

State of California
THE RESOURCES AGENCY
Department of Fish and Game

NORTHEASTERN CALIFORNIA BOBCAT STUDY 1/

by

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ABSTRACT

Ten adult (5 male, 5 female) and five juvenile (4 male, 1 female) bobcats were captured and radio-collared between September 1976 and October 1978. Density of adult bobcats was 0.05 bobcats per km² (0.13 per mi²). Home range sizes of adult bobcats ranged from 29.5-94.5 km² (11.5-36.5 mi²) with little home range overlap between males but up to 30% overlap between females. Male-female bobcat home range overlap was as high as 100%. Six female bobcats produced an average of 2.7 kittens per female in 1977 and four female bobcats produced an average of 3.0 kittens per female in 1978. Female bobcats reduced their home range size 70-95% at parturition and attained their original home range dimensions by the October-November period of kitten dispersal. A bimodal activity pattern with peaks at dawn and dusk was associated with hunting behavior and major movements within each bobcat home range. Longer distances were moved during the evening hours and the average distance moved varied among individuals (2.2-4.2 km or 1.4-2.6 mi). During 1976 through 1979, 162 bobcats caught by trappers on adjacent national forest land revealed a sex ratio of 0.96 males per female and that 75% of these bobcats were less than two years old. These aspects of population dynamics are probably indicative of an expanding population or a population responding to moderately heavy man-induced mortality.

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RECOMMENDATIONS

1. The trapping and hunting season for bobcats in northeastern California should end one month prior to the current February 28 closing. The reproductive organs of adult females trapped in February, observed copulation and the brief pairing of radio-collared bobcats indicate that reproduction is occurring during February.
2. The pursuit of bobcats with hounds, regardless of take, should be prohibited except during the trapping season. Juvenile bobcats are dependent on females for 6 to 7 months and separation of family groups may induce increased juvenile mortality,
3. Population dynamics for specific areas of California can be obtained if trappers are required to submit the lower jaw and sex of each bobcat trapped. This would be feasible in view of the recent requirement of a bobcat tag for exported hides. Life tables and age/sex structure constructed from these data would delineate any local restrictions of bobcat take required. The expense of sectioning the teeth can be added to the current tag fee. Reproductive rates need to be determined in various portions of the state in order to estimate recruitment.
4. Juvenile mortality rates need to be examined. The natality rates are more useful if the juvenile mortality rate is known. If actual recruitment can be determined, the extent that man-induced mortality could replace natural mortality might be known.
5. The proposed bobcat management plan should be implemented using counties as the artificial unit of population management. Localized management action should occur within these units or groups of counties as the bobcat population parameters dictate.

INTRODUCTION

Biopolitics

Declining populations and concomitant Federal and International restrictions on trade of spotted cat-pelts has increased the demand for bobcat (*Felis rufus*) and lynx (*Felis lynx*) hides in domestic and foreign fur markets. Prices of bobcat pelts from California have tripled during the past five years. Presently, the value of a prime bobcat pelt may exceed \$400. The increased demand and high market values of bobcat pelts have resulted in an appreciable increase in trapping pressure.

Prompted by an apparent reduction of bobcat population levels in some areas of the nation and the increased market/trapping pressure imposed on the bobcat, the Defenders of Wildlife filed a petition on 20 January 1977 with the Department of the Interior to place the bobcat on the United States List of Endangered and Threatened Wildlife. Pursuant to the Endangered Species Act of 1973, a review of the status of the bobcat was begun 13 July 1977 (Federal Register- July 1977). The bobcat was subsequently listed as an Appendix II species by the Convention on International Trade in Endangered Species of Wild Fauna and Flora and the Endangered Species Scientific Authority (ESSA) banned international export of bobcat pelts taken after 29 August 1977 (Endangered Species Technical Bulletin-August 1977). The ESSA later allowed a quota of 6000 bobcat pelts to be exported from California during the 1977-78 trapping season, provided that each pelt was tagged to indicate its origin (Endangered Species Technical Bulletin-August 1978). In October 1978, the ESSA approved export of bobcat pelts from 34 states, including California, with quotas set for only two states, New Mexico and Wyoming (Endangered Species Technical Bulletin-October 1978). The California Department of Fish and Game (CDFG) elected to continue its quota for bobcat pelts exported to fur markets despite the easing of restrictions.

Historically, the bobcat was an unprotected predator in California; but was classified as a nongame mammal in 1971. Subsequently, the California Fish and Game Commission established a no-limit season which allowed trapping of bobcats only from mid-November through February. For the 1979-80 trapping season, bobcats could be taken between mid-November and the end of January, or until 6000 bobcat pelts were tagged for export.

Current CDFG proposals include provisions requiring a bobcat hunting tag and a season limit of two bobcats for sport hunters. While no bag limit is proposed for commercial trappers, the take may be reduced through shorter trapping seasons: December 1 through December 21 in northeastern California; December 1 through January 31 in coastal southern California; and December 1 through January 15 in the balance of the state. The bobcat trapping season will be closed earlier if the ceiling level of 6000 bobcats is reached before the season closing dates.

Federal and state agencies initiated several research contracts in anticipation of the need for detailed data on the biology and status of the bobcat. This report documents the results of a study on bobcats in northeastern California during the period from June 1976 through November 1978. The study was contracted by the CDFG from July 1977 through September 1978.

Literature

At least one of four subspecies of bobcat are present in most, if not all, counties of California (Grinnell, 1937). The northwestern bobcat (*F. r. fasciatus*) occupies the moist, coastal portions of northern California. The desert bobcat (*F. r. baileyi*) is found in arid, desert regions of southeastern California. The pallid bobcat (*F. r. pallescens*) is found on the western edge of the great basin habitat; extreme northeast California. The California bobcat (*F. r. californicus*) is found throughout the balance of the state with the exception of areas under extensive agriculture. All vegetation types or life zones are occupied by the bobcat in California.

Bobcats were historically distributed throughout the United States and most of Mexico and utilized a variety of habitat types. Habitat preference shown by bobcats in Minnesota was primarily for thick cedar (*Thuja occidentalis*) or spruce (*Picea mariana*) swamps (Rollings, 1945). McCord (1974) found that bobcats preferred cliff areas, spruce plantations (*P. abies*) and hemlock (*Tsuga canadensis*) - hardwood habitat in Massachusetts. Bailey (1972) classified areas dominated by sagebrush (*Artemisia tridentata*) with nearby caves and sagebrush/ juniper (*Juniperus osteosperma*) areas near volcanic outcroppings as good bobcat habit in Idaho. Most of the bobcat preference for these habitats was accounted for by prey density and cover availability.

The density of several bobcat populations has been estimated. Bailey (1972) believed that the number of adult bobcats in a three year study of the pallid bobcat in Idaho remained constant at 0.05 bobcats per km² (0.02/mi²). Lembeck (1978) determined densities of 1.27 to 1.52 bobcats per km² (3.27 to 3.94/mi²) for the California bobcat in the chaparral of San Diego County, California. Two density estimates are available for the desert bobcat; Brownlee (1977) estimated bobcat densities ranging from 0.37 to 0.89 bobcats per km² (0.95 to 2.3/mi²) in Texas whereas Jones (1977) estimated that bobcat density in his study area in Arizona was 0.28 bobcats per km² (0.73/mi²). Brownlee based his estimate on the results of intensive removal trapping while the lower estimates of Bailey and Jones were based on the number of bobcats captured and released within their respective study areas. Lembeck and Bailey also utilized data from radio-collared bobcats in formulating their density estimates.

Several investigations have been made to determine home range parameters of bobcats (the home range of an animal is generally understood to be the area it utilizes during the course of normal activity]. Marston (1942) reported home range estimates of 47 to 104 km² (18 to 4.0 mi²) for bobcats in Maine. Erickson (1955) estimated bobcat home range size to be 38 to 52 km² (15 to 20 mi²) in Michigan, and Rollings (1945) estimated that bobcats in Minnesota have home ranges of 25 to 38 km² (10 to 15 mi²). Kight (1962) described maximum bobcat home ranges of 2.6 km² (1.0 mi²) in South Carolina, and Pollack (1949, 1950) reports that bobcats in northeastern United States have home ranges from 3.9 to 14.2 km² (1.5 to 5.5 mi²). These data were obtained by snow-tracking techniques as investigators trailed hunting bobcats through swamps, spruce, hemlock or cedar thickets. Some estimates were made of the area utilized by bobcats which left distinctive, identifiable tracks.

As the feasibility of utilizing radio-telemetry equipment in wildlife investigations increased, home range estimates based on repeated locations of individual bobcats were obtained. Bailey (1974) reported home ranges of 42.1 km² (16.3 mi²) for four male, and 19.3 km² (7.4 mi²) for eight female bobcat, in Idaho. Marshall and Jenkins (1966) reported 4.64 km² (1.79 mi²), 3.52 km² (1.36 mi²), and 2.46 km² (0.95 mi²) home ranges for an adult female, a juvenile male, and a juvenile female bobcat, respectively, in South Carolina.

Bobcat movement patterns have been the subject of several investigations. Bailey (1974) found no significant difference between the average daily consecutive movements of female (1.2 km or 0.8 mi) and male (1.8 km or 1.1 mi) bobcats in Idaho. These averages were based on movements from one day to the next and represent the minimum movements in terms of distance traveled. Marshall and Jenkins (1966) reported average daily movements of telemetered bobcats in South Carolina to be from 1.83 to 4.78 km (1.17 to 2.97 mi). Bobcats are reported to move up to 11.7 km (7.3 mi) per day in Michigan (Erickson, 1955) and 4.8 to 11.2 km (3.0 to 7.0 mi) per day in Minnesota (Rollings, 1945). It should be noted that the data from Michigan and Minnesota, as well as a 3.2 km (2.0 mi) bobcat movement in Idaho (Bailey, 1974) were obtained via snowtracking; and the effects of snow on the extent of bobcat movements has not as yet been determined.

Bobcat sex ratios vary greatly with lows of 0.40 males per female in Vermont (Foote, 1945) and 0.60 adult males per adult female in Idaho (Bailey, 1972) to a high of 2.1 males per female in San Diego county (Lembeck, 1978). Ratios of male to female bobcats have been observed between these extremes: 1-04:1 in the northeast United States (Pollack, 1950); 1.11:1 and 1.29:1 in Utah (Gashwiler et al., 1961); 1.7:1 in Arkansas (Fritts and Sealander, 1978), 1:26:1 in Arizona (Young, 1958); 1.01:1 in Wyoming (Crowe, 1975). These sex ratios may not be indicative of actual sex ratios since the larger home range and greater movements of male bobcats may create a differential susceptibility to trapping resulting in a higher male to female ratio than actually exists. For example, Robinson and Grand (1958) determined that the mean recapture distance for 22 male and 24 female bobcats was 8.5 km (5.3 mi) and 5.1 km (3.2 mi) respectively. Bailey (1972) found that male bobcat home ranges were 4 to 12 times as large as those of females.

Crowe (1975) determined that female bobcats are capable of breeding at one year of age, whereas males are sexually mature at two years of age. Both sexes remain reproductively active throughout their life which may extend beyond 14 years in the wild. Fritts and Sealander (1978) reported an average of 2.5 bobcats per litter in Arkansas. An average litter size of 2.8 bobcats was determined in studies in Idaho (Bailey, 1972) and in Wyoming (Crowe, 1975). Gashwiler et al. (1961) found that litters averaged 3.5 in Utah. Crowe (1975) and Gashwiler et al. (1961) report a higher number of corpora lutea (averages of 3.4 and 4.8 respectively) than the actual number of bobcats born which indicated the possibility of intrauterine embryo loss. While the majority of bobcat young are born in April or May in Utah (Gashwiler et al., 1961) and in May and June in Wyoming (Crowe, 1975), both studies indicated that young may be born between March and October.

Various studies of food habits have been conducted where the frequency of occurrence, percent by weight or percent by volume of various prey species have

been determined from bobcat stomach contents. Rodents are the most frequent bobcat prey item in California (Leach and Frazier, 1954; Grinnell et al., 1937; McLean, 1934), Vermont (Hamilton and Hunter, 1939), and in Virginia and North Carolina (Progulske, 1955). Rabbits and hares constitute the next most important prey item in these-states (except in Vermont) but are the most important prey item in Utah and eastern Nevada (Gashwiler et al., 1960) and Minnesota (Rollings, 1945). Deer were the most important prey item in Massachusetts (McCord, 1974) but ranked second in Utah, Nevada, and Minnesota. These three groups of prey are consistent food items of bobcats and probably vary in importance with their relative abundance within the habitats studied.

OBJECTIVES

Previous studies documented that bobcat sex ratios, reproductive rates, density, home range size and extent of overlap, movements, and prey items consumed vary greatly as a function of habitat type and the population of bobcat studied. The present study was undertaken to provide data necessary to establish an effective bobcat management plan in northeastern California. Objectives were to determine: (1) density and home range; (2) population dynamics; and (3) test procedures for censusing bobcat populations.

STUDY AREA

This study focused on the subspecies known as the pallid bobcat (*F. r. pallidus*). Its range in California is confined to northeastern California and includes Modoc County and parts of Siskiyou, Lassen and Shasta counties (Hall and Kelson, 1959). The study area included Lava Beds National Monument and adjacent portions of the Tule Lake National Wildlife Refuge and Modoc National Forest and encompassed 410 km² (158 mi²) in Siskiyou and Modoc counties.

The selection of Lava Beds National Monument as the primary study area was based upon many criteria. National Monuments create a degree of protection from human disturbance which contributes to the stability of the age/sex structure of resident animal populations. The topography and vegetation, typical of the open habitat of northeastern California, facilitated visual observations and enhanced the precision of radio-telemetry techniques. Additional information obtained on the population of bobcats extending over the adjacent National Forest, where both hunting and trapping occurred, provided a comparative data base.

Geological aspects of the study area reflect recent vulcanism typified by lava flow fronts and outcroppings, lava tubes and collapsed lava tubes forming caves, cinder cones and a very shallow soil consisting of lava ash and pumice. The study area elevation increases gradually from 1227 meters (4,025 ft) at the agricultural fields on the Tule Lake National Wildlife Refuge to the north, to 1674 meters (5,492 ft) near the southern boundary of the monument.

The temperate semi-arid climate of the study area is characterized by temperatures ranging from a mean minimum of -4.4°C (24°F) to a mean high of 25°C (77°F) and a mean annual precipitation of 33 cm (13 in). Snow and freezing temperatures may occur in any month and summer thunderstorms are common.

Vegetation at the lower elevations is shrub-steppe type, dominated by big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus nauseosus* and *C. viscidiflorus*) and horsebrush (*Tetradymia canescens*). Approximately two-thirds of the study area is composed of this vegetation type. As the elevation increases there is a transition into a chaparral-type vegetation dominated by western juniper (*Juniperus occidentalis*), mountain mahogany (*Cercocarpus ledifolius*) and antelope bitterbrush (*Purshia tridentata*). Native bunch grasses are common to both vegetation types and include blue-bunch wheatgrass (*Agropyron spicatum*), needlegrass (*Stipa thurberiana* and *S. occidentalis*), Sandberg's bluegrass (*Poa sandbergii*), Idaho fescue (*Festuca idahoensis*) and squirreltail (*Sitanion hystrix*). The introduced annual cheatgrass (*Bromus tectorum*) and tumbling mustard (*Systembrium altissimum*) are common in both vegetation types. At the highest elevations a coniferous forest occurs, dominated by ponderosa and lodgepole pine (*Pinus ponderosa* and *P. contorta*) and white fir (*Abies concolor*). Understory vegetation in this vegetation type consists of antelope bitter brush, greenleaf manzanita (*Arctostaphulus patula*) and snowbrush (*Ceanothus velutinus*).

METHODS AND MATERIALS

Bobcats were trapped with padded number 3 leg-hold traps and in box-type live traps (61 x 61 x 122 cm or 2 x 2 x 4 ft.). Bobcats were immobilized with ketamine hydrochloride with drug dosages which varied between 17 and 21 mg/kg (7.6 to 9.7 mg/lb). Heart and respiration rates were monitored while bobcats were tractable. Standard taxonomic measurements and weights were recorded and each bobcat was tagged with numbered, size 3 fingerling tags in both ears and fitted with a collar containing a radio transmitter.

Transmitters were manufactured by AVM Instrument Co. and operated at frequencies from 150.85 MHz to 151.15 MHz. Flexible antennas (30.5 cm or 12 in long) were attached to the transmitters and size 660 or 660-3 lithium batteries (Power Conversion, Inc.) were used for power. The transmitter package was embedded in dental acrylic and laminated between two layers of neoprene-impregnated nylon belting (2 x 38 mm or 0.06 x 1.5 in). The ends of the belting material were adjusted to the size of each bobcat's neck, trimmed in length and fastened together with aluminum pop-rivets. The antenna was placed between belting layers of the collar and protruded dorsally approximately 17 cm (6.5 in). The finished transmitter-collar weighed 150 to 165 grams (5.3 to 5.8 oz) and possessed a theoretical life expectancy of 26 to 31 months.

Radio receivers and null-peak directional antenna systems (AVM Instrument Co.) were used to locate the bobcats. Directional bearings were taken using the receiver/antenna system mounted in a 4-wheel drive vehicle from monitoring sites which provided the most accurate triangulation of each bobcat's position. These bearings were corrected for deviation from true north and plotted on plastic overlays of 15 minute U.S. Geological Survey maps of the study area. Animal location points were plotted when two or more intersecting bearings were obtained. Distances between each plotted point were measured and the minimal home range size for each bobcat was determined from irregular polygons made by connecting the peripheral location points with lines.

Activity levels were determined by changes in the signal strength of 10 transmitter pulses monitored at the time each radio-location was taken. Zero change

in the strength of the transmitter pulses indicated an immobile animal whereas ten changes within the 10 monitored radio signals indicated an animal in constant motion (constant motion might include behavior such as eating, grooming, or travel). Intermediate changes of radio signal strength (1 to 9 changes) indicated various degrees of animal activity. The validity of the pulse-strength as an indicator of animal activity was verified by direct observation via spotting scope or binoculars. Weather conditions were noted at the time telemetry readings were taken.

The effectiveness of various census techniques was tested on this bobcat population. Line transects were performed after fresh snowfalls during the winter of 1977-78. Scent-post stations (630 station nights) were established in the spring and summer of 1978. Bobcat urine was used on the scent-posts and the surrounding soil was raked smooth.

Statistical evaluation and comparisons of distance, activity and home range data were analyzed using analysis of variance, SS-STP test for differences of means, Student's t-test and Chi-square tests where appropriate (Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

Capture of Bobcats

Fifteen bobcats were captured 18 times during the study (Table 1). Two methods of trapping were employed during different phases of this study (Table 2). Initial trapping efforts utilized padded leg-hold traps in classic cubby, scent-post and trail sets. The padding on the trap jaws presented a problem in that it prevented the trap jaws from closing sufficiently which resulted in some bobcats being able to pull free of the trap. The remedy, removal of the padding, was undesirable since the study of the bobcat home range dictated that the bobcats be free-ranging and physically unimpaired. For these reasons the transition to the exclusive use of box-type traps was completed by August 1977. As a result of the increased efficiency of box-type traps, trapping success improved from 954 trap nights per bobcat capture using leg-hold traps to 356 trap nights per bobcat capture employing box-type traps.

Comparison and Evaluation of Census Techniques

Census techniques were employed to allow comparisons between methods and to results of other studies. In 1932-33 a predatory animal study program was performed on 17 California game refuges (McLean, 1934). Professional trappers were employed to collect information on predators captured during the study. An average of 246 trap nights (range 56-792) and 313 km (195 mi) of trapline (range 102-570 km or 63-354 mi) were required for each bobcat capture. Bailey (1974) averaged 149 trap nights per capture but 567 trap nights were required for each initial capture of adult bobcats in Idaho. These trapping results are probably invalid as a method of censusing bobcat populations due to differences in the specific biology of bobcats in each area since different bobcat subspecies and habitat are involved. The value of these data may be the indication of trends and in making comparisons since they are commonly collected in bobcat studies. An example is that the number of trap nights (average for both methods = 589) and the kilometers of trapline (107 km or 66 mi) required

Table 1. Temporal and biological characteristics of bobcats captured on Lava Beds National Monument and the Tule Lake National Wildlife Refuge, Siskiyou and Modoc Counties, California

BOBCAT No.	AGE	SEX	WEIGHT		CAPTURE DATE	STATUS
			<u>kg</u>	<u>(lbs)</u>		
1	J	M	3.8	(8.4)	10 Sep 76	Died on 23 September, 1976
2	J	M	5.0	(11.0)	17 Oct 76	Last observed in August, 1977
3	J	M	7.0	(15.4)	4 Jan 77	Died on 27 January , 1977
4	A	F	7.4	(16.3)	7 Jan 77	Died on 7 January, 1977 - trap injury
5	A	F	7.5	(16.5)	28 Jan 77	Viable throughout study
6	A	M	13.0	(28.7)	10 Feb 77	Viable throughout study
7	A	M	8.3	(18.3)	15 Jun 77	Viable throughout study
8	J	F	2.7	(6.0)	3 Sep 77	Slipped out of collar
9	A	F	8.3	(18.3)	5 Sep 77	Viable throughout study
10	J	M	2.9	(6.4)	14 Oct 77	Slipped out of collar
11	A	M	12.0	(26.5)	8 Dec 77	Recaptured on 7 January, 1978 and caught by commercial trapper in December, 1978
12	A	F	8.9	(19.6)	17 Dec 77	Viable throughout study
13	A	F	8.5	(18.7)	15 Jan 78	Recaptured on 2 February and on 7 March, 1978
14	A	M	11.8	(26.0)	27 Jul 78	Caught by commercial trapper in December, 1979
15	A	M	11.2	(24.7)	31 Jul 78	Caught by commercial trappers in December, 1978

Table 2. Summary of trapping activity during the northeastern California bobcat study at Lava Beds National Monument and on Tule Lake National Wildlife Refuge, Siskiyou County, California.

	PRECONTRACT			CONTRACT	
	1975	1976	JAN-JUN 1977	JUL 77-SEP 78	TOTAL
NUMBER OF TRAP NIGHTS					
Leg-hold traps	490	4159	1539	492	6680
Box-type traps	---	----	511	3402	3913
Total					10593
NUMBER OF CAPTURES					
Leg-hold traps	---	2	5	----	7
Box-type traps	---			8*	8*
KILOMETERS (MI) OF TRAPLINE	188 (117)	1001 (622)	521 (324)		1710 (1063)
NUMBER OF BOBCAT TRACKS	5	33	21		59
TRANSECT KM (MI) PER TRACK	37.6 (23.40)	30.0 (18.8)	24.8 (15.4)		29.0 (18.0)

* Three recaptures also occurred.

for each bobcat capture in this study fell within the range of those required by nine trappers trapping bobcats in 18 California counties almost 50 years ago.

Scent station techniques were probably the least effective method used for monitoring this bobcat population. Scent stations were located in areas that contained a minimum of five bobcats based on the home range data for radio-collared bobcats. Nine bobcats and thirty coyote (*Canis latrans*) visits occurred during 630 scent-post station nights. On 16 June 1978 a bobcat walked 1.9 km down a road and passed through three scent stations. On 21 June 1978 a bobcat walked 0.9 km down a road and passed through two scent stations. Therefore, only six individual visits occurred. Of these six visits, five involved a single scent station. Tracks indicated that in only 1 of 9 visits did a bobcat actually break stride and approach the scent source. All other visits appeared to be simply related to the fact that the bobcat happened to pass through the area of the scent station. Visits were probably more related to the proximity of the scent station to an area heavily utilized by a bobcat than the ability of the scent station to attract bobcats. While 630 scent station nights are hardly sufficient to criticize a census technique, this technique appeared to be of little value as a density indicator for these bobcats. These results assume greater validity since the technique was performed in an area within the home range of five radio-collared bobcats. If bobcats were not attracted by scent, the scent station technique becomes one in which a sample of terrain is monitored for tracks. Transect techniques achieve the same goal and can allow more diverse habitat coverage per unit of surface area.

In the process of checking traps, a transect of bobcat tracks was performed. An average of 30.8 km (19.2 mi) per bobcat track was required during the three year period (Table 2). The decrease in distance per bobcat track over the three year period was probably due more to the experience of the investigator in recognizing prime bobcat habitat for trap placement than any increase of bobcat densities. Transect methods were used during all seasons. Fresh snow provided an excellent tracking medium, but the high pumice content of the soil obscured many bobcats' tracks during snowless periods. To avoid inconsistencies of tracking conditions and to avoid seasonal fluctuations of bobcat abundance, another set of bobcat track transects were performed after periods of fresh snowfall.

During the winter of 1977-78 track transects were performed after fresh snowfalls in areas known to be used by at least two bobcats with radio collars. Thirty-five bobcat and 147 coyote tracks were encountered in 241 km (150 mi) of transects. An average of 6.89 km (4.28 mi) per bobcat and 1.63 km (1.02 mi) per coyote were required to locate each set of tracks. The large decrease of transect distance per bobcat track demonstrates the potential bias imposed by various tracking conditions and emphasizes the degree of caution required in making any conclusions using this type of data. Transect data may have some value in indicating trends in bobcat densities if applied to the same subspecies in the same habitat during the same season, but do not reveal actual bobcat densities.

HOME RANGE

More than 5000 radio-locations were used to determine bobcat home range parameters during this study (Table 3). Because of inherent differences of age and

Table 3. Home range size of 12 bobcats determined by radio-location techniques at Lava Beds National Monument, Siskiyou and Modoc Counties, California.

	BOBCAT NUMBER *											
	<u>1(JM)</u>	<u>2(JM)</u>	<u>3(JM)</u>	<u>5(AF)</u>	<u>6(AM)</u>	<u>7(AM)</u>	<u>9(AF)</u>	<u>11(AM)</u>	<u>12(AF)</u>	<u>13(AF)</u>	<u>14(AM)</u>	<u>15(AM)</u>
RADIO LOCATIONS	51	412	42	1322	1099	721	356	340	276	312	44	36
PERIOD STUDIED												
date captured	9-10-76	10-17-76	1-4-77	1-28-77	2-10-77	6-15-77	9-5-77	12-8-77	12-17-77	1-15-78	7-27-78	7-31-78
date last located	9-23-76	8-15-77	1-27-77	3-5-79	10-14-79	10-14-79	8-11-78	11-17-78	10-14-79	10-12-78	10-14-79	11-17-78
days studied	14	303	24	661	655	531	341	299	295	271	40	27
HOME RANGE SIZE												
kilometers ²	9.0	36.0	6.8	38.9	88.1	94.5	59.4	38.9	46.6	25.9	27.2	33.7
miles ²	3.5	13.9	2.6	15.0	34.0	36.5	22.9	15.0	18.0	10.0	10.5	13.0

* (Age, Sex)

reproductive status among these bobcats, data on bobcat home range were analyzed following these life history stages:

1. Stable adult stage
2. Dependent kitten stage
3. Nonreproductive juvenile stage
4. Pubescent/transient adult stage

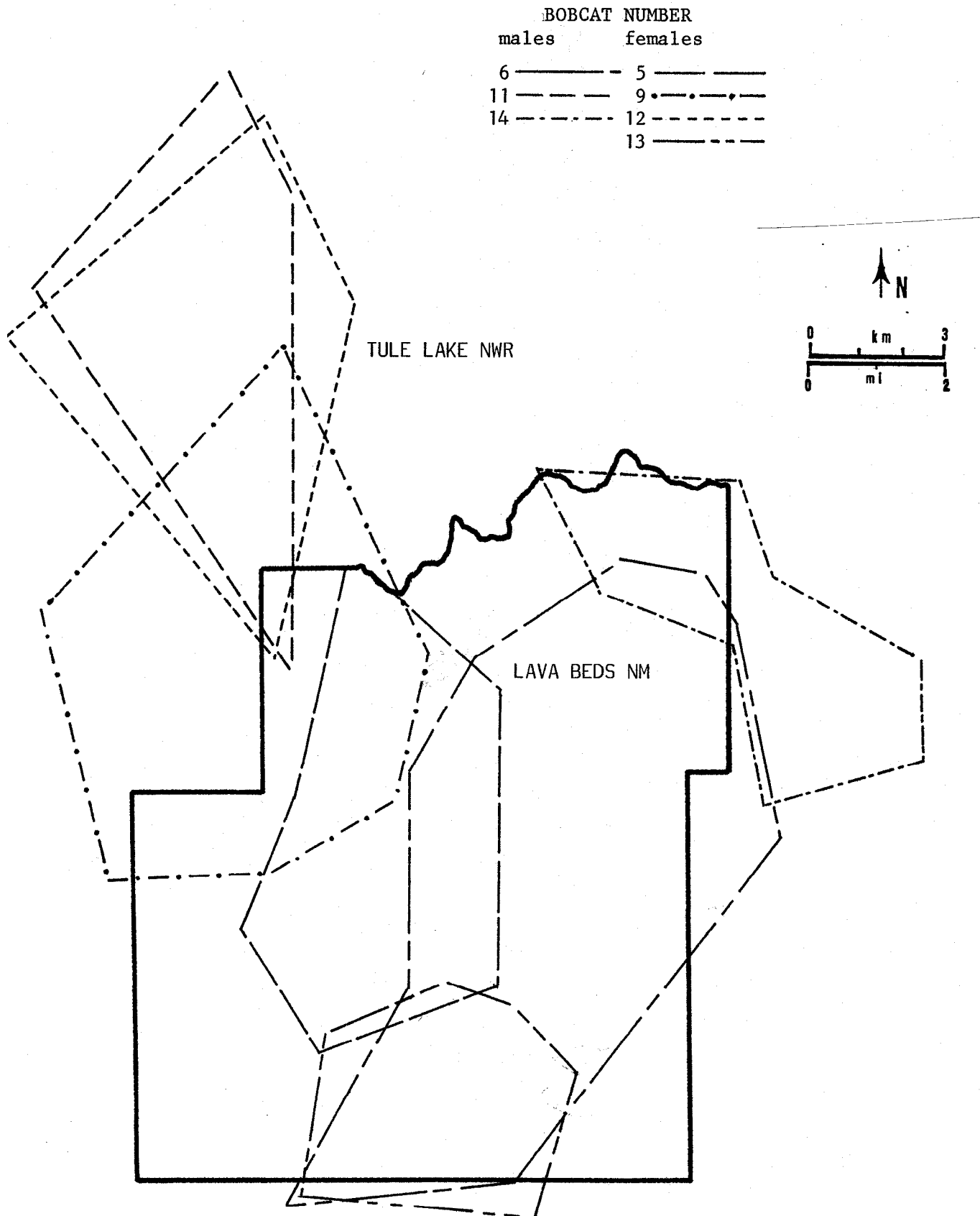
Stable Adult Stage -- This classification of home range represents the spatial utilization exhibited by mature, established bobcats. The ultimate home ranges of these animals did not vary substantially during the period of study. Seven adults (3 males and 4 females) displayed this type of spatial organization (Figure 1). Home range size of these bobcats ranged from 25.9 to 88.1 km² (10.0-34.0 mi²) and there was no difference ($P < 0.05$) between the home range size of males and females (Table 3).

The home range size and degree of home range overlap among conspecifics largely determines the density of a particular population (Figure 1). Two adult males averaged 12.5% home range overlap and the four adult females averaged 14.4% home range overlap. Some female home ranges were overlapped as much as 30% by another female and individual female ranges were overlapped by two other females in two instances. Male-female home range overlap was as high as 100%. Temporal spacing occurred within areas of overlapping home range. The density of bobcats in this study was increased as a result of mutual avoidance in areas of home range overlap and territoriality was maintained by a combination of spatial and temporal avoidance. Territorial behavior was expressed most strongly between bobcats of the same sex.

Bailey (1972, 1974) indicated that pallid bobcats expressed intrasexual territoriality in Idaho where home range overlap of bobcats was slight among males and practically nonexistent among females. Lembeck (1978) also reported almost no overlap among females but as much as 89% overlap between male California bobcats in San Diego County, California. Male desert bobcats had as much as 66% overlap and as many as four males might utilize a common area in the Mojave Desert of California (Zezulak and Schwab, 1980). In all of these studies, bobcats of opposite sex could have total home range overlap and male-male overlap was common. However, a large degree of female-female overlap has not been previously reported.

A facet of territorial behavior peculiar to reproductive females may bear on these results. Bobcat 5 reduced her home range from 38.9 km² (15 mi²) to 6.5 km² (2.5 mi²) and began using a single den site in April, 1977. Bobcat 5 also reduced her pattern of two distinct hunting sessions to one session per day and multiple fecal deposits were noted in distinct clusters spaced as close as 40m (43.7 yd) apart in the immediate vicinity of the den site. During other portions of the year bobcat feces seldom occurred in multiple-clusters and appeared to be located throughout bobcat home ranges according to the degree of use of that area by respective bobcats. Furthermore, bobcats seldom utilized the same den/rest site repeatedly although sites close to previous dens might be utilized while a bobcat remained in a particular part of its home range. Fifty-two days after this home range reduction Bobcat 5 moved to a second den site. At that time, two previously undetected kittens were observed with Bobcat 5. By October, Bobcat 5 and her kittens had resumed use of nearly all of the home range she utilized during pre-parturient periods. This parturition

Figure 1. Home ranges of seven bobcats during the Stable Adult Stage of home range development in northeastern California.



related phenomena was repeated by all four females during the next reproductive season and resulted in home range reductions that ranged from 70% to 95%. This phenomena manifested the most extreme territorial behavior observed during the study. During this period no overlap of female home ranges occurred. The temporarily reduced home range utilization by females was related to the birth of kittens in all cases. These females reattained their respective home range characteristics by the following autumn and the ultimate home range boundaries were unchanged.

Territorial maintenance offers several advantages to solitary predators. Large, exclusive areas provide the prey base required during seasonal and annual fluctuations of prey abundance and usually assures an adequate prey base during times of low prey abundance. Males excluding other males from large areas enhance their reproductive fitness by increasing the probability of overlapping female home ranges (Ewer 1973, Eaton 1974). Similarly, females may insure sufficient food supply for their young by excluding other females from their territory. Strict territoriality in bobcats may be a luxury afforded a population during conditions of low conspecific density. The economic feasibility of territoriality is subject to phylogenetic and environmental constraints. It is doubtful that bobcats have the combination of mating system type and resource defensibility that is requisite to the classic pattern of strict territoriality.

As more bobcat field data are accumulated it appears that this small, solitary cat employs mutual avoidance and temporal spacing to reduce contact with conspecifics. Under conditions of low bobcat density this avoidance manifests itself in nearly exclusive home ranges. In situations of high density bobcats attempt to avoid one another but the extent of contact and overlap between individuals increases. Stable adult home ranges are characterized by the fact that regardless of bobcat density and extent of home range overlap, the home range boundaries remain stable. Access to sufficient resources may be insured by the ability of bobcats to temporally and spatially segregate the available habitat under moderate to high bobcat densities.

Dependent Kitten State -- The first distinct stage of bobcat home range development occurred at the kitten or newborn stage of life. Bobcats are born with closed eyes and are essentially helpless and dependent on their mother. Bobcat kittens were not radio-collared during these early stages but were observed by their presence with radio-collared females. Five natal dens were detected during this study, 1 in 1977 and 4 in 1978. Kittens appeared to stay within natal dens and were not observable at these sites. After 6 to 8 weeks natal dens were abandoned and the first of many subsequent dens were utilized (Figure 2). This movement between dens constitutes the first expansion of space by bobcat kittens. Thereafter, kittens could be observed in the immediate vicinity outside den sites. As kittens matured, activity outside of dens and movement between various den sites gradually increased the extent of space utilized by kittens.

Kitten home range was apparently defined by the mother since kittens were never observed far from dens except while following their mother to new den sites. The development of kitten home range was a gradual expansion of space that depended on kitten maturity and the location of den sites selected by the mother.

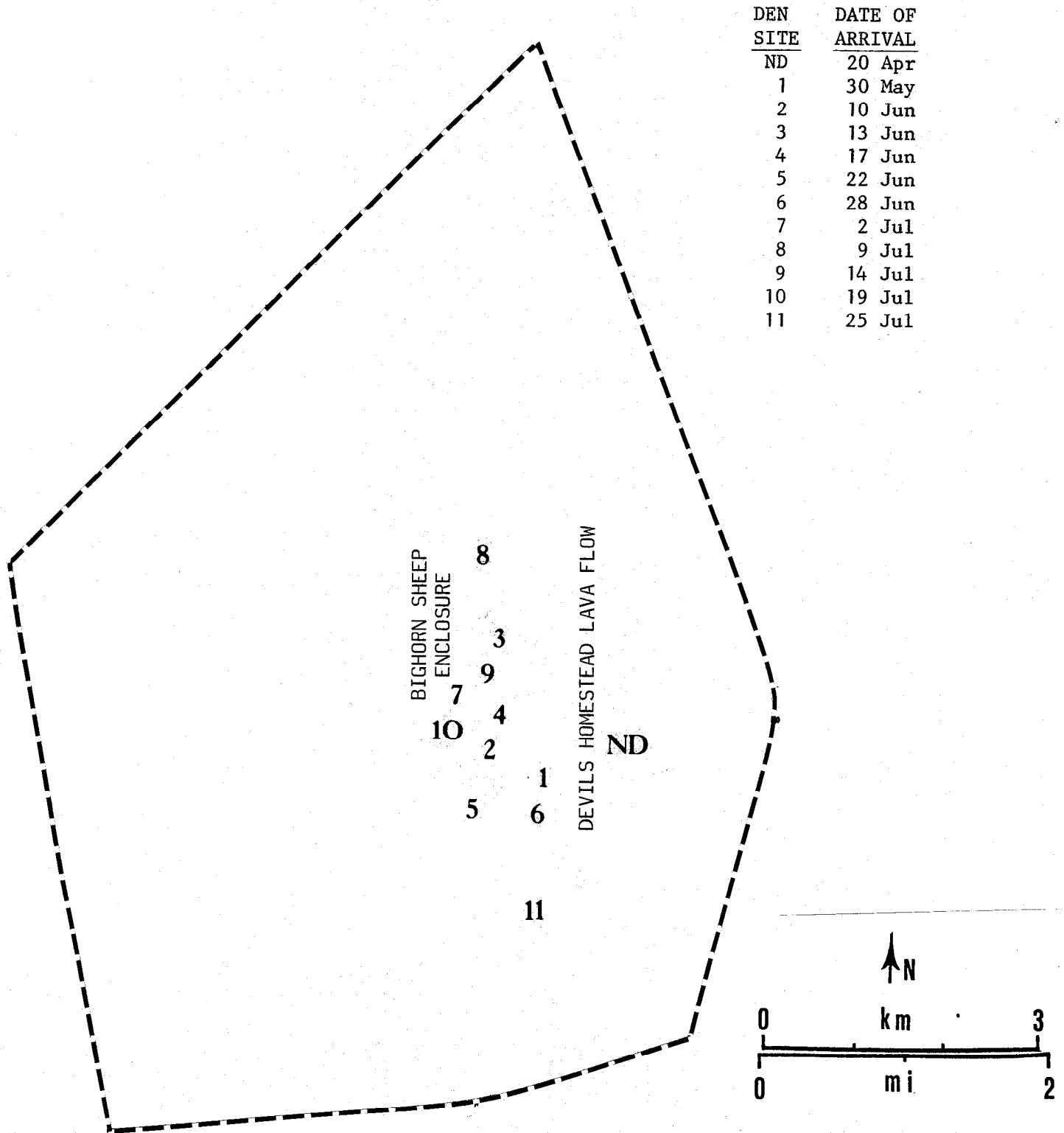


Figure 2. The location of the natal den (ND) and subsequent den locations of Bobcat 9 and her kittens during the first three months of the 1978 bobcat reproductive season in northeastern California.

Nonreproductive Juvenile Stage -- Juvenile bobcats were fitted with radio-collars with sufficient circumference to allow growth. Two of the five juveniles slipped free of these radio collars shortly after capture. The remaining three juveniles provided data regarding the home range use by independent juvenile bobcats prior to the breeding season in late winter. The nonreproductive juvenile home ranges (Figure 3) were small and ranged between 4.5 and 9 km² (1.7-3.5 mi²). Two of these juveniles died of starvation (details discussed in population dynamics section) and therefore provided limited information. However, the surviving juvenile demonstrated how a non-reproductive juvenile might attain the home range characteristics of adult bobcats and is discussed in the following category of home range development.

Nonreproductive juvenile home ranges were considerably smaller than stable adult home ranges. The duration of this stage of home range development was short; limited either by high juvenile mortality rates (Brand and Keith, 1979) or by attainment of reproductive condition.

Pubescent/Transient Adult Stage -- The onset of reproductive capacity began the third phase of home range development for young bobcats. While Crowe (1975) noted that female bobcats bred after age one and males bred after age 1½ years, Bobcat 2 was observed copulating at an age of about ten months. Although the viability of this copulation was not determined, sufficient hormonal levels were present to prompt the behavior. Bobcat 2 survived its first winter and expanded its initial home range from 4.5 km² (1.7 mi²) to 36 km² (13.9 mi²) during the subsequent reproductive season (Figure 4). It appeared that juveniles occupy small home ranges within the home range of their mothers immediately after dispersal, but maturing juveniles expanded their home range in response to physiological changes and in response to interaction with conspecifics.

Bobcat 7 was also in this category. According to Crowe's (1975) formulations relating body weight to age of juvenile bobcats, Bobcat 7 was approximately 300 days old, although the synchrony and timing of reproduction in northeastern California indicated a probable age of 14 months. Bobcat 7 occupied a home range of 16 km² (6.2 mi²) during the 38 days following its capture. The home range of Bobcat 7 slightly overlapped the home range of an adult male (Bobcat 6) that was 36% larger in body size.

On July 23, 1977 these bobcats were radio-located within a half km (0.3 mi) of one another. Subsequently, Bobcat 7 moved 25 km (15.5 mi) into an area 10.4 km² (4 mi²) in size. This movement required three days. Bobcat 7 returned to its original home range on 29 August 1977. Bobcat 7 repeated this alternate use of home range areas, leaving its initial home range on 19 September 1977 and returning on 18 October 1977. Bobcat 7 left its initial home range again on 19 January 1978 and did not return. In two of the three instances when Bobcat 7 left the initial home range, Bobcat 6 and 7 had been within a half km (0.3 mi) of one another. The last and final time that Bobcat 7 left its initial home range was at the onset of the bobcat breeding season in northeastern California. Additionally, it was during the trapping season and the area of its second home range was in Modoc National Forest where bobcats were harvested. During the next six months, Bobcat 7 expanded its second home range to 54.5 km² (21 mi²). The removal of bobcats by commercial trappers vacated large areas of bobcat habitat. An animal operating under a solitary mode of existence, may seek areas where less competitive

Figure 3. Home ranges of three male bobcats during the Nonreproductive, Juvenile Stage of home range development in northeastern California.

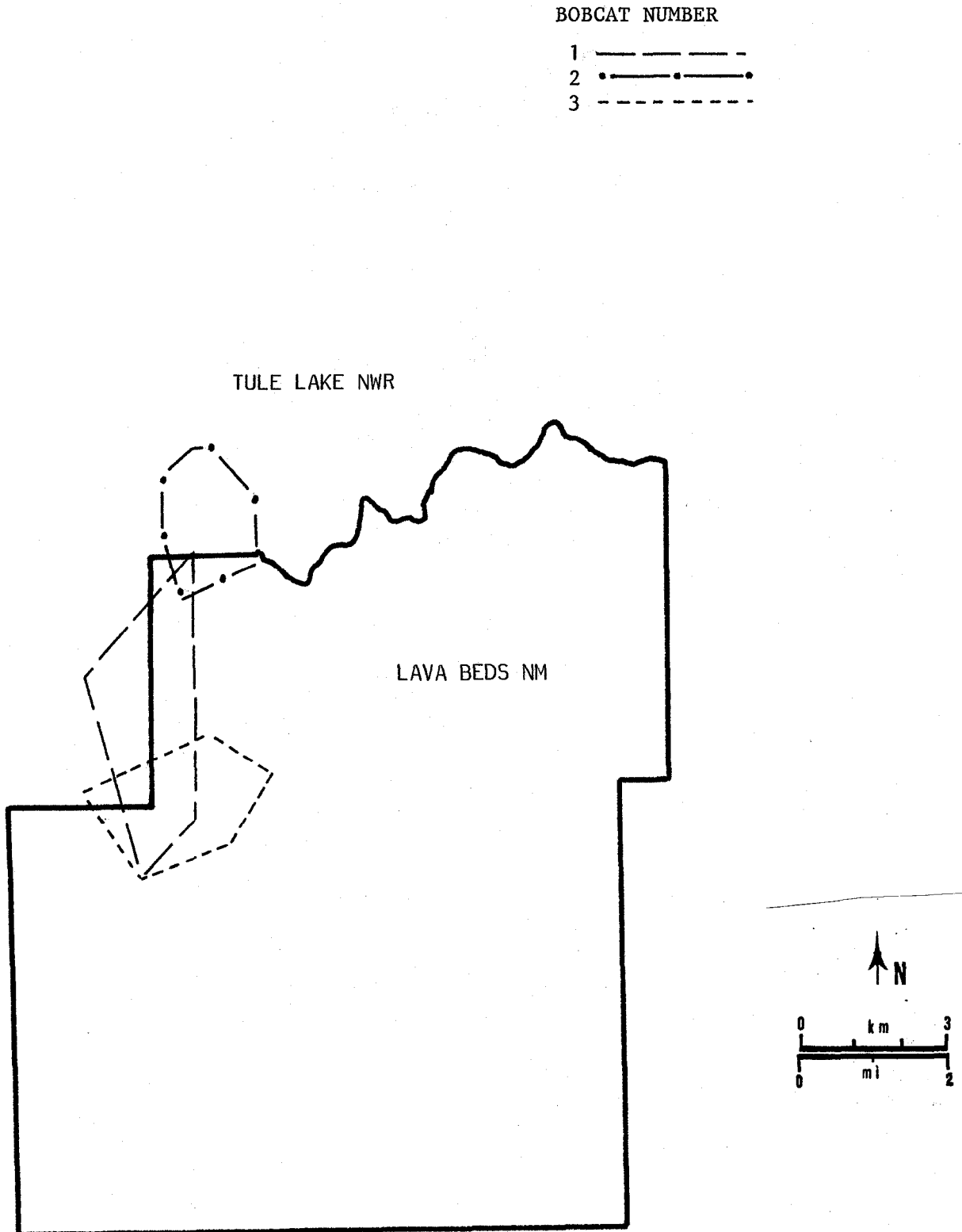
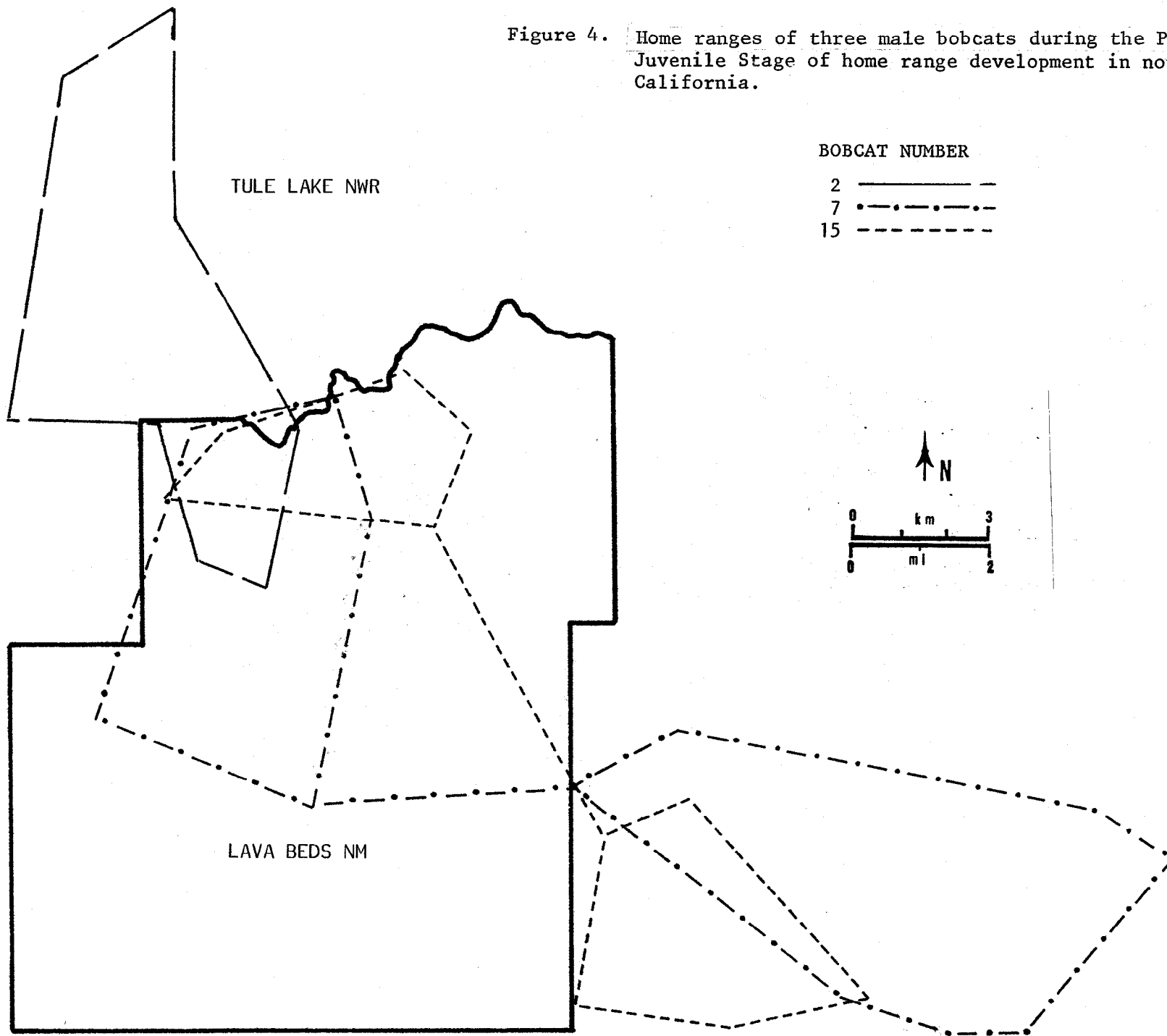


Figure 4. Home ranges of three male bobcats during the Pubescent/Juvenile Stage of home range development in northeastern California.



situations are encountered. This is accentuated in individuals which are physically inferior. These factors probably exerted considerable pressure for yearling bobcats to immigrate into vacated areas as was the case for Bobcat 7. Yearling bobcats exhibiting reproductive behavior within the confines of their parental home range presented a competitive aspect to conspecifics.

The onset of reproductive behavior in yearlings initiated home range instability, emigration and subsequent home range expansion. Similar patterns of home range use are occasionally exhibited by adult bobcats termed transients by Bailey (1972). Bobcat 15 displayed this pattern. Bobcat 15 was captured in and occupied the vacated home range of Bobcat 7 (Figure 4). After 16 days, Bobcat 15 left this first area and occupied a home range 13 km (8 mi) distant and located immediately to the southeast of the second home range of Bobcat 7. Bobcat 15 was harvested during the next trapping season. Different behavioral factors accounting for this variation may include dominance and phenotypic variation. Environmental disturbances such as fire also may precipitate the transient behavior of adult bobcats.

Assuming that the best natal dens and hunting areas will be occupied by reproductively experienced females, impending parturition may present a problem to yearling females. These pressures may drive yearling females to seek (immigrate to) areas where less competition for natal den sites and prime hunting areas is experienced. Likewise, yearling males in reproductive condition represented competition to adult males, in that breeding females are a resource. Bobcat 6, an adult male, was observed eating a bobcat it had apparently killed. Genitalia had been eaten from the carcass but internal examination revealed the absence of a female reproductive tract. While this was an isolated observation, observations of this nature are difficult to obtain in wild populations. The fact that lions (Schaller 1972, Bertram 1978), cheetahs (Eaton 1974, Frame and Frame 1980) and leopards (Charsley, 1977) are known to kill conspecifics adds to the credence of extreme agonism between bobcats.

Adults would be favored in any conflict between adult and yearling bobcats. An approximate 30% size dimorphism exists between sexes of bobcats. Juvenile bobcats do not attain adult body size until about 1½ years of age (Crowe, 1975). A strong selective pressure to emigrate is probably exerted on yearling bobcats in the presence of adult competition. Bobcat number 7 displayed a sequence of movements and home range shifts which illustrate this phenomenon. Similar behavior exhibited by adult transients could be due to some unmeasured dominance among individuals or, more likely, to the tendency of adults of the same sex to avoid contact.

The abrupt, exaggerated movements, instability of home range and the use of multiple home ranges exhibited by pubescent juveniles and transient adults probably occurred as a result of intra-specific competition within the established home ranges of adult bobcats. Pubescent juveniles and transient adults have either lost or never had a stable home range. Immigration into suitable unoccupied habitat of sufficient size may lead to development of a stable home range.

Activity Patterns and Movement

The activity pattern and movements of bobcats are related. Bobcats typically began and terminated their daily activity cycles in relation to the peaks of prey activity and were more crepuscular than nocturnal. This is exemplified by the activity pattern during the winter of 1978. A bimodal activity pattern with peaks at 0700 hours and 1800 hours corresponded to dawn and dusk during that period. Similar activity patterns were expressed in fall, spring and summer with the timing of the activity peaks shifting with the times of sunset and sunrise. More nocturnal activity and less daytime activity occurred when daytime temperatures exceeded 22°C (75°F). Levels of bobcat activity varied individually, not by sex ($P < 0.05$).

Bobcat movement was, for the most part, confined to movements while hunting and movements between prime habitat areas. During an entire hunting session bobcats frequently remained within an area as small as 0.5 km² (0.19 mi²). Bobcat 2 captured as many as nine voles (*Microtus montanus* and *M. longicaudus*) in a 55 minute period, five voles in a 25 minute period and 4 voles and a woodrat (*Neotoma fuscipes*) in 35 minutes during different hunting sessions. The hunting success demonstrated by bobcats did not require the use of large areas. Moreover, intensive predation in small, but widely separated geographic areas dispersed throughout a bobcat home range may reduce the impact of predation on prey species.

Extreme movement was associated with movements between the prime habitat of bobcat home ranges. Bobcats typically occupied a particular prime habitat area for 2 to 5 days before moving to a second area. No sequential pattern of movement between these areas was noted. The pronounced bimodal activity pattern exhibited by bobcats suggested that bobcat movement might be a function of discrete portions of the day. To test this assumption winter movements were analyzed on the basis of distance traveled during different times of the day. The mean distance traveled during daytime was 1.76 km (1.1 mi) whereas nighttime travels averaged 2.47 km (1.5 mi). The mean distance traveled during hours of darkness was significantly greater than the mean distance during daylight hours ($P < 0.05$). Bobcat activity patterns were related to specific behaviors chiefly comprised of sleeping, resting, grooming, hunting and movements within home ranges.

Population Dynamics

Bobcat density fluctuated greatly during an annual cycle. Depending on the density and fecundity of breeding females and their abundance in relation to males, summer density can more than double the previous winter density. Large rates of population growth are generally countered by mortality. The aspects of age related fecundity and mortality as influenced by population size and the number of breeding females are major factors determining the density and vigor of a population.

Only two adult females were radio-collared during the 1977 breeding season. Bobcat 5 had two kittens and Bobcat 9 had one kitten as observed prior to the kitten dispersal period. Additionally, four uncollared females were observed with kittens. The location of each observation indicated that no repetition of observations occurred. One unmarked female had four kittens and the other three females had three kittens each. A total of 16 kittens were observed with six female bobcats in 1977. During 1978 four radio-collared females had kittens as follows: Bobcat 5 - two kittens; Bobcat 9 - three kittens; Bobcat 12 - four kittens; Bobcat 13 - three kittens. These

observations represent a minimum reproductive rate of 2.7 kittens per female in 1977 and 3.0 kittens per female in 1978. The observed reproductive rate is within the 2.8 to 3.5 range determined by other studies of this subspecies (Gashwiler et al. 1961, Bailey 1972, Crowe 1975). Reproduction during 1978 increased the density from 0.05 bobcats per km² (0.13 mi²) to a density of 0.13 bobcats per km² (0.33 mi²) during the summer. This large rate of population increase was probably countered by high juvenile mortality and emigration,,

Bobcat mortality in northeastern California was composed of natural and man-induced mortality. The man-induced mortality included automobile related deaths and harvest by hunting and trapping. Two bobcats, an adult female (1976) and a juvenile female (1980) were killed by automobiles. Hunting mortality occurred by two methods. Some bobcats were taken incidental to the pursuit of other game. A more specific and successful method of take employed the use of hounds. The major portion of man-induced mortality was commercial fur trapping. Despite the protection afforded by hunting and trapping prohibitions on the Tule Lake National Wildlife Refuge and on Lava Beds National Monument, 20% of the 15 study bobcats were legally harvested on adjacent Modoc National Forest land-. Three of the more prolific trapper groups in the area supplied trapping results over the last four trapping seasons (Table 4). These trapper groups included two or more trappers, usually relatives. It should not be interpreted that the average licensed trapper achieved the given success rate since these trappers accounted for about 70% of the bobcats trapped in the local area. These trappers trapped in the same respective areas and tended to use the same trap lines and degree of trapping effort each season. The bobcat catch by these trappers did not vary appreciably during the four seasons.

Table 4. Bobcat harvest by three trapper groups over four trapping seasons. The bobcats were harvested adjacent to the northeastern California bobcat study area; Siskiyou and Modoc Counties, California.

Area	1975-76	1976-77	1977-78	1979-80
Clear Lake Hills (Modoc County)	22	19	12*	23
Timber Mountain (Modoc County)	18	21	20	18
Mt. Dome (Siskiyou County)	8	16	19	7*
Total	48	56	51	48

*Reduced trapping effort.

Natural mortality occurred in the form of starvation, death from agonistic encounters and accidental or unexplained mortality. Necropsy reports prepared by Veterinarians revealed that Bobcats 1 and 3 died of apparent malnutrition complicated by parasitism. Bobcats 1 and 3 lost 36% and 43% of their body weight, respectively between capture and death. Bobcat 3 died during winter when ambient temperatures were as low as -29°C (-21°F) and more than 25 cm (10 in) of snow covered the ground. Bobcat 3 was observed hunting but no successful stalks occurred. Necropsy revealed 277 *Physaloptera* sp. 15 *Toxacara* sp., and 15 *Taenia* sp. in the stomach and intestinal tract of Bobcat 3. Agonistic encounters may result in death directly, as was the case of the male bobcat cannibalized by Bobcat 6 in 1977. The dead bobcat had blood and puncture marks on the neck. Death due to infection and abscess could be the more frequent consequence of agonistic encounters. An adult male bobcat was found dead during the breeding season of 1978. The bobcat had not been shot and its stomach was full. Broken bones that could have been caused accidentally or by an automobile were not detected. The cause of death could not be determined in the case of this bobcat. The extent that man-induced mortality is compensatory to natural mortality determines the feasibility and the permissible extent of hunting and trapping harvest.

The generation of life tables, survivorship curves and fertility schedules may occur from two basic forms of data. Cohort life tables result from the fecundity and mortality of one cohort (age class) during its entire existence. Static life tables are based on a sample of a population at any particular point in time and are subject to the particular environmental conditions during that period. Data for static life tables generally fall into three categories where either the survivorship, the age structure, or the age at death are directly observed (Krebs, 1972).

The classic theoretical requisites permitting construction of life tables include direct knowledge of age specific survival and fecundity rates and the distribution of each age class from a population of known size. Ecologists seldom attain absolute values for these parameters, except under laboratory conditions. In lieu of exact knowledge of these parameters demographers often use a sample of the population to construct hypothetical life tables to predict the parameters of that population (Caughley, 1977). If assumptions are noted and the life table information is regarded as an indication rather than an absolute demographic description of the population, some insight of the biology of that population may be gained. The alternative is a qualitative judgment of population vigor.

Data from animals trapped or otherwise collected are widely used to estimate demographic parameters of fish and wildlife populations. It is assumed that the sample is unbiased and adequately expresses the actual population, although these assumptions are rarely met. During three trapping seasons, the age of 162 harvested bobcats was determined by the number of cementum annuli present in canine teeth (Crowe, 1972). The sex of 112 of these bobcats was also determined and revealed a sex ratio of 0.96 males per female.

Data from the three years were combined and three assumptions were made:

- (1) environmental conditions were constant over the three years; (2) the

three year sample represents an instantaneous sample; (3) all age/sex categories in the population were equally susceptible to the sampling technique.

Analysis of reproduction and population parameters are traditionally performed using the age-specific survival rates of only the female portion of the population (Figure 5). The assumption of a stable age distribution was tested and met by Chi-square examination ($P < 0.05$). The age-specific survival (l_x) is multiplied by the age-specific average of female offspring produced (m_x) the reproductive gain for each age class. Assuming that equal numbers of male and female bobcat kittens were born, 1.5 female kittens were produced by each reproductive female. This was derived from direct observation of the number of kittens born by radio-collared females during 1978. The additional assumption that females did not reproduce during the first year but, thereafter maintained a constant fecundity until death, resulted in a female life and fecundity table with resulting population parameters (Table 5).

A population experiencing the same rates of mortality and fecundity under a constant set of environmental conditions will eventually reach a stable age distribution (Lotka, 1922). Furthermore, the population size will continue to increase (or decrease) at the rates dictated by the schedule of births and deaths. Under these conditions the finite rate of increase (λ) indicates the direction of population growth. A value less than one would indicate a declining population. A finite rate of increase greater than one does not necessarily indicate increasing population growth, but does indicate the vigor which a population responded to the particular set of environmental conditions (Caughley, 1977). The bobcats in northeastern California appear to be responding vigorously since the finite rate of increase was 1.35. The bobcat population had a stable age distribution and the age/sex distribution assumed the shape of a population undergoing expansion.

This hypothetical life table is subject to the constraints and validity of the assumptions and type of data utilized in its construction. Ecological data from wild animal populations generally violate the restrictions of demographic theory. However, demographic techniques are frequently used to indicate rather than describe the demography of populations. The nature and extent of assumptions violated often adds rather than detracts from the information. The California Department of Fish and Game has obtained the sex and age of bobcats sold for export during the last two trapping seasons. As more annual data becomes available, the survival of kittens born in a particular year may be followed over time. These data are subject to fewer assumptions and will more accurately lend themselves to demographic theory.

Management Implications

Bobcat management has been stymied by the lack of adequate population estimates. Due largely to bobcat behavior, conventional census techniques are ineffective or, at best, provide trends of bobcat abundance. High bobcat fur prices result in increased trapping effort invalidating the use of harvest data for estimates of bobcat abundance. Radio-telemetric techniques

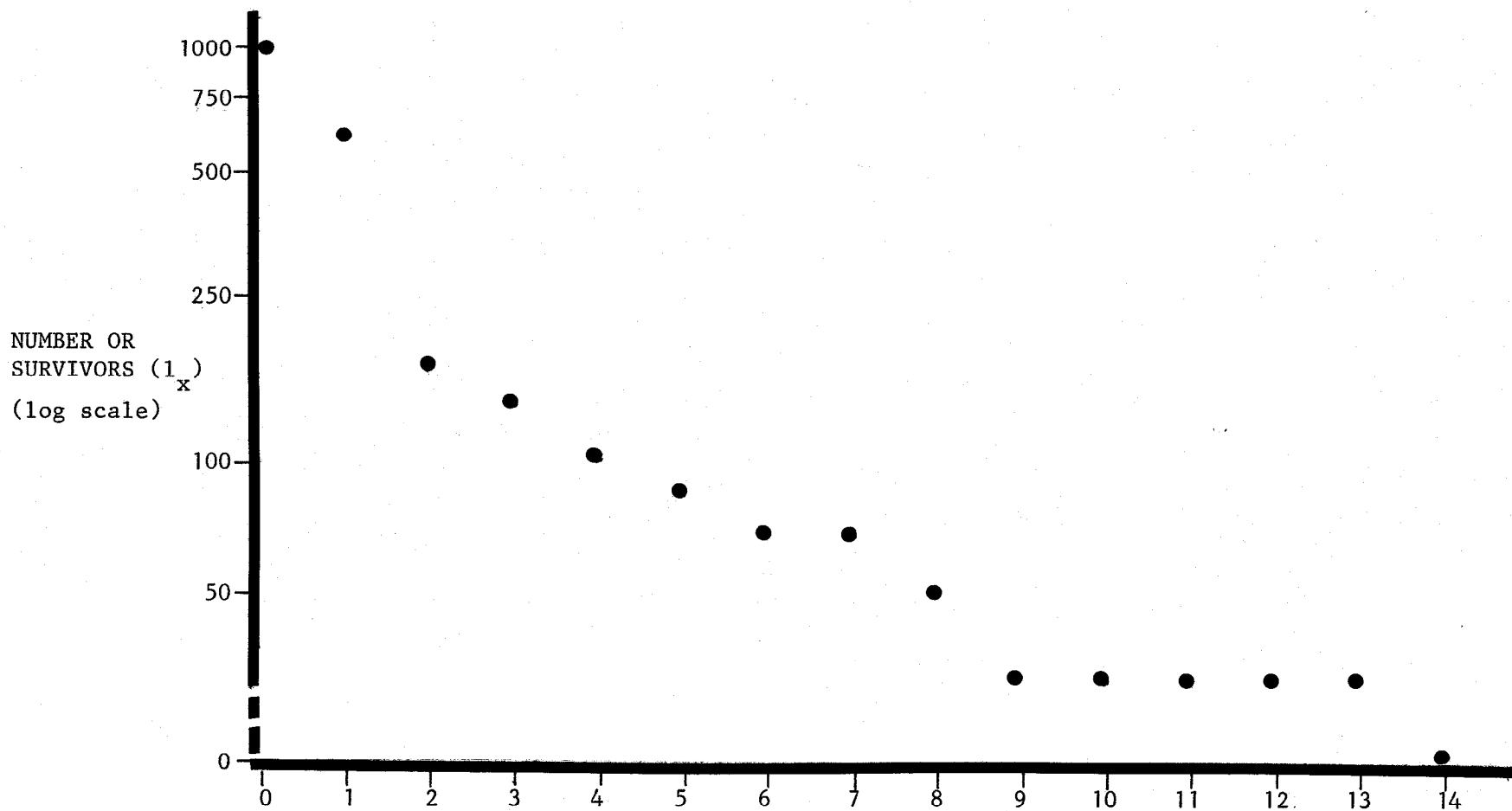


Figure 5. Survivorship curve estimated from the ages of 57 female bobcats harvested during three trapping seasons in Siskiyou and Modoc Counties, California (1976-77, 1977-78 & 1978-79). Broken line denotes interruption of scale on Y-axis.

Table 5. Life and fecundity table constructed from the age distribution of 57 harvested female bobcats during three combined trapping seasons (1976-1979) in Modoc and Siskiyou Counties, California.

Age	Frequency	Survival	Mortality	Age Specific Birth Rate	
X	f_x	l_x	d_x	m_x	$l_x \cdot m_x$
0	22	1.000	.386	0	---
1	25	.614	.439	1.5	.921
2	2	.175	.035	1.5	.263
3	2	.140	.035	1.5	.210
4	1	.105	.018	1.5	.158
5	1	.087	.018	1.5	.131
6	0	.069	0	1.5	.104
7	0	.069	0	1.5	.104
8	1	.069	.018	1.5	.104
9	1	.051	.018	1.5	.077
10	0	.033	0	1.5	.050
11	0	.033	0	1.5	.050
12	0	.033	0	1.5	.050
13	2	.033	.033	1.5	.050
14	0	0	----	----	----

Net Reproductive Rate = $R_0 = \sum l_x m_x = 2.267$

Generation time = $G = \frac{\sum l_x m_x x}{R_0} = 3.768$

Apparent innate capacity for increase = $r_a = \frac{\ln R_0}{G} = 0.217$

Innate capacity for increase = $r_m = 0.30$ when $\sum l_x m_x e^{-r_m x} = 1.00$

Finate rate of increase = $\lambda = e^{r_m} = 1.35$

provide the best density estimates but are time consuming and expensive. Moreover, caution must be used in applying these estimates to different bobcat populations due to habitat and subspecific variation. The demographic vigor of populations provide an estimate of population response to current environmental conditions. The finite rate of increase measures this response and has been used to model lynx (*Felis lynx*) and bobcat populations.

Brand and Keith (1979) documented a 38% decline in the finite rate of reproductive increase of lynx during cyclic lows in Alberta. The reduction corresponded to decreased snowshoe hare (*Lepus americanus*) abundance. Diminished finite rate of reproductive increase occurred as lynx population density and fecundity waned. Lynx demonstrated decreased late winter fat reserves and a reduction of litter size and in the rate of ovulation and pregnancy during this period. The authors calculated a finite rate of increase of 1.34 during years of lynx population growth. Additionally, they proposed a model whereby a three year harvest cessation would increase the number of lynx harvested in subsequent years. This model assumed that declines of lynx population size were caused by food shortage and not density-dependent social restrictions.

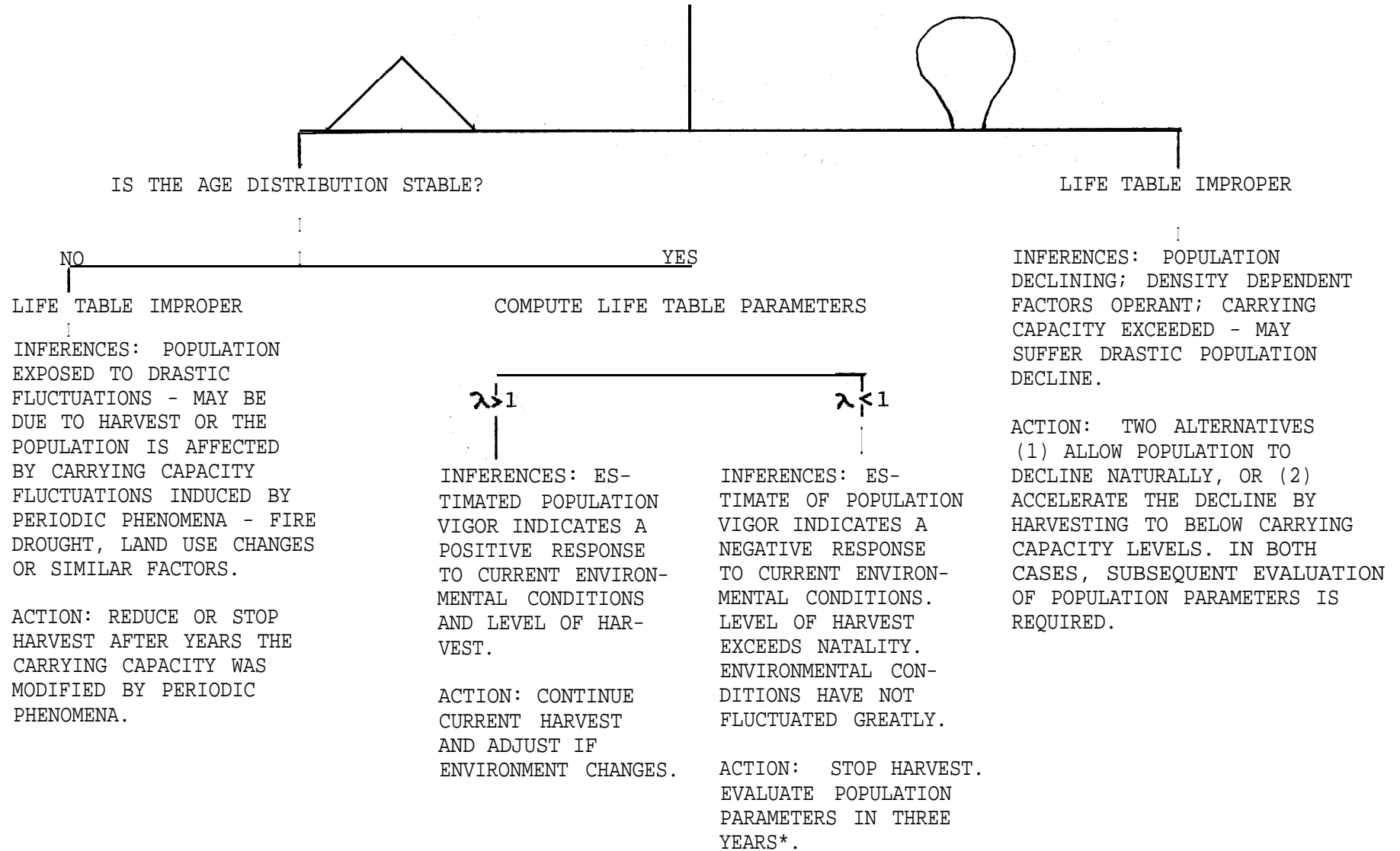
Crowe (1975) demonstrated that the finite rate of increase fluctuated between 0.42 and 1.65 according to low and high densities of Wyoming bobcats between the years of 1948 and 1972. He suggested that the finite rate of increase be utilized to manage the harvest of bobcats.

The previous lynx and bobcat models assumed that sex ratios were equal and that density-dependent population regulation through social restrictions did not occur or was not measured. Recent studies indicate that bobcat age/sex ratios may become highly skewed toward adult male bobcats (Lembeck 1978, Zezulak and Schwab 1980). In the same studies bobcat reproduction was extremely low or non-existent. Additionally, these bobcats exhibited a high degree of home range overlap in contrast to the bobcats in Idaho (Bailey, 1974) and, to a lesser degree, during this study. Under conditions of high density bobcats lose the luxury of large exclusive areas and social interactions occur with more frequency. Delayed maturity, sexual size dimorphism and parturition related stress may precipitate a shift favoring adult male bobcats in exceedingly dense populations. Furthermore, the shortage of snowshoe hares which caused measurable changes in physiological parameters of lynx (Brand and Keith, 1979) were density dependent when one relates the density of prey to predator density (Curio, 1976). It follows that relatively long-lived animals with low natural adult mortality rates and high innate capacity for increase would be adapted to sudden favorable environmental conditions. At some point the population must be regulated by density-dependent factors. These situations are detectable by physiological and behavioral changes within a population.

Considering these factors, bobcat management is relegated to two specific courses of action which require treatment at the local population level: (1) to raise the density of a small or declining population; and (2) to exploit a population with the goal of extracting a sustained yield (Caughley, 1977). A management scheme combining demographic theory and bobcat biological parameters was developed (Figure 6).

FIGURE 6
PROPOSED BOBCAT MANAGEMENT SCHEME

EVALUATE SHAPE OF AGE/SEX DISTRIBUTION



*Three years allows sufficient time for recruitment of breeding females.

Tests of such schema take years to evaluate and, where rates of harvest fluctuate, may produce a variety of results. The value of radio-telemetry studies is that detailed biological information is gained. The disadvantage is that sample size is generally small due to the extensive nature and cost of such studies. Having performed two such studies of bobcats, I can document the results of two reproductive seasons under extremely divergent population parameters.

First, if the population described by this paper were taken through the management scheme we would conclude that under the conditions existing during 1978, the estimate of population vigor was good. Consequently, the current extent of bobcat harvest could continue if environmental situations remain the same. This conclusion was made because the age/sex distribution was favorable and because the finite rate of increase was greater than one (sex ratio 0.96 males/female, females assumed a stable age distribution and $\lambda=1.35$).

In reference to direct observations, a minimum of four male and four female adult bobcats occupied an area of 215 km² (83 mi²) during the 1978 and represented the pre-reproductive density. Reproduction by these females yielded a post-reproductive population size of 20 bobcats. Density estimates based on two years of telemetry data yield a pre-reproductive density of 10.8 bobcats and a post-reproductive density of 28 bobcats. The discrepancy between measured and observed density exists because the density estimates are based on the known home range size modified by the degree of home range overlap and does not take uncaught bobcats into account. Utilizing the predicted pre-reproductive density and the finite rate of increase determined for this area, the post-reproductive density should have been 14.5 bobcats as opposed to the 20 bobcats observed and the 28 bobcats predicted by density estimates. The difference between the predicted rate of increase (1.35) and the observed rate of increase (2.5) may be due to a combination of two factors. Juvenile bobcats could be less susceptible to trapping and were, therefore, underrepresented in the population sample. The other factor would be due to the extent of natural juvenile mortality that occurred between summer and the end of the trapping season. This period corresponded to the juvenile dispersal period of home range development.

During this study two of three radio-collared juveniles died during the dispersal period. Both were malnutrition related deaths and neither bobcat was observed in a successful act of predation. Crowe (1975) noted that only 25% of live Richardson's ground squirrels (*Spermophilus richardsoni*) placed in captive juvenile bobcat pens were successfully predated. Brand and Keith (1979) determined that lynx kitten mortality between May and November was 65% during years of snowshoe hare abundance and 95 and 88% during two years of snowshoe hare decline. Since the small sample of juvenile mortality observed in this study was consistent with mortality rates of lynx kittens, I used 66% natural mortality to estimate the number of kittens susceptible to harvest. The susceptible trapping density was, therefore, 16.2 bobcats of all ages for that trapping season. The population fluctuations exhibited by the radio-collared bobcats was closely predicted by the demographic estimate.

The second test of the management scheme arose from a radio-telemetry study of bobcats at Joshua Tree National Monument, Riverside County, California during 1979 (Zezulak and Schwab 1980). This population was entirely protected

and bobcats were not subjected to trapping mortality. Although this was a short-term study and had a small sample size, the degree of trapping effort assured the validity of results during the 1979 reproductive season. The sex ratio of this population was seven males per female and all were adults. The shape and distribution of the age/sex structure of this population indicated that extreme density-dependent regulatory mechanisms were operating. No reproduction occurred in this study during the 1979 breeding season. The female bobcat was recaptured in September and had not lactated nor was she pregnant. A life table is not only unnecessary but would be invalid if constructed. The population was stressed and was undergoing a decline. Local extirpation of this population could occur.

The management alternatives became more complex for a population exhibiting these characteristics. Two alternatives exist. The first alternative is to stop all bobcat harvest and wait until natural mortality reduces the effect of the density-dependent population regulation. This may lead to local extirpation but may be eventually countered by immigration if adjacent bobcat populations are viable. This approach relieves the manager of all responsibility since the outcome is a natural phenomenon. The problem is that if neighboring bobcat populations are not available or are unable to provide immigration, the population is extinct.

A more aggressive and responsible approach would be to selectively harvest males or to rely on the sex distribution and equal trap-susceptibility of sexes to lower the population below the point where density-dependent population regulation is operative. At some future point the population would begin to assume a stable age distribution and may be evaluated by the stability of the age distribution. This involves the two remaining categories of the management scheme.

Since a stable age distribution will eventually occur if conditions remain constant, commercial fur harvest should be terminated for populations with unstable age distributions. Once a bobcat population reaches a stable age distribution it may be evaluated for the estimated finite rate of increase or decrease. Bobcat populations exhibiting a finite rate of increase below one should not be harvested since deaths exceed births for that population. This situation should not persist long if environmental conditions favor bobcats. The persistence of a finite rate of decrease probably indicates some environmental change that is not beneficial to bobcats. Conversely, the persistence of a finite rate of increase indicates that the extent of bobcat harvest is consistent with the population dynamics of that population under the existing conditions.

The California Department of Fish and Game has adopted the practice of recording the sex and age of each bobcat harvested for export. These data will provide a test of the proposed bobcat management scheme. Manipulative studies or purposeful violation of the bobcat management scheme may also elucidate its validity.

SUMMARY

This bobcat population was partially protected from man-induced mortality by Lava Beds National Monument and the Tule Lake National Wildlife Refuge. However, the degree of protection was modified because the protected area was small in relation to the large adult bobcat home ranges measured. Thirty percent of radio-collared adult bobcats were harvested by commercial trappers and two of three dispersing juveniles died of natural mortality. These mortality factors were countered by the observation of 28 bobcat kittens born to 10 females during the study. These mortality and natality rates were reflected by the age and sex ratios of bobcats harvested in the area. It was felt that the study bobcats reflected the biology of bobcats in northeastern California.

The density of adult bobcats was determined by the home range and extent of home range overlap displayed by radio-collared bobcats. Adult bobcats represent a pre-reproductive density of 0.05 bobcats per km^2 (0.13/ mi^2). Post-reproductive bobcat densities were 0.13 bobcats per km^2 (0.33/ mi^2). Adult male bobcat home ranges were, for the most part, exclusive ranges. Adult female home ranges overlapped considerably except during the parturition-related contraction of home range. Male and female bobcat home ranges exhibited up to 100% overlap. Four types of home range utilization were discussed which were related to the age, reproductive and social development of bobcats.

A management scheme was proposed that combines biological parameters and demographic estimates. It was deemed that this population was viable and responding positively to the level of exploitation under the environmental conditions during the study.

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LITERATURE CITED

- Bailey, T. N. 1972. Ecology of bobcats with special reference to social organization. PhD thesis. University of Idaho. 93 pp.
- _____ 1974. Social organization in a bobcat population. J. Wildl. Manage. 38(3): 435-446.
- Bertram, B. 1978. Pride of lions. Charles Scribner's Sons, New York. 253 pp.
- Brand, C. J. and L. B. Keith. 1979. Lynx demography during a snowshoe hare decline in Alberta. J. Wildl. Manage. 43(4): 827-849..
- Brownlee, W. C. 1977. Special Report - Status of the bobcat (*Lynx rufus*) in Texas. Texas Parks and Wildlife Dept., Austin, mimeo report, 20 p. plus appen.
- Caughley, G. 1977. Analysis of vertebrate populations. John Wiley and Sons, Chichester. 234 pp.
- Charsley, G. 1977. Cannibalism in adult leopards. Zoologica Africana. 12: 508.
- Crowe, D. M. 1972. The presence of annuli in bobcat tooth cementum layers. J. Wildl. Manage., 36:1330-1332.
- _____ 1975. Aspects of ageing, growth, and reproduction of bobcats from Wyoming. J. Mammal. 56(1): 177-198.
- _____ . A model for exploited bobcat populations in Wyoming. J. Wildl. Manage. 39(2): 408-415.
- Curio, E. 1976. The ethology of predation. Springer-Verlag, Berlin. 249 pp.
- Eaton, R. L. 1974. The cheetah. Van Nostrand Reinhold Co., New York. 178 pp.
- Erickson, A. W. 1955. An ecological study of the bobcat in Michigan. M.S. Thesis. Mich. State Univ. 133 pp.
- Ewer, R. F. 1973. The Carnivores. Weidenfeld and Nicolson, London.
- Foote, L. E. 1945. Sex ratio and weights of Vermont bobcats in autumn and winter. J. Wild. Manage. 9(4): 326-327.
- Frame, G. W. and L. H. Frame. 1980. Cheetahs: in a race for survival. Nat. Geographic 157(5): 712-728.

- Fritts, S. H. and J. A. Sealander, 1978. Reproductive biology and population characteristics of bobcats in Arkansas. *J. Mammal.* 59(2): 347-53.
- Gashwiler, J. S., W. L. Robinette, and O. W. Morris. 1961. Breeding habits of bobcats in Utah. *J. Mammal.* 42(1): 76-83.
- Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-bearing mammals of California. Berkeley, Univ. Calif. Press, 2: 590-625.
- Hall, E. R. and K. R. Kelson. 1959. The mammals of North America. Ronald Press, New York.
- Hamilton, W. J., Jr., and R. P. Hunter. 1939. Fall and winter food habits of Vermont bobcats. *J. Wildl. Manage.* 3: 99-103.
- Jones, J. H. 1976. Density and seasonal food habits of bobcats on the Three Bar Wildlife Area, Arizona. M.S. Thesis, Univ. of Arizona. 48 pp.
- Jones, J. H. and N. S. Smith. 1979. Bobcat density and prey selection in central Arizona. *J. Wildl. Manage.* 43(3): 666-672.
- Kight, J. 1962. An ecological study of the bobcat. *Lynx rufus* (Schreber), in West-Central South Carolina. M.S. Thesis. Univ. of Georgia. 52 pp.
- Krebs, C. J. 1972. Ecology. Harper and Row, New York. 694 pp.
- Leach, H. R. and W. H. Frazier. 1954. A Study of the Possible Extent of Predation on Heavy Concentration of Valley Quail with Special Reference to the Bobcat. *California Fish and Game.* 39(4): 527-538.
- Lembeck, M. 1978. Bobcat study, San Diego County, California. Final report to Calif. Dept. of Fish and Game. 20 pp.
- Lotka, A. J. 1922. The stability of the normal age distribution. *Proc. Nat. Acad. Sci. U.S.* 8: 339-345.
- Marshall, A. D. and J. H. Jenkins. 1966. Movements and home ranges of bobcats as determined by radio-tracking in the upper coastal plain of west-central South Carolina. *Proc. Ann. Conf. Southeast Game Comm.* 20:206-14.
- Marston, M. A. 1942. Winter relations of bobcats to white tailed deer in Maine. *J. Wildl. Manage.* 6(4): 328-337.
- McCord, C. M. 1974. Selection of winter habitat by bobcats on the Quabbin reservation, Massachusetts. *J. Mammal.* 55(2): 428-437.
- McLean, D. D. 1934. Predatory animal studies. *Calif. Fish and Game*, 20: 30-36.
- Pollack, E. M. 1950. Breeding habits of the bobcat in northeastern United States. *J. Mammal.* 31: 327-330.

- Pollack, E. M. 1951. Observations of New England bobcats. *J. Mammal.* 32 (3): 589-603.
- Progulske, D. R. 1955. Game animals utilized as food by the bobcat in the southern Appalachians. *J. Wildl. Manage.* 19(2): 249-253.
- Robinson, W. B., and E. F. Grand. 1958. Comparative movements of bobcats and coyotes as disclosed by tagging. *J. Wildl. Manage.* 22(2): 117-122.
- Rollings, C. T. 1945. Habits, foods and parasites of the bobcat in Minnesota. *J. Wildl. Manage.* 27(3): 131-145.
- Schaller, G. B. 1972. *The Serengeti lion: a study of predator-prey relations.* Univ. of Chicago Press, Chicago. 480 pp.
- Sokal, R. R. and F. J. Rohlf. 1969. *Biometry.* W. H. Freeman and Company, San Francisco. 776 pp.
- Young, S. P. 1958. *The bobcat of North America: its history, life habits, economic status and control, with list of currently recognized subspecies.* Stackpole Co., Harrisburg, PA and Wildl. Mgmt. Inst., Washington, D. C. 193 pp.
- Zezulak, D. S. and R. G. Schwab. 1980. *Bobcat biology in a Mojave desert community.* Report to the Bureau of Land Management. 25 pp.