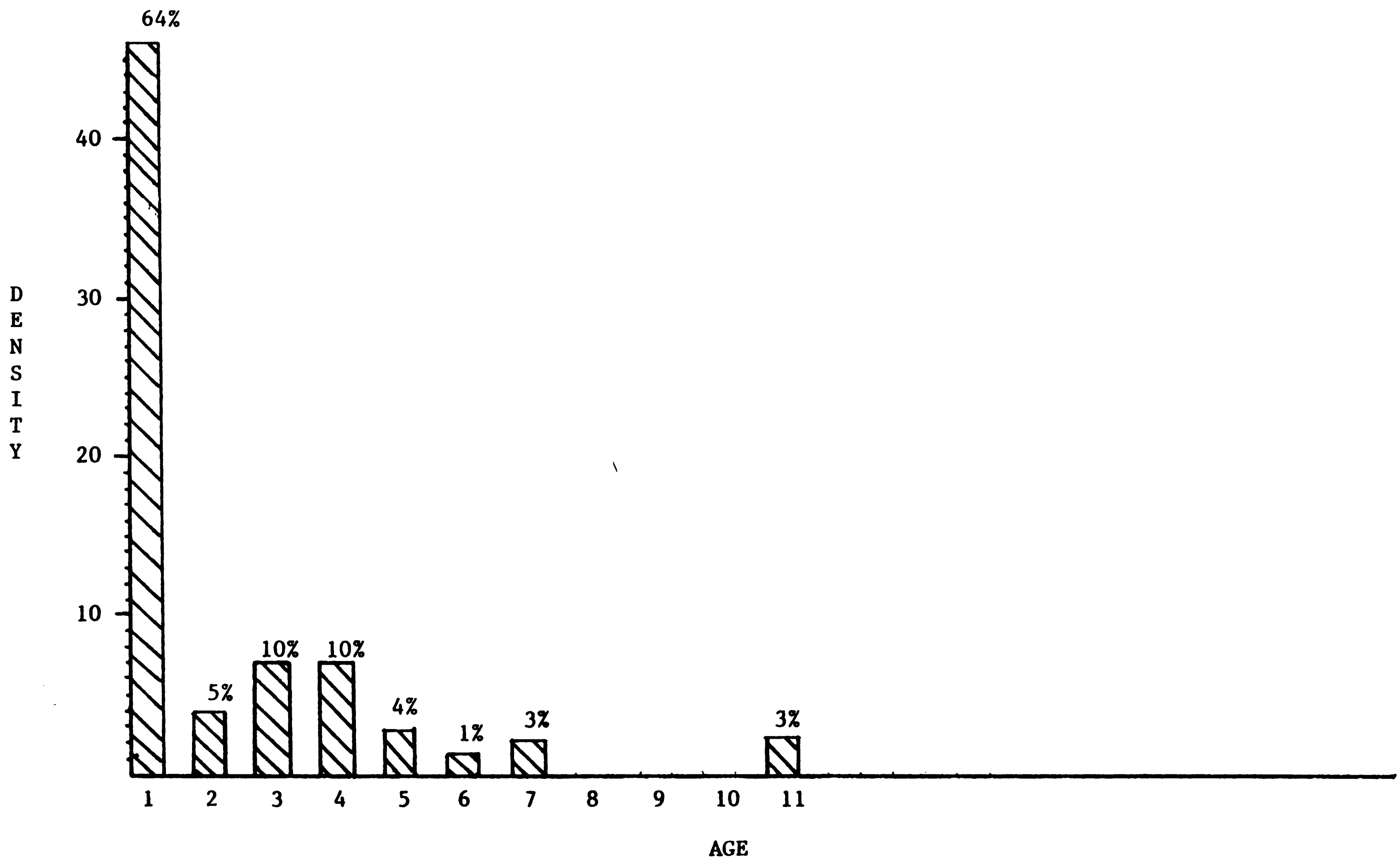

Figure 7. Age structure of 72 bobcats from Michigan, 1978-1979.

The life table presented in Table 7 was constructed from sample age frequencies from ages one to eleven. Erickson's (1955) data on litter size was used. To calculate the zero age frequency, the number of offspring was determined by multiplying the mean litter size of 2.5 by 75 (3 of these specimens were excluded from the frequency due to inability to age) (Erickson 1955). Assuming 50:50 sex ratio, the total number of females at the zero age frequency is just one-half the number possible.

A life table can be calculated directly from a stationary age distribution only when the frequency of each age class X is equal to or greater than that of X + 1. When variation and bias violate this requirement, an age distribution must be smoothed. If this were not done then d_x (probability of dying in each age interval X to X + 1) would be negative. Frequencies of ages one to eleven were smooothed by the regression equation

$$\log_{10}(y) = 1.4369 - 1.4172 \log_{10}(x)$$

where

$$y = \text{actual sample frequency}$$

and

$$x = \text{age.}$$

The regression had an $r = 0.89$ with MSE = 0.061. Once smoothed, subsequent calculations follow that outlined in Table 8.

Various assumptions should be met in the calculation of the life table. First, we assume that there is a stable age distribution throughout the population and second, that there is a known rate of increase (Caughley 1978). Although neither of these assumptions was satisfied, the calculated life table is the best approximation currently available.

Table 7. Sampled bobcat age frequencies and derived life table.

Age	Frequency N = 72	Adjusted Smoothed Frequency	Number surviving to age X L_x(1000)	Number dying in interval X to X + 1 D_x(1000)	Mortality rate from X to X + 1 Q_x(1000)	Survival rate X to X + 1 P_x(1000)
0		93.60*	1000	708	.708	.292
1	46	27.35	292	183	.626	.374
2	4	10.24	109	47	.431	.569
3	7	5.76	62	21	.338	.662
4	7	3.83	41	11	.268	.732
5	3	2.79	30	7	.233	.767
6	1	2.16	23	4	.174	.826
7	2	1.73	19	4	.211	.789
8	0	1.43	15	2	.133	.867
9	0	1.21	13	2	.154	.846
10	0	1.04	11	1	.91	.909
11	2	0.91	10			r = 0.89 MSE = 0.06

*2.5 embryos per female (Erickson 1955)

Table 8. Life table statistics from animals in a cohort still surviving at various ages.

Statistic	Symbol	Calculation
Age	x	-
Number surving in each age class	f_x	Adjusted through regression
Probability at birth of surviving to age x	l_x	f_x/f_o
Probability of dying in each age interval x to x + 1	d_x	$l_x - l_{x+1}$
Mortality	q_x	d_x/l_x
Survival rate	p_x	$1 - q_x$

An attempt was made to iteratively estimate r_s (exponential rate of increase) by means of Lotka's equation

$$\Sigma l_x e^{-r_s x} m_x = 1$$

where

l_x = probabilities at birth of surviving to age x,

and

m_x = fecundity (number of females born to a female in age class x).

To solve this equation one needs prior knowledge of l_x and m_x. Since l_x values must come from a life table where assumptions of stability and known r_s are met, this is a circular arrangement. However, one may take the sample age distribution and construct a life table without meeting the assumptions and, thus, find approximations of l_x, d_x, q_x, and p_x. Then, using p_x calculated above, a leslie matrix model can be used to determine an appropriate r_s. Taking Caughley's (1978) life table correction factor when $r_s \neq 0$ allows for calculation of a life table with "better" approximations of l_x, d_x, q_x, and p_x and subsequently r_s. Thus taking r_s and running through the correction factor will enable new p_x values to be determined. Repeating this process of calculating p_x and determining r_s from the projection model until r_s equals the previous r_s , enables one to find an estimator for the exponential rate of increase. Results in this study show $r_s = 0.253$ and, thus, the population is not stationary ($r_s \neq 0$) but increasing. If r_s were negative, the population would be decreasing.

Reproductive Parameters

A sex ratio of 18 females to 17 males (51.4% females) was only six percent different from Erickson's (1955) ratio of 40 females to 48 males (45.4% females) and almost identical to Crowe's (1975a) 81 females to 80 males (50.3% females) and Pollack's (1950) 88 females to 92 males (48.8% females).

A regression was constructed whereby measured volume (MV) was plotted against actual volume (AV), thus allowing actual volume of ovary to be determined (Figure 8). The regression equation is

$$y = 0.0647 + 0.0005x$$

where

x = measured volume

and

y = actual volume displacement.

Although measured volume of each ovary (length X width X height) is an over-estimation due to irregularity in shape from CL and follicles, it is consistent and will not invalidate the results.

Based on the assumption that body weight increases with age and testis volume increases with body weight (Erickson 1955, Crowe 1975a) a regression of AV on MV was constructed (Figure 9). The regression equation is

$$y = 0.0936 + 0.0005x$$

where

x = measured volume

and

y = actual volume displacement.

The two regression lines seem to show a good fit. This technique would enable a regression line to be used to determine actual volume displacement (AVD). The biologist using this technique could determine MVD quite easily in the field through measurement, and then determine actual volume displacement by the regression equation. Over a period of

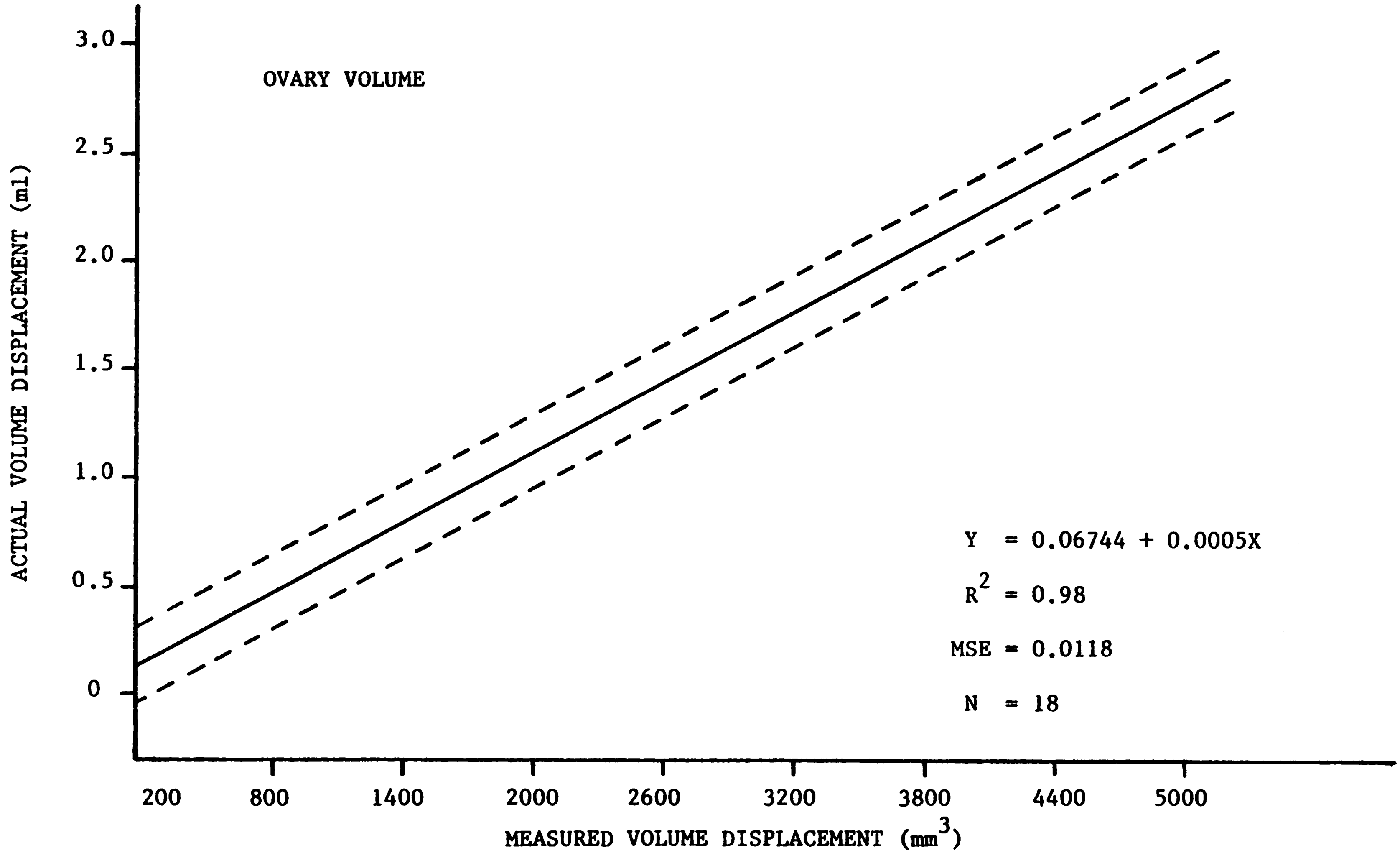

Figure 8. Regression line with 95% confidence limits on bobcat ovaries.

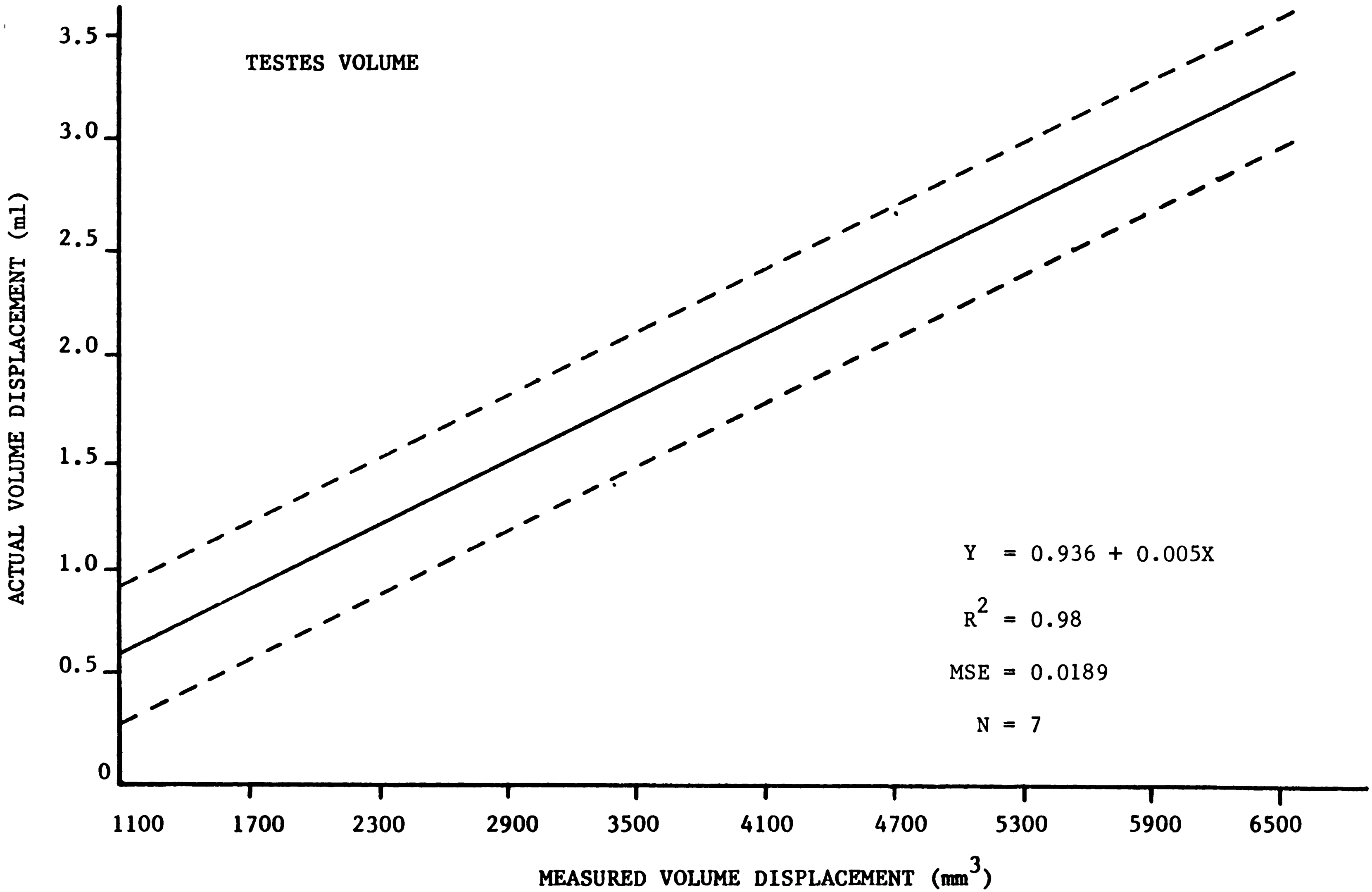

Figure 9. Regression line with 95% confidence limits on bobcat testes.

time, once a well collected sample size has been established, this technique can be extrapolated to determine actual age groups, since testes and ovary volume are directly related to age.

Examination of the 18 female reproductive tracts showed no signs of pregnancy; however, various tracts did show differences in size of left and right ovary (Figure 10). The breeding season for bobcats in northern states is believed to occur between January and March (Pollack 1950, Erickson 1955, Crowe 1975a). Registration records showed 8 out of 11 bobcats taken prior to January. Dates for the remaining 7 were unavailable. Of the 3 animals taken after January, 2 were immature and 1 showed no signs of pregnancy. Data suggests that possible reasons for lack of pregnancy is due to the date of collection and large juvenile sample size. The data showed 5 of 8 cats collected prior to breeding season had recently ovulated. Ovulation in the bobcat is followed by formation of corpora lutea (Duke 1949). Ovaries fixed in Mossman's AFA show corpora lutea as large white bodies, whereas corpora rubra resulting from degeneration of CL are light to dark brown (Provost *et al*. 1973) (Figure 11). A sharp delineation between luteal bodies is clearly seen.

Follicles, corpora lutea, and corpora rubra can be used to determine potential litter size. Follicle counts ranged from 1-9 per set having a mean and mode of 3.4 and 1 respectively. Corpora lutea counts ranged from 1-7 per set, having a mean and mode of 4.6 and 5. Corpora rubra counts ranged from 5-17 per set having a mean and mode of 9.7 and 5. Taking the mean ratio (0.68:1) of the actual litter size to CL counts from prior research, enables potential litter size to be estimated from

Figure 10. Female reproductive tract, showing difference in size of left and right ovary.

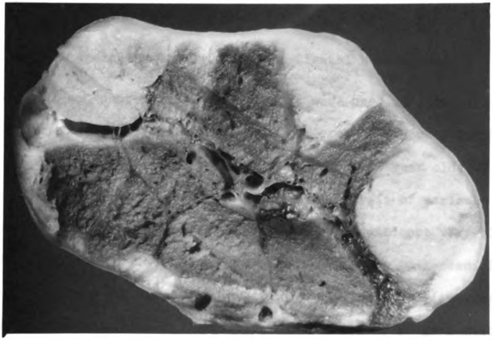

Figure 11. Section of ovary, showing three white corpora lutea and eight darker corpora rubra.

the collected data. Litter size is 3.1 with 90% confidence intervals of 2.6 and 3.6. This estimate may be biased by regional location, seasonal variation, climatic factors, and dietary needs; however, it is a reasonable approximation of the true average litter size. Erickson (1955), Gashwiler (1961), Bailey (1974), Crowe (1975a), and Fritts et al. (1978) determined actual litter size to be 2.5, 3.5, 2.8, 2.8, and 2.5 respectively.

Ageing by Cranial and Post-Cranial Measurements

Cranial and post-cranial measurements were used in determining a possible new ageing method. Three main age groups were used in the discriminant analysis. The groups were made up of 1 year olds, 2 to 3 year olds, and 4 to 11 year olds. One-way analysis of variance (ANOVA) procedures were used for selection of the most significant variables ($p<0.05$). Variables having greatest significance for post-cranial measurements were RGL (greatest length of radius) and FGL (greatest length of femur). These two variables did not result in good discriminating power.

Cranial measurements worked better. One-way analysis of variance showed MB (mastoidal breadth), ZB (zygomatic breadth), IC (interorbital constriction), PL (palatal length), CL (condylobasal length), and TRD (temporal ridge) as being significant at $p<0.05$. Various combinations of these variables were tried but the best set of variables appeared to be simply ZB and PL.

Table 9 indicates that considerable discriminating power exists in these two variables since the smaller the value of Wilks lambda, the more discriminating power the variables will have. Age groups are

Table 9. Summary table of discriminant analysis.

Step number	Variable entered	Variable removed	F to enter or remove	Number included	Wilks Lambda	Sig.	Raos V	Change in Raos V	Sig.
1	ZB		24.05462	1	.58919	.000	48.10923	48.10923	.000
2	PL		4.35184	2	.52234	.000	61.18946	13.08022	.001

Number Removed	Eigen value	Canonical correlation	Percent of trace	Wilks Lambda	Chi-square	D.F.	Significance
0	.85442	.67878	96.3	.52234	44.48682	4	.000
1	.03238	.17711	3.7	.96863	2.18316	1	.140

2 Functions will be used in remaining analyses

Standardized Discriminant Function Coefficients

	1	2
ZB	2.14532	-1.47513
PL	-.99495	2.04625

Centroids of Groups in Reduced Space

Group 1	-.71686	-.03812
Group 2	.64619	.35359
Group 3	1.40154	-.18485

clearly separated with minor overlap (Table 10). A fair percentage of the discrimination is statistically significant ($p<.001$) and 78% of known age groups were correctly classified. The percent of trace should be used in judging the importance of the discriminant function. This statistic shows the relative percentage of the eigenvalue dealing with the function. A single eigenvalue allows for an easy reference to the relative importance of the associated function. Variable ZB has an eigenvalue of 0.854, making up 96.3% of the function, whereas PL has an eigenvalue of 0.032 or 3.7% of the function. Canonical correlation measures the function's ability to discriminate among groups. The canonical correlation squared is the proportion of variance in the function explained by the groups. ZB accounts for 46% of the variance while only 3.1% is accounted for by PL.

All measured variables making up ZB and PL were used in determining discriminant prediction scores (Morrison 1976). The equation can be written as

$$w_{ij} = x' S^{-1}(\bar{x}_i - \bar{x}_j) - \tfrac{1}{2}(\bar{x}_i + \bar{x}_j)' S^{-1}(\bar{x}_i - \bar{x}_j)$$

where

x_j = sample mean vector of j^{th} groups,

K = number of groups,

A_j = sums of the squares and products matrix for j^{th} groups,

$$S = \frac{1}{N - K} \sum_{j=1}^{k} A_j .$$

Three prediction equation scores were computed for each of the three groups. The discriminant statistics are

Table 10. Prediction results from discriminant analysis, showing how prediction equation separated age groups out.

Actual Group		N of	Predicted Group Membership		
Name	Code	Cases	Group 1	Group 2	Group 3
Group 1	1	43	36. 83.7 pct	4. 9.3 pct	3. 7.0 pct
Group 2	2	13	2. 15.4 pct	8. 61.5 pct	3. 23.1 pct
Group 3	3	16	1. 6.3 pct	3. 18.8 pct	12. 75.0 pct

77.8 percent of known cases correctly classified

$$w_{12} = x'S^{-1}(\bar{x}_1 - \bar{x}_2) - \tfrac{1}{2}(\bar{x}_1 + \bar{x}_2)' S^{-1} (\bar{x}_1 - \bar{x}_2)$$

$$w_{13} = x'S^{-1}(\bar{x}_1 - \bar{x}_3) - \tfrac{1}{2}(\bar{x}_1 + \bar{x}_3)' S^{-1} (\bar{x}_1 - \bar{x}_3)$$

$$w_{23} = x'S^{-1}(\bar{x}_2 - \bar{x}_3) - \tfrac{1}{2}(\bar{x}_2 + \bar{x}_3)' S^{-1} (\bar{x}_2 - \bar{x}_3).$$

When using these equations it is only necessary to use w_{12} and w_{13}, because $w_{23} = w_{13} - w_{12}$. The three prediction equations are

$$w_{12} = -0.28981476x_1 + 0.12370988x_2 + 18.405795$$

$$w_{13} = -0.58738272x_1 + 0.53714847x_2 + 24.242442$$

$$w_{23} = -0.29756795x_1 + 0.41343858x_2 + 5.8366465.$$

The classification rule is defined as

1 year old if $w_{12}>0$ and $w_{13}>0$

2-3 year old if $w_{12}<0$ and $w_{13}>w_{12}$

4-11 year old if $w_{13}<0$ and $w_{12}>w_{13}$.

After ZB (zygomatic breadth) and PL (palatal length) are measured, these measurements are substituted back into the prediction equation. For example, if ZB measures 90.5 mm and PL measures 53.4 mm then substituting these back into prediction equation we have

$$w_{12} = -0.28981476(90.5) + 0.12370988(53.4) + 18.405795 = -1.2163$$

$$w_{13} = -0.58738272(90.5) + 0.53714847(53.4) + 24.242442 = -0.2319$$

and the classification rule shows $w_{12}<0$ and $w_{13}>w_{12}$, thus estimating the age group to be in the 2-3 year old age class. The amount of confidence placed on this method can be seen by looking back to the prediction results (Table 10). There were 43 one year old cats, out of which 36 (83.7%) were correctly classified; 13 two to three year olds, out of which 8 (61.5%) were correctly classified, and 16 four to eleven year olds out of which 12 (75%) were correctly classified. It should be mentioned that this method of predicting age from ZB and PL all falls back on the assumption that age prediction through cementum annuli is correct.

Comparisons with Previous Research

Age determination as reported by Erickson (1955) was mainly through the presence or absence of CL and CR. This method seems to be a good estimator in comparison to ageing by cementum annuli. Comparing the two ageing methods gave a regression of r = 0.84 (Table 11). Erickson postulated that if corpora lutea were present, animals bred at least once. Studies by Pollack (1950), Erickson (1955), and Crowe (1975a) report that bobcats from northern states breed during their first season (one year of age). Females showing no corpora lutea were judged to be young of the year. If only CL were present it appeared animals bred once and were therefore one to two years old. If both CL and CR were present the animals had bred two or more times. Follicles added three-quarters to one year. Erickson (1955) reported that the average number of CL to follicles was 5.5 to 5.6, implying but one ovulation per breeding season. Erickson also determinined that 5.0 ova/ovulation were considered average for the Michigan bobcat. Therefore, each set of 5 CL or CR indicated a year of age. These results do not mean the methodology used in each case was correct, but indicate that Erickson's method is quite adequate when compared to the more accepted method of tooth sectioning.

Table 11. Relationship between aging methods (ovary analysis and cementum annuli of teeth) in bobcats.

Tag	Follicles	Corpora Lutea	Corpora Rubra	Age (Ovary)	Age (Tooth)
401	0	5	5	2	3
101	6	7	17	5	6
255	4	5	16	5	7
2156	6	3	0	2	1
535	5	5	0	2	1
706	4	3	7	3	0.5
142	1	0	0	1	0.5
700	3	5	8	3	3
245	1	7	0	2	3
704	1	1	5	3	2

During this study it was determined that the mean number of CL/ ovulation was 4.6, whereas Erickson stated 5.0 was the mean. Potential litter size was determined to be 3.1, while Erickson determined actual litter size to be 2.5.

Comparing age structure between this study and Erickson's was incompatible. Erickson's method used ovaries as a form of ageing. Males were differentiated by weight alone as either being juveniles or adults. Only 20 females were used in Erickson's analysis even though 40 were collected. Table 12 shows a comparison between Erickson's data and mine. There is a large juvenile class in both cases but because of small size, any further analysis between Erickson's data and mine would be meaningless.

Ageing by cementum annuli and ageing by ovary analysis were compared in both studies with respect to ovary volume displacement (Table 12).

In the juvenile age class, Erickson had a mean of 0.39 ml. While in this study data showed a mean of 0.40 ml. Erickson's next age class was 1.5-2.5 years, while this study's was 2-3 years. Ranges for Erickson and data herein were $\bar{x} = 0.88$ (0.64-1.0 ml.) and $\bar{x} = 1.35$ (1.2-1.7 ml.) respectively. A two-sample t-test was used to compare the means for equality. The null hypothesis was rejected with $p<0.05$, thus concluding there is a difference between the means of group two. Discrepancy may be due to the extra half year on age distribution as well as extremely small sample size. In the third age class, (3 years or greater) Erickson showed a range of $\bar{x} = 2.66$ (1.4-3.6 ml.), while data within this study (4 years or greater) showed $\bar{x} = 2.16$ (2.0-2.5 ml.). Using a t-test once again at $p<0.05$, the null hypothesis was accepted, thus

Table 12. Ovary volume displacement comparing results from Erickson's study with the results in this study. Volume displacement is in milliliters.

DATA FROM THIS STUDY						DATA FROM ERICKSON'S STUDY					
Age 0-1		Age 1-3		Age 4-11		Age 0-1		Age 1.5-2.5		Age 3.0>	
Tag	Volume	Tag	Volume	Tag	Volume	Tag	Volume	Tag	Volume	Tag	Volume
142	0.30	704	1.2	101	2.0	768	0.21	103	0.64	771	1.4
242	0.20	245	1.7	703	2.0	812	0.30	778	1.00	796	3.0
252	0.20	401	1.3	255	2.5	223	0.63	220	1.00	761	2.3
707	0.10	700	1.2			754	0.20			763	3.1
143	0.30					795	0.40			814	3.1
706	0.06					802	0.23			224	1.8
702	0.30					827	0.88			753	2.2
535	1.32					785	0.31			801	3.5
2156	1.10									232	3.6
103	0.20										
321	0.30										
N	= 11	N	= 11	N	= 3	N	= 8	N	= 3	N	= 9
$\bar{x}$	= 0.40	$\bar{x}$	= 1.35	$\bar{x}$	= 2.16	$\bar{x}$	= 0.39	$\bar{x}$	= 0.88	$\bar{x}$	= 2.66
s^2	= 0.17	s^2	= 0.05	s^2	= 0.08	s^2	= 0.05	s^2	= 0.04	s^2	= 0.59
min.	= 0.06	min.	= 1.20	min.	= 2.00	min.	= 0.20	min.	= 0.64	min.	= 1.40
max.	= 1.32	max.	= 1.70	max.	= 2.50	max.	= 0.88	max.	= 1.00	max.	= 3.60

concluding there is no difference between the means. Therefore, there seems to be little difference between Erickson's method and the method used in this study.

DISCUSSION

Sexing Technique

Reliability of the sexing technique now being used by the MDNR seems questionable. Field personnel in the MDNR register pelts from cats as trappers and hunters bring them in. Hunters and trappers must bring their bobcats into field stations for registration and sexing. When registration sheets were compared to 19 known sex bobcats, over 42% of the sexes marked were incorrect. Registration data showed a ratio of 17 females to 2 males, when in fact the true ratio was 9 females to 10 males. A high percentage of males being mistaken for females could easily result in an over estimate of reproductive capacity within the population. A possible way of avoiding such an error would be to make hunters and trappers more aware of sexing techniques by possibly offering seminars through the Michigan Trappers Association. Bias could also be eliminated by performing a quick cut in the groin area where female tract is easily observed. Discussing sexing techniques with other bobcat researchers, it seems the majority have also noticed this problem in their states. Wildlife biologists are quite concerned in obtaining accurate data for use in management practices. There is no way this data should be used for future management practices, unless the sexing technique now being used in Michigan is changed to a more reliable method.

Life Table

Caughley (1978) reports the accuracy of a calculated age distribution depends on the size of the sample, the number of age classes, sampling bias, and the accuracy of ageing. The ageing technique used in this study was the best available; however, the size of the sample in each age class was quite small. Results show a very high juvenile age class, suggesting a good reproductive potential. The results relate directly to Region I, since 93% of sample size was obtained from that area. This life table does not portray the overall population during the whole year, but only during winter months. It is not unlikely for 70% of the juvenile age class in this study to die off the first year in an exploited population. We must remember that young bobcats are not experienced to trapping pressures. Another point of interest is that kittens stay close to denning sites while the female hunts (Bailey 1974). Bailey believes that for the first year, kittens wander very little from denning sites. Thus, chances of harvest are greatly increased once a trapper or hunter knows of an area holding kittens.

Crowe (1975*b*) reported a proportionate survivorship of 0.67 per annum through years one to ten, suggesting adult survivorship remained constant. Data from this study suggest adult survivorship remains constant during years 2-5. By the time cats reach 6 years or older the number in each age class is too small to derive actual survivor rates.

Better representation of age classes must be obtained to assure an accurate life table. A large enough age distribution can only be obtained over a period of time. An extensive drive to obtain age structure is called for if the goals warrant a life table. Only by obtaining future data and comparing it to other factors in the field can researchers predict the trends in the population.

Reproductive Parameters

It is believed the corpora rubra remain in the ovary, causing volume to increase over time (Crowe 1975a). Ovary volumetric displacement in bobcats was investigated by Erickson (1955) and Crowe (1975a) who found a direct relation between age and ovary volume.

Crowe felt bobcats in Wyoming cycle more than once during the breeding season. It was also postulated by Duke (1954) that bobcats may be polycyclic like the domestic cat (*Felis catus*). It is unsure at this time why 5 of 8 cats collected prior to the breeding season showed signs of ovulation. Possibly, Michigan bobcats are cycling early without being receptive to the male.

Even though reliability of determining potential litter size may be quite biased, (Gashwiler *et al*. 1961, Provost 1973, Crowe 1975a) it does show reproductive potential which can later be used in understanding the population dynamics of the species.

Ageing by Cranial Measurements

The use of multi-variate statistics is becoming more and more common in the life and agricultural sciences. Multivariate statistical analysis is concerned with data collected on several dimensions on the same sample.

A new way of separating age groups by cranial measurements was developed by using discriminant function analysis. This study did not consider the numerous sub-species throughout the United States and, thus, these prediction equations should be used only on the Michigan bobcat. Due to possible diversity in other sub-species, new prediction equations should be derived.

Even though 78% of the 72 skulls were correctly classified, error in the prediction is still possible. A better percentage of skulls may be classified by using more variables, but this defeats the original purpose since this method was devised to be used by wildlife biologists, by measuring the least number of parameters possible and still maintaining reasonable accuracy.

There are advantages and disadvantages between this method (Case I) and the cementum annuli method (Case II).

1) <u>Material Used For Ageing</u>

Case I Skull must be cleaned in order to take measurements. This procedure is not difficult, but is very time consuming.

Case II A tooth must be extracted from the animal, preferable the canine. This is quite difficult on a dead specimen and probably next to impossible on a live one. Root must not be damaged in any way.

2) <u>Procedure and Equipment</u>

Case I No special procedure other then knowing what measurements are needed and how to take them. Only equipment is a vernier calipers.

Case II Each tooth must be decalcified and cut into thin sections on cryostat. Once cut, they are stained. This procedure can take considerable time.

3) <u>Ageing</u>

Case I Once measurements are taken, they are plugged into prediction equations to see what age group they fall into.

Case II After staining they are aged by counting cementum annuli.

Case I categorizes age into groups while Case II supposedly gives exact age. Financial considerations, time, space, and goals of the biologist must be taken into account when evaluating these two cases. If the biologist has limited funds, considerable time, ample space, and wants to determine the basic group age structure of the population (young of the year, middle-aged, older), I would suggest Case I. On the other hand, if the biologist has considerable funds, limited time, considerable space, and wants the greatest accuracy of age, I would suggest Case II. Once again we must remember that the prediction equations developed in this study were from ageing, originally done by cementum annuli.

Comparisons with Previous Research

Ageing technique used by Erickson showed a positive correlation with Crowe's method. If female bobcats are polycyclic, the correlation seems hard to understand. Erickson assumed bobcats as being monocyclic with an average of 5.0 ova/ovulation. For every 5 CL or CR, one year of age was added to the cat's life. If the bobcat ovulates in March with no insemination occurring there is still luteal formation. If the female once again ovulates in May, luteal bodies are once again formed. The problem arises by possibly counting this cat as a two year old, due to twice the number of ovaries.

CONCLUSIONS

Erickson's method of ageing seems quite accurate, even though bobcats may be polycyclic. Further research in reproduction should direct attention to the polycyclic theory and determine its relation to luteal formation.

Ageing through cementum annuli worked very well; however, problems still exist. First, a collection of teeth showing cementum annuli from known age cats must be obtained. This collection should be made in different regions of the country, due to considerable discrepancy between sub-species. Second, consistency in the ageing method should be developed. If researchers continue to use teeth as an ageing method, it must be consistent to allow for consistent interpretation.

The life table in this study has minimal use regarding management practices. The two factors causing this problem are sample size and age distribution. Having over one-half the bobcats young of the year does suggest a good reproductive potential, but continued studies are needed to verify this.

Even though assumptions were not met during the construction of the life table, methodology and reasoning behind it are very important. Future studies with known population sizes are a way of achieving known r_s values. Prior to this time, a known estimate of r_s or stability must be assumed.

Determining volume from the ovary seems to be a good indicator for age. Problems can arise, depending on the time of the year samples are taken. Cats during estrus are obviously going to have different ovary weights than those during anestrus periods. Another problem may be cats ovulating more than once, thus increasing the weight of the ovary. Future research is needed in this area to determine reliability of method.

Determining age groups through discriminant analysis is very helpful, not only in biological fields but other fields as well. Having age groups broken up gives the biologist an overall view of the younger age class as well as older, thus allowing management of population.

Some of the management implications of this study are:

1) In managing bobcats it should be kept in mind that because of fur prices and fluctuations in the market, pressure placed on the bobcat is unpredictable.

2) Accurate bobcat sexing techniques must be incorporated into the Michigan management plan.

3) A mail survey should be incorporated to census bobcat hunters and trappers. This survey would allow biologists to direct management to those areas where bobcat exploitation is greatest. The survey would also permit managers to obtain data on the number of bobcat hunter and trapper days. Through this method biologists could observe if over-pressure was being applied to population and adjust accordingly. If areas are found where definite over-harvest is evident, restrictive seasons could be considered in these areas.

4) A system should be developed where bobcat hunters and trappers could send bobcat lower jaws into Michigan research stations, so ageing by cementum annuli could be done. The data base established by this method would enable biologists to observe fluctuations within the population from year to year, thus allowing management to adjust to extrinsic factors.

APPENDIX

MICHIGAN STATE UNIVERSITY

DEPARTMENT OF FISHERIES AND WILDLIFE
NATURAL RESOURCES BUILDING

EAST LANSING · MICHIGAN · 48824

ATTENTION: BOBCAT TRAPPER OR HUNTER

YOU ARE OFFERED A $4.00 PAYMENT FOR EACH SKINNED BOBCAT CARCASS OR SKULL TURNED-IN AT A DNR FIELD OFFICE. NOT MORE THAN 110 WILL BE PURCHASED.

PURPOSE OF THE COLLECTION IS TO DETERMINE THE AGES OF BOBCATS TAKEN IN THE U.P. TO ASSIST IN MANAGEMENT. THE PROJECT IS A COOPERATIVE STUDY OF MSU AND THE DNR. PROJECT LEADER IS RICHARD HOPPE, GRADUATE STUDENT, MICHIGAN STATE UNIVERSITY.

IF YOU WANT TO RECEIVE A CHECK, YOU MUST DO THE FOLLOWING:

1. TAKE THE PRE-NUMBERED TAG WHICH IS TAPED TO THIS NOTICE AND ATTACH IT TO YOUR BOBCAT SKULL OR CARCASS.
2. DELIVER TAGGED SKULL OR CARCASS TO THE DNR OFFICE WHERE YOU REGISTERED YOUR CAT.
3. THE DNR WILL SUBMIT YOUR NAME AND ADDRESS TO MSU. YOU WILL RECEIVE A CHECK BY RETURN MAIL.

THANKS FOR YOUR HELP.

RICHARD HOPPE
GRADUATE STUDENT
MICHIGAN STATE UNIVERSITY

Figure A1. Letter to trappers and hunters in Region I describing instructions to follow in order to receive payment.

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LITERATURE CITED

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