AN ABSTRACT OF THE THESIS OF

FRANK MALCOLM ANDERSON for the DOCTOR OF PHILOSOPHY
(Name) (Degree)

in AGRICULTURAL ECONOMICS presented on Jan. 4, 1972
(Major) (Date)

Title: COMPUTER SIMULATION OF A BIOMANAGEMENT SYSTEM - THE MENDOCINO COUNTY DEER POPULATION IN CALIFORNIA

Abstract approved: ______________________
A. N. Halter

Management of deer populations is directed toward multiple objectives. Deer populations on public and private lands belong to the public and thus management is a political process. Four components for an effective management system for deer populations are identified. These are the set of objectives relating to the resource, the set of regulations which will achieve the objectives, knowledge of the expected population response to alternative management strategies, and a means of monitoring these responses to determine whether or not the objectives are being achieved.

Deer provide benefits mainly through the associated recreational opportunities and cause costs by interacting with land based economic activities such as agricultural crop production and reforestation. At certain times of the year deer may also compete with domestic

livestock for forage. Deer also cause significant costs through collisions with automobiles on the highways.

The extent of these benefits and costs, and others, is related to the biosystem through parameters such as the size and composition of the population, the extent of the hunting kill, and so on. In this thesis a computer simulation model of the Mendocino County, California, deer population is presented. The population is modeled as a density dependent birth and death process. Hunting strategies are potentially the most flexible management tool. Thus the model is structured to permit detailed examination of the response over time of the population to alternative hunting strategies.

In California, a bucks-only hunting strategy has been followed since about the turn of the century. This study demonstrates that the bucks-only strategy neither effectively controls the size of the deer population, nor does it provide for the greatest recreational opportunities. The extent of the costs referred to above are directly related to the size of the population and the consumptive recreational benefits, that is those due to hunting, are directly related to the size of the hunting kill. Experiments with the model show that population control can be achieved and the hunting kill can be increased by a mixed buck and antlerless deer hunting strategy. Other results show that the computer simulation model can provide information about the biosystem which is not otherwise available.

Simulation methods permit considerable insights into the operation and control of complex biosystems where the status of the systems is time dependent and the systems are influenced by uncontrollable elements so that at best the outcomes resulting from particular management actions are uncertain. The simulation model used in this study is applicable to other deer populations and other wildlife species.

Computer Simulation of a Biomanagement System - the Mendocino County Deer Population in California

by

Frank Malcolm Anderson

A THESIS

submitted to

Oregon State University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

June 1972

APPROVED:

Professor of Agricultural Economics
in charge of major

Head of Department of Agricultural Economics

Dean of Graduate School

Date thesis is presented Jan. 4, 1973

Typed by Mary Jo Stratton for Frank Malcolm Anderson

ACKNOWLEDGMENTS

I wish to express my appreciation to the following persons who stimulated and encouraged me throughout this study.

Dr. A. N. Halter and Dr. W. M. Longhurst for their counsel and invaluable criticisms.

Mr. G. E. Connolly for his various efforts and criticisms of earlier drafts of this thesis.

The members of my graduate advisory committee.

The study has been supported by financial assistance from Oregon State University and the University of California at Davis.

TABLE OF CONTENTS

LIST OF TABLES

## LIST OF FIGURES

# LIST OF APPENDIX TABLES

# COMPUTER SIMULATION OF A BIOMANAGEMENT SYSTEM - THE MENDOCINO COUNTY DEER POPULATION IN CALIFORNIA

## I. INTRODUCTION

The average American, 100 years ago, did his hunting and gathering for sustenance reasons. Today, he satisfies his hunting and gathering instincts mainly through recreational pursuits. Fishing and hunting are carried out amid natural and seminatural scenes for fun, something akin to ancient patterns of the chase for meat. Today, berry-picking, nut gathering, and mushroom searching have a similar basis to the one-time necessity of the food and plant harvest.

In a 1960 survey of outdoor activities, conducted by the Outdoor Recreational Resources Review Commission, 90 percent of the American people sought some kind of outdoor activity (Rockefeller et al., 1962). Of 12 outdoor pastimes included in the survey, hunting ranked eighth with 12 percent of the population participating.

The U.S. Bureau of Sport Fisheries and Wildlife reported from a 1965 survey, that 13.5 million Americans went hunting (1966). They spent 185.8 million days in the field and drove 8.4 billion passenger miles by automobile to carry out the activity. There were 10.5 million small game hunters and 6.5 million big game hunters.[1] The

---

[1] Includes considerable overlap between the two types of game hunting.

hunters spent, on average, \$6.05 per recreation day for goods and services, or a total of \$1.12 billion. The states collected \$138 million in hunting and fishing license fees in 1965 and the sportsmen paid \$28 million in federal excise tax on equipment and supplies.

Projections for the future, made by the Outdoor Recreation Resources Review Commission (Rockefeller et al., 1962), indicate that while the human population might double by the year 2,000, the need for outdoor recreation is likely to triple. The greatest interest of the public in outdoor activities centers on the simple pastimes of driving, walking, swimming, and picnicking. The need for increased opportunities for these pursuits is greatest near large cities where the supply of land and water is currently inadequate to meet the need. Thus, these activities must be continually carried out on lands and water farther from the city which ultimately will compete with other land uses, including agriculture, forestry, and other forms of recreational use such as hunting.

The increasing interest in non-consumptive uses of wildlife and associated lands which may be competitive with hunting, is shown by the doubling of membership in the National Audubon Society in the three years following the 1965 survey of the outdoor activities. The survey also found that there were 8 million birdwatchers and 3 million wildlife photographers in the nation.[2] In 1967, there were 140 million

---

[2] There is possibly some overlap between birdwatchers and photographers and hunters.

visitors to areas in the national park system, nearly a threefold increase since 1950 (National Research Council, 1970).

In California, all forms of recreational use of lands are growing at an accelerated rate. This growth is exceeding the rate of population growth. For example, in 1940 the population of California was 7 million, while visitors to the state's parks numbered about 6-1/2 million. Projections for 1980 indicate there will be 28.1 million people in California and there will be 100 million visitors to the state's parks (California Fish and Game Commission, 1966).

The number of hunting license sales is a good indicator of the number of hunters (see Appendix A, Table A.1). In 1930, there were about 124,000 deer tags sold in California (California Fish and Game Commission, 1966). In 1956, the peak year, there were in excess of 448,000 deer tag sales. The average number of deer tag sales for the last six years, 1965 to 1970, was 417,535. Deer tags were sold to over 50 percent of the total number of hunters in the state up to 1949 (except for 1942). From 1949 to 1962 deer tags were sold to over 60 percent of the total number of hunters. In 1980, it is expected that deer hunters will be 65 percent of the total. In 1980, deer hunters in California are expected to increase to 525,000 (California Fish and Game Commission, 1966).

From a peak in 1947, the ratio of hunters to total population has declined. This ratio is expected to continue to diminish as the population increases and huntable land and land open to hunting continues to decline.

In 1963 there were 17.6 million people in California; by 1980 there will be 28.1 million. Most of the present population lives in or near urban centers. In 1980, 24 million of the 28.1 million are expected to live in metropolitan areas. The expansion of urban-industrial areas replaces land and native vegetation with asphalt and concrete. Urban-industrial developments today occupy 2,744,000 acres. By 1980 the area of urban-industrial land is estimated to expand to about 4,153,000 acres. By 1980, 4,750,000 new dwellings will occupy a half million new acres of land. Another effect of urban growth is the increase in land closed to the use of firearms. By 1980, it is probable that 8,300,000 acres will be closed to firearms and hunting. Firearms closures are intended to protect the public safety, but it is easier to write laws covering county-wide closure rather than for restricted areas in populated areas. Consequently, whole counties can be dropped from hunting areas as urbanization proceeds.

The extent and use of agricultural lands also impinge upon areas available to hunting. Agricultural crops occupy 10.5 million acres in California. Crop acreage is expected to increase in 1980 to 11.2 million acres or about 11.2 percent of the total land in the state. The trend toward more intensive use of crop land reduces wildlife habitat and reduces the carrying capacity of cultivated areas. Grazing of livestock takes place on about 26.3 million acres. According to studies by the California Fish and Game Commission (1966), grazing is one of several factors that has greatly changed the wildlife habitat of California and has an effect on most of the wildlife populations in the state. Livestock grazing in some areas has benefited deer, and the converse in others, depending on vegetation type, and intensity and season of livestock use.

The construction of roads and highways and the use of motor vehicles affect the wildlife habitat, the animals themselves, and the ability of people to use this resource. It is estimated that the 118,804 miles of county, state, and federal roads and highways occupy over 560,000 acres of land.

In addition to these directly competitive uses for land and hunting, other recreational uses of land may conflict with hunting of wildlife. Family camping, picnicking and sightseeing are not entirely compatible with hunting. There is increasing pressure for lands to be set aside for non-consumptive recreational uses and exclude hunters.

In total, from all competing uses, the California Fish and Game Commission estimates that by 1980 there will be a decrease of 16 percent in the present 50 million acres of big game hunting lands. This means that as the human population increases, and there are more people wanting to hunt, the concentration of hunters per square mile will become greater. The increasing density of hunters will, in turn, have an effect on numbers and distribution of wildlife populations, on their habitat, and the demand for instate hunting. Thus, the changing land use pattern and the increasing demand for recreational activities including hunting, are expected to intensify the need for wildlife management in California. Deer are found on approximately half the land area of California, or some 56 million acres, and are the most important game animal in the state. Future prospects for the deer populations are more favorable than for many other wildlife species. But wise game management will be required if the populations are to be maintained at a healthy and productive level. It is hoped that this thesis will contribute to the wise management of wildlife resources, in particular deer, in California and elsewhere. With appropriate modification, this approach should be applicable to other species and other areas.

## Wildlife Management

Wildlife management attempts to direct a complex dynamic biosystem to respond in ways that satisfy certain objectives. Vital components of a wildlife management system are at least four in number. These are: (1) a well-defined set of policy objectives for the resource; (2) knowledge and understanding of the significant interactions between the population of interest and the habitat, and between the population of interest and other animal populations, both domestic and wild; (3) the ability to tailor regulations and their enforcement to the management strategies which will move the biosystem toward satisfying the set of objectives, and (4) a means of monitoring the response of the biosystem to various management strategies.

## Policy Objectives

The following set of policy objectives was adopted by the California Fish and Game Commission on February 2, 1968 in regard to the management of deer in California.

1. Produce and maintain a maximum breeding stock of deer on all lands of California, public or private, suitable as deer habitat and consistent with local forage conditions and other uses of such lands. Utilize through public hunting the available crop of deer produced annually by this breeding stock and all surplus animals, of either sex, over and beyond what the range can carry in a healthy condition.
2. Maintain for deer the best possible range conditions consistent with other uses, improve deer ranges which are open to public hunting, and encourage private landowners or tenants to improve their deer ranges even though hunting is limited.
3. Keep deer populations in balance with local forage supplies and conflicting uses, and manage deer herds on the basis of natural forage without recourse to artificial feeding.
4. Subject to the policy on Depredation, which follows, control populations of deer which are damaging land or property by regulated public hunting whenever possible, otherwise by permit shooting.
5. The demands of deer shall have priority over other big game species, native or introduced, whenever conflicts arise over the allocation of forage.

6. Regulate the number of deer predators on the basis of local deer needs, particularly on under-stocked ranges or ranges where hunters are fully harvesting the annual deer crop.
7. Make objective surveys of the deer herds annually and report the results to the Commission as soon as they are compiled.

## Biological Information

Deer are members of complex dynamic biosystems. They interact with their habitat, compete with other animals, are affected by diseases and predators, and without natural controls can explode in number or vanish under extreme hardships. It is not the intent of this section to specify the relevant biological information necessary to manage a deer population, for that will be one of the tasks of subsequent chapters. Instead, an example of the management of the Kiabab deer population in the Grand Canyon National Game Preserve is discussed to illustrate how management can be misdirected by inadequate biological information.

In 1906, a strategy of complete protection was adopted for the management of the Kiabab deer population. The population was protected from hunting, and natural predators (puma and coyote) were systematically removed. Also, from 1889, the number of livestock using the range was steadily reduced. A reported total of 200,000 sheep grazed the plateau in 1889. By 1908 this number was reduced to 5,000 (Russo, 1964).

Ungulate populations are prone to occasional massive fluctuations, or eruptive fluctuations, in numbers quite distinct from the annual random variations explicable in terms of seasonal and annual variations in forage conditions. Following Caughley (1970), an eruptive fluctuation is defined as a steady rise in numbers over at least two generations followed by a marked decline. Beginning in 1906, the Kiabab deer population underwent such an eruptive fluctuation. Data on the population are inconsistent for the period 1906 to 1939, but indications are that the population reached a peak, variously estimated at between 30,000 and 100,000, sometime between 1924 and 1930, after which it declined sharply to a level estimated at between 10,000 and 20,000 by 1940.

Two conflicting theories have been presented in the literature regarding the cause for the eruptive fluctuation in the Kiabab deer population. One theory, found in many textbooks on ecology and wildlife management (Lack, 1954; Odum, 1959), considers the fluctuation to be a consequence of a systematic removal of the natural predators of the deer. According to this theory, the population expanded in response to the removal of the predators until forage conditions deteriorated to the level where the impact of two severe winters after 1924 caused the population to suffer a much increased natural mortality with a consequent 60 percent (estimated) reduction in numbers. The other theory, more plausible, and consistent with eruptive fluctuations in other ungulate populations[3], attributes the massive fluctuation in numbers in the Kiabab population to intensive use of the range by livestock prior to 1906, which altered the climax stands of forage plants to successional stages more favorable to deer. The increase in deer numbers following the favorable change in climax vegetation caused deterioration in the habitat, depletion of the food supply, and increases in natural losses due to starvation, diseases and parasites which combined to cause a rapid decline in the size of the population. By 1945, the condition of the biosystem was such that the managers instituted a bucks-only hunting season. As is now well-known, bucks-only hunting is not an effective means of population control for deer, particularly when the population is below the carrying capacity of the habitat (Longhurst et al., 1952). By 1952, the population of deer in the Kiabab was again in excess of 25,000. The bucks-only hunting regulation was dropped in that year and in spite of heavy hunting in successive years, the population rose to 37,000 in 1954. In response to adverse seasons and the heavy hunting pressure, the population was reduced to 12,000 in 1955. Current management of the Kiabab deer population utilizes a diversity of strategies including antlerless hunts, and special permit areas to

---

[3] Leopold et al. (1947) reported that about 100 odocoileid deer populations in the United States entered an eruptive fluctuation between 1900 and 1945. These eruptions were suspected or shown to be checked by depletion of food supplies.

manipulate the hunter kill. The fluctuation in yield and population in the Kiabab population of the 1950's could have been avoided if there had been available a biomanagement model capable of indicating the outcome of the bucks-only hunting strategy using biological principles and facts that are currently available. It is the purpose of this thesis to present a biomanagement model based upon biological principles, and upon empirical observations about the deer population in Mendocino County, California.

Hunting Regulations

Regulations have been used to restrict the utilization of various wildlife species throughout wildlife management history (Leopold, 1933). The difficulty is not in the specification of regulations and enforcement of particular regulations but the specification of regulations which will achieve the policy objectives for the wildlife resource. To illustrate how regulations can lead to outcomes that may not be consistent with stated policy objectives, an example of a recent change in the deer regulations in California is given. California traditionally has an early (coastal) and a late (inland) deer season. Each deer license includes an A and a B tag. Prior to 1970 either or both tags could be used in the coastal season but only the B tag was valid inland. Many hunters used their A tags in the coastal areas and saved the B tags for the late season. For the 1970 and 1971 seasons a new regulation was instituted by the California Fish and Game Commission, requiring both the A and B tags to be attached to any deer taken in the late season. This precluded hunters who were successful in the early season from hunting in the late season.

The intent of the new regulation apparently was to reduce hunting pressure in the eastside ranges, assuming that hunters would fill one or both tags during the early season and forego the opportunity for a larger mule deer. However, the most obvious effect of the change in regulations was that hunting pressure in the coastal areas was reduced by an estimated 40 to 50 percent (California Department of Fish and Game, final 1970 deer kill report). There was no apparent reduction in hunting pressure in much of the inland area as the Modoc and Lassen wildlife management units of the California Department of Fish and Game reported an increased kill in the 1970 season, apparently due to increased hunting pressure (California Department of Fish and Game, . . . wildlife unit reports, 1971). This effect was the reverse of the intended effect of the altered regulations.

Although the biomanagement model to be discussed in subsequent chapters could not forecast this kind of hunter response, it does serve to illustrate that information about hunters' response to regulations is a vital component of a wildlife management system. However, information about hunters' response to regulations, deer density, and hunting success, along with the deer biomanagement model of this thesis, would serve to tailor regulations which would move the biosystem toward satisfying the policy objective as specified earlier.

## Monitoring the Biosystem

To effectively manage a wildlife species, such as deer, a routine data collection procedure needs to be followed in order to monitor the responses of the system to changes in habitat, weather, competition, and hunting regulations.

Deer populations are characterized by potentially high birth and death rates, that is, high rates of turnover, and given the appropriate sets of physical and biological conditions, populations can increase explosively, or vice versa. Unless the monitoring facilities are sensitive to all significant changes in the population size and composition, and can gauge the relation between the population and habitat and important other species in the biosystem, management and regulations can at best hope to move the population toward the objectives in an uncertain manner. Another objective of constructing a biomanagement model of the Mendocino County deer population is to pinpoint the kinds of variables that need to be monitored from a biological point of view and those that need to be monitored from a social and economic point of view. The social and economic variables are important in specifying hunting strategies to be tested on the model.

## Biomanagement Models

Wildlife management has been presented as a procedure for moving a complex biosystem toward achieving policy objectives. The manager must formulate strategies that not only achieve these policy objectives, but also are consistent with biological principles and data, and cognizant of likely political, social, and economic responses of human populations. In early days of wildlife management, a few facts were used with simple paper and pencil models to develop management strategies. However, as mistakes were made and wildlife biologists like Leopold (1933) elucidated biological principles, greater demands for data and analytical models were made in order to increase the manager's confidence in how current strategies affect the wildlife population. Yet these analytical models are inadequate from a prescriptive and predictive standpoint in evaluating changes in strategies. In order to provide information on how a biosystem is likely to respond to different strategies, more complex models are formulated. With the facilities of electronic computers, such models can be manipulated with ease, and experiments performed with the model which simulate the biosystem and its responses to changes in management strategies.

This thesis proposes the formulation and application of simulation models of certain classes of biosystems as positive adjuncts to the sets of analytic procedures currently available for biosystem management. It is not proposed that simulation models be adopted for routine use in all cases where management involves manipulation of a complex biosystem. The decision for adoption and use of such models will depend on benefit-cost relationships. Comprehensive simulation models can provide information in addition to that available from the simplistic models, but perhaps at a higher cost. The value of the additional information will depend on factors such as the dimension and type of the increments in utilization of the resource occurring as a direct result of the modeling effort and application. The additional costs will be incurred in activities such as more comprehensive data collection, analysis, model formulation, testing and operation of the model.

## Outline of Thesis

The study upon which this thesis reports has as its objectives the following:

1. To develop, test, and refine models simulating existing relationships and values with resources related to deer production and use.
2. To assemble and/or determine knowledge needed to clarify pertinent bioeconomic relationships and values with

resources relating to deer production and use needed in developing models encompassing these relationships and values.

3. To demonstrate the application of these models to deer management and related public policy decisions.

The study was carried out by a team of agricultural economists from Oregon State University and big game biologists from the University of California. Through much interaction with each other and personnel from the California Department of Fish and Game, a biomanagement model of the Mendocino County deer population was formulated. The model was run on the CDC 3300 computer at Oregon State University. Through subsequent interaction with the big game biologists, the model was tested, modified, and validated. Together, experiments were designed and simulated with the model to evaluate possible hunting strategies and regulations not now in force in Mendocino County, California. This thesis presents some of the details of this interdisciplinary effort.

The specific objectives of the thesis are:

1. To formulate a biomanagement model of the Mendocino County deer population.
2. To validate the biomanagement model using data from the Hopland Field Station and the California Department of Fish Game.

3. To experiment with the model using various hunting strategies.

4. To interpret results from the experiments in terms of biological and economic criteria.

The next chapter presents some of the background material on Mendocino County, the relevant data resources of the Hopland Field Station of the University of California in Mendocino County, and selected data from the California Department of Fish and Game. Also some facets of the problem of deer population management in Mendocino County are made explicit by discussing some of the costs and benefits relating to the population. The third chapter presents the deer population simulation model and the biological principles upon which it is based. The validity tests and modifications made in earlier formulations of the model are presented in the last part of Chapter III. Results from experiments with the model are given in Chapter IV. A summary, some interpretations, and conclusions are given in Chapter V.

# II. MENDOCINO COUNTY: GENERAL CHARACTERISTICS, DEER POPULATION AND ITS MANAGEMENT

This chapter presents data on the general characteristics of Mendocino County that make it habitable for black-tailed deer (Odocoileus hemionus columbianus). The size and composition of the deer population are described, based on various sources of information. Following this, the management of the population is discussed in relation to the intentional and unintentional activities of man that affect these deer.

## General Characteristics of Mendocino County

Mendocino County covers an area of approximately 3,510 square miles. The county includes a diversity of habitat types, some highly productive of deer, others less so. The various habitat types and their acreages are listed in Table 2.1. Also, because of expected changes in land use, projections of the habitat types in 1980 made by the California Fish and Game Commission (1966) are shown.

The habitat types that are excellent from the standpoint of carrying capacity for deer make up about 31.7 percent of the county and include coastal forest lands (particularly after logging), woodland-grass lands, and hardwood lands. Habitat types intermediate in carrying capacity make up 51.9 percent of the county and include redwood forest lands, pine-fir-chaparral lands, chaparral lands,

Table 2.1. Habitat types in Mendocino County.

| Habitat types | Acreage 1963 | Percent of county | Acreage 1980 (projected) | Percent of county |
|---|---|---|---|---|
| Redwood | 667,000 | 29.7 | 680,000 | 30.1 |
| Coastal forest | 339,000 | 15.1 | 310,000 | 13.8 |
| Pine-fir-chaparral | 200,000 | 8.9 | 196,000 | 8.7 |
| Minor conifer | 31,000 | 1.4 | 31,000 | 1.4 |
| Hardwood | 133,000 | 5.9 | 111,500 | 5.0 |
| Woodland-chaparral | 99,000 | 4.4 | 100,000 | 4.5 |
| Woodland-grass | 239,020 | 10.6 | 191,820 | 8.5 |
| Chaparral | 163,000 | 7.3 | 154,000 | 6.9 |
| Coast sage brush | 4,000 | 0.2 | 4,000 | 0.2 |
| Grassland | 297,425 | 13.2 | 356,609 | 15.9 |
| Agriculture | 35,795 | 1.6 | 40,411 | 1.8 |
| Urban-industrial | 9,500 | 0.4 | 13,000 | 0.6 |
| Lakes, bays, reservoirs | 5,960 | 0.3 | 32,860 | 1.5 |
| Riparian | 400 | trace | 400 | trace |
| Barren | 22,300 | 1.0 | 24,800 | 1.1 |
| Total | 2,246,400 | 100.0 | 2,246,400 | 100.0 |

Source: California Fish and Game Commission (1966), p. 882.

woodland-chaparral lands, riparian lands, and agricultural lands. The remaining 14.8 percent of the land inhabitable by deer is of lowest carrying capacity and includes grassland, minor conifers, and coast sagebrush. The remaining 1.6 percent of the land is essentially uninhabitable by deer.

Forestry is the leading industry in the county. Timber land use practices have varied in the past 20 years. About 10,000 acres are logged annually. This yields about 500,000,000 board feet of logs. At an average stumpage price of $40 per thousand board feet, the annual cut has a total stumpage value of $20,000,000.

The second largest industry that is land related is agriculture and livestock production. Agriculture produced over 11 million dollars of field crops, fruits and nuts, and vegetable crops in 1970. The breakdown by crop is shown in Appendix A, Table A.2. The total value of livestock production in 1970 was nearly 4.5 million dollars. Details of livestock production and animal inventories are given in Appendix A, Table A.3. The total sheep and cattle range and pasture land in 1970 was 1,019,323 acres. During 1970, approximately 37,000 cattle and 71,000 sheep grazed these lands. In addition, the U.S. Forest Service leases a limited number of grazing allotments to livestock operators. In 1967, these areas leased permitted grazing for approximately 600 cattle.

The next largest industry is tourism and recreation. One important aspect of the recreational use of Mendocino County lands is hunting of deer. A characteristic of land that affects its accessibility to deer hunting (as well as to other recreational uses) is the type of ownership. In Mendocino County about 80 percent of the land is privately owned and the remaining 20 percent is publicly owned. Much of the private land is posted against trespassing, resulting in heavy hunting pressure on public lands. The land ownership pattern for 1948, which is believed not to differ from the current pattern, is shown in Table 2.2.

Table 2.2. Mendocino County land ownership, 1948.

| Ownership class | Area in thousands of acres | Percent of county |
|---|---|---|
| Public ownership | | |
| Federal | | |
| National forest | 174 | 7.8 |
| Bureau of Indian Affairs | 21 | 0.9 |
| Bureau of Land Management, and others | 164 | 7.3 |
| Total federal | 359 | 16.0 |
| State, county, and municipal | 102 | 4.6 |
| | 461 | 20.6 |
| Private ownership | 1,785 | 79.4 |
| Total land | 2,246 | 100.0 |

Source: Baker and Poli (1951).

## Mendocino County Deer Population

The number of deer in the Mendocino County population is known only within certain limits. Estimates of the total number have been made and indicate a range of 180,000 to 225,000 animals. These estimates are made by several methods, two of which are discussed here. The first method uses ratio estimates based upon observation and field counts and the second uses estimated habitat carrying capacity and the acreages of each habitat type.

### Ratio Estimation Method

Using ratio estimates, the total number of deer are calculated as follows: (1) the actual buck kill is determined from adding together the reported kill and an assumption about the cripple loss, illegal and unreported kill, (2) the number of bucks is calculated after assuming the percentage of legal bucks killed of all mature bucks, (3) the buck to doe ratio estimated from herd composition counts is applied to the total buck numbers to obtain the number of does, (4) the fawn to doe ratio estimated from herd composition counts is applied to the number of does to obtain the number of fawns, and (5) the numbers of bucks, does, and fawns are added together to obtain the total number of deer in the county.[1] An example will illustrate the procedure.

[1] The basic assumption in herd composition counts is that each animal has an equal chance of being counted. No attempt is made to

The reported buck kill in Mendocino County for the regular buck season (August - September) is shown in Table 2.3 for 1958 to 1970. (Also see Appendix A, Table A.4.) For this 13 year period, the average take has been 4,226 bucks. Supposing the cripple loss, illegal and unreported kill amounts to 50 percent of reported kill, then the actual kill of bucks is 6,339. Assuming 25 percent of the legal bucks killed and a spike to legal bucks ratio of 1 to 2, the total number of bucks is 3 x 6,339 x 1.50 = 28,526. The ratios of bucks to does, and fawns to does are determined in herd composition counts made by the unit wildlife manager of the Department of Fish and Game. The numbers upon which these ratios are based are shown in Table 2.4 for the fall count from 1958 to 1970. The average fall buck to doe ratio for 1958 to 1970 is 26.8 to 100 and the average fawn to doe ratio is 59.8 to 100. Applying the buck to doe ratio to the number of bucks gives an estimated total of 106,440 does. Applying the fawn to doe ratio ot 59.8 to 100 to the number of does gives 63,651 fawns. The number of bucks, does, and fawns added together gives the estimated total of 198,617 deer in the population. For management purposes this would be rounded to 200,000.

---

enumerate the entire population. The age and sex classes usually distinguished are does, fawns, spike bucks, and legal bucks, although the two buck classes cannot be separated in the spring count when antlers are in an early stage of growth.

Table 2.3. Mendocino County regular season buck kill, 1958-1970.

| Year | Sample size | Percent yearling | Percent 2 year | Percent 3 year | Percent 4+ year | Total kill | Kill per square mile |
|---|---|---|---|---|---|---|---|
| 1958 | 207 | 1 | 33 | 14 | 52 | 3,754 | 1.07 |
| 1959 | 341 | 0 | 31 | 24 | 45 | 3,655 | 1.04 |
| 1960 | 459 | 5 | 28 | 20 | 47 | 4,426 | 1.26 |
| 1961 | 630 | 1 | 36 | 21 | 42 | 4,585 | 1.30 |
| 1962 | 317 | 1 | 28 | 29 | 42 | 4,002 | 1.14 |
| 1963 | 383 | 2 | 28 | 26 | 44 | 4,367 | 1.24 |
| 1964 | 325 | 2 | 34 | 26 | 38 | 4,681 | 1.33 |
| 1965 | 463 | 1 | 30 | 30 | 39 | 4,869 | 1.39 |
| 1966 | 411 | 1 | 29 | 28 | 42 | 4,427 | 1.26 |
| 1967 | 200 | 2 | 29 | 24 | 45 | 3,315 | 0.92 |
| 1968 | 193 | 6 | 23 | 19 | 52 | 4,222 | 1.20 |
| 1969 | 254 | 3 | 31 | 23 | 43 | 4,473 | 1.27 |
| 1970 | 380 | 2 | 23 | 31 | 44 | 4,158 | 1.18 |
| Mean | | 2.1 | 29.5 | 24.2 | 44.2 | 4,226 | 1.20 |

Source: California Department of Fish and Game (1971).

Table 2.4. Mendocino County herd composition counts, 1958-1970.

| Year | Spring herd composition | | Fall herd composition | | |
|---|---|---|---|---|---|
| | Sample size[a] | Fawns/100 adults | Sample size[a] | Bucks/100 does | Fawns/100 does |
| 1958 | 621 | 37 | 791 | 36 | 69 |
| 1959 | 972 | 31 | 750 | 37 | 64 |
| 1960 | 1,284 | 39 | 887 | 33 | 69 |
| 1961 | 1,104 | 41 | 1,093 | 34 | 45 |
| 1962 | 708 | 34 | 824 | 29 | 70 |
| 1963 | 887 | 45 | 1,402 | 23 | 66 |
| 1964 | 1,173 | 37 | 1,571 | 31 | 55 |
| 1965 | 1,096 | 28 | 1,229 | 17 | 41 |
| 1966 | 1,142 | 18 | 810 | 20 | 46 |
| 1967 | 1,167 | 27 | 1,200 | 19 | 62 |
| 1968 | 1,018 | 38 | 561 | 25 | 61 |
| 1969 | 1,175 | 42 | 1,656 | 24 | 77 |
| 1970 | 1,401 | 50 | 1,356 | 20 | 52 |
| Mean | | 35.9 | | 26.8 | 59.8 |
| Standard deviation | | 8.4 | | 6.9 | 11.1 |

Source: California Department of Fish and Game (1971).

[a]Number classified by herd composition counts.

## Habitat Type Estimation Method

This method is based on information obtained from estimates of carrying capacity of various habitat types obtained from the California Department of Fish and Game. The range of carrying capacity and the average carrying capacity per square mile of habitat is shown in Table 2. 5 along with the area in square miles of each habitat type and the estimated deer numbers. The population obtained by this method is 181, 312 deer when the average carrying capacity is used. The reasonably close approximation of the estimates from these two procedures lends credence to these approaches.

## Age and Sex Distribution

Estimates of the age distribution of the Mendocino County deer population can be made from several sources. The age distribution of bucks can be approximated from the buck kill age distribution given in Table 2. 3. This distribution is probably biased toward younger animals if one accepts the hypothesis that the older bucks are relatively less susceptible to hunting. Also, the data of Table 2. 3 are based on samples collected mainly from public lands where the hunting pressure is greatest, which reduces the average age of bucks. The age and sex distribution of the entire population can be approximated from examination of animals killed on the highways of Mendocino

Table 2.5. Deer numbers by habitat type in Mendocino County.

| Habitat type | Square miles | Deer per square mile | Average deer per square mile | Deer population | | |
|---|---|---|---|---|---|---|
| | | | | Minimum | Average | Maximum |
| Redwood | 1,042 | 30-60 | 45 | 31,260 | 46,890 | 62,520 |
| Coastal forest | 530 | 60-100 | 80 | 31,800 | 42,400 | 53,000 |
| Grassland | 465 | 10-30 | 20 | 4,650 | 9,300 | 13,950 |
| Woodland-grass | 374 | 60-100 | 80 | 22,440 | 29,920 | 37,400 |
| Pine-fir-chaparral | 313 | 30-60 | 45 | 9,390 | 14,085 | 18,780 |
| Chaparral | 255 | 30-60 | 45 | 7,650 | 11,475 | 15,300 |
| Hardwood | 208 | 60-100 | 80 | 12,480 | 16,640 | 20,800 |
| Woodland-chaparral | 155 | 30-60 | 45 | 4,650 | 6,975 | 9,300 |
| Agriculture | 56 | 30-60 | 45 | 1,650 | 2,520 | 3,360 |
| Minor conifers | 48 | 10-30 | 20 | 480 | 960 | 1,440 |
| Coast sagebrush | 6 | 10-30 | 20 | 60 | 120 | 180 |
| Riparian | .6 | 30-60 | 45 | 18 | 27 | 36 |
| Barren | 35 | - | - | - | - | - |
| Urban-industrial | 15 | - | - | - | - | - |
| Lakes, bays, reservoirs | 9 | - | - | - | - | - |
| Totals | | | | 126,528 | 181,312 | 236,066 |

Source: Longhurst *et al*. (1969).

County. An annual average of 1,084 animals has been collected on highways in the county over the period 1964 to 1970. Assuming that any age or sex deer has an equal chance of being hit and killed, then the age and sex distribution can be approximated from these data. The sex distribution of the highway kill is given in Table 2.6.[2]

In addition, data from the Hopland Field Station on herd composition and carcass counts give another indication of the age and sex distribution used in this study. These data are given in Table 2.7. While the Hopland Field Station data may not be representative of the entire county, they are used as a starting point in the development of age and sex distributions which are used in the simulation model described in the next chapter. An indication of the representativeness of the Hopland Field Station data of the entire county is given in Table 2.7. The various ratios indicate that the Hopland Field Station population is more productive than the county population (Connolly, 1970). Thus, in formulating parameters from the Hopland Field Station data to represent the county deer population, recognition was given to this difference.

## Management of the Mendocino County Deer Population

The management of the Mendocino County deer population and

---

[2] The age distribution is unavailable at this time.

Table 2.6. Mendocino County highway deer kill, 1964-1970.

| Year | Classification | | | | | | Unclassified | | Total | Kill per mile of checked highway[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bucks | | Does | | Fawns | | | | | |
| | No. | % | No. | % | No. | % | No. | % | | |
| 1964 | 257 | 23 | 590 | 52 | 251 | 22 | 31 | 3 | 1,129 | 3.2 |
| 1965 | 239 | 19 | 673 | 55 | 294 | 24 | 22 | 2 | 1,228 | 3.5 |
| 1966 | 294 | 22 | 718 | 54 | 317 | 24 | 0 | 0 | 1,329 | 3.7 |
| 1967 | 205 | 22 | 426 | 46 | 255 | 27 | 45 | 5 | 931 | 2.6 |
| 1968 | 242 | 26 | 431 | 45 | 276 | 29 | 0 | 0 | 949 | 2.8 |
| 1969 | 251 | 23 | 499 | 46 | 303 | 28 | 35 | 3 | 1,088 | 3.2 |
| 1970 | 180 | 19 | 491 | 53 | 224 | 24 | 35 | 4 | 930 | 2.7 |
| Mean | 238 | 22 | 547 | 50 | 274 | 25 | 24 | 3 | 1,084 | 3.1 |

Source: California Department of Fish and Game (1971).

[a]Each year, 345 miles of state and federal highways are regularly checked for deer kills in the county. This includes 320 miles of two-lane and 25 miles of four-lane highway.

Table 2.7. Deer population comparisons of Hopland Field Station versus the remainder of Mendocino County using herd composition and carcass examination data.

| Parameter | Hopland Field Station[a] | Remainder of county[a] |
|---|---|---|
| Herd composition counts | | |
| April | | |
| Fawns/100 adults | 44 | 36 |
| October | | |
| Fawns/100 does | 74 | 60 |
| Fawns/100 adults | 56 | 47 |
| Bucks/100 does | 33 | 27 |
| Legal bucks/100 does | 17 | 19 |
| Spike bucks/legal bucks | .94 | .42 |
| Carcass examinations | | |
| Fawns dying/100 adults during period November 1 to April 30 | 123 | 90 |

Source: California Department of Fish and Game (1971), and Longhurst (1970).

[a]Averages for years 1958 to 1970.

its habitat is carried out in various intentional and unintentional ways. The California Department of Fish and Game intentionally sets hunting regulations which affect the population. On the other hand, many animals are killed by automobiles on the highways which exerts an unintentional management influence on the population. The acreages of the various habitat types of the county are relatively stable, but changes within habitat type are constantly taking place as forest and agricultural practices change. Little intentional habitat improvement has taken place, however, burning of thick brush to improve livestock and deer ranges has taken place in the past. Increasing air pollution controls are preventing this type of management to continue.[3] Some control over population numbers is exerted on the population from farmers and private forestry personnel through depredation permit killing when excessive damage to crops and coniferous trees has occurred. However, this population control effect is usually localized. The complex relationships between diseases and parasites of deer and domestic animals exerts another unintentional type of control on the deer population of the county. These various influences have costs and/or benefits associated with them. These are the subject of this section.

---

[3] State air resources unit denies Mendocino burning. Santa Rosa Press Democrat (Santa Rosa, California). November 25, 1971. p. 2.

Benefits of the Deer Population

The major sources of benefits of deer in Mendocino County are from recreational use, either from hunting or nonconsumptive pursuits. The recreational value of deer has been expressed in various ways, none of which are satisfactory to use in a management context (Clark, 1969). To use the recreational value of deer in a management context would require the estimation of a demand function encompassing both consumptive and nonconsumptive aspects and incorporating as arguments, variables from the biosystem and the hunting regulations. Since this task is beyond the scope of this thesis, some indicators of the value of deer in Mendocino County are given to show the possible magnitudes of economic worth associated with the hunting activity. No estimates of the nonconsumptive benefits in Mendocino County are available.

The economic value of hunting can be expressed through the meat value of the venison, hunter expenditures, hunting club fees, and other economic activities associated with the handling of venison and hides. The value of venison taken in Mendocino County is shown in Table 2.8 using a range of meat values from 25 cents to one dollar per pound. The value is based on the annual take of deer for the period of 1958 to 1970. At a value of 25 cents per pound, an average deer is worth about $13.75, while at one dollar per pound it is worth about $55.00. Since venison is not sold in the commercial meat market in California, it is difficult to say that any of these values expresses the amount that venison consumers would be willing to pay for a pound of venison.

Table 2.8. Value of venison taken in Mendocino County.

| Meat value/ pound[a] ($) | Weight of all meat taken[b] (lb) | Value of all meat taken ($) | Average weight of one deer carcass (lb) | Value/ deer ($) |
|---|---|---|---|---|
| .25 | 232,430 | 53.107 | 55 | 13.75 |
| .50 | 232,430 | 116.215 | 55 | 27.50 |
| 1.00 | 232,430 | 232,430 | 55 | 55.00 |

[a] These are assumed values.
[b] Mean reported deer kill 1958 to 1970 = 4,226.
Mean field dressed weight = 80 pounds.
Mean carcass weight = 55 pounds.

Hunter expenditures, found through a 1965 survey, amount to over 1.5 million dollars annually (Connolly, 1966). Residents of the county reported expenditures of $164 in 1965 and non-residents of the county reported an average of $207. Since many of the hunters interviewed also hunted elsewhere, it is not possible to say that this is the value to them of hunting deer in Mendocino County.

A measure of value which has a market basis is the fee that hunters pay to private landowners for the right to hunt on their lands. In a 1967 survey of deer hunting clubs, carried out by the Regional Office of the California Department of Fish and Game (1967), it was found that club members paid an average of $115 per year per member for hunting rights in Mendocino County. The fees and other statistics for the deer clubs in the county are shown in Table 2. 9. Based on the $115 per member fee and the 1.21 deer per member that were bagged, the average value per deer to hunting club members is $95.04. If every deer that is taken by hunting in the county were evaluated at this figure the average 1958 to 1970 reported hunter kill (4,226 deer) is worth over $400,000 annually.

Table 2. 9. Information on Mendocino County deer hunting clubs, 1967.

| | | |
|---|---|---|
| Average fee per member | $115 | |
| Highest fee per member | 250 | |
| Average number of deer killed per club | | 33.5 |
| Average number of hunting days per club | | 89.0 |
| Average number of hunters per club[a] | | 32.0 |
| Average number of days to bag deer | | 4.45 |
| Deer bagged per hunter[a] | | 1.04 |
| Deer take per member[b] | | 1.21 |
| Average value per deer | $95.04 | |

Source: California Department of Fish and Game (1967).

[a] Includes guests.
[b] Does not include guests.

Deer hides also have a value if sold. An estimate of the hide value is $1.25 per hide or $5,283 for the average of 4,226 deer taken for the period 1958 to 1970. Tanning of these hides also contributes to the economic activity of California. Another contributing factor to economic activity is the cutting and wrapping of venison for hunters by meat locker plants. The average charge for these services is $7.50 to $10.00 per animal. If 50 percent of the deer killed are processed by meat markets, the total income to these establishments would range from about $16,000 to $21,000 per year.

## Costs of Population Management

The direct costs of population management include regulation and enforcement, and habitat manipulation and improvement. This section discusses some aspects of each of these categories. Indirect costs of management like agricultural crop and forest damages will be considered in the next section.

### Cost of Regulation and Enforcement

The costs associated with population management, and in particular the hunting phase, are easily identified in the salaries and other costs of hiring and maintaining seven game wardens and one game manager in Mendocino County. The California Department of Fish and Game spends about $50,000 per year for big game work in this county. This includes: $30,854 for enforcement, $12,625 for management, and $5,675 for administration based on 1966-1967 expenditures. These estimates are provided by the California Department of Fish and Game.

## Current Vegetation Manipulation and Habitat Improvement Practices

Changes in vegetation, both accidental (as in wildfires) and deliberate (as accomplished by controlled burning) have some effects on deer populations (Taber and Dasmann, 1958; Longhurst and Connolly, in press). Records of controlled burns (1960-1969) and wildfire burns (1963-1966) in the county are given in Table 2.10 and Table 2.11 respectively. There is an average of about 3,000 acres burned by wildfire per year in Mendocino County. The acreage burned by controlled burning has been diminishing, and in 1969 amounted to about another 3,000 acres.

Costs of controlled burning and wildfire suppression developed by the California Division of Forestry indicate that about $30,000 per year are spent in these activities. A cooperative study conducted in California by the Bureau of Land Management, the California Department of Fish and Game, and the U.S. Forest Service has summarized cost figures for various types of habitat improvement work (as cited by Longhurst _et al._, 1969). This study listed the following costs as being representative:

| | |
|---|---|
| Browse regeneration (crushing, burning, seeding) | $30/acre |
| Type conversion (crushing, burning, seeding, multiple spraying) | $35-$55/acre |
| Browseways | $30/acre |
| Controlled burning for sprout production (fire lines, crushing and clearing brush at vital points, labor, equipment, travel and overhead) | $ 5/acre |

Table 2.10. Controlled burns in Mendocino County, 1960-1969.

| Year | Number of burns | Acres burned | Pretreatment acreage | Acres seeded[a] | Reburn acreage[b] |
|---|---|---|---|---|---|
| 1960 | 102 | 20,785 | 474 | 3,728 | 6,453 |
| 1961 | 82 | 22,253 | 217 | 5,135 | 8,316 |
| 1962 | 74 | 10,955 | 934 | 2,853 | 2,059 |
| 1963 | 51 | 9,286 | 137 | 1,119 | 3,860 |
| 1964 | 58 | 19,323 | 345 | 1,067 | 7,062 |
| 1965 | 32 | 10,269 | 169 | 1,464 | 1,768 |
| 1966 | 50 | 16,683 | 1,065 | 3,310 | 8,286 |
| 1967 | 44 | 10,352 | 40 | 305 | 8,300 |
| 1968 | 31 | 5,575 | 416 | 33 | 3,225 |
| 1969 | 32 | 3,469 | 115 | 300 | 1,018 |

Source: Longhurst _et al_. (1969).

[a]The brush is burned and grass seed sown.

[b]These acreages have been burned previously.

Table 2.11. Acreage burned by wildfire in Mendocino County by vegetation type, 1963-1966.

| Year | Total (acres) | Timber (acres) | Woodland (acres) | Grass (acres) | Misc. conifers (acres) | Woodland grass (acres) | Brush (acres) | Cultivated land (acres) |
|---|---|---|---|---|---|---|---|---|
| 1963 | 446 | 228 | 35 | 126 | 2 | 4 | 46 | 5 |
| 1964 | 2,960 | 871 | 906 | 431 | 1 | 57 | 694 | - |
| 1965 | 3,962 | 644 | 2,416 | 245 | 17 | 76 | 562 | 2 |
| 1966 | 6,159 | 1,093 | 149 | 437 | 218 | 161 | 4,101 | - |
| Total | 13,527 | 2,836 | 3,506 | 1,239 | 238 | 298 | 5,403 | 7 |
| Mean | 3,381 | | | | | | | |

Source: Longhurst *et al.* (1969).

Most of the habitat improvement work done in Mendocino County falls into the last category above. This $5 per acre cost does not include the cost of reburning or grass seeding. Reburning is often necessary to reduce brush density to maintain it in a productive condition and within reach of the deer.

Research documenting the effects of vegetation manipulation on deer numbers is relatively restricted in amount, particularly as pertains to chaparral vegetation. There are approximately 120,000 acres of this vegetative type in Mendocino County. Most of the intentional deer habitat improvement work is carried out on this vegetative type.

Several factors operate to make it difficult to assess the effects of vegetation changes in deer numbers on this habitat type. These problems are related to the characteristically high densities of plants and the restricted visibility associated with unburned chaparral. Estimates based on pellet plot counts are commonly used in population studies; however, their use is restricted in these areas. The low visibility associated with unburned chaparral areas seriously limits the use of population composition counts or other sight-index methods of estimating population levels and changes in mortality and reproductive success.

Some studies conducted by University of California researchers in chamise brushlands in the north coast region of California provided the following estimates of deer population changes following burning (Biswell *et al.*, 1952). Densities of 10 to 30 deer per square mile were recorded in heavy chaparral stands prior to burning. Following managed burning, densities increased to 40 to 110 deer per square mile, or approximately a four-fold increase. Other characteristics of the population which were included in the study were ovulation rates and fawn production. In adult does the ovulation rates were 84 percent in heavy unburned brush and 147 percent in managed brush. A ratio of 85 fawns to 100 does was observed in heavy unburned brush as opposed to a ratio of 115 to 140 fawns to 100 does in managed brush. Bucks from managed brush were heavier than those from heavy unmanaged brush, particularly in the younger age classes.

Studies conducted on chamise brushland adjacent to the Hopland Field Station indicate that the general state of nutrition is improved in deer collected in burned areas, as compared to deer in unburned areas. Data regarding population changes have not been gathered; however, it is thought that the major effect of burning has been to improve hunter access to deer (Longhurst and Connolly, In press).

Logging in timbered areas also has a marked influence on deer numbers. Deer populations generally reach a peak 6 to 10 years after logging takes place, with the increase being more rapid and the peaks higher in areas that have also been burned.

Dasmann and Hines (1959) used pellet counts and degree of browsing of shrubs to measure deer population changes in logged areas of Humboldt County. They noted that pellet counts were at the lowest level in virgin forest and increased to over 20 times this level in 6 to 10 years following logging. After about 20 years the deer population, as indicated by pellet counts, had decreased to a level only slightly higher than that found in virgin forest.

In Mendocino County an average of 10,000 acres is logged each year. The proportion of this land which is virgin timber is not known; however, it is apparent that the changes in vegetation following logging have definite effects on the deer population. Some of the highest deer densities in the state (well over 100 deer per square mile) have been recorded on cutover timber lands.

### Other Costs Associated with Maintaining the Mendocino County Deer Population

Other costs associated with maintaining the Mendocino County deer population include value of damage to: agricultural crops, forestry regeneration, automobiles, domesticated animals in the form of diseases and parasites, and competition for range.

Agricultural Damage. A survey of agricultural deer damage in Mendocino County was conducted in the spring of 1968 (Longhurst *et al.*, 1969). It was found that there is approximately $43,000 damage to crops per year and approximately $30,000 is spent on damage prevention and control. Since most of the damage is on fruit crops, the $43,000 loss is based on an average age of trees of 18 years and a total damage estimate of $774,000. The $30,000 spent on preventive measures include shooting, perimeter fencing, repellents, individual plant fencing and other measures. Some funds are also spent to prevent or control deer damage on timberlands but this expenditure has been relatively small.

Damage to Forest Regeneration. A survey of damage on forest regeneration areas conducted in 1962 in the north coast region of California found 86 percent of the reforested acreage incurred deer damage (Lauppe, 1963). Based on a mean annual increment in growth of 500 board feet for Douglas-fir and 800 board feet for Redwood and the number of years that growth is set back due to deer damage, the economic loss from the damage was estimated. On Douglas-fir the damage is estimated at $166 per acre over the entire 50 year rotation. On Redwood the damage is estimated at $121 per acre over the entire 50 year rotation. Approximately 10,000 acres of land are reforested each year in Mendocino County. Thus, over a 50 year rotation, the loss is about $1,195,000 or $23,900 per year. The calculations are detailed in Table 2.12.

Deer may also provide benefits to forest regeneration which have not been measured in the above calculations. In areas where deer have been excluded from forest plantings, there has been extensive growth of tobacco bush (*Ceanothus velutinus*) and other species of

Table 2.12. Deer damage to Douglas-fir and Redwood regeneration in Mendocino County.

| Acreage damaged[a] | Average years setback | Board feet losses per acre[b] | Total board feet losses | Value of losses[c] (dollars) | Total value of losses (dollars) |
|---|---|---|---|---|---|
| | | | Douglas-fir | | |
| 1,031 | - | - | - | - | |
| 3,677 | 3 | 1,500 | 5,515,500 | 220,620 | |
| 1,226 | 8 | 4,000 | 4,904,000 | 196,160 | |
| 258 | 10 | 5,000 | 1,290,000 | 51,600 | |
| 258 | 60 | 30,000 | 7,740,000 | 309,600 | |
| 6,450 | | | 19,449,500 | 777,980 | 777,980 |
| | | | Redwood | | |
| 344 | - | - | - | - | |
| 1,226 | 3 | 2,400 | 2,942,400 | 117,696 | |
| 408 | 8 | 6,400 | 2,611,200 | 104,448 | |
| 86 | 10 | 8,000 | 688,000 | 27,520 | |
| 86 | 60 | 48,000 | 4,128,000 | 165,120 | |
| 2,150 | | | 10,369,600 | 414,784 | 414,784 |
| Total losses to Douglas-fir and Redwood | | | | | 1,192,804 |

[a] 7,500 acres of Douglas-fir and 2,500 acres of Redwood are cut each year; 86 percent is affected by deer damage.

[b] The mean annual increment is 500 board feet for Douglas-fir and 800 board feet for Redwood.

[c] Stumpage value is $40.00 per thousand board feet.

shrubs which may present a shading problem for the young trees and compete for moisture and nutrients with the growing trees. Thus, deer should be credited with some beneficial effects from decreased competition afforded forest regeneration by deer browsing on competing vegetation.

There is also a theory that a browsed tree will catch up to its potential unbrowsed state when it reaches a height beyond the reach of the deer. This is based on the supposition that a browsed tree increases its lateral branch system and has a more extensive root system which then accounts for a more rapid growth rate later in its life. There is currently no data available regarding this factor.

Damage to Automobiles. Deer-automobile collisions not only result in a substantial number of dead deer, as was shown in Table 2.6, but also in a substantial number of damaged automobiles. The estimated annual cost of repairing deer-damaged automobiles in Mendocino County alone is $75,446.[4] It is also estimated that 8.4 percent of the deer-automobile collisions result in personal injury to the occupants of the car and that at least one human death results each year.

---

[4]It is estimated that 29 percent of the deer-automobile collisions result in damage. The average cost of repairing the damage is $240. These data are from the California Highway Patrol as reported in the Santa Rosa Press Democrat (Santa Rosa, California). May 19, 1968.

Deer-Livestock Parasite and Disease Relationships. The relationships between deer and livestock as regards parasites are quite complex and difficult to evaluate economically (Longhurst and Douglas, 1953). Research experiments have indicated many parasite species are transferable between livestock and deer (Baker et al., 1957). Since these classes of animals occur together on most range land in the county, and the intermediate hosts of the parasites requiring them are also present, it is reasonable to assume that transmission takes place on the range. Data are limited regarding the economic losses sustained by the livestock operator as a result of parasites and diseases and even less information is available on the role which deer play in carrying and transmitting livestock parasites on the range.

Several genera of roundworms have been found to be quite important, in association with malnutrition, in causing mortality in deer, particularly in the fawn and yearling age classes (Longhurst, 1955)[5]. Since these worms can infect both deer and sheep, and since both deer and sheep share common range, it is apparent that any measure to control parasites in sheep will be complicated by the presence of deer, which continue to harbor these parasites.

---

[5] These worms include the genera Ostertagia, Trichostrongylus and Dictyocaulus and infect the abomasum, small intestine and lungs, respectively. Sheep infected with these worms usually do not experience any mortality but do suffer some material debilitation.

Anaplasmosis has long been recognized as an important disease of cattle in California. This disease, caused by the infection and destruction of erythrocytes by an anthropod-borne organism, *Anaplasma marginale*, is especially prevalent in range cattle in the coastal area. The species of ticks which serve as the principal vectors for the disease in this area are commonly found on both deer and cattle during certain periods of the year. Recent research has indicated that anaplasmosis is readily transferable from deer to cattle and in the reverse order (Osebold *et al.*, 1959).

Practicing veterinarians in Mendocino County estimate that probably more than 95 percent of the cattle in the county are infected with Anaplasma although they have no means of arriving at a definite figure. The only occasion on which notable losses of adult cattle occur is when cattle originating in an anaplasmosis-free area, and which have not acquired immunity to the disease, are brought into the county. Veterinarians believe that anaplasmosis has some effect on the incidence of abortion in range cows but indicate that further research is necessary before the importance of this factor can be stated. The widespread infection of deer which share the same range with cattle also influences the effectiveness of control measures aimed at eliminating the disease in cattle. It is unlikely that anaplasmosis can be eliminated, using present methods, in areas where deer and cattle occupy the same range lands. On the basis of present information it would be unrealistic to attempt to place an economic value on the role of the deer in contributing to anaplasmosis losses in cattle.

The relationship between deer and livestock as regards fascioliasis in Mendocino County is similar to that seen in anaplasmosis. Deer serve as a carrier of the liver fluke (Fasciola hepatica) causing the disease and are apparently little affected by the infection.[6]

The most obvious economic effect of liver fluke infection is the condemnation of the livers of infected animals at the time of slaughter. These livers are classed as unfit for human consumption and constitute a loss to the slaughter house operator. Another effect of liver fluke infection in sheep which is probably not often diagnosed results in a bacterial infection and often terminates in death. A Clostridium bacillus, normally dormant in healthy livers, uses the liver cells killed by the migrating flukes as food. These bacilli multiply rapidly and produce a highly lethal toxin. Sheep apparently in good health often die quickly of what is called "black disease."

---

[6] Fasciola hepatica is the common sheep liver fluke and utilizes certain species of snails as intermediate hosts. The larval stage which is infective to livestock encysts on vegetation after emerging from the snail host. This larval stage enters the digestive tract of the definitive host when the vegetation is eaten. The larvae then migrate to the bile ducts of the liver where they develop into the adult form. The eggs of the adult fluke are shed with the feces of the host animal and hatch in water. This larval stage then re-infects snails by burrowing into their body tissues.

The liver fluke also infects deer and cattle in this area. Estimates by the meat inspector of the California Department of Agriculture, stationed in Ukiah, provide the figure of about 50 percent infection in cattle countywide and about 10 percent infection in sheep.

Control of the liver fluke is aimed primarily at destroying the intermediate snail host and in this way disrupting the infective chain by eliminating one segment of the life cycle. The Hopland Field Station regularly distributes copper sulfate in wet areas to control snails but this is one of the few areas where control work is done routinely. The presence of deer on range lands will complicate and decrease the effectiveness of any control measures which may be undertaken.

Competition for Range Forage. Food habit studies conducted on deer and sheep on the Hopland Field Station indicated that deer are primarily browsers, with some 70 percent of their total intake consisting of the leaves and twigs of woody forage plants (Longhurst *et al.*, 1969). The diet of sheep was found to be about 80 percent grass. The diets overlap to some extent, with deer taking about 18 percent grass and sheep consuming about 7 percent browse in the yearly diet. The period of maximum overlap of diets occurs from November until mid-April. This period coincides with the beginning of grass growth following fall rains. During this period both deer and sheep feed almost exclusively on grass.

Measurements made in California's north coast region, where resident deer populations approach or exceed 100 per square mile, indicate that deer may remove up to 100 pounds of grass and herbaceous forage per acre, on a dryweight basis, per year. This consumption can increase to 1,000 pounds or more per acre on fertilized pastures with improved production and palatability.

There are about 1,000,000 acres of land used for grazing in Mendocino County and deer are present on most of these areas. The average deer density of these lands is approximately 50 per square mile. Assuming that deer populations of this level annually remove 50 pounds of forage per acre, and using an average annual production figure of 1,500 pounds dryweight of herbaceous forage per acre, then about 3 percent of the total production would be lost to deer each year.

Several factors need to be considered which reduce this loss somewhat. Firstly, the vegetation on the 1,000,000 acres is not exclusively herbaceous forage. Deer take larger amounts of browse on these areas than either sheep or cattle and this results in better overall use of the range forage produced than with livestock alone. A second factor which decreases the relative competitive effect is the fact that deer are generally more mobile than cattle or sheep. Deer often feed in areas which would not be grazed by sheep or cattle, especially the latter. Thus, deer are using woody forage and some herbaceous forage which would not be used by livestock.

However, in total, deer and livestock are definitely in competition for part of the forage, primarily grass and herbaceous plants, during certain periods of the year. Not all of the forage taken by deer would ultimately be used by livestock. Better total use of range is obtained when both deer and livestock are present because of their differences in food habits.

## Summary

Mendocino County is not unlike many Pacific coastal counties of California, Oregon, and Washington, in its habitat and land use pattern which influences the number and productivity of black-tailed deer. Forestry is the leading industry, agriculture is second, and recreational uses of land is third. Forestry and agricultural land use practices have diminished the acreages of natural habitat for black-tailed deer, but at the same time have provided areas of improved grazing and browsing for deer. However, from the standpoint of farmers and foresters the deer inflict costly damages to fruit and nut trees and to forest regeneration efforts. Tourism and recreational uses of lands in Mendocino County and areas to the north have brought thousands of automobiles to the highways of the county. Some, no doubt, bring people to view the forests and the presence of deer. In the course of traversing the county, automobiles kill many deer annually. This not only exerts an unintentional control influence on the deer population, but also results in considerable damages to automobile and in some cases personal injury to the occupants. Other recreationalists come to the area for the excellent hunting prospects in Mendocino County. However, much of the land is in private ownership which forces hunters to exert an excessive amount of hunting pressure on public lands. The deer compete with cattle and sheep on grazing lands for grass and herbaceous forage, particularly at times when browse vegetation is in short supply. In other areas, the presence of deer improves the grazing for cattle and sheep because the deer will feed on vegetation on which cattle and sheep will not, thus cutting down the competition with vegetation that the cattle and sheep prefer. The converse is also true. Although there are these competitive-complementary relationships in the use of feed, there are parasite and disease relationships between deer and domestic animals the effects of which are detrimental to both deer and other animals.

Game managers in Mendocino County believe that there are more deer than the present pattern of land use and habitat structure can maintain at productive levels. They argue that if the deer density (number per square mile) were reduced, many of the damages occurring in agriculture and forestry, and on the highways, would be reduced. At the same time, to reduce the density would require a greater hunter kill and would provide greater hunting opportunities for the growing demand for this type of outdoor recreation. In addition, a smaller population would allow the natural habitat to improve, reduce intraspecific competition, and thus provide a higher level of nutrition for each animal. This would result in healthier, more attractive deer for the general outdoor recreating public to view.

It is within the above context of deer population management that this study was based. The next chapter describes the development of a simulation model to provide numerical estimates of deer population responses to various hunting practices in Mendocino County. Within the context of the deer population management problem described above, the emphasis in the model is upon the biological characteristics of the relationship between the population size and its habitat. This is believed to be a necessary first stage to modeling some of the broader aspects of the management problem. Results of experimental tests with the model assuming various hunting strategies, which are a subset of management practices, are reported in Chapter IV.

# III. FORMULATION AND VALIDATION OF THE MENDOCINO COUNTY DEER POPULATION SIMULATION MODEL

The Mendocino County deer population and its interaction with its habitat and predators, including man, comprise a complex system. Some of the more important components and interactions in this system were identified in Chapter II. The model presented in this chapter is an abstract representation of the real biosystem, formulated to bring together the relevant features of the deer biosystem in a concise and explicit form. The model consists of a system of mathematical equations, the solution to which is the status of the system at specified points in time. When a change in hunting regulations is considered, deer population managers are interested in predicting the status of the population at many points in time, but particularly at points far enough in the future so that the population will have responded fully to the proposed management change.

The real biosystem includes non-linearities, time dependent events, negative feedback mechanisms and stochastic or random components. A mathematical model which includes these complexities is beyond solution by analytical procedures; that is, the system of mathematical equations cannot be solved for all variables for all points in time with the usual simultaneous equations methods. Therefore, a solution must be found by step-by-step calculations for all variables sequentially through time. This step-by-step solution is called simulation. These calculations are most efficiently performed by electronic computers. In the next section of this chapter, the methodology of computer simulation is presented. Subsequent sections cover the description and validation of the deer population model.

## Computer Simulation Methodology

Computer simulation methodology has been described by Halter *et al*. (1970). In that paper, the authors stressed the iterative nature of the methodology. The four phases of the methodology which they distinguished are: (1) problem definition, (2) mathematical modeling and simulation, (3) model refinement and validation, and (4) design and execution of experiments with the model. This methodology was followed in this study. First, as was discussed in Chapter II, the management problem was defined in the context of the policy objectives relating to the deer resource. The problem definition included recognition of the interrelationships within the biosystem, and the links between the biosystem and the political, economic, and social systems.

Next, attempts were made to construct an informal diagrammatic model. Several different approaches were taken before the final formulation was decided upon. Each approach resulted in feedback to problem definition. Changes in the approach to the formulation of the model were made, resulting in compromises between model realism and data availability. Analysts involved in the formulation found that they were required to think clearly about policy objectives for the population, biological relationships, and the feasibility of alternative management strategies. It is the consensus of the researchers involved that an important contribution to improved management is made even if the simulation does not proceed beyond the problem definition and attempts at mathematical modeling.

From the diagrammatic model, the mathematical formulation was developed in computer programming format. The model relies upon biological principles as well as available data. The relationships included in this model resulted not only from routine transformations of data into functional relationships, but from opinions of biologists familiar with the deer biosystem as well. Details of this model are given in the next section. Validation procedures included comparison of the results of the model with field data for Mendocino County and the Hopland Field Station and with outcomes consistent with applicable biological principles. Examples of these comparisons are given in the last section of this chapter.

The fourth phase of the methodology was the design and execution of experiments with the model. These experiments were also designed in cooperation with biologists and unit game managers, consistent with the policy objectives of the California Fish and Game

Commission as given in Chapter I. The results of these experiments are given in Chapter IV.

## Components of the Deer Population Simulation Model

A diagrammatic model and flow chart of the important components and interactions of the Mendocino County deer population was developed (Figure 3. 1). The flow chart was developed cognizant of biological population theory and the available empirical data. The expertise of persons involved directly in the particular biomanagement problem was utilized in this phase of the modeling process. The flow chart characterizes the deer population biosystem as a birth and death process. Each year, variability in exogenous factors, such as weather, generates variability in the birth and death rates in the deer population via a complex of interactions. There is an upper limit to the number of deer which can be supported by the finite habitat, that is the deer range. Divergence of the total population from this upper limit causes a complex of forces to tend to move the population toward the level of the carrying capacity. This is referred to in the systems science literature as "negative feedback." The deer population is not a steady-state equilibrium system, as it is subject to random shocks such as changes in the weather and variable hunting strategies (Bertalanffy, 1968). The carrying capacity of the deer range is changing continuously, due, for example, to deliberate habitat

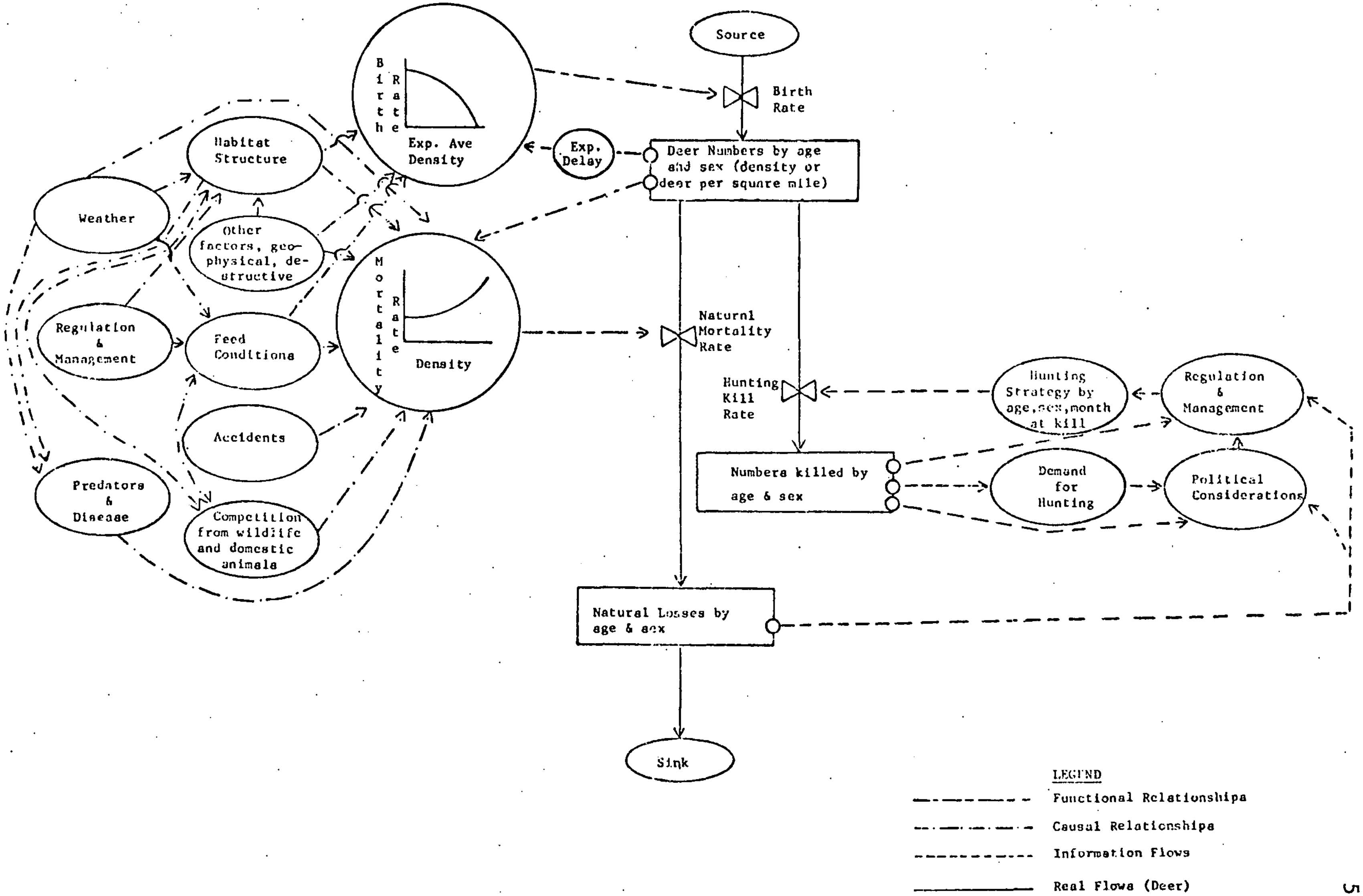


Figure 3.1 Biomanagement model of the Mendocino County deer population.

improvement practices of the type described previously, or due to natural changes such as those which occur in the natural species succession in forest areas. Weather variables may also cause short or long term changes. These changes in habitat may interact to give a trend to carrying capacity. The population will then vary about this trend over time due to the negative feedback effects in the system.

In Figure 3.1 the real flows, causal relationships, and information flows relate to the interactions of the real biosystem. The functional flows indicate those relationships which are utilized in the computer simulation model. Real flows are those which account for the deer numbers, by age and sex, at any time. Thus, given a particular number of deer by age and sex, subsequent births and deaths will result in another population level and another age and sex composition of the population. The population dynamics are generated by time differentials in the three rates shown in Figure 3.1. These rates are the birth rates, natural mortality rates, and the hunting kill rates. The total of natural mortalities and hunting kills, which are mutually exclusive, includes all the losses in both the real biosystem and the simulation model.

The complex of factors in the real biosystem which are considered to influence the birth rates and natural mortality rates are shown by the causal linkages. Because these causal relationships could not be quantified directly, primarily because of a lack of suitable data, it was necessary to devise proxy variables. The proxy variables used in the model are indicated by the functional flows in the figure. In the simulation model, the birth rates and natural mortality rates are generated endogenously, whereas the hunting kill rates are specified explicitly for each run of the model. Thus, in the model, the hunting kill rates are exogenous variables.

In the real world the particular hunting kill rate, or hunting strategy, is formulated cognizant of political considerations, regulations, management capability, and the demand for hunting. As Figure 3. 1 indicates, biological performance variables such as the natural losses, total population, and the dimension of the hunting kill also are inputs into the formulation of hunting strategies. Those factors in the real world which determine the hunting strategy at any time are connected by information flows as shown in Figure 3. 1.

Following is a discussion of the natural mortality rates, birth rates and the hunting kill rates. These discussions indicate the nature of the interactions in the real system and the rationale for using the particular form of approximation in the computer model.

## Natural Mortality Rates

Natural mortalities are those losses due to age, the plane of nutrition, the action of predators, parasites and diseases, and accidents on the highways and so on. The hunter kill, in addition to the reported kill, includes both cripple losses and the unreported kill. The latter occur when hunters remove or cripple and lose animals or fail to mail the report card attached to each deer tag.

Given that the deer range has a finite carrying capacity, the increase in the size of the population beyond this capacity will diminish the plane of nutrition. Natural losses are related directly to the plane of nutrition. Natural losses diminish as the size of the population decreases below the carrying capacity. In addition to the losses due directly to the plane of nutrition, the incidence of parasites is greater at higher deer densities and is likewise negatively correlated with nutrition. Effects of bacterial and virus diseases are accentuated in animals which are malnourished. These three factors support the hypothesis that natural mortalities are density dependent for all carrying capacities. The losses of deer on highways are also assumed to be positively related to the number of deer per unit area. The action of natural predators on deer is not distinguished explicitly in the simulation model. Annual losses due to deer predators such as the mountain lion, coyote and bobcat do occur, but total losses in the population due to these causes cannot be regarded as dependent on deer density in the short run. Short run variations in deer density will not cause substantial changes in the number of deer taken by a population of the predator species. The only short run density dependent predator-prey relationships in the deer population which might be anticipated would occur at high densities with a low plane of nutrition. This may make the deer more susceptible to predation; however, in Mendocino County natural predation is a minor deer mortality factor.

In the model, density dependent natural mortality functions are of the general form shown in Figure 3.2. For each month of the year, natural mortality schedules are defined for the following age and sex groups of deer; fawns, yearling bucks, yearling does, adult bucks two to six years, adult does two to six years, old bucks seven plus years, and old does seven plus years. Sixteen age categories of deer are used in the program. The mechanics of the calculations are as follows. At the beginning of each time period (month), the total inventory of deer is computed which determines the density for a particular area of deer range. Then the natural mortality function for each age category is referenced and the mortality rate is determined and the inventory in each age category is reduced correspondingly. Different mortality functions are described for different age classes of deer because the impact of a particular density on mortality is age selective in the deer population.

The different curvatures and positions of the mortality functions in the two dimensional space reflect the relative sensitivity to density dependent factors. For example, in the model, the natural mortality functions for fawns for each month are above the comparable functions for adult bucks and does in the two to six year age category. Also the

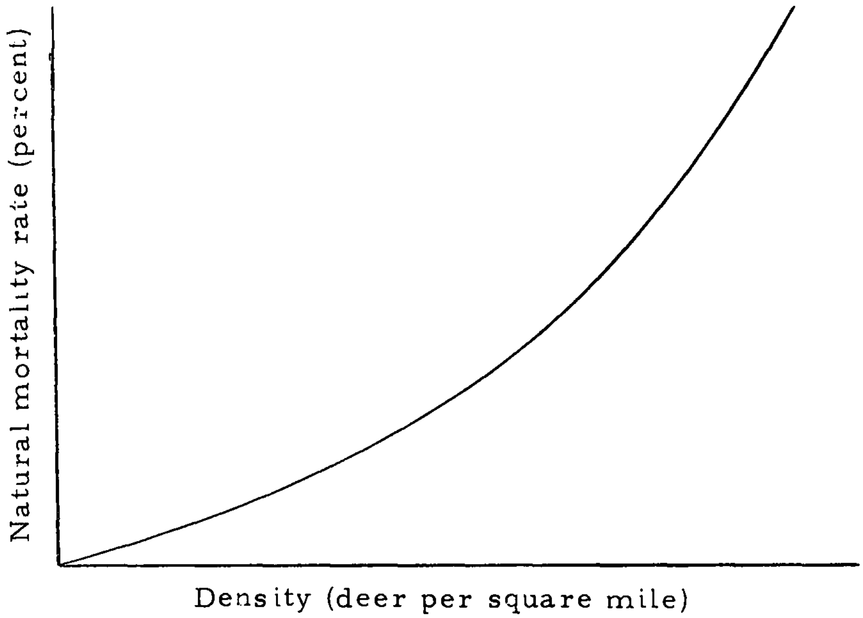


Figure 3.2. General form of natural mortality functions in the simulation model.

first derivative of the function evaluated at all densities is greater implying the increment to mortality for a marginal' increase in density is greater in the fawns than the adult classes. Determining the relative sensitivity of the various age groupings to natural mortality was an important part of the modeling process. These natural mortality functions are based upon biological theory and the available empirical evidence. The paucity of data precluded statistical estimation and use was made of interpolation techniques between data points to derive the natural mortality rates for particular densities.

Weather conditions, that is temperature and rainfall, influence the natural mortality rates directly and indirectly. Indirect effects are most important. Weather directly influences the feed conditions and the effect of parasites and diseases which in turn influence the mortality rates. The seasonal pattern of weather, as reflected mainly in the seasonal distribution of feed conditions is made explicit by having natural mortality functions described for each month. Variability in weather conditions between years is accounted for by a forage factor which is discussed below.

The above discussion is directed toward short term changes in mortality rates due to changes in density. There is a longer term dimension to density dependent effects. In the long run, say several years, there can be significant changes in the habitat structure. Such changes can alter the relationships between the carrying capacities of the range in various months of the year. Months when the supply of forage is relatively limited can become periods of extreme shortage. These changes could influence the shape and position of the natural mortality schedules over time. Thus the habitat structure could be linked directly to the natural mortality rate functions.

However, in the model the assumption is made that the short run effects on natural mortality rates of relative feed shortages are so severe as to rapidly reduce the total population toward the carrying capacity of the current habitat structure. Thus, no allowance is made for a density dependent change in habitat structure and the consequent carrying capacity of the range. Due to lack of data, no long range upward or downward trend in carrying capacity is included in the model.

Competition for forage with commercial livestock can also influence the relationship between deer density and mortality. Excessive numbers of cattle and sheep will diminish the supply of forage otherwise available to deer. For those periods of the year when deer and domestic livestock are competitive for forage, the natural mortality functions reflect this competition in the slope of the functions used in the model.

## Birth Rates

In the simulation model, birth rates in the various age categories of does are related explicitly to a function of deer density. The general form of the birth rate functions used in the model is given in Figure 3. 3. Whereas the natural mortality rates are shown as increasing functions of density, the birth rates are decreasing functions of the exponential average density at the time of ovulation.[1]

---

[1] The exponential average density each time period is computed as follows:

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

where $t$ = Time period (month),

$D$ = Density (total deer per square mile),

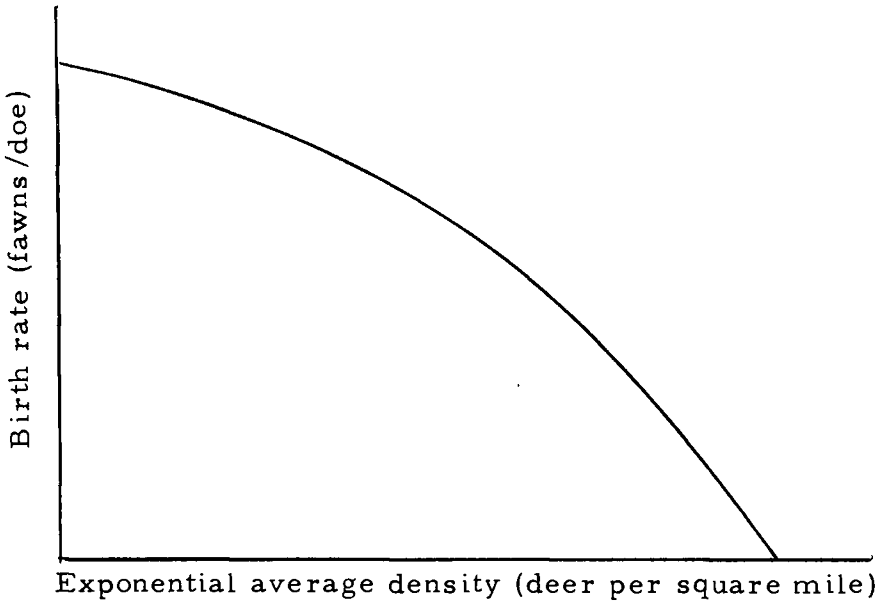


Figure 3.3. General form of the birth rate functions in the simulation model.

The physical condition of the does at the time of ovulation is related to the feed conditions prevailing immediately prior to that time, with greatest weight attached to the most recent time periods. Thus, the exponential average density at the time of ovulation is used as the proxy variable for the array of factors which interact in the real system to determine birth rates. In the exponential averaging method, greatest weight is given to the density at the time of ovulation and progressively decreasing weights are given to more previous time

---

EAD = Exponential average density (total deer per square mile),

T = Exponential smoothing time constant (number of months).

periods. The number of time periods used in the exponential averaging is optional. In this model a period of three months is used. Thus, the condition of the doe at the beginning of November is reflected in the exponential average of density for the months of August, September, and October. This averaging procedure results in a less variable index than would result if the density in one month were used.

In the model four reproductive age groups of does are distinguished. For each function described, there is a biological limit to the reproductive ability of each group and this is given by the intercept of the function with the vertical axis. The general form of the function also intersects the horizontal axis. These intersection points are not based upon empirical observations as data available on the Mendocino County deer population do not include observations on these extreme high and low densities. Thus, experiments with the model should be interpreted with caution when the results are based on these extreme points on the functions.

### Hunting Kill Rates

The hunting kill rates in the simulation model are set for every computer run and are not determined endogenously as are the natural mortality and birth rates described above. Thus, the status of the system in the model does not influence the particular hunting rates once they are specified. This is a simplification of the real world where the status of the system may influence the hunting kill rates. The accent is on formulating a reasonable biological model where the hunting losses can be manipulated explicitly.

As shown in Figure 3.1, there is a complex of factors which results in a particular hunting strategy being formulated and implemented. A hunting strategy is a particular set of hunting kill rates on the components of the population at particular times of each year. Few changes in the hunting strategy in Mendocino County have been made since about 1901 when bucks-only hunting was introduced as a general management strategy.[2] Under the current hunting regulations in California, a buck becomes legal game when it has at least one forked antler.

It is estimated on the basis of available data that approximately 25 percent of the legal bucks present at the start of the open season are taken by hunting each year under the current regulations. However, the annual buck take under the current hunting strategy is variable (see Appendix A, Table A.4). Variability results from two factors. First, there is year to year variability in the numbers of legal bucks in the population, and second, there is year to year variability in the hunting effort and hunter success rates. Hunting effort is defined as the total number of hunter days in a

---

[2] Deer tags were first issued in the 1927 hunting season. A history of deer hunting regulations in California is given in Longhurst _et al_. (1952).

particular area. The hunter success rate is defined as the average number of deer taken per hunter in one season in a particular area. Many combinations of hunter success rates and hunting effort can generate the same total kill or more specifically a particular percentage kill. This model does not relate explicitly the hunter success rate and the hunting pressure to the percentage hunting kill achieved for the various age categories of deer. This is suggested as a possible research extension of the current study. However, particular hunting strategy specifications used in the simulation experiments lend themselves to interpretation in terms of numbers of hunters required and hunting regulations.

## The Forage Factor

In the above discussion, the model is presented as deterministic. The real biosystem is subject to random shocks from variability in weather conditions and other natural phenomena. Initially, attempts were made to relate particular temperature and rainfall conditions to the amount of deer forage produced on the range. Although long time series data were available for the weather conditions, the lack of data on forage production precluded any reasonable estimation of the relationship. The problem of statistical estimation is compounded by different forage production patterns for each habitat type. The difficulty is that it is not only forage quantity which is important in determining forage conditions but also forage quality. It was necessary to formulate a forage quality-quantity index and then investigate the time series data available to generate the probability distribution of the index.

According to Longhurst and Connolly (in press), fawn survival rates are a reliable index of annual forage conditions. Based on this observation, and after study of fawn survival rates for the Hopland Field Station, the fawn survival data for Mendocino County were classified into five categories. The resulting frequency distribution was then used as the frequency distribution of five types of forage quality-quantity years in the model. A forage factor is associated with each type: a factor of one for poor forage years, two for below average, three for average, four for above average, and five for excellent. The probability distribution of forage factors is given in Figure 3.4.

The forage factor is used in the model as follows. On November 1 each year of a simulation run, the forage factor for that year is randomly selected from the probability distribution by using a pseudo-random number generator.[3] Then, given the forage factor, the

---

[3] For a particular start number, a pseudo-random number generator provides a particular sequence of numbers which satisfy statistical tests for randomness. Different start numbers give different sequences of numbers. In this program, the pseudo-random number generator is used as follows. The interval 0 to 9999 inclusive is partitioned into five segments, the length of which corresponds to the

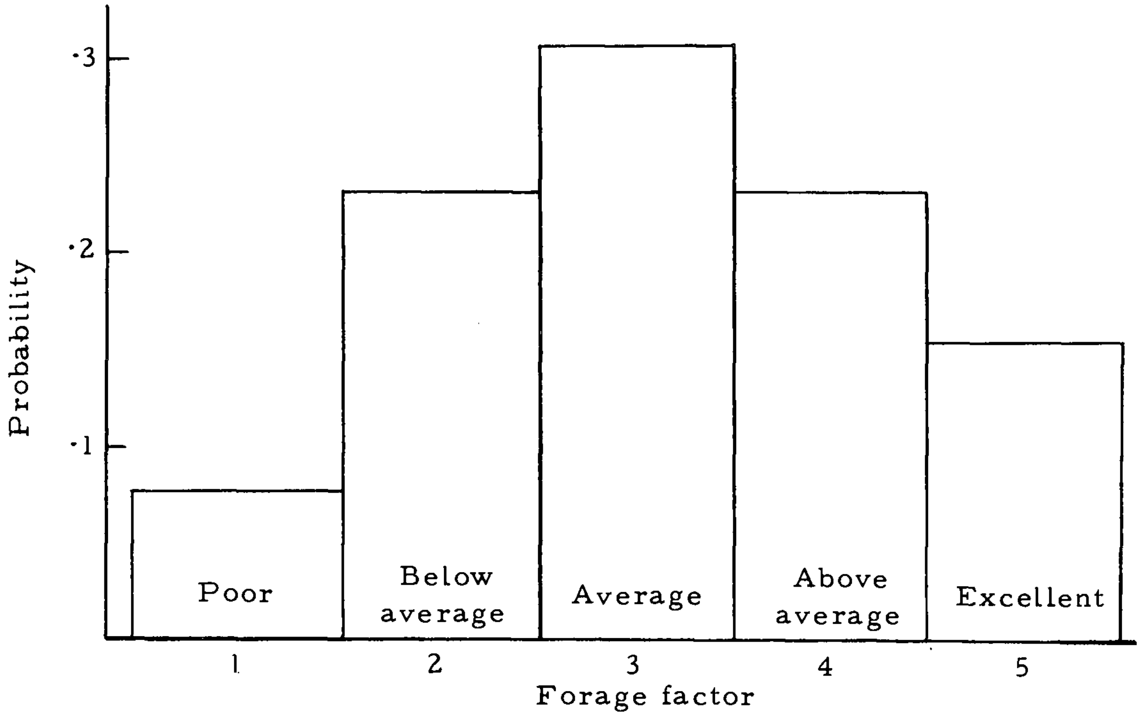


Figure 3.4. Probability distribution of forage factors.

natural mortality rates in each month for the next 12 months and the birth rates for the following May are modified by referencing the appropriate vector of a matrix of modification coefficients. For example, if an above average year is selected, that is a forage factor of four, the following takes place on December 1. The density is computed and using the natural mortality schedules, the mortality rates for each age category are computed. Each rate is then multiplied by the appropriate modification coefficient, which for an above

---

probabilities assigned to each forage factor. A start number between 0 and 9999 is selected from random number tables and a sequence of pseudo-random numbers, each between 0 and 9999, is provided by the generator. The segment in which each number lies determines the forage factor to be applied that year.

average year is between zero and unity and reduces the rates to less than would occur for an average year. In a below average year each mortality rate is multiplied by a coefficient greater than unity. In average years, natural mortality rates and birth rates are not modified.

By specifying in the input data for any run that average years will always be selected (that is, it has a probability of one and other forage factors have a total probability of zero), the simulation model is no longer stochastic and it reduces to a steady-state equilibrium model. Operationally, this facility has advantages which are discussed later in Chapter IV.

## Time Sequence of Events in the Model

In the previous section, the particular functional forms used in the simulation model as approximations to the interactions in the real biosystem were presented. These functional forms are incorporated in a computer program written in Fortran language, which simulates the biosystem. In this section the time sequence of events in the computer simulation program is discussed.

The simulation program abstracts from the time sequence of events as they occur in the real system. For example, in the real system breeding (the rut) occurs from mid-September through mid-December each year and in the model this is approximated by defining breeding as occurring on November 1 each year. Similarly, on the range fawning occurs through May and most of June, and in the model fawning occurs on May 31. Taber and Dasmann (1958) presented a schematic diagram of the annual cycle of deer and deer range which approximates to the annual cycles of deer in the Hopland area in Mendocino County. The reproductive cycles and phenology from Taber and Dasmann (1958) are reproduced in Figure 3.5. The reproductive cycle is later in the northeastern part of Mendocino County.

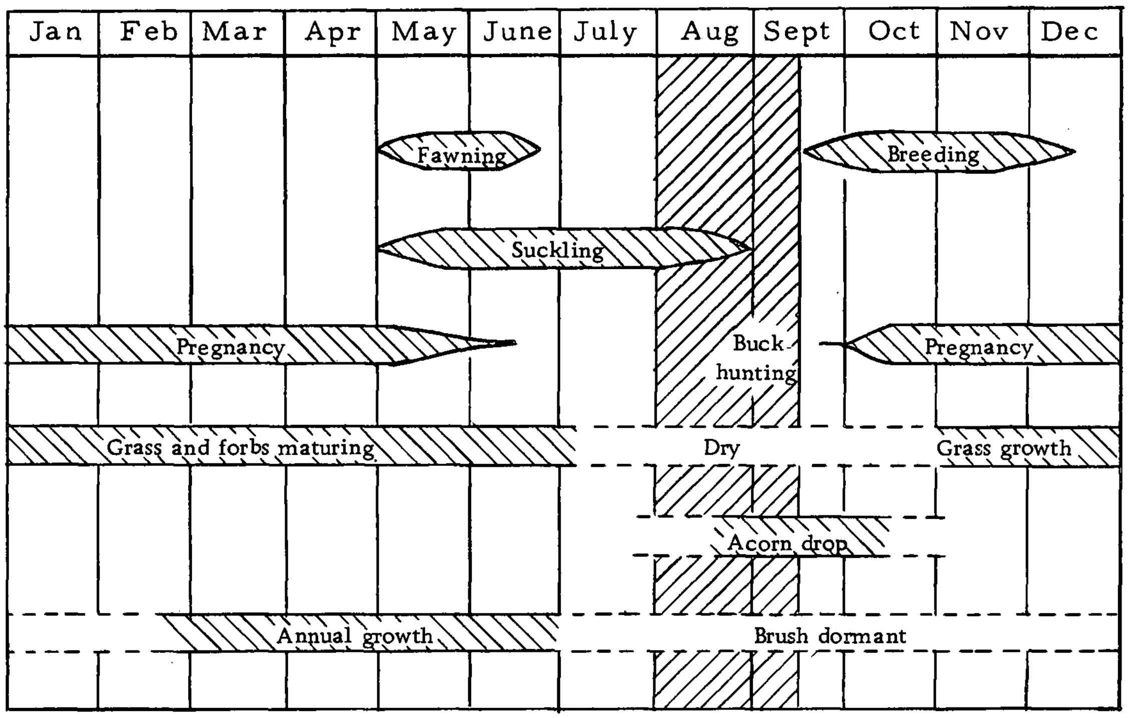


Figure 3.5. Time sequence of events for deer population.

Source: Taber and Dasmann (1958).

In the simulation program, a unit of time is defined for purposes of calculation. The unit of time selected for the deer population program is one month. A period of one month is considered short enough to be able to represent the dynamics of the population and long enough to keep the data requirements for the model within reasonable bounds.

The status of the real biosystem at any time can, at least conceptually, be represented by a network of flows, rates, and levels. This is also the case in the deer population simulation program. In each month of a simulation run, particular calculations are made as required and the status of the system at the end of the month is generated. The status of the system is an array of rates and levels for all variables in the system. The status of the system at the end of one time period is therefore the status of the system at the beginning of the next time period. After completing the calculations in any month, the time counter is advanced one unit and the calculations for the next month are made. The particular calculations to be made in any month are defined explicitly in the computer program. The status of the real biosystem and the simulation model at any time might best be referred to as a conditional status. That is, the status is conditional upon past events only.

Figure 3.6 shows the main calculations made in each month and each year of a computer run. Each computer run starts on November 1 and finishes on October 31 after completing the specified number of

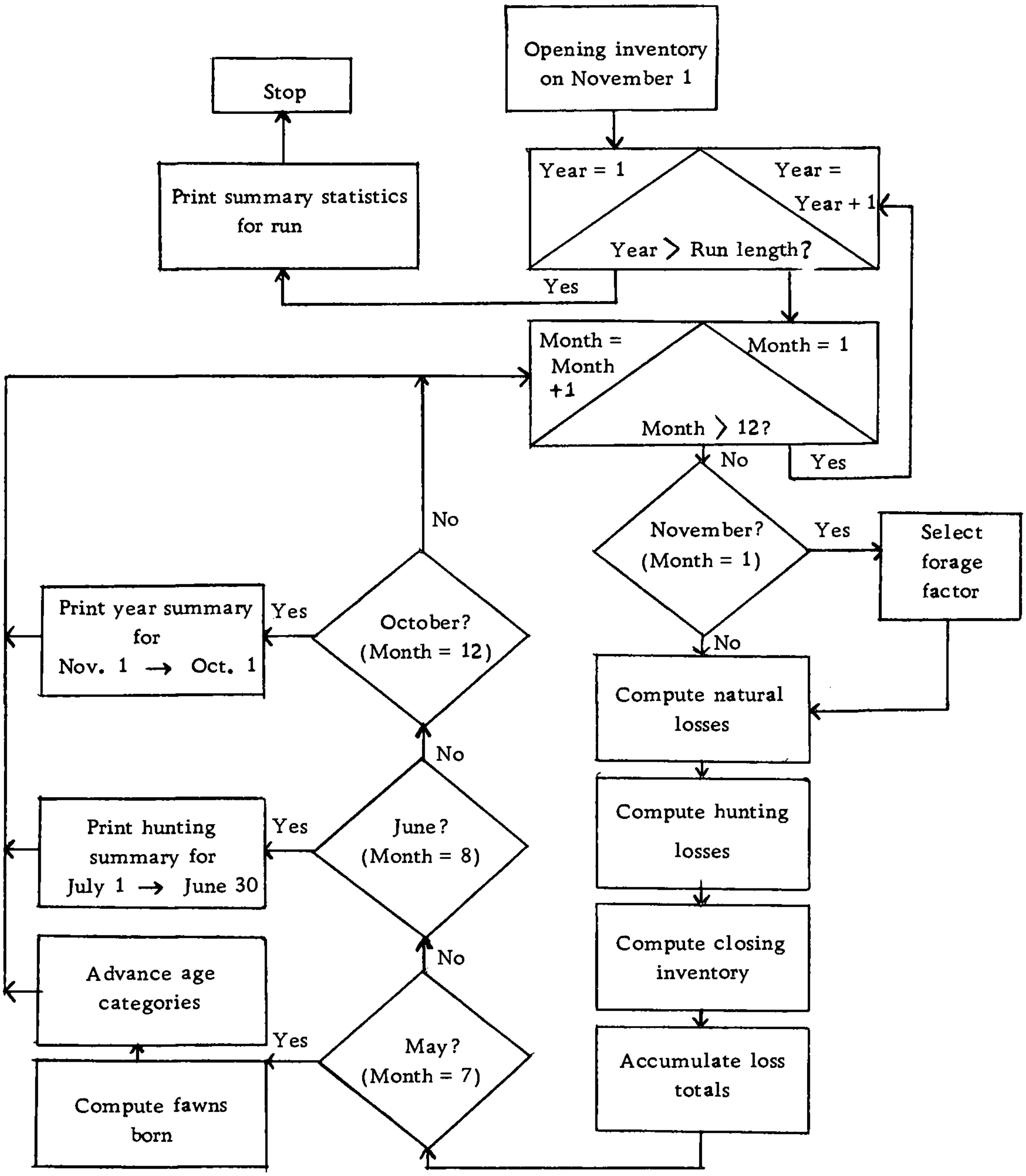


Figure 3.6. Time sequence of events for deer population model.

years. In general terms the program operates as follows. Starting with an opening inventory of bucks, does, and fawns on November 1, the density and exponential average density is computed. On November 1 the forage factor to be used for the year is also selected. Natural losses and hunting losses (if specified) are computed following the procedures described in previous sections. Loss totals are accumulated by age and sex and the closing inventory for the month is calculated. The closing inventory for the month is the opening inventory for the next month. This basic set of calculations for losses are made each month of the run, but as indicated by Figure 3.6, other operations are carried out at certain times each year, such as the calculation of births and the accounting of population characteristics and hunting statistics.

Two accounting years are defined in the computer program. The first is from November 1 to October 31. November is the time when managers are best able to make population counts indicative of the age and sex composition of the population. This accounting year is therefore a practical consideration to make the model comparable to the real situation. The second accounting year used in the model, July 1 to June 30, permits mixed buck and doe hunting strategies to be summarized within the same accounting year. Buck hunting is traditionally carried out in August and September, while antlerless hunts should occur in November. For each accounting year, performance variables are provided by the computer model, including parameters which can be estimated in the field. Details of the various calculations are discussed month by month in the following sections.

November Events

The forage factor for each year is generated on November 1 and is applied in all natural mortality and birth rate computations for the next 12 months. The forage factor selected in each year is independent of the forage factor selected in the previous year. This assumes there is no carry-over effect. This abstracts from the real system where successive forage years are not independent. The model does not include this refinement due to data limitations but the effect is not considered sufficient to alter the conclusions of the research. As discussed in the section on birth rate determination, the exponential average density on November 1 is the proxy variable for the condition of the does at the time of conception. All does are assumed to conceive on November 1 with the condition of the does given by the exponential average density at that time. The November 1 exponential average density each year is stored in the computer for application to the number of does of the various ages in the population on May 31 the immediately following year, to determine the number of fawns born. This allows for the normal gestation period of seven months.

## May Events

After accounting for all losses in May and computing the closing inventory, the age categories are advanced and the number of fawns brought into the system is calculated. Fawns are separated by sex at the beginning of their second year. At that time they are separated into males and females according to an empirically derived ratio. Current data from the Hopland Field Station suggest that on average, about 40 percent of the fawns at one year of age are male, and 60 percent are female. This ratio appears to vary from year to year.

Bucks and does leave the fawn category at 12 months of age and thereafter are accounted for in the other 15 age categories. At the end of their sixteenth year, the remaining bucks and does incur a 100 percent mortality rate and are removed from the system. Under a wide range of hunting strategy experiments with the model, the number of deer removed each year by this restriction is trivial compared with the total population and the total natural losses in each year. The number of fawns brought into the system on June 1 is calculated by multiplying the birth rate for each age category of does by the number of does on May 31. The birth rates are based upon the November 1 exponential average density of the previous year.

## June Events

In the program the mortality of fawns in the first month after birth (June) is a function of the exponential average density of the prior three months. This reflects the assumption that the condition of the doe during the last three months of gestation is the principal factor in influencing early fawn mortality. In the month of June, fawns are dependent upon the doe for survival. If the does are in poor (good) condition, then there is high (low) fawn mortality.

The hunting accounting year finishes on June 30. Thus, after accounting for losses in that month the hunting performance variables and other parameters of interest are provided by the program. The quality of the hunting kill is sometimes regarded as a function of both the size of the kill and the age and sex composition of the kill. This output summary section includes a breakdown of the kill into legal bucks, spikes, does, and fawns in addition to the total kill.

### October Events

October 31 completes the main accounting year in the simulation program. At this time, after computing the closing inventory for the month, the performance of the system for the previous year is summarized by a set of selected parameters. These include the same parameters which can be monitored at this time each year in the real system. If the specified number of years for a simulation run is completed, summary statistics for selected performance parameters are calculated. The sample means, standard deviations, and coefficients of variation are calculated using as the sample the values computed each year of the run.

## Input Data

Input variables to the computer program consist of parameter values, hunting strategies, and initial conditions. The general specifications of the parameters, hunting strategies, and initial conditions are given in outline form below. These input variables must be specified before the program can be run on the computer. The total number of values used for each run amounts to over 2,000. The procedures used for developing the numerical estimates for some of the input variables are given in Appendix B.

1. Initial value specifications
   a. Inventory of deer by age, of bucks, does, and fawns. (31 values)
   b. Random number to start the generator. (1 value)
2. Parameter specifications
   a. Area of deer range in square miles. (1 value)
   b. Exponential smoothing time constant for computing the exponential average density. (1 value)
   c. Proportion of 12 month old fawns which are male. (1 value)

d. Proportions of bucks in their second and third years which are legal game. (2 values)

3. Parameter array specifications

a. Probability distribution of forage factors. (1 array, 5 values)

b. Natural mortality and birth rate modification coefficients for each forage factor. (5 arrays, 40 values)

c. Natural mortality schedules for each month for seven age groupings.

1) Fawns (12 arrays)

2) Bucks

a) Yearlings (12 arrays)

b) Two to six year olds (12 arrays)

c) Seven to 15 year olds (12 arrays)

3) Does

a) Yearlings (12 arrays)

b) Two to six year olds (12 arrays)

c) Seven to 15 year olds (12 arrays)

d. Birth rate schedules for four age groupings (at breeding) of does.

1) Yearlings (1 array)

2) Two year olds (1 array)

3) Three to six year olds (1 array)

4) Seven to 15 year olds (1 array)

4. Hunting strategy specifications

a. Reported and unreported hunter kill for each month.

1) Fawns (12 values)

2) Bucks for 15 age categories (180 values)

3) Does for 15 age categories (180 values)

b. Cripple losses for each month.

1) Fawns (12 values)

2) Bucks for 15 age categories (180 values)

3) Does for 15 age categories (180 values)

## Output Specification and Format

Any rates and levels generated during a simulation run can be provided as output of the model. Because routine use of the model can involve large numbers of runs, the input data for each run discussed above are provided in the output of all runs. In addition, the results of any run are summarized by selected performance variables. The results are provided in four parts as follows:

1. Twelve variables are provided in this section of the output which summarizes the performance of the system for each November 1 to October 31 accounting year. The variables are: the forage factor operative for the year; the total inventory at the end of the year; the deer density at the end

of the year; the total natural losses and hunting losses during the year; three end of year ratios, namely the legal buck to doe ratio, the spike buck to doe ratio, and the fawn to doe ratio; the average ages of bucks and does on November 1; and two parameters which are calculated during the accounting year, namely the spring fawn to doe ratio and the average birth rate of does.

2. For the section of the output based on the July 1 to June 30 accounting year in the model, the following variables are provided. They are the July 1 population composition data including the total number of deer, and the numbers of legal bucks, spike bucks, does and fawns. Hunting kill data for the previous year is also given, including the total kill and the numbers of legal bucks, spike bucks, does and fawns which comprise this total. The ratio of the total season kill for the previous year to the total number of deer on July 1, before the hunting season, is also given.

3. Because game managers are sometimes concerned with the performance of the system at some point in time in the future after initiation of a particular management strategy, one section of the output provides the detail of the system performance in the last year of the run. For each month of the last year, natural losses and hunting losses are given

for each age category of deer, in addition to the inventory by age and sex. The losses for each age and sex category for each month are also summarized according to the age groupings used in the specification of the natural mortality schedules.

4. At the end of a simulation run, selected performance variables are used to summarize the characteristics of the system during the run. The characteristics are summarized by the sample means, standard deviations, and coefficients of variation of these parameters. The parameters include those which can be estimated in the field such as the June fawn to doe ratio, the November fawn to doe ratio, and the hunting performance data as summarized by the total kill, legal buck kill, spike buck kill, doe kill and fawn kill. The other parameters provided in this section which cannot be estimated directly from field data are the total November 1 population, the total July 1 population and its components, the total legal bucks, spike bucks, does, and fawns, and the total natural losses.

The parameters provided for each run are designed to provide the resource managers with a set of information which can be used to improve management decisions. Prior to this prescriptive function, the output parameters were used to validate the model.

## Model Validation

To run a simulation model, it is necessary to generate numerical values for the input parameters. To validate a simulation model, results from the program are compared with available field data, and checked for consistency with outcomes predicted by biological theory and with previous experience of the investigators with similar biosystems.

In previous sections of this chapter, the theory was presented which results in the particular model formulation and structure described. The primary data source was the University of California Field Station at Hopland where the population has been under continuous and intensive study since 1951. The cooperating investigators at the Hopland Field Station, Longhurst and Connolly, compiled these data and integrated them with the California Department of Fish and Game data for the remainder of the county. The methods these researchers used to develop the more important input data for the model are summarized in Appendix B.

There are two phases in validating a simulation model. First, the initial estimates of the necessary parameters are made. These estimates rely upon the available data, biological theory, the expertise of the researchers, and their experience with the system under study. Using these first estimates, experiments are then carried out using the program. Results from these experiments are then compared for consistency with available field data. Comparison of mean values of parameters is more important here than comparisons of variability, as given by various measures of dispersion.

The model must provide results which satisfy the following general validation criteria given by biological theory.

1. At any point in time there is an upper limit to the number of deer which can be supported by the habitat--even in the absence of hunting. This is the notion of carrying capacity. This upper limit is based upon the availability and distribution of food, water, shelter, and space. Animal numbers tend toward the carrying capacity through habitat limitations when numbers exceed capacity, or reproductive and survival pressures within the population when numbers are below capacity.
2. The fall buck to doe ratio increases or decreases respectively with decreases or increases in the intensity of buck hunting and conversely if does are taken.
3. The fall fawn to doe ratio increases with increases in the intensity of doe hunting.
4. The average ages of the components being hunted decrease as increasing percentages of those components are taken by hunting.

5. The birth rate per doe increases as the intensity of hunting increases, particularly with regard to increases in the intensity of fawn and/or doe hunting.

The second phase of the validation process is iterative and involves repeated revision of the data input, experimentation on the computer, and checking for consistency, until a satisfactory correspondence is achieved. The acceptable degree of correspondence is a matter of judgment by the cooperating wildlife biologists.

To illustrate the procedure of validation, the results from three computer runs that were made in the validation process are compared with field data in Table 3. 1. Each run shows the progression in the degree of correspondence when the input data were revised. Each run is described below.

Run 1

The mean November fawn to doe ratio of 71 to 100 is high compared with the mean ratio of 60 to 100 for the field data. The coefficient of variation of 31 percent is also larger than the value of 19 percent computed from the field data. Similarly, the sample range of this ratio is large, over twice that for the field data. Variations in the fawn to doe ratios in both spring and fall are due to variations in fawn births as well as deaths. In Run 1 the natural mortality modification coefficients are calculated to give the required variability with

Table 3.1. Comparison of simulated output with field data for Mendocino County, 1958-1970.

| Parameter | Run 1[a] | Run 2 | Run 3 | Field data average of 1958-1970[b] |
|---|---|---|---|---|
| November fawn/doe ratio | | | | |
| Mean | .71 | .66 | .56 | .60 |
| Coefficient of variation | 31% | 28% | 20% | 19% |
| Extreme values | (.37;1.10) | (.42;1.06) | (.38;.76) | (.41;.77) |
| Range | .73 | .64 | .38 | .36 |
| November buck/doe ratio | | | | |
| Mean | .43 | .42 | .29 | .27 |
| Coefficient of variation | 8% | 10% | 5% | 26% |
| Extreme values | (.36;.47) | (.28;.50) | (.26;.32) | (.17;.37) |
| Range | .11 | .22 | .06 | .20 |
| Annual buck kill[c] | | | | |
| Mean | 7789 | 7531 | 5859 | 4226 |
| Coefficient of variation | 9% | 12% | 7% | 10% |
| Extreme values | (6277;8874) | (4164;9008) | (5314;6620) | (3315;4869) |
| Range | 2597 | 4844 | 1306 | 1554 |

[a] The same hunting strategy of removing 25 percent of all adult bucks of each age category, each year, is used for Run 1, Run 2, and Run 3.

[b] California Department of Fish and Game (1971).

[c] Field data do not include cripple loss or unreported kill; these are included in the figures for Run 1, Run 2, and Run 3.

births held constant. However, variability in births is also explicitly related to the forage factor. These two sources of variability compound to give the high variability in the fawn to doe ratio. These forage factor modification coefficients are altered in Run 2 to correct this compounding error.

By contrast, under the data assumptions for Run 1, the mean November buck to doe ratio is higher than that given by the field data but is substantially less variable as indicated by the coefficients of variation of 8 percent and 26 percent, respectively. The adult buck to doe ratio is reduced if the proportion of fawns at 12 months of age which are male is reduced in the input data. In Run 1, this parameter was specified at a value of .5. Reducing this ratio, in turn, reduces the ratio of adult bucks to does in the population. It is possible, however, that the field data overestimate the annual variability of this parameter because in some years the field counts have not coincided completely with the rut.

The mean annual buck kill in Run 1 of 7,789 is over 84 percent greater than the corresponding figure from the field data of 4,226. The kill in the model should be higher than that indicated by the field data which is based on actual deer tag returns with no correction for unreported kills or for cripple losses. If the total of the unreported kill and cripple losses equal 50 percent of the reported kill, the estimated mean total kill for the county based on the tag returns of 4,226 is 6,339.

The above results indicate the input data for Run 1 required revision. In particular, to reduce the variability in the fawn to doe ratio, the coefficients which modify the birth rates and natural mortality rates for the five types of forage years were revised. To reduce the buck to doe ratio and the annual buck kill, the proportion of fawns at 12 months of age which are male also was reduced. For Run 2, only the birth rate and natural mortality rate modification coefficients were changed to effect a reduction in the variability of the fawn to doe ratio. In Run 3, further changes of these parameters were included and in addition, the proportion of fawns at 12 months of age which are male was reduced from .5 to .4. This progression of changes from Run 1 to Run 2 to Run 3 illustrates the process of model validation.

Run 2

The coefficients of the vector which modifies the mortality rates of fawns for each forage factor were altered to reduce the sensitivity of the fawn mortality to changes in the forage factor from year to year. This was accomplished by reducing the coefficients for below average and poor years, and increasing the coefficients for above average and excellent years. The increases to be made in the birth rates for above average and excellent forage years were also reduced.

As shown in Table 3.1, these changes in the input data reduce the November fawn to doe ratio from .71 to .66 and reduce the variability of the ratio as given by the lower coefficient of variation of 28 percent. Both these statistics are larger than desired. Changing these forage factor modification coefficients did not significantly alter the statistics for the November buck to doe ratio except to double the range of variation of this parameter. As anticipated, these changes reduce the annual buck kill trivially (by 3.3 percent) but cause the parameter to become more variable.

Run 3

Reducing the ratio of male to female fawns at 12 months of age reduces the number of bucks available in the population and hence reduces the total kill to approximately the field data value after it is increased to include an allowance for the unreported kill and cripple losses.

The data change from Run 2 to Run 3 reduces the November fawn to doe ratio to 56 to 100 with a coefficient of variation of 20 percent compared with the field data values of 60 to 100 and 19 percent respectively. The county unit manager and the wildlife biologists believe that this parameter is estimated with a greater degree of confidence than any other parameter of the biosystem. Thus, the coincidence in the results from the model and the field data lend credence to the validity of the model.

The November buck to doe ratio reduces from 42 to 100, to 29 to 100, compared with the field estimate of 27 to 100. However, the variability of this parameter is still low compared to the field data. The reliability of the field data for this parameter has been questioned. Because the bucks are more easily seen during the rut, if the observations are not taken at the same time each year in relation to the rut, the ratio estimates made by direct observation may not be biased, but they will demonstrate more variability than actually occurs.[4] Recent calculations indicate that the proportion of males among the 12 month old fawns may vary annually. In the program, it was fixed at .4, which would reduce variability in the simulated buck to doe ratios. The possibility of annual variability in this parameter was discovered so recently that it has not yet been incorporated in the program.

## Summary

Management of the Mendocino County deer population involves manipulation of the biosystem in attempts to move it toward satisfaction of wildlife policy objectives as specified by the California Fish

---

[4] The ratios could also be biased by making the field observations consistently at a time when the bucks and does are not observable in the true population proportions.

and Game Commission. Managers of deer populations are typically interested in the time flows of outcomes, or solutions, for particular management strategies. Solutions can be generated using a computer simulation model of the biosystem. In this chapter, the first three steps of the computer simulation methodology are described in relation to the formulation of the simulation model of the Mendocino County deer population. These three steps are problem definition, mathematical modeling and simulation, and model refinement and validation. The remaining step, the design and execution of experiments with the model is the subject of Chapter IV of this thesis.

Problem definition was initiated by the development of a comprehensive diagrammatic flow chart of the biosystem. From this flow chart, a particular structure was developed for the computer simulation model. The biosystem was characterized as a stochastic, density-dependent, birth and death process. Births are introduced into the system each year as a decreasing function of the exponential average density; natural mortality occurs each month as an increasing function of density; and the other source of losses from the system, those due to hunting, are specified to be determined exogenously. The stochastic component of the model, as given by an index of forage quality-quantity conditions, is the counterpart of variability in the real system caused by random shocks such as changes in weather conditions and other natural phenomena.

The computer program incorporates this structure, and calculates the time sequence of events and their interactions, month by month, year by year, for any length of time specified.

To operate the computer program requires numerical values for the input data. The input data include: natural mortality and birth rate schedules, opening inventory of deer by age and sex, probability distribution of forage factors, modification coefficients for each forage factor, and other parameters. These are estimated from Mendocino County field data and other sources. Hunting strategies are specified at the initiation of any run. Using the initial data estimates, experiments were carried out with the computer program to develop solutions for comparison with field data to check the consistency of the model. This phase of the research relied upon biological theory, and the expertise of the cooperating wildlife biologists. Examination of the results indicated changes were necessary in particular data inputs. These changes were made, followed by more experiments with the revised data. Validation of the model proceeded by this interative process of examining the results of experiments, revision of data, assumptions, and generation of more results. The biologists determined when a satisfactory degree of correspondence was achieved between the results of experiments with the model and the field data and outcomes as predicted by biological theory. They concluded that the model structure and data input represented the dynamics of the Mendocino County deer population to a degree sufficient for testing of alternative hunting strategies. Results of experiments using alternative hunting strategies in the program are presented in the next chapter.

# IV. RESULTS OF EXPERIMENTS USING ALTERNATIVE HUNTING STRATEGIES

A great variety of management strategies can be tested with the simulation model described in the previous chapter. Hunting strategies, unless constrained by political considerations, are the most flexible management tool of the wildlife manager. Because hunting strategies are the most flexible tool, the emphasis in the design of experiments with the model is directed toward this particular aspect of management. However, in the design of hunting strategies, the options of resource managers are limited because certain hunting strategies that are biologically feasible may be socially or politically unacceptable or, alternatively, socially or politically desirable strategies may be biologically undesirable. For example, heavy selective fawn hunting would be an effective means of maximizing the annual hunting kill but the strategy has never been seriously considered because fawn hunting is not likely to be generally accepted by hunters. Alternatively, the intent of resource managers may be to maximize the legal buck kill. The upper limit of the kill is given by the number of hunters and by the accessibility of the bucks. Accessibility is limited by factors such as type of vegetation, length of hunting season, and time of year of the hunt.

In this chapter the results of eight simulation runs with different hunting strategies are presented in detail. This array includes the range of options which could be practically implemented in Mendocino County. In addition to being presented in table form, some results are summarized graphically. The results of additional runs not presented in table form are given graphically for illustrative purposes. The emphasis in this chapter is on describing the impact on population dynamics of selected hunting strategies. The conclusions drawn from the experiments with the model are given in the following chapter.

## Performance Variables Presented

Three classes of parameters are provided to summarize the performance of the system under each strategy. First, some parameters are included which might be conceived as indicators of performance relative to management objectives. This class of parameters includes the legal buck kill, the total hunting kill, the total annual natural losses, and the total November 1 population. To illustrate, some people may be concerned with reducing the level of natural mortality, and at the same time maintaining some minimum total population. Agriculturalists and foresters may be interested in reducing deer damages to crops and trees by reducing the total November 1 population. Game managers may be interested in numbers of animals killed by hunting as an indicator of the recreational benefits.

The next class of parameters includes some ratios which can be estimated in the field such as the November fawn to doe ratio, the November spike buck to doe ratio, and the legal buck to doe ratio. Other parameters presented are included to highlight the status of the population. These include average age, number of fawns born, and fawn mortality. These are not generally estimated by game managers in the field but are a useful adjunct to those parameters which are estimated in the field.

Two sets of tables are presented for each of the eight hunting strategies. The results in the first set of tables are generated by suppressing the stochastic component of the model used to generate the random sequence of forage years. Suppressing this component causes each year of a simulation run to be an average forage year. These are referred to as results with deterministic assumptions. Under these deterministic assumptions, a steady-state solution is achieved if a run of sufficient length is specified to permit the effect of the initial conditions to be "worked out."

The second set of tables for each hunting strategy are referred to as results with stochastic assumptions. They are generated as follows. A random sequence of forage years is generated in accordance with the specified probability distribution of forage factors. The initial or opening inventory for the run is the solution inventory from the simulation run with deterministic assumptions for the same hunting strategy. The values shown for the parameters generated with stochastic assumptions are calculated as the mean value of the parameter over a 30 year simulation run. Starting each run with the corresponding deterministic solution values has the effect of removing the transient effect of prior hunting strategies.

In all the simulation runs presented in this chapter, buck hunting, when specified, is conducted in August and September in accordance with the existing custom. Approximately two-thirds of the bucks are taken in August and the remainder in September, in agreement with field data. Antlerless hunting, when specified, is on the spike buck, fawn, and doe components of the population, and is specified to occur in November each year. For convenience, and in the absence of evidence to the contrary, the hunting effect for all runs is assumed to be constant across all ages of adult bucks and does. When buck hunting is specified in the various runs, for August and September, allowance is made for a cripple loss and an unreported kill. The cripple loss consists mainly of wounded legal bucks, and spike bucks mistaken for legal bucks. Some does and a few fawns may also be included.

## Results of Deterministic Assumptions

In this section, the results generated with deterministic assumptions are discussed. Comparisons between results with deterministic and stochastic assumptions are made in the following section. The results referred to in the detailed discussion of the eight simulation runs are included in Table 4.1 and Table 4.2.

Run 1, No Hunting

Computer simultion Run 1 assumes no hunting, that is, complete protection from hunters. The total November 1 population is 193,715 and 94,092 deer of mixed ages die of natural causes each year (Table 4.1). The November 1 legal buck to doe ratio of 45 to 100 and the spike buck to doe ratio of 12 to 100 give a total buck to doe ratio of 57 to 100. The birth rate is 1.19 fawns per doe. Differential natural losses from June through October result in a November 1 fawn to doe ratio of 56 to 100. Table 4.2 shows that less than 30 percent of the fawns born each year reach one year of age. Fawns are the class of deer most susceptible to natural mortality at any given density. The average ages, in years, of bucks and does are given in Table 4.2 and are 4.76 and 4.86, respectively. The results of the other runs are discussed with Run 1 as the reference point.

Run 2, Twenty-five Percent Legal Buck Kill

In this run, 25 percent of the legal bucks are taken each year. The hunting strategy specification includes an allowance for cripple losses and thus 5,568, or 88.0 percent of the 6,325 deer taken are

Table 4.1. Population statistics and hunting kill for deterministic computer runs of Mendocino County deer population model.

| Parameter | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 |
|---|---|---|---|---|---|---|---|---|
| Hunting specifications[a] | | | | | | | | |
| Legal bucks | 0 | 25 | 50 | 0 | 25 | 50 | 25 | 50 |
| Spike bucks | 0 | 0 | 0 | 0 | 0 | 50 | 5 | 5 |
| Does | 0 | 0 | 0 | 25 | 25 | 15 | 15 | 15 |
| Fawns | 0 | 0 | 0 | 0 | 0 | 80 | 5 | 5 |
| November 1 population | 193,715 | 192,977 | 193,145 | 147,144 | 148,283 | 28,043 | 171,761 | 172,619 |
| Annual natural losses | 94,092 | 101,043 | 104,835 | 28,094 | 31,046 | 1,037 | 54,201 | 57,183 |
| Annual hunting kill | 0 | 6,325 | 8,144 | 11,461 | 25,207 | 15,480 | 23,534 | 27,118 |
| Legal buck kill | 0 | 5,568 | 6,948 | 0 | 8,315 | 643 | 7,155 | 8,807 |
| Hunting kill/ July total population | 0 | .03 | .04 | .08 | .15 | .52 | .12 | .14 |
| Natural losses/hunting kill | - | 15.98 | 12.87 | 2.45 | 1.23 | .07 | 2.30 | 2.11 |
| Birth rate (fawns/doe) | 1.19 | 1.18 | 1.18 | 1.24 | 1.23 | 1.71 | 1.19 | 1.19 |
| November 1 ratios | | | | | | | | |
| Legal bucks/does | .45 | .18 | .09 | 1.33 | .44 | .07 | .29 | .14 |
| Spike bucks/does | .12 | .12 | .11 | .23 | .22 | .07 | .17 | .16 |
| Fawns/does | .56 | .56 | .56 | .65 | .65 | 1.40 | .62 | .62 |

[a]Hunting specifications give percentages of each component taken by hunting each year.

Table 4.2. Fawn mortality and average age statistics and percent composition of kill for deterministic computer runs of Mendocino County deer population model.

| Parameter | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 |
|---|---|---|---|---|---|---|---|---|
| Hunting specifications[a] | | | | | | | | |
| Legal bucks | 0 | 25 | 50 | 0 | 25 | 50 | 25 | 50 |
| Spike bucks | 0 | 0 | 0 | 0 | 0 | 50 | 5 | 5 |
| Does | 0 | 0 | 0 | 25 | 25 | 15 | 15 | 15 |
| Fawns | 0 | 0 | 0 | 0 | 0 | 80 | 5 | 5 |
| Total fawns born | 94, 360 | 107, 568 | 113, 187 | 40, 534 | 56, 316 | 16, 192 | 77, 840 | 84, 400 |
| Percent fawns surviving to 12 months of age | 29.7 | 30.2 | 30.4 | 60.0 | 60.1 | 18.7 | 44.9 | 45.2 |
| Average age on November 1 (years) | | | | | | | | |
| Bucks | 4.76 | 3.12 | 2.29 | 6.10 | 3.59 | 2.59 | 3.37 | 2.38 |
| Does | 4.86 | 4.84 | 4.83 | 3.50 | 3.49 | 5.51 | 4.08 | 4.08 |
| Percent composition of kill | | | | | | | | |
| Legal bucks | 0 | 88.0 | 85.3 | 0 | 33.0 | 4.2 | 30.4 | 32.5 |
| Spike bucks | 0 | 8.1 | 11.5 | 0 | 2.6 | 3.8 | 5.2 | 6.7 |
| Does | 0 | 3.4 | 2.8 | 100.0 | 64.3 | 10.9 | 53.4 | 50.5 |
| Fawns | 0 | .5 | .4 | 0 | .1 | 81.1 | 11.0 | 10.3 |

[a]Hunting specifications give percentages of each component taken by hunting each year.

legal bucks (Table 4. 1). This 5, 568 includes the reported and unreported kill. From Run 1 to Run 2, the total population is reduced from 193, 715 to 192, 977 in response to hunting the legal bucks. The legal buck to doe ratio reduces from 45 to 100 to 18 to 100 from Run 1 to Run 2, but the spike buck to doe ratio and the fawn to doe ratio are not changed from Run 1. The hunting removal of 6, 325 deer is 3 percent of the July 1 total population. In response to hunting, the average age of the bucks on November 1 reduces from 4. 76 to 3. 12 years. This run approximates the current deer hunting strategy in Mendocino County. The strategy provides essentially no control of total deer numbers.

Because the population includes relatively more does, the number of fawns born in Run 2 is higher, 107, 568 versus 94, 360 in Run 1 (Table 4. 2). The birth rate remains approximately the same at 1. 18 fawns per doe.

Run 3, Fifty Percent Legal Buck Kill

This run assumes that 50 percent of the legal bucks are taken annually. Again, as in Run 2, allowance is made for cripple losses in the antlerless deer as well as among bucks. The total November 1 population of 193, 145 is slightly reduced from Run 1 with no hunting, but is slightly larger than under the 25 percent legal buck hunting strategy. The total natural losses of 104, 835 in Run 3 are a further increase from Run 2 over Run 1. The increased percentage removal of the legal bucks increases the relative and absolute doe numbers in the population. Since the birth rate of 1.18 is the same as Run 2 (the birth rate is a function of density), more fawns are born in Run 3. Again, as in Run 2 about 30 percent of fawns reach one year of age.

The total kill in Run 3 is 8,144 of which 85.3 percent or 6,948 are legal bucks. The natural loss to hunting kill ratio is reduced to about 13 to 1.0. The average age of the bucks on November 1 reduces to 2.29 years. Also, the legal buck to doe ratio reduces to 9 to 100.

Assuming the same hunter success rates (deer taken per hunter) for Run 2 and Run 3, the total kill of 8,144 in Run 3 would require a hunting pressure (number of hunter days) about 29 percent higher than that needed to achieve the total kill of 6,325 in Run 2. However, because of the lack of accessibility to many areas in the county it would probably require more than the 29 percent increase in hunters to find the additional bucks in accessible areas. Thus, a 50 percent legal buck kill represents about the upper limit of the percentage of bucks that can be taken in a bucks-only hunt.

### Graphical Summary of the Impact of Legal Bucks-Only Hunting on Population Dynamics

The percentage of bucks taken in Run 1, Run 2, and Run 3 are three points on a continuous scale of percentages. Other data inputs are the same for the three runs. Hence the response of the system, as represented by selected parameters, can be plotted against the percentage of legal bucks taken annually. Figure 4.1 gives the total November 1 population, the total annual natural losses, and the total annual hunting kill as functions of the percentage of legal bucks hunted. In Figure 4.2, the dependent variables presented are the average birth rate and three November 1 ratios, namely the legal buck, spike buck, and fawn to doe ratios. Figure 4.3 gives the plots of the average ages of bucks and does versus the percentage of the legal bucks taken by hunting. Figure 4.1 indicates that the legal bucks-only hunting strategy at any level between zero and 50 percent does not alter total population numbers or natural losses significantly. Figure 4.2 and Figure 4.3 show that the impact on herd performance of the legal bucks-only hunting is restricted primarily to the buck component of the population. The reproductive performance of the does does not change appreciably. Similarly, the average age of does is not influenced by restricting hunting to the adult male component of the population; however, the average age of bucks declines.

Run 4, Twenty-five Percent Doe Kill

In this run, 25 percent of the adult does in each age class are taken by hunting each November. This is not necessarily a politically feasible hunting strategy at present, but is used to illustrate the population control effected by does-only hunting compared with the

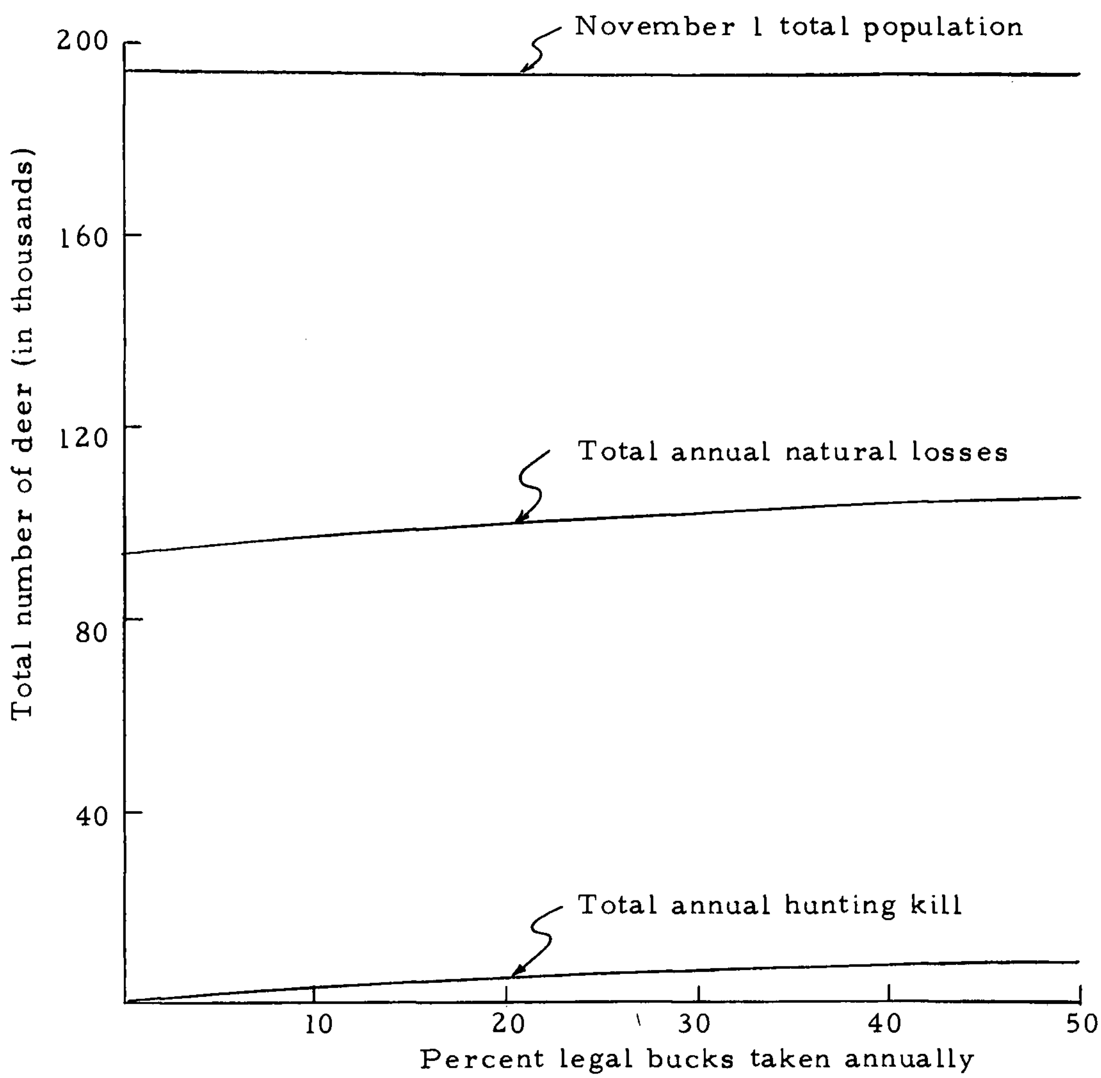


Figure 4. 1. November 1 population, natural losses and hunting kill as functions of the percentage of legal bucks hunted.

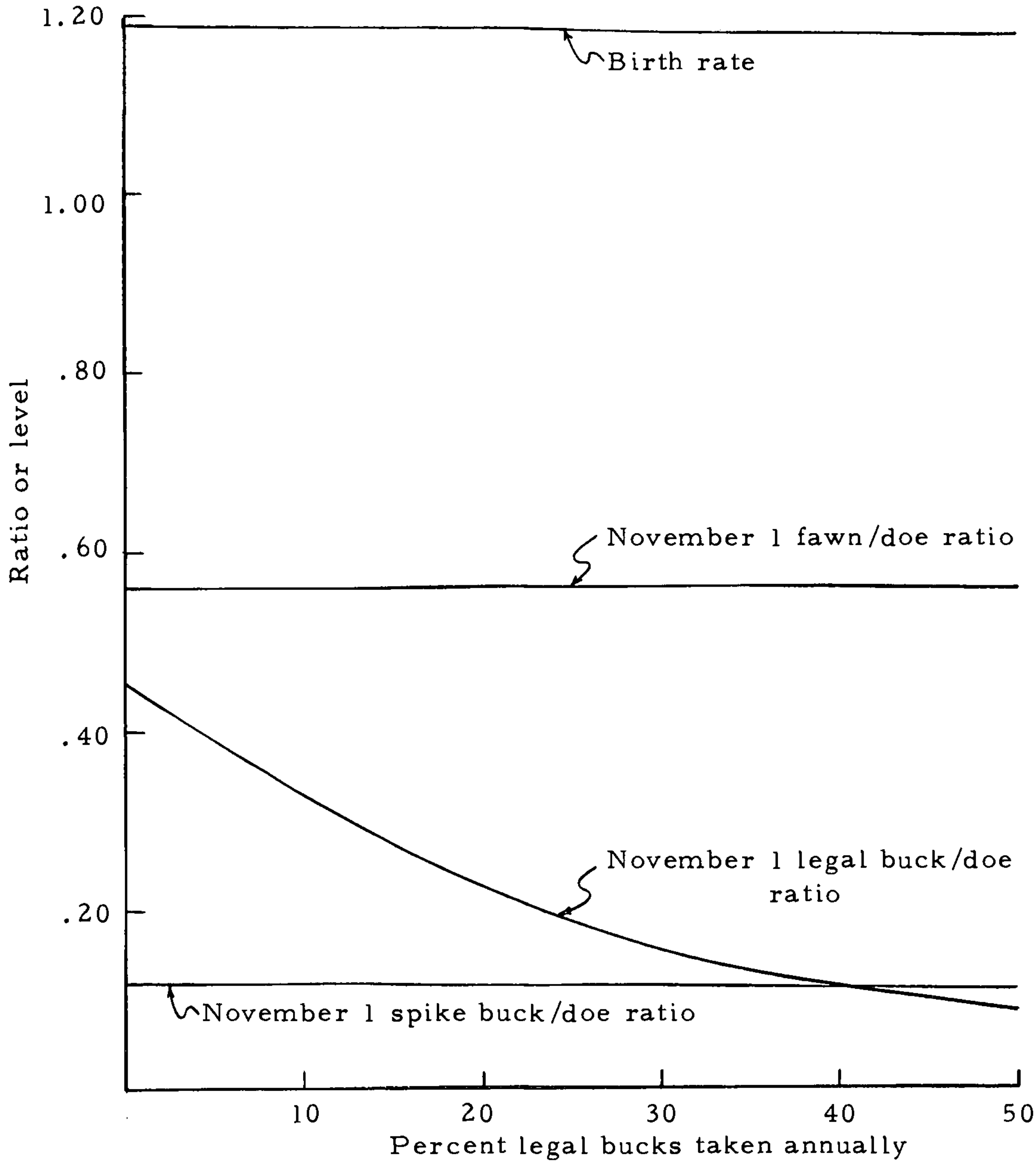


Figure 4.2. Birth rate, November 1 fawn to doe ratio, November 1 legal buck to doe ratio, and November 1 spike buck to doe ratio as functions of the percentage of legal bucks hunted.

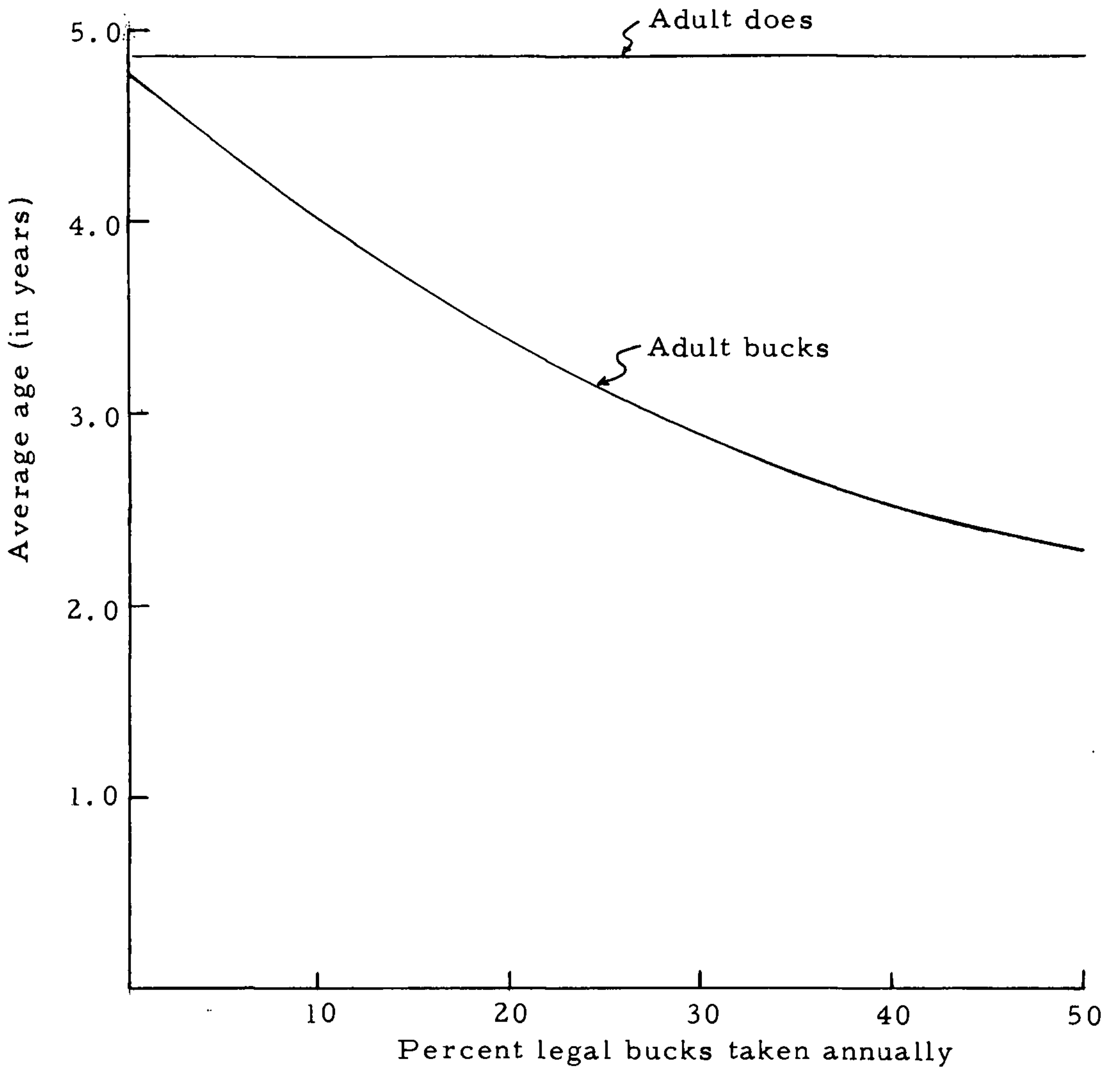


Figure 4.3. Average ages of adult bucks and does as functions of the percentage of legal bucks hunted.

bucks-only hunting. Compared with Run 1, the total November 1 population is reduced by over 24 percent to 147,144 from 193,715 by doe hunting. The total natural losses are reduced by over 70 percent from 94,092 to 28,094. Because the does are hunted, the November 1 legal buck to doe and spike buck to doe ratios increase to 133 to 100 and 23 to 100 respectively. Further more, the reduction in total numbers reduces the exponential average density at the time of conception, enhancing the birth rate to a level of 124 fawns born per 100 does. Sixty percent of fawns born reach 12 months of age under this strategy, reflecting the lower natural mortality rates at lower densities. The November 1 fawn to doe ratio of 65 to 100 also reflects the reduced natural mortality rate of fawns. The average age of the bucks increases in response to doe hunting to 6.10 years and the average age of the does reduces to 3.50 years.

Direct comparison of Run 4 with Run 2 is useful. In both strategies hunting is directed toward one component of the population, and the intensity of the strategies is approximately the same, as 25 percent of the hunted deer are killed in each case. The total kill in Run 4, of which 100 percent are does, is 11,461 versus the total of 6,325 for Run 2. Total natural losses are 28,094 in Run 4 and 101,043 in Run 2. The total November 1 population in Run 4 is 147,144 versus 192,977 for Run 2. The total kill when 25 percent of the does are hunted is higher than the kill resulting from legal bucks-only hunting at the 50 percent level (Run 3).

## Graphical Summary of the Impact of Does-Only Hunting on Population Dynamics

Comparison of Run 4 with Run 2 as above demonstrates significant differences in the impact on population dynamics of does-only hunting and legal bucks-only hunting. The impact on selected parameters of increasing the percentage of does taken annually is summarized in Figure 4.4, Figure 4.5, and Figure 4.6.[1] The sets of parameters presented in these figures correspond to the parameters in Figure 4.1, Figure 4.2, and Figure 4.3 respectively. This permits a direct comparison of does-only versus legal bucks-only hunting.

This comparison shows that hunting up to 50 percent of the bucks has little effect on the density of deer, whereas the hunting of does has a marked effect on population numbers at low doe hunting percentages. Thus, if diminishing the density of deer is required to reduce agricultural and forestry damages, and other damages, a bucks-only strategy will not be successful. Similarly, if the objective of management is to increase the buck to doe ratio so that, from a sightseeing point of view, an aesthetically more pleasing herd results, a bucks-only hunting strategy is not the proper approach. From the standpoint of the hunters, if they are interested only in the number of game bagged, then the doe hunting strategy provides them a greater kill.

---

[1]Other runs with does-only hunting, in addition to the 25 percent does strategy, were made to generate points in these figures. These runs are not discussed separately in the text.

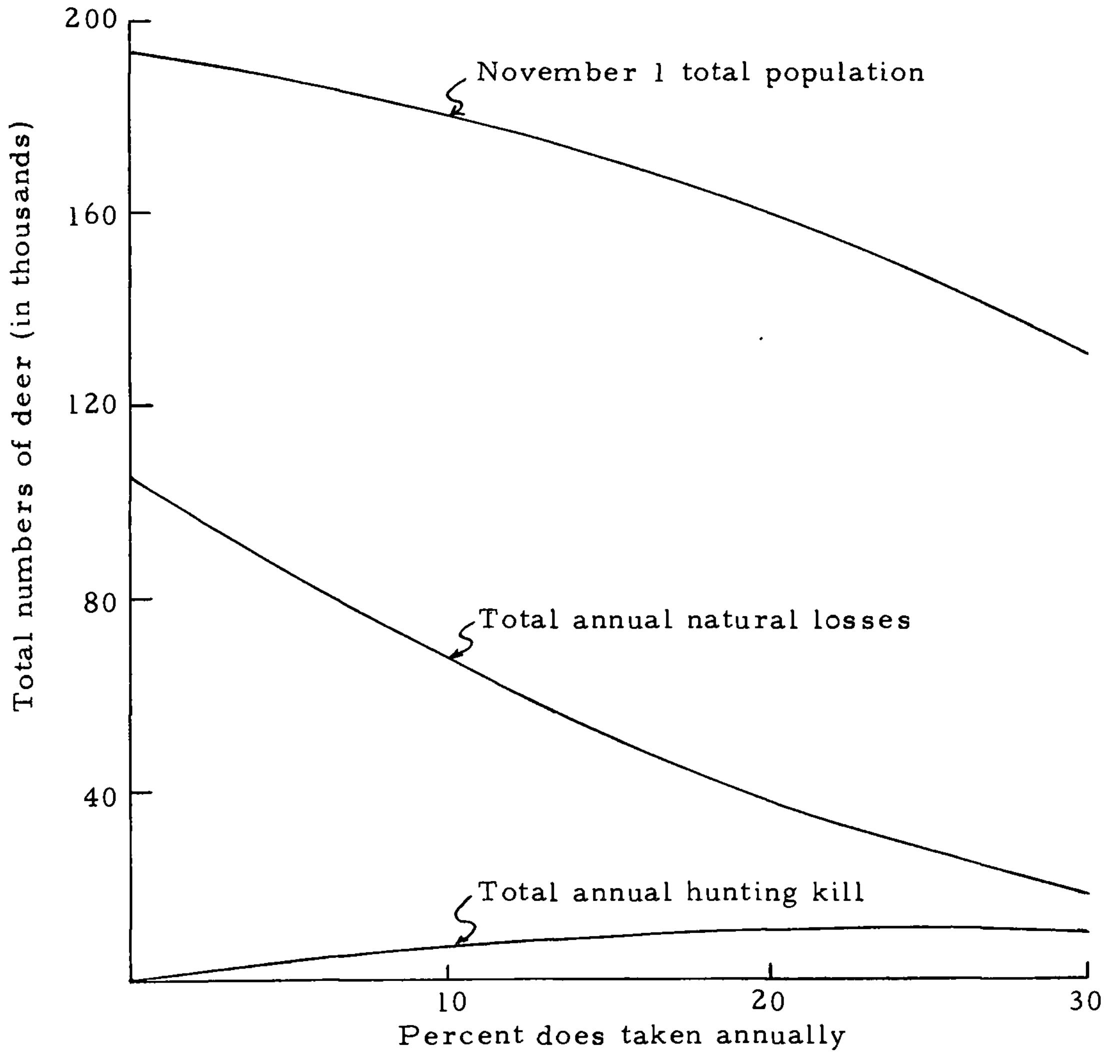


Figure 4.4. November 1 population, natural losses, and hunting kill as functions of the percentage of does hunted.

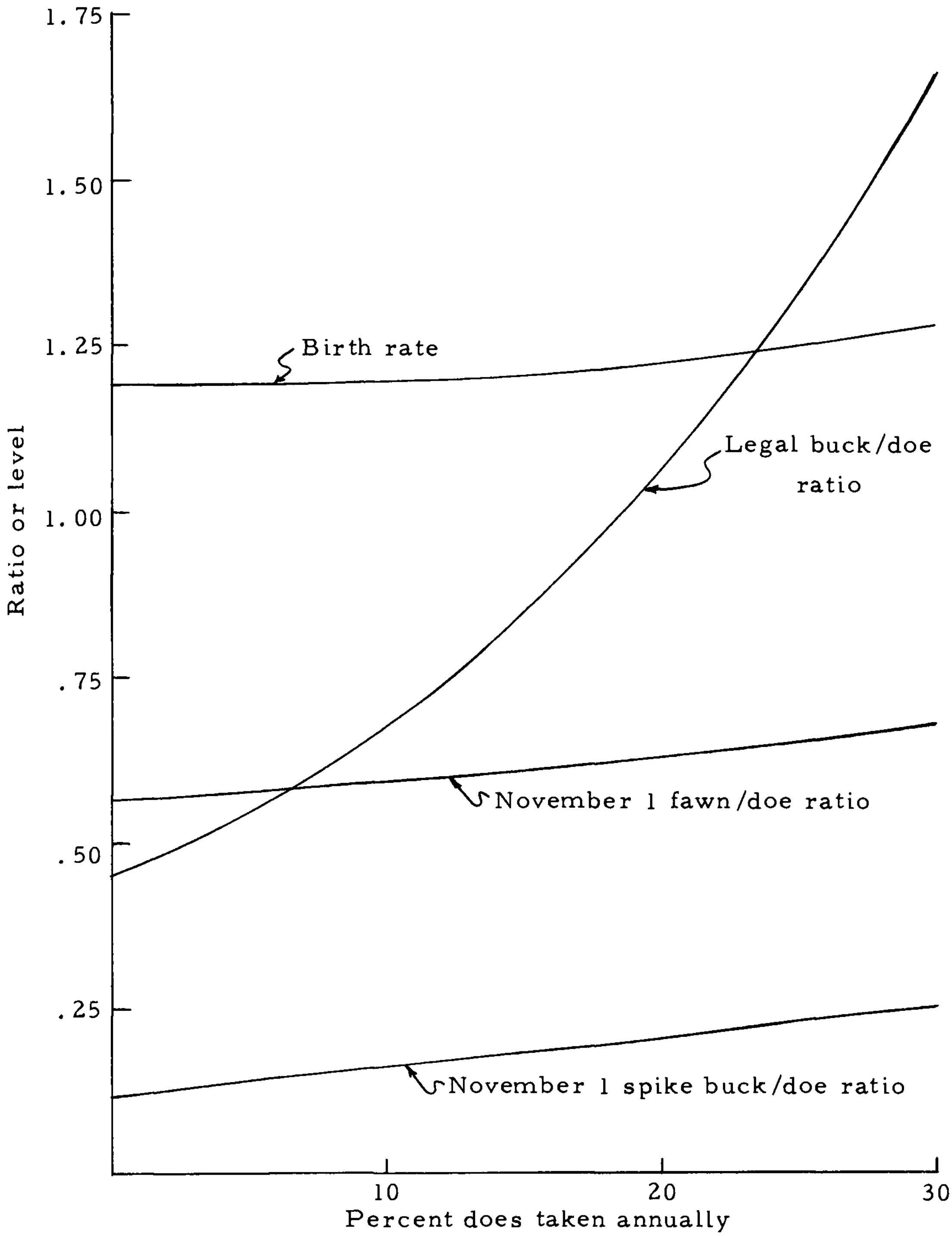


Figure 4.5. Birth rate, November 1 fawn to doe ratio, November 1 legal buck to doe ratio, and November 1 spike buck to doe ratio as functions of the percentage of does hunted.

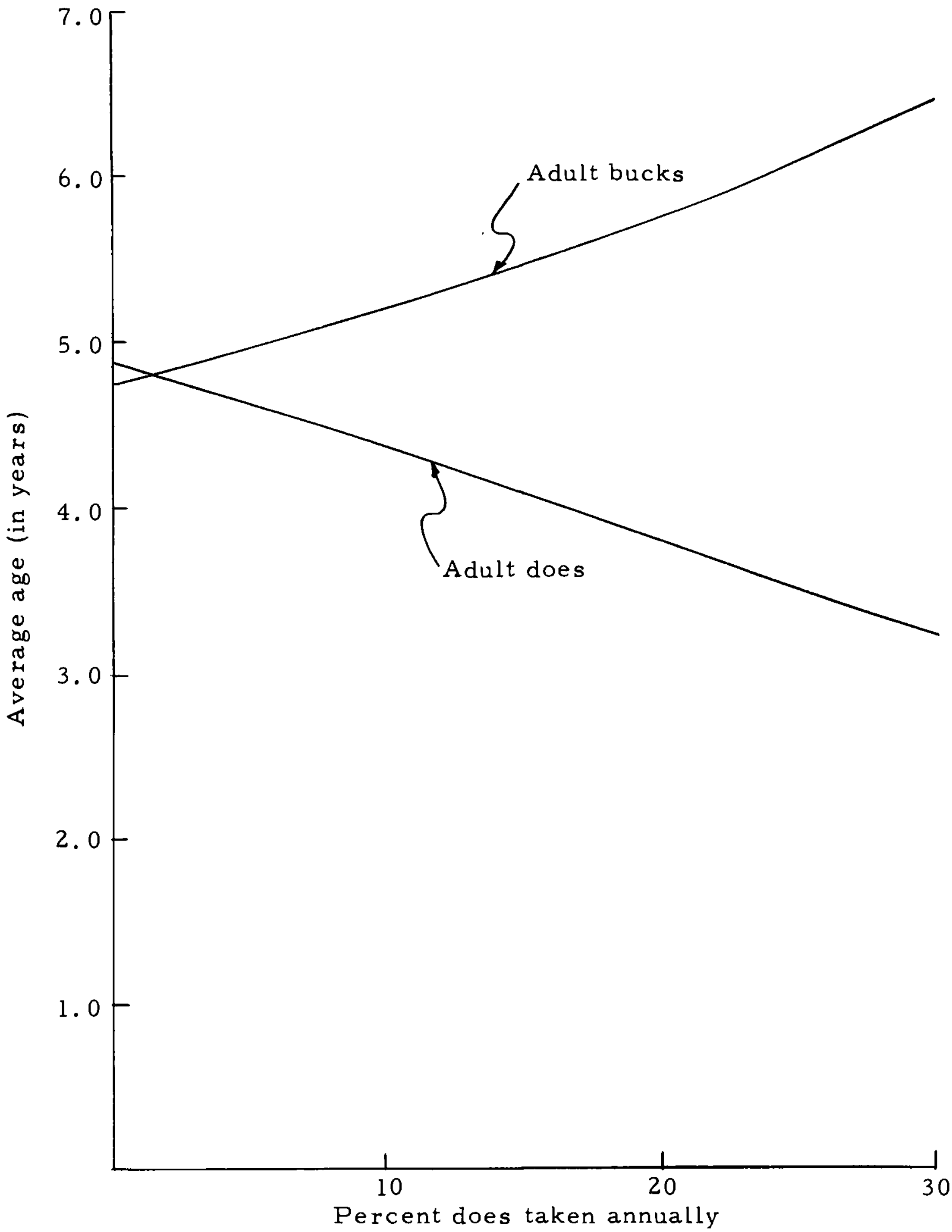


Figure 4.6. Average ages of adult bucks and does as functions of the percentage of does hunted.

However, trophy hunting is also an important part of deer hunting and does-only hunting would not satisfy this objective. These considerations lead to the examination of a combination of buck and doe hunting.

Run 5, Twenty-five Percent Bucks and Twenty-five Percent Doe Kill

In this run, 25 percent of the legal bucks and 25 percent of the does are removed annually by hunting. Thus the strategy is a composite of Run 2 and Run 4. Comparing Run 5 with Run 4, a consequence of hunting legal bucks in addition to does is to increase the hunting kill, the November 1 population, and the total natural losses. The hunting kill increases from 11,461 to 25,207. The number of legal bucks taken, in Run 5, is 33.0 percent of the total kill or 8,315, which is 124 percent of the legal bucks taken in Run 2 under the 25 percent legal bucks-only strategy. In Run 5, the legal buck to doe ratio of 44 to 100 is of the same order of magnitude as in Run 1 under no hunting. The total natural losses increase from Run 4 to Run 5 paralleling the increase from Run 1 to Run 2.

In Run 4, the average age of bucks is 6.10 years and it reduces to 3.59 years in Run 5. This also parallels the reduction in average age of bucks from Run 1 through Run 5. Because the density is lower in Run 5 than Run 2, as indicated by the lower total November 1 population, the natural mortality rates of bucks not taken by hunting is lower and hence the average age of bucks is higher in Run 5 than Run 2. In Run 5, about 12 deer die of natural causes for every 10 taken by hunting, giving the lowest natural loss to hunting kill ratio of the strategies considered so far.

### Run 6, Fifty Percent Buck, Fifteen Percent Doe, and Eighty Percent Fawn Kill

In this run, 50 percent of all bucks, including legal bucks and spike bucks, are taken by hunting in August and September each year, and 15 percent of the does and 80 percent of the fawns are taken in November. This strategy is comparable with the usual sheep management strategy in Mendocino County where a high proportion of the lambs is marketed annually. Fawns are the deer population counterpart of lambs. Assuming for purposes of illustration that this strategy can be implemented, the following can be observed. A high rate of removal of fawns substantially reduces the total population. Further, because of the resulting low density, the total fawn natural mortality of 842 is small relative to the number born of 16, 192 and total natural losses are low at 1, 037. Almost 15 deer are taken by hunting for one which dies of natural causes and the total removal of 15, 480 is 52 percent of the July 1 population. The low deer density increases the birth rate to 1. 71 fawns per doe.

Run 6 is not a practicable deer management strategy, but it does demonstrate that if fawns are hunted extensively and selectively, the control of total population numbers can be achieved. Over 80 percent of the deer taken by hunting are fawns. Also, sufficiently intense hunting will reduce the total hunting kill; for example, the kill of 15,480 in Run 6 is less than the kill of 25,207 in Run 5. The total biomass yield in Run 6 will be proportionally less because of the relatively small size of fawns compared with adult deer. Run 6 is not acceptable because it almost exterminates the population.

### Run 7, Twenty-five Percent Buck, Fifteen Percent Doe, Five Percent Spike, and Five Percent Fawn Kill

In this run, 25 percent of the legal bucks are taken annually, and in addition, an antlerless hunt is carried out in November where 15 percent of the does, and 5 percent of the spike bucks and fawns each are removed annually. This run is a practicable management option for Mendocino County and is an extension of the current strategy to include an annual antlerless deer hunt. Therefore, the results are compared with the results for Run 2. The impact of the antlerless hunt is to reduce the total November 1 population from 192,977 to 171,761. The total natural losses are also reduced by over 46 percent from 101,043 to 54,201. The total kill in Run 7 is 23,534 of which 7,155 are legal bucks compared with a total of 5,568 legal bucks taken in Run 2 under the legal bucks-only hunting strategy. In Run 7, the natural loss to hunting kill ratio is 23 to 10, and the hunting kill is in excess of 12 percent of the July 1 total population versus about 3 percent in Run 2.

Run 8, Fifty Percent Buck, Fifteen Percent Doe, Five Percent Spike, and Five Percent Fawn Kill

The change from Run 7 to Run 8 is an increase in the percentage of legal bucks taken from 25 percent to 50 percent. The total kill increases from 23,534 to 27,118 and the total legal buck kill increases from 7,155 to 8,807. The total November 1 population increases from 171,761 to 172,619 and natural losses increase from 54,201 to 57,183. Other experiments with the simulation model demonstrate that the strategy specified for Run 8 gives an approximation to the maximum legal buck kill possible in the Mendocino County deer population. Thus, under a buck and doe hunting strategy, the total legal buck kill is higher than the maximum possible under a legal bucks-only hunting strategy. Under this strategy, 14 percent of the July 1 population is removed by hunting each year and the natural loss to hunting loss ratio is about 21 to 10.

## Results with Stochastic Assumptions

The results presented in the previous section assume that average forage conditions occur each year. Here, using the same set of eight hunting strategies as in the previous section, the variations in the deer population due to annual variability in the forage conditions are illustrated.

Table 4.3 gives the results with deterministic and stochastic assumptions for the hunting strategy where 25 percent of the legal bucks are taken each year by hunting. An important feature of these results is the similarity in corresponding values. This similarity in corresponding values occurs for all eight hunting strategies presented, as shown in Table 4.4 when compared with the corresponding parameter values in Table 4.1 and Table 4.2. Given that hunting strategies are implemented and maintained for long periods of time, say 30 years, the implications of these results is that random shocks do not change the conclusions from the deterministic model.

Another important characteristic of the deer population demonstrated by the results with stochastic assumptions is the considerable year to year variability in the parameters of the population as a result of changes in the forage conditions. Of particular interest are those parameters which are collected in the field and used to make recommendations for changes in hunting regulations. Recognition of this variability is important to management because inferences drawn from small sample data from stochastic systems such as the deer population can be erroneous and can result in the abandonment of a preferred strategy in favor of a less preferred alternate.

Table 4.3. Comparison of simulation results with deterministic and stochastic assumptions for the 25 percent legal buck hunting strategy (Run 2).

| Parameter | Deterministic assumptions | Stochastic assumptions[a] |
|---|---|---|
| November 1 population | 192,977 | 195,204 |
| Annual natural losses | 101,043 | 99,621 |
| Annual hunting kill | 6,325 | 6,373 |
| Legal buck kill | 5,568 | 5,301 |
| Hunting kill/July total population | .03 | .03 |
| Natural losses/hunting kill | 15.98 | 15.63 |
| Birth rate (fawns/doe) | 1.18 | 1.17 |
| November 1 ratios | | |
| Legal bucks/does | .18 | .18 |
| Spike bucks/does | .12 | .12 |
| Fawns/does | .56 | .57 |
| Percent composition of kill | | |
| Legal bucks | 88.0 | 83.2 |
| Spike bucks | 8.1 | 12.9 |
| Does | 3.4 | 3.4 |
| Fawns | .5 | .5 |
| Average age on November 1 (years) | | |
| Bucks | 3.12 | 3.10 |
| Does | 4.84 | 4.83 |

[a] The values presented for the stochastic assumptions are the sample means over a 30 year simulation run.

Table 4.4 Selected population statistics for stochastic computer runs of Mendocino County deer population model.

| Parameter | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 |
|---|---|---|---|---|---|---|---|---|
| Hunting specification[a] | | | | | | | | |
| Legal bucks | 0 | 25 | 50 | 0 | 25 | 50 | 25 | 50 |
| Spike bucks | 0 | 0 | 0 | 0 | 0 | 50 | 5 | 5 |
| Does | 0 | 0 | 0 | 25 | 25 | 15 | 15 | 15 |
| Fawns | 0 | 0 | 0 | 0 | 0 | 80 | 5 | 5 |
| November 1 population[b] | 191, 750 | 195, 204 | 197, 921 | 151, 461 | 150, 965 | 22, 044 | 169, 248 | 170, 198 |
| Annual natural losses | 94, 092 | 99, 621 | 104, 777 | 28, 728 | 32, 771 | 782 | 51, 596 | 53, 802 |
| Annual hunting kill | 0 | 6, 373 | 8, 362 | 11, 735 | 25, 592 | 12, 041 | 23, 186 | 27, 286 |
| Hunting kill/July 1 population | 0 | .03 | .04 | .08 | .15 | .52 | .12 | .14 |
| Natural losses/hunting kill | - | 15.63 | 12.53 | 2.45 | 1.28 | .06 | 2.23 | 1.97 |
| Birth rate (fawns/doe) | 1.16 | 1.17 | 1.18 | 1.26 | 1.20 | 1.69 | 1.16 | 1.17 |
| November 1 ratios | | | | | | | | |
| Legal bucks/does | .48 | .18 | .09 | 1.32 | .42 | .07 | .29 | .15 |
| Spike bucks/does | .13 | .12 | .11 | .23 | .21 | .06 | .17 | .16 |
| Fawns/does | .57 | .57 | .58 | .67 | .64 | 1.38 | .62 | .62 |
| Average age on November 1 (years) | | | | | | | | |
| Bucks | 4.91 | 3.10 | 2.28 | 6.08 | 3.47 | 2.60 | 3.37 | 2.47 |
| Does | 4.80 | 4.83 | 4.80 | 3.49 | 3.57 | 5.51 | 4.11 | 4.01 |

[a] Hunting specifications give percentages of each component taken by hunting each year.

[b] The values presented for all parameters are the sample means over a 30 year simulation run.

To highlight the importance of recognizing the year to year variability in the population due to changes in forage conditions, some results are presented based on a 30 year run with stochastic assumptions for the strategy where 25 percent of the legal bucks are taken by hunting each year. Table 4.5 gives the mean, minimum, and maximum values of selected parameters for the strategy. The absolute difference between the minimum and maximum values is given and the minimum value is expressed as a percentage of the maximum value. The table also shows the length of time, in years, which separates the minimum and maximum values. To illustrate, for the November 1 total population, the maximum of 217,224 occurs in year six and the minimum of 169,502 is four years later in year ten of the run.

The sequence of forage years used to derive the values given in Table 4.5 is the same as that used to compute the mean values for the stochastic run given in Table 4.3. The sequence does not purport to reflect all the potential variability in the deer population due to changes in forage conditions, but the results do serve to illustrate that the values of the parameters can reduce or increase substantially in a short period of time in response to changing forage conditions.

For the same simulation run, Table 4.6 shows the differences in the status of the system which can occur over short periods of time, as given by sets of parameters. Sets of parameters are given for year six and year ten of the simulation run.

Table 4.5. Mean, minimum, and maximum values and other statistics of selected parameters for a 30 year simulation run with stochastic assumptions for the 25 percent legal buck hunting strategy.

| Parameter | Mean | Minimum | Maximum | Minimum as percent of maximum | Range | Years between maximum and minimum |
|---|---|---|---|---|---|---|
| November 1 population | 195,204 | 169,502 | 217,224 | 78.0 | 47,722 | 4 |
| Annual natural losses | 99,621 | 80,926 | 120,448 | 67.2 | 39,522 | 4 |
| Annual hunting kill | 6,373 | 5,981 | 6,665 | 89.7 | 684 | 6 |
| June 1 yearling to doe ratio | .37 | .28 | .52 | 53.9 | .24 | 2 |
| November 1 fawn to doe ratio | .57 | .38 | .76 | 50.0 | .38 | 4 |
| Birth rate (fawns/doe) | 1.17 | .91 | 1.37 | 66.4 | .46 | 4 |
| Average age on November 1 (years) | | | | | | |
| Bucks | 3.10 | 2.90 | 3.42 | 85.0 | .52 | 2 |
| Does | 4.83 | 4.64 | 5.07 | 91.5 | .43 | 5 |

Table 4.6. Selected parameters from two years of a 30 year simulation run with stochastic assumptions for the 25 percent legal buck hunting strategy.

| Parameter | Year 6 | Year 10 |
|---|---|---|
| November 1 population | 217,224 | 169,502 |
| Annual natural losses | 86,572 | 96,821 |
| Annual hunting kill | 6,342 | 6,429 |
| June 1 yearling to doe ratio | .39 | .27 |
| November 1 fawn to doe ratio | .76 | .38 |
| Birth rate (fawns/doe) | 1.37 | .91 |
| Average age on November 1 (years) | | |
| Bucks | 3.10 | 3.26 |
| Does | 4.88 | 4.86 |

The change in the system performance from year six to year ten of the simulation run, using only the November 1 fawn to doe ratio and the birth rate as indicators of performance, could be used to support the hypothesis that population numbers are increasing thereby causing progressive reduction in reproductive performance and fawn survival. As shown in Table 4.6 the reverse is the case and the population on November 1 reduces from year six to year ten from 217,224 to 169,502. The change in the status of the system from year six to year ten is a reflection only of population response to a sequence of poor forage years. These results support the need for caution in the use of short time series data in the formulation of recommendations for changes in hunting regulations.

## Summary

In this chapter, results of experiments with the computer simulation model of the Mendocino County deer population have been presented. The eight hunting strategies presented in detail include the array of management options available to the resource managers, as well as other biologically feasible but politically unacceptable strategies. Comparison of the runs showed that the current level of hunting neither provides an effective means of population control nor maximizes the legal buck kill. The legal buck kill is maximized when a mixed buck and antlerless deer hunting strategy is followed.

Population control is desirable and can be achieved only by antlerless hunting. For each of the eight strategies, results were presented using the model with both deterministic and stochastic assumptions. Comparison of the corresponding runs showed that deterministic runs are adequate for comparing strategies if the strategies are implemented for long term periods, say 30 years. The results show that the stochastic model can provide information, not otherwise available, on the expected ranges of values for each parameter of the system prior to the adoption of the strategy. The results highlight the need for caution in drawing inferences from small sample data as indicated by the substantial changes in the system which can occur due only to changes in the forage conditions.

Since the deterministic model has a lesser data requirement for implementation than the stochastic model, it is more likely to be formulated and adopted in instances where resource managers are concerned primarily with the aggregate performance of the biosystem under various strategies.

The results of the simulation run using the same strategy currently in use in Mendocino County showed the values of the output parameters to be consistent with the corresponding field data for the county. The purpose of simulation of a biomanagement system is to test the impact on variables of interest, of particular management strategies or policies, before they are implemented and influence the real system. The results presented in this chapter have shown that this purpose can be satisfied by this computer simulation model.

# V. SUMMARY AND CONCLUSIONS

## Summary of the Problem

Deer populations are representative of wildlife populations managed by man in attempts to satisfy particular objectives. The activities of man impinge intentionally and unintentionally, directly and indirectly, on such species. Management for hunting is an intentional activity with direct effects. The objective of this thesis was to develop, and experiment with, a biomanagement model of the Mendocino County deer population with particular emphasis on the response of the population to alternative hunting strategies.

There is a complex of benefits and costs associated with conserving and managing a deer population. Benefits are most importantly related directly to the consumptive (hunting) and non-consumptive (sightseeing and photography) utilization of the resource. From the standpoint of management, consumptive utilization can be estimated and quantified; however, no satisfactory procedure is currently available to quantify the extent and value of non-consumptive utilization of the resource.

Costs can be usefully divided into two categories. The first category includes the direct costs of management, that is regulation and enforcement and the direct costs of deliberate vegetation and habitat improvement practices. The second category are the liability costs associated with the presence of the deer population, including the costs of deer damage to agricultural crops, forest regeneration and those resulting from collisions of automobiles with deer on the highways in the county.

Also in this second category are costs resulting from interactions between deer and domestic livestock. Deer and livestock have either a complementary or a somewhat competitive relationship in regard to forage utilization on the range. This depends upon their respective diets, the relative sizes of the deer, sheep and cattle, stocking rates, and the seasons of the year when livestock compete for the same kinds of forage. Greatest competition occurs after the fall rains (about November) until mid-April each year when all of these species feed almost exclusively on green grasses and herbage. Also at this time when large numbers of animals share a common range and a common diet, a number of parasites and diseases are transferred between them. However, disease and parasite transference is not limited to this season. The costs to livestock producers as a consequence of these parasite and disease interrelationships appear to be related to the relative and absolute numbers of deer, sheep and cattle using the range. Thus all of the liability costs are directly related to the size of the deer population. By contrast, the direct costs of management, the first category of costs considered, are not necessarily so related, while many of the benefits and costs have not been quantified, for those costs related to the size of the population, the direction of the change in costs can be related to the changes in the size of the population.

If a new hunting strategy reduces the total population and increases the hunter kill, then the consumptive value of the population will increase; agricultural and forest damage costs related to deer will tend to reduce; automobile damages will tend to reduce; competition for grasses and herbage will be reduced during the winter months if the population is reduced during this time of the year, and the number of sheep and cattle utilizing the range is not increased; the impact of parasites and diseases on both the deer and the commercial livestock will tend to reduce; and depending upon the size of the deer population under the new strategy, and other factors, the non-consumptive value of the population may be enhanced or reduced. Appendix C illustrates the types of assumptions and calculations which can be made to assist in the evaluation of two or more alternative management strategies.

Before a new strategy can be considered for adoption, the decision makers need predictions about the impact of the strategy on the size of the population and other biological performance variables. To make these predictions, the decision makers need a model of the biosystem which can be used to generate the values of these performance variables (size, composition, births, deaths, and hunter kill, for example). Experimentation on the real biosystem is not practical because of costs and the length of time involved to get results. However, a computer simulation model of the biosystem can be utilized to provide this information. In this thesis such a model has been presented.

## Summary of the Model

The computer simulation model characterizes the deer population in Mendocino County as a dynamic density-dependent birth and death process. The real biosystem is a discrete event birth and death process in continuous time. The model approximates this by a discrete event process in discrete time. The time unit for calculations in the model is one month. Birth rates are defined in the model as a decreasing function (convex from below) of the exponential average density (deer per square mile) at the time of conception each year (November 1) and the number of fawns born at the end of May is computed by applying these birth rates to the numbers of does in each age category at that time. Two types of losses are defined. First, natural losses due to causes such as competition for forage, disease, malnutrition, and automobile accidents are determined endogenously. The natural mortality rates for each age and sex class in each month is defined as an increasing function (concave from below) of the density (deer per square mile) at the beginning of the month. These rates are then applied to the appropriate categories of deer to compute these losses. The second type of losses are those resulting from hunting. These include allowances for the reported kill, unreported kill and cripple losses. For each run of the model hunting is specified in the desired months as proportions of the inventory in each age and sex category. These proportions, or rates, are then applied to these inventories to compute the numbers of deer taken by hunting.

The real biosystem is dynamic and is subject to random shocks due to changes in weather and hence forage conditions. In the model these random components are represented by a proxy variable called the forage factor, which simulates the probability and magnitude of annual variations in forage quality-quantity conditions. Five alternatives are defined corresponding to poor, below average, average, above average, and excellent forage conditions. Using fawn survival data, as given by the fawn to doe ratio, for the Mendocino County deer population as an index of the forage quality-quantity conditions, a probability distribution of forage factors was derived. In simulation runs where annual variability of forage conditions is desired, a forage factor is randomly selected from this probability distribution each November and conditional upon the forage factor selected, the birth rates and natural mortality rates are modified for the subsequent 12 months (one year). To illustrate, in above average forage years the birth rates are increased and natural mortality rates are decreased. The modification coefficients used reflect the relative sensitivity of the various age and sex components of the population to changes in forage conditions. The forage factor can be suppressed, permitting runs based on average forage conditions each year. The computer program of the deer population includes additional detail not mentioned above, which is used to complete the representation of the workings of the biosystem.

Certain kinds of field data on the deer population are not extensive, particularly estimates of numbers at all times of the year. The process of model formulation, data synthesis, and model validation was only partially carried out by routine inferences from data, and relied upon the expertise of the wildlife biologists and their experience with the Mendocino County deer population and other similar wildlife populations.

Primary data used in the model are from the California Department of Fish and Game records for the Mendocino County deer population and the records for the deer population on the Hopland Field Station of the University of California in southeastern Mendocino County. These data were compiled and critically reviewed by the cooperating wildlife biologists and transformed into a format consistent with the structure of the simulation model. After using these initial estimates in validity checks of the model, the data assumptions were reviewed and revised. This model validation phase of the simulation was terminated when the biologists considered the model adequately representative of the Mendocino County deer population, as determined by its ability to generate outcomes consistent with biological theory and with additional field data.

The model does not consider deliberate habitat and vegetation improvement practices as they relate to changes in the carrying capacity of the range but these could readily be incorporated into the model if desired.[1] The model is also a simplification of the real world as the hunting strategies are defined as constant proportions of the numbers of deer available each year. Variability in the annual kill of deer over time for the same hunting strategy is most likely a function of the variability in the population numbers and composition, and variability in the hunting pressure (number of hunter days) and the hunter success rates (deer taken per hunter) over time. Variability is not accounted for in hunting pressure or the hunter success

---

[1] For example, consider progressive improvements in the habitat and vegetation which alter the levels of births and deaths at particular densities, and result in increased carrying capacity of the range over time. These improvements can be incorporated by defining a scaling factor for each year of a simulation run which reflects the percent improvement in carrying capacity relative to the carrying capacity in the base period or the beginning of the run. The independent variable used to compute the birth rates and natural mortality rates would be the total inventory divided by the product of the area in square miles and the scaling factor. A scaling factor of unity defined for each year of the run would reduce the model to the form presented in this thesis. Similarly, progressive deterioration of the habitat would be defined by using a sequence of scaling factors from unity toward zero.

rate. Hunting pressure is most influenced by policy decisions of the California Fish and Game Commission through the regulations they implement. Hunter success rates may be functionally related to the status of the biosystem and field conditions at the time of the hunt, including hunter accessibility to the deer which varies with weather conditions and the timing of the hunting seasons.

## Conclusions

The computer simulation model can be used to investigate any desired hunting strategy. However, the options of the wildlife manager are limited for various biological, political, and social reasons. The results of eight computer simulation runs, representing eight different hunting strategies, are presented. The hunting strategies were: no hunting; two legal bucks-only hunting strategies (one of which corresponds to the current practice); one does-only hunting strategy; and four strategies where hunting is carried out on two or more components of the population. The results vividly demonstrated several important biological principles pertinent to deer population management. These are summarized below:

1. In the absence of hunting, deer numbers oscillate around an upper limit consistent with the carrying capacity of the range.
2. Control of population numbers can be achieved by doe and/or

heavy fawn hunting but bucks-only hunting does not control total population numbers.

3. Certain combinations of buck and antlerless hunting will produce a greater legal buck kill than can be achieved with bucks-only hunting.
4. The fall buck to doe ratio increases or decreases respectively with decreases or increases in the intensity of buck hunting.
5. The fall fawn to doe ratio increases with increases in the intensity of doe hunting.
6. The average ages of the components of the population hunted decrease as increasing percentages of those components are taken by hunting.
7. The birth rate per doe increases as the intensity of antlerless hunting increases, but is not affected by buck hunting.

In addition to the general principles outlined above, the details of the results have particular implications for management of the Mendocino County deer population. If a policy objective of the California Fish and Game Commission is to implement a hunting strategy which maximizes the buck take each year, this objective cannot be achieved by the current hunting strategy. Similarly, the current strategy, approximated by simulation Run 2 in Chapter IV, does not provide any control over total deer numbers. If the costs of having deer in the county are directly related to deer density, the current strategy provides no significant reduction in costs relative to the management strategy of complete protection. The density can be reduced and the legal buck kill increased by mixed hunting of bucks and does. In this way costs can be reduced and recreational benefits from the population can be increased.

This thesis does not examine directly the determinants of the demand for hunting, or more specifically, the factors which determine the numbers of hunters or their response to changes in hunting regulations. However, to achieve an increased hunting kill changes in regulations are required to adjust the time of the open season or liberalize the bag limits.

## Directions for Future Research

The areas of further research suggested by this study are three-fold.

1. As emphasized in this thesis, time series data relating only to one particular hunting strategy are of little assistance in predicting the response of the biosystem to alternative hunting strategies. These data provide only one point on the natural mortality and birth rate functions as they relate to density. These functions could be specified in this model only because detailed data collected over a 20 year

period from the Hopland Field Station could be incorporated into the model.

Additional data are needed in order to empirically test the predicted outcomes of the model for hunting strategies other than the current bucks-only hunting strategy. Such data could be collected by designing and implementing a monitoring system in other areas where different hunting strategies are used or in Mendocino County if a different strategy is implemented.

2. In addition to more research needed to quantify the structural relationships in the biosystem, search of the literature for this study indicated that the current data do not lend themselves to estimation of the costs and benefits of having the deer population in the county, particularly those costs incurred by agricultural and forest enterprises. Deer predation permits are issued by the state on the assumption that reduced deer density will reduce the extent of deer damage. It is anomalous that these costs have not been quantified as functions of the deer density.

   Similarly benefits from hunting and nonconsumptive recreational uses have not been related to the concept of density of the deer. Thus, before the model presented in the broader context of costs and benefits, further research of these relationships will be required.

3. The model presented in this thesis can be regarded primarily as a supply model. It can be used to generate the supply response of the population to alternative hunting strategies. Specification of the hunting strategies as exogenously determined, abstracted from the complex of factors which determine the hunting pressure and hunter success rates. The determinants of these factors should be investigated in Mendocino County and in other areas in the state to permit regulations to be specified consistent with the objectives for each deer population in the state.

   In the broad context of management, it is clear that the policy objectives relating to deer, at least in California, are not being achieved. This may be due to lack of a systems management perspective. Considerably more research is needed before a systems planning approach can be implemented in the formulation of hunting strategies and regulations throughout the state of California.

This thesis has shown that computer simulation of deer populations as biosystems leads to conclusions not readily apparent, or derivable, from piecemeal analyses. Results from the three research areas above would need to be integrated to produce an ideal management system for statewide planning of hunting strategies and hunting regulations. This would necessarily require an interdisciplinary approach similar, but more extensive, to the one reported here. The research upon which this thesis is based was, most importantly, a combined effort by the interdisciplinary research team of wildlife biologists and agricultural economists.

# BIBLIOGRAPHY


Anderson, F. M., A. N. Halter, G. E. Connolly, and W. M. Longhurst. 1971. Simulation experiments with a biomanagement model of a deer herd. In: Proceedings of Annual Symposium of Systems, Man and Cybernetics Group of IEEE, Anaheim, California. p. 297-302.

Baker, H. L. and A. Poli. 1951. Area and ownership of forest land in Mendocino County, California. 23 p. (California Forest and Range Experiment Station, Forest Survey Release no. 10)

Baker, N. F., W. M. Longhurst, and J. R. Douglas. 1957. Experimental transmission of gastrointestinal nematodes between domestic sheep and Columbian black-tailed deer. In: Transactions of 22nd North American Wildlife Conference. Washington, D. C. p. 160-168.

Bertalanffy, Ludwig von. 1968. General system theory. New York, George Braziller. 289 p.

Biswell, H. H., R. D. Taber, D. W. Hedrick, and A. M. Schultz. 1952. Management of chamise brushlands for game in the north coast region of California. California Fish and Game 38(4):453-484.

California Crop and Livestock Reporting Service. 1970-1971. [Annual] California livestock report. Sacramento, California.

California Department of Fish and Game. 1962-1971. Annual wildlife management unit reports and recommendations for antlerless deer hunts. Sacramento, California.

California Department of Fish and Game. 1966-1970. [Annual] Report of the game take hunter survey. Sacramento, California.

California Department of Fish and Game. 1969-1970. [Annual] Final deer kill report. Sacramento, California.

California Department of Fish and Game. 1967. Characteristics of deer clubs in central coastal California. Unpublished report. San Francisco, Regional Office. 11 numb. leaves.

California Department of Fish and Game. 1971. Unpublished records of Willits wildlife management unit. Sacramento, California.

California Fish and Game Commission. 1966. California fish and wildlife plan. Sacramento, California. 3 v.

Caughley, G. 1970. Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. Ecology 51:53-72.

Clark, G. G. 1969. A literature review relating to values of big game. Master's thesis. Fort Collins, Colorado, Colorado State University. 90 numb. leaves.

Connolly, G. E. 1966. Deer hunters and deer management - an opinion survey in Mendocino County, California. Unpublished report. Hopland, California. Hopland Field Station. 21 numb. leaves.

Connolly, G. E. 1970. A population model for deer on the Hopland Field Station, Mendocino County, California. M.A. thesis. Rohnert Park, California, Sonoma State College. 54 numb. leaves.

Connolly, G. E. 1971. Associate Staff Researcher, University of California, Hopland Field Station. Personal communication.

Dasmann, R. F. and W. W. Hines. 1959. Logging, plant succession, and black-tailed deer in the redwood region. Unpublished mineo held at University of California, Hopland Field Station. 13 p.

Davis, L. W. 1967. Dynamic programming for deer management planning. Journal of Wildlife Management 31(4):667-679.

Dent, J. B. and J. R. Anderson (eds.). 1971. Systems analysis in agricultural management. Sydney, Wiley. 394 p.

Eriksen, T. 1960-1970. [Annual] Mendocino County crop report. Mendocino County Department of Agriculture, Ukiah, California.

Halter, A. N., M. L. Hayenga, and T. J. Manetsch. 1970. Simulating a developing agricultural economy: Methodology and planning capacility. American Journal of Agricultural Economics 52(2):272-284.

Lack, D. 1954. The natural regulation of animal numbers. Oxford University Press. 343 p.

Lauppe, E. M. 1963. Deer eat trees. Outdoor California 24(9):5-7.

Leopold, A. 1933. Game management. New York, Scribner's. 481 p.

Leopold, A., L. K. Sowls, and D. L. Spencer. 1947. A survey of over-populated deer ranges in the United States. Journal of Wildlife Management 11:162-177.

Longhurst, W. M. 1955. The role of parasitism in the population dynamics of a herd of black-tailed deer. Proceedings of Annual Conference of Western Association of State Game and Fish Commissioners, Moran, Wyoming. 34:145-149.

Longhurst, W. M. 1970. Records of the deer population on the University of California, Hopland Field Station, Hopland, California.

Longhurst, W. M. and G. E. Connolly. (In press) The effects of brush burning on deer. In: Transactions of Annual Meeting, California-Nevada Section, The Wildlife Society. January 1970.

Longhurst, W. M. and J. R. Douglas. 1953. Parasite interrelationships of domestic sheep and Columbian black-tailed deer. In: Transactions of 18th North American Wildlife Conference. Washington, D. C. p. 168-188.

Longhurst, W. M., A. S. Leopold, and R. F. Dasmann. 1952. A survey of California deer herds, their ranges and management problems. 136 p. (California Department of Fish and Game, Game Bulletin no. 6)

Longhurst, W. M., J. A. Rochelle, G. E. Connolly, R. D. Teague, and P. S. Parsons. 1969. Assessing big game management alternatives through bioeconomic models. Progress report on Western Regional Project W-97. Hopland, California. University of California, Hopland Field Station. Unpublished mimeo. 25 numb. pages.

National Research Council. Committee on Agricultural Land Use and Wildlife Resources. 1970. Land use and wildlife resources. Washington, National Academy of Sciences. 262 p.

Odum, E. P. (in collaboration with H. T. Odum). 1959. Fundamentals of ecology. 2d ed. Philadelphia, Saunders. 546 p.

Osebold, J. W., J. F. Christensen, W. M. Longhurst, and M. N. Rosen. 1959. Latent Anaplasma Marginale in wild deer demonstrated by calf inoculation. Cornell Vet. 49(1): 97-115.

Rockefeller, L. S. et al. 1962. Outdoor recreation for America. Outdoor Recreation Resources Review Commission. 246 p.

Russo, J. P. 1964. The Kaibab north deer herd. Its history, problems and management. 195 p. (Arizona Game and Fish Department, Wildlife Bulletin no. 7)

Taber, R. D. and R. F. Dasmann. 1958. The black-tailed deer of the chaparral. 163 p. (California Department of Fish and Game, Game Bulletin no. 8)

Tillett, P. 1963. Doe day: The anterless deer controversy in New Jersey. New Jersey, Rutgers University Press. 126 p.

U.S. Bureau of Sport Fisheries and Wildlife. 1966. National survey of fishing and hunting. 1965. U.S. Department of Interior Resource Publication 27.

Watt, K. E. F. 1968. Ecology and resource management. New York, McGraw-Hill. 450 p.

# APPENDICES

# APPENDIX A

Appendix Table A.1. California state population, hunting license sales, and deer tag sales, 1930-1970.

| Year | State population | Hunting license sales | Hunters per 10,000 population | Deer tag sales | Deer hunters as percent of total |
|---|---|---|---|---|---|
| 1930 | 5,711,000 | 231,970 | 406 | 123,999 | 53.45 |
| 1931 | 5,824,000 | 214,577 | 368 | 129,005 | 60.12 |
| 1932 | 5,894,000 | 154,031 | 261 | 96,702 | 62.78 |
| 1933 | 5,933,000 | 171,139 | 288 | 95,776 | 55.96 |
| 1934 | 6,060,000 | 174,667 | 288 | 108,923 | 62.36 |
| 1935 | 6,175,000 | 190,257 | 308 | 110,808 | 58.24 |
| 1936 | 6,341,000 | 225,448 | 356 | 126,855 | 56.27 |
| 1937 | 6,528,000 | 248,365 | 380 | 136,389 | 54.91 |
| 1938 | 6,656,000 | 252,117 | 379 | 141,598 | 56.16 |
| 1939 | 6,785,000 | 270,095 | 398 | 152,924 | 56.62 |
| 1940 | 6,950,000 | 291,507 | 419 | 163,285 | 56.01 |
| 1941 | 7,237,000 | 331,878 | 459 | 173,699 | 52.34 |
| 1942 | 7,735,000 | 268,128 | 347 | 116,121 | 43.31 |
| 1943 | 8,506,000 | 284,370 | 334 | 147,795 | 51.97 |
| 1944 | 8,945,000 | 318,910 | 357 | 178,250 | 55.89 |
| 1945 | 9,344,000 | 393,282 | 421 | 214,662 | 54.58 |
| 1946 | 9,559,000 | 487,307 | 510 | 282,060 | 57.88 |
| 1947 | 9,832,000 | 507,552 | 516 | 299,610 | 59.03 |
| 1948 | 10,064,000 | 504,173 | 501 | 300,405 | 59.58 |
| 1949 | 10,337,000 | 496,735 | 481 | 309,829 | 62.37 |
| 1950 | 10,668,000 | 491,424 | 461 | 312,652 | 63.62 |
| 1951 | 11,108,000 | 534,684 | 481 | 342,900 | 64.13 |
| 1952 | 11,633,000 | 588,764 | 506 | 369,149 | 62.70 |
| 1953 | 12,093,000 | 613,928 | 508 | 370,938 | 60.42 |
| 1954 | 12,511,000 | 620,587 | 496 | 397,566 | 64.06 |
| 1955 | 13,003,000 | 634,136 | 488 | 410,205 | 64.69 |
| 1956 | 13,578,000 | 668,165 | 492 | 448,663 | 67.15 |
| 1957 | 14,168,000 | 647,252 | 457 | 420,400 | 64.95 |
| 1958 | 14,735,000 | 608,104 | 413 | 382,588 | 62.91 |
| 1959 | 15,277,000 | 613,308 | 401 | 399,103 | 65.07 |
| 1960 | 15,860,000 | 631,479 | 398 | 419,478 | 66.43 |
| 1961 | 16,455,000 | 646,076 | 393 | 416,710 | 64.50 |
| 1962 | 16,995,000 | 641,015 | 377 | 404,861 | 63.16 |
| 1963 | 17,557,000 | 658,025 | 375 | 389,911 | 59.26 |
| 1964 | 18,077,000 | 681,345 | 377 | 405,264 | 59.48 |
| 1965 | 18,403,000 | 699,983 | 380 | 417,591 | 59.66 |
| 1966 | 18,802,000 | 741,560 | 394 | 440,838 | 59.45 |
| 1967 | 18,992,000 | 751,000 | 395 | 425,500 | 56.66 |
| 1968 | 19,179,000 | 759,163 | 396 | 418,369 | 55.11 |
| 1969 | 19,443,000 | 762,732 | 392 | 410,914 | 53.87 |
| 1970 | n.a. | 756,000 | n.a. | 394,000 | 52.12 |

Source: California Fish and Game Commission, 1966.
California Department of Fish and Game, various dates.

Appendix Table A.2. Mendocino County crops: acreage, production, and value, 1970.

| Crop | Acreage | | Production | | | Value in dollars | |
|---|---|---|---|---|---|---|---|
| | Total | Bearing | Per acre | Total acres | Unit | Per unit | Total |
| Apples[a] | 843 | 703 | 5.76 | 4,050 | ton | 63.50 | 257,000 |
| Grapes | 6,150 | 5,336 | 2.44 | 13,000 | ton | 252.00 | 3,276,000 |
| Pears | 4,815 | 4,073 | 7.81 | 31,800 | ton | 112.00 | 3,562,000 |
| Prunes[a] | 749 | 734 | 1.91 | 1,400 | ton | 286.00 | 285,000 |
| Walnuts | 660 | 516 | .232 | 120 | ton | 417.00 | 50,000 |
| Misc. fruits & nuts[b] | 147 | | | | | | 40,000 |
| Total fruits and nuts, 1970 | | | | | | | 7,470,000 |
| Hay, alfalfa | 2,000 | | 4.0 | 8,000 | ton | 37.00 | 296,000 |
| Hay, other | 16,000 | | 2.0 | 32,000 | ton | 31.00 | 992,000 |
| Barley | 900 | | 1.0 | 900 | ton | 45.0 | 40,500 |
| Oats | 550 | | .85 | 468 | ton | 47.00 | 22,000 |
| Wheat | 200 | | .93 | 186 | ton | 45.00 | 8,370 |
| Corn, grain | 200 | | 1.7 | 340 | ton | 52.00 | 17,700 |
| Corn silage | 1,000 | | 18.5 | 18,500 | ton | 10.00 | 185,000 |
| Sorghum | 700 | | 18.5 | 12,950 | ton | 10.00 | 130,000 |
| Miscellaneous[c] | | | | | | | 70,000 |
| Pasture | | | | | | | |
| Irrigated | 5,500 | | | | acre | 50.00 | 275,000 |
| Woodland | 350,000 | | | | acre | .45 | 158,000 |
| Other | 625,000 | | | | acre | 2.15 | 1,344,000 |
| Total field crop, 1970 | | | | | | | 3,538,570 |
| Vegetables[d] | 300 | | | | | | 135,000 |
| Total vegetable crop, 1970 | | | | | | | 135,000 |
| Total fruit, nut, field and vegetable crops | | | | | | | 11,143,576 |

Source: Eriksen (1970).

[a] Preliminary

[b] Includes winter pears, peaches, chestnuts, cherries, berries, table grapes, and black walnuts.

[c] Includes dry beans, seed crops, milo, etc.

[d] Includes tomatoes, lettuce, cabbage, peas, green beans, watermelons, potatoes, pumpkins, etc.

Appendix Table A. 3. Mendocino County livestock production and value in 1970 and livestock inventories for 1970 and 1971.

| Item | Total production | Unit | Value / unit (dollars) | Total value (dollars) |
|---|---|---|---|---|
| Production and value[a] | | | | |
| Sheep and lambs | 44, 900 | cwt. | 24.00 | 1, 078, 000 |
| Cattle and calves[b] | 115, 000 | cwt. | 27. 90 | 3, 208, 000 |
| Hogs and pigs | 5, 560 | cwt. | 22. 90 | 127, 000 |
| Miscellaneous | | | | 65, 000 |
| Total livestock, 1970 | | | | 4, 478, 000 |

Livestock inventory[c]

| | All cattle and calves | All milk cows and heifers that calved | Stock sheep and lambs |
|---|---|---|---|
| January 1971[b] | 40, 400 | 1, 700 | 65, 800 |
| January 1970 | 37, 100 | 1, 900 | 71, 100 |

[a]Source: Eriksen (1970).

[b]Preliminary

[c]Source: California Crop and Livestock Reporting Service (1970-1971).

Appendix Table A. 4. Mendocino County regular season buck kill for 1927-1970.

| Year | Total season buck kill | Year | Total season buck kill | Year | Total season buck kill |
|---|---|---|---|---|---|
| 1927 | 1,475 | 1942 | 1,652 | 1957 | 3,847 |
| 1928 | 1,468 | 1943 | -[a] | 1958 | 3,754 |
| 1929 | 1,355 | 1944 | 2,297 | 1959 | 3,655 |
| 1930 | 1,483 | 1945 | 2,365 | 1960 | 4,426 |
| 1931 | 1,706 | 1946 | 2,980 | 1961 | 4,585 |
| 1932 | 1,273 | 1947 | 3,067 | 1962 | 4,002 |
| 1933 | 1,234 | 1948 | 3,627 | 1963 | 4,367 |
| 1934 | 1,185 | 1949 | 3,354 | 1964 | 4,681 |
| 1935 | 1,207 | 1950 | 2,927 | 1965 | 4,869 |
| 1936 | 1,372 | 1951 | 3,665 | 1966 | 4,427 |
| 1937 | 2,072 | 1952 | 4,252 | 1967 | 3,315 |
| 1938 | 2,700 | 1953 | 4,394 | 1968 | 4,222 |
| 1939 | 2,967 | 1954 | 5,232 | 1969 | 4,473 |
| 1940 | 3,517 | 1955 | 4,587 | 1970 | 4,158 |
| 1941 | 3,460 | 1956 | 4,051 | | |

Source: California Department of Fish and Game (1971).

[a]No hunting reported to the Department of Fish and Game in 1943 for Mendocino County.

# APPENDIX B

# PROCEDURES USED IN DEVELOPING INPUT DATA

## Initial Estimate of Deer Numbers

It was necessary to reconstruct the performance of the population in the county and at the Hopland Field Station for a number of years to determine the particular hunting strategy which has been carried out. Part of this reconstruction involved determination of the mean total population on November 1 for the past several years. Average deer numbers in Mendocino County during 1958-68 on November 1 were calculated by assuming that 25 percent of the legal bucks are killed by hunters each year and that the reported kill equals two-thirds 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 population composition counts are made. The population 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 by graphic methods. The total population was estimated to include about 200,000 deer on November 1.

## Birth Rate Schedules

Fetal examination data at 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. These were yearlings, two year olds, three to seven 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 biological theory of the effects of forage competition on ovulation rates, the expected productivity at greater and lesser densities was estimated. The functions provide for productivity in young does to be affected more by density changes than productivity in prime and old does, which is consistent with available information.

## Mortality Schedules

To produce these data it was necessary to construct a paper and pencil model of the average Mendocino County deer population during recent years. Because deer population data for the county as a whole are relatively limited, a preliminary model was first made for the Hopland Field Station. The Hopland model includes average estimates of deer in four sex and age classes at four seasons of the year during 1964-66 (Appendix Table B. 1). These estimates, calculated from population composition, hunter kill, carcass examination, trapping, 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 are accurately determined. The computations are given in detail by Connolly (1970). This model was expanded by additional calculations to provide estimates for each month of the year of fawns, bucks in the second, third to seventh, and seventh plus age categories, and does in the second, third to seventh, and seventh plus age categories.

Careful examination of available data revealed that the deer population at Hopland differs from the overall Mendocino County deer population in a number of ways: The Hopland population exhibits higher

Appendix Table B. 1. Average numbers of deer on the Hopland Field Station, 1964-1966.

| Class of deer | 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 per sq. mi. | 95 | 88 | 77 | 61 |

fawn survival, lower average age, greater density, lower legal buck to doe ratios, higher spike buck to doe ratios, and heavier hunting pressure than the county population 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 population as described above was used to produce 84 natural mortality curves (seven sex and age classes for 12 months). The sex and age categories are fawns, yearling does, yearling bucks, adult does and bucks (deer in their third to seventh years), and old does and bucks (deer over seven years old). The paper and pencil model indicated that 5.3 percent of the yearling does present on February 1 die 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.

## Exponential Average Density

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

## Sex Ratio of Fawns at One Year of Age

The model separates fawns into males and females at 12 months of age. The sex ratio at birth appears to be about 120 males to 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 40 males to 60 females is used in most runs to date.

## Probability Distribution of Poor, Below Average, Above Average, 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 are relatively limited, the April fawn to doe ratio taken annually on the Hopland Field Station during 1957 to 1969 was used to estimate this variability. The average value for these 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 determined. Considering the classes to correspond with poor, below average, average, above average, and excellent forage conditions, the probability of the conditions was estimated to 1/13, 3/13, 4/13, 3/13, and 2/13 respectively.

## "Forage Factor" Corrections for Mortality and Natality

The basic principles of the forage factor corrections are:

1. In average forage years no corrections are made.
2. In response to forage conditions above or below average, mortality is below or above average and natality is above or below average, respectively.
3. Year-to-year variations in mortality in response to forage conditions are greatest among fawns, less in yearlings and old (in eighth year and older) deer, and least among prime (in third to seventh years) animals.
4. Annual variations in natality in response to forage conditions is greatest among yearling does and least in prime does.

The forage correction factors are 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, below average, average, above average, and excellent years, respectively. Initially, fawn mortality in above average years was specified as 50/30 = 1.67 times as great as in the average year; in an above average year mortality was specified as 50/70 = 0.71 times as great as in the average year.

Values for the other forage categories are 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 show 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 percent to 110 percent of average values among yearlings and 70 percent to 120 percent for the does in the fourth to seventh years. Values for does in the second year and eighth plus year classes are intermediate.

# APPENDIX C

## ILLUSTRATION OF POSSIBLE BENEFIT-COST CALCULATIONS FOR COMPARISON OF HUNTING STRATEGIES

Illustrated below are a set of definitions, assumptions, and calculations which might be made for a benefit-cost comparison of two or more hunting strategies. The comparison here is based on the results for Run 2 and Run 7 in Table 4.1. Run 2 approximates to the current strategy in Mendocino County. In Run 2, 25 percent of the bucks with at least a forked antler (or legal bucks) are taken by hunting in August and September each year. No antlerless deer can legally be taken under the current regulations. In Run 7, 25 percent of the legal bucks are taken in August and September each year, and in addition, an antlerless deer hunt is held in November where 15 percent of the does and 5 percent each of the spike bucks and fawns are taken by hunting. The benefits and costs, in dollar terms, are based on those presented in Chapter II.

### Assumptions and Definitions

1. Legal game are those deer which can be taken by hunting as given in the hunting regulations.
2. In Run 2, bucks with at least a forked antler are legal game in August and September (defined as legal bucks). In Run 7, bucks with at least a forked antler are legal game in August and September and antlerless deer (does, spike bucks, and fawns) are legal game in November each year.
3. Deer taken by hunting which are not legal game comprise the unreported kill.

4. The reported kill is the number of legal game taken less a 10 percent allowance for cripple losses.
5. The total kill is the sum of the reported kill, the unreported kill, and an allowance for cripple losses.
6. Benefits deriving from the deer population are consumptive and non-consumptive.
7. The consumptive benefits are calculated only for the reported kill.
8. The consumptive benefits include the value of the hunting experience, the value of the hide, the value of the venison, and the costs of cutting and wrapping the venison.
9. The value of the hunting experience is $100.00 each for legal bucks and $50.00 each for all antlerless deer. For all deer, hides are valued at $1.25 each, and venison at $27.50 per deer. Cutting and wrapping is $8.75 per deer and this applies to 50 percent of the reported kill. These values give an average consumptive value for each legal buck of about $133.00, and an average consumptive value for each antlerless deer of about $83.00.
10. The nonconsumptive value of the deer population is the same in Run 2 and Run 7. The lower number of deer in Run 7 is compensated for by an improvement in the condition of the deer at the lower density.
11. Costs of deer damage to agricultural crops, including preventive measures, and reforestation are directly proportional to total deer numbers on November 1. Under the current strategy, the costs to agricultural crops amount to $73,000 annually. Costs to reforestation are currently $24,000 annually. Costs of damage to automobiles are also proportional to total deer numbers on November 1. These costs currently amount to $75,000 per year.

12. Costs of management are proportional to the total kill. Currently these costs are $50,000 per year.

13. The costs of parasites and diseases and competition for forage arising from the interaction of deer with domestic livestock are the same for Run 2 and Run 7.

The benefit-cost calculations in Appendix Table C. 1 are based on the above assumptions and definitions. Only those benefits and costs which are assumed to differ for the two strategies are included. Benefits and costs are rounded to the nearest thousand dollars.

Appendix Table C. 1. Benefit-cost calculations for comparison of two hunting strategies for the Mendocino County deer population.

| Parameter | Run 2 | Run 7 |
|---|---|---|
| November 1 total population | 192,977 | 171,761 |
| Total kill | 6,375 | 23,534 |
| Legal game | | |
| Legal bucks | 5,568 | 7,155 |
| Antlerless | 0 | 16,379 |
| Reported kill | | |
| Legal bucks | 5,011 | 6,439 |
| Antlerless | 0 | 14,741 |
| Benefits (dollars) | | |
| Consumptive | | |
| Legal bucks | 666,000 | 856,000 |
| Antlerless | 0 | 1,224,000 |
| Total benefits | 666,000 | 2,080,000 |

(Continued on next page)

Table C. 1. (Continued)

| Parameter | Run 2 | Run 7 |
| --- | --- | --- |
| Costs (dollars) | | |
| Agricultural crops | 73, 000 | 65, 000 |
| Reforestation | 24, 000 | 21, 000 |
| Automobiles | 75, 000 | 67, 000 |
| Management | 50, 000 | 185, 000 |
| Total costs | 222, 000 | 338, 000 |
| Total benefits - total costs | 444, 000 | 1, 742, 000 |