BOBCAT POPULATION RECONSTRUCTION, HABITAT, AND HARVEST MANAGEMENT

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THE OUTSIDE IS IN US ALL.

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EXECUTIVE SUMMARY

We backdated ages of 35,916 bobcats to estimate populations of bobcats in each of the 7 trapping districts (TDs) in Montana and statewide, for the years 2000-2016. These population estimates were minimum population estimates (MPEs) because they accounted for harvested animals only. We developed harvest scalars for each trapping district, based on harvester effort, to account for the effects of variable effort on harvest and population estimates. The estimates that resulted from scaling harvest were called Scaled Population Estimates (SPEs). We believe the MPEs and SPEs account for uncertainty in the effects of harvester effort on bobcat population estimates.

Adult population trends in western Montana for TDs 1-3 are similar to each other while adult population trends in eastern Montana, TDs 4-7 are also similar to each other. Adult population trends in the west appear to be quite different than the trends observed in the east. Adult populations in the eastern part of the state were well below average in 2014 and although predictions are for populations to increase after 2014, numbers will likely remain below average. Adult populations in the western part of the state were slightly below average in 2014 and predictions are for populations to increase after 2014, to numbers near or above average.

Statewide, adult populations peaked in 2007 and were ~ 45% below average using either MPE or SPE in 2014. Statewide, populations are predicted to increase following 2014, however numbers of adults will likely remain below average for several years.

We calculated lambda for adults ≥ 1.5 for all years in each TD and for the state. As expected, the trends for lambda in the western TDs were more similar to each other than they were to TDs in the east and vice versa. Lambda was especially low in all TDs in 2009 but improved in the western part of the state following 2009 while lambda in the eastern part of the state remained well below 1.0 for most years and in most eastern TDs for the period 2009-2014.

We regressed harvest in year *t* against total population growth rate in year *t+1* to determine levels of harvest that historically produced a stable, increasing or decreasing growth rate.

We estimated the number of square miles of bobcat habitat in each TD using two different methods. One estimate was made by drawing a 2-mile buffer around 33,350 known harvest sites, dissolving boundaries between buffers, and calculating the number of square miles of habitat. The second estimate of bobcat habitat was completed using a maximum entropy (max-ent) model, generated by FWP and the Montana Natural Heritage Program. TDs 7, 5, and 3, in that order, had the greatest area of bobcat habitat using the 2-mile buffer model while TDs 7, 4, and 3, in that order, had the greatest area of habitat using the max-ent model. The amount of habitat estimated using the max-ent model was much higher than when using the 2-mile model buffer in TDs 4, 6, and 7.

Once the amount of bobcat habitat and populations were estimated we calculated bobcat densities for each TD. No matter which combination of habitat models and population estimates were used TDs 1, 5, and 7 had the highest densities of bobcats at maximum populations. At high populations, bobcat densities in Montana are higher or comparable to densities reported in the literature for bobcat habitat at similar northern latitudes although our densities are calculated for much larger areas than most research projects.

We looked for metrics that could predict populations and population growth for each TD. The metrics selected needed to be available for each TD and collected prior to the time quota recommendations were due. We found that the best predictor of adult populations in year $t+1$ was the number of bobcats harvested per day in year t. We found that the best predictor of population growth of the adult population was the number of juveniles per adult captured in year t. In general, the relationships were better when using the MPEs instead of the SPEs, however the slopes of the trend lines using either population estimate were similar.

By using the population estimates, managers will be able to look at the long-term population trends, 2000-present, and to consider the predictions for population and population growth one year into the future.

We recommend that the department continue to collect teeth from bobcats for cementum aging but suggest that we could decrease the number of teeth used annually by up to 50% and still get valid population estimates. Additional management recommendations are made, and research needs suggested.

INTRODUCTION

Historical Management
Prior to 1977-78 there were no limits or regulations on the take of bobcats (*Lynx rufus*) in the state of Montana. The first regulated bobcat season was initiated in the winter of 1977-78 and ran from December 1-February 28. In 1977-78 harvesters could harvest 2 bobcats or 2 Lynx (*Lynx canadensis*) or one of each. This season type was in effect until 1980-81 when it was changed to 1 bobcat and 1 lynx per trapper and the season was shortened to February 15. To get information on reproductive potential trappers were required to present the entire bobcat carcass to a Montana Fish, Wildlife, and Parks (FWP) employee for inspection starting in 1980-81. The following year 1981-82, the export of bobcats was prohibited by a court injunction due to a lawsuit filed by Defenders of Wildlife. In that year, states were required by the United States Fish and Wildlife Service (FWS) to estimate a pre-harvest population of bobcats, develop an upper limit on the number of cats that could be harvested without determent to the survival of the species, and develop a method with the FWS for tagging cats for export.

Baseline 1983: Quota Oriented Management
Through a series of meetings and discussions among biologists, wardens, and trappers, populations were estimated for each of 7 trapping districts (TDs) in the state of Montana (Fig. 1). The estimate was derived by ranking bobcat habitat in each TD into three categories based on perceived suitability and bobcat occupancy. An index of relative bobcat density was applied to each of the habitat categories and the number of cats was estimated. The knowledge of biologists, wardens, and trappers, a literature review and harvest records were considered when developing the indices used for each habitat category. Bobcat habitat for the state was estimated at 109,795 square miles (mi^2) and total population was estimated at 8,154 bobcats.

Once the population estimate was made in 1982-83, harvest quotas were set for each of the TDs based on taking 20% of the estimated population. Because of the mandatory carcass turn-in, FWP was able to gather data on age structure of the population, reproductive success, and harvest mortality. Carcass data showed that 86% of the adult females produced an average of 2.2 kittens and 38% of the yearlings produced 0.3 kittens per year. Using the population estimates and this reproductive information, the number of cats that could be harvested from each TD was estimated and quotas were established. Along with the TD quotas, a statewide quota of 1,595 was established (19.5%). Each license holder could harvest 2 bobcats and the season closed in a TD within 48 hours of reaching the TD quota or the entire state closed if the statewide quota was reached. The season was also shortened and ran from Dec 1 to Jan 31. Between the 1982-83 and 1997-98 seasons TD quotas, individual bag limits, and season lengths remained relatively stable with small adjustments made annually to any one of those season components.

In 1997-98 every TD in the state had an individual harvester bag limit which varied from 7-10. When quotas for the 7 TDs were summed, a total of 1,490 bobcats could be

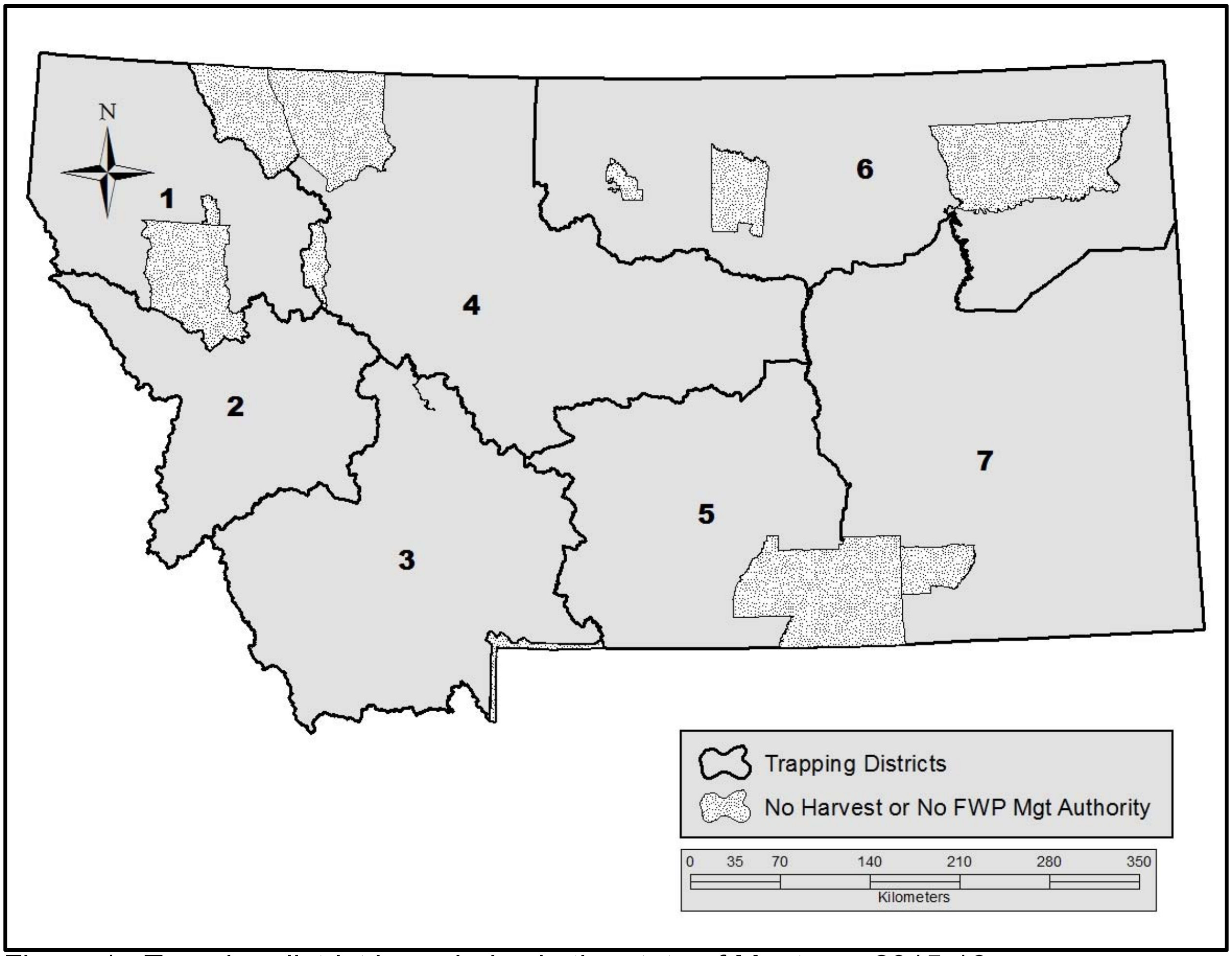


Figure 1. Trapping district boundaries in the state of Montana, 2015-16.

harvested. At that time, the longest season length in the state was 77 days and all TDs closed on February 15 even if the total quota had not been met.

In 1998-99, the season length in TDs 4-7 was extended to March 1, 91-92 days total, and the individual harvester bag limit on bobcats was eliminated in those 4 TDs. In March of 2000 the lynx season in Montana was closed and remains closed to this date. Individual bag limits in TDs 1-3 remain and are currently more restrictive in TD 1 and 3 than they were in 1997-98 (Table 1). In 2008-09, the sum of TD quotas reached a record high of 2,480 bobcats and a record number of bobcats (2,435) were harvested. Statewide, total harvest in 2008-09 was nearly double the total harvest in 1998-99. The 2016-17 season structure (Table 1), although not as liberal as in 2008-09, was slightly more liberal than season structures were 40 years ago. Even though harvest levels across the state increased dramatically between 1997-98 and 2008-09, there was no established statewide method for estimating bobcat population trends. Rather, TD biologists used historical information and a variety of harvest metrics to make inferences about population status and appropriate quotas.

Table 1. Trapping district quota, harvester quota and season dates for bobcats, 2016 trapping season.

Trapping District	Quota	Individual Limit	Season Dates
1[1]	275	4 from TD 1	Dec. 01 – Feb. 15
2[1]	200	7 from TD 2	Dec. 01 – Feb. 15
3[1]	250	5 from TD 3	Dec. 01 – Feb. 15
4	100	None	Dec. 01 – Mar. 01
5	200	None	Dec. 01 – Mar. 01
6	50	None	Dec. 01 – Mar. 01
7	600	None	Dec. 01 – Mar. 01
State	1675	NA	NA

[1]No more than 7 bobcats could be taken in combination from TDs 1-3.

Metrics Commonly Used to Index Populations and Adjust Quotas

In 2013 a working group made up of FWP biologists, statisticians, and the statewide furbearer coordinator began meeting to discuss the results of this bobcat data analysis and to develop a bobcat strategy document. Each participant put together a list of metrics that they considered important for informing FWP recommendations to the Fish and Wildlife Commission for changes in quota levels of bobcats in a TD. The list of metrics and the interpretation of the values generated by those metrics differed slightly from one biologist to another, however many of the metrics used were common among TDs.

Rate of Harvest and Effort. -- Biologists in every TD used some measure of rate of harvest and effort to help in the decision-making process for setting quotas although specific effort numbers did not cause a predictable response across TDs. Biologists interpreted increases in rate of harvest as evidence of an increasing population of cats and decreases in rate of harvest as evidence for declining populations. Biologists realized that rate of harvest could also be influenced by number of harvesters, quotas, weather conditions and pelt prices. The metrics most commonly used to measure rate of harvest and effort included number of bobcats harvested per day, number of bobcats harvested per day per harvester, number of successful harvesters, catch per unit effort and season length.

Productivity. -- A second category of metrics used by biologists to facilitate quota setting was some measure of productivity. This metric was usually number of juveniles per adult female ≥ 1.5 years old. However, some biologists also used other metrics of productivity as indices of population size or population trend. These included percent juveniles in the harvest, percent juveniles summed with percent yearlings in the harvest, or the number of juveniles per adult. In most cases biologists compared the current year’s data with long-term averages for those metrics and made recommendations to raise or lower quotas if the metrics measured were above or below average. Measures of productivity that were above average may have triggered a recommendation to increase the quota whereas measures of productivity that were below average may have triggered a recommendation to decrease the quota. One of the drawbacks of using such a system is that the average juvenile:adult ratio varies between TDs, which can lead to conflicting signals when data for quota changes are presented to the Commission by biologists from different TDs. For example a juvenile:adult ratio of 0.30 in TDs 4-7 might be considered average/high but would be considered below average in TD 1 and 2. In addition, higher pelt prices may result in fewer kittens being released, resulting in higher juvenile to adult ratios. The differences in productivity and other metrics observed across the state are likely the result of habitat quality differences, and as the group analyzed the data it became apparent that it was important to continue to use common metrics that were measured for each TD when attempting to predict population trend or bobcat numbers.

Percent Adult Females/Sex Ratio. -- A third metric evaluated by biologists for quota setting purposes was the percentage of adult females either 1) in the harvested adult population or 2) in the total number of animals harvested. Gilbert (1979) suggested that in lightly and moderately harvested populations there would be a majority of males. Lembeck and Gould (1979) noted that in an unharvested population of bobcats, the sex ratio was 2.1 males:female at high densities of animals and 0.86 males:female at low densities. Zezulak and Schwab (1979) observed a ratio of 7.0 males:female in the Mojave Desert. They theorized that males were selected for at high densities when competition for resources was elevated. The high number of males in the population would help to limit reproduction until competition was reduced. Biologists in Montana presumed that as the percentage of females in the harvest approached or exceeded a “defined” amount above the long-term average, then harvest might be taking too many breeding females, which would subsequently reduce productivity. It is possible that a long-term increasing trend in this metric might cause a measurable decrease in population as hypothesized by Montana biologists, that increased male:female ratios might indicate a higher density of animals (Zezulak and Schwab 1979), or that increased male:female ratios might cause a decrease in productivity. As with other metrics, lack of clarity on how to interpret male:female ratios again pointed FWP toward the need for metrics that are more directly linked to population trend so that interpretation is accurate and can be used consistently. McCord and Cardoza (1982) warned that sex ratio data might be suspect because of misidentification of sex, and more recent literature also suggests that misidentification of sexes by harvesters is a continuing problem (Hiller et al. 2014, Williams et al. 2011). During the 2009-2010 trapping season in Oregon, harvesters and biologists identified 46.8% of the harvested cats as females. In Oregon, if the percentage of females in the total harvest exceeds 45% more restrictive regulations may be recommended (Hiller et al. 2014). Hiller et al. (2014) showed that the actual percentage of females in the harvest in 2009-2010, based on genetic identification, was 42.1%, not 46.8, which would not have triggered a change to a more restrictive season type. Issues with sex misidentification also have implications for any other harvest metric that is tied to sex, for instance, juveniles per adult female ≥ 1.5 years old.

Percent Yearlings Harvested. -- Several biologists also used the percentage of yearlings in the annual harvest or percentage of yearlings in the adult harvest as an index of population growth. In using this index, biologists assumed that an increasing percentage of yearlings in the population indicated greater recruitment and therefore an increasing population. But, conversely, a high percentage of yearlings could be an indicator of decreased survival of adults older than1.5 or a heavy harvest rather than an indicator of higher recruitment (Lembeck and Gould 1979).

The Need for Reliability and Consistency

Given the difficulty of clearly and confidently interpreting the variety of harvest metrics in a consistent manner, it became apparent that FWP would benefit from an effort to determine which metrics were most directly linked to population trend and most capable of guiding decisions such as adjusting quota levels in response to population changes.

For populations of bobcats as well as other carnivores, obtaining field-based estimates of population size or even population trend remains a challenging task (Hochachka et al. 2000; Wilson and Delehay 2001; Conn et al. 2004). Nevertheless, population estimates and/or population trends would be very informative for management or harvest decisions, especially when setting quotas on an annual basis. Population modeling could be a valuable tool for synthesizing our knowledge of population demography, developing population trends, predicting outcomes of management decisions, and approximating population size.

Age data from harvested animals are often used to estimate population trends over time (Crowe 1975), and FWP has collected bobcat age data since 1994. Between the 1994-95 and 2014-15 seasons, bobcat harvesters were required to submit a skull to FWP so that a tooth could be removed for cementum aging (Crowe 1972). Skulls were collected by TD personnel and sent to the state wildlife research lab in Bozeman where a tooth was extracted, cleaned and sent to a private lab for cementum aging. Starting in 2015-16 harvesters were required to turn in a lower jaw which was sent directly to a private lab where a tooth was extracted for aging. In 2009 FWP began a more rigorous analysis of these bobcat age and sex data to develop more accurate indices of bobcat population sizes that would allow wildlife managers to set quotas that maximize harvest opportunity and maintain viable bobcat populations. Prior to this analysis, bobcat age data had primarily been used to classify individuals as adult or juvenile to be used in assessing the metrics noted above. Thus, the full dataset had not been exploited. In addition, little had been done with these data on a statewide basis or to compare TDs to each other.

Objectives

- Estimate bobcat population numbers and trend in each TD using population reconstruction from tooth age data.
- Estimate annual population growth rates (lambda) in each TD from the age structure data.
- Estimate the amount and distribution of bobcat habitat in each TD.
- Estimate bobcat density in each TD.
- Determine which, if any, commonly used bobcat harvest metrics accurately reflect population trend to the degree that they can be confidently used to set future quotas.

- Estimate average capacity for harvest of bobcats in each TD and determine if the high harvests observed in 2009 are sustainable.
- Evaluate if FWP should keep collecting bobcat teeth/ages, and if so, whether FWP could maintain data quality with a sub-sample of the number of teeth we are currently collecting.
- Develop an Excel based tool that reconstructs and estimates bobcat populations.
- Determine if FWP should pursue a field study on bobcats to verify the population models developed.

METHODS

Amount, Distribution, and Relative Quality of Habitat

Buffering Harvest Locations

We used two estimates for determining amounts of bobcat habitat in each TD and the state. The first estimate was derived by placing a 2-mile buffer around harvest locations for the period 1978-2013. A 2-mile buffer results in 12.6 mi^2 polygon, which in northern latitudes was within the range of estimates of home range sizes for females (Knowles 1985 - 6.9 mi^2; Brainerd 1985 - 22.6 mi^2; Apps 1996 - 21.5 mi^2; Newbury 2013 - 16.4 mi^2). Since harvest locations are usually reported in a Township, Range and Section (TRS) format, we used the latitude and longitude for the center of that section as the location of each harvest site. To reduce the probability that harvest locations were recording or reporting errors, we did not use harvest locations that resulted in single circular polygon with only one location at its center. This resulted in using approximately 33,350 harvest site locations gathered between 1978 and 2013 to determine suitable habitat with the 2-mile buffer model. Once locations were buffered and boundaries were dissolved, we determined the amount of habitat per TD by clipping polygons on TD boundaries. We did not include reservations and national parks in any of the habitat calculations. We also did not reduce the amount of habitat by eliminating areas within polygons such as water and urban areas that might not be considered bobcat habitat. Assumptions made when using the 2-mile buffer model are: 1) harvest locations are accurately reported, 2) the amount of bobcat habitat has not changed over time, 3) home range sizes are similar for all age/sex classes, 4) home range sizes do not vary by the quality of habitat, and 5) home range sizes do not vary over time.

Maximum Entropy

FWP and the Montana Natural Heritage Program (MNHP) generated a second estimate of the area and distribution of bobcat habitat with a maximum entropy (max-ent) model. The bobcat max-ent model was an early evaluation for the Crucial Areas Planning System (CAPS). The max-ent approach for species habitat modeling takes as input a set of layers or environmental variables (Table 2), as well as a set of occurrence locations, and then, predicts the probability of an animal location occurring in every 90x90 meter pixel across Montana. Because habitats used in the western and eastern parts of the state varied so much two models were built, one for the western and one for the eastern part of the state. If the probability of occupancy for a pixel was under 7% in the western model or under 11% in the eastern model that pixel was not likely to have bobcat use, based upon the model thresholds used by MNHP and FWP during initial model development. Therefore, those pixels were not summed as potential bobcat habitat. In general, the western model was best for TDs 1-3 and the eastern model was best for TDs 4-7. When a boundary for a TD passed through a 90x90 meter pixel that pixel area was summed in both TDs resulting in an over-estimation of bobcat habitat in the state by approximately 2,000 mi^2, which was <2% (Adam Messer, FWP, pers. communication). Assumptions made when using the max-ent model are: 1) The amount of bobcat habitat has not changed over time, 2) harvest locations are accurately reported, 3) the environmental variables found in the center of sections are the same as the environmental variables found at the actual harvest location, 4) habitat quality in pixels with a ≥ 7% (western MT) or 11% (eastern MT) probability of having a bobcat was the same, and 5) the environmental variables measured affect habitat selection by bobcats.

Table 2. Environmental variables used in max-ent models.

Variable	Type	Description
Aspect	Categorical	Dominant degrees of aspect grouped into 9 categories.
Eco-region	Categorical	Olnernik ecoregion grid.
Elevation	Continuous	Elevation in meters from the National Elevation Dataset.
Geology	Categorical	931 categories of surficial geology.
Land Cover	Categorical	1992 National Land Cover Data – 21 classes.
Max. Temp.	Continuous	Estimated average maximum daily July temperature in degrees Fahrenheit for 1971-2000.
Min. Temp	Continuous	Estimated average minimum daily January temperature in degrees Fahrenheit for 1971-2000.
Precipitation	Continuous	Relative Effective Annual Precipitation in 1 cm intervals as an indicator of available soil moisture.
Ruggedness	Continuous	Vector ruggedness measure of local terrain.
Slope	Continuous	Degrees of slope
Soils	Categorical	694 soil mapping units from the state soil geographic data on general soil associations developed by the National Cooperative Soil Survey.
Soil Temp.	Categorical	Soil temperature and moisture regime – 12 categories.
Solar E	Continuous	Solar radiation index (SRI) at each tenth degree of latitude at the equinox.
Solar SS	Continuous	SRI at each tenth degree of latitude at the summer solstice.
Solar WS	Continuous	(SRI at each tenth degree of latitude at the winter solstice.
Stream ED	Continuous	Euclidian distance from major streams in 1-meter intervals.

Population Reconstruction for Population Estimates, Trends in Adult Population and Growth Rates, Densities, and Capacities for Harvest

Minimum Known Population Size (MPE)

We reconstructed bobcat population numbers, age distributions, and population trend from cementum aging of bobcat teeth using the Virtual Population Analysis (VPA) method (Fry 1949, 1957). The primary step for this method is determining the birth year of each harvested bobcat, which allows back-calculation to year-specific, age-specific abundance levels. Summing all bobcats known to have been alive in each year provides a known minimum population size. Data from all years provides an estimate of population trend. Since the VPA method does not account for losses to the population from sources other than harvest, the resulting population estimates can only be described as a minimum population estimate (MPE). An excellent review of the many methods available for population reconstruction can be found in (Skalski et al. 2005).

Scaled Population Size - Calibrating Harvest Based on Effort (SPE)
For MPEs to provide an index proportional to underlying true populations, the number of animals harvested each year should reflect the number of animals available for harvest in that year. This requires that harvest effort remains relatively constant. However, the number of trappers and hunters can change substantially due to factors including pelt prices, weather, and harvest regulations. One concern with the VPA method, therefore, is that if effort changes over time, and if the number of harvested animals varies with changes in effort, MPEs could represent changes in effort rather than changes in population.

Biologists in the 7 TDs managed bobcat harvest and users differently (Fig. 2). In TDs 1-3 there was a total bobcat quota set annually, an individual harvester bag limit, and a season end date of February 15. TDs 4-7 also had a total bobcat quota set annually, however they had no individual harvester bag limit, and the bobcat season closed on March 1. Because these regulation differences probably affected effort we developed and applied harvest scalars to each TD separately.

FWP has been collecting effort data for bobcat hunters and trappers since 1992 in a mail-out harvest survey (HSV) that includes questions such as: 1) Did you trap, snare, hunt, or use hounds, 2) Number of traps/snares set, 3) Number of days set, 4) Number of days hunted without hounds, and 5) Number of days hunted with hounds. We used these data to examine the relationship between the number of users and harvest for each TD and the state. Even though there were differences in how bobcats and bobcat harvesters were managed in each TD, the number of users does affect harvest. As indicated by the slope of the regressions (Fig. 3), when harvester numbers increased, take increased; conversely as harvester numbers decreased, take decreased.

We used data from each TD collected during the HSV to develop 7 TD-specific linear regressions that predict expected harvest from observed effort. To rescale the observed harvests to the maximum effort value, we then divided by the ratio of expected harvest in year *t* to the maximum expected harvest in the year with the greatest effort using the formula:

Scaled harvest Yt = observed harvest Yt / (expected harvest Yt/max expected harvest Y1 – n).

The TD-specific scalars were multiplied by harvest in each year to estimate a harvest had there been participation like the year with the greatest participation. The scaled harvests were then assigned to age classes based upon the proportion of animals in

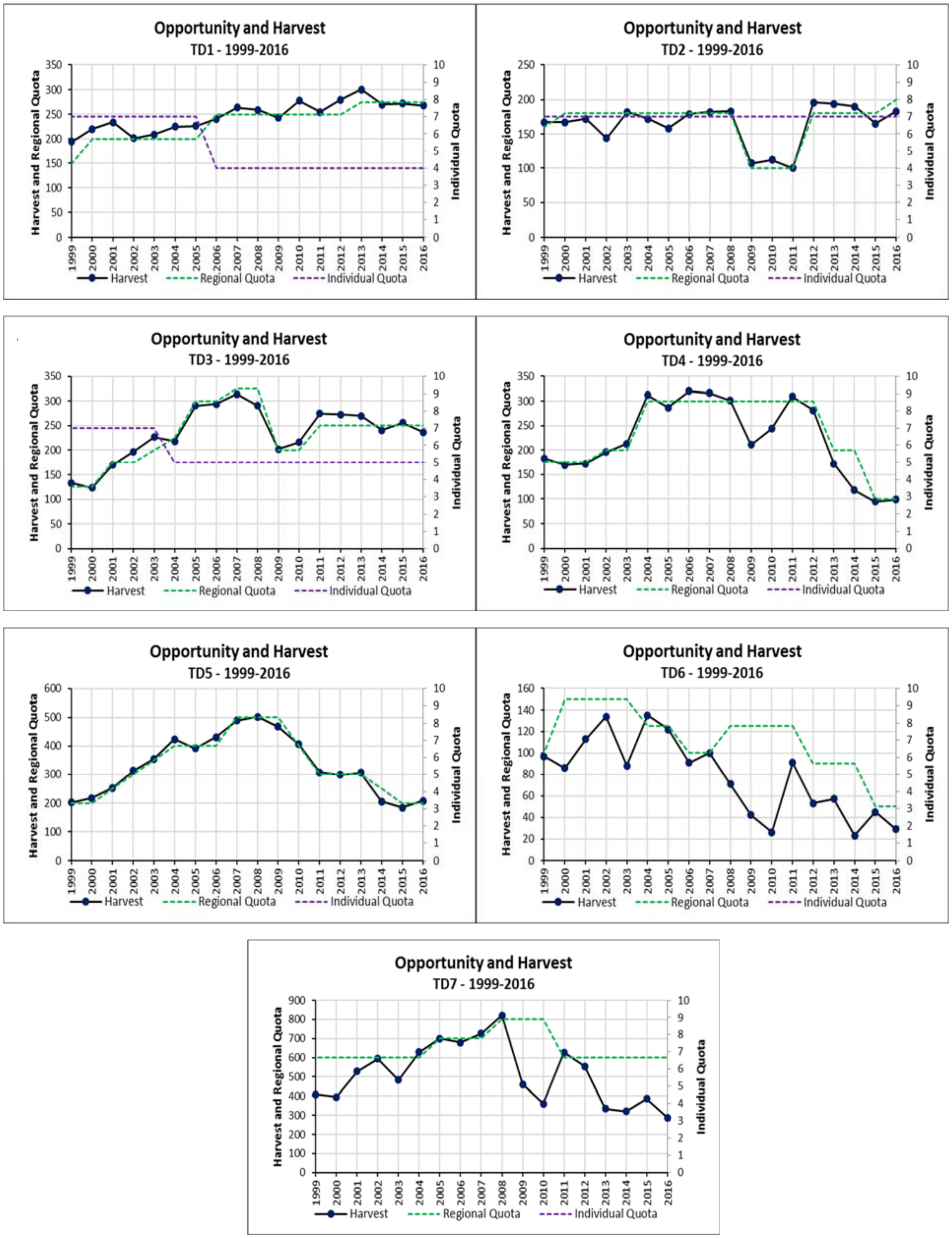


Figure 2. Trapping district quota, individual quota and harvest by trapping district, 1999-2016.

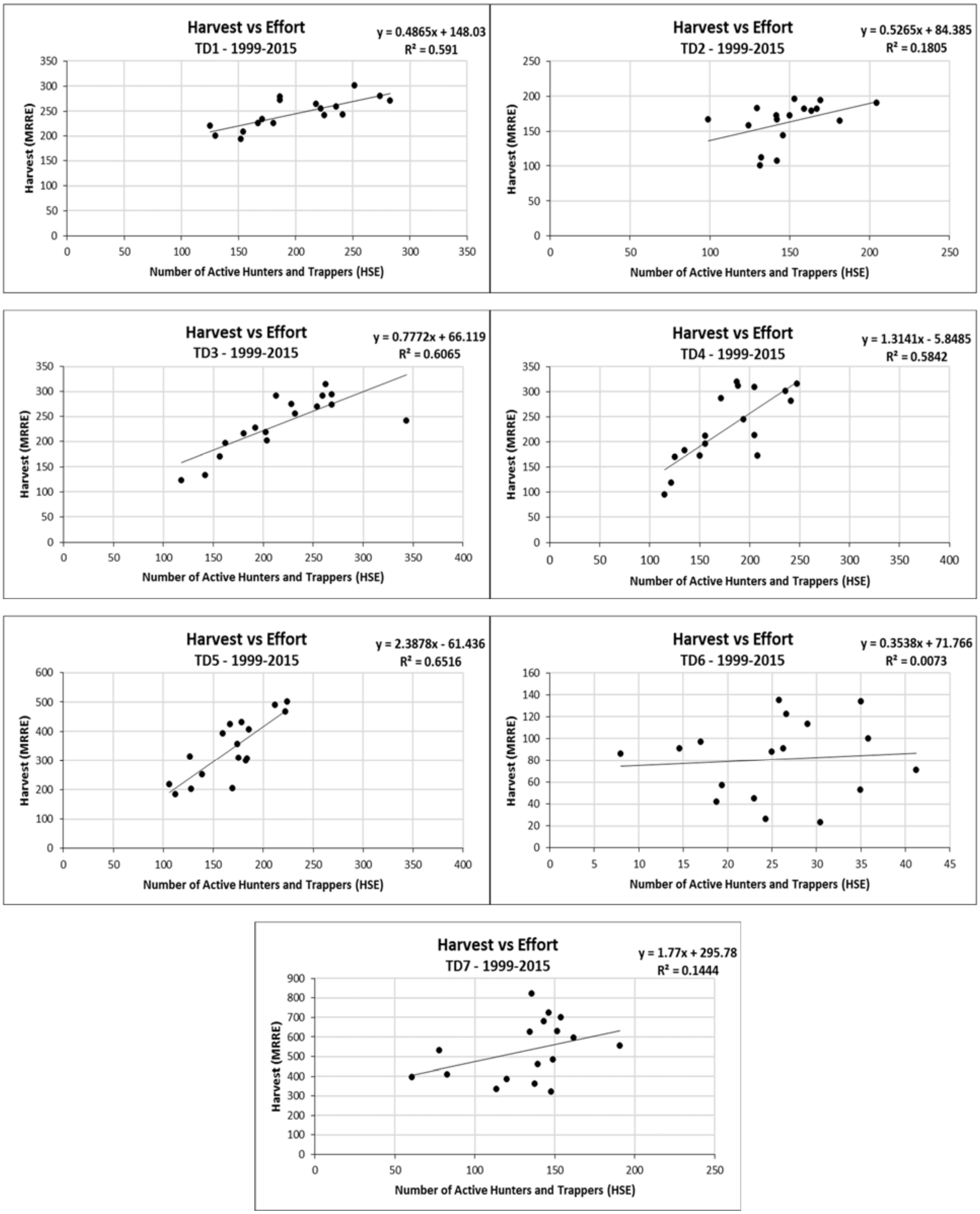


Figure 3. Estimated regression relationship between the number of users and harvest in each trapping district (TD), 1999-2015. The estimated regression equation in the upper right of each panel was subsequently used to scale harvest estimates to calculate the scaled population estimate for each TD.

each age class in the harvested population and the new cohorts were backdated to their birth year. We then estimated annual abundance, in the same way it was estimated without the scalar by summing across age classes. We refer to this population estimate as the scaled population estimate (SPE). The scalars varied by TD and year ranging from 1 (year with highest participation) to 2.5 (year with lowest participation).

Period of Data Analyzed
Statewide, effort for the period 1994-1998 was much lower ($\bar{x}$=645 users) than effort for the period 2011-2015 ($\bar{x}$=1042 users) (Fig. 4). Low effort caused SPEs for the period 1994-1999 to be much higher than estimates made by backdating only (MPEs). Although we have data available to estimate populations back to 1994 we have chosen to limit our backdated population estimates to the time-period 2000-present for the following reasons: 1) data used to forecast populations and lambda were available for all TDs from 1999 on, while only available for some of the TDs prior to 1999, 2) from a regulation setting standpoint it is less important what happened prior to 2000 than what has happened since 2000, 3) prices of bobcat furs prior to 2000 were low and it was likely that low participation rates were in part, a result of low prices, 4) low harvest rates, prior to 2000, may have been affected by restrictive regulations, and 5) number of participants has stabilized at a higher level since 2003 (Fig. 4).

Including Harvested Bobcats of Unknown Age
For the period 1994-2010 an average of 5% of the bobcats were not aged annually. Because these animals represented individuals known to be alive and part of a minimum known population size, we included them as follows. To complete the population reconstruction for each TD we placed unknown aged animals into age classes. To do that, we assumed that unknown aged animals had an age structure proportional to the known-aged animals in that year. We assigned each unknown aged animal, proportionally, into each age class using the observed age structure of known-age harvests, resulting in harvests that were in decimals (Table 3a). In 2011, TD 1 did not submit most of their bobcat skulls for aging so nearly 20% of the bobcats were not aged in that year.

Maximum Age
The oldest bobcat in our sample was 19.5 years old, however since 99.9% of all bobcats aged were ≤15.5 years old at the time of harvest the age class at harvest matrix was truncated at 15.5 and bobcats older than 15.5 were assigned to the 15.5-year age class.

Estimating Incomplete Cohort Data and Populations
The VPA method of population reconstruction estimates incomplete cohort data to abundance estimates by using available information on exploitation rates. We calculated a harvest rate for each age class by dividing the number of animals harvested in that age class by the numbers of animals in that age class for completed cohorts only (Table 3b). Once a harvest rate for each age class was determined, we estimated the total number of animals in that age-class by dividing the number of animals harvested in the last year that had age data by the harvest rate. Although

population estimates for years prior to 2000 were excluded from this document, all age data 1994 to 2016 were used to estimate harvest rates by age class. In the example depicted in Table 3, complete cohorts for each age class are highlighted in red. Each year that additional age data becomes available allows for additional years to be used in calculating an exploitation rate for each age class.

After assigning all harvested bobcats to an age class and estimating incomplete cohort data, animals were backdated to their birth year and a population estimate was calculated for each TD and the state by summing across age classes in each year. On average, most bobcats were harvested by the time they reached the age of 3.5 (73%) and 4.5 (81%) years old. This means that the most completely informed MPEs and SPEs are ≥ 3-4 years prior to the last year age data are available. It also means that population estimates for the most current 3-4-year period could change the most as future age data are collected.

Table 3. Matrix of age-at-harvest data (a) and the corresponding matrix of age and year-specific abundance levels and population estimate (b). Sum of numbers outlined with a dark border in (a) equals number of kittens alive in 2000 outlined with a dark border in (b).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	a.	Number of Bobcats harvested by age-class, 1994-2015																Total
	Year	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	Harvest
1	1994	372.6	160.7	382.9	285.4	215.4	73.5	56.4	44.4	25.6	5.1	10.3	17.1	1.7	0.0	0.0	0.0	1651
2	1995	206.1	260.1	194.7	181.6	150.5	75.3	50.7	27.8	8.2	4.9	6.5	6.5	1.6	1.6	3.3	3.3	1183
3	1996	396.2	217.2	236.3	118.9	154.1	123.3	96.9	41.1	38.2	19.1	14.7	0.0	4.4	2.9	2.9	4.4	1470
4	1997	194.8	298.2	259.8	200.1	99.4	94.1	121.9	67.6	43.7	19.9	23.9	9.3	2.7	2.7	2.7	1.3	1442
5	1998	438.4	203.5	264.9	158.6	175.1	70.3	82.3	85.3	43.4	28.4	13.5	16.5	6.0	3.0	3.0	3.0	1595
6	1999	473.2	463.7	159.1	187.6	127.8	127.8	78.9	84.3	54.4	70.7	21.8	13.6	12.2	1.4	4.1	4.1	1885
7	2000	549.7	442.8	388.6	128.5	145.5	77.4	86.7	48.0	54.2	35.6	38.7	24.8	10.8	3.1	3.1	3.1	2041
8	2001	449.1	535.6	421.1	216.3	86.5	92.9	57.3	77.6	36.9	24.2	31.8	24.2	2.5	8.9	3.8	0.0	2069
9	2002	435.7	331.6	496.8	382.4	213.3	66.3	71.5	50.7	59.8	57.2	36.4	35.1	19.5	5.2	5.2	3.9	2271
10	2003	585.4	331.4	348.1	268.3	206.3	109.7	48.9	45.3	35.8	29.8	22.7	22.7	17.9	7.2	6.0	0.0	2085
11	2004	514.2	805.6	361.3	234.8	161.4	132.5	89.1	36.1	28.9	19.3	31.3	8.4	15.7	15.7	3.6	8.4	2466
12	2005	590.2	745.8	482.5	232.2	148.4	103.0	85.0	68.2	35.9	12.0	16.8	13.2	13.2	8.4	4.8	8.4	2568
13	2006	600.8	698.1	437.4	256.2	117.5	77.2	64.9	52.6	39.2	13.4	17.9	6.7	12.3	6.7	4.5	4.5	2410
14	2007	556.7	811.5	487.1	240.9	131.7	76.0	60.0	36.4	41.8	18.2	15.0	13.9	5.4	4.3	3.2	5.4	2507
15	2008	406.1	479.5	893.5	304.6	163.6	85.7	77.8	53.0	36.1	24.8	11.3	9.0	5.6	5.6	3.4	3.4	2563
16	2009	264.7	433.8	457.1	291.5	160.9	112.0	57.1	38.5	28.0	37.3	23.3	5.8	4.7	7.0	5.8	4.7	1932
17	2010	345.6	251.2	386.1	301.5	248.8	143.4	66.2	45.3	39.2	25.7	19.6	20.8	13.5	7.4	3.7	7.4	1925
18	2011	431.1	268.0	290.5	315.7	299.8	233.5	161.8	86.2	42.4	30.5	34.5	11.9	10.6	5.3	1.3	2.7	2226
19	2012	467.7	429.1	276.9	150.0	131.3	136.8	129.1	84.9	55.2	36.4	24.3	7.7	12.1	6.6	4.4	4.4	1957
	2013	353.3	414.5	304.6	148.4	129.1	83.8	84.9	95.1	78.1	55.5	21.5	7.9	11.3	1.1	2.3	4.5	1796
	2014	374.4	291.6	208.9	145.3	95.4	76.4	42.4	58.3	33.9	36.1	22.3	9.5	9.5	5.3	2.1	0.0	1412
	2015	2229.9	2220.5	686.8	407.4	189.4	244.1	217.5	86.8	180.4	99.5	59.9	25.9	9.1	12.1	2.6	0.0	
	Yellow=Complete cohorts																	
		Total number of bobcats known to be alive by backdating harvested animals.																
	b.	**0.5**	**1.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**	**MPE**
21	1994	1695.1	922.5	1150.6	966.2	670.7	306.1	194.3	135.1	64.9	24.5	30.9	27.3	7.6	7.7	3.3	0.0	Not Used
22	1995	1257.6	1322.5	761.8	767.7	680.7	455.3	232.6	137.9	90.6	39.3	19.4	20.7	10.2	5.9	7.7	3.3	Not Used
23	1996	1593.8	1051.5	1062.3	567.1	586.1	530.2	380.1	181.9	110.0	82.4	34.4	12.8	14.1	8.6	4.3	4.4	Not Used
24	1997	1014.9	1197.6	834.3	826.1	448.3	432.0	406.9	283.2	140.8	71.9	63.4	19.7	12.8	9.7	5.6	1.3	Not Used
25	1998	2089.5	820.1	899.4	574.5	625.9	348.9	337.9	285.0	215.6	97.1	52.0	39.5	10.4	10.2	7.1	3.0	Not Used
26	1999	2326.0	1651.1	616.6	634.5	415.9	450.9	278.5	255.6	199.7	172.2	68.7	38.5	23.1	4.5	7.2	4.1	Not Used
27	2000	2336.3	1852.8	1187.4	457.5	446.9	288.1	323.1	199.7	171.3	145.3	101.5	46.9	24.9	10.8	3.1	3.1	7598.8
28	2001	1817.5	1786.6	1410.0	798.8	329.0	301.4	210.7	236.4	151.7	117.1	109.7	62.8	22.1	14.1	7.7	0.0	7375.5
29	2002	1794.0	1368.4	1251.0	988.9	582.5	242.4	208.5	153.4	158.7	114.8	92.9	77.9	38.7	19.6	5.2	3.9	7100.9
30	2003	2568.6	1358.4	1036.7	754.2	606.5	369.2	176.1	137.0	102.7	98.9	57.6	56.5	42.8	19.1	14.4	0.0	7398.7
31	2004	2525.1	1983.2	1026.9	688.6	486.0	400.3	259.5	127.2	91.7	66.9	69.1	34.9	33.9	24.9	12.0	8.4	7838.5
32	2005	2805.2	2010.9	1177.6	665.6	453.8	324.6	267.8	170.4	91.1	62.8	47.7	37.8	26.5	18.2	9.3	8.4	8177.5
33	2006	3437.2	2215.0	1265.0	695.1	433.4	305.3	221.6	182.8	102.2	55.2	50.8	30.9	24.6	13.3	9.8	4.5	9046.8
34	2007	2555.0	2836.4	1516.9	827.6	438.9	315.9	228.1	156.8	130.2	63.0	41.8	32.9	24.2	12.3	6.6	5.4	9192.0
35	2008	1886.0	1998.3	2024.9	1029.8	586.7	307.2	239.9	168.2	120.4	88.5	44.8	26.8	19.0	18.8	8.0	3.4	8570.7
36	2009	1379.5	1479.9	1518.8	1131.4	725.2	423.1	221.5	162.1	115.1	84.3	63.7	33.6	17.8	13.3	13.2	4.7	7387.0
37	2010	1378.3	1114.8	1046.1	1061.7	839.8	564.2	311.2	164.3	123.6	87.2	46.9	40.3	27.7	13.1	6.3	7.4	6833.0
38	2011	1499.6	1032.7	863.5	660.0	760.2	591.1	420.8	245.0	119.0	84.4	61.4	27.3	19.5	14.2	5.7	2.7	6407.1
39	2012	1498.6	1068.5	764.8	573.0	344.3	460.4	357.6	259.0	158.8	76.6	53.9	26.9	15.4	8.9	8.9	4.4	5679.9
	2013	1331.8	1030.8	639.3	487.9	423.0	213.0	323.6	228.5	174.1	103.6	40.1	29.6	19.2	3.3	2.3	4.5	Not Used
	2014	2594.8	978.5	616.3	334.7	339.5	293.9	129.2	238.7	133.4	95.9	48.1	18.6	21.7	7.9	2.1	0.0	Not Used
	2015	2229.9	2220.5	686.8	407.4	189.4	244.1	217.5	86.8	180.4	99.5	59.9	25.9	9.1	12.1	2.6	0.0	Not Used
40	**Harvest Rate**	**0.214**	**0.243**	**0.306**	**0.290**	**0.295**	**0.258**	**0.283**	**0.290**	**0.300**	**0.303**	**0.357**	**0.389**	**0.415**	**0.415**	**0.488**	**1.000**	
41	**Harvest Rate=Sum of Age Classes Highlighted in Yellow/Sum of Age Classes Highlighted in Red**																	

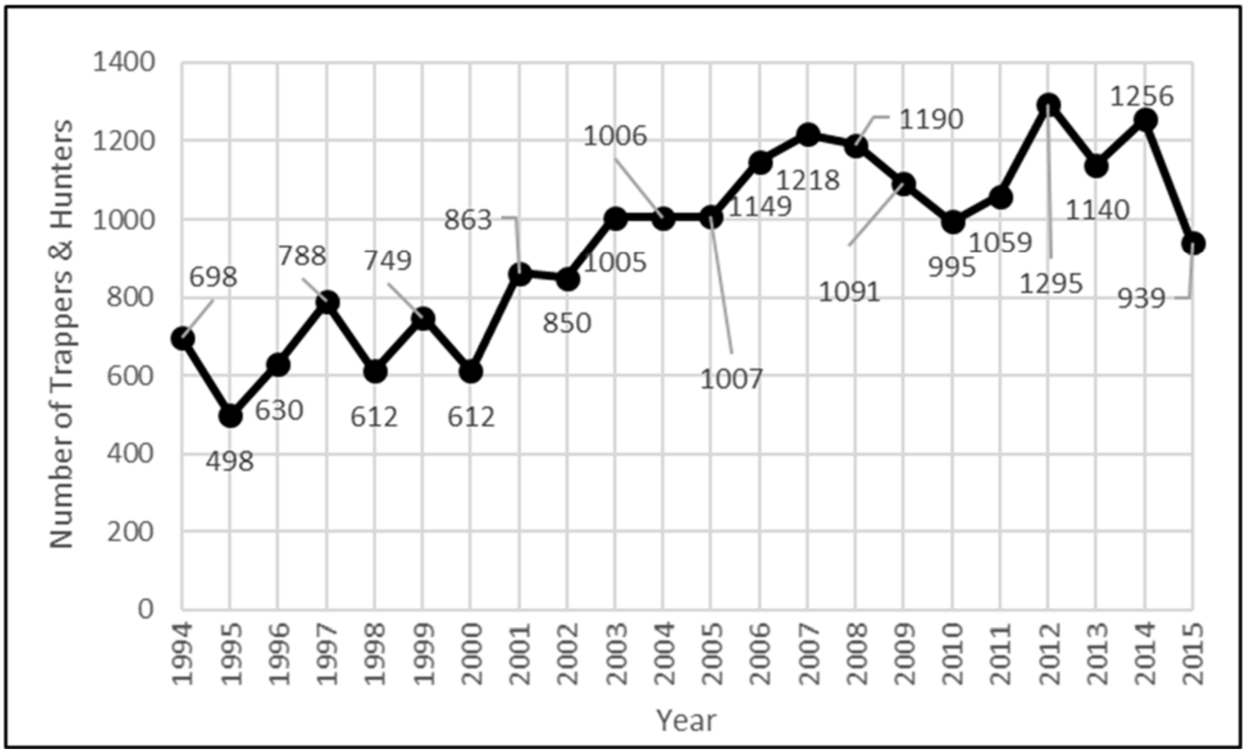


Figure 4. Number of trappers and hunters pursuing bobcats 1994-2015.

Adult Population Growth Rate (Lambda)
We determined adult MPE lambda by dividing the adult MPE population estimate for a year by the adult estimate for the previous year. For instance, an MPE adult estimate of 1000 for 2004 and an estimate of 1200 for 2005 would yield a growth rate of 1.2, or a 20% increase. We determined lambda for SPEs in the same way.

Assumptions of the VPA Method
Assumptions of the VPA method are: 1) age classification is accurate, 2) harvest numbers are reported accurately, 3) harvest mortality is the primary source of mortality, 4) natural mortality is low and constant over time, 5) harvest mortality is constant, allowing extrapolation from annual MPEs which have incomplete cohorts and 6) effort does not change over time. Assumptions 1, 2, 5 and 6 must be met whether one views the resulting population reconstruction as a total population estimate or a MPE. In addition, all assumptions must be met to state that the population reconstruction is an actual population estimate. Assumptions of the scalar are: 1) estimates of harvester numbers are accurate, 2) harvest is related to the number of users, and 3) the proportion of bobcats in each age class wouldn't change with increased harvest.

Determining Harvest Metrics that Best Predict Population and Growth Rate

Total populations varied greatly on an annual basis with much of that variation due to the number of kittens produced. In fact, statewide, 1994-2013, the numbers of kittens estimated via reconstruction in year *t* varied by as much as 34% below to 104% above the number of kittens in year *t+1* (range = 138%). The number of adults in year *t* varied far less, from 13% below to 18% above the number of adults in year *t+1* (range = 28%); and in all but 1 year, the change in adult numbers between year *t* and *t+1* was ≤ 15%. Because of the large variation in population estimates when kittens were included and because none of the metrics we were measuring in year *t* would predict productivity in year *t+1* we looked for metrics that predicted populations and lambda of adults in year *t+1* rather than metrics that would predict total populations with kittens. For management purposes, we were also interested in metrics that could be collected in year *t*, that would help predict adult populations in year *t+1* prior to the time quota change recommendations must be made.

To find metrics that best predicted adult populations and lambda of adults one year into the future we regressed indices, commonly used by biologists to set quotas, against adult population estimates. We believed that if lambda and populations for adults in year *t+1* could be predicted using metrics available in year t, our ability to set quota levels commensurate with population and population trend would be much improved. Data used for this analysis were available in all TDs from 1999 on, so the earliest year used for these comparisons was 1999. In addition, because we know that population and lambda estimates will change as age information is collected in the future and we know that 81.9 % of bobcats harvested are 4.5 years old or younger we only used data through 2011 for our predictions. Therefore, for the years 2012-2016, the last year with age data, there were two population estimates made, one using the VPA method and one using the harvest metric that best predicted population.

Estimating Average Capacity for Harvest with Lambda

For each TD, we regressed harvest in year *t* against total population growth (kittens and adults) in year *t+1* to determine the level of harvest where lambda = 1.0 (a stable population). We assumed this to be an indication of average capacity for harvest, and that lambda >1.0 indicated growth or <1.0 indicated decline. In this case, we regressed harvest in year t against lambda of the total population instead of lambda of adults in *t+1* because we wanted to test the effect of total harvest on total population. As with the other metrics we only used data collected between 1999 and 2011 to predict the average capacity for harvest from 2000-2012.

Sub-Sampling Ages

To examine the effect of reducing annual FWP expenditures for aging harvested bobcats, we randomly selected 50% of the ages in each year in each TD and ran them through the VPA model to calculate MPEs from the reduced sample size. We then assigned the animals that were not randomly selected and the unknown aged animals into age classes by assuming that animals without ages, proportionally, had the same age structure as randomly selected aged animals in that year. Since we selected 50% of the animals with known ages and there were already animals in the sample without ages, less than 50% of the total number of animals in the subsample had ages. We then compared the MPEs generated using the entire sample of ages against the MPEs generated using 50% of the ages.

RESULTS

Amount, Distribution and Relative Quality of Habitat

Amount and Distribution of Habitat

Total amount of bobcat habitat was greatest in TDs 7, 5, 4, and 3 (Fig. 5). When compared to the 2-mile buffer estimates, the best max-ent estimates for bobcat habitat in all TDs were 28.6% (TD 5) to 174.9 % (TD 6) greater. The amount of habitat estimated by the max-ent model was much greater than the amount of habitat estimated by the 2-mile buffer in TDs 4, 6, and 7, all found in eastern Montana (Figs. 6-7). There

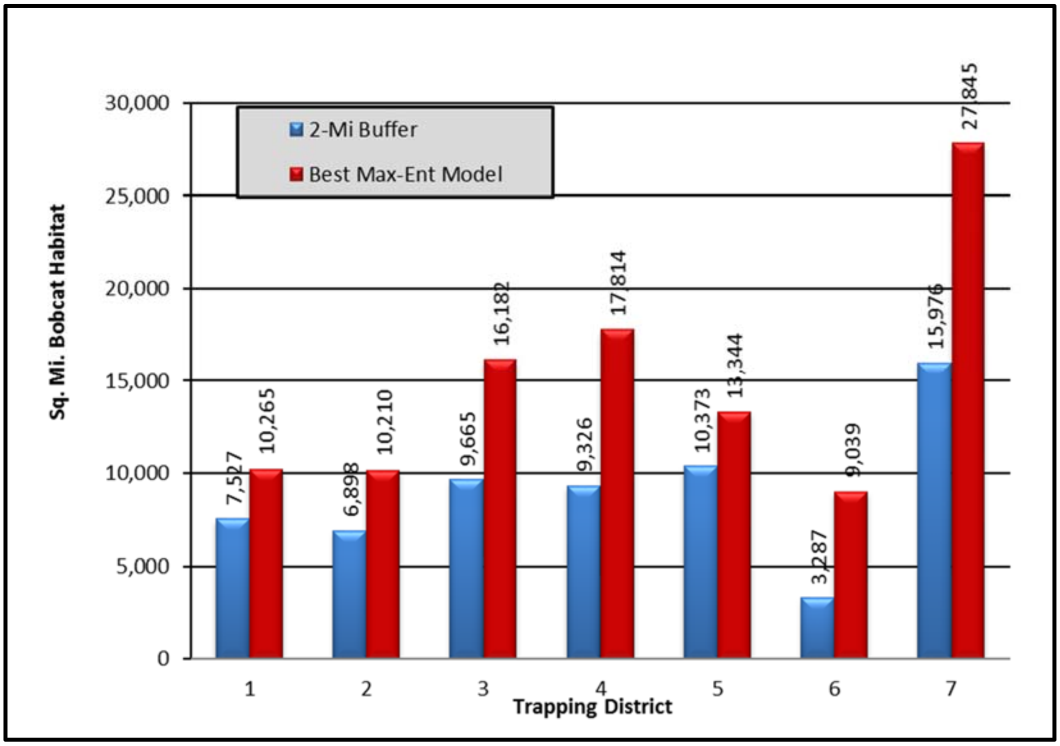


Figure 5. Estimated mi^2 of bobcat habitat, excluding national parks and reservations, using a 2-mile buffer calculated from harvest locations from 1978-2013 and the max-ent model most appropriate for each TD.

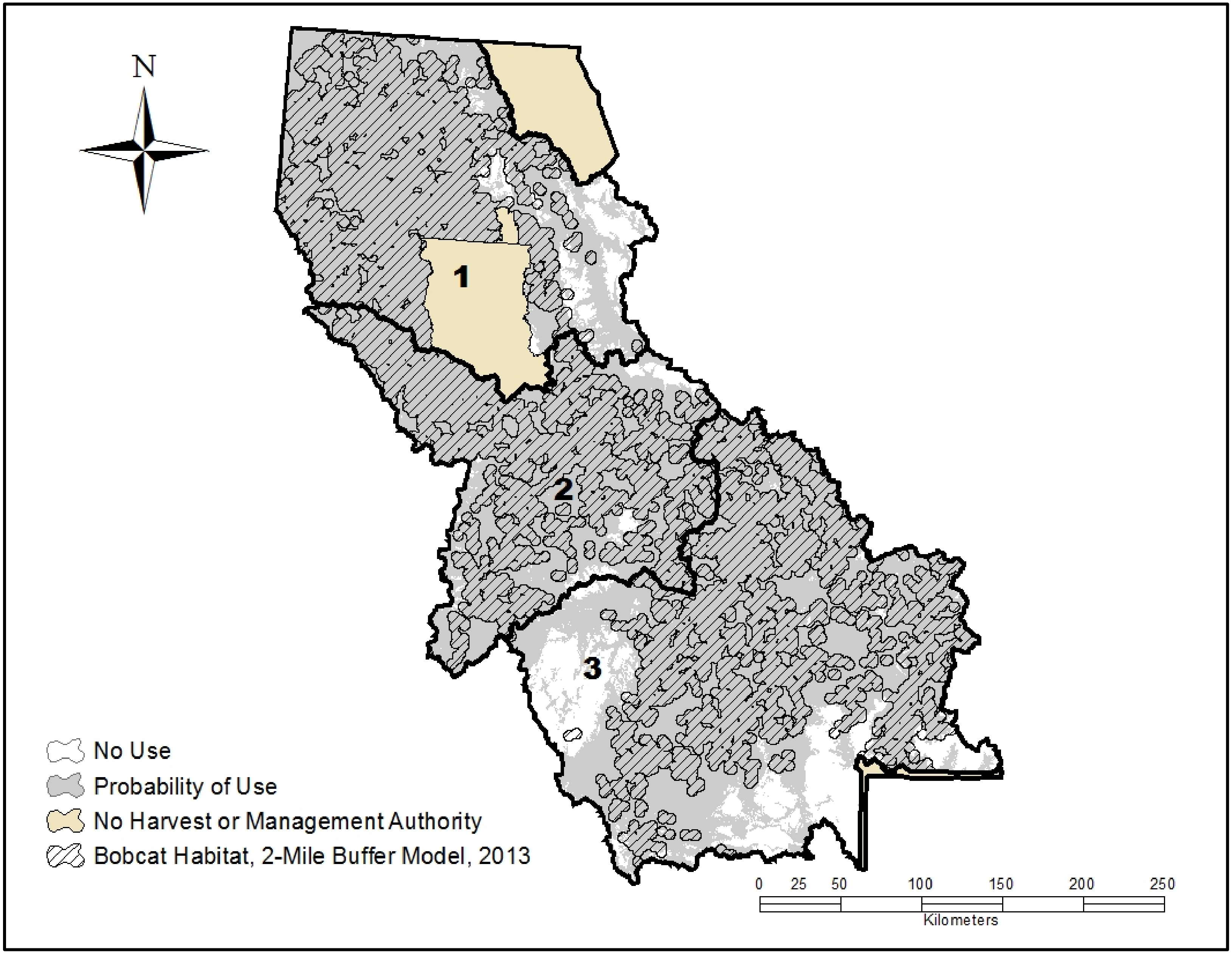


Figure 6. Map of TDs 1-3 showing habitat using the 2-mile buffer and the max-ent model. Habitat not shaded gray has no bobcat use.

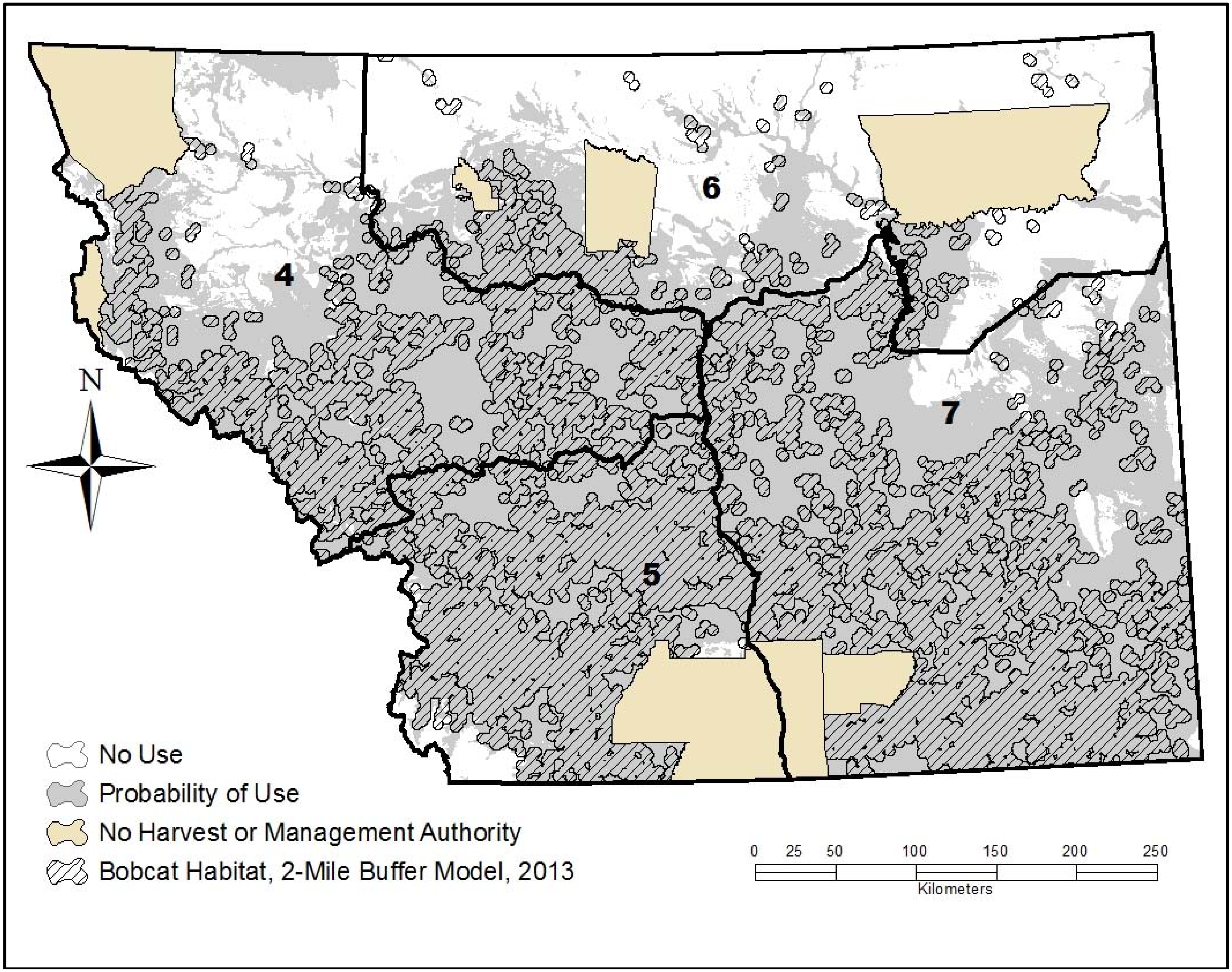


Figure 7. Map of TDs 4-7 showing bobcat habitat using the 2-mile buffer and the max-ent model. Habitat not shaded gray has no bobcat use.

are several plausible reasons for these differences 1) the amount of habitat estimated by the max-ent model includes any pixel with a probability >11% (eastern model) and > 7% (western model) of having a bobcat so it may include more non-habitat 2) the eastern max-ent model may not be as accurate as the western max-ent model (no bobcats in predicted suitable habitat in eastern model), 3) bobcat harvesters were removing bobcats from relatively marginal bobcat habitat in the western part of the state, 4) bobcats in the eastern part of the state use a wider variety of habitats available to them or 5) the greater amount of private land in the eastern part of the state restricts the amount of habitat available to harvesters.

Population Estimates, Trends in Adult Population and Adult Growth Rates, Densities, and Capacities for Harvest

Trapping District 1

For the period 2000-2016, 4,285 harvested bobcats were used in the reconstruction of populations in TD 1. TD 1 had its highest MPE and SPE in 2006 when population reconstruction estimated 1,136 and 1,249 animals, respectively (Table 4). Trends in adult populations exhibited by both population estimates were similar with the adult population increasing substantially between 2000 and 2007 and then declining between 2007 and 2013 to a level comparable to numbers observed in 2000 (Fig. 8). Between 2013 and 2016 population reconstruction estimated an increase in the adult population.

Table 4. Trapping district 1 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	168	576	744	212	724	936
2001	242	524	767	295	641	935
2002	262	533	795	317	650	966
2003	288	594	882	339	699	1037
2004	276	672	948	314	772	1086
2005	300	723	1023	337	810	1146
2006	342	793	1136	378	871	1249
2007	234	892	1126	259	980	1238
2008	95	860	955	105	941	1046
2009	211	695	906	231	765	996
2010	272	658	929	302	730	1032
2011	241	645	886	260	695	955
2012	221	627	848	234	668	902
2013	301	567	868	333	617	950
2014	347	562	909	392	628	1020
2015	369	639	1008	431	750	1180
2016	284	731	1015	335	852	1187
Avg.[1]	262	664	926	298	753	1051

[1]Average is for the years 2000 through 2016.

These increases appear to be realistic. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as harvest data in the future are collected and backdated.

Annual adult growth rates also showed similar trends between the two population estimates with lambdas above or close to 1.0 in all years 2002-2007, a very low lambda in 2009 followed by 5 years of lambdas just below 1.0 (Fig. 8). Between 2013 and 2016 population reconstruction estimated an increase in lambda and although these numbers appear to be reasonable they can change the most as harvest data in the future are collected and backdated.

Estimates of bobcat density in TD 1 averaged 7.5–10.3 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 5).

In TD1, the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* indicated that an annual harvest of less than 250 (MPE) or 245 (SPE) has historically been correlated with a stable or increasing population (Fig. 9).

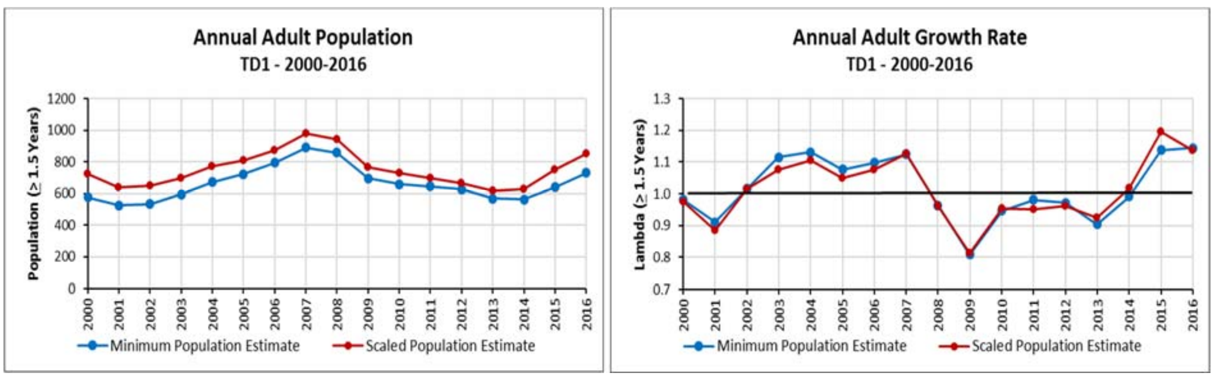
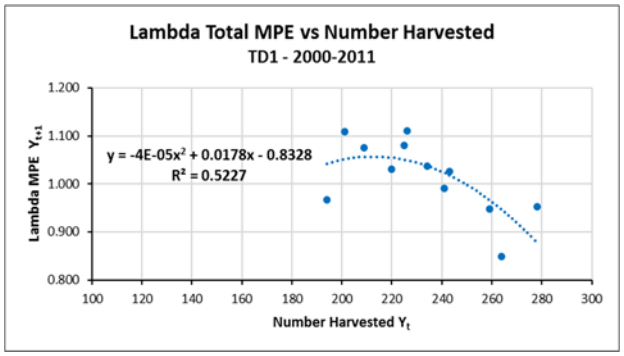


Figure 8. Annual minimum and scaled estimates of adult numbers and adult growth rate in TD 1, 2000-2016.

Table 5. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 1, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	6.6	9.0	-	10.1	13.8	-
SPE	6.0	8.2	-	8.3	9.0	-
All	-	-	7.5	-	-	10.3



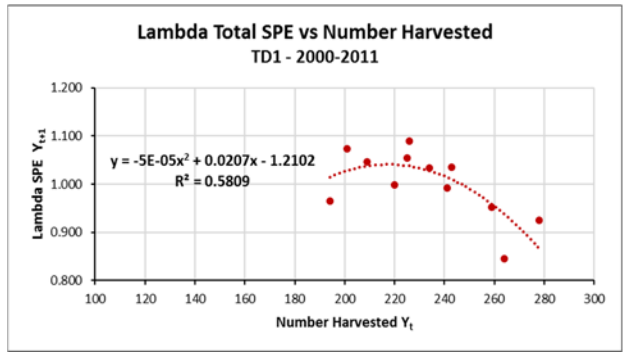


Figure 9. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 1.

Trapping District 2

For the period 2000-2016, 2,831 harvested bobcats were used in the reconstruction of populations in TD 2. TD 2 had its highest MPE and SPE in 2015 when reconstruction estimated 740 and 854 animals, respectively (Table 6).

Table 6. Trapping district 2 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	117	444	561	146	543	690
2001	154	394	547	179	461	639
2002	169	375	544	198	439	638
2003	210	398	607	246	466	712
2004	174	424	598	204	505	709
2005	171	425	596	200	503	703
2006	220	437	657	255	503	758
2007	187	478	665	216	558	775
2008	83	478	561	99	568	668
2009	129	377	506	149	440	589
2010	123	398	521	142	461	602
2011	143	407	550	162	462	624
2012	153	446	599	170	497	666
2013	182	399	581	200	436	636
2014	247	385	632	278	420	698
2015	302	439	740	348	505	854
2016	150	570	720	174	673	847
Avg.[1]	171	428	599	198	496	695

[1]Average is for the years 2000 through 2016.

Trends in adult populations exhibited by both population estimates were very similar with the adult population decreasing slightly between 2000 and 2002 and then increasing between 2002 and 2008, followed by a relatively stable population during

2010-2013 (Fig. 10). Between 2013 and 2016 population reconstruction estimated an increase in the adult population. These estimates seem to be fairly high however, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate and change as harvest data in the future are collected and backdated.

Annual adult growth rates also showed similar trends between the two population estimates with lambdas above or close to 1.0 during 2003-2008 followed by one year of lambda well below 1.0 and three years of lambdas above 1 and then another year below 1 (Fig. 10). Between 2013 and 2016 population reconstruction estimates an increase in lambda although these numbers can change the most as harvest data in the future are collected and it is unlikely that the 30% increase estimated for 2016 will remain that high.

Estimates of bobcat density in TD 2 averaged 10.7–15.8 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 7).

In TD2, the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* indicated that an annual harvest of less than 170 (MPE) or 167 (SPE) has historically been correlated with a stable or increasing population (Fig. 11).

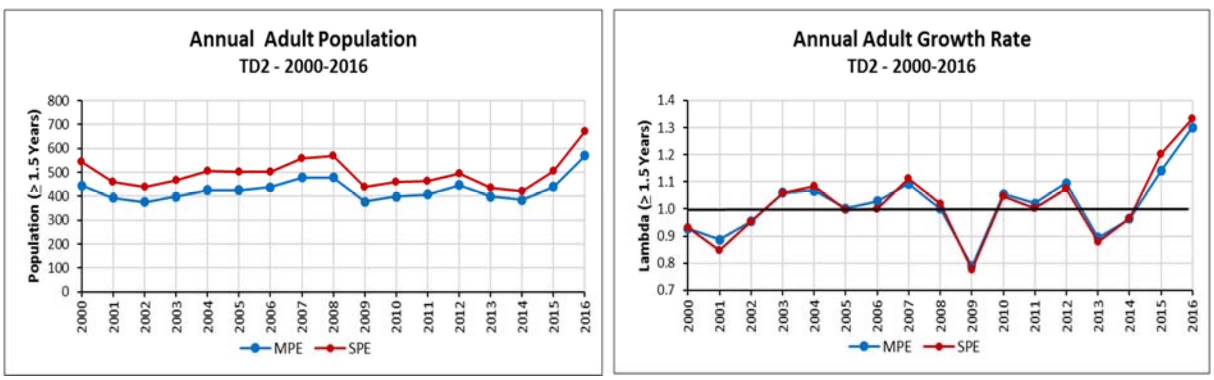
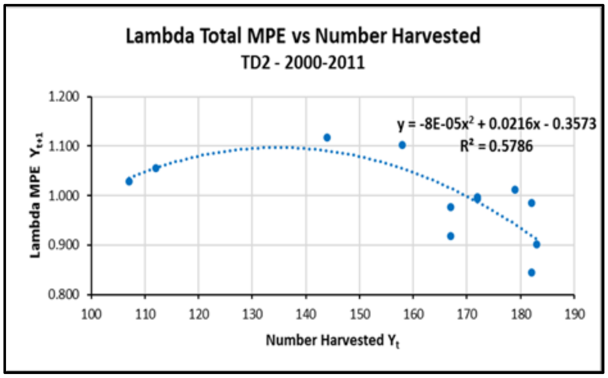


Figure 10. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 2, 2000-2016.

Table 7. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 2, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	9.3	13.6	-	13.8	20.2	-
SPE	8.1	11.7	-	12.0	17.3	-
All	-	-	10.7	-	-	15.8



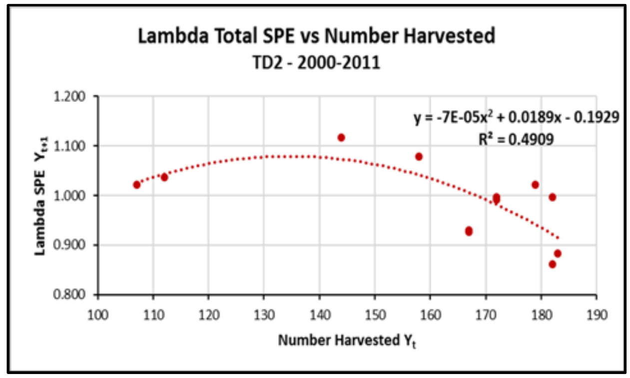


Figure 11. Polynomial relationships between number of bobcats harvested in year t and lambda of the total population in year *t+1*, trapping district 2.

Trapping District 3

For the period 2000-2016, 4,168 harvested bobcats were used in the reconstruction of populations in TD 3. TD 3 had its highest MPE in 2006 and highest SPE in 2015 when population reconstruction estimated 1,062 and 1,400 animals, respectively (Table 8).

Table 8. Trapping district 3 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	134	513	647	220	870	1090
2001	197	524	721	307	832	1138
2002	258	549	807	378	835	1212
2003	292	601	894	408	856	1264
2004	296	658	954	399	900	1298
2005	310	734	1044	402	971	1373
2006	310	752	1062	395	954	1349
2007	262	765	1027	348	990	1338
2008	209	700	909	287	935	1223
2009	258	612	870	356	854	1210
2010	275	667	942	365	909	1274
2011	243	725	968	307	925	1231
2012	168	692	860	206	854	1060
2013	174	585	759	210	727	937
2014	276	482	758	350	588	938
2015	538	513	1051	707	693	1400
2016	243	788	1031	316	1046	1362
Avg.[1]	261	639	900	351	867	1217

[1]Average is for the years 2000 through 2016.

Trends in adult populations exhibited with both population estimates were very similar, with adult populations increasing between 2000 and 2007 and then declining between 2007 and 2014 to a number comparable to those observed in 2003 for the MPE but quite low for the SPE (Fig. 12). Between 2014 and 2016 population reconstruction estimated a substantial increase in the adult population. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as harvest data in the future are collected and backdated. We suspect, that as more age data is collected in the future, population estimates for 2015 and 2016 will probably be lower and estimates for 2014 will be higher.

Annual adult growth rates also showed similar trends between the two population estimates with growth rates above or near 1.0 in all years 2000-2007, except 2001, followed by two years of growth rates below 1.0, and two years of growth rates above 1 (Fig 12). Between 2014 and 2016 population reconstruction estimated a substantial increase in lambda although these numbers can and most likely will change as harvest data in the future are collected and backdated. It is very unlikely that the growth rate between 2015 and 2016 will remain at 1.5.

In TD3, the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* indicated that an annual harvest of less than 265 (SPE) or 275 (MPE) has historically been correlated with a stable or increasing population (Fig. 13).

Estimates of bobcat density in TD 3 averaged 10.7–16.9 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 9).

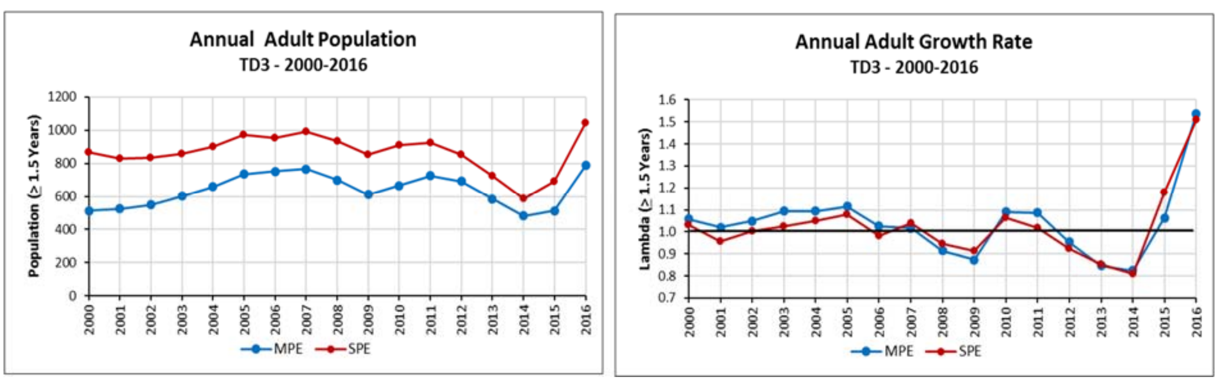


Figure 12. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 3, 2000-2016.

Table 9. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 3, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	9.1	15.2	-	15.0	25.0	-
SPE	6.9	11.6	-	10.3	17.3	-
All	-	-	10.7	-	-	16.9

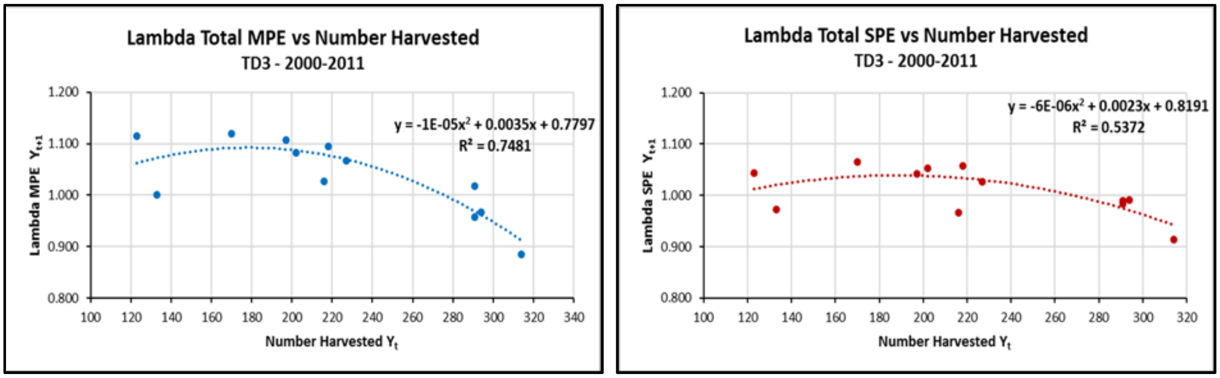


Figure 13. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 3.

Trapping District 4

For the period 2000-2016, 3,838 harvested bobcats were used in the reconstruction of populations in TD 4. TD 4 had its highest MPE in 2005 and highest SPE in 2004 when population reconstruction estimated 1,054 and 1,397 animals, respectively (Table 10).

Table 10. Trapping district 4 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	227	522	749	366	857	1223
2001	232	580	812	333	861	1193
2002	224	640	864	305	894	1200
2003	321	667	988	427	872	1298
2004	273	774	1046	361	1036	1397
2005	319	734	1054	419	976	1395
2006	342	767	1108	406	967	1373
2007	253	788	1041	317	939	1256
2008	194	724	919	256	939	1195
2009	164	618	782	222	878	1100
2010	194	568	762	260	743	1002
2011	229	516	745	294	681	976
2012	138	432	570	188	591	779
2013	70	289	359	127	490	617
2014	108	184	292	231	406	636
2015	254	171	425	494	369	863
2016	157	329	485	299	635	934
Avg.[1]	218	547	765	312	773	1085

[1]Average is for the years 2000 through 2016.

Trends in adult populations exhibited with both population estimates were very similar, with adult populations increasing between 2000 and 2004, remaining relatively stable through 2007 and then declining to 66.2% and 64.3% below the 2000 MPE and SPE, respectively in 2014 (Fig. 14). Between 2014 and 2016 population reconstruction estimated a substantial increase in the adult population. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as harvest data in the future are collected and backdated. We suspect that the 2016 population estimate is higher than it should be and that the 2015 population estimate may be lower than it should be.

Annual adult growth rates showed similar trends although the lambdas observed when using the MPEs were higher than the lambdas for the SPEs. Between 2014 and 2016 population reconstruction estimated a rapidly growing population although these numbers will change the most as harvest data in the future are collected and backdated. It is very unlikely that the growth rate between 2015 and 2016 will remain above 1.7 once more data are collected (Fig. 14).

Estimates of bobcat density in TD 4 averaged 11.0–31.7 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 11).

In TD4, the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* indicated that an annual harvest of less than 240 (SPE) or 250 (MPE) has historically been correlated with a stable or increasing population (Fig. 15).

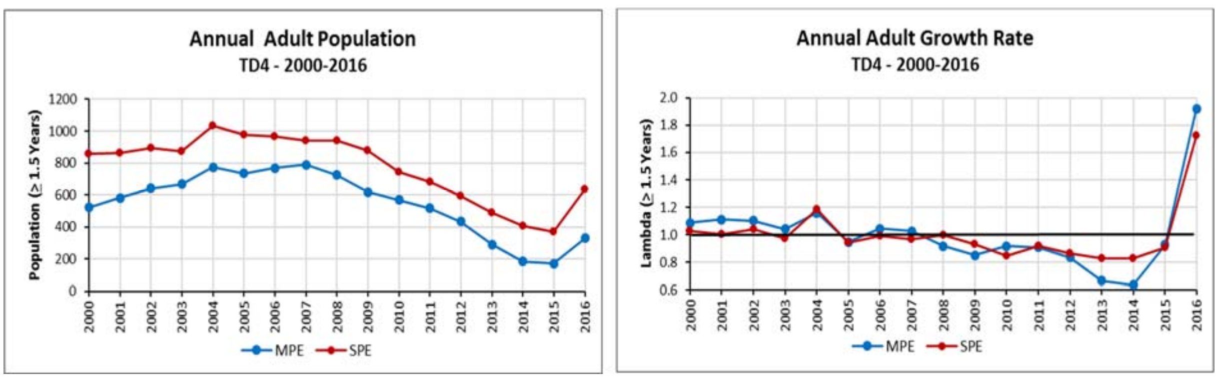
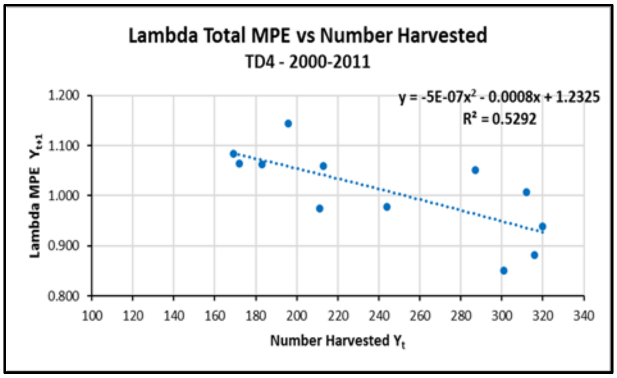


Figure 14. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 4, 2000-2016.

Table 11. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 4, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	8.4	16.1	-	31.9	61.0	-
SPE	6.7	12.8	-	15.1	18.8	-
All	-	-	11.0	-	-	31.7



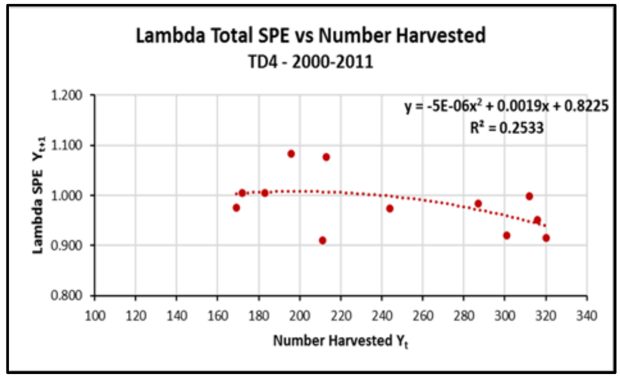


Figure 15. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 4.

Trapping District 5

For the period 2000-2016, 5,799 harvested bobcats were used in the reconstruction of populations in TD 5. TD 5 had its highest MPE in 2007 and highest SPE in 2006 when population reconstruction estimated 1,604 and 1,841 animals, respectively (Table 12).

Table 12. Trapping district 5 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	335	664	998	590	1190	1780
2001	296	778	1074	453	1236	1689
2002	297	820	1117	436	1245	1680
2003	435	802	1237	585	1064	1649
2004	395	881	1276	522	1173	1695
2005	468	846	1314	584	1092	1676
2006	657	920	1577	748	1094	1841
2007	457	1146	1604	511	1282	1792
2008	453	1109	1562	507	1265	1772
2009	255	1056	1311	315	1266	1581
2010	199	840	1040	279	1107	1385
2011	191	632	822	264	881	1145
2012	250	513	763	339	736	1075
2013	160	461	622	248	693	941
2014	302	315	617	589	557	1146
2015	434	411	845	845	862	1707
2016	171	659	830	317	1281	1599
Avg.[1]	339	756	1095	478	1060	1538

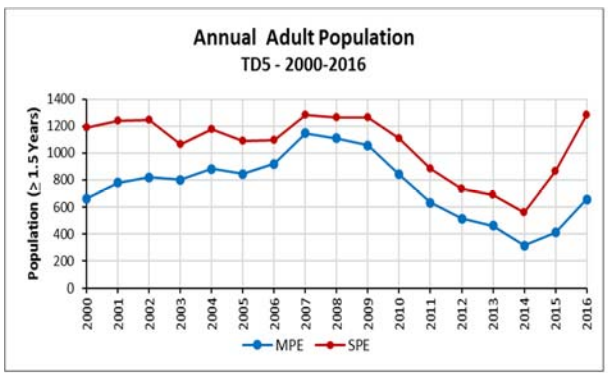
[1]Average is for the years 2000 through 2016.

Prior to 2003 trends in adult populations were somewhat dissimilar with the SPE showing a relatively large population decrease and the MPE showing a population increase. Following 2003, both estimates showed a population that was steadily increasing until 2007 followed by two years of stability and then a population decline through 2014 (Fig. 16). The 2014 adult population estimates were 52.5% and 53.2% below the 2000 MPE and SPE, respectively. Between 2014 and 2016 population reconstruction estimated a substantial increase in the adult population. The increase between 2014 and 2016 is probably too high and we suspect as data are collected in the future the estimate for 2014 will go up and the estimate for 2016 will decrease.

Annual adult growth rates showed similar trends when using either the SPE or MPE. Between 2014 and 2016 population reconstruction estimated an increase in lambda although these numbers can change the most as teeth in the future are collected and backdated. It is very unlikely that the growth rate between 2016 and 2017 will remain above 1.6 once more data are collected (Fig. 16).

Estimates of bobcat density in TD 5 averaged 6.9–15.9 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 13).

In TD5, the observed relationship between total harvest in year *t* and lambda of the total population inyear *t+1* indicated that an annual harvest of less than 325 (SPE) or 400 (MPE) has historically been correlated with a stable or increasing population (Fig. 17).



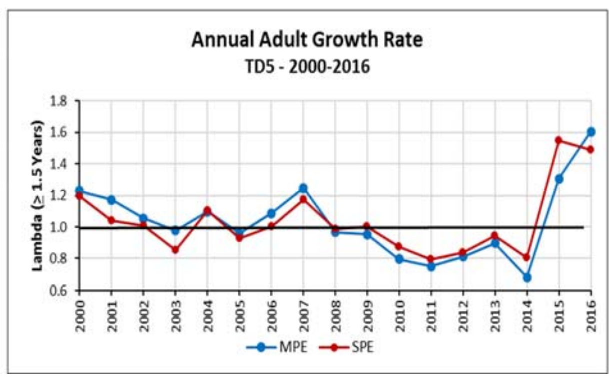


Figure 16. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 5, 2000-2016.

Table 13. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 5, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	6.5	8.3	-	16.8	21.6	-
SPE	5.6	7.2	-	11.0	14.2	-
All	-	-	6.9	-	-	15.9

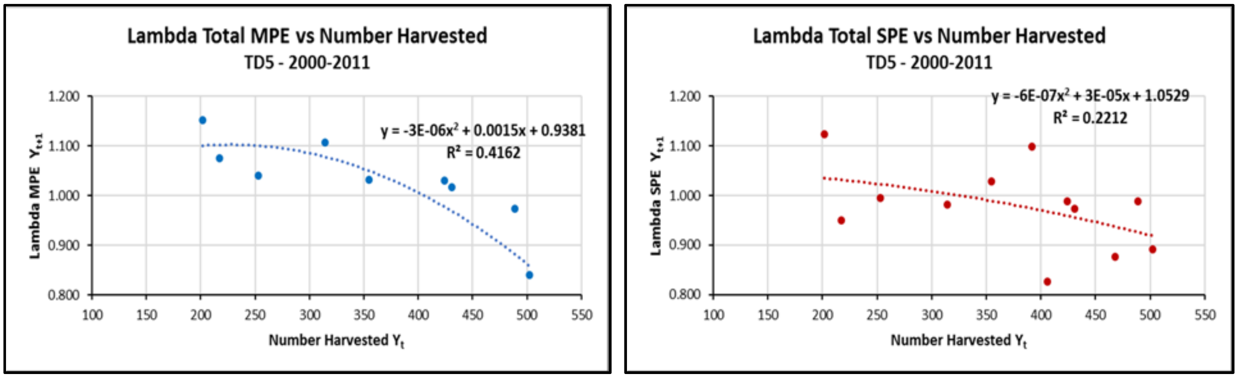


Figure 17. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 5.

Trapping District 6

For the period 2000-2016, 1,315 harvested bobcats were used in the reconstruction of populations in TD 6. TD 6 had its highest MPE in 2001 and SPE in 2000 when population reconstruction estimated 391 and 435 animals, respectively (Table 14).

Table 14. Trapping district 6 minimum and scaled population estimates 2000-2016.

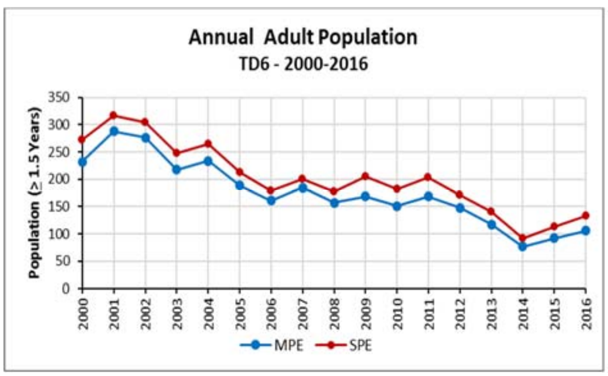
	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	142	232	374	163	272	435
2001	103	288	391	114	317	432
2002	74	277	351	83	305	388
2003	105	217	323	121	247	368
2004	90	234	323	101	265	366
2005	95	188	283	106	212	318
2006	115	161	276	125	179	304
2007	76	185	261	85	201	286
2008	82	157	239	98	177	276
2009	25	168	193	29	205	233
2010	44	151	194	52	182	234
2011	72	168	240	84	204	288
2012	22	148	170	26	171	197
2013	19	117	136	23	141	164
2014	39	77	116	47	92	139
2015	58	93	151	72	114	186
2016	11	106	117	13	134	146
Avg.[1]	69	175	243	79	201	280

[1]Average is for the years 2000 through 2016.

Trends in adult populations with both population estimates were almost identical from 2000-2014 showing a steady decline in numbers (Fig. 18). The 2014 adult population estimates were 66.8% and 66.1% below the 2000 MPE and SPE, respectively. Between 2014 and 2016 population reconstruction estimated an increase in the adult population. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as age data in the future are collected and backdated. We suspect that the 2016 population estimate, using this method, may be higher than it should be.

Annual adult growth rates using either estimator showed almost identical trends with annual fluctuations in lambda until 2011 followed by a steady decline through 2014. Between 2014 and 2016 population reconstruction estimated an increase in lambda although these numbers can change the most as harvest data in the future are collected and backdated (Fig. 18).

Estimates of bobcat density in TD 6 averaged 17.0–46.8 mi^2/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 15). Bobcat densities in TD 6 were low compared to the other TDs especially when comparing densities using the max-ent model.



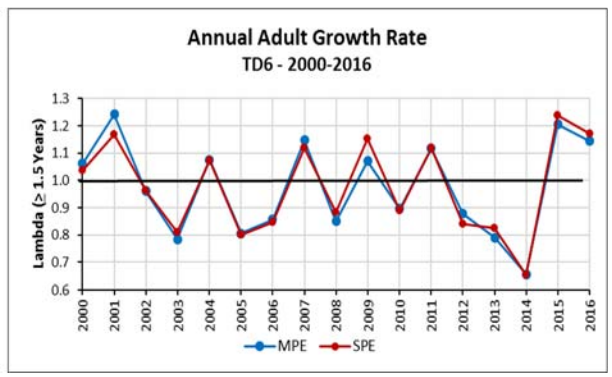


Figure 18. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 6, 2000-2016.

Table 15. Range of bobcat densities (mi^2/bobcat) based on highest and lowest observed total population estimates, trapping district 6, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	8.4	28.4	-	23.1	78.2	-
SPE	7.6	23.6	-	20.8	64.9	-
All	-	-	17.0	-	-	46.8

We suspect that the small sample sizes of harvested animals reduce the accuracy of population estimates and lambda estimates in TD 6. We believe that population estimates, and predicted population estimates, in this TD were unreliable and warn managers to use caution when interpreting them. That being said, the overall downward trend in recent years was similar to the trends observed in the rest of eastern Montana in TDs 4, 5, and 7.

In TD 6, the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* indicated that an annual harvest of less than 70 (MPE) and 70 (SPE) has historically been correlated with a stable or increasing population (Fig. 19).

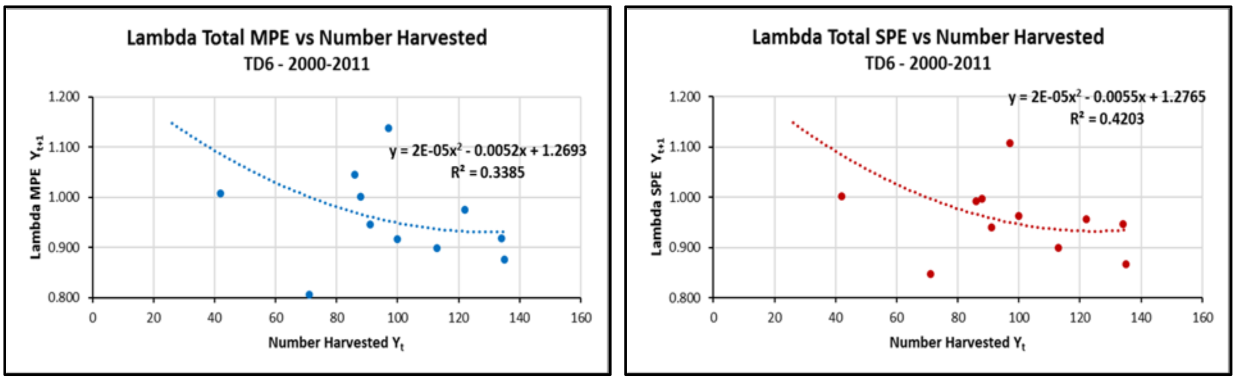


Figure 19. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 6

Trapping District 7

For the period 2000-2016, 8,987 harvested bobcats were used in the reconstruction of populations in TD 7. TD 7 had its highest MPE and SPE in 2007 when population reconstruction estimated 2,769 and 3,258 animals, respectively (Table 16). Trends in adult populations exhibited with both population estimates were similar showing a decline from 2000 to 2003 followed by 5 years of steady growth and then a steep decline in numbers from 2008 to 2014 (Fig. 20). The 2014 adult population estimates were 62.1% and 65.9% below the 2000 MPE and SPE, respectively. Between 2014 and 2016 population reconstruction estimated a substantial increase in the adult population. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as harvest data in the future are collected and backdated. We suspect that the 2016 population estimate may be too high, and it is likely that the 2014 estimate is too low.

Annual adult growth rates showed similar trends and fluctuated greatly. Between 2014 and 2016 population reconstruction estimated an increase in lambda although these numbers can change the most as harvest data in the future are collected and backdated. It is very unlikely that the growth rate between 2015 and 2016 will remain at 1.4 once more data are collected (Fig. 20).

Table 16. Trapping district 7 minimum and scaled population estimates, 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	739	1206	1945	970	1610	2580
2001	311	1551	1862	376	1930	2306
2002	273	1333	1607	309	1502	1811
2003	622	1013	1634	710	1160	1871
2004	771	1124	1895	886	1287	2173
2005	909	1260	2169	1057	1452	2509
2006	1179	1444	2623	1386	1693	3079
2007	825	1944	2769	972	2285	3258
2008	559	2039	2598	661	2414	3075
2009	139	1775	1914	164	2086	2250
2010	119	1449	1569	140	1699	1839
2011	362	1209	1571	414	1409	1823
2012	286	937	1223	329	1059	1387
2013	137	658	795	168	822	990
2014	472	457	929	577	549	1126
2015	696	607	1303	809	756	1565
2016	298	914	1211	335	1070	1405
Avg.[1]	512	1231	1742	604	1458	2062

[1]Average is for the years 2000 through 2016.

Estimates of bobcat density in TD 7 averaged 7.3–24.8 mi²/bobcat at the highest and lowest population levels, depending on the habitat and population model used (Table 17).

In TD7, the observed relationship between total harvest and lambda was very weak, and the harvest estimates that would generate a lambda of 1.0 or greater are probably not useful (Fig. 21).

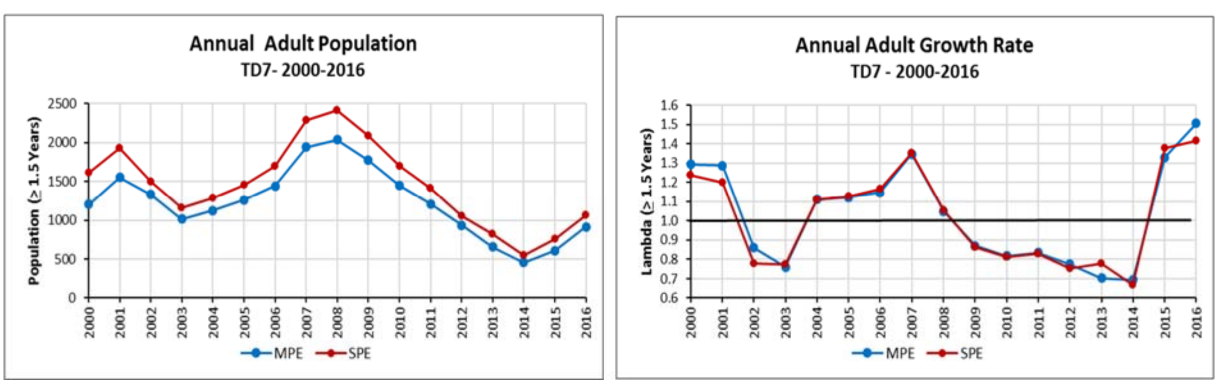


Figure 20. Annual minimum and scaled estimates of adult numbers and adult growth rates in TD 7, 2000-2016.

Table 17. Range of bobcat densities (mi²/bobcat) based on highest and lowest observed total population estimates, trapping district 7, 2000 – 2016.

	Highest Population Estimate			Lowest population Estimate		
Pop. Model	2-mile Buffer Model	Max-Ent Model	Overall Average	2-mile Buffer Model	Max-Ent Model	Overall Average
MPE	5.8	10.1	-	20.1	35.0	-
SPE	4.9	8.5	-	16.3	28.1	-
All	-	-	7.3	-	-	24.8

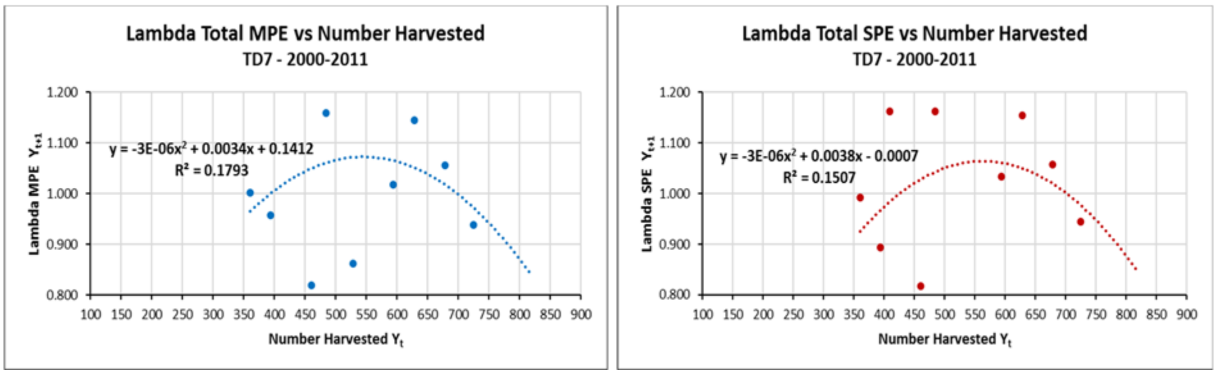


Figure 21. Polynomial relationships between number of bobcats harvested in year *t* and lambda of the total population in year *t+1*, trapping district 7

State

For the period 2000-2016, 35,916 harvested bobcats were used in the reconstruction of populations for the state. The state had its highest MPE and SPE in 2007 when population reconstruction estimated 8,484 and 9,199 animals, respectively (Table 18). Trends in adult populations exhibited with both population estimates were very similar showing a declining population between 2000 and 2003 followed by 5 years of steady growth and then 5 years of a decline in numbers from 2008 to 2014 (Fig. 22). The 2014 adult population estimates were 41.3% and 48.4% below the 2000 MPE and SPE, respectively. Between 2014 and 2016 population reconstruction estimated an increase in the adult population. However, because of the way backdated populations are calculated the closer you get to the current year the more the population estimates will fluctuate as harvest data in the future are collected and backdated. We suspect that the 2016 population estimate, using this method, may be too high and that the 2014 estimate may be too low.

Annual adult growth rates for MPE and SPE showed similar trends and fluctuate greatly. (Fig. 22). Lambda was estimated to be below 1 for 6 consecutive years between 2009 and 2014. The very low growth rate of adults in 2013 and 2014 and the high growth rate of adults in 2015 and 2016 are likely to change as data are collected in the future.

Table 18. Statewide minimum population and scaled population estimates 2000-2016.

	MPE			SPE		
Year	Juvenile	Adults≥1.5	Total	Juvenile	Adults≥1.5	Total
2000	1859	4153	6012	2403	5416	7818
2001	1536	4628	6164	1854	5675	7529
2002	1545	4517	6062	1822	5407	7229
2003	2266	4268	6535	2603	4897	7500
2004	2280	4735	7015	2570	5381	7951
2005	2575	4885	7460	2833	5446	8278
2006	3181	5241	8422	3429	5670	9098
2007	2306	6178	8484	2520	6671	9191
2008	1715	6058	7773	1909	6663	8572
2009	1200	5331	6531	1349	5991	7339
2010	1214	4780	5993	1355	5381	6735
2011	1449	4338	5787	1578	4776	6354
2012	1237	3800	5037	1319	4090	5409
2013	1024	3080	4104	1152	3452	4603
2014	1788	2439	4227	2104	2793	4898
2015	2624	2841	5465	3153	3483	6636
2016	1375	4039	5414	1627	4888	6515
Avg.[1]	1834	4430	6264	2093	5064	7156

[1]Average is for the years 2000 through 2016.

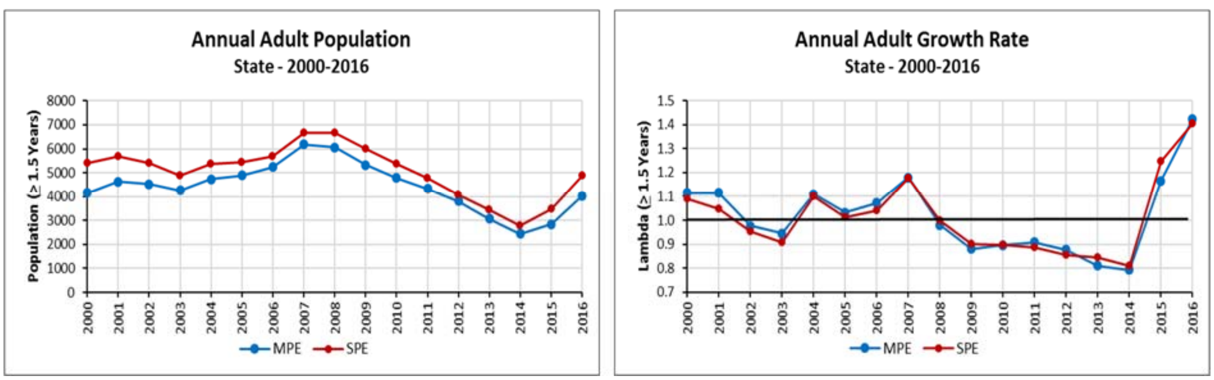


Figure 22. Annual minimum and scaled estimates of adult numbers and adult growth rates in the state, 2000-2016.

Harvest Metrics that Best Predict Population and Growth Rate

Bobcats Harvested Per Day

We found that the best linear relationship was between the number of bobcats harvested per day in year *t* and the population of bobcats ≥1.5 in year *t+1* (Table 19, Fig. 23). For MPEs, 5 of 7 TDs showed positive associations ($P \leq 0.10$) between bobcats per day in year *t* and adult population in year *t+1* with R^2 values all >0.40 Table 19). For SPEs, 4 of 7 TDs showed positive associations ($P \leq 0.10$) between bobcats per day in year *t* and adult population in year *t+1* with R^2 values all >0.30 (Table 19). Although the R^2 values were poorer for SPEs the trend lines had a positive slope, like the MPE trend lines, and in all TDs, except 6, as the number of bobcats per day harvested increased the estimated number of adults in the population increased.

Juveniles Per Adult

Both the mean juvenile to adult female and juvenile to adult ratios varied among TDs, however it appeared that the juvenile to adult ratio varied less (Table 20). We tested the relationship between juvenile to adult ratios and juvenile to adult female ratios in year *t* against lambda of adults in year *t+1* for both MPEs and SPEs (Table 19) (Figs. 24 and 25). TDs 1, 5, and 7 showed positive associations ($P \leq 0.10$) between juveniles per adult and juveniles per adult females in year *t* and adult lambda in year *t+1* with R^2 values all >0.40 (Table 19). In addition, TD 4 showed a positive association ($P \leq 0.10$) between juveniles per adult females in year *t* and adult lambda (MPE) in year *t+1* with a low R^2 value of 0.287 (Table 19).

Although the R^2 values and *p*-values for this relationship were good in only three of the seven TDS, the trend lines all had a positive slope indicating that as the juvenile to adult or juvenile to adult female ratios increased in year *t* the value of lambda of adults increased in year *t+1.*

Table 19. Correlation coefficients (R^2) between various harvest metrics and either adult population size or adult population growth rate. Bold italics indicates that the slope of the value is significant at p<0.1

Metric Measured (Year t)	TD	Adult Population Size (Year t+1) MPE Slope	Adult Population Size (Year t+1) MPE R^2	Adult Population Size (Year t+1) SPE Slope	Adult Population Size (Year t+1) SPE R^2	Adult Lambda (Year t+1) MPE Slope	Adult Lambda (Year t+1) MPE R^2	Adult Lambda (Year t+1) SPE Slope	Adult Lambda (Year t+1) SPE R^2
Bobcats Harvested Per Day	1	**+**	***0.554***	**+**	***0.409***	.	.	.	.
	2	+	0.201	+	0.196	.	.	.	.
	3	**+**	***0.507***	**+**	***0.509***	.	.	.	.
	4	**+**	***0.561***	**+**	***0.352***	.	.	.	.
	5	**+**	***0.694***	+	0.114	.	.	.	.
	6	-	0.005	-	0.028	.	.	.	.
	7	**+**	***0.415***	**+**	***0.356***	.	.	.	.
Juveniles per Adult	1	.	.	.	.	**+**	***0.471***	**+**	***0.484***
	2	.	.	.	.	+	0.066	+	0.111
	3	.	.	.	.	+	0.101	+	0.075
	4	.	.	.	.	+	0.218	+	0.102
	5	.	.	.	.	**+**	***0.711***	**+**	***0.652***
	6	.	.	.	.	+	0.118	+	0.061
	7	.	.	.	.	**+**	***0.780***	**+**	***0.754***
Juveniles per Adult Female	1	.	.	.	.	**+**	***0.421***	**+**	***0.433***
	2	.	.	.	.	+	0.115	+	0.136
	3	.	.	.	.	+	0.100	+	0.092
	4	.	.	.	.	**+**	***0.287***	+	0.121
	5	.	.	.	.	**+**	***0.784***	**+**	***0.646***
	6	.	.	.	.	+	0.097	+	0.063
	7	.	.	.	.	**+**	***0.801***	**+**	***0.777***
% Ad. Females in Adult Harvest	1	+	0.141	+	0.181	+	0.023	+	0.017
	2	+	0.090	+	0.080	-	0.003	+	0.000
	3	+	0.185	+	0.083	-	0.005	-	0.012
	4	-	0.062	-	0.060	-	0.187	-	0.069
	5	+	0.000	-	0.194	**-**	***0.282***	-	0.128
	6	+	0.002	+	0.000	+	0.003	-	0.012
	7	-	0.058	-	0.103	**-**	***0.508***	**-**	***0.517***
% Yearlings in Adult Harvest	1	**+**	***0.261***	**+**	***0.358***	.	.	.	.
	2	**+**	***0.527***	**+**	***0.646***	.	.	.	.
	3	+	0.176	**+**	***0.475***	.	.	.	.
	4	**+**	***0.258***	**+**	***0.351***	.	.	.	.
	5	+	0.074	**+**	***0.293***	.	.	.	.
	6	-	0.024	-	0.069	.	.	.	.
	7	**+**	***0.293***	**+**	***0.303***	.	.	.	.

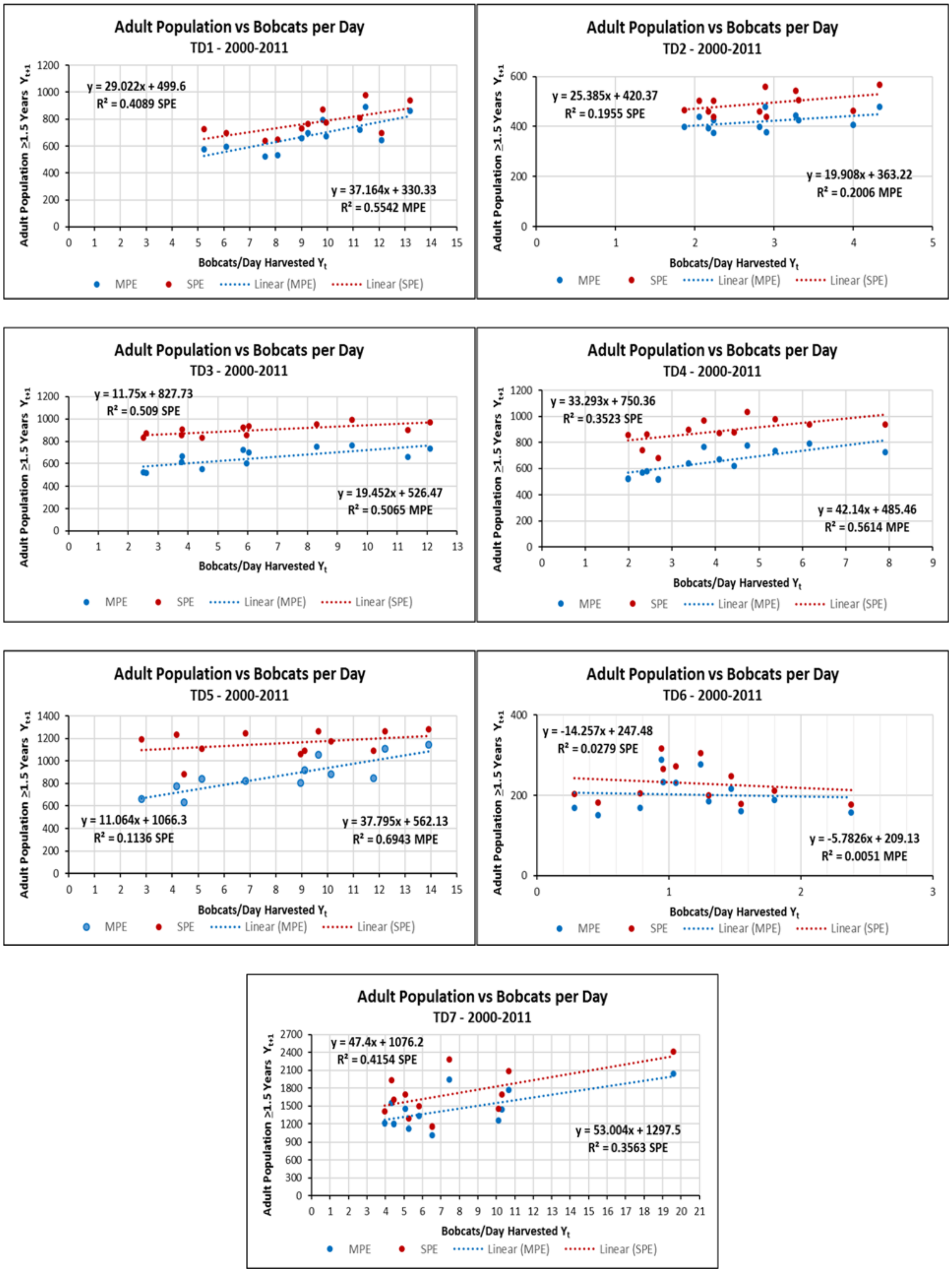


Figure 23. Linear relationship between bobcats harvested per day in year *t* and MPE and SPE of adults ≥1.5 in year *t+1* by trapping district.

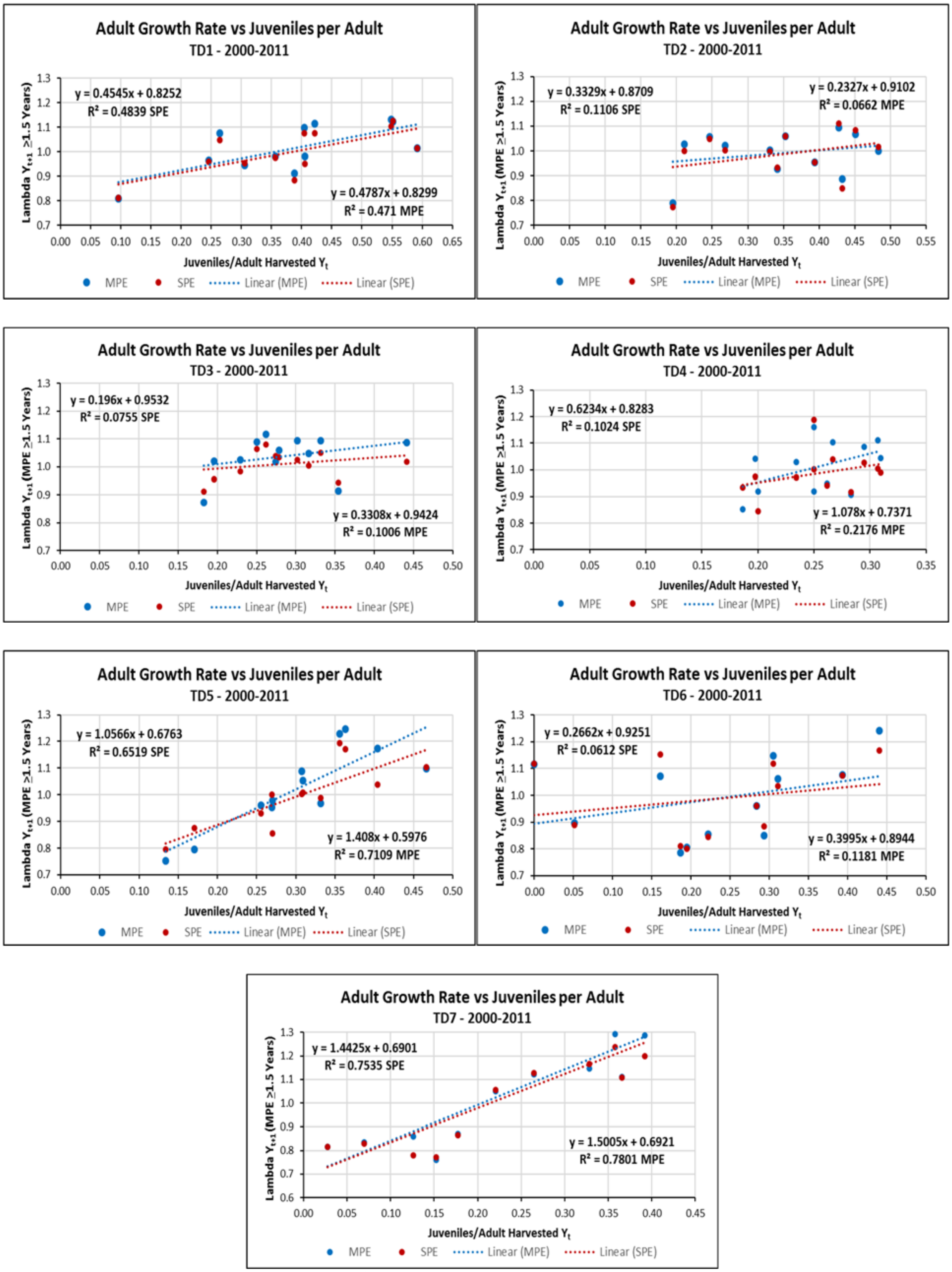


Figure 24. Linear relationship, R^2 between number of juveniles per adult harvested in year *t* and lambda of adults ≥ 1.5 from year *t* to year *t+1*, by trapping district.

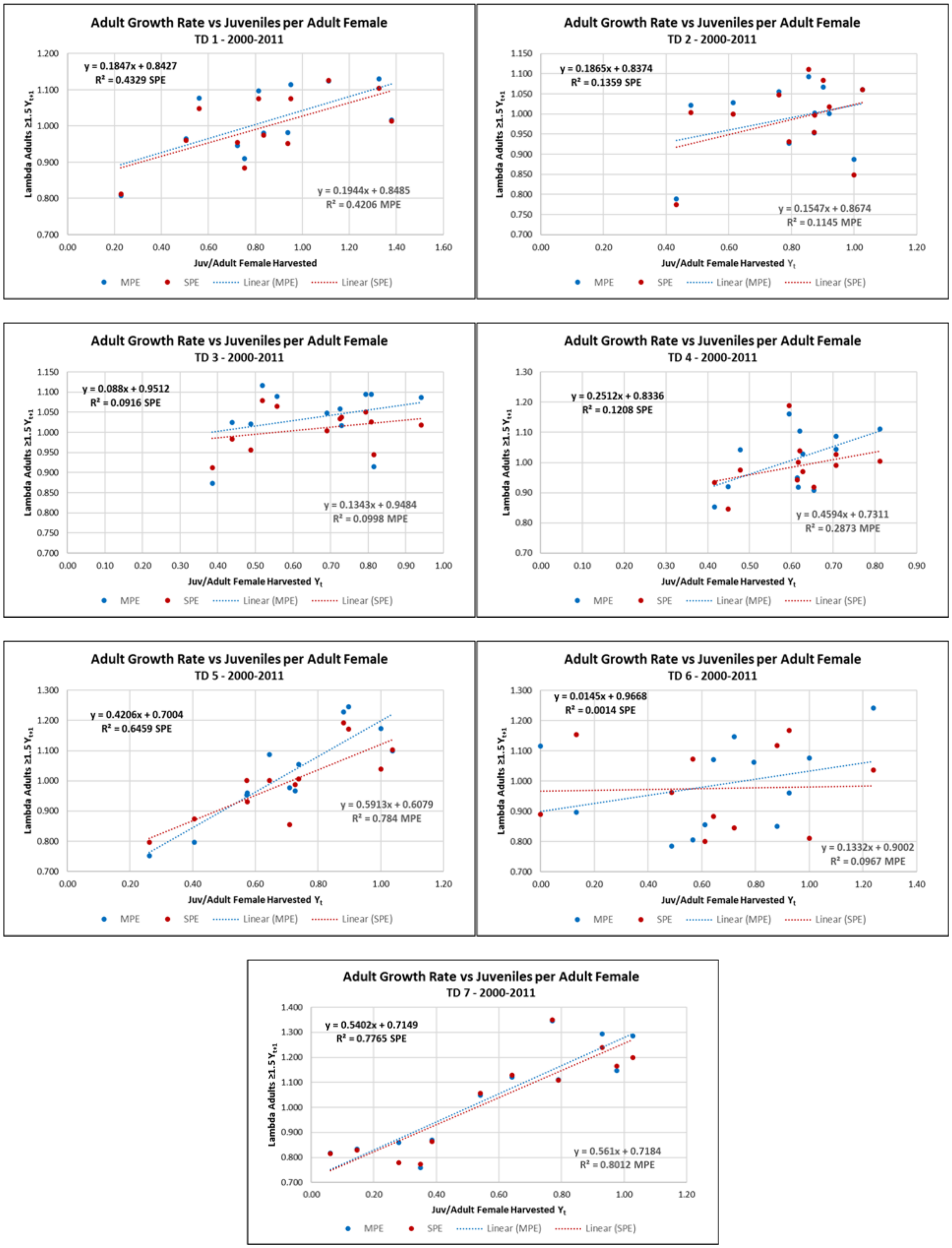


Figure 25. Linear relationship, R^2 between number of juveniles per adult female trapped in year *t* and lambda of adults ≥ 1.5 from year t to year *t+1* TD.

Table 20. Variation among trapping districts in the number of juveniles per adult female and juveniles per adult, 1999-2016.

Trapping District	Juv:Ad Female Mean	Juv:Ad Female Range	Juv:Ad Mean	Juv:Ad Range
1	0.87	0.23 – 1.37	0.39	0.10-0.59
2	0.81	0.43 – 1.03	0.36	0.19-0.48
3	0.67	0.38 – 1.01	0.30	0.18-0.53
4	0.68	0.41 – 1.32	0.30	0.19-0.61
5	0.69	0.26 – 1.04	0.30	0.13-0.46
6	0.57	0.00 – 1.24	0.21	0.00-0.44
7	0.54	0.06 – 1.03	0.23	0.03-0.39

Percent Adult Females

As with other metrics, the percentage of adult females in the adult harvest varied from one TD to the next with TD 1 having the highest (46.1%) and TD 6 having the lowest average percentage (39.0%). Statewide, an average of 44.5% of all adults harvested were identified as females (Table 21).

Table 21. Average percentage of adult females in the adult harvest, 1999-2016.

Trapping District	Mean % of Ad. Females in Ad. Harvest	Range
1	46.1%	38.7 – 53.0%
2	45.2%	32.5 – 57.5%
3	46.0%	37.1 – 54.3%
4	44.3%	37.3 – 51.2%
5	44.6%	38.1 – 53.3%
6	39.0%	25.0 – 66.7%
7	43.7%	34.6 – 50.4%
State	44.5%	41.0 – 49.8%

We were unable to detect a very strong linear or consistent relationship between the percentage of adult females in the adult harvest in year *t* and population estimates of adults (Fig. 26) or lambda of adults (Fig. 27) in year *t+1* (Table 19). For MPEs, only 2 of 7 TDs, and for SPES only 1 of 7 TDs showed positive associations ($P \leq 0.10$) between percentage of adult females in the adult population in year *t* and adult population growth rates in year *t+1*. There were no positive associations between percentage of adult females in the adult population in year *t* and adult populations in year *t+1*. All the R^2 values, except in TD 7 were <0.30 and most were under 0.20(Table 19). The slopes of the lines for these relationships were not consistent across TDS with some being negative and some being positive.

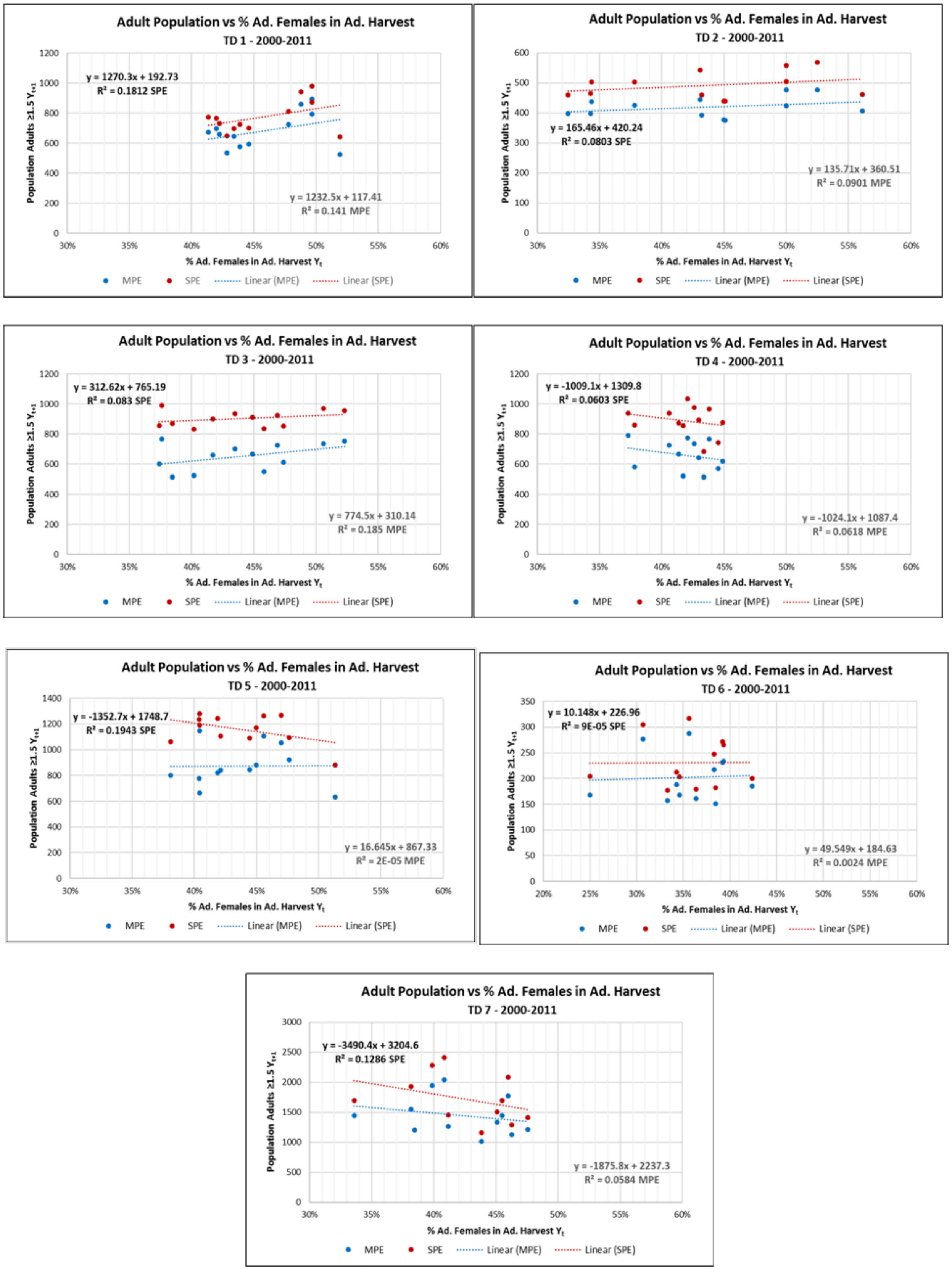


Figure 26. Linear relationship, R^2 between percent adult females in the adult harvest in year t and MPE and SPE of adults ≥ 1.5 in year $t+1$.

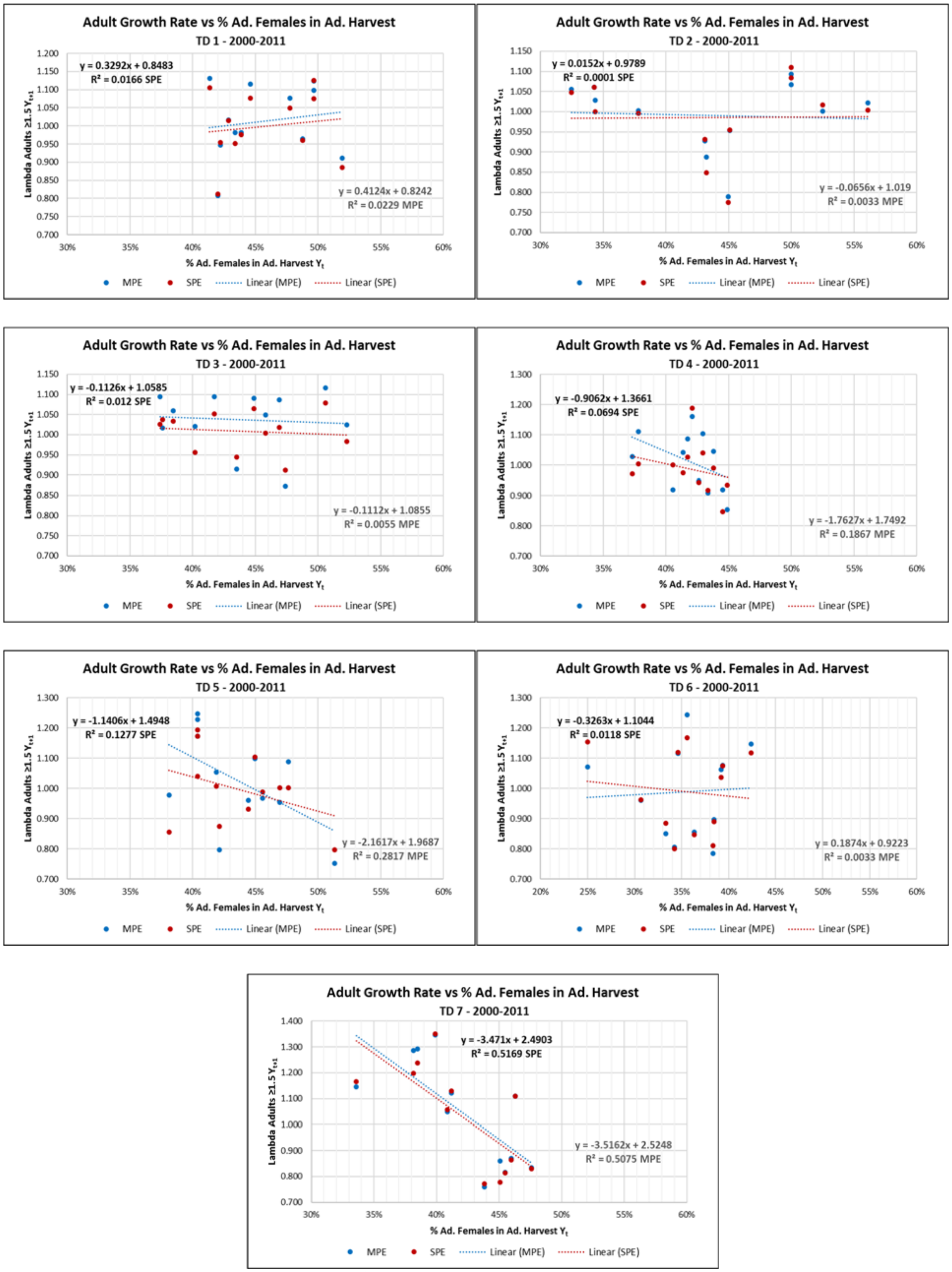


Figure 27. Linear relationship, R^2 between percent adult females in the adult harvest in year *t* and lambda of adults ≥ 1.5 in year *t+1*.

It is possible that the percentage of adult females in the adult harvest was not variable enough to cause detectable changes in numbers of animals or that these relationships trends were not obvious because of misidentification of sex.

Percent of Yearlings in Adult Population

The percentage of yearlings in the population varied by TD, and although TD 1 had the highest average juvenile to adult ratio in the state it had the lowest average percentage of yearlings in the adult population (Table 22).

There appeared to be a relationship between the percentage of yearlings in the adult population in year *t* and MPE and SPE in year *t+1* (Fig. 28) as all lines in each TD, except TD 6, sloped positively indicating that as the percentage of yearlings in the population increased in year *t* the adult population increased in *t+1*. In addition, TDs 1, 2, 4, and 5 for MPEs and all but TD 6 for SPEs showed positive associations ($P \leq 0.10$) in the relationship.

Table 22. Variation across trapping districts in the average percentage of yearlings in the adult population, 1999-2016.

Trapping District	Mean Percentage of Yearlings in Adult Harvest	Range
1	23.6%	9.9 – 31.4%
2	25.0%	10.4 – 38.6%
3	27.5%	13.8 – 47.3%
4	30.6%	19.1 – 61.1%
5	34.2%	18.8 – 53.7%
6	30.9%	7.7 – 49.3%
7	34.3%	2.1 – 61.2%
State	30.6%	14.9 – 47.7%

Best Metrics for Predicting Adult Population Size and Adult Population Growth Rate in Year *t+1*

Once the relationships between (1) bobcats harvested per day in year *t* and the adult populations in year *t+1* and (2) juveniles per adult in year *t* and growth rate of the adult population from year t to year *t+1* were developed, we could predict populations and growth rates for the current and recent years on a TD basis. Depending upon the time of year predicted populations might be used in up to five years including: 3 years where harvested bobcats have been aged but where population estimates will change the most as data is collected in the future; the year with harvest information and ages for juveniles only; and one year into the future (Figs. 29 and 30).

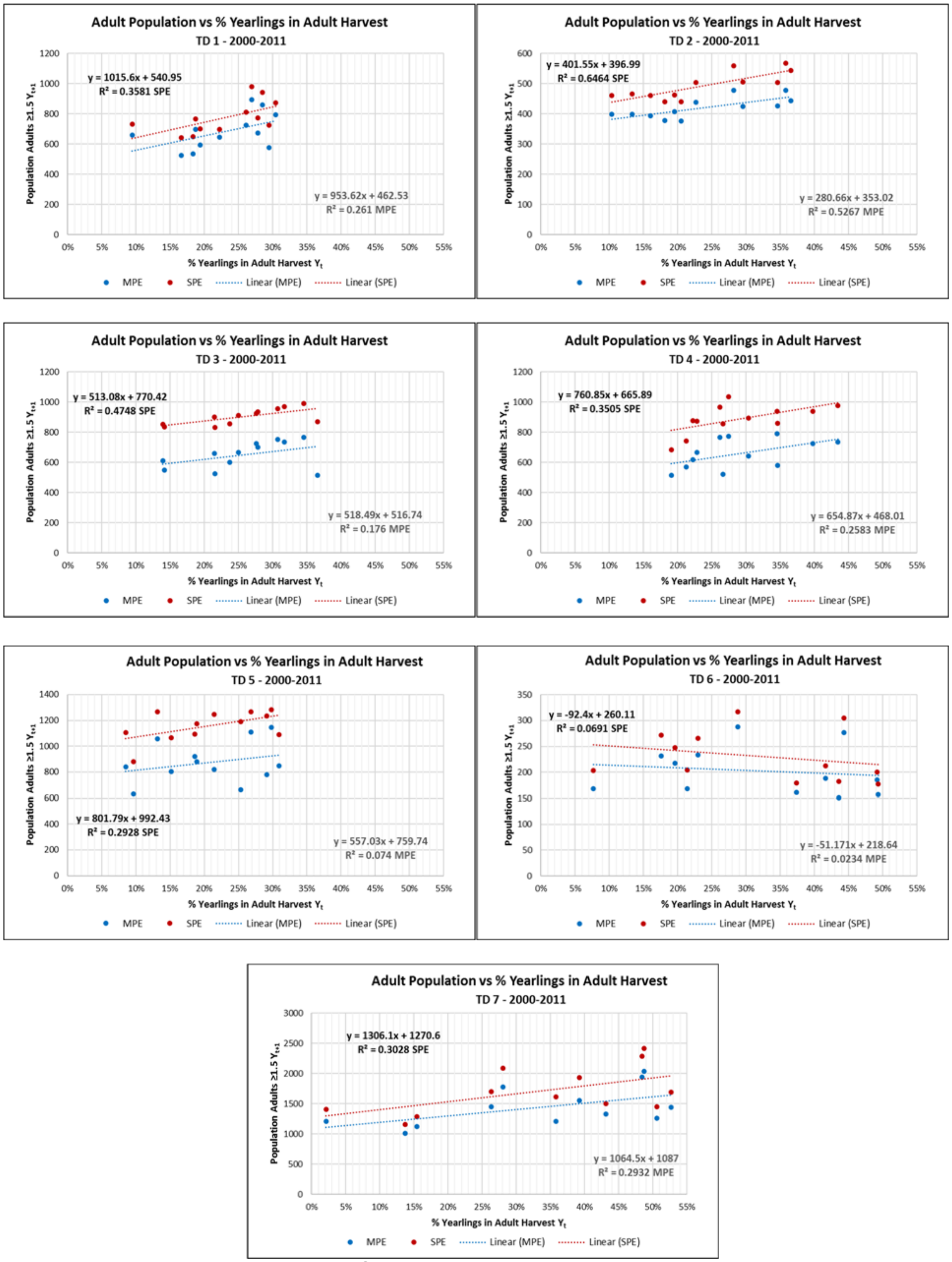


Figure 28. Linear relationship, R^2 between percent yearlings in the adult harvest in year *t* and population estimates of adults ≥ 1.5 in year *t+1*.

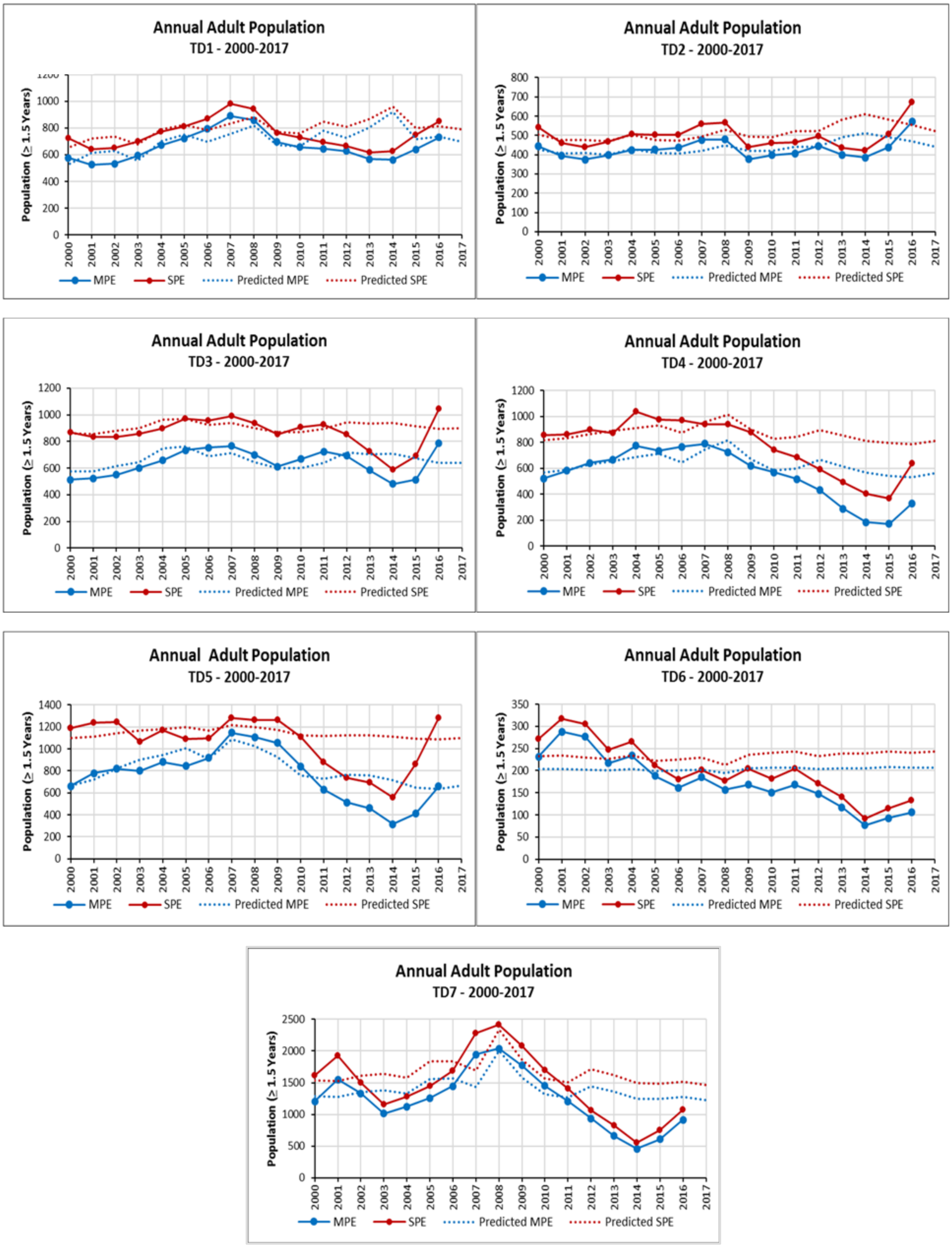


Figure 29. Populations calculated from backdating and predicted from the relationship between number of bobcats harvested per day in year *t* and the adult population in year *t+1*.

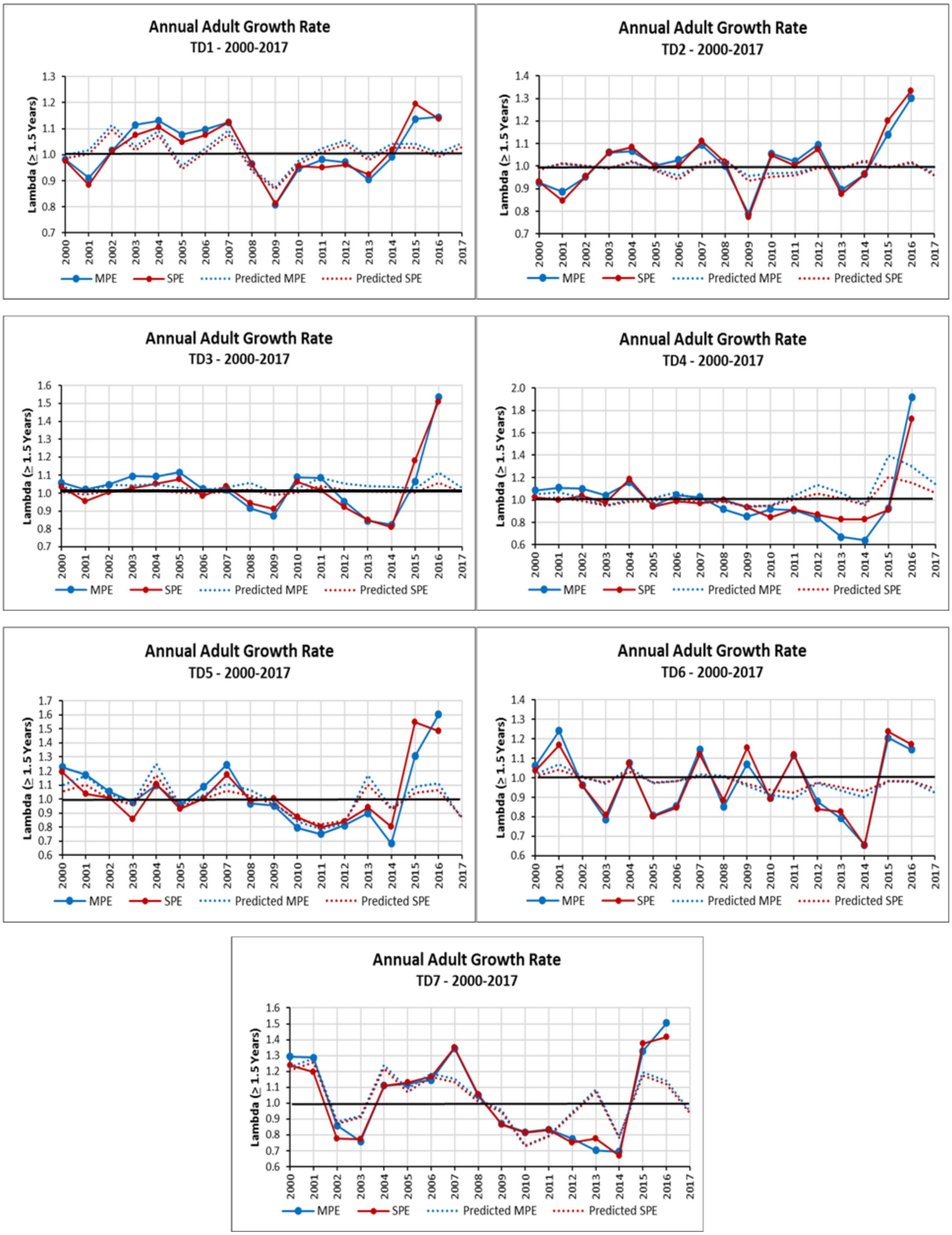


Figure 30. Growth rate of adults calculated from backdating and predicted growth rate from the relationship between juvenile:adult ratio in year *t* and lambda of adults in year *t+1*.

Sub-Sampling Ages

When using only 50% of the ages randomly chosen from known ages in TD 1-7, MPEs were still comparable to the original estimates using all known ages in most of the TDs (Table 23). The difference between MPEs using 50% of the ages, versus MPEs using 100% of the ages, ranged from 8.4 % below in 2009 in TD 1 to 11.2% above in TD 2 in 2009.

Table 23. Differences of MPEs using 50% of the ages and 100% of the ages, 1994-2009

TD	Range of Differences[1]	Mean Absolute Difference[1]	Range of % Differences	Mean Absolute % Difference
1	-82 – +48	25.5	-8.4% - +6.6%	2.9%
2	-26 – +64	23.4	-4.4% - +11.2%	3.9%
3	-28– +19	13.4	-2.9% - +2.2%	1.7%
4	-40– +75	28.6	-5.2% - +6.3%	3.2%
5	-16– +75	26.6	-2.4% - +7.9%	2.3%
6	-17– +19	8.2	-4.8% - +6.5%	2.7%
7	-21– +65	34.5	-0.7% - +3.5%	2.0%

[1]Number of bobcats.

DISCUSSION

Do Population Estimates Approximate Actual Population Size?
It is difficult to compare bobcat densities between study areas because densities are dependent upon the size of the area, the habitat quality within the defined area, and the size of the population at the time the density was calculated. We believe that the 2-mile buffer model and the max-ent habitat models represent a minimum and maximum amount of bobcat habitat in each TD. Our densities vary from an estimated highest density of 4.9 mi^2 habitat per bobcat in TD 7 over a geographic area of 15,976 mi^2 to a low of 78.2 mi^2 habitat per bobcat in TD 6 over a geographic area of 9,039 mi^2. Although there are not many studies reporting bobcat densities in northern latitudes Koehler & Hornocker, (1989) in Idaho estimated 1 bobcat per 9.0 mi^2 of habitat, while Knick (1990), also in Idaho, estimated 1 bobcat per 4.3 mi^2 and Berg (1979) in Minnesota estimated 1 bobcat per 6.4-9.7 mi^2. Those densities are similar to the densities reported in all the TDs in Montana at their highest SPEs using the 2-mile buffer model but are higher than the densities reported using the max-ent model at the lowest MPEs (Table 24). The density estimates calculated here, unlike many reported in the literature, were calculated on very large geographic areas that includes good, as well as marginal habitats.

Although home range sizes are not directly comparable to density estimates it is interesting that in a recent bobcat study completed in northwestern Montana (Newbury 2013) estimated home range sizes, albeit with very small sample sizes, of 16.4 mi^2 and

34.7 mi^2 for females and males, respectively. During that same time-period (December 2009 to February 2011), we estimated, using MPE, 1 adult bobcat for every 10.6 mi^2 using the 2-mile buffer and 1 adult for every 15.0 mi^2 using the max-ent model. Using the SPEs, we predicted 1 adult bobcat for every 9.6 (2-mile buffer) and 1 adult for every 13.8 mi^2 using the max-ent model.

Table 24. High and low estimates of the number of mi^2 of habitat per bobcat using minimum and scaled population estimates along with two habitat models for the period 2000-2016.

	Lowest Observed Density	Highest Observed Density
TD	Using Max-Ent Model and Minimum Population Estimate	2-Mile Buffer Model and Scaled Population Estimate
1	13.8 mi^2	6.0 mi^2
2	20.2 mi^2	8.1 mi^2
3	25.0 mi^2	6.9 mi^2
4	61.0 mi^2	6.7 mi^2
5	21.6 mi^2	5.6 mi^2
6	78.2 mi^2	7.6 mi^2
7	35.0 mi^2	4.9 mi^2

MPEs and SPEs Compared to 1983 Population Estimate

In 1982-83 a working group of biologists, trappers and wardens estimated that there was 109,795 mi. of bobcat habitat in the state and 8,154 bobcats. That estimate of bobcat habitat was comparable to the max-ent model statewide estimate, of between 102,106 mi^2 (using the eastern model) and 111,175 mi^2 (using the western model) for the entire state, respectively. The 1982-83 working group classified bobcat habitat into three categories for each TD. Those categories were based upon suitability, and they estimated the numbers of bobcats per mi^2 of habitat with high, medium and poor-quality habitats. The number of mi^2 of habitat per bobcat varied by category with biologists in TDs 1-6 estimating that a bobcat needed 12, 18 and 36 mi^2, of category 1 (best), 2 or 3 habitats, respectively, to survive while biologists in TD 7 estimated that it took 5, 10 and 24 mi^2, of category 1, 2 and 3 habitats, respectively, for a bobcat to survive. Population estimates made in 1982-83 were lower than the highest MPEs and lower than the low end of the SPEs in all TDs except TDs 6 & 7 where the 1982-83 estimates were higher (Table 25).

Statewide, estimates ranged from a low of 4,104 (MPE) 4,603 (SPE) animals in 2013 to a high of 8,484 (MPE) 9,191 (SPE) animals in 2007. The 1982-83 estimates represented a static one-time estimate of bobcat populations whereas this method allows biologists to see trends in populations over time and to predict populations at least one year into the future.

Table 25. Population estimates from 1982-83 and MPEs/SPEs from 2000-2016.

TD	Population Estimate 1982-83	MPE Low-High	SPE Low-High
1	680	744-1136	935-1249
2	670	506-720	589-854
3	912	759-1062	937-1400
4	763	292-1108	617-1397
5	815	617-1604	941-1841
6	515	116-391	139-435
7	3801	795-2769	990-3258
State	8156	4104-8484	4603-9191

Harvest Effort Scalar

Population estimates from reconstruction can be influenced by quotas, in that quotas sometimes limit users, which could cause an apparent decrease in backdated populations that may not be related to an actual decrease in the population of bobcats. Harvest can also be influenced by furbearer prices, which affects effort, weather especially snow and ice conditions, which can affect accessibility to the cats, and other factors unrelated to the actual population of bobcats. Furthermore, we know that the MPEs do not account for bobcats in the population that die of causes other than harvest. Therefore, we multiplied harvest by an effort-based scalar which resulted in higher population estimates. Use of the scalar could be very important when MPEs change for reasons other than changes in the bobcat population.

We believe that by considering both the MPE (ignoring the effect of variable effort) and SPE (using the TD-specific relationship between effort and harvest) managers will bracket the range of possibilities for the population in each TD. This will provide the user with a range of estimates that captures the uncertainty in what we know, given the VPA method we are using.

Utility of Population Estimates and Harvest Metrics for Annual Season Setting

Reconstruction of populations appears to be a valid technique to estimate populations of bobcats. We found estimates based on reconstruction changed the least after 3-4 years of harvest data were collected following the year of interest. This means that the most recent years population estimates were not as useful for annual season setting as we would have liked them to be. The number of bobcats harvested per day in year *t* can be used to predict populations of adults in year *t+1* in hunting districts where there is a positive association (p< 0.10) in the relationship. Even though we did not get statistically significant responses in TDs 2, 5 (SPE), and 6 biologists can look at trends and predictions from adjacent TDs to help set quotas. The number of juveniles per adult in the current year's harvest can be used to predict lambda of adults in year *t+1* in TDs 1, 5, and 7 where there is a positive association (p< 0.10) in the relationship Although R^2 values were much lower for this predictor and only three of seven TDs had a statistically significant response we believe that because all slopes were positive this predictor can be of use to help with quota setting in all TDs (see Appendix 1 for more information on using model outputs for quota setting recommendations)..

The advantage of using these indices are that they provide real-time estimates and allow predictions one year into the future which should be useful for annual season-setting processes.

Level of Exploitation in Montana

Other studies have indicated that the proportion of young animals (<2.5-year-old) in a population may be related to the intensity of harvest. Lembeck and Gould (1979) found that 16% and 43% of the bobcats in an unexploited and exploited population of bobcats in similar habitats were < 2 years old, respectively. In Montana, between 1994 and 2016, 44.1% of the bobcats harvested were < 2.5 years old. Neither MPEs or SPEs will predict or prevent high effort causing high harvest in a given year however, we believe that we have several safeguards in place that should prevent overharvest. First, if a population in year *t* begins to decline we should see fewer cats captured per day in year *t+1* which should cause biologists to recommend a decrease in the quota in year *t+2*. Second, we have regressed a decade of population growth rates against harvest levels and we have developed an estimate of general capacity for harvest. This tool gives us a science-based estimate of what levels of harvest have resulted in population decline, stability, or growth over a long time-frame. Finally, we can now look at long-term trends in populations and respond appropriately to those trends instead of responding only to a one-year change in numbers of bobcats.

Differences Among Trapping Districts in Maximum Harvest Levels

This analysis pointed out differences between bobcat populations in the 7 TDs in the state of Montana. TD 1, on average, has the highest juvenile to adult ratios (0.39) of all the TDs. Because of the high production of kittens, this TD should be able to sustain a relatively high harvest of cats on an annual basis. Bobcat densities were remarkably high in this TD, and harvest may be the primary mortality factor. It would appear that TD 1 can sustain a harvest of around 250 bobcats on an annual basis while maintaining an adult population of ~650 (MPE) to 800 (SPE) bobcats.

TD 2 has the second highest average productivity with 0.36 juveniles per adult, however density calculations reveal that there was a lower density of animals in TD 2 than in either TD 1 to the north or TD 3 to the east. Because habitat conditions in the north part of TD 2 are similar to habitat conditions in TD 1 and habitat in the east part of TD 2 was similar to TD 3, it seems that densities in TD 2 should be similar to TD 1 and/or 3, yet densities in TD 2 were almost always lower than in TD 1 and 3. It is possible that TD 2 has not maximized its harvest of cats, and there is a more conservative harvest in TD 2 than in TD 1 or 3. A more conservative harvest in TD 2 might also explain why the relationship between the number of cats harvested per day in year t and population of adults in year *t+1* was poorer in TD 2 than in 1 or 3. In other words, restrictions on harvest may be limiting population estimates rather than MPEs or SPEs reflecting actual populations of bobcats in this TD. It is possible that this TD could sustain a higher level of harvest although a more conservative approach will not harm the population.

TDs 3 has an average juvenile:adult ratio lower than those ratios observed in TDs 1 and 2. It appears that in TD 3 harvest/quota levels are in balance with the population with all indications that the population was relatively stable through 2013 and that an adult population of ~650 MPE or ~850 SPE can sustain an annual harvest of around 270 bobcats.

In TD 4 populations have been declining since 2006 and bobcats may have been over-harvested during the period 2004-2011 when over 300 bobcats were taken in 5 of 8 years and productivity was below average in 6 of those 8 years. It is likely that TD 4 can't sustain a harvest of 300 bobcats especially in years when productivity is below average. Once adult populations recover, this population, should be able to sustain a harvest of around 200-225 animals on an adult population of ~650 MPE to ~800 SPE

TD 5 has the fourth highest average productivity and one of the highest densities observed. The highest population in TD 5 was observed in 2007. Between 2004 and 2010, 392 or more bobcats were taken annually. Following those years of high take coupled with below average productivity from 2008-2011 the population began to decline and in 2012, populations were lower than in 2000. These observations would suggest that this TD can't sustain a harvest of 400 or more bobcats. Once populations recover to a higher level it is likely that an adult population of ~800 MPE to ~1000 SPE could sustain a harvest of 300-325 bobcats per year.

In TD 6 the relationship between numbers of bobcats harvested per day and the following year's population of adults as well as the relationship between number of juveniles per adult and lambda was poor. In addition, the predicted populations and lambdas were nearly static, an indication that there was not a good relationship between the indices used and the predictions made. It is likely that the small sample sizes in TD 6 may reduce data quality and predictive abilities of the indices. In addition, harvest in TD 6 may be affected by low populations of harvesters, poor access, and periodic difficult winters, all of which may serve to protect bobcats from exploitation in some years and allow for high exploitation in other years. Although the actual population estimates may be suspect it appears that trends in populations were like trends in TDs 4, 5, and 7 with populations declining following highs observed earlier in the decade.

TD 7 has a very high density of bobcats, however TD 7 also has highly variable productivity, and in recent years some of the lowest juvenile to adult ratios have been recorded in this TD. Like TD 6, TD 7 is also affected by the ability of harvesters to access bobcat habitat in the winter and a small number of harvesters living in TD 7, however recent declines in harvest and the declines in the population estimates were probably due more to the poor productivity than declining participation. In TD 7 quotas have been 600 or higher since prior to 2000 and held steady at 600 since 2010. Quotas in TD 7 have been met in only 5 of the last 16 years even during a time with high pelt prices and high use. In fact, the highest user number for the period 1994 to 2015 was recorded in 2012, and user numbers have been above average in all but one year since 2002. Since user numbers were high, relative to other years, and the quota was seldom met it is likely that harvest, and consequently population estimates, have been driven more by bobcat numbers than by quota manipulation.

Differences Between Eastern and Western Montana

Adult population trends in western Montana for TDs 1-3 are similar to each other. Trends in eastern Montana, TDs 4-7 are also similar to each other. Adult population trends in the west are quite different than the trends observed in the east.

In 2014-15, TDs 1, 2, and 3 MPEs were down 15.4%, 10.0%, and 24.6% from the long-term average, respectively while SPEs were down 16.6%, 15.3%, and 22.9% from the long-term average, respectively. Following the 2014-15 season all three TDs showed an upward trend in their backdated adult population estimates as well as their predicted adult population estimates to a level at least as high as the long-term average in each TD. In addition, the predicted adult populations for each TD in 2017 is higher than the long-term average population in each of these TDs.

Adult populations in eastern Montana have seen much steeper declines than in western Montana. In 2014-15 TDs 4, 5, and 7 MPEs were down 66.4%, 58.3%, and 62.8%, from the long-term average, respectively while SPEs were down 47.5%, 47.5%, and 62.3%, from the long-term average, respectively. Following the 2014-15 season all three TDs showed an upward trend in their backdated adult population however, unlike the western TDs, the backdated MPEs and SPEs in the eastern TDs for 2015 and 2016 remain well below the long-term average. The populations predicted from the relationship between bobcats trapped per day and adult populations are much more optimistic than the backdated population estimates and are near or above average.

Since 2009, TDs 4 and 5 have reduced their quota by over 60% while TD 7 reduced their quota by 25%. During that same period TDs 4 and 5 reached their reduced quota in most years while TD 7 did not reach their quota. Since quotas were seldom reached in TD 7, and populations still showed similar declines to TDs 4 and 5, we believe that TD 7 provides evidence that the declines in the MPEs and SPEs observed in eastern Montana are due to declines in bobcat populations and not a result of reductions in quota causing a lower effort by harvesters.

As the number of bobcats harvested in year *t* increased, lambda of the population in year *t+1* decreased, and this relationship was stronger in TD’s 1-3 than in TD’s 4-7. Conversely, as the number of juveniles per adult in year *t* increased lambda of the adult population in year *t+1* increased, and this relationship was stronger in TDs 5 and 7 (eastern TDs) than in any of the other TDs in the state. The number of kittens produced annually in TDs in the east was also more variable than in the west. Collectively, this information suggests that recruitment into the population may be a more important driver of population growth in the eastern TDs than in the western TDs, while harvest may play a more significant role in driving population growth in the western TDs than in the eastern TDs. This is not to suggest that harvest and recruitment are the only drivers affecting these populations, nor that only harvest or only recruitment is driving populations completely in either area.

Model Validation

We have done our best to capture the uncertainty in population estimates by using and presenting both the MPE and SPE. The MPE represents a known minimum population and it is likely that the SPE represents, in most cases, the maximum population. This uncertainty can be further reduced, if warranted, by using auxiliary information in the population reconstruction model (Clawson et al. 2013). Independent estimates of bobcat population vital rates, such as survival, fecundity, or recruitment, or independent estimates of population density, would help to improve the accuracy and precision of estimates generated by either of the methods we presented here.

Currently FWP has a contract with the University of Montana to develop a bobcat integrated population model (IPM). This model will take the age information we have used for backdating, along with additional auxiliary data from the scientific literature, such as age-class and sex-specific survival probabilities, fecundity by age-class, and independent estimates of population size to improve population estimates done by backdating alone. Very little bobcat research in Montana has been done since the 1980's so current information on vital rates, specific to Montana, will not be available to inform the IPM. Because of this lack of information almost any bobcat research would be beneficial to our understanding of bobcat populations, however research that would focus on estimating populations/densities in large geographic areas, survival rates of bobcats, fecundity and/or recruitment rates may be the most beneficial to help improve the IPM estimates and to test whether the VPA method described here is accurate. Additional research will cost more money, and therefore it may not be justified, but it should result in greater confidence in our population estimates and additional confidence that we are managing harvest at an appropriate level.

MANAGEMENT RECOMMENDATIONS

1. Continue to collect bobcat teeth for aging. It appears that populations could be accurately estimated by aging a subsample of all teeth, and we should test by how much we could reduce the number of bobcats aged. If the sample size of aged cats was reduced, all skulls would still need to have a preliminary age of adult or juvenile assigned to them. This step is important since we use juvenile to adult ratios to predict lambda. Once a preliminary age is assigned, a specific number of adult bobcat jaws could be randomly selected for cementum aging.

2. Continue to collect and use location data to estimate bobcat habitat. Plotting bobcat harvest locations and buffering those locations continues to be a tool that could be used by managers to monitor changes in bobcat habitat use and distribution over time. In addition, continue to run the max-ent model and look for ways to improve inputs to the model as additional harvest site locations are added to the database. Harvest location data may also be used in a standard multi-year occupancy model where harvests are treated as detections (MacKenzie et al. 2003).

3. Set numeric objectives with a reasonable range on each side of the point objective for the number of adult bobcats ≥ 1.5 in each TD. The objective could be based upon the average population estimates observed in each TD.

4. Management goal statement(s) for each TD should be established. This goal may be a statement such as: “Maintain a well distributed numerically robust population of bobcats, while providing for recreational opportunities to harvest bobcats.”

5. Test if backdating and our predictions of populations provide a reasonable estimate of population sizes. For example, population estimates from genetic sampling could be a viable technique for comparison to the MPEs and SPEs calculated in this document. A genetic study could be completed in specific study sites across a large geographic area, like the work done on bears in Montana (Mace and Chilton-Radandt 2011) or in in a smaller geographic area like the work done on bobcats in Michigan, to determine density and then to compare those densities to densities in this document (Stricker et al. 2012). Also, spatial capture recapture techniques like those used on lions in western Montana (Proffitt et al. 2015) might be used to estimate populations in relatively large geographic areas. Independent estimates of bobcat vital rates would also be useful to compare to estimates generated from the VPA techniques, including estimates of population trend.

APPENDIX 1

Model Output Interpretations and Use, 2018

An excel based population model was developed that calculates populations from backdating bobcat ages to their birth year. This model also produces estimates of the R^2 values of the relationship between 1) bobcats trapped per day in year t and adult populations in year t+1, and 2) juvenile per adult ratios in year t and lambda of adults in year t+1. In addition, the model predicts populations of adults and lambda of adults from those linear relationships for each year in the past and one year into the future. As more age data is collected and added to the model some of the specific recommendations below will likely change.

1) Model users should run the model with and without the scalar. Once the models have been run the model user will have several outputs to look at, which together capture the uncertainty in our knowledge of bobcat population sizes given our methods, to help decide whether to raise, lower or maintain the bobcat quota for the following year. The following model outputs are important to look at: 1) the graphs of the populations which will show the adult population ≥ 1.5, adult population trend ≥ 2.5 and total population trend since 2000 using and not using scalars, and 2) the predictions for adult populations and lambda for adults in more recent years. Model users in TDs 1-3 should look at the trends for the other TDs in the western part of the state and model users in the eastern part of the state should look at outputs for TDs 4, 5, and 7. The trends in population will be of value in setting quotas.

2) Use the number of bobcats harvested per day in year *t* to predict populations of adults in *t+1* for recent years, including 3 years prior to present year as well as the next year. This will allow managers to fill in population data for all years not estimated as accurately by backdating and to predict adult populations one year into the future. The MPEs and SPEs predicted from this relationship in TDs 2 and 6 and the SPE for TD 5 were extremely poor and should be used with caution. Because the linear relationships between bobcats harvested per day and adult populations, and juvenile to adult ratios and lambda were so poor in TDs 2 and 6, using outputs/predictions from other TDs to help decide on proposed quota changes should be considered.

3) Use the juvenile to adult ratio in year *t* to predict adult population growth in year *t+1* for recent years, including 3 years prior to present year as well as the next year. This will allow managers to predict population growth for all years not estimated as accurately by backdating and to predict population growth one year into the future. The growth rates predicted from this relationship in TDs 2, 3, 4, and 6 were not very good and should be used with caution.

4) We recommend using the juvenile to adult ratios instead of juvenile to adult female ratios to predict lambda of adults since the literature indicates that

misidentification of sexes is common, and the two relationships generate comparable results.

5) Because there was no indication that the percentage of adult females in the adult population has an influence on population growth or population estimates we would recommend dropping it from the metrics monitored and not use it in season justifications.

6) The percentage of yearlings in the adult population was a good predictor of adult population in *year t+1*. Even though it can't be collected in time in year *t* to set the quota in year *t*+1 it still may be valuable to consider, especially if other data is providing conflicting information.

7) Although not part of the actual population model, we recommend using the observed relationship between total harvest in year *t* and lambda of the total population in year *t+1* to help with setting quotas. Currently this relationship does not work very well for TDs 6 and 7.

8) Update the following relationships on an annual basis as age information is collected.
    a. The relationship between bobcats trapped per day in year *t* as a predictor of adult population in year *t+1*.
    b. The relationship between juveniles per adult in year *t* as a predictor of growth rate of adults in year *t+1*.
    c. The relationship between total harvest in year *t* as a predictor of growth rate of the total population in year *t+1*.

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