COMPUTER SIMULATION OF VASECTOMY FOR WOLF CONTROL

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Abstract: Recovering gray wolf (*Canis lupus*) populations in the Lake Superior region of the United States are prompting state management agencies to consider strategies to control population growth. In addition to wolf removal, vasectomy has been proposed. To predict the population effects of different sterilization and removal strategies, we developed a simulation model of wolf dynamics using simple rules for demography and dispersal. Simulations suggested that the effects of vasectomy and removal in a disjunct population depend largely on the degree of annual immigration. With low immigration, periodic sterilization reduced pup production and resulted in lower rates of territory recolonization. Consequently, average pack size, number of packs, and population size were significantly less than those for an untreated population. Periodically removing a proportion of the population produced roughly the same trends as did sterilization; however, more than twice as many wolves had to be removed than sterilized. With high immigration, periodic sterilization reduced pup production but not territory recolonization and produced only moderate reductions in population size relative to an untreated population. Similar reductions in population size were obtained by periodically removing large numbers of wolves. Our analysis does not address the possible effects of vasectomy on larger wolf populations, but it suggests that the subject should be considered through modeling or field testing.

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Key words: *Canis lupus,* Lake Superior region, management, modeling, population control, population simulation, productivity, pups, reproduction, sterilization, vasectomy, wolf.

Gray wolf populations in the Lake Superior region are recovering rapidly. In the last 2 decades, individuals from northern Minnesota have colonized central Minnesota, northern Wisconsin, and northern Michigan. In spring 1997, the populations in Wisconsin and Michigan each numbered between 100 and 150 wolves (A. P. Wydeven, Wis. Dep. Nat. Resour., unpubl. data; J. H. Hammill, Mich. Dep. Nat. Resour., unpubl. data), and the Minnesota population exceeded 2,000 animals (W. Berg, Minn. Dep. Nat. Resour., unpubl. data). Assuming that wolf numbers in Wisconsin and Michigan grow, the criteria for recovery of the wolf population in Minnesota, Wisconsin, and Michigan should be satisfied by 1998 and subsequently the wolf could be removed from the endangered species list in this area (U.S. Fish and Wildl. Serv. 1992). Wolf management would then revert to the states.

With this forecast for population growth, state management agencies are considering strategies for wolf control. Control may be necessary where wolves colonize areas close to human settlement (Fritts et al. 1992, Mech 1995). Wolf management often involves creating zones and setting population-size targets. Where wolf numbers exceed targets, control measures may be implemented to reduce population size. Because killing wolves to control population size is divisive (Stephenson et al. 1995), vasectomy has been proposed as a control strategy that might have wider public acceptance (Mech et al. 1996).

To evaluate and compare wolf control strategies, we developed a model that predicts the effects of both vasectomy and removal on wolf population trend. Our model and findings are meant to apply to disjunct or scattered wolf populations, but a few variations give insight into the possible effects of vasectomy on more extensive populations.

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METHODS

Considerations for Model Design

A wolf pack usually consists of a breeding pair of wolves and their offspring from one or

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more generations (Mech 1970). In the Lake Superior region, mid-winter pack size averages 4–8 wolves, about half of which are pups (Mech 1973, 1987; Fuller 1989, Wydeven et al. 1995). The dominant adult female in each pack breeds yearly, producing a single litter of pups in spring. In North America, litter size averages 4–7 pups (Mech 1970, Fuller 1989). Pups are adult-sized by winter, and most disperse when they are yearlings (Fuller 1989, Gese and Mech 1991, Wydeven et al. 1995). Dispersing wolves either may pair with the opposite sex and colonize a vacant territory or join another pack and replace a missing breeding member (Rothman and Mech 1979, Fritts and Mech 1981, Gese and Mech 1991, Meier et al. 1995). When both breeding adults die, the pack usually disintegrates, leaving the territory vacant and creating an opportunity for recolonization (Meier et al. 1995).

Model Description

Our model was developed for a hypothetical population of wolves in an area that included 8 pack territories in a core of high-quality range plus 8 territories in a periphery of low-quality range. At any time, each territory either was occupied or vacant. The model predicted the mortality, dispersal, and birth of wolves in each pack and the fate of dispersing wolves. The demographic parameters below were similar to those of wolves in Wisconsin (Wydeven et al. 1995).

To simulate wolf life history, we created a stage-class model for pack dynamics. Each pack was characterized by the number of wolves of each sex in each of 4 stages beginning 1 October. The stages were defined in terms of age and breeding status. The 3 stages for nonbreeding wolves were pup (6 mon. old), yearling (18 mon. old), and adult (>30 mon. old). A fourth class was defined for the breeding pair, each of which must be at least 18 months old on 1 October. Breeding took place in spring, and minimum breeding age was 22 months (Fuller 1989).

The annual change in number of wolves in each pack was calculated with the following sequence of events. The first was winter mortality. The number of wolves that died in each life-history stage was a binomial random variable with a mean that depended on habitat quality. We assumed that wolves living in core range were subject to a 20% mean annual mortality rate. Mean mortality rate in peripheral range (35%) was higher because of greater contact with humans.

Dispersal rate depended on the survival of the breeding pair. If the breeding pair died, remaining pack members dispersed. If one or both breeders were present, the number of dispersers from each age class was a binomial random variable. Dispersal probabilities for pups, yearlings, and adults were 25, 50, and 90, so that most wolves dispersed before reaching 4 years old.

We assumed that 20% of the dispersing wolves were long-distance dispersers that immediately emigrated from the area. Each remaining disperser searched the area for a suitable site, which was defined as a vacant site or a site with an available mate. To account for immigration from an outside population, we assumed that 1 outside wolf joined the pool of dispersing wolves searching for suitable sites. In the sensitivity analysis, we increased annual immigration to 10 wolves. Each dispersing wolf was assumed to sample with replacement 6 sites (see Lande 1987 and Lamberson et al. 1994 for other applications of this kind of search model). The implication of this assumption was that spatial coordinates and shapes of pack territories were not needed. The probability of finding a suitable site was 1 minus the probability of failing to find a suitable site within the given number of trials:

$$\mathrm{Prob}(\mathit{success}) = 1 - \left[1 - \frac{\mathit{no.\ suitable\ sites}}{\mathit{total\ no.\ sites}}\right]^6. \quad (1)$$

A uniform random number was drawn for each dispersing wolf and compared with the probability of success. A successful wolf was assigned randomly to a site with an available mate, and if none was available, to a vacant site. An unsuccessful wolf was assumed to leave the area adding to the number of long-distance dispersers.

Elements of our dispersal model were consistent with observations of dispersing wolves in northern Minnesota (Gese and Mech 1991). Those authors found that 15–25% of pup and yearling dispersers moved more than 200 km and crossed more than 10 territories. Many of these dispersers seemed predisposed to moving long distances rather than searching closer to their natal territories for mates. Most of the remaining wolves traveled less than 100 km cross-

Table 1. Management strategies.

Strategy	Treatment	Wolves treated	When
1	None		
2	Sterilize	All breeding males	Year 0
3	Sterilize	All breeding males	Year 0, 5, 10, 15
4	Sterilize	All fertile males in random trapping of 20% of population	Population size >50
5	Sterilize	All fertile males in random trapping of 50% of population	Population size >50
6	Remove	20% of the population[a]	Population size >50
7	Remove	50% of the population[a]	Population size >50

[a] Both sexes.

ing 1 to 3 territories. Many local dispersers already had engaged in predispersal forays that increased their search areas. Our assumption of a random search process is based on the observation that wolves tended to disperse in all directions equally.

A litter of pups was produced in spring if a breeding pair was present and the male was not sterilized. Litter size was chosen from a discrete probability distribution with mean 4.5 pups and range 0 to 8 pups. The sex of each pup was a Bernoulli trial with equal probability. If the dominant male was sterile, pups were not produced, but the dominant pair held its territory (Hayes 1995, Mech et al. 1996). If one member of the dominant pair died, the remaining wolves held their territory but did not produce a litter. Recent evidence suggested that mother/son or sibling matings rarely, if ever, occur (Smith et al. 1997).

Early pup mortality, which was different than winter mortality described above, was modeled as a binomial random variable with mean 40%. This mortality process attempted to simulate the situation in Wisconsin and northeastern Minnesota where canine parvovirus caused significant early pup loss (Mech and Goyal 1995, Wydeven et al. 1995). In places where early pup loss is minimal, these simulations will yield untreated populations that grow much too slowly and will underestimate the difference between treated and untreated populations. Thus, we also conducted simulations with much lower early pup mortality, which seems to characterize most wolf populations (Fuller 1989: Table 4; Mech 1995).

Following early pup mortality, the distribution of wolves in each pack was updated by moving the yearlings to the adult stage, the older pups to the yearling stage, and the new litter to the pup stage. The updated distribution was the basis for the next year's projection. In the management simulations that follow, this annual sequence of events was repeated over a 20-year horizon.

Management Simulations

We used the model to evaluate various management strategies for controlling the size of the hypothetical wolf population. We assumed that the initial population was in a colonizing stage with 4 packs occupying half of the potential territories in the core area. The territories in the peripheral area were vacant. Each pack included 2 pups, 2 yearlings, and a breeding pair.

We simulated 7 management strategies spanning a range of possibilities (Table 1). Strategy 1 (no treatment) was the baseline, and strategies 2–7 featured variations in treatment type (vasectomy or removal), wolf selection (breeding M or any M), and treatment frequency. In strategies 2 and 3, all breeding males were sterilized in year 0 or every 5 years. Because sterilizing only breeding males might be difficult, strategies 4 and 5 simulated trapping a percentage (20 or 50%) of the population at random (with replacement) and vasectomizing all fertile males obtained. Trapping took place each year in which population size exceeded 50 wolves. To contrast the effects of sterilization, we simulated 2 removal strategies in which a random sample of either 20% (strategy 6) or 50% (strategy 7) of the population was removed each year in which population size exceeded 50 wolves.

To estimate the effects of the different management strategies, we used the simulator to predict attributes of the population (total size, no. of packs, average pack size) over a 20-year horizon. Each population prediction was an average obtained from 1,000 independent simulations of the wolf model.

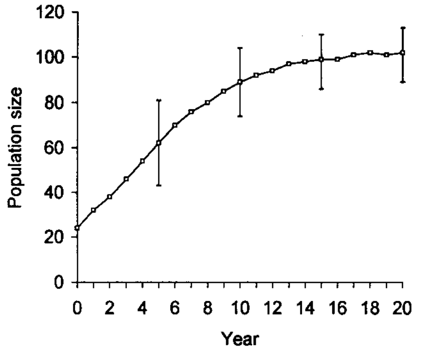

Fig. 1. Growth of a simulated untreated wolf population (strategy 1) with immigration of 1 wolf per year and early pup mortality rate of 40%. Each bar is plus or minus one standard deviation around the mean and represents the range in which roughly two-thirds of the 1,000 simulated outcomes occurred.

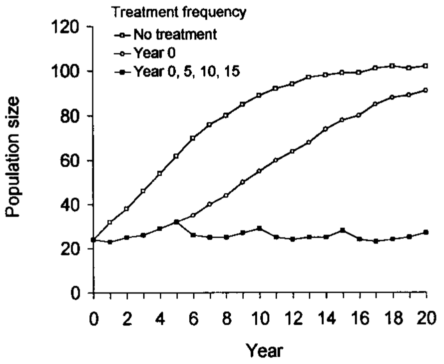

Fig. 2. Growth of simulated wolf populations treated by sterilizing all breeding males in year 0 (strategy 2) or years 0, 5, 10, 15 (strategy 3). The growth of the untreated population (strategy 1) is shown for comparison. Immigration is 1 wolf per year and early pup mortality rate is 40%. Average of 1,000 simulations.

RESULTS

Management Simulations

With no treatment, the wolf population quickly occupied the available space. Within 10 years, the initial population of 24 wolves in 4 packs grew to 90 wolves in 15 packs (Fig. 1). By year 20, mean population size leveled near 100 with most of the 16 territories filled. Although this population growth compared favorably with the actual recolonization of wolves in northern Wisconsin and upper Michigan from 1975 to 1995 (Wydeven et al. 1995), the growth rate was probably low for most areas because of our assumption of high early pup mortality (40%).

To measure the range of outcomes produced by the model, we computed standard deviations of simulated population sizes in selected years. The standard deviations were 10–30% of the mean population sizes (Fig. 1). In the simulations that follow, the standard deviations of population size outcomes were the same magnitude. To compare different management strategies, we first focus on mean population response. Then, we evaluate the strategies using performance measures based on the frequency distributions of simulated outcomes.

Vasectomizing all breeding males in year 0 (strategy 2) reduced the rate of population growth from strategy 1 (Fig. 2). In year 5, the size of the treated population (32 wolves) was 52% of the size of the untreated population (62 wolves). Compared with the untreated population, the treated population contained fewer packs (9 vs. 12) and smaller mean pack size (3.5 vs. 4.8). Reduced pup production caused slower population growth. With fewer pups, fewer wolves dispersed, settled, and started new packs. After year 5, however, the treated population grew rapidly as fertile males gained breeding status. By year 20, the size of the treated population was 90% of the size of the untreated population.

Sterilizing all breeding males every 5 years (strategy 3) had a dramatic effect on population size (Fig. 2). Mean population size varied between 20 and 30 wolves over the 20-year horizon. The mean number of packs varied between 8 and 9 with an average pack size between 2 and 3 wolves. This periodic sterilization strategy curtailed pup production and reduced both pack size and the rate at which vacant territories were colonized throughout the 20-year simulation.

Sterilizing males during random trapping whenever population size exceeded 50 wolves (strategies 4 and 5) slowed population growth compared with the control (Fig. 3), but not as much as periodic vasectomy of breeders. Mean population size grew rapidly during the first 5 years and then varied between 40 and 60 wolves once sterilization began. Trapping intensity (20 or 50%) did not greatly affect population attributes. With a 20% trapping rate (strategy 4), mean population size varied between 50 and 60 wolves (14 packs with an average of 4 wolves/pack). Trapping took place every 1 or 2 years with 3 or 4 animals sterilized in each trapping. Between 25 and 30% of the males in the population were sterilized at any time. With a 50% trapping rate (strategy 5), population size varied

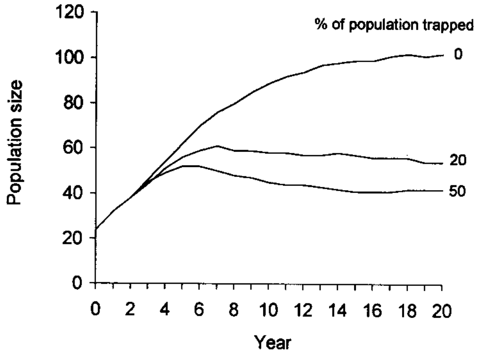

Fig. 3. Growth of simulated wolf populations treated by sterilizing all fertile males in random trappings of 20% (strategy 4) or 50% (strategy 5) of the population whenever population size exceeds 50. The growth of the untreated population (strategy 1) is shown for comparison. Immigration is 1 wolf per year and early pup mortality rate is 40%. Average of 1,000 simulations.

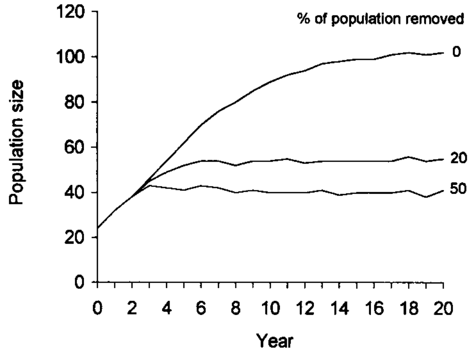

Fig. 4. Growth of simulated wolf populations treated by removing 20% (strategy 6) or 50% (strategy 7) of the population whenever population size exceeds 50. The growth of the untreated population (strategy 1) is shown for comparison. Immigration is 1 wolf per year and early pup mortality rate is 40%. Average of 1,000 simulations.

between 40 and 50 wolves (12 packs with an average of 4 wolves/pack). The higher trapping intensity required fewer trappings (every 3 yr on average) with more wolves sterilized in each trapping (6 on average). Between 30 and 40% of the males in the population were sterilized at any time with this approach.

Removing a fixed percent of the population whenever population size exceeded 50 wolves produced population statistics strikingly similar to those obtained with sterilization (Fig. 4). With a 20% removal rate (strategy 6), mean population size varied between 50 and 60 wolves (13 packs with 4–5 wolves/pack). With a 50% removal rate (strategy 7), population size varied between 40 and 50 wolves (10 packs with 4–5 wolves/pack). However, a much larger number of wolves was removed compared with the number of wolves sterilized. With a 20% removal rate, 12 wolves were taken every 2 years, on average. With a 50% removal rate, 28 wolves were taken every 5 years.

Sensitivity Analysis

Immigration rate significantly affected predicted size of the untreated population (Fig. 5). With annual immigration of 10 wolves, the untreated population grew rapidly during the first 5 years as immigrants settled and reproduced in vacant territories available at the start. By year 5, the population reached 100 wolves occupying all 16 territories. By year 20, the population stabilized at 114 wolves, 12% greater than the size of the population with annual immigration of 1 wolf. Increasing annual immigration beyond 10 wolves had no additional effects because the area became saturated.

High annual immigration had similar effects on the predicted size of the population subject to 20% random trapping and sterilization (Fig. 6). With 10 immigrants per year, the population grew rapidly during the first 5 years, quickly occupying all 16 territories. Thereafter, mean population size numbered between 70 and 80 wolves (60–70% of the untreated population). The main effect of sterilization was to reduce mean pack size from 7–8 wolves in the untreated population to 4–5 wolves in the treated population. Because the population exceeded 50 wolves almost every year, trapping occurred annually with 4–5 males newly sterilized in each trapping.

High annual immigration coupled with periodic 20% removal resulted in mean population

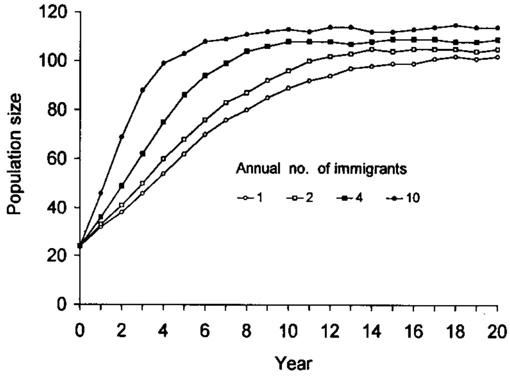

Fig. 5. Effect of immigration rate on the growth of simulated untreated wolf populations (strategy 1). Early pup mortality rate is 40%. Average of 1,000 simulations.

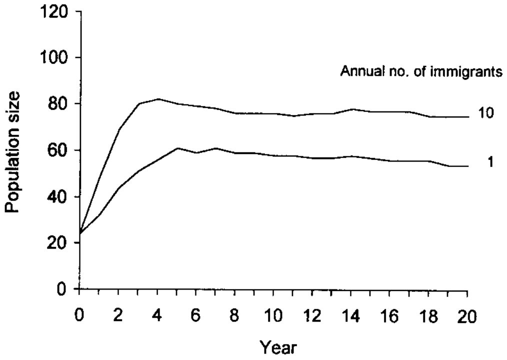

Fig. 6. Effect of immigration rate on the growth of simulated wolf populations treated by sterilizing all fertile males in random trappings of 20% of the population when population size exceeds 50 (strategy 4). Early pup mortality rate is 40%. Average of 1,000 simulations.

sizes between 80 and 90 wolves (70–80% of the untreated population; Fig. 7). Removals took place almost every year, taking 16–17 wolves per year on average. Although each removal reduced the population by 20%, numerous immigrants plus local dispersers quickly colonized vacant territories. Consequently, the population grew rapidly following each removal.

As expected, the model was highly sensitive to early pup mortality. With early mortality rates of 0 and 20% and a single immigrant per year, the untreated population reached 100 wolves in 4–6 years (Fig. 8) and peaked at 125–150 wolves because of larger packs (means 8–9 wolves/pack in autumn). Even with 20% early pup mortality, which is high for many areas, sterilizing all males (strategy 4) or removing all wolves caught (strategy 6) in random trappings of 20% of the population when numbers exceeded 50, greatly attenuated the population (Figs. 9 and 10). If early mortality were less, the effect of sterilization would be even greater.

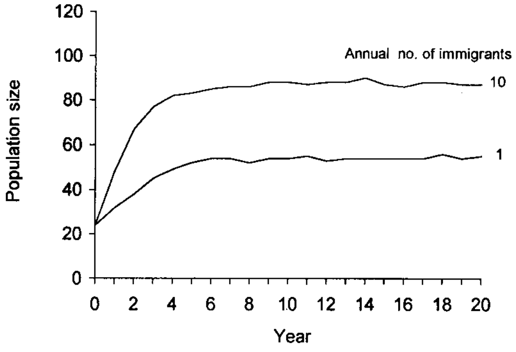

Fig. 7. Effect of immigration rate on the growth of simulated wolf populations treated by removing 20% of the population when population size exceeds 50 (strategy 6). Early pup mortality rate is 40%. Average of 1,000 simulations.

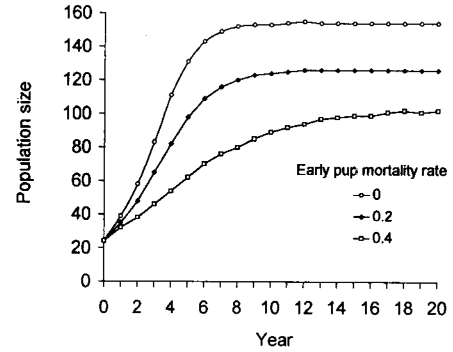

Fig. 8. Effect of early pup mortality rate on the growth of simulated untreated wolf populations (strategy 1). Immigration rate is 1 wolf per year. Average of 1,000 simulations.

DISCUSSION

Our modeling of various wolf-control strategies involving vasectomy or removal of wolves indicated that either approach effectively can control a disjunct population. To further compare the different management strategies, we defined 4 performance measures (Table 2). The first 2 measures were probabilities of attaining different population size outcomes at the end of the 20-year horizon. The population size outcomes were either desirable (<50 wolves) or undesirable (>100 wolves). The third and fourth performance measures were average number of wolves treated and number of treatment years.

We evaluated the 7 management strategies (Table 1) assuming that early pup mortality rate

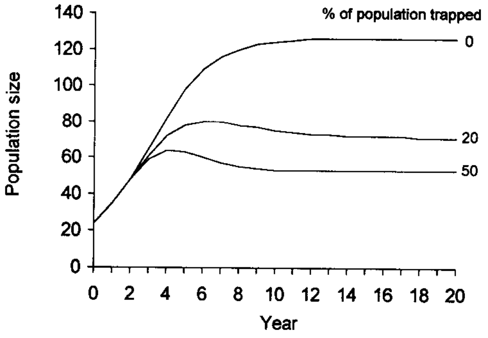

Fig. 9. Growth of simulated wolf populations treated by sterilizing all fertile males in random trappings of 20% (strategy 4) or 50% (strategy 5) of the population whenever population size exceeds 50. The growth of the untreated population (strategy 1) is shown for comparison. Immigration rate is 1 wolf per year, and early pup mortality rate is 20%. Average of 1,000 simulations.

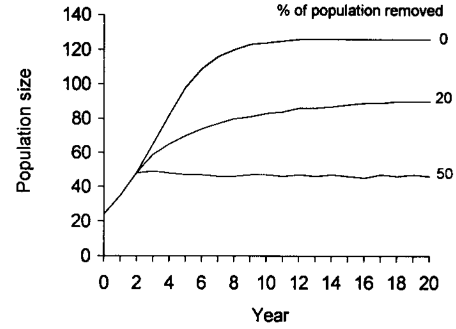

Fig. 10. Growth of simulated wolf populations treated by removing a 20% (strategy 6) or 50% (strategy 7) of the population when population size exceeds 50. The growth of the untreated population (strategy 1) is shown for comparison. Immigration rate is 1 wolf per year, and early pup mortality rate is 20%. Average of 1,000 simulations.

was 40% and that immigration was either 1 or 10 wolves per year. With 1 immigrant per year (Table 2), strategies with either periodic sterilization or removal (strategies 3–7) had zero probability of producing populations >100 wolves in 20 years. In contrast, with no action (strategy 1), there was 50% probability that the population would exceed 100 wolves. Periodic sterilization of breeding males (strategy 3) was most efficient, producing an 88% chance of a population <50 wolves in 20 years with averages of 18 treated wolves and 4 treatment years. Periodically trapping 50% of the population and sterilizing males (strategy 5) performed almost as well as strategy 3 relative to population size outcomes but with more than twice the number of wolves treated. The removal strategies (6 and 7) performed the same as the corresponding sterilization strategies (4 and 5) relative to population size outcomes; however, the numbers of wolves removed were more than twice the numbers of wolves sterilized in strategies 4 and 5.

In addition to reducing population size, maintaining a minimum number of wolves might be important. With the exception of strategy 3, none of the control strategies resulted in populations <10 wolves in 20 years. Strategy 3 produced a 25% chance of a population <10 wolves because all breeding males were sterilized every 5 years regardless of population size. A strategy in which all breeding males were sterilized only when population size exceeded 50 always resulted in a population >10 wolves.

With an immigration rate of 10 wolves per year (Table 3), immigration partially offset the effects of periodic vasectomy and removal so that strategies 3–7 were all likely to result in populations of 50–100 wolves in 20 years. Periodically removing 50% of the population (strategy 7) produced the greatest chance of a population <50; however, this strategy required removing >400 wolves on average during the 20-year period. In contrast, the sterilization strategies (3 to 5) required treating between 42 and 113 wolves on average.

The number of long-distance dispersers from a disjunct wolf population might be an important performance measure because of its relation to other management objectives (e.g., increasing genetic interchange between populations or decreasing the likelihood of livestock depredation). In our model, the number of long-distance dispersers depended largely on the number of packs and vacant territories. With 1 immigrant per year, all the control strategies kept the number of packs below carrying capacity so that dispersing wolves colonized vacant territories rather than emigrated. Emigration averaged 1–3 wolves per year (4–6% of mean population size). With 10 immigrants per year, emigration was higher under all control

Table 2. Performance of different management strategies for a wolf population subject to an immigration rate of 1 wolf/yr.

Performance measure[a]	Strategy[b]						
	1	2	3	4	5	6	7
	No action	Sterilize				Remove	
Probability population size <50	0.01	0.06	0.88	0.44	0.73	0.35	0.73
Probability population size >100	0.50	0.36	0.00	0.00	0.00	0.00	0.00
No. of wolves treated	0	4	18	43	42	119	105
No. of treatment years	0	1	4	11	6	10	4

[a] Performance measures are either outcomes at the end of 20 years (population size) or totals for the 20-year period (e.g., no. of wolves treated).

[b] Management strategies: 1 = no action, 2 = sterilize all breeding males in year 0, 3 = sterilize all breeding males years 0, 5, 10, 15, 4 = sterilize all fertile males in random trapping of 20% of the population whenever population size exceeds 50, 5 = sterilize all fertile males in random trapping of 50% of the population whenever population size exceeds 50, 6 = remove 20% of the population whenever population size exceeds 50, 7 = remove 50% of the population whenever population size exceeds 50.

Table 3. Performance of different management strategies for a wolf population subject to an immigration rate of 10 wolves/yr.

Performance measure[a]	Strategy[b] 1	2	3	4	5	6	7
	No action	Sterilize				Remove	
Probability population size <50	0.00	0.06	0.02	0.00	0.19	0.00	0.35
Probability population size >100	0.87	0.36	0.09	0.01	0.00	0.07	0.00
No. of wolves treated	0	4	42	82	113	302	408
No. of treatment years	0	1	4	18	16	18	13

[a] Performance measures are either outcomes at the end of 20 years (population size) or totals for the 20-year period (e.g., no. of wolves treated).

[b] Management strategies: 1 = no action, 2 = sterilize all breeding males in year 0, 3 = sterilize all breeding males years 0, 5, 10, 15, 4 = sterilize all fertile males in random trapping of 20% of the population whenever population size exceeds 50, 5 = sterilize all fertile males in random trapping of 50% of the population whenever population size exceeds 50, 6 = remove 20% of the population whenever population size exceeds 50, 7 = remove 50% of the population whenever population size exceeds 50.

strategies (9–12 wolves/yr; 10–15% of mean population size) because the population occupied all the territories.

Because our model was developed to examine the possible effects of vasectomizing wolves in relatively small, disjunct populations such as in Wisconsin, Michigan, and possibly central Minnesota, our results have limited applicability to larger populations. Such populations contain a large reservoir of dispersers and floaters that facilitate turnover of breeders (Meier et al. 1995). This characteristic would tend to limit the value of vasectomy for population control.

On the other hand, one feature of most large populations tends to render the potential of vasectomy greater than our basic model might indicate. Most large wolf populations inhabit regions where canine parvovirus has not been causing early pup mortality, in contrast to the Lake Superior region. Vasectomizing breeding males in such a population would reduce the number of pups much more than our model indicates, which in turn would much reduce the number of dispersing wolves that become surplus floaters. Without a more complex model, we cannot predict the degree to which reduced pup production because of sterilization would affect the number of floaters and turnover of breeders in a large population.

MANAGEMENT IMPLICATIONS

The primary reason that vasectomy might be practical for controlling wolves is that single pairs of adult wolves usually occupy large territories (100–2,500 km^2) and thus control the number of offspring over a large area for 5 years or more. Pairs that fail to produce young because of vasectomies (Mech et al. 1996) or natural reasons (Hayes 1995) continue to hold territories for years. Vasectomy techniques with chemical sclerosing agents to harden and block the sperm tract without affecting hormones are available and can be applied in the field (Freeman and Coffey 1973, Pineda and Hepler 1981). Thus, merely by sterilizing one individual (the breeding M) in a territory, theoretically a manager could restrict the number of wolves in that large area for years.

A second advantage of vasectomy is that the technique might be more acceptable to the general public than would lethal control. Because the wolf has been on the federal endangered species list and has been legally protected since 1974, killing wolves is not acceptable to many people (Kellert 1986).

Vasectomizing free-ranging wolves for population control has never been attempted. Our results suggest that for small, relatively disjunct wolf populations such as inhabit much of Wisconsin, Michigan, and central Minnesota (Fuller et al. 1992, Mladenoff et al. 1995), vasectomy may be a practical, cost-effective method of controlling wolf numbers. The method would require handling fewer wolves than would lethal trapping, although vasectomizing the captured wolves would require more highly trained workers.

Whether vasectomy would be effective or practical in larger populations is unknown. As indicated above, the high turnover in average breeding tenures (Meier et al. 1995) would tend to reduce the effectiveness of sterilization. However, lethal methods are also effective for only 1–2 years in such populations (Ballard et al. 1987, Hayes 1995). Thus, experimentally comparing sterilization with lethal control appears to be worth trying even in larger populations.

If managers decide to experiment with vasec-omy as a means of controlling populations, we suggest an adaptive-management approach starting with disjunct populations with relatively low immigration. Strategy 4 seems to us to be the most practical approach. For populations on the order of 100 wolves, this approach would involve trapping every 1 or 2 years and sterilizing 3 or 4 males each year. As populations are assessed each year, trapping frequency and/or number of wolves treated can be adjusted to attain population size targets. By entering the results in a population model, increasingly better estimates of future treatment needs should be attainable.

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