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A Predictive Population Model for Cougars in Oregon

Abstract

Cougar numbers in Oregon declined between 1928 and 1961, primarily due to excessive harvest from the bounty system. Cougars were classified as a game mammal in 1967 and sport harvest began on a limited basis in 1970. Because determining population size of cougars by direct count methods is impractical, indirect methods to evaluate status are needed. We analyzed harvest levels, damage complaints, and data obtained from harvested cougars to evaluate their status in Oregon. Biological data obtained from Oregon and other states were used to develop a density dependent model of the cougar population of Oregon. As indicated by the model, numbers increased from an estimated low of 214 in 1961 to 2,830 in 1992, which coincided with other indicators including increased livestock damage, human safety complaints, and sport harvest. The model indicated higher mortality rates for hunted populations and lower proportions of juvenile cougars in populations at carrying capacity. For the modeled population in 1993, sport harvest rates of 5.4% allowed a 5% annual growth. A sport harvest of 10% of the population and a total mortality rate of 35% was needed to stabilize that population. The model predicted that if sport harvest ceased, cougar numbers would increase until carrying capacity is reached in the year 2009. We believe the model is a useful tool to summarize existing data, explore effects of hypothesized management plans, and adaptively aid in management decisions. The model can be adapted to other states if appropriate population parameters can be determined.

Introduction

Historically, cougars (*Puma concolor*) were considered an undesirable predator in the western United States. Perceived as a threat to livestock, state and federal agencies implemented programs that resulted in a substantial reduction in cougar numbers and elimination of cougars from much of their historic range (Dixon 1978). In Oregon, a bounty system for cougars existed until 1961. Statistical analyses in the early 1970s, based on population estimates from harvested cougars, indicated that the statewide population in 1961 was extremely low and without protection, cougars would likely have been extirpated from Oregon by the early 1970s (Warren W. Aney, 1973, unpublished letter on file at Oregon Department of Fish and Wildlife, Portland).

Cougars were afforded game mammal status by the 1967 Oregon Legislature and no season was authorized until 1970. Limited hunting began in 1970 when 25 tags were authorized, primarily in response to livestock damage concerns in a small area of northeastern Oregon. Since then, livestock damage complaints, cougar sighting reports, and past harvest history have been the primary factors used to recommend hunting seasons. Legal challenges to cougar hunting in 1988 prompted the Oregon Department of Fish and Wildlife (ODFW) to look for additional ways to assess the status of cougar populations.

Because of their low densities, secretive nature, and large home ranges, wildlife managers and researchers have struggled with the problem of accurately measuring cougar populations. We are unable to measure, on an annual basis, most of the parameters necessary to know precisely what is happening with local cougar populations at all times. Our poor monitoring capability is because methods are simply not available to measure cougar populations with the precision possible for other species (e.g. Douglas-fir trees, bald eagles, mule deer, pronghorn) and money is rarely available to use the methods that are available. The best population estimates come from intensive field work (Lindzey 1987). Track counts have been used in several areas (Ashman et al. 1983, Neal et al. 1987). However this method only provides an index to population, depends on a good tracking substrate such as snow or dust, and has been costly. Most commonly, radio telemetry has been employed in mark-recapture and complete capture studies. Several years are necessary to determine

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a population estimate. Both methods are costly and time consuming because of the logistics involved in capturing a high proportion of the population in a large area of rugged habitat. In addition, results of such studies may represent only a small portion of the state. We employed statistical analysis and population modeling to assess status of cougar populations throughout the state. We relied on data accumulated over many years and results of studies in Oregon and other states. Whereas it appears there are numerous pieces of unrelated information relative to cougars, through population modeling we can combine this information in a way that approaches reality and better explains cougar population performance. Our objectives for this paper were to: 1) analyze historical data to help determine status of cougar populations in Oregon and 2) develop a biologically intuitive model that relies on data that are readily available and which can be created and used by managers.

Study Area

Habitats in Oregon are diverse. Temperate coniferous forests dominate the Coast Range and western slope of the Cascades. Several interior valleys of western Oregon are used for agriculture, such as grass seed production, fruit and vegetable farming, dairy farming, and livestock operations. Most (87%) of the human population (~3,000,000) reside in the western interior valleys (Levine 1995). East of the Cascade Mountains, habitats are drier and include coniferous forests on the east slope of the Cascade Range and in the Blue Mountains; shrub steppe dominates the southeastern third of the state. Intensive agriculture occurs at lower elevations in the Columbia and Snake River basins.

Cougars are distributed statewide except for areas where agricultural practices and human development have altered habitat suitability for cougars and their prey. For the most part, cougars are closely associated with deer and elk distributions in the state. In the 1990s, reports to ODFW of cougars in urban and suburban areas became increasingly common.

Methods

A mandatory check-in of all cougars taken during hunting seasons in Oregon was instituted in 1970, while check-in of cougars killed on depredation has occurred since 1980. Reproductive status, stomach contents, age, and sex of harvested cougars were determined at the ODFW Wildlife Laboratory in Corvallis.

Analysis of Harvest and Complaint Data

We used regression analysis to examine hunter harvest and success and to determine if there were significant trends through time. Several dependent variables (bountied cougars, sport-harvested cougars, hunter success) were individually regressed against time. The analysis was broken into two periods: 1) 1928-61 during the cougar bounty years, and 2) 1970-92 when cougars were hunted as a big game mammal with an annual limit on the number of tags issued per hunt unit. In addition, "other losses" (e.g. depredation, accidents), 1980–1992, and damage complaints, 1970–1992, were used as dependent variables in simple regressions against time. Relationships between dependent and independent variables were considered significant at $P \leq 0.05$. Damage complaints most commonly included complaints to ODFW from depredation on livestock and sightings of cougars on private property where there were concerns for human safety.

Biological Parameters

Many biological parameters affecting cougar populations must be considered in model development. Factors that affect productivity were age at first breeding, birth interval, litter size, sex ratio, and longevity. Factors affecting age-specific mortality included natural and human-caused mortality (e.g. sport or depredation harvest, auto collision). Several studies of cougars in the western states and Canada have reported results relative to these factors (Table 1). We used plausible values for these parameters based on data collected mostly in Oregon or representative of cougar populations throughout their range.

Seidensticker et al. (1973) believed young females usually breed only after establishing a home range. Data collected in Oregon support that hypothesis (Trainer and Golly, 1989). Based on these data and results found elsewhere (Table 1), we assumed that all females > 3 yr old and 69% of those between 2 and 3 yr of age breed. Thereafter, females normally breed soon after loss of kittens or dispersal of their litter (Lindsey 1987) causing the birth interval to vary (Table 1). We assumed

TABLE 1. Factors affecting cougar populations and the range of values reported by various authors.

Productivity factor	Values reported	Source
Age at first breeding	16 - 29 mo	Eaton and Velander 1977
	27 - 33 mo	Young and Goldman 1946
	29 mo	Rabb 1959
	22 - 24 mo	Ashman et al. 1983, Logan et al 1986
	20 mo	Lindzey 1987
Birth interval	24 mo	Johnson and Couch 1954
	24 mo	Robinette et al. 1961
	12-20 mo	Hornocker 1970
	17.4 mo	Ashman et al. 1983
	18 - 24 mo	Lindzey 1987
	12 - 17 mo	Lindzey et al. 1994
	19.9 mo	Anderson et al. 1992
Litter size	2.0	Johnson and Couch 1954
	2.5	Hornocker 1971
	2.5	Eaton and Velander 1977
	2.6	Anderson 1983
	2.8	Ashman et al. 1983
	2.7	Logan et al. 1986
	2.4	Hemker et al. 1982
	2.4	Lindzey et al. 1994
	2.8	Toweill et al. 1984
	2.4	Toweill et al. 1988
	2.4	Trainer et al. 1993
Sex ratio (male:female)	100:100 (population)	Johnson and Couch 1954
	100:100 (population)	Tanner 1975
	125:100 (kittens)	Ashman et al. 1983
	125:100 (harvest)	Anderson 1983
	100:100 (capture)	Logan et al. 1986
	120:100 (harvest)	Toweill et al. 1984
	150:100 (harvest)	Trainer et al. 1993
Longevity	18 yr	Anderson 1983
	15-18 yr	Young and Goldman 1946
	10 yr	Johnson and Couch 1954
	7 yr	Logan et al. 1986
	12-17 yr	Trainer et al. 1993
Age Specific Mortality Rates	Adults—10%	Johnson and Couch 1954
	Kittens—26%	Tanner 1975
	Adults—12%	Tanner 1975
	Overall—32%	Robinette et al. 1977
	Kittens—28%	Ashman et al. 1983
	Overall—30%	Ashman et al. 1983
	Overall—26-28%	Lindzey et al. 1988
	Overall—12%	Anderson et al. 1992

an average birth interval of 19 mo, which is equivalent to a 63% (12 mo/19 mo) annual pregnancy rate.

Documented litter sizes are somewhat consistent among existing studies (Table 1). Litter size can be indicated by counting corpora lutea in

harvested females each year. However, we do not know how long corpora lutea may last for cougars and corpora lutea counts tend to over-estimate litter size. We, therefore, used a value of 2.4 kittens/litter in our model because it was based on fetuses present in pregnant cougars rather than corpora lutea (Trainer et al. 1993). It was the most recent and complete measurement of litter size for cougars in Oregon and was similar to values reported elsewhere.

Sex ratios at birth are commonly equal whereas sex ratios in the harvest are often skewed toward males (Table 1) due to either higher vulnerability of males or selection for males by hunters. In the interest of simplicity, we assumed equal sex ratios.

A wide range of longevity values has been reported (Table 1). In Oregon, 22 of 1,089 (2%) cougars aged from 1987 through 1992 were between 12 and 17 yr of age (Trainer et al. 1993), therefore we used a maximum age of 17 yr for this model.

Age-specific, natural mortality rates are difficult to assess accurately. Specific mortality rates are not available for each age (Table 1), but are necessary for modeling. Several authors agree that kittens, dispersing subadults, and very old cougars experience higher mortality than prime-aged adults (Tanner 1975, Russell 1978, Anderson 1983). For our model, the following natural mortality rates were assumed: 5% for kittens (<1 yr-old); 20% for 1, 2, and 10-13 yr-old; 8% for prime-aged adults (3-9 yr-old); 25% for 14-17 yr-old; and 100% for 18 yr-old.

Human-caused mortality includes losses due to accidents (e.g. road kills), cougars killed on livestock depredation and safety complaints, illegal harvest, and sport harvest. These losses must be accounted for and distributed among age classes at different rates from natural mortality. Records of "other losses" (e.g. accidents and depredation kills) in Oregon have been kept since 1980 and ranged from 10 in 1983 to 50 in 1993. To account for such sources of mortality before 1980 and after 1993, "other losses" were estimated at an annual mortality rate of 2.3% of the adult population, which provided close calibration between predicted and observed mortality for the 1980 through 1993 period.

Losses of cougars from illegal harvest have been reported (Anderson 1983); however, actual rates of illegal kill have been difficult to document. Anderson et al. (1992) reported that two of 49 radio-marked cougars in an unhunted population in Colorado were illegally killed from 1981 through 1988. Neal et al. (1987) reported 11% to 16% of 19 marked cougars were lost illegally in Northern California over a two-year period. In Washington, eight of 26 marked cougars were illegally killed from 1974 through 1986 (Dave Brittell, 1987, Washington Department of Fish and Wildlife, personal communication). Average annual illegal mortality in an ongoing study in southwestern Oregon was 6.2% for 65 radio-collared cougars from 1993 through 1998 (DeWaine H. Jackson, 1999, Oregon Department of Fish and Wildlife, personal communication). In northeastern Oregon, one of 27 collared cougars was illegally killed between 1989 and 1994 (Mark G. Henjum, 1995, Oregon Department of Fish and Wildlife, personal communication). For our model, a value of 3.5% of the adult population was chosen to represent illegal kill for the entire state.

Legally harvested cougars were added to "other losses" and estimated illegal kill to obtain total human-related loss. Based on ages of 1,089 cougars killed in Oregon between 1987 and 1993 (Trainer et al. 1993), human-related loss was apportioned to the 0 to 1 yr age class at 5.6%; and to the 1 to 2 yr age class at 11.4%. However, for adults (age 3 to 17 yr), we assumed losses in each age class occurred in proportion to availability of that age class in the population.

Model Development

A mathematical model of Oregon's cougar population was developed in the form of a life table using spreadsheet software on a microcomputer. To create a model that behaved realistically during and after bounty years, we began the model in 1928 when numbers of bountied cougars were relatively high. Number of cougars in each age class was initially estimated based on ages of cougars checked in during 1987–1993 (Trainer et al. 1993). We used iteration, that is we ran the model several times changing the beginning age ratios each time based on results, to determine the age distribution that best represented the 1928 population and its harvest pressure. Input for each year included legal (i.e. sport or bounty) harvest, other losses, and illegal kill. Number of cougars in each age class, except kittens, was determined

by starting with the number of cougars in the prior age class, during the previous year and adjusting for age specific mortalities (both natural and human-caused). To calculate number of kittens (young born and surviving for one year) in a particular year, number of breeding adults surviving from the previous year was multiplied by proportion female, proportion pregnant, and litter size. Number of kittens was then adjusted for mortality. We assumed that kittens died if their mother died during the first year of the kitten's life.

An independent estimate of population was used to calibrate the population model. Warren W. Aney (1973, unpublished letter on file at Oregon Department of Fish and Wildlife, Portland) used formulas provided by Johnson and Couch (1954) to calculate the Oregon population based on harvest (1913 - 1961). A statewide population estimate for 1961 was 214 cougars. Total population for the starting year of 1928 was adjusted in the model until the 1961 population was as near as possible to 214 without causing the population to crash thereafter. The 1961 population estimate was the only and best available and indicates the population in the state was very low, but not extinct.

We assumed that cougar populations could not grow indefinitely. Tanner (1975) estimated intrinsic growth rates for several prey species and their predators using differential equations. He determined that for the cougar-deer predator/prey system, equilibrium can be achieved when cougars are limited by deer numbers if deer numbers are low, or by a certain maximum predator population if deer numbers are high. Seidensticker et al. (1973) believed that cougar density in the Idaho Primitive Area was probably controlled by social behavior interacting with habitat factors (e.g. vegetation and topography) and prey numbers to produce maximum densities characteristic of particular areas and habitat types. Cougars are territorial and males defend that territory against other males, often killing them as well as kittens (Dixon 1978). Adult females are occasionally killed by other cougars (Lindzey 1987). As density increases, territories overlap more, probably causing a higher incidence of intraspecific predation.

Cougar densities have been documented at 1.0 to 1.6/100 km^2 in Nevada (Ashman et al. 1983) and as high as 5.2/100 km^2 in eastern Fresno County, California (Neal et al. 1987), 6.7/100 km^2 in Black Gap, Texas (Parsons 1976), and 9.2/100 km^2 in Glenn and Colusa Counties, California (Sitton 1972). In Oregon, preliminary study results indicate present densities of 3.9/100 km^2 in the northeastern Blue Mountains (Mark G. Henjum, 1995, Oregon Department of Fish and Wildlife, personal communication) and 5.4/100 km^2 in the southwestern Cascades (Jackson et al. 1999). To allow the model to behave in a density dependent manner, a maximum population was estimated for Oregon by assigning maximum densities to each region of the state based on findings of studies in Oregon and other areas of similar habitat in the West. Maximum density estimates for western Oregon ranged from 8.0/100 km^2 in southwestern Oregon to 4.0/100 km^2 in northwestern Oregon. In eastern Oregon, maximum density estimates ranged from 1.6/100 km^2 in southeastern Oregon to 3.2/100 km^2 in central Oregon, and 3.9/100 km^2 in the Blue Mountains of northeastern Oregon. A weighted average (based on area of each region in Oregon) of 3.2 cougars/100 km^2 was obtained for the state, which corresponds to a maximum possible population of 8,064 cougars.

To incorporate density dependence into the model, a density factor (DF) was assumed when the population reached 75% of the 8,064 cougar maximum. The DF was used to increase age specific, natural mortality rates (mortality rate x DF) and decrease productivity (proportion pregnant each year/DF). The DF depended on the proportion of maximum population (M) and was calculated using a quadratic equation ($DF = 2.8–4.9 M + 3.5 M^2$). The quadratic equation was determined algebraically to fit a curve that produced a DF that increased as the population approached maximum so that when applied to productivity and mortality, a logistic curve characteristic of a population growing to carrying capacity was created. We applied the density factor at 75% of the maximum population because we felt 75% would be a high enough density in the wild to begin to influence lower productivity and higher mortality. However, we built into the model the ability to readily change parameter values so we can modify the model as we learn more information or want to try different assumptions. Thus, other equations for DF or how and when DF is applied can be explored. In fact, for purposes of comparison, we calculated a different quadratic equation that was applied at 50% of maximum population. The difference between the two curves was trivial.

We conducted sensitivity analysis to determine which factors were most important in affecting population performance. We varied proportion pregnant, litter size, natural mortality rates, and rates of "other losses" and illegal kill by 10%, then noted the resulting change in cougar population after 1 yr and 20 yr.

Results

Data Analysis

Number of cougars taken annually under the bounty system peaked at 337 in 1930 and thereafter declined to a low of 26 in 1961. Analysis of harvest data between 1928 and 1961 showed a significant decline in cougars bountied (Figure 1). Since

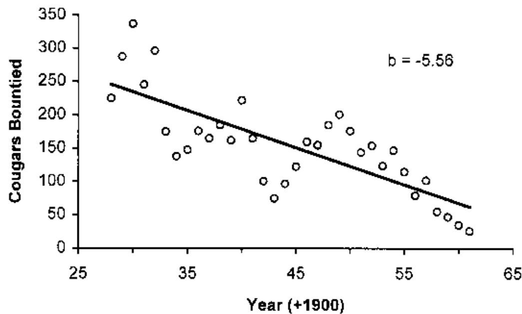

Figure 1. Simple linear regression of number of cougars bountied vs. time in Oregon ($r^2 = 0.59$), 1928-1961.

limited sport harvest began in 1970 (Figure 2), annual harvest increased significantly through 1992 from 10 in 1970 to a high of 187 in 1992. Hunting success averaged 41% during the period and did not decline signigicantly. Since 1970, damage complaints increased significantly (Figure 3), as did "other losses" (Figure 4).

Population model

The modeling process allowed the logical combination of seemingly unrelated information into an understandable form that helped explain cougar population trends and status in Oregon. The model indicated over-exploitation of the population during the period of the bounty system, with the population reaching a low in 1961 and rebounding under limited harvest regulations to a high of 2,830 in 1992 (Figure 5).

The model was used to predict population performance under four scenarios (Table 2). For 1993 conditions in Oregon, hunted and below carrying capacity, 5.4% of the modeled population was legally harvested. The total mortality rate, kitten mortality rate, and mortality rates for dispersing juveniles (1-2 yr-old and 2-3 yr-old) were greater than for an unhunted population below carrying capacity (Table 2). For an unhunted population below carrying capacity, mortality rates were reduced to natural mortality rates for 1-2 yr-old,

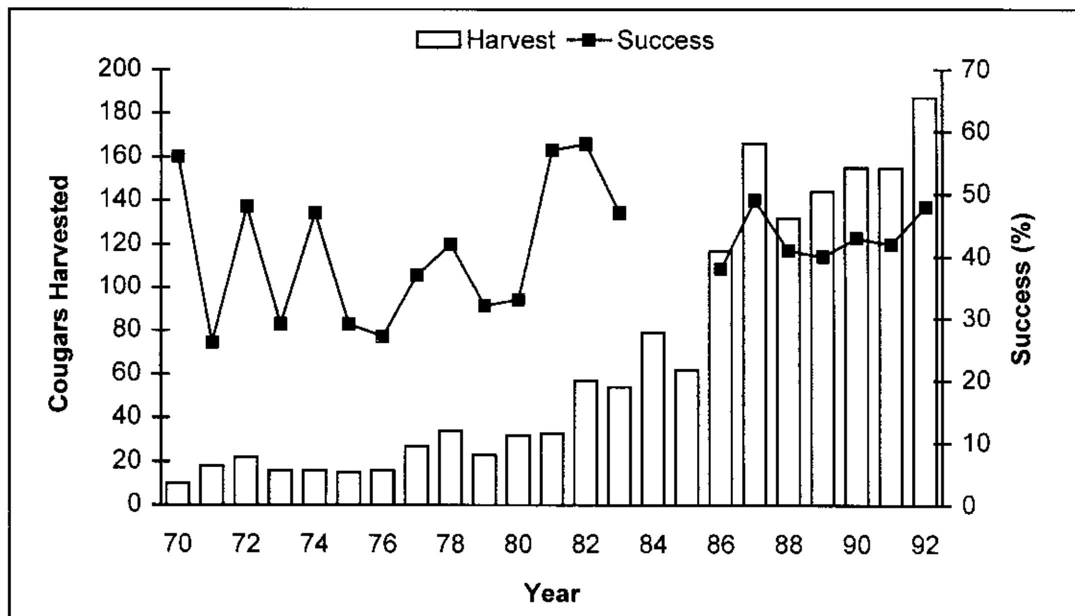

Figure 2. Number of harvested cougars and hunter success (%) in Oregon, 1970-1992 (No hunter survey in 1984 and 1985).

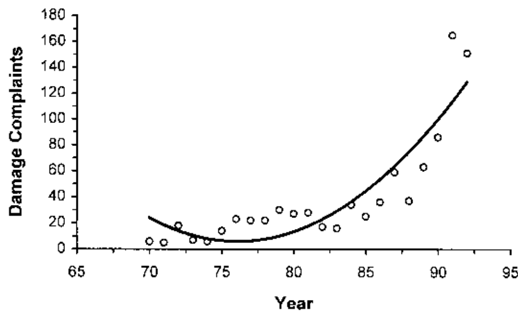

Figure 3. Polynomial regression of cougar damage complaints in Oregon vs. time ($r^2 = 0.79$), 1970-1992.

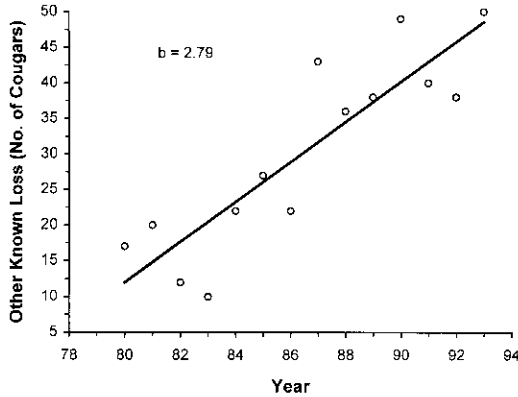

Figure 4. Simple linear regression of known cougar mortalities from other than legal harvest in Oregon ($r^2 = 0.73$), 1980-1992.

and adults between 3 and 9 yr (Table 2). However, the mortality rate for kittens was higher (19%), because in addition to the 5% direct natural mortality built into the model, kittens also died when adult females died of natural causes. The modeled population stabilized at carrying capacity through a combination of decreased productivity and increased mortality (Table 2).

TABLE 2. Characteristics of a hypothetical cougar population in Oregon determined by a simulation model.

	Population Status			
	Below carrying capacity		At carrying capacity	
	Hunted	Unhunted	Hunted	Unhunted
Mortality Rates (%)				
Total	30	24	29	26
Kittens	31	19	27	20
1 yr	23	20	29	32
2 yr	27	20	31	32
3-9 yr	16	8	16	13
10-13 yr	27	20	31	32
14-17 yr	35	25	36	40
Birth Interval (mo)	19	19	26	30
Age Structure (% of population)				
Kittens	26	27	23	23
1-2 yr	19	18	17	15
3-17 yr	55	55	60	62

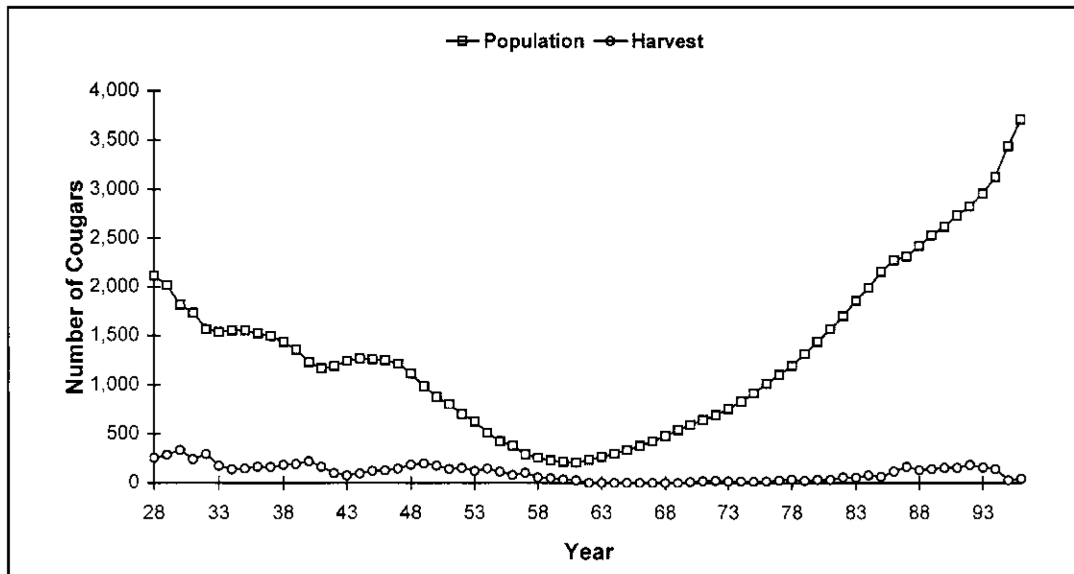

Figure 5. Cougar population, as determined from simulation modeling, and harvest in Oregon, 1928-1992. Cougars were bountied until 1961. The season was closed until 1970 when limited hunting began.

Age distribution of the modeled population depended primarily on the status relative to carrying capacity rather than on whether it was hunted (Table 2). Proportion of 0-2 yr-old animals was greatest for populations below predicted carrying capacity (45% juveniles: 55% adults). At carrying capacity, age structure of a hunted population (40% juveniles: 60% adults) was similar to an unhunted population (38% juveniles: 62% adults).

Sensitivity analysis showed that 10% changes in litter size and proportion pregnant could change the predicted population after 20 yr by 159% and 143%. A 10% change in natural mortality rate had a 117% effect on population performance. In contrast, 10% changes in "other losses" and illegal kill had only 16% and 22% effects on population.

Discussion

Our analysis of harvest data agreed with Warren W. Aney (1973, unpublished letter on file at Oregon Department of Fish and Wildlife, Portland), who used linear regression of number of cougars bountied versus time (1913–1961) to conclude that if the state's cougar population had continued to decline at the same rate, it would have reached zero by 1973. Cessation of the bounty system in 1961 and limited hunting, which began in 1970, resulted in significant increases in sport harvest, with stable hunter success, and increases in damage complaints and "other losses". Significant increases in harvest, "other losses", and damage complaints indicate cougar populations in Oregon have grown and adds support to the validity of the model.

Increases in damage complaints and "other losses" may be somewhat influenced by increases in the state's human population. The state's population increased from ~2,092,000 to 3,082,000 (47%) from 1970 to 1994 (Levine 1995). But in the 11 eastern counties that constitute about half the land area, the human population increased only 26% (~176,000), 1970–1994. In addition, land ownership patterns are such that most human habitation is in more developed, lowland areas and not in historic cougar habitat. In Oregon, 55% of the land is publicly owned (Levine 1995), most of which is located at higher elevations; private lands are primarily located at lower elevations. While human populations have increased, particularly on the west side of the Cascades and in central Oregon, that increase has mostly been confined to those lower elevation areas.

For model development, we input basic biological data relative to productivity and age specific mortality obtained from numerous sources, mostly Oregon. We then compared population performance (total population mortality and population age ratios), as calculated by the model, to results from several different sources.

Comparison of studies of wild cougar populations with model simulations is complicated for several reasons. Researchers are often unable to monitor all members of a particular population and small sample sizes are common. Kitten mortality is often underestimated because kittens are usually not found until several months after birth. Population status (below or at carrying capacity) is often not known or stated in study results. In addition, researchers have sometimes not defined ages for kittens, juveniles, and subadults and have sometimes used these terms to represent different aged animals in different studies.

In spite of difficulties in precisely measuring wild cougar populations and comparing with model simulations, results of several studies allow some comparisons of population performance in terms of mortality rates and age composition. We calculated mortality rates from data presented by Hornocker (1970) for a cougar population in a central Idaho wilderness during 1964–69. That population received light hunting pressure during the study, but was hunted for bounty prior to the late 1950s. Therefore, this Idaho population likely represented an unhunted population below carrying capacity. Overall mortality was 17%, with 21% for juveniles and 14% for adults. From data collected in the same area by Seidensticker et al. (1973), we calculated a mean of 27% juveniles in the population between 1964 and 1972. These results are similar to mortality rates and age composition determined by our model for a hypothetical unhunted population below carrying capacity in Oregon. Overall mortality was 24% with 19% for kittens, 20% for 1-2 yr-old, and 8% for adults (3-9 yr-old). The population comprised 27% kittens and 18% 1–2 yr-old (Table 2). However, Anderson et al. (1992) calculated a lower overall mortality rate (12%) for a population in Colorado which was unhunted during the study, but had been hunted before the study. For cougars captured during that study, 46% were kittens and 21% were 1–2 yr.

Our model generally agreed with findings from several hunted populations and mortality rates were greater than for unhunted populations. For a hunted population below carrying capacity, the model predicted mortality rates of 30% total and 31% for kittens, and an age ratio of 26% kittens and 19%, 1-2 yr-old (Table 2). These proportions suggest an age ratio of approximately 38% (26.0% + 9.5%) for juveniles <1.5 yr-old and 45% (26% + 19%) for juveniles < 2 yr-old. In a hunted population in Nevada, Ashman et al. (1983) likewise observed 30% overall mortality with 28% mortality of kittens, and estimated that 40% of the population were kittens still with their mothers (probably 1 mo to 16-24 mo of age). Overall mortality rates in Utah were similar at 32% for a hunted population (Robinette et al. 1977) and 26-28% for a population with limited hunting (Lindzey et al. 1988). For the same population, we calculated from data presented by Lindzey et al. (1994) a mean of 41% juveniles (0–1.5 yr) for 1979 through 1987. Logan et al. (1986) estimated that a hunted population in Wyoming consisted of 50% juveniles (0-24 months).

It is important to note that the model we developed was deterministic rather than stochastic. There are parameters that vary from year to year with weather, such as survival, productivity, susceptibility to human harvest (varies with snow conditions), or disease. Whereas we can measure harvest from year to year, we have no way to measure the other variables on an annual basis. The rest of the variables were determined over several years from measurement of dead cougars or from intensive study in several locations or were assumed.

Management Implications

This model can be used as an adaptive tool to help make management decisions concerning cougars in Oregon. We used the model to answer several questions. One such question was: What would happen to the population if harvest continued at a particular level? To answer that question, we input the 1993 harvest of 160 cougars for each year after 1993. The model predicted that the cougar numbers would continue to grow initially at 5% annually then stabilize at a maximum by the year 2016 (Figure 6).

Because use of hounds for sport hunting of cougar was banned in Oregon in 1994, we asked

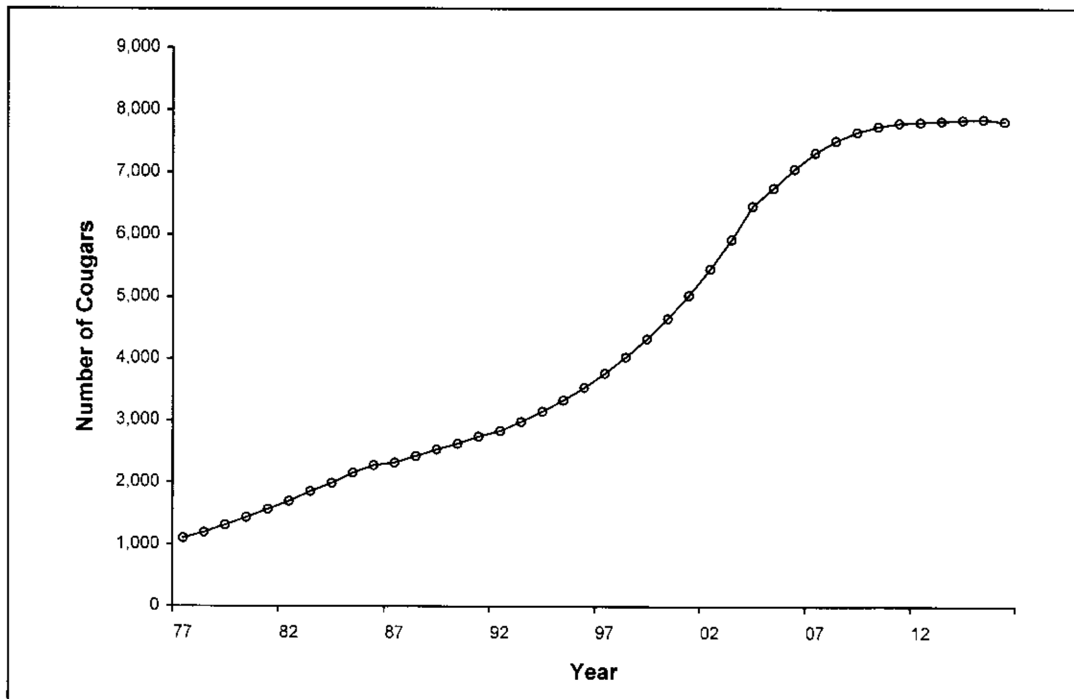

Figure 6. Modeled cougar population of Oregon with sport harvest held at 160 cougars/yr after 1992.

what would happen if sport harvest were discontinued after 1993 but other human-caused losses continued? The model predicted the population would initially increase at a 13% annual rate. The rate of increase would decline by year 2000, when density dependency became a factor, and the population would stabilize in the year 2009 at about three times the 1993 level. If this hypothesized population increase is correct, we should see further increases in human-cougar interactions that could include increased damage complaints, more cougars killed as a result of depredation, more sightings, more instances of cougars in urban and suburban areas, and possibly attacks on humans.

Another pertinent question was: What harvest was necessary to stabilize the population at the 1993 level? To answer that question, harvest rates were adjusted after 1993 until the modeled population stabilized near the 1993 estimate of 2,960. We found that an annual sport harvest rate of 281 cougars (10% of the population) and a total mortality rate of 35% would be necessary to stabilize the population. Population performance could be tested in the future if methods allowed a significant increase in sport harvest in Oregon. Harvest rates could be increased to the level necessary to stabilize or reduce the population as indicated by the model. We would expect a leveling or decrease in damage complaints, depredation kills, sightings, and other human-cougar interactions.

As knowledge increases about those parameters that control the model or as conditions change, the model will need adjustment. Intensive field research across the state could provide independent population estimates that could be used to re-calibrating the statewide model and would allow development of more localized models for smaller areas of the state. Sensitivity analysis indicated that of those factors examined, productivity (i.e. proportion pregnant and litter size) and mortality rates had the greatest effect on population performance over time; therefore, emphasis should be focused on determining those rates. Productivity, mortality rates, and age ratios measured in the field could be compared to population performance predicted by the model. As habitat conditions and prey populations change, carrying capacities for cougars may change, affecting the maximum density function in the model.

We believe this model has application for other states that manage cougars. Reproductive rates, age-specific mortality rates, rates of illegal kill and depredation loss, estimates of maximum density, and some knowledge of the population level and trend are needed to model those cougar populations.

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