BOBCAT HABITAT ASSESSMENT AND POPULATION DENSITY IN PENNSYLVANIA [a]

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Abstract: The objective of this project was to construct a habitat-based bobcat population model and to assess the feasibility of permitting a regulated bobcat hunting and trapping season. We used geographic information systems, multivariate modeling techniques, and remotely-sensed landcover and physiographic data to model bobcat habitat selection and to predict the state-wide distribution of suitable habitat conditions. Bobcats (27 females, 34 males) were radio-collared and monitored within a 2,320 km^2 study area during 1986-97. We developed Mahalanobis distance-based models of habitat selection within the study area and used logistic regression techniques to extrapolate patterns of habitat selection. Total area of 18,564 km^2 (15.8% of Pennsylvania) was classified as suitable for both male and female bobcats, whereas 39,067 km^2 (33.3%) was suitable for males but not for females. Female home range size was inversely correlated ($r = -0.67$, $P = 0.004$) with percent composition of areas classified as suitable habitat suggesting that model predictions reflected habitat gradients that were linked to individual behavior and home range use. Analyses of habitat availability and bobcat distribution suggested a current bobcat population of $\geq$3,150 adult resident animals. Population modeling suggests that the current population is growing at a rate of 4-6% annually. These findings suggest that regulated harvest is feasible provided that annual harvest levels do not exceed 240 adult bobcats. A bobcat management plan was developed and has been circulated for public and professional review.

Public attitudes concerning the management of the bobcat (Lynx rufus) in Pennsylvania have changed dramatically during the last century. Bobcats, and other predators, were considered vermin in the 1700s and 1800s. As early as 1819 a $1 bounty was established to promote the harvest of bobcats in the Commonwealth. This bounty was increased to $15 during 1916 and greater than 7,000 bobcats were killed for bounty during 1916-37. A realization that bounties were ineffective for controlling predator populations resulted in the removal or reduction of bounties on many predators. The bounty was removed from bobcats in 1937, but they remained unprotected and were widely harvested until classified as a game animal in 1970. This reclassification occurred in response to concerns for bobcat populations and was implemented to allow populations to expand throughout the Commonwealth. This reclassification empowered the Pennsylvania Game Commission (PGC) to set regulations to manage bobcat populations. There was no legal harvest of bobcats in Pennsylvania during 1970-99.

During the past 15 years, Pennsylvania trappers and hunters have witnessed dramatic geographic and numeric expansion of bobcat populations and have continually requested PGC to estimate population size and to conduct an assessment of harvest feasibility. Sixty percent of 2,056 licensed furtakers surveyed during 1994 indicated they would like to participate in a regulated bobcat harvest season (Lovallo 2000). During this period, the PGC conducted intensive field research to assess factors affecting bobcat density and distribution, and implemented surveys and carcass collection programs to monitor distribution and to assess population characteristics. Annual management, research, and harvest recommendations have focused on the PGC bobcat management goal: "To maintain, conserve, and promote sustainable bobcat populations in regions of Pennsylvania that provide suitable habitat conditions and to provide recreational opportunities for consumptive and non-consumptive users of bobcats".

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A comprehensive assessment of bobcat-habitat relationships, relative to bobcat distribution and density, was developed to assess the state-wide distribution of suitable habitat conditions for bobcats in Pennsylvania. These analyses served as the geographic basis for initial population estimates. Habitat modeling procedures were used to assess the potential impact of harvest on population growth. Our objectives were: 1) to construct a habitat-based bobcat population model, 2) to assess the feasibility of a regulated bobcat hunting and trapping season, and 3) to develop a bobcat management plan.

METHODS

We estimated bobcat habitat selection, using radio-telemetry determined bobcat locations, and used multi-variate modeling techniques and remotely-sensed land cover and physiographic data to develop and apply habitat selection models state-wide. Initial efforts to model habitat suitability were based on radio-locations collected from tagged bobcats in Lycoming County, Pennsylvania. Habitat suitability models were extrapolated beyond the initial study area and evaluated using radio-locations from additional bobcats tagged in the northcentral region. Habitat modeling procedures were based on the combined use of Mahalanobis distance statistics and logistic regression techniques; additional information of model design is presented in Lovallo (1999).

Wildlife Conservation Officers use a kill report form to provide information on observed bobcat mortalities (e.g., vehicle-caused, illegal harvest, disease). When possible, carcasses were collected and examined to determine sex and age and to estimate productivity. We used reports of bobcat roadkills and surveys of wildlife conservation officers to refine state-wide maps of bobcat distribution and to determine the range of established bobcat populations.

We used population-modeling techniques to project population growth and to assess the potential impact of regulated harvest. Vital rates in the model (e.g., age-specific survival and fecundity) were estimated from field research studies in Pennsylvania or from available bobcat literature. Age-specific survival rates for adult bobcats were estimated from age-distribution data collected from vehicle-caused bobcat mortalities (Crowe 1975). Age-specific fecundity was estimated from available literature on litter size and pregnancy rates. The bobcat population model used a 65% pregnancy rate and an average litter size of 1.5 kittens for yearling bobcats (<2 years old) and an 80% pregnancy rate and average litter size of 2.5 kittens for adult bobcats. When a range of parameter estimates were available, we chose the most conservative values (e.g., low survival and fecundity).

Initial population estimates (population size at time 0) were determined from geographically-based habitat suitability estimates, analyses of potential female home ranges, and state-wide distribution data based on surveys of field personnel, incidental captures, and vehicle-caused bobcat mortalities. The model considered a maximum 80% occupancy rate of potential female home ranges in areas (Wildlife Conservation Officer districts) known to support established bobcat populations. The population model incorporated stochastic parameters to develop confidence intervals for model projections. The model used a coefficient of variation to express the variation of vital parameters. The coefficient of variation was based on a standard deviation of $\pm$5% of parameter estimates. The model also considered demographic stochasticity (variations in sex ratios and age distributions) in model output. The model was replicated 500 times to assess stochastic effects.

RESULTS

Habitat Selection and Modeling

Sixty-one bobcats (27 females, 34 males) were captured, radio-tagged, and monitored in northcentral Pennsylvania during 1986-95. Initial efforts to estimate habitat selection and to model habitat suitability were based on radio-locations collected from 20 females and 24 males in Lycoming Co. Habitat suitability models were extrapolated beyond the initial study area and evaluated using radio-locations from seven female and 10 male bobcats (Lycoming, Tioga, and Bradford counties).

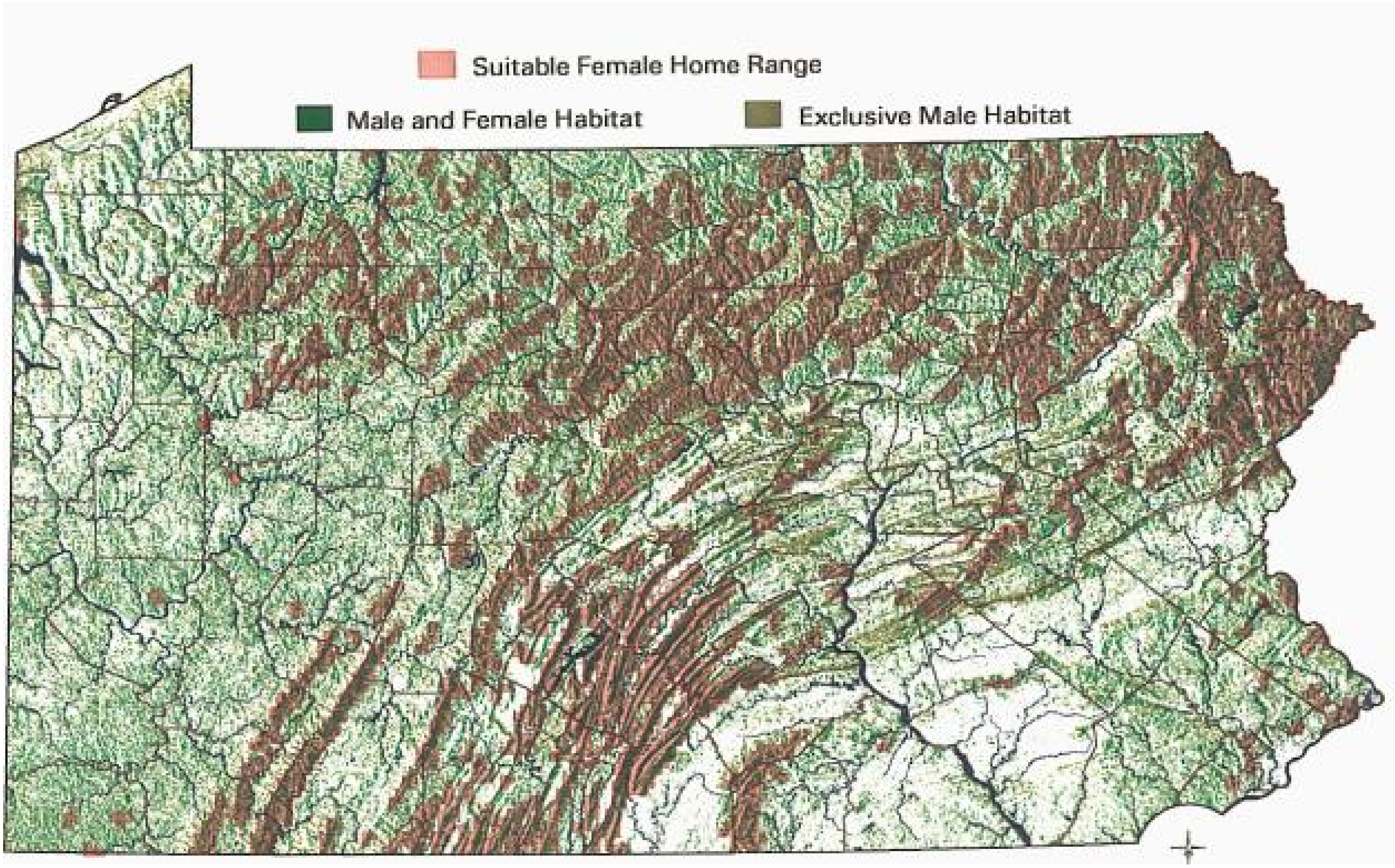
Bobcats in northcentral Pennsylvania exhibited strong physiographic associations; males and females were most frequently located on seven toeightdegree slopes on eastern to southeastern exposures. Male and female bobcats selected broadleaf deciduous forest during both summer and winter. Female bobcats avoided herbaceous and unvegetated areas during both summer and winter. Male bobcats avoided herbaceous areas during summer and mixed forest, unvegetated areas and perennial herbaceous habitats during winter. Median male home ranges (n = 17, mean = 42.2 km^2) were 2.5 times larger than those of females (n = 17, mean = 17.2 km^2), and were similar to previous reports of bobcat home range size from other northeastern states.

Mahalanobis distance-based models of habitat selection, using bobcat locations and unclassified satellite imagery, identified 70% of the initial (2,320 km^2) study area as suitable for males (1,625 km^2) and 54% as suitable for females (1,250 km^2). Validation of Mahalanobis distance-based models indicated a reclassification success rate of 85.7% for males and 86.4% for females. Both males and females used areas of high suitability (e.g., $P \geq 0.50$) disproportionate to their occurrence in the study area. Prediction success of Mahalanobis distance based models for males, as estimated from independent validation, was 13% less than that estimated by cross-validation. Predictive success of Mahalanobis distance based models for female bobcats, as estimated by independent validation, was similar to estimates from cross-validation.

Logistic regression-based habitat models were developed using cover type, slope, and aspect conditions associated with radio-telemetry determined bobcat locations and at random points throughout the study area. Models were developed independently using all random points in the study area (complete) and using only random points located in unsuitable areas as predicted by Mahalanobis distance based models (conditional). Parameter estimates were similar for both approaches, but reclassification success was greater using conditional randomization. Model validation using an independent sample of radio-tagged bobcats indicated a 78% classification success rate for females and a 71% classification success rate for males. The use of conditional randomization provided a method to link the predictive success of Mahalanobis distance-based models, developed from unclassified satellite imagery and physiographic characteristics, to logistic regression models developed from cover type, slope, and aspect.

Extrapolation of logistic regression based habitat selection models produced state-wide, sex-specific maps of bobcat habitat suitability. Total area of 18,564 km^2 (15.8%) was classified as suitable for both male and female bobcats, whereas 39,067 km^2 (33.3%) was suitable for males but not for females (Table 1). Female bobcat habitat was a subset of a broader spectrum of male habitat; only 2,791 km^2 (2.4%) of exclusive female habitat was identified.

Suitable male and female habitat was extensively identified in northcentral, central and southcentral portions of the state.



Female home range size was inversely related to percent composition of suitable habitat, as predicted by Mahalanobis distance-based models and logistic regression (e.g., r = -0.67, P = 0.004) suggesting that associated P-values reflected gradients in habitat suitability that were inherently linked to the ability of bobcats to acquire resources.

Female home ranges with less than 25% suitable habitat were larger and more variable than those with 25% or greater habitat composition. Evaluation of 18,770 potential female home ranges suggested that 4,222 (22.5%) contained greater than 25% suitable habitat. These ranges were distributed throughout northcentral, northeast, and southcentral Pennsylvania (Fig.1).

Figure. 1. Distribution of sex-specific habitat suitability predictions and optimal home range conditions for female bobcats (Lovallo 1999).

Table 1. Predicted area (km^2) of suitable habitat for male and female bobcats and percent composition of female habitat within each of 67 Pennsylvania counties.

	Suitable Habitat

County	Unsuitable	Exclusive Male	Male and Female	Exclusive Female	Total Female (%)[a]	
Lycoming	1,052.85	1,432.43	662.04	75.22	737.26	22.9
Bradford	1,101.44	1,201.69	637.67	64.44	702.11	23.4
Tioga	973.83	1,285.02	603.10	82.02	685.13	23.3
Blair	1,070.95	573.57	572.49	87.27	659.76	28.6
Bedford	1,390.77	593.86	566.52	77.74	644.25	24.5
Potter	973.37	1,203.39	572.08	52.54	624.62	22.3
Clearfield	1,262.61	1,137.49	502.25	85.43	587.68	19.7
Wayne	601.55	764.50	518.54	57.19	575.72	29.6
Clinton	649.78	1,102.63	512.68	49.05	561.73	24.3
Susquehanna	808.91	800.20	507.60	38.47	546.07	25.3
Centre	1,181.19	1,167.56	475.34	63.12	538.45	18.6
Somerset	1,516.07	788.75	428.09	68.72	496.81	17.7
Luzerne	927.32	925.78	418.87	74.61	493.47	21.0
McKean	903.73	1,160.82	445.29	38.21	483.50	19.0
Warren	929.71	923.81	407.86	65.43	473.29	20.3
Elk	736.55	959.05	420.85	40.79	461.64	21.4
Pike	399.77	616.13	371.59	79.30	450.89	30.7
Monroe	506.19	667.58	356.53	62.97	419.50	26.3

Westmoreland	1,399.05	881.75	349.85	55.11	404.96	15.1
Fayette	916.75	783.04	315.62	52.82	368.45	17.8
Indiana	1,121.74	679.68	304.29	57.03	361.32	16.7
Schuylkill	820.79	854.93	278.30	75.22	353.52	17.4
Franklin	1,405.60	248.07	309.37	39.29	348.66	17.4
Perry	585.25	530.77	275.75	51.85	327.60	22.7
Washington	1,264.13	639.93	295.13	32.42	327.55	14.7
Venango	785.69	659.86	301.96	22.02	323.99	18.3
Huntingdon	698.50	346.38	293.83	27.33	321.15	23.5
Crawford	1,581.43	785.59	285.51	35.55	321.06	11.9
Bucks	752.49	539.62	250.02	65.18	315.20	19.6
Greene	650.37	547.39	264.83	34.21	299.04	20.0
Fulton	621.47	215.80	251.68	45.95	297.62	26.2
Butler	1,168.65	602.73	258.58	29.07	287.65	14.0
Allegheny	1,086.22	556.83	259.84	24.13	283.96	14.7
Armstrong	930.18	513.30	234.35	44.54	278.89	16.2

Table 1. (Cont.) Predicted area (km^2) of suitable habitat for female bobcats and percent composition of female habitat within each of 67 Pennsylvania counties.

			Suitable Habitat			

County	Unsuitable	Exclusive Male	Male and Female	Exclusive Female	Total Female (%)[a]
Jefferson	848.83	571.69	218.23	57.58	275.80 (16.3
Clarion	871.69	426.72	214.58	60.02	274.60 (17.5
Cambria	946.64	576.62	241.82	31.25	273.07 (15.2
Forest	360.64	487.66	223.86	47.07	270.93 (24.2
Sullivan	384.19	525.14	234.45	27.41	261.85 (22.4
Wyoming	367.04	427.03	233.98	20.92	254.90 (24.3
Mifflin	527.22	298.01	221.80	24.53	246.32 (23.0
Berks	1,396.59	598.10	225.99	20.32	246.31 (11.0
Lackawanna	548.44	409.86	218.27	27.64	245.91 (20.4
Adams	831.07	274.43	181.31	64.02	245.33 (18.2
Cameron	301.49	488.31	230.04	15.13	245.18 (23.7
Chester	1,142.94	579.25	225.83	18.47	244.30 (12.4
York	1,740.36	400.72	169.98	51.58	221.56 (9.4
Juniata	468.99	329.70	190.39	29.76	220.15 (21.6
Montgomery	655.35	413.80	146.67	45.94	192.61 (15.3
Columbia	640.46	443.51	157.37	26.68	184.04 (14.5
Erie	1,293.78	595.76	156.09	25.99	182.08 (8.8
Mercer	1,128.50	460.18	161.97	15.71	177.68 (10.1
Carbon	369.96	460.71	146.77	28.77	175.54 (17.4

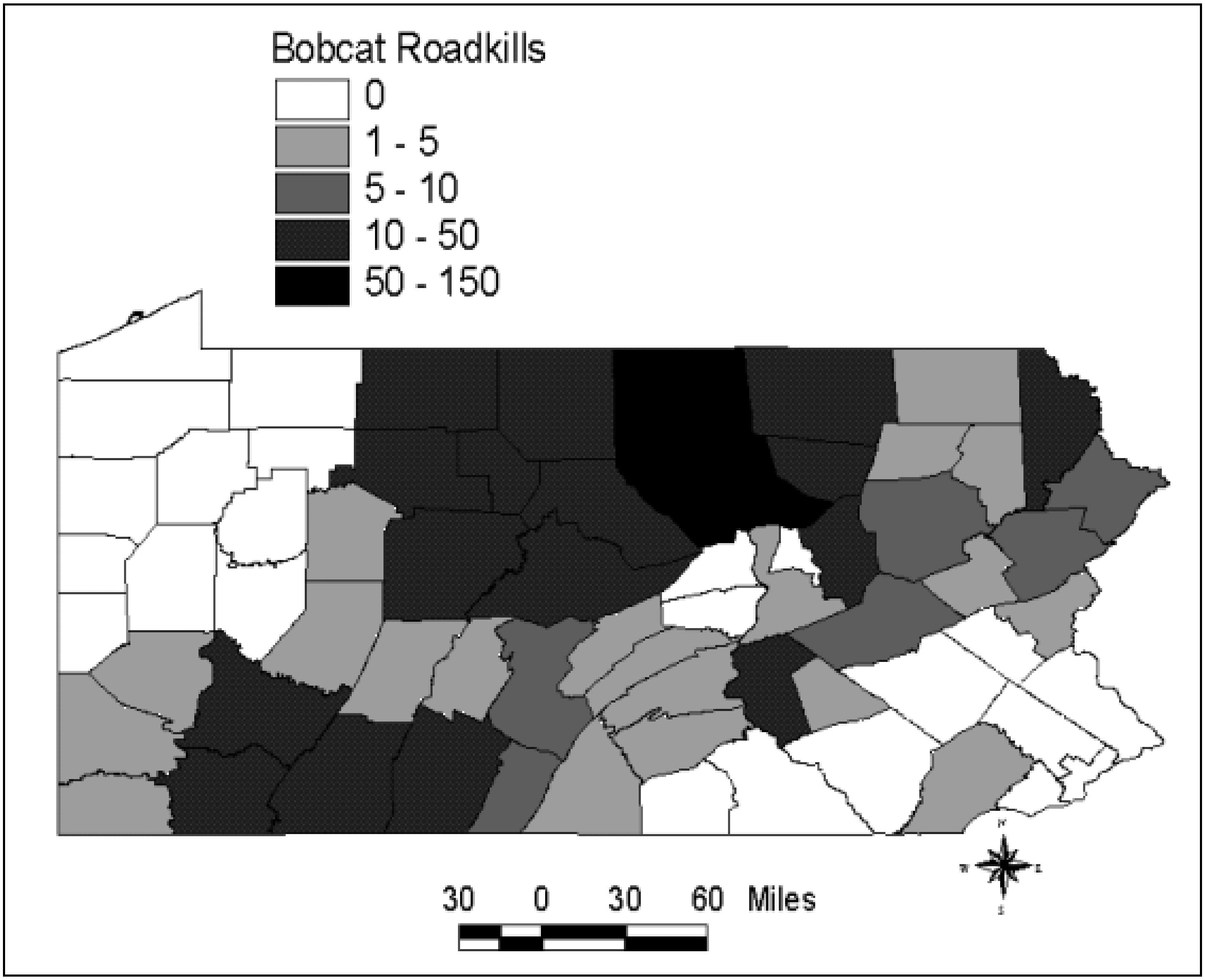
Beaver	620.14	362.20	153.26	15.03	168.29 (14.6
Cumberland	945.30	318.61	125.38	36.98	162.37 (11.4
Northampton	608.63	221.41	127.63	18.28	145.91 (15.0
Dauphin	851.20	450.80	107.29	27.62	134.91 (9.4
Union	318.99	373.49	116.71	17.43	134.14 (16.2
Snyder	430.71	304.68	99.37	26.23	125.59 (14.6
Lancaster	2,161.29	263.03	85.86	35.02	120.89 (4.7
Northumberland	686.76	435.12	81.09	28.07	109.16 (8.9
Lehigh	595.17	204.49	90.76	11.49	102.25 (11.3
Lawrence	628.94	210.49	86.20	13.96	100.16 (10.7
Delaware	246.61	151.88	64.27	30.03	94.31 (19.1
Lebanon	675.78	175.96	78.24	10.19	88.42 (9.4
Philadelphia	284.46	46.60	15.40	22.68	38.08 (10.3
Montour	221.62	91.47	24.75	4.71	29.46 (8.6

[a] Percent of county area.

Questionnaire results from Wildlife Conservation Officers supported habitat and home range predictions. Wildlife Conservation Officer estimates of percent composition of their district supporting bobcats was highly correlated to model predictions. During a 1998 survey of Wildlife Conservation Officers, bobcat populations were reported as stable within 59 Wildlife Conservation Officer districts (49%), increasing within 36 districts (30%), and declining in 1 district. Nineteen of 35 districts in furbearer management zones 2 and 3 (proposed harvest areas) reported increasing bobcat populations and 15 of 35 districts in these zones reported stable bobcat populations. Also, Wildlife Conservation Officer reports of established bobcat populations versus occasional sightings corresponded with the spatial distribution of suitable female home range conditions.

Model predictions of the distribution of suitable habitat were further supported by the spatial distribution of vehicle-caused mortalities. Six hundred and thirty seven roadkills were reported in 23 counties during 1985 to June 2000 (Fig. 2).

Figure 2. Distribution of vehicle-cause bobcat mortalities during 1985-2000.



Population Modeling

Based on habitat availability, state-wide distribution, and an 80% occupancy rate of potential female home ranges, we determined an initial population size of 3,156 adult resident bobcats. Bobcat age structure data indicated that survival rates range from 50-87% until age 5 when survival increases to greater than 80% and then remains constant (Fig. 3). The population model used a 33% survival rate for juveniles. This rate was based on values in the literature and is thought to be very conservative for an unharvested population.

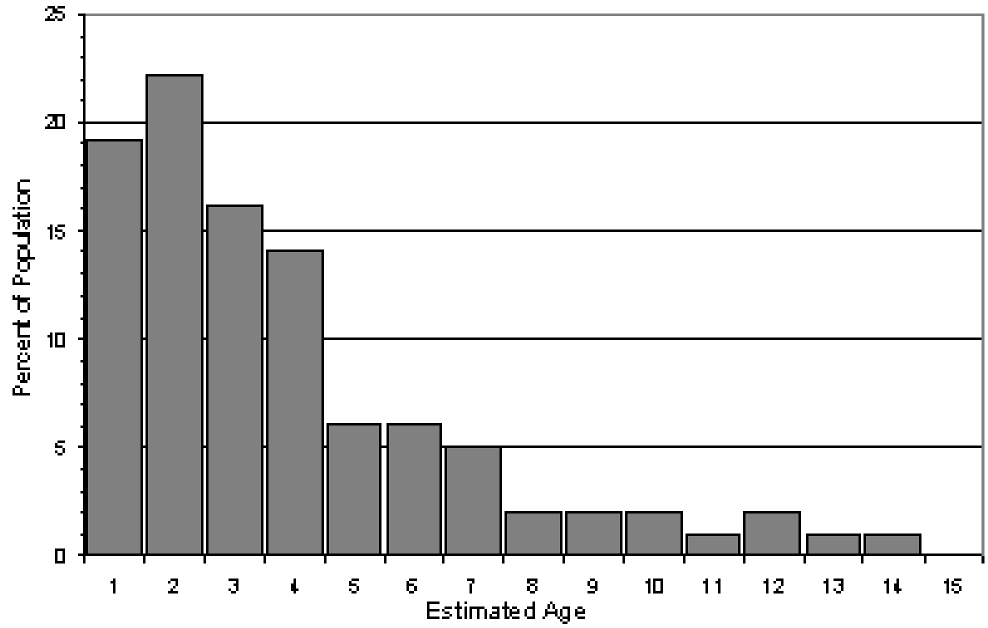
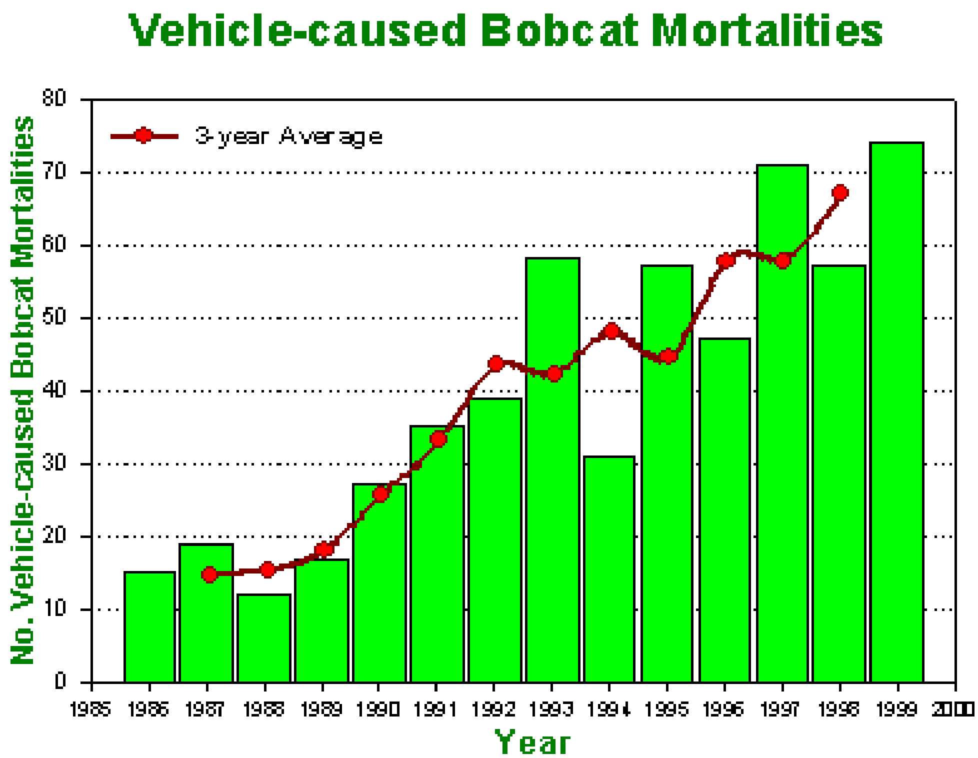


Fig. 3. Estimated age distribution of bobcats in Pennsylvania (1985-1995).

The current bobcat population model suggests that Pennsylvania's bobcat population is increasing at an annual rate of 4-6%. The population model assumes no compensatory (density-dependent) response to increased mortality due to harvest although the potential for a compensatory response exists. Also, the model considers harvest mortality to be 100% additive to other causes (e.g., vehicle-caused mortalities). We simulated effects of varying harvest levels on population growth and determined that a harvest of less than 240 bobcats would result in stable to increasing populations.

Initial estimates of population size were conservative; the PGC has substantial evidence (observations, vehicle-caused mortalities, and incidental captures) that bobcats currently occupy habitats beyond the geographic extent identified in these analyses. Additionally, we conducted preliminary winter track count surveys during February 2000 to collect additional distribution data. We conducted 4 independent surveys (16 km each) with areas of potential habitat in northcentral and northeastern PA. PGC staff detected bobcat tracks along every (100%) route surveyed and encountered 17 unique sets of bobcat tracks during the 4 surveys. The mean detection rate (# unique tracks/km) was 0.27 tracks/km surveyed. Bobcat detection rates for each of the 4 surveys were: 0.25, 0.13, 0.19, 0.50, respectively. The mean detection rates for coyote, fisher, and gray fox were 0.17, 0.08, and 0.03, respectively.

Vehicle-caused Bobcat Mortalities



We detected a steady increase in the number of reported vehicle-caused bobcat mortalities each year since this effort began in 1986. Annual reports of vehicle-caused bobcats have increased at a rate consistent with population model projections (Fig 4). A 3-year running average approach is presented to temper effects of WCO position vacancies.

Figure 4. Numbers of vehicle-caused bobcat mortalities reported by Wildlife Conservation Officers.

Bobcat Management Plan

A comprehensive bobcat management plan (draft form) was developed during January 2000. This plan was distributed to the public and sent for independent review among prominent scientists and furbearer managers throughout the country (Lovallo 2000). The plan was reviewed by The U.S. Fish and Wildlife Service, Office of Management Authority during March-October 2000. During mid-October the PGC received single-year export status from the U.S. Fish and Wildlife Service.

RECOMMENDATIONS

1) Future efforts to monitor population parameters (e.g., age structure data) and bobcat distribution using WCO surveys and bobcat mortality data should be continued under a different project plan.

2) These findings suggest that a highly regulated hunting and trapping season is feasible based on current bobcat population estimates and population modeling procedures. Details regarding harvest regulation are provided in the Bobcat Management Plan.

3) The bobcat management plan should be updated at 5-year intervals or as warranted by new research findings.

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LITERATURE CITED

Crowe, D. M. 1975. A model for exploited bobcat populations in Wyoming. The Journal of Wildlife Management. 39:408-415.

Lovallo, M. J. 1999. Multivariate models of bobcat habitat selection for Pennsylvania Landscapes. Ph.D. Thesis. The Pennsylvania State University, University Park. 145pp.

Lovallo, M. J. 2000. Status and Management of the Bobcat (Lynx rufus) in Pennsylvania. PGC Research Report. 52pp.