# A COMPUTER SIMULATION MODEL FOR EVALUATING DEER HUNTING STRATEGIES

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Abstract: A population dynamics model of the deer herd in Mendocino County, California is presented. Environmental influences are modeled as density dependent birth and death rate functions. The development of the model and preparation of input from herd composition, hunter kill, productivity and other field data are discussed. The output shows the impact of selected hunting strategies on productivity, natural mortality, and other population parameters. Tests of alternative hunting strategies are summarized. Maximum yield will be achieved with a hunting removal of 20-25% of the does, 15-30% of the fawns, and over 50% of the bucks annually. Population size is not affected by buck hunting but decreases as doe hunting increases. The model is applicable to other big game populations without major alterations.

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## INTRODUCTION

Models of biological systems have become increasingly common in recent years due to the availability of computer simulation techniques. Such models use series of mathematical equations to represent the important features of the biosystem. Computer simulations of real world situations in which management influences the behavior of the system permit the impact of particular management policies to be tested before such policies are actually implemented.

Simulation methods are particularly appropriate for wildlife populations, in which the numbers of individuals and the age composition change over time due to environmentally induced fluctuations in birth and death rates. Measurements of these fluctuations in the field are often incomplete, as observations can be made only at certain times of the year. A simulation model can provide estimates of desired parameters throughout the year, and comparisons can be made with field data collected at any point in the annual cycle. In this way the model provides a year round picture despite the seasonal nature of field data. The model therefore may improve the biologist's understanding of population dynamics under current management as well as enabling him to predict the responses of the population to other prospective management policies.

In this paper we will describe a population dynamics model of the Mendocino County deer herd. The model is our contribution to USDA Western Regional Research Project W-97 entitled "Assessing Big Game Management Alternatives Through Bioeconomic Models" and involving cooperators in 6 western States.

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## PROCEDURES

### Development of Concepts

A comprehensive flow chart of the components and interrelationships of the Mendocino County deer biosystem was developed. It was apparent that existing data was not sufficient to model forage production for each habitat type within the County. However, the data did demonstrate fluctuations in birth and death rates in response to forage conditions, permitting the estimation of averages and ranges for each parameter. Our model summarizes the environmental influences into density-dependent natality and mortality curves, consistent with the basic game management theory that animal numbers are regulated by forage supplies.

The model is basically constructed around the notion of average forage conditions. Under these average conditions deaths, whether from hunting or natural causes, result in lower population density and increased survival rates for the survivors because of decreased competition for forage. These effects vary in intensity among age classes and seasons of the year. Birth rates likewise increase or decrease inversely with density during the period or ovulation.

When the basic model was operational it was modified to permit the annual random selection of forage conditions (poor, fair, average, good, or excellent) for the next year, with appropriate correction factors to be applied to the average birth and death rates. These "forage factors" will be described in greater detail later in this paper.

## Operation of the Model

For any simulation model concerned with the flow of variables over time, a time unit must be specified for calculation purposes. The computer moves in discrete steps through time and calculates the variables at each step. The time period is chosen by the investigator according to his data and interests. In our model the time unit is one month. For each month the relevant calculations are made and deer numbers are summarized at the end of the month to provide the opening inventory for the next month. These calculations are presented schematically in Figure 1.

The basic accounting year in our model begins on November 1 because at this time deer numbers in Mendocino County could best be estimated. Beginning with the initial estimate of deer numbers the computer selects a "forage factor" and proceeds to calculate natural and hunting losses, if any, during November. The time counter is advanced one month and losses are similarly computed for December. The calculations proceed month by month until June 1, when all age categories are advanced one year and new fawns are born. At that time bucks and does in their sixteenth year are removed from the system. Mortality calculations then proceed as before. On July 1 a summary of hunting statistics for the previous 12 months (8 months in the first year) is printed. At the end of October a year-end summary is printed, a new forage factor is selected, and the second year of the run begins. At the end of the final year of the simulation run, summary statistics are printed. The number of years in each run is specified by the investigator.

In the model, hunting may be conducted in any month. Hunting specifications show the percentage of animals in each age class to be killed in each month. All losses from causes other than hunting are regarded as natural losses. The annual selection of the forage factor may be easily suppressed, so that each year of the run is considered an average year. When this is done, a stable solution is reached in 10 to 20 years under reasonable hunting strategies.

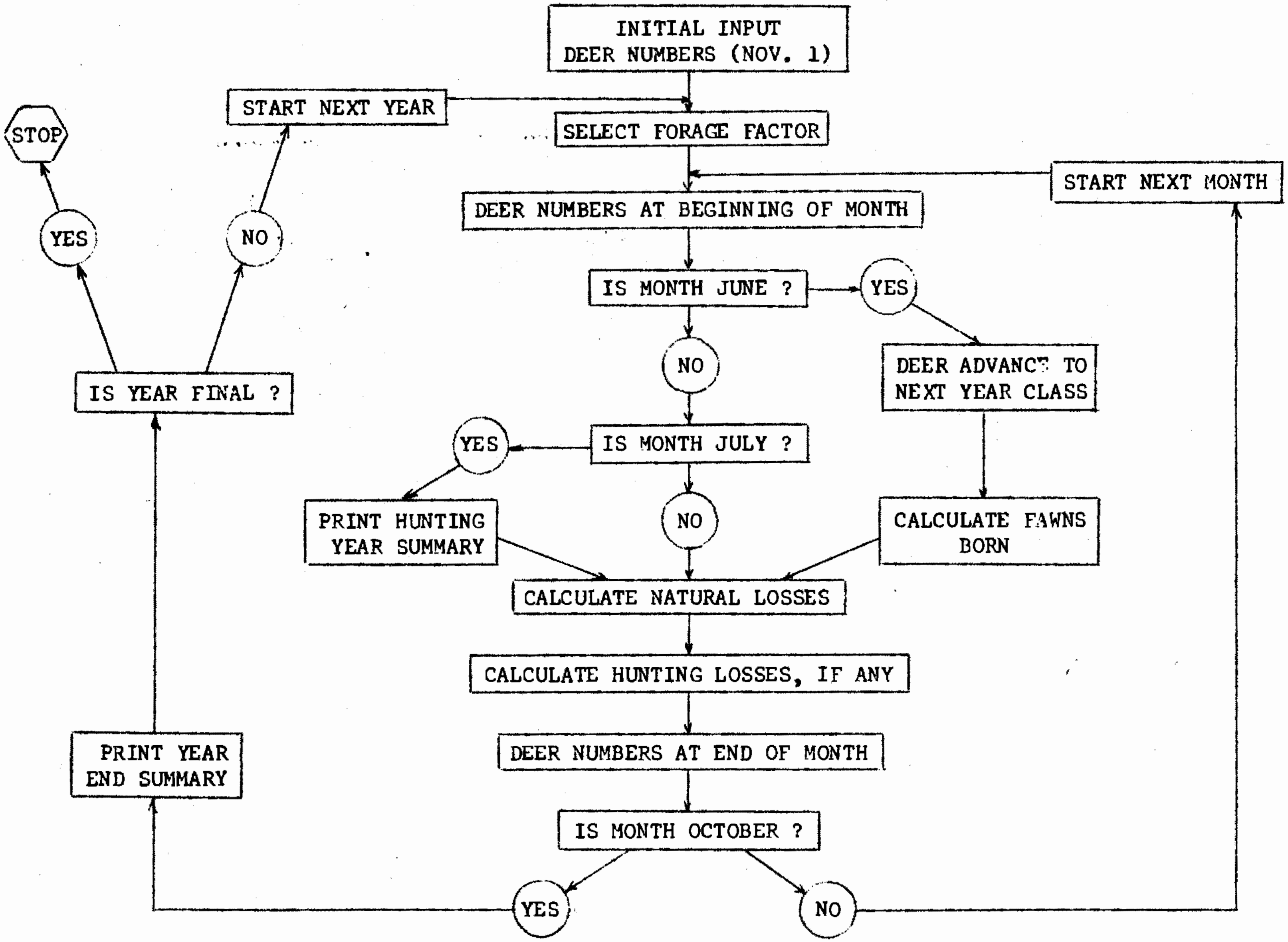
## Data Requirements

The following parameters are specified for each run of the model:

(1) Initial estimate of deer numbers
(2) Natality schedules for each age class of does
(3) Natural mortality schedules for each age and sex class for each month
(4) The area of occupied deer range in square miles
(5) Number of years of the run
(6) The initial exponential average density
(7) The sex ratio of fawns surviving to one year of age
(8) The output to be provided during and after the run
(9) A random number to begin the forage factor selection process
(10) Probability distribution for poor, fair, average, good, and excellent forage years
(11) Mortality and natality correction factors for the five categories of forage years
(12) Hunting specifications for each age and sex class

Several of these items are self-explanatory; the remainder are discussed below:

FIGURE 1. FLOW DIAGRAM OF THE MENDOCINO COUNTY DEER POPULATION MODEL



(1) Initial estimate of deer numbers: Average deer numbers in Mendocino County during 1958-68 on November 1 were calculated by assuming that 25% of the legal bucks were killed by hunters each year and that the reported kill equals 2/3 of the actual kill. These percentages and the reported kill were used to calculate the number of legal bucks in the population during late October when herd composition counts are made. The herd count data indicated the fractions of fawns, does, spike bucks, and legal bucks, so that the numbers of deer in each class could be calculated from the legal buck estimate derived above. Does and bucks were then apportioned among the age classes 1 through 15 by graphic methods. The total population was estimated to include about 200,000 deer on November 1.

(2) Natality schedules: Fetal examinations of the Hopland Field Station during 1951-69 were summarized to estimate productivity under existing deer densities. Based on these data four productivity classes were specified: Yearlings, 2-year olds, 3-7 year olds, and older does. For each class the estimated average productivity was plotted against the estimated current density at ovulation. The data also gave an indication as to the probable range of variation in productivity in each class. From these data and our general interpretation of the effects of forage competition on ovulation rates, the expected productivity at greater and lesser densities was estimated graphically as in Figure 2. These graphs are entered numerically in the input and the computer reads the productivity at any density by interpolating between the points given. The graphs provide for productivity in young does to be affected more by density changes than productivity in prime and old does, consistent with available information.

(3) Mortality schedules: To produce these data, it was necessary to construct a paper and pencil model of the average Mendocino County deer herd during recent year. Because deer population data for the County as a whole was relatively limited, a preliminary model was first made for the Hopland Field Station. The Hopland model initially involved average estimates of deer in four sex classes at four seasons of the year during 1964-66 (Table 1). These estimates, calculated from herd composition, hunter kill, carcass examination, and autopsy data, represent the minimum deer population required to support the known buck kill, assuming that the average birth rate, sex and age composition, and mortality ratios in the population were accurately determined. The computations are given in detail by Connolly (1970. A population model for deer on the Hopland Field Station, Mendocino County, California. M. A. Thesis, Sonoma State College, Rohnert Park, Calif., v + 54 p.). This model (Table 1) was expanded by additional calculations to provide estimates for each month of the year of fawns, bucks 1, 2-6, and 7+ years, and does 1, 2-6, and 7+ years old.

Careful examination of available data revealed that the deer herd at Hopland differed from the overall Mendocino County herd in a number of ways: the Hopland population exhibited higher fawn survival, lower average age, greater density, lower legal buck:doe ratios, higher spike buck:doe ratios, and heavier hunting pressure than the County herd as a whole. Taking these differences into account a paper and pencil model for the entire County was developed, with estimates for each month for seven sex and age classes as in the expanded Hopland Field Station model described above. Deer densities for each month were computed, based on an estimated 3,451 square miles of occupied deer habitat in the County.

The paper and pencil model for the Mendocino County deer herd, as described above, was used to produce 60 natural mortality curves (5 sex and age classes x 12 months). The sex and age categories were fawns, yearling does, yearling bucks, adult (2-6 years) does and bucks, and old (7+ years) does and bucks. One of the curves is included here for illustration (Figure 3). The paper and pencil model indicated that 5.3% of the yearling does present on February 1 died by March 1 at the estimated February 1 density of 50 deer per square mile. This point was plotted and the curve drawn to approximate the expected mortality at greater and lesser densities. Curves for the other age classes and other months were similarly derived.

(6) Exponential average density (EAD): The number of fawns born each year is influenced by the condition of the does at ovulation. The condition of the does varies with available forage and in this model is considered a function of deer dencity. While the ovulation rate is most responsive to forage conditions just before ovulation, it is also influenced by forage conditions in previous months. The EAD in this model permits ovulation to be influenced by forage conditions (density) over any desired number of

FIGURE 2. NATALITY SCHEDULE FOR YEARLING DOES (18 MONTHS OLD AT BREEDING)

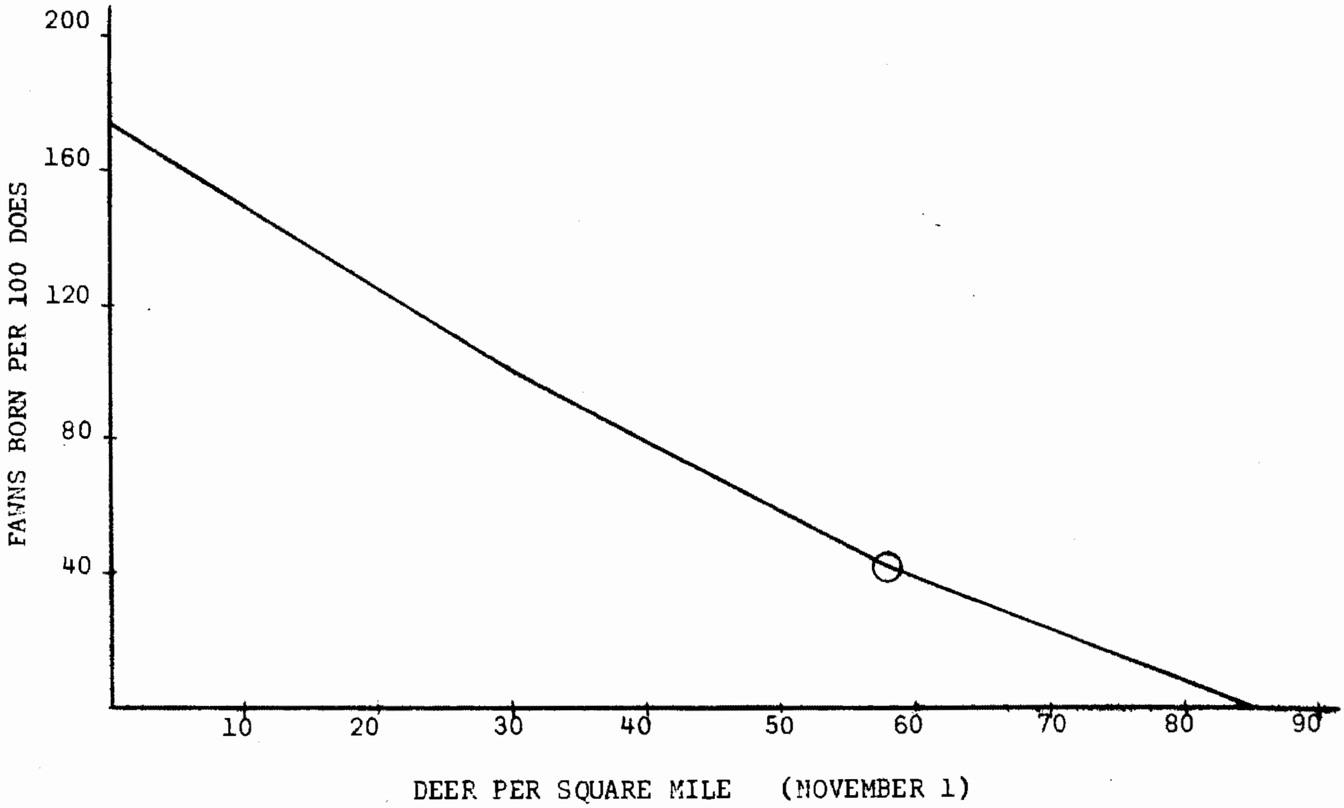
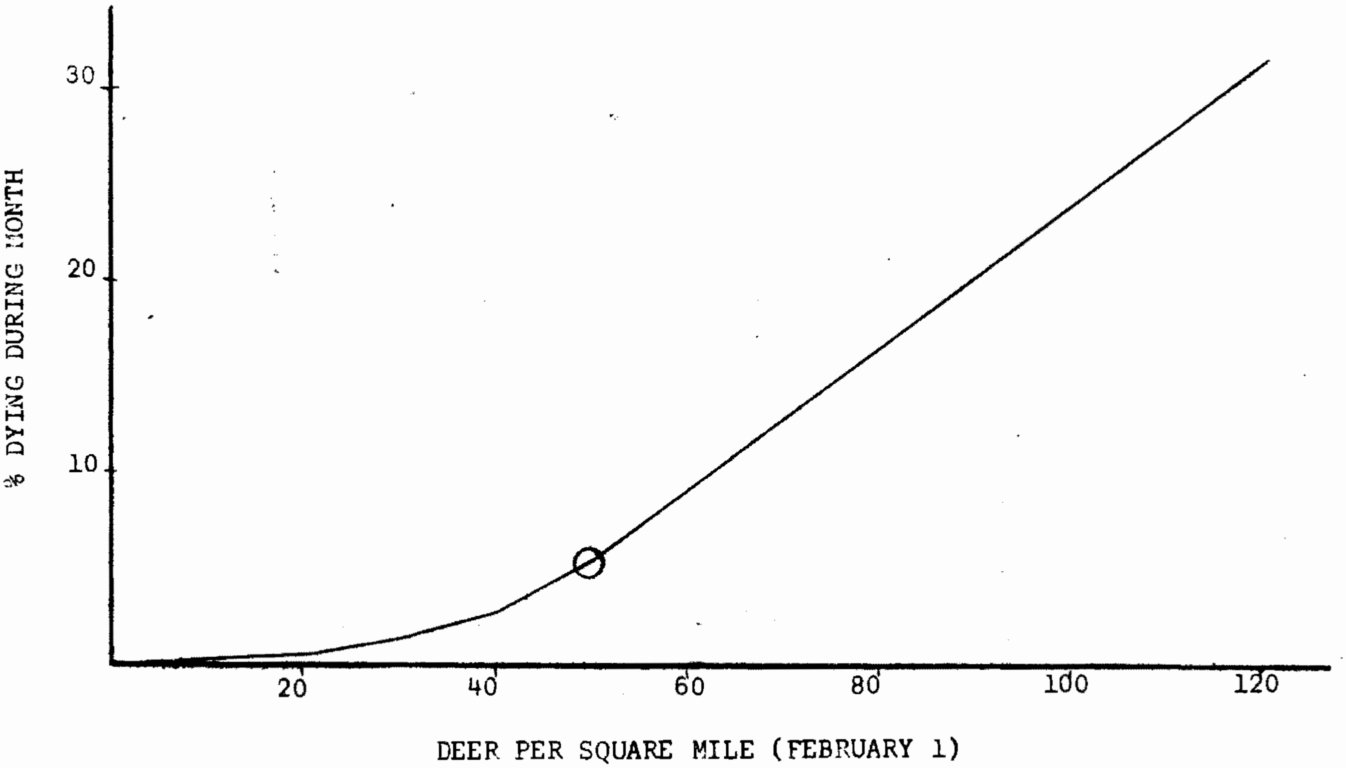



FIGURE 3. NATURAL MORTALITY SCHEDULE FOR YEARLING DOES IN FEBRUARY



months prior to ovulation. The EAD is computed each month as follows:

$$EAD_t = EAD_{t-1} + \frac{1}{T} (D_t - EAD_{t-1})$$

where t = time period (month)
D = density (deer/square mile)
T = number of months affecting ovulation rate
(T = 3 in runs to date)

(7) Sex ratio of fawns at one year of age: Our model separates fawns into males and females at 12 months of age. The sex ratio at birth appears to be about 120 males: 100 females but may change during the first year because of sex differential mortality. Available data do not elucidate this point because of the difficulty of distinguishing the sex of small fawn carcasses. The model is constructed to permit adjustments in the sex ratio at 12 months of age. A ratio of 50:50 has been used in most runs to date.

(10) Probability distribution of poor, fair, average, good, and excellent forage years: Variations in deer production and survival in response to weather-induced fluctuations in forage production are well known. Although few data specifying these weather-forage production relationships are available, such relationships appear to be the primary cause of year to year variations in fawn survival rates in Mendocino County. As fawn survival data for the entire County were relatively limited, the April fawn:doe ratios taken annually on the Hopland Field Station during 1965-69 were used to estimate this variability. The average value of the 16 years' data was 50 fawns per 100 does. Grouping the data into five classes with midpoints of 10, 30, 50, 70, and 90 fawns per 100 does, respectively, the frequency of fawn:doe ratios in these classes was 1:4:6:4:1. Considering the classes to correspond with poor, fair, average, good, and excellent forage conditions, the probabilities of such conditions appeared to be 1/16, 4/16, 6/16, 4/16, and 1/16. The model permits this specified probability distribution to be changed as an experimental variable.

(11) "Forage factor" corrections for mortality and natality: The basic principles of the forage factor corrections are:

(a) In average forage years no corrections are made;

(b) In response to forage conditions above or below average, mortality will be below or above average and natality will be above or below average, respectively;

(c) Year-to-year variations in mortality in response to forage conditions will be greatest among fawns, less in yearlings and old (7+ years) deer, and least among prime (2-6 years) animals; and

(d) Annual variations in natality in response to forage conditions will be greatest among yearling does and least in prime does.

The forage correction factors used to date were based on the fawn survival rates associated with the forage classes specified above; i.e. 10, 30, 50, 70, and 90 fawns per 100 does in poor, fair, average, good, and excellent years, respectively. Fawn mortality in fair years will be 50/30 = 1.67 times as great as in the average year; in a good year mortality will be 50/70 = 0.71 times as great as in the average year. Values for the other forage categories were calculated similarly. Corrections for other age classes were set relative to the fawn corrections, with mortality among yearlings and old deer half as variable and among prime deer one-quarter as variable as that in fawns.

Correction factors for natality were derived from productivity data, which showed that the productivity of yearling does is more variable in response to forage conditions than that of older does. Current values specify that productivity varies from 30% to 110% of average values among yearlings and 70% to 120% for 3-6 year old does. Values for 2-year and 7+-year classes are intermediate. The natality and mortality correction factors are currently under revision.

## RESULTS AND DISCUSSION

Although this model can be used to test an infinite variety of hunting strategies, the options of the wildlife manager are limited because hunters can distinguish only a few age and sex classes in the field. Moreover, some hunting strategies may be socially or politically unacceptable even though they are biologically feasible. Most of the practicable management options in Mendocino County have been tested by the model. A small portion of the output for these runs is shown in Table 2. The full output includes many summary statistics comparable with field data to check the performance of the system and others subject to maximization as management goals.

In the simulation runs presented in Table 2, buck hunting was conducted during August and September, in accordance with existing custom, and does and fawns were hunted in November and December when antlerless deer are in the best condition. The principle features of each strategy are discussed below:

NO HUNTING

Presented for comparison with other runs, this strategy is characterized by a high buck: doe ratio, low productivity, and high natural mortality.

25% ADULT BUCKS: This run simulates the hunting effected in Mendocino County during the past 10+ years. Hunting is limited to males with two or more points per antler. The sex and age structure of the population differs markedly from that of the unhunted population although overall deer numbers are the same. Natural mortality is higher because the population contains more does, so that the number of fawns born and dying each year is greater than in the "no hunting" strategy. For every deer taken by hunters approximately 12 die of starvation and other natural causes. Although the management goals are not explicitly defined, current regulations result in the maintenance of maximum deer numbers and maximum natural losses. Exclusive hunting of adult males provides no constraint upon deer numbers.

25% BUCKS + DOES: If current regulations were modified to permit taking 25% of the adult does annually in addition to the current level of buck hunting, the hunting kill would increase and natural losses would decrease markedly. The hunting kill would include more bucks each year than are now being taken with "bucks only" hunting. Increased production and survival would compensate for the 17% decrease in overall deer numbers.

45% BUCKS, 30% DOES, 15% FAWNS: Where the hunter is allowed to select either bucks or does, this strategy represents the results of the heaviest hunting pressure likely of achievement. Although hunters generally avoid killing fawns if possible, data from other areas indicate that fawns comprise 15% to 20% of the kill in antlerless hunts.

50% BUCKS, 15% DOES, 60% FAWNS: The previous strategy would tend to maximize the hunting kill if hunters were allowed their free choice of animals, but the kill could be further increased by heavy selective fawn hunting. Domestic sheep are typically managed in this way. Although the kill would be considerably higher than in the previous strategy, the total biomass yield would be slightly lower because of the relatively small size of fawns. It may be unrealistic to propose that 50% of the bucks can be killed annually, but if the goal of management is to maximize the number of animals taken by hunters, it is necessary to maintain the highest possible proportion of breeding does in the herd. This can be achieved only by heavy hunting of adult males.

Many simulation runs in addition to those shown in Table 2 have been made. These studies show that the maximum yield of the Mendocino County deer population will be achieved with a hunting removal of about 20-25% of the does, 15-30% of the fawns, and over 50% of the bucks annually. At this rate of buck removal, there is no possibility of reducing the breeding success of the population, but it is unlikely that such a high buck kill can be achieved due to the dense cover on much of the deer range in the County.

The hunting of bucks only has little effect on overall deer numbers, but the population size is very sensitive to doe hunting. As hunting pressure on does increases overall deer numbers decrease at an increasing rate. Removal of does is the most powerful means

TABLE 1. AVERAGE NUMBERS OF DEER ON THE HOPLAND FIELD STATION, 1964-66.

| | MAY | JULY | OCTOBER | APRIL |
|---|---|---|---|---|
| LEGAL BUCKS | 40 | 90 | 50 | 40 |
| SPIKE BUCKS | 110 | 60 | 50 | 40 |
| DOES | 330 | 320 | 300 | 270 |
| FAWNS | 260 | 220 | 200 | 130 |
| TOTALS | 740 | 690 | 600 | 480 |
| DEER/MI$^2$ | 95 | 88 | 77 | 61 |

TABLE 2. THE EFFECTS OF VARIOUS HUNTING STRATEGIES ON THE MENDOCINO COUNTY DEER POPULATION

| HUNTING STRATEGY | TOTAL DEER NOV. 1 | ANNUAL LOSSES NATURAL | ANNUAL LOSSES HUNTING | FAWNS/100 DOES FALL | FAWNS/100 DOES SPRING | BUCKS/100 DOES FALL |
|---|---|---|---|---|---|---|
| NO HUNTING | 191,000 | 85,000 | --- | 64 | 41 | 86 |
| 25% ADULT BUCKS | 191,000 | 95,000 | 7,900 | 64 | 41 | 43 |
| 25% BUCKS + DOES | 159,000 | 41,000 | 22,000 | 68 | 66 | 74 |
| 45% BUCKS }<br>80% DOES }<br>15% FAWNS } | 117,000 | 15,000 | 36,000 | 83 | 90 | 41 |
| 50% BUCKS }<br>15% DOES }<br>60% FAWNS } | 141,000 | 22,000 | 53,000 | 96 | 50 | 22 |

of population control since it reduces total reproductive potential. This finding is readily applicable to the special management problems in National Parks where big game numbers must be controlled but public hunting is incompatible with primary management goals. In such situations hunting pressure should be directed solely against adult females to provide the most effective population control. This would minimize the number of animals to be killed and the manpower requirements of the shooting program. Additionally, it would maintain a high proportion of the aesthetically desirable adult males in the population.

## CONCLUSION

This paper has demonstrated the utility of a simulation model in evaluating the effects of various hunting strategies on deer population dynamics. The model is particularly valuable in identifying gaps in existing knowledge, and can be applied to other deer herds and other big game species without major alterations.

The model presented in this paper is essentially a population dynamics simulator. It should be viewed as the first generation of a sequence of models which hopefully will be capable of evaluating the economic and social consequences as well as biological effects of deer management strategies.