A MEASURE OF THE NATURAL POTENTIAL OF LAND FOR SUPPORTING DEER POPULATIONS

by

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INTRODUCTION

The white-tailed deer (Odocoileus virginianus) is a wildlife species valuable to society in four main ways (Dasmann 1964:6-8): recreational, esthetic, economic, and scientific. The white-tail supplies recreation almost nation-wide for hunters as well as for observers and photographers of nature and adds esthetic appeal to wildlands for campers, picknickers, and sightseers (Lime and Cushwa 1969). As a game animal, the white-tail plays a large role in the support of local economies of many areas located in regions of wildlife concentration. The sport of deer hunting also stimulates the economies of larger towns through hunter expenditures for arms, ammunition, and supplies. Wild populations of deer also afford opportunities for scientific studies of natural community interaction, aiding man in grasping a better understanding of the dynamics and balances in these communities.

The recreational and scientific values of the white-tail have not been quantified. Such social values are not as easy to evaluate as are the monetary returns by hunters to the commerce of a state. In New York State alone, the monetary value of the resident deer herd as a state asset is estimated at over 1.1 billion dollars (Ruhl 1956:328). However, such estimates of monetary value based on sales of hunting supplies and accommodations need to be evaluated against the costs and losses experienced by other land uses and wildlife. Such losses include the effects of deer populations on agricultural and forest crops as well as on highway accidents. The role deer play in all these areas will determine the net value of a herd to society.

In most states the number of hunters attempting to harvest deer has been increasing. However, as the intensity of hunting pressure increases in an area, the private landowners often become less willing to allow hunters access to their property (Kruzan and Harding 1970). The state, in its legal position as custodian of the publicly-owned game resource, can respond to increasing hunter demand in three ways. The first is to ignore the problem, letting the demand and supply come into natural equilibrium. The second and third alternatives, which may be used together, are to reduce the demand by educating hunters to be satisfied with smaller bag limits, or to increase the supply of game for the hunters.

Of these three alternatives the first is inappropriate in society today. With increasing populations and greater land use demands from many interest groups, wildlands need more and better management. The alternative of reducing demand will become more significant as population increases. However, the alternative of implementating demand-reduction policies needs to be dealt with by conservation educators and public relation specialists.

The alternative of increasing the supply of game to meet the increasing demand is the strategy most often thought of by game managers. There are four major means whereby the supply of game available for hunters can be increased. These means may be undertaken in any combination and are: (1) to enter into some form of cooperative agreement with the private landowners (Kruzan and Harding 1970; Swanson 1970); (2) to encourage the development of private shooting preserves; (3) to expand and intensify game management of publicly-owned lands

(Rasmussen and Doman 1947); or (4) to acquire more public land for hunters' use. The latter problem is the subject of this thesis.

Land acquisition is an important problem for public wildlife agencies. Acquisition affects land use practices as well as the economy of the wildland area. Management and use of the wildlands will change due to the nature of the ownership of the land. Public ownership of wildland may affect the economy by shifting the tax base of the political subdivisions and by drawing recreationists into the area.

Acquisition of land is an intra-agency problem as well. With limited funds, wildlife agency administrators need to decide if funds should be used for development of presently-owned land or for acquiring new real estate. To choose between these two alternatives, the administrator must determine which will give the greatest productivity per dollar expended. Another consideration, in light of present population increase, is that land is a basic resource and may not be available for acquisition in the near future. For these reasons criteria are needed for acquiring and developing land. It is necessary that these criteria be based on biological and sociological knowledge to allow estimation of the productivity of the land and effective utilization of that productivity by the public. This thesis specificly deals with evaluating the biological productivity of land, thus establishing a basic criteria for the land acquisition decision.

The productivity of a deer herd can be defined in several ways. The number of deer killed per season is one of the best established measures of productivity. However, as more stress is being placed on non-consumptive wildlife recreational activities, sighting of deer by the recreationist may become a more descriptive measure. In either case, the productivity of the herd is a function of the quantity of animals in the population, once other factors affecting the kills or sightings are defined. This productivity is also weighted to some extent by the quality of the animals in the herd as reflected in trophy value, meat quality, and appearance. The production unit of a wildlife species can then be defined as a quality-ranked interaction between man and the wildlife species which provides some product for man, be it sightings made, shots fired, animals harvested, or some other related unit.

Production from wildlife differs from agricultural crop and industrial production in that, generally, there may be some wildlife production under conditions of no management. Wildlife production which occurs in habitats not managed for wildlife is the natural production of the habitat. This natural production is unstable because, as succession changes the habitat, the suitability of the habitat changes for a species of wildlife. Wildlife management enables man to stabilize habitat conditions so that wildlife populations can be stabilized. Some management practices, such as fertilization, allow increases in wildlife production beyond the natural productivity of the land. Wildlife management, then, allows changes to be made in the natural production from a habitat unit. The wildlife production caused by management projects which alter the habitat by habitat amelioration (fertilizing, feeding, etc.) or by altering the stage or rate of succession (burning, chaining, planting, etc.), thereby causing greater wildlife production than could be expected without such projects, is here termed the managed production.

Since wildlife production is composed of two types of production, natural and managed, each differing in the degree of management involvement, consideration of the relative returns of each type of production is important in order to relate them to the demand placed on wildlife resources by society. If a wildlife species' natural production in a habitat is sufficient to meet the expected recreational or other user demand on that area, any money expended to achieve a managed production increment will be wasted. There would be more animals available for the production of recreation but too few people to utilize the opportunities sufficiently to make the management expenditures worthwhile. Lobdell (1972) at Virginia Polytechnic Institute and State University developed criteria for optimizing the development of the managed production. The problem remains, however, of evaluating the potential natural production of deer from a habitat, the theoretical production which might be realized if constraints such as predators, parasites, and poachers, as well as fluctuations in weather, forage production, and hunting pressure, etc., were eliminated. As mentioned previously, production from wildlife species is partially a function of quantity of animals present. Since the effect that other variables have on production have not been quantified, the best first approximation may be made by concentrating on the animal density which is a direct function of the land unit itself.

The development of this hypothesis is theoretical, geared to elaborating the concept of potential. Many of the wildlife population constraining factors listed can be modified by management investment. Those that cannot, are stochastic, not usually under the influence of man, and represent the major dimension of uncertainty in the allocation decision.

One factor in evaluating the animal density that can be stabilized on a unit of land is the energy environment of the animal population there. Energy is the basic medium of exchange in the existence of an organism. It is analogous to the dollar in economics. If an organism does not receive enough energy from its habitat to balance the energy requirements for living in the habitat, it will not survive. A population of animals living in a poor habitat has relatively little energy income compared to energy expense just as people living in the ghetto have low dollar income compared to dollar expense.

The knowledge of basic energy exchange may allow managers to make comparisons between areas based on estimated potentials. Such comparisons would be based on metabolizable energy available to animals from forage and the energy expense for living in each thermal-activity environment. Partitioning the energy dynamics of the animal-environment relationship may make it possible to evaluate the relative cost of providing energy for deer production by different development projects or by acquiring different land areas. In addition, the comparative long-term efficiency of useful energy produced per dollar invested for acquisition and development may be better evaluated.

The purpose of this project was to develop a model which would incorporate the major environmental parameters which affect deer and show how these parameters and the deer interact to cause fluctuation in the balance of energy flow through the deer population. The second objective was to develop that model into a system for evaluating the potential deer productivity of different land areas.

LITERATURE REVIEW

Interest in the bioenergetics of ecosystems is a recent development springing largely from the work of Lindeman (1942), Odum (1956), Slobodkin (1960), and others. The concepts of bioenergetics have held little interest to those in wildlife management until recently. These early studies were largely theoretical and dealt with lower organisms and classically experimental populations. Recently, however, the relationships between the concepts and applied management have been articulated in lectures by A. N. Moen at Cornell University, R. H. Giles, Jr. at Virginia Polytechnic Institute and State University, and others.

Moen (1966) presented the use of bioenergetic concepts in studying white-tailed deer behavior and habitat use. Moen also has in preparation a book discussing these concepts and their applications in wildlife management. Giles has a booklet in press (Virginia Agricultural Extension Service) containing several computer-generated tables relating to deer-energy requirements. Verme (1968) used bioenergetic concepts in developing a winter weather severity index for winter deer yards in Michigan. However, there is still a sparseness of research on the bioenergetics of the larger wild animals. Such studies are limited by their inherent difficulty and expense.

In this day of cybernetics, mathematical modeling adaptable to computer use is gaining a strong foot-hold in the field of natural resource management. There are abundant applications of modeling in the literature. Modeling and computer simulation are often used where destructive sampling would adversely alter the population studied, where costs are prohibitive, where experimental controls cannot be feasibly obtained, or where the theoretical limits of a system are sought.

A comprehensive review of modern computer simulation techniques is available in references by Churchman et al. (1957) and Naylor et al. (1966). General coverage of modeling in ecology and natural resource management has been provided by Watt (1968). The simulation of the management of white-tailed deer herds by means of computer has recently been explored by Hayne (1969) and Riffe (1970). Smart's (1970) work on a rabies simulation represents a local application of modeling on wildlife populations. Mechler (1970) developed mathematical models for predicting county deer harvests which have been applied locally in a simulation mode.

This study unites the development of ecological bioenergetics and modeling in an application of importance. There is currently a great interest in the use, disposition of, and acquisition of public lands (Aspinall 1970). The Federal Aid in Wildlife Restoration Act of 1937 provides for land acquisition for wildlife purposes. Between the years 1939 and 1967, $284.6 million were obligated to projects under the Federal Aid in Wildlife Restoration Act (USDI 1968). Of this amount, 19.2% was for land acquisition and 50.7% for development. Proper allocation of these Federal Aid funds for maximum effectiveness is a major concern.

Most wildlife agencies seek maximum effectiveness but the concept is complex and the methods for determining such effectiveness are difficult to apply. Maximum effectiveness of allocating funds may best be described as decision-making to select projects which will, over a specified time period, provide the greatest return of product (recreation hours, harvested deer, or other measures or groups of measures) per dollar expended for initial cost and cost of required development and maintenance. The *a priori* hypothesis is that the lands to acquire are those that best provide thermal-forage energy regimes of maximum opportunities to the largest number of target species. The success or productivity of a species is determined by the balance of the energy dynamics of that species in a given habitat.

In this study, the target species considered is the white-tailed deer. This species was chosen for its importance nation-wide. The white-tailed deer is also ecologically prominent in most seral stages of many of the major North American biomes and is subject to management. Furthermore, there is a substantial literature on the biology and ecology of deer which is required for successful, useful modeling to be accomplished.

The major dimension of this problem is the modeling of the energy dynamics between a deer population and its habitat. The land acquisition problem, its rationale, and history are described by Susan Rayburn (1972). The economic considerations of this project are relatively simplistic and limited to an evaluation of cost of a unit of favorable energy balance for deer on an area of land.

Energy Systems in Wildlife Populations

The energy dynamics between an animal and its habitat are a function of the animal's biology and ethology and the physical environment available to the animal. This energy system can be analyzed as a system of inputs and outputs, which, if in balance, can sustain life. Once analyzed structurally, the components of the system must be quantified.

Energy Outputs

The basic outputs, or animal requirements for energy, are those for maintaining basal metabolism, stabilizing body temperature, and making body movements. Environmental conditions, particularly wind, temperature and snow conditions, influence these requirements. Blaxter (1962) discussed these environmental variables and their influence on the energy dynamics of domestic ruminants. Gates (1970) developed a model for the thermal parameters which predict the thermal environmental extremes in which an animal can survive. However, this model is not very useful for evaluating the energy expenditures of animals in the normal range of thermal environments. Moen (1963a) presented a model of the thermal energy exchange between a deer and its environment. This model is of use in evaluating the energy output by deer in maintaining body temperature under a given set of thermal conditions.

Habitat Influence on Energy Dynamics of Wildlife

The habitat influences the energy output of an animal through its influence on wind, radiation, and snow accumulation and interactively through its influence on the behavior of the animal. Geiger (1965) and Sellers (1965) discussed the effect of plant canopies on wind flow and radiation near the ground. Moen and Evans (1971) also discussed the effect of wind-breaks on wind flow in deer habitat. They pointed out that the movement of air causing heat loss from the deer's body is not the same as that measured at a weather station, due to the air flow in vertical turbulence patterns.

Lull and Relgner (1967) measured the radiation flux into mature oak and pine stands in New Jersey. Their study showed that during the growing season oak and pine stands respectively transmitted 53 and 73% of the radiation (total of shortwave, visible and longwave radiation) received in an open field. During the dormant season these stands transmitted 76 and 70% of the open field radiation. Moen (1968b) and Moen and Evans (1971) discussed the effect of winter night-time air temperature on the infrared radiation from different cover types and in the open. They presented regression equations of field data on this relationship.

Moen and Evans (1971) discussed the relation of environment to the accumulation and condition of snow packs in deer habitat. Kelsall and Prescott (1971) reported on the effect of snow density on the depth deer sink into the snow pack. Deer sank 87% of the snow pack depth when the snow density was 0.10 to 0.19 g/cc and only 47% when the density increased to 0.40 to 0.49. Verme (1968) discussed a device used for estimating the density of snow. This method consisted of a weighted pipe dropped into the snow from a standard height. This technique gave close correlation with observed sinking of deer into the snow.

Kelsall and Telfer (1971) discussed the physical adaptations of big game species for snow. Their results gave theoretical credence to the results Verme obtained. The basis for the close correlation between the measures of snow condition is that the load of weight to surface area is similar between the deer foot load and the pipe surface load on the snow. Kelsall and Telfer also found that the foot load on female elk was less than for male elk. This would compensate to some extent for the lower chest height in females when traveling through harder snow packs. Such compensation is likely to be comparable to differences between sexes in the white-tailed deer.

Rongstand and Tester (1969) reported on a study of the behavior of deer in Minnesota and found a close relationship between snow accumulation and cover type used by deer. They observed an increase in the use of cedar lowland cover with snow depths over 10 inches. Kelsall and Prescott (1971) observed that deer moved to lower elevations (less deep snow condition) in maritime Canada when snow accumulation exceeded 8 inches. Gilbert et al. (1970) correlated changes in deer concentrations with snow depth approaching 20 inches. This is the depth at which deer have extreme difficulty in moving through an unbroken snow pack of low density and is related to the chest height of mature deer (Kelsall and Prescott 1971; Kelsall and Telfer 1971). The difference between these two classes of snow depth behavior is probably related to the degree of difficulty of movement confronting the deer. At the 10 inch depth, deer may be more variable in their response due to the lesser hinderance to their movement than would be caused by a 20 inch snow pack. Also, at the lower snow depth, deer are not forced to concentrate in heavy cover although they are hindered in moving, while a 20 inch snow forces them to the areas of lesser snow depth.

Energy Inputs

To gain energy needed to balance the above outputs, the animal must expend energy. This energy expense occurs in moving to feeding areas, feeding, and escaping from danger. The energy gains are a function of the food habits of the animal and the metabolizable energy in the ingested forage (Crampton and Harris 1969). The energy to meet primary needs must be furnished before energy can be used for growth, reproduction or lactation (Blaxter 1962; Crampton and Harris 1969).

Forage Utilization

Many authors have discussed the importance of food for wildlife. No doubt the number of forage surveys conducted over North America runs into the thousands. However, a large proportion of the forage research reported in the literature is restricted to woody browse. Research on foraging habits of deer should warn against such unbalanced research programs. Petrides (1941) reported that white-tailed deer in New York foraged on succulent plants, using woody browse little before the accumulation of snow. Kirkpatrick et al. (1969) studied the seasonal changes in the rumen contents of deer in the Southeast. They found that woody stems and buds constituted 1.5, 5.2, 6.3, and 9.1 percent of the spring, summer, fall, and winter rumen contents respectively. Whelan et al. (1971) reported a large utilization of green leaves and flowers (88%) in the spring diet of lead deer in western Virginia. From studies such as these, it is apparent that more consideration needs to be given the study of forage types other than browse.

Forage Availability

Measures of forage production for wildlife management planning should account for the production of available forage by forage types. The available forage is that portion of the growth of plants in the habitat which may be utilized by wildlife without detriment to the growth of the plants in subsequent years or to other management goals desired on the area. The concept of availability must include the total management plans for the area and the interaction of different animal species with each other and the plant growth. The estimation of forage production by forage class type (browse, grass, herbs, mast, etc.) further allows the change in available forage to be evaluated over the season. Duvendeck (1964) outlined such a system for mast production. In the case of mast, 100% of the gross production could be consumed without hurting the growth of the mast-producing plants, yet only 10% is actually available to the deer due to insect destruction and competition with other animals (Duvendeck 1962). Coblentz (1970) reported that snow accumulation greater than 3 inches resulted in elimination of use of forage types other than browse. Before the snow, browse had constituted only 37% of the forage consumed.

Emphasis here is placed on production of available forage. This is the only managerially functional concept, except for one that incorporates the aspects of game theory, involving a play against nature and the deer population. The game theory dimension and decision-making under conditions of uncertainty are not incorporated here. Morgan (1971) discussed the making of decisions under conditions of uncertainty by state fish and wildlife agencies.

The concept presented in this thesis is one of habitat potential, a limit to populations as well as an upper criterion for managerial performance and budget allocation. Variable phenomena like hunting season kills or weather may cause available forage to be under-utilized or over-utilized. If this occurs, it does not make the manager "wrong" but simply may explain why the available forage was not utilized as expected and may provide suggestions for alternative managerial strategies to achieve better utilization of available forage.

A measure of available forage production can provide a meaningful estimate of energy inputs for management planning.

Forage Energy

The actual energy input per individual animal in a population from a forage supply is dependent on intake and digestibility of the forage. Digestibility studies are common for domestic animals (Crampton and Harris 1969) but not for deer, which are more difficult to maintain for such study. Forbes et al. (1941) studied the digestive capacity of deer and concluded that the digestive efficiency of deer is of the same order as that of domestic ruminants. However, Short (1966) concluded that for digesting cellulose, cattle are more efficient than deer.

Ullrey et al. (1964) and Ullrey et al. (1968) studied the difference in digestibility between cedar, aspen and balsam browse in an effort to evaluate the value of the browse species as winter food for deer. However, the results were very variable. Snider (1971) reported the *in vitro* digestibility of forage used by deer in Missouri. Observations of deer rumen contents served as the basis for selecting from the field forage samples on which *in vitro* digestion trials were conducted. He found organic matter digestibility of forage classes as follows: forbs, 53.6%; fruits, 44.5%; leaves of woody species, 36.1%; and twigs, 25.2%. Whelan (1971) reported *in vitro* digestibilities of diets selected by lead deer in Virginia. Whelan's results were similar to those calculated by Snider.

Succession

For the continuance of good deer hunting on an area, management plans must be made to keep a desirable habitat mixture about constant, though each sub-area may change with time. Grange (1949) expounded on the inter-relationship between plant succession and game production. Giles and Snyder (1970) discussed a means to achieve such a stable forage production on western ranges. With this system a game manager can simulate various management techniques and predict the effect that management will have on the deer herds of the area in the future. In order to achieve a stable, balanced habitat mixture, information is needed on the effect of management practices on the succession of forest types.

This thesis presents a model of the effect habitat, climate, and forage availability have on the energy inputs and outputs of a deer herd. The model integrates the relationship between these variables over the seasons of the year. From such a model, estimates of the balance of energy input and output can be made. These estimates provide insight into the magnitude and nature of energy available for the potential production of deer. By use of the Giles-Snyder technique of successional projection, these estimates of energy balance (energy available for the potential production of deer) are projected into the future.

TECHNIQUES AND PROCEDURES

This study is based entirely on work reported in the literature. The literature of deer ecology was studied, emphasizing behavior; food habits; measures of forage quality; nutritional requirements; deer-environment energy exchange; effects of altitude, aspect, and exposure on vegetation and energy exchange; and the changes in vegetation associated with ecological succession.

After an initial, general study of the literature, the ecological variables that were to be considered in evaluating the potential of an area for deer production were identified. The variables so identified were those which are known to have a major influence on the animal-environment energy exchange and which can be measured readily and inexpensively on a unit of land. Fig. 1 outlines the approach taken in the development of the land evaluation model. This development will be followed in the text.

First, a list was prepared of the ecological variables identified from the literature. Then a study of previously reported bioenergetic models (Moen 1968a; Gates 1970) was undertaken. The listed variables were subsequently compared in light of these models to evaluate their importance and their interactions in the energy dynamics of the white-tailed deer.

It was necessary that some variables be dropped from further consideration due to limited information on their energy value to deer. Other variables were also dropped due to the complexity and cost of data collection which has limited their measurement on lands already owned and managed by game agencies.

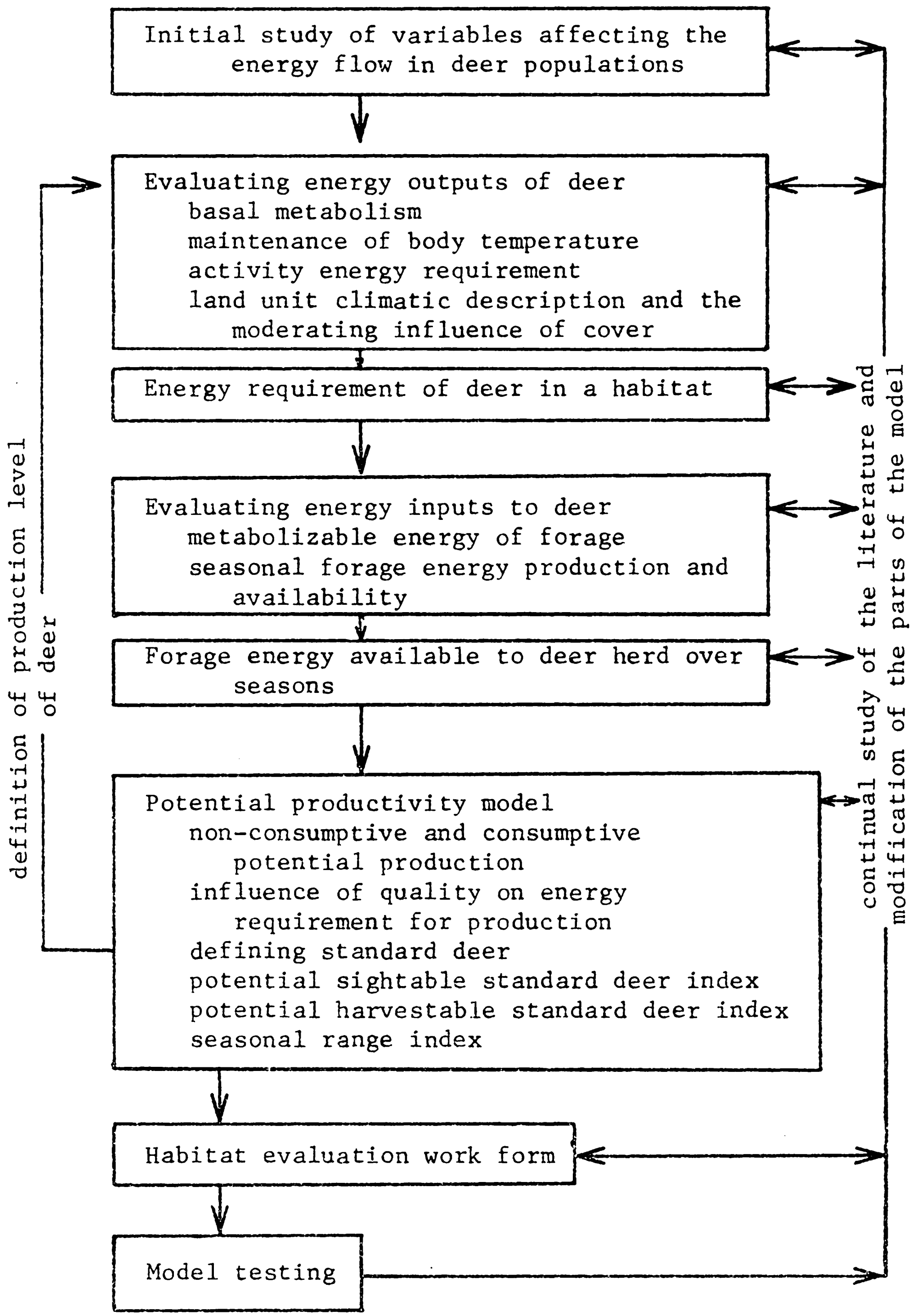

Fig. 1. Flow chart of the development of the potential biological productivity land evaluation model.

A mathematical model was constructed for determining the availability of energy on a land unit, usable by a deer population for production. Finally, a heuristic computer model was built for evaluating the variables which were identified as having a strong influence on the energy available to deer. This model takes the data supplied by a land evaluator describing the basic properties of a unit of land and converts them into indices of energy potentially available to deer for conversion into production useful to man. The computer model was written in Fortran IV and run on an IBM Model 370 computer at the Virginia Polytechnic Institute and State University.

A work form was prepared for evaluating the potential of a tract of land for deer productivity. This form furnishes the needed inputs for the above computer program to evaluate the tract.

Variables Influencing the Energy Flow of a Deer Population

The factors which were identified as affecting the potential productivity of an area of land, by influencing the energy flow of deer in the habitat, are presented in Table 1. Potential productivity of a deer herd may be conceptualized as the production achieved when all the energy which is available for conversion, is converted into some form of product for man. The energy available for conversion into recreation is a function of the total energy available to a population of animals and the energy required by those animals for normal maintenance in that habitat.

Such energy might be measured as the energy required for achieving a given probability of sighting a deer feeding in spring, for producing a harvested animal, for generating a quality-ranked man-hour of

Table 1. Factors which are of major importance in affecting the productivity of a deer population.

Habitat Factors	
	Food production
	Cover availability
	Habitat interspersion
	Topography
	Soils
	Climate
	Parasites available
	Nuisance insects
Population Factors	
	Sex ratio
	Age ratio
	Natality
	Mortality
	Disease
	Parasite load
	Behavior of subspecies
	Endocrine balance and fluctuation
Management factors	
	Management of habitat
	Management of harvest

recreation from a particular deer population, or for a combination of these and other measures. The factors listed in Table 1 influence the energy available for production by causing variation in the energy required by a population for living in the habitat or by causing variation in the energy available to the population in forage. The individual factors will be discussed in relation to their influence on the inputs and outputs of energy from the deer-habitat energy system.

This research deals with the habitat factors which affect the natural potential of land for producing deer. Therefore, the population factors and management factors will not be discussed in detail. Simply, once a unit of land is identified, the management of that unit will determine how a deer population interacts with the physical and biotic environment to attain some level of productivity. The optimum management of the habitat and population might be defined as that cost-effective management which allows the population to reach and stabilize a net productivity (natural plus managed) equal to the demand placed on the habitat and population by society. This is to be maintained over time and at the least cost.

Habitat Factors Not Considered

Of the nine habitat factors listed in Table 1, parasites available, nuisance insects, and predators will not be considered in land evaluation for the following reasons. Due to the interaction of nutritional level on susceptibility to parasites and the complications of determining a population's actual parasite load, it was considered that this factor should be omitted. In some areas available parasites will affect the productivity of the population, as in the case of lone star ticks in

Oklahoma (Bolte et al. 1970). More important is the parasite load on the population which affects the energy drain from the population. Nuisance insects are known to influence the behavior of deer and thereby their energy drain. However, due to the difficulty in quantifying the magnitude of this drain, and the infeasibility of doing so on lands simply under consideration for acquisition, it was considered best to omit it.

Predators, other than dogs and poachers, do not appear to have large effects on huntable deer populations in most areas (Cain 1972: 191-194). This is in part due to the low population level of natural deer predators in most areas. In addition to the low predator densities, Mech and Frenzel (1971) found that wolves killed deer which hunters were least successful in harvesting. Deer over 5-1/2 years old constituted 48% of wolf kills but only 10% of hunter kills. Therefore, many of the deer killed by wolves are of ages not normally harvested by hunters. Poachers may have substantial effects on deer mortality, as indicated by the work of Vilkitis (1971). In some areas, domestic dogs are blamed for high rates of deer mortality. However, there is some question as to the significance of dogs in influencing deer populations (Perry and Giles 1970). The sociological relations of these losses need to be considered more before a quantitative measure of them can be made.

Deer-Habitat Energy System

As discussed previously, the dynamic energy system existing between a deer population and its habitat can be visualized as a system of inputs and outputs. The inputs and outputs are measured in units of energy. Energy inputs are the energy received by a deer population from the habitat. This is used to meet the needs of the deer's energy outputs. Energy output from the population is the energy expended by the population for maintaining the basal metabolism of the body; for maintaining the body temperature; for use by the animals for activity; and for the production of replacements for exhausted or shed body tissue.

In the development of this model, the energy system is partitioned into three subunits. These divisions are: (1) energy requirements for sustaining the basic needs of deer in a given habitat (energy outputs); (2) energy available to the deer from the habitat, through forage (energy inputs); and (3) the balance of the energy outputs and inputs over the seasons (potential productivity energy model). The development of these three units of the total model and how they relate to each other will be discussed in the following sections. The computer program of the model is in Appendix Table 1.

Energy Outputs of Deer

Basal Metabolism

Silver et al. (1969) reported major differences in fasting metabolic rate (FMR) of deer in summer and winter coats. These metabolic rates were:

52.2 Kcal/kg/24 hr   Summer coat

33.8 Kcal/kg/24 hr   Winter coat

In many cases metabolic rate is defined on the basis of metabolic size of an animal ($w^{0.75}$). However, in agreement with Silver, metabolic rate is here expressed as a function of weight. Silver (1969:493) stated: "A large difference in FMR of deer in summer and winter coats tends to override the differences attributable to size. . . The data show only a slight tendency for higher heat production per unit of weight in deer of smaller size. . . Metabolic rate is, therefore, perhaps more realistically expressed as heat production per unit of weight." Furthermore, when I compared Mrs. Silver's published data for adult deer by use of regression analysis, the equation for FMR as a function of body weight had a smaller residual mean square than did the equation using metabolic size. The correlation coefficient (R) for winter coats was 0.70 and that for summer coats was 0.82 (rounded to two decimal places), when metabolic rate was expressed as a function of body weight or metabolic size.

The energy requirement for basal metabolism is a constant minimum energy requirement. Though this energy can be used in maintaining body temperature at low ambient temperatures, other energy requirements are additive to this one.

<u>Maintenance of Body Temperature</u>

Moen (1968a) summarized the relationship between the deer in thermal equilibrium and the thermal environment as:

$$H_n + H_e = H_m \pm H_s \quad (1)$$

Where H_n = net heat exchange by radiation, conduction and convection

H_e = heat lost by surface and respiratory evaporation

H_m = heat produced by metabolic processes

H_s = heat storage change in body.

This thermal energy exchange between the deer and its environment can be partitioned into the various components by the following three equations (Moen 1968a). These are respectively the thermal energy losses by radiation, conduction, and convection.

Radiant Energy Exchange

Radiation, the transfer of energy in waves propagated as a result of movement of molecules and atoms, is dependent on the effective surface temperature of the deer and surface area participating in radiative heat loss (the radiation profile). The effective surface temperature itself is a function of the movement of heat from the body core to the radiative surface (Blaxter 1962:124) and of the temperature and air flow across the radiative surface (Stevens and Moen 1971) and radiation absorbed from the environment. The energy loss from an object by radiation is expressed as:

$$Q_r = E\sigma T \qquad (2)$$

Where Q_r = radiation flux in calories

E = emissivity of the surface

σ = Stefan-Boltzmann constant (4.93×10^{-8} Kcal m^{-2} hr^{-1} k^{-1})

T = temperature of the surface (K, or °C + 273.2).

The net radiation exchange is the difference between the radiant energy lost from the animal and that absorbed from the environment. The environmental radiation received is in the form of infrared radiation from the surrounding habitat and sky, and during the day, from shortwave and visible light radiation absorption. However, the absorption coefficient for visible light and shortwave radiation is not the same as for longwave infrared radiation. Infrared radiation is almost entirely absorbed by hair, which has an emissivity coefficient of approximately 1.0. The other wave lengths are more poorly absorbed. Blaxter (1962:160) reported emissivities in the solar radiation wave lengths as being

0.78 and 0.83 for coats of red cattle.

Gates (1970) and Moen (1968a) implied that environmental radiation, once absorbed, is entirely useful to the deer. However, due to the insulative effect of the coat, much of this energy is immediately re-radiated or conducted back to the habitat. This was accounted for by Moen in his discussion of net radiation. Blaxter (1962:161) discussed the actual energy gained from solar radiation by sheep. For a sheep with a 4 cm fleece in still, humid air, the heat absorbed through the hair coat is approximately one-tenth (0.09) of the radiation absorbed at the fleece surface. With a slight breeze (300 ft/min), this value falls by half, to about one-twentieth (0.04). These estimates were made at 32°C. For deer in winter thermal conditions, these values would likely be lower, due to greater convection in the colder air (see equation 4). Stevens and Moen (1970) also showed evidence for this occurrence. Since Moen's model does not contain a term for estimating the net radiation from an animal's surface, it was decided to use the lower value of 4% of the radiant energy absorbed at the surface to partially account for lower temperatures and air flow in the deer's habitat.

Conductive Energy Exchange

Conductive heat transfer is accomplished by collisions between oscillating molecules, transferring energy. As equation 3 shows, this energy transfer is a function of the conducting surface area and the temperature gradient between the surfaces participating in the exchange. Thus a deer standing would conduct heat to the ground only through the hooves while a bedded deer would conduct heat through a much larger surface area. The energy loss from a body by conduction is expressed as:

$$Q_c = K\ A\ \Delta T/D \quad (3)$$

Where Q_c = calories of heat conducted

K = thermal conductivity coefficient

A = area

ΔT = temperature difference between the two surfaces (°C)

D = distance between the two surfaces.

At present, little information has been presented in the literature on the conductive characteristics of deer. Moen and his associates are studying these characteristics at Cornell University (Moen and Evans 1971). However, at this time, the conductive energy exchange portion of Moen's model will not be used. For purposes here, it is assumed that the deer is standing, conducting energy only through its feet to the ground. This small amount of energy is ignored.

Convective Energy Exchange

Convective heat transfer occurs when molecules move from one place to another. Equation 4 shows that aside from surface area exposed to convection and the temperature gradient between the convective surface and the fluid, convective heat loss is proportional to a convection coefficient. The value of this coefficient is dependent upon the size, shape, roughness, and orientation of the animal's surface. Moen approximated the convection coefficient for deer by using the coefficient for a 12 inch diameter cylinder from a table by Blaxter (1962:152). Convection coefficient values are given in Table 2. The energy loss from a body by convection is expressed by:

$$Q_h = H_c\ A\ \Delta T \quad (4)$$

Where Q_h = calories transferred by convection

Table 2. Effect of wind velocity on the convective heat loss from a 12 inch diameter cylinder (Blaxter 1962:152).

Wind velocity mph	Convective heat transfer Kcal m^{-2} $24h^{-1}$ c^{-1}
0.5	45
1.0	67
2.0	135
4.0	225
6.0	288
8.0	351
10.0	413
12.0	468

H_c = convection coefficient

A = area

ΔT = temperature difference between the surface of the convector and fluid (°C)

Thermal Model

Moen approximated the energy loss by a deer to its environment using the above equations and stated that this needs to be equal to the energy released by the animal's metabolism if that animal is to maintain a stable body temperature in any thermal environment. This relationship is expressed in the following equations:

$$E_d = E_m \tag{5}$$

$$E_d = S_r \, E \, \sigma \, T_s^{\,4} + S_t \, H_c \, \Delta T + I(T_b - T_a) + H_e \, S_t - S_r \, R_e \tag{6}$$

$$E_m = H_b \, H_f \, H_a \tag{7}$$

Where E_d = energy drain (loss) to the environment

E_m = energy released in the metabolic activity of the deer

S_r = radiation profile ($0.85s_t$

E = emissivity of deer hair

σ = Stefan-Boltzmann constant (4.93×10^{-8} Kcal m^{-2} hr^{-1} k^{-1})

T_s = surface temperature of deer

S_t = total surface area of deer

H_c = convection coefficient of the deer

ΔT = $T_s - T_a$ (°C)

I = mass of food ingested

T_b = body temperature (°C)

T_a = air temperature (°C)

H_e = evaporative heat loss

H_b = basal metabolic rate

H_f = heat increment for diet level

H_a = heat increment for activity

R_e = environmental radiation to the deer.

These equations are similar to those presented by Moen (1968a). Those values not defined or explained previously are explained in the following paragraphs.

Surface Temperature of Deer

Moen (1968b) has reported on the relationship between the air temperature and surface temperature of deer in still night air. He presented an equation which describes this relationship. This is:

$$Y = 6.559 + 0.944X \quad (8)$$

Where Y = surface temperature of the deer (°C)

X = temperature of the air (°C).

Stevens and Moen (1971) reported on studies made with a physical deer simulator exposed to different wind velocities. They reported a marked change in the surface temperature to air temperature relation as the wind velocity increased from 2 mph to 7 mph.

Total Surface Area of Deer

The surface area of the deer can be approximated from an equation reported by Moen (1968a):

$$Y = 0.879 + 0.016X \quad (9)$$

Where Y = total surface area (m^2)

X = weight of deer (kg).

Body Temperature

The average body temperature of white-tailed deer subjected to low temperatures in a respiratory chamber was reported by Silver (1971) to be 37.5°C.

Evaporative Heat Loss

Evaporative heat loss from deer has not been reported. However, in sheep (Blaxter et al. 1959) this energy loss can be reduced by the animal to 10.33 Kcal m^{-2} hr^{-1}, remaining fairly stable below 20°C. This is the value used by Moen in his calculations. Under hyperthermal conditions, sheep in air containing water vapor at a pressure of 20 mm Hg can lose up to 75 Kcal m^{-2} hr^{-1} of heat energy by evaporation of water from the respiratory tract and skin (Blaxter 1962:138). These extremes seem to set reasonable limits for consideration when studying the deer.

Heat Increment for Diet

The heat increment for dietary level (H_f) is that energy which is produced by the digestion and absorption of ingested food. This heat increment is energy not useful to the deer other than for maintaining body temperature. Blaxter (1962:141) tabulated the FMR of sheep at different dietary levels. From these values, the heat increments (ratio of dietary level to FMR) for fasting, maintenance, and full feed are respectively 1.00, 1.47, and 1.88.

Heat Increment for Activity

The heat increment for activity (H_a) is that energy which is produced by the animal's musculature in movement (standing, walking, running). Crampton and Harris (1969:151) gave the ratios of oxygen consumption while an animal is active to that while it is standing, as in Table 3. A similar ratio between standing and reclining in sheep and cattle is 1.1. If these ratios are expressed as the ratio of oxygen consumption at a given activity to the oxygen consumption in the lying position, they would be as in the lower half of Table 3. The energy requirement for activity, which is discussed later, will be used as the estimate of this parameter.

Use of the Thermal Model

This model of the energy exchange between the deer and its thermal environment can be used to predict the energy balance between a deer and its environment as was done by Moen (1968a). If the deer is in an environment where the energy loss (drain) as predicted by Equation 7 is greater than the energy production as predicted by Equation 8, then the metabolism of the deer would need to be increased to furnish the energy difference once a minimum body temperature is reached. On the other hand, in a hyperthermal situation, if Equation 7 predicts a value less than Equation 8, then heat loss by the deer must be increased by evaporation, panting, or posture once a maximum body temperature is reached. Both cases assume that the goal is maintenance of a relatively constant and narrow range of body temperature.

Moen's model of the flow of energy from deer forms the basis for determining the energy output from deer. The values used for temperature, wind flow, and radiation are supplied by other portions of the model, which alter the climatic description of the land unit. The climatic description of the land unit and how this input data is modified by habitat conditions to give an estimate of the effective climatic conditions on deer is discussed in a later section.

Table 3. Relative increase in the metabolic rate of domestic ruminants due to degree of activity (Adapted from Crampton and Harris 1969:151).

Increment expressed as an increase over the metabolic rate of the animal in the standing position	
Walking	2.0
Sustained heavy work (6-10 hr/day)	3.0-8.0
Maximum activity per day	20.0
Maximum energy during maximum brief effort	100.0
Increment expressed as an increase over the metabolic rate of the animal in the lying position	
Standing	1.1
Walking	2.2
Sustained heavy work (6-10 hr/day)	3.3-8.8
Maximum activity per day	22.0
Maximum energy during maximum brief effort	110.0

Activity Energy Requirement

Blaxter (1962:103-115) discussed the energy expended by sheep in body movement. These estimates of energy expense are those which could be used for estimates of deer energy expense since little is known of related values in deer. Since the basal metabolism and anatomy of sheep and deer are quite similar, it is believed that little difference will be found between these estimates and measurements made with deer.

As mentioned previously, when an animal makes body movements there is heat energy released which may be used to maintain body temperature or which must be dissipated to the environment. The energy required by sheep for making horizontal and vertical movements as reported by Blaxter (1962:108) are presented in Table 4. Blaxter (p. 109) summarized the difference between species as follows:

> ". . . Between species the energy cost of moving 1 kg of the body horizontally is fairly constant, declining slightly in the larger animals. The energy cost of vertical movement is also much the same in all species, and the efficiency of muscular work expressed in terms of work done per calorie of energy expended is about 30% in all."

Giving an example of sheep under range conditions, Blaxter estimated an increased energy requirement of only 20% above basal for movement. A similar estimate can be made for the minimum energy requirement for activity in deer. This is presented in Table 5. The minimum activity is estimated as follows: Marchington (1968) observed an average minimum total distance moved in 24 hr of about 2700 m in a

Table 4. Energy required by sheep in making horizontal and vertical movements (Blaxter 1962:108)

Speed of movement	Calories required to move 1 kg of sheep 1 m horizontally	Calories required to move 1 kg of sheep 1 m vertically	
		Gradient	
		1 in 22	1 in 11
24 m/min	0.61+/-0.10	5.1+/-1.3	4.4+/-1.3
48 m/min	0.69+/-0.10	6.4+/-1.3	5.4+/-1.3

Table 5. Estimate of minimal energy requirement for activity of a 50 kg deer in one day.*

Energy expense	Hours	Meters	Kcal
FMR	24	--	1690
Standing	15	--	103
Movement			
Horizontal	--	2700	82
Vertical	--	100	32
Total energy expended			1907
Increase over FMR			113%

* See text for discussion.

telemetry study. In hilly country a vertical movement of 100 m would be conservative. For our estimate, energy requirements for movement are from Table 4 for a velocity of 48 m/min and a gradient of 1 in 22. Standing requires approximately one-tenth of the FMR requirement (Table 3). FMR is calculated for a 50 kg deer in winter coat. Fifteen hours of standing were assumed, as Blaxter did for sheep.

The example for deer (Table 5) is comparable to what was reported by Blaxter. However, it should be noted that horizontal movement was minimal, since the study was conducted by telemetry. The distance moved depended on the time interval between radio locations of the deer (Heezer and Tester 1967). Also, due to differences in behavior during the season and between populations, the value could change.

At this time it may not be feasible to make separate estimates of the energy used by deer in moving through different habitats. Such an estimate using telemetry data is minimal, dependent on many factors, and would require much expense for pre-acquisition land appraisal. The alternative to the calculation of this energy requirement on different areas of land is to assume an average requirement for both areas.

Moen (1968a), concerned only with deer in a standing posture, used a correction factor of 1.1 times basal metabolism for estimating the energy required for activity. Moen's value is more comparable to the estimate herein (Table 5) than is Blaxter's value of 1.2. However, knowing that the estimate is minimal, it is believed that Blaxter's estimate would be more representative of natural conditions for deer. Therefore, the estimate of energy required by deer for activity will be 1.2 times basal metabolic rate, for snow-free conditions. Herein, this value is the maximum mean, daily activity energy production usable in maintaining body temperature.

Snow Influence on Activity Energy Requirement

As discussed in the literature review, deer change behavior patterns as the snow depth increases. The snow depths of 10 and 20 inches appear to be specific points of influence on deer behavior (Kelsall and Prescott 1971; Kelsall and Telfer 1971). Though there is no data on the energy requirement of animals in snow, a first approximation of this energy requirement can be made from this observed influence of snow on deer behavior and known energy requirements for different levels of work (Table 3).

Deer do not appear to encounter difficulty in moving through soft snow until it is about 10 inches deep. When the snow depth approaches 20 inches, deer encounter great difficulty in traveling off established trails. It is assumed that walking in snow up to 8 inches deep, requires 2.0 times the basal metabolic rate energy requirement. As the snow approaches 20 inches in depth, an energy requirement of 6 times basal metabolic rate is assumed. This value is the middle of the range of the energy required by an animal in sustained heavy work, as discussed earlier. From this, Fig. 2 can be constructed on the assumption that the change between these snow depth limits is linear.

This is a first approximation of energy required for walking in snow. However, as the snow depth increases, the distance of movement or the area in which movement occurs decreases, according to the observations or Rongstad and Tester (1969) and others.

Deer will lose more energy under snow conditions than under snow-

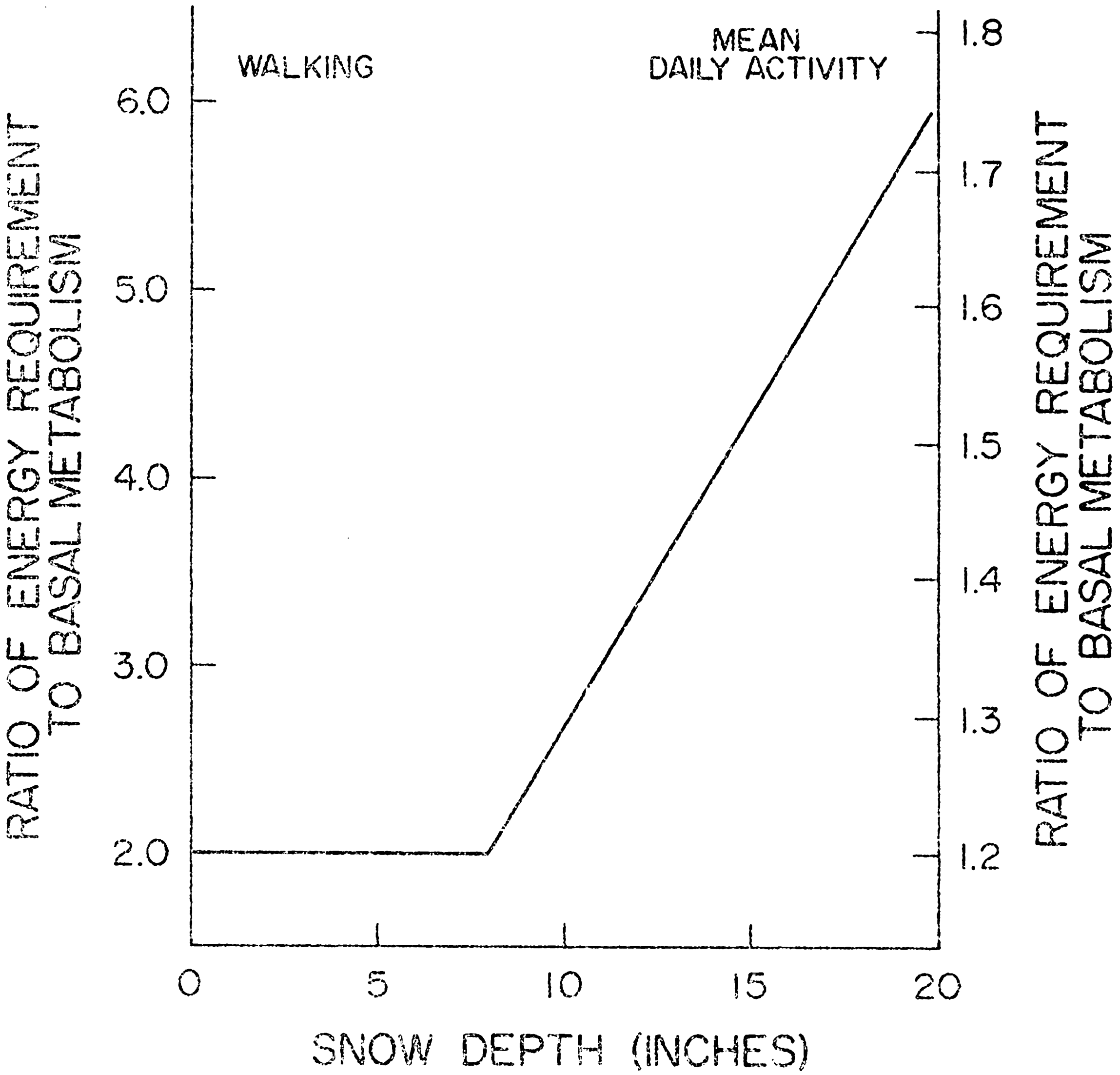

Fig. 2. Ratios of the estimated energy required by deer for walking in moderately dense snow and the energy required by deer for mean daily activity (defined in text) both compared to the energy required for basal metabolism.

free conditions. If the animal was to move about as much as normal, energy would be lost in a manner similar to that displayed in Fig. 2. If the animal reduces activity, thereby reducing energy expense, it does so at the expense of forage energy intake. The point at which it would be more profitable (energy-wise) for the deer to "hold up" would be where more energy is expended in moving than gained from ingested forage.

For the purposes of this model, it is assumed that the level of activity will be the same for snow-free and snow-pack conditions. This assumption, though not biologically descriptive, should give an estimate of the relative effect of snow-pack conditions on deer. The use of this assumption under-estimates the decrease in forage energy intake by the population and over-estimates the degree of activity of the population as the snow depth increases. Though the changes in these parameters are not likely to be linear, they will to some extent compensate for the lack of behavioral descriptiveness of the interaction.

Fig. 2 shows the estimated effect snow has on the instantaneous energy requirement for movement. The right-hand axis of Fig. 2 represents the effect the snow may have on the daily activity energy requirement. The daily energy requirement was obtained by using the above assumptions and calculations similar to those shown in Table 5.

The activity energy requirement of deer is predicted as described by Fig. 2 and data supplied on the snow conditions of the evaluated land area.

Land Unit Climatic Description

The seasonal climate of an area can be described in terms of the temperature, radiation, wind, and precipitation over that area. These factors have major impact on deer through the loss or gain of energy (Moen 1968a; Gates 1970). Verme (1968) reported on a weather severity index for deer in Michigan. In this study he measured five variables to estimate thermal flux. These variables were: temperature, wind, solar radiation, snow fall and relative humidity. In multiple regression analysis these variables accounted for 88% of the variation in air chill as measured by an instrument known as chillometer. (For further discussion of the chillometer, see Verme 1968). In terms of partial correlation coefficients, temperature and wind greatly affected heat loss. Solar radiation, snowfall and relative humidity were comparatively minor agents. However, since the chillometer was shielded, overhead effects of radiation and precipitation were appreciably reduced.

Moen's deer energy dynamics model integrates these climatic values for deer if the appropriate input data are available. The means of obtaining data for this model and how habitat factors modify the weather station climate are discussed below.

Temperature

The mean, monthly maximum and minimum temperature as observed at the nearest representative weather station are the input data for temperature conditions found on the appraised land unit. The use of these temperature data allows an accurate estimate of the mean temperature as well as the mean monthly extremes (U.S. Department of Agriculture 1941:690). These data are readily available and applicable for the model used. Ozoga (1968) reported that the mean temperature of different deer habitats was similar, only the range of temperature differing (Table 6). However, deer can change their effective mean temperature by using the

Table 6. Cover-type influence on winter microclimate in Michigan (Ozoga 1968).

Cover-type	Wind flow*	Mean Jan temperature(F) Max	Min	Mean snow depth (ft)	Mean sink in snow***
Open field	4552	25.5	3.9	1.71	.59
Conifer forest					
Sapling	373	23.9	3.2	2.42	.82
Pole	118	22.4	3.4	1.97	.60
Mature	22	23.3	6.2	1.33	.46
Hardwoods					
Mature	1262**	22.3	4.3	1.52	.67
Mixed woods					
Mature	631	23.0	3.8	1.79	.60

* Miles in 52 days.

** Estimated from text.

*** Feet to which a standard weight sank in the snow similar to the depth deer sank in the snow.

different habitats during different portions of the day. Therefore, an estimate of mean temperature conditions alone will not be sufficient. The use of the monthly mean extremes is used for this purpose of estimating the effective mean temperature on deer.

Radiation

Moen (1968b) reported the nighttime infrared radiation production from three cover types in relation to temperature. The cover type equations are:

Open field $Y = \sigma((-10.9 + 1.000X) + 273.0)^4$ (10)

Hardwood $Y = \sigma((-5.6 + 0.964X) + 273.0)^4$ (11)

Cedar $Y = \sigma((+0.2 + 0.962X) + 273.0)^4$ (12)

Where Y = infrared radiation (Kcal M^{-2} Hr^{-1})

X = air temperature (°C).

Moen and Evans (1971) reported further infrared radiation-air temperature relations for open field conditions derived from data extending over a wider range of air temperatures than used for the above equations. They also reported the outgoing ground radiation as well as the incoming radiation. Equation 13 describes the relationship between nighttime air temperature and incoming infrared radiation in Kcal m^{-2} hr^{-1}. Equation 14 is for outgoing radiation or the radiation from snow-covered ground in this case. These equations are used for predicting the infrared radiation in the deer habitat from the air temperature. Thus:

Incoming $Y = \sigma((-0.049 + 1.03X) + 273.2)^4$ (13)

Outgoing $Y = \sigma((-8.92 + 1.10X) + 273.2)^4$ (14)

Lull and Relgner (1967) studied the daytime radiation flux into mature oak and pine stands in New Jersey. The energy values measured are summarized in Table 7. Measurements of this nature will vary from place to place due to differences in cloudiness and latitude. However, the values reported by Lull and Relgner are a good approximation of the expected radiation coming into deer habitat. The values in Table 7 for shortwave and visible radiation are used herein to approximate the non-infrared radiation in the deer habitat. When land units within a small area are being compared, the difference between the radiation coming into a habitat type on the different areas should not be great.

<u>Wind</u>

Geiger (1965:312-314) has several graphs of wind flow through differing forest canopies. Diminuation of wind at 1 m above the ground to that of 2 m above the forest canopy ranged from 17% for a 65 year-old pine forest with an association of different age fir understory, to only 67% for a similar pine forest with no understory. It should be noted, though, that the wind speed at 2 m above the forest canopy is most likely less than the wind speed over an open field, due to the friction caused by the uneven canopy top.

Sellers (1965:149) presented an equation for predicting wind flow over land surfaces:

$$U = U'/K\ (\mathrm{Ln}\ Z/Z_0) \qquad (15)$$

Where U = wind velocity at height Z

U' = friction velocity

K = von Kormon constant (0.4)

Z = height in centimeters

Table 7. Mean daily incoming solar radiation in mature oak and pine stands in New Jersey (Lull and Relgner 1967).

	Energy flow in $Kcal/m^2/day$		
Season	Open	Oak	Pine
	Shortwave radiation		
Growing	5250	2050	3410
Dormant	3610	2780	2210
	Visible radiation		
Growing	5280	1020	2870
Dormant	3600	1970	1860
	Longwave radiation		
Growing	4430	4770	4530
Dormant	2690	2750	2890

Z_0 = roughness parameter of surface, the height at which velocity is zero.

Table 8 gives roughness length for various surfaces as reported by Sellers (1965:150).

Ozoga (1968) reported the effects different cover types used by deer have on the flow of wind. His results are presented in Table 6. The input used by the model herein developed is the mean monthly open field wind flow reported at the nearest representative weather station. These data are modified by the general observations of Geiger (1965) and Ozoga to estimate the wind flow through the various deer habitats. The equation of Sellers (1965) is used to estimate the wind flow at the height of deer in the open.

Moen and Evans (1971) discussed some of the limitations of wind flow predictions in deer habitat. The estimate used herein is a general mean wind flow and does not account for variations observed in the habitat due to blow-through, slope, exposure, vertical turbulence, or air movement due to thermal air drainage on otherwise still nights.

Precipitation

Precipitation directly influences the energy loss from an animal due to increased evaporative and conductive heat loss. This form of energy loss is not accounted for in this model. The energy loss due to precipitation in the form of snow as it affects energy cost for walking and degree of movement is considered, and is discussed elsewhere.

For a proper integration of the influence of climatic variables on the energy exchange of deer (besides knowing what effect the various cover types have on modifying the climate), it is necessary to know the

Table 8. Roughness lengths for various land surfaces (Sellers 1965:150).

Type of surface	H(cm)	Z_0(cm)
Fir forest	555	283
Citrus orchard	335	198
Large city (Tokyo)	-	165
Corn	300	-
$U_{5.2}$ = 35 cm/sec	-	127
$U_{5.2}$ = 198 cm/sec	-	71.5
Corn	200	-
$U_{4.0}$ = 29 cm/sec	-	84.5
$U_{4.0}$ = 212 cm/sec	-	74.2
Wheat	60	-
$U_{1.7}$ = 190 cm/sec	-	23.3
$U_{1.7}$ = 1384 cm/sec	-	22.0
Grass	60-70	-
$U_{2.0}$ = 148 cm/sec	-	15.4
$U_{2.0}$ = 1343 cm/sec	-	11.4
$U_{2.0}$ = 1622 cm/sec	-	8.0
	5-6	0.75
	4.0	0.14
	2.3	0.32
Alfalfa brome	15.2	-
$U_{2.0}$ = 260 cm/sec	-	2.72
$U_{2.0}$ = 2625 cm/sec	-	2.45
Smooth desert	-	0.03
Dry lake bed	-	0.003
Tarmac	-	0.002
Smooth mud flats	-	0.001

proportion of time the deer spends in the various cover types. The use of the various cover types will be dependent on factors such as forage supply in the cover types, psychological desire for a cover type (as during hunting season), protection from adverse weather conditions, ease of access to a cover type, and other variables. Most of these factors have not been studied quantitatively in relation to their influence on deer use of cover.

Moen (1966) observed that deer on a high plane of nutrition in Minnesota had a high resistance to adverse weather conditions. The population studied by Moen spent most of their time outside of forest cover, feeding on crop wastage, retreating to the forest only during severe storms. This was at a time when snow conditions reached 15 inches in undrifted areas. Rongstad and Tester (1969), on the other hand, found a closer relation than did Moen of the use of dense protective cover by deer due to snow accumulation during the winter in a population not able to feed on crop wastes. Table 9 presents the use of cover types as observed by these authors.

Due to the variability of cover types available and the effect of factors influencing changes, it is difficult to make a generalized statement of the percent of time spent by deer in various habitats. For the purposes of this model, the proportioning of habitat type use within a subunit of the unit being evaluated will be carried out on the basis of mean monthly snow depth. (If an entire portion of the area being evaluated is likely not to be used, this can be so indicated so that it is not considered as being available to the deer.) For a month having a mean snow depth equal to or greater than 10 inches, use of the

Table 9. Proportion of time spent by deer in various cover types in relation to snow depth (Adapted from Rongstad and Tester 1969).

Cover type	Snow depth (inches)			
	0-3	5-7	10-20	20-40
		Daytime		
Cedar lowland	44.	63.	73.	81.
Non-cedar lowland	21.	26.	21.	13.
Upland	35.	11.	6.	6.
		Nighttime		
Cedar lowland	17.	55.	70.	83.
Non-cedar lowland	17.	17.	20.	13.
Upland	66.	28.	10.	4.

most favorable cover available will be proportioned as observed by Rongstad and Tester (1969). During periods of light snow cover, the cover use is proportioned relative to the forage available in that cover type during that month. This is comparative to the general trend observed by Moen (1966) for deer on higher planes of nutrition. This trend may not hold for deer on lower quality diets since the deer would encounter unfavorable thermal microenvironments at temperatures higher and wind speeds lower than would deer on a higher plane of nutrition. However, as discussed in a following section, this model assumes that the model deer is managed so as to keep it on a maintenance diet.

Energy Input to Deer

Forage production is the only energy input considered in estimating the productivity of a deer herd. Moen (1968a) pointed out that abundance of high quality food, such as harvest-wasted corn and soybeans, can to some extent replace cover requirements. However, in the natural environment of the deer, such high quality food is not frequently available during seasons of adverse weather.

The forage energy input into a deer herd is not equal to the gross energy of the forage supply, since not all of this energy is available for use in body functions. The partitioning of the gross energy into its available and unavailable fractions is shown in Fig. 3. In the case of meat-type livestock, only a part of the net energy is directly used for production (growth and fattening). The remaining net energy is the energy cost of "overhead." However, for wildlife this overhead energy is available for conversion to some forms of production. This concept

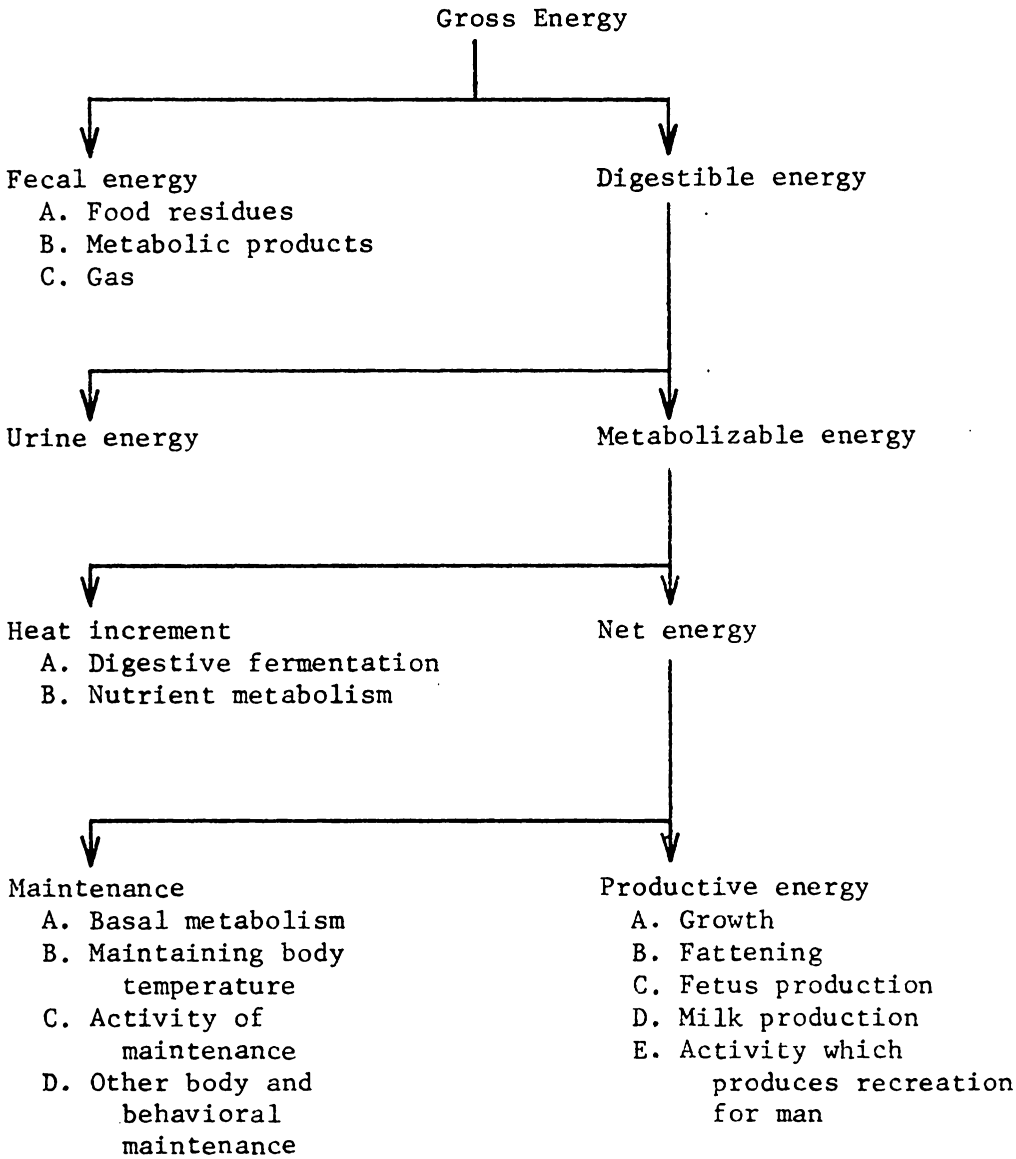

Fig. 3. Partitioning loss and use of gross energy intake of a deer population (Adapted from Crampton and Harris 1969:140).

is discussed further in a later section on the productivity model.

Digestible Forage Energy

Gross energy of most herbaceous materials is approximately 4000 cal/g. Hough (1969) reported a range of 3501 to 5244 cal/g in plant material in the southern United States. Major variations in gross energy can be attributed to variation in oil and ash content. Table 10 shows that little relationship exists between gross energy and digestible energy available from forages used by deer. It is well known that proximate analysis data do not give reliable information for predicting digestibility of a forage. Most analysis of deer forage has been done by the proximate analysis method. In Van Soest method of determination of forage quality (Van Soest 1967) provides more information about the digestibility of a forage. However, since little information obtained by this method is available for forages, it cannot now be considered for use.

It was decided to use the general forage type digestibility reported by Snider (1971) for the first approximation of forage energy available from the habitat. Part of the reason for this decision was that evaluating the species composition and abundance in a habitat would be too expensive to consider in appraising land for acquisition. General forage classification and abundance can be approximated in the field and the effect that succession will have on forage production can be projected by use of the Giles-Snyder technique(1971). Combining the use of this estimate of forage production over time and Snider's general forage class digestibilities, provides a way to project the digestible energy production in a habitat over a given planning horizon.

Table 10. Gross and digestible energy for some forages used by white-tailed deer.

Forage type	Gross energy cal/gram	Digestible energy cal/gram	Percent of gross digestible	Source
Formulated	4407	2750	62.4+/-1/5	Ullrey et al. 1968
ration	3480	--	56.5+/-1.1	Ullrey et al. 1969
Forbs	--	--	53.5	Snider 1972
Fruits	--	--	44.5	Snider 1972
Leaves of Woody species	--	--	36.1	Snider 1972
Browse				
General	--	--	25.2	Snider 1972
Balsam	2600*	--	33+/-4	Ullrey et al. 1968
			-153+/-104	Ullrey et al. 1968
Cedar	2370	--	39+/-3	Ullrey et al. 1968
Jack pine	2490*	--	44+/-6	Ullrey et al. 1967
Aspen	2590*	--	29+/-14	Ullrey et al. 1964
			-379+/-299	Ullrey et al. 1964
Pasture				
Alfalfa	4560**	2557	55.6	Crampton and
Bluegrass	4597**	2278	49.6	Harris 1966

* Wet weight basis.

** Dry weight basis for sheep.

Metabolizable Energy Production

Since it is the metabolizable energy rather than the digestible energy used by the deer, it is necessary to estimate the portion of the digestible energy which is metabolizable.

Ullrey et al. (1970) reported that the diet he used in studying the metabolizable energy requirements of deer had 82% of the digestible energy metabolizable. Upon inspection of tables of forages and supplements (Crampton and Harris 1969), it was found that this ratio of metabolizable to digestible energy was 0.82, or very close for agronomic feeds, be they concentrates or roughages. However, the data for some browse show that this ratio may vary appreciably over the season for such material (Table 11). The values in this table range from 54 to 88% of the digestible energy being metabolized. Of the nine species or growth stages, six were comparable to 82% of the digestible energy being metabolized. Therefore, the estimate used herein is that all forages have 82% of their digestible energy metabolized. No doubt this is an over-estimate in the case of some browse species; however, due to the variability observed, it is believed that this is model and therefore a good, working, first approximation.

Estimation of Forage Production

The land evaluation needs to provide an estimate of the available forage production by the various forage classes. The capability to furnish these estimates will depend on previous forage surveys in similar cover types, as well as experience of the land appraiser.

There are numerous articles in the literature on amounts of forage produced per acre in different habitat types. Of these, of special

Table 11. Relationship between the digestible and metabolizable energy of some western browse species (Crampton and Harris 1969).

Species	Forage type	Energy*			Percent**	
		Gross	Dig.	Met.	Dig.	Met.
Salvia sp.	Browse, dormant	3847.	1582.	854.	41.	54.
Artemisia spp.	Browse, early	1060.	639.	502.	60.	79.
	Browse, immature	--	803.	658.	--	82.
	Browse, mid bloom	--	1314.	1077.	--	82.
	Browse, mature	--	1477.	1211.	--	82.
	Browse, dormant	3877.	1751.	964.	45.	55.
	Browse, dormant	--	1446.	1186.	--	82.
Atriplex spp.	Browse, dormant	2771.	1119.	990.	40.	88.
	Browse, dormant	2906.	1006.	704.	35.	70.

* On an as-fed basis for sheet.

** Percent gross energy that was digestible and the percent of the digestible energy that was metabolizable.

importance in providing the above estimates are the studies in which are reported the production of browse and grass and forbs for different cover types. Murphy and Crawford also reported (1970) the effect of crown closure on forage production.

Soil quality has been credited with a strong influence on game production through its influence on forage quality. However, measurements of browse chemical composition (Murphy 1970) have not shown differences between areas of different levels of deer productivity. There does appear to be a relationship between soil quality and land use. Murphy stated that, "Soil fertility is related to quality of deer range by its influence on land use." Thus, soils of high quality tend to be under cultivation to a greater extent than low quality soils. This may provide higher quality forage than is available under woodland conditions, as observed by Moen, increasing the deer range quality even though it may decrease the absolute range area available. Also, areas which were at one time in agriculture and then abandoned, have good range conditions. This is due to forage production and cover availability found in these areas in the earlier stages of succession.

In areas where the main vegetative types are of a woodland nature, soil quality may affect the quantity of forage produced if not quality. The rate of succession in communities can be expected to be influenced by soil quality.

Due to the scarcity of information directly relating soil quality to forage quality or quantity produced, and since soil quality will be reflected to some extent in land use patterns, successional stages in some forests and expected rate of succession, soil quality was not used as a direct measure of habitat quality in this work.

Forage Utilization

For a discussion of herbivore forage utilization, three definitions must be agreed upon (Mott 1960). These are stocking rate, grazing pressure, and carrying capacity. Mott defined them as follows:

Stocking rate. The number of animals per unit area of land (e.g. head per acre, head per hectare, or the reciprocal, acres per head). This term bears no relationship to the amount of forage.

Grazing pressure. The number of animals per unit of available forage.

Carrying capacity. The stocking rate at the optimum grazing pressure.

The optimum grazing pressure is here considered to be the grazing pressure at which all forage managerially or physically available (see previous discussion) for the deer is utilized. Thus, the same habitat may have different optimum grazing pressures for different managerial goals, this occurs by defining forage availability on the basis of the managerial goal. This definition of optimum grazing pressure is used since potential productivity is of concern. Without complete utilization of the available forage energy, potential can not be reached. Therefore, to measure potential productivity, the potential forage energy input must be used.

For a given set of climatic and habitat-cover conditions, the forage supply and utilization determines the potential productivity of the habitat. Thus, by defining managerial goals for an area, the available forage base for deer can be defined. This forage base in conjunction with the energy requirement of the animals will define the carrying capacity or stocking rate desired at the optimum grazing pressure. This stocking rate will define the level of potential production of deer. To modify the potential deer production from an area, the manager can increase the forage base by increasing the absolute amount of herbage or by re-defining the managerial goals.

Seasonal Forage Supplies

The utilization of forage by deer differs between the summer and winter seasons. In summer, as a population feeds, plant growth will replace at least part of what is consumed. If the population is at a high grazing pressure, the portion of consumed forage that is replaced will be low. At a low grazing pressure, a higher proportion of consumed forage will be replaced. However, in the winter season, there will be no replacement of consumed forage. The forage supply will be continually decreasing, with some forage types being consumed at higher rates than others. As snow accumulates, the grazing pressure increases and is concentrated on a few forage types.

In evaluating the seasonal forage supplies, a distinction must be made between the forage available for summer feeding and the forage growth to be accumulated for winter. A given forage type may be available for either season (browse and some grasses like fescue), for only the summer (fungi and some grasses), or for fall and winter only (mast). The absolute production of some forage types will be dependent on utilization, as for grasses (especially so in the example of pasture land management), or it may be independent of utilization, as is mast.

It is beyond the scope of this thesis to deal with the effect utilization has on present and future production of forage plants. However, in estimating the forage available for utilization by deer, consideration must be made of the forage base required for the maintenance of good plant growth and the managerial goals for an area.

This model assumes that the reported forage production is available at the beginning of each season and is used by the population as required. The utilization of the various forage types is discussed below.

Forage type production and rate of forage consumption must be considered when evaluating the availability of forage over the season. For the summer season, it is assumed that all the forage is utilized in proportion to its preference-ranked availability. In cases where natural phenological events occur in the summer, which may greatly change the forage energy supply, the model will not be descriptive. However, the effects of events such as these can be limited to some extent by the evaluators defining the months in which growth is well begun and in which growth ceases. These points in the year are used to define the beginning of the summer and winter seasons, respectively.

The utilization of forage during part of the winter months affects the subsequent availability of forage. If the rate at which a forage type is used is known, the availability over each month of the season can be determined. Harlow (1971) reported on a detailed study based on rumen analysis of food habits of deer in the Southeast. He emphasized that surveys of forage and feeding habits must distinguish between the classes of forage. Harlow grouped forages in several classes. For purposes here, these classes were lumped into three general classes comparable with the classes used by Snider (1971). These classes are: woody browse, the twigs and buds of woody plants; succulents, leaves of woody species, grasses, and fungi; and fruits, consisting of all fruits and nuts. No distinction is made between succulent or hardened twigs, or succulent or dry leaves, since season will largely influence the availability and use of one or the other. Table 12 presents Harlow's findings as grouped by these definitions. The arithmetic means of spring and summer values and the fall and winter values are reported as the growing season and dormant season means respectively and are those values used in the model.

To estimate the utilization over the winter, the relative consumption rates of the three forage types is supplied. This can be done by using the values from Table 12 or values determined independently. The model assumes that the winter consumption of forage will not exceed 5.0 lb. of forage per 100 lb. of body weight, if this is not supplied by the land evaluator. This value is the higher value reported by Ozoga and Verme (1970) for deer entering the winter in different body conditions. Those being in better condition consumed less forage than those in poor condition. For consumption during times with more than 3 inches of snow on the ground, all foraging is assumed to be from browse and succulents (assuming them to be leaves of evergreens). Coblentz (1970) observed this to occur with white-tailed deer. However, he did not distinguish between woody and leafy browse.

Consumption is calculated so that the ingested metabolizable energy in a month is equal to the energy requirement of the deer in that month as calculated by the preceeding thermal-activity energy model. This

Table 12. Percent volume occurrence of forages, grouped in three general classes, as found in deer rumens in the Southeast (Adapted from Harlow 1971:59).

Season	Woody Browse	Succulents	Fruits
Southern Appalachins			
Spring	6.4	86.6	7.0
Summer	2.7	91.6	5.7
Growing season mean	4.6	89.1	6.4
Fall	3.0	42.8	54.1
Winter	4.9	78.8	14.7
Dormant season mean	4.0	68.8	34.4
Coastal plain			
Spring	7.5	91.0	1.5
Summer	11.3	67.6	20.3
Growing season mean	9.4	79.3	10.9
Fall	12.6	54.7	32.7
Winter	5.2	84.7	10.1
Dormant season mean	8.9	69.7	21.4
Piedmont			
Spring	10.1	38.9	3.0
Summer	3.6	78.7	17.3
Growing season mean	6.9	82.8	10.2
Fall	5.2	24.5	70.3
Winter	4.9	73.0	22.1
Dormant season mean	5.1	48.8	46.2

assumes that the deer regulates its intake near maintenance, if possible (Moen 1966:77). The consumed energy is subtracted from the available forage by forage type proportional to the expected utilization. Where behavior limits intake below the required maintenance level, the lower rate of intake is used.

Estimates of the present and the successional maximum summer and winter available forage production, in different cover types are to be made by the land evaluator and given as data inputs to the model. The successional changes in forage production and cover are estimated by use of equations presented by Lobdell (1972). This successional projection of forage production allows an estimation of the natural potential production on an area over a given time span, thus allowing for an estimation of the potential productivity which may be available without expending funds for development.

Productivity Model

A model of the effect of energy inputs and energy outputs on production, needs to be developed to interpret calculations made from the preceding thermal and forage energy relations.

Production from wildlife populations differs from the production of livestock in that, for wildlife, production is measured in units other than the weight of animals harvested from the habitat. The concept of wildlife production has been generalized in the term, man-days of recreation. This is a complex function. For the hunter, the man-day is partly composed of production subunits, which are sightings made, shots fired, and animals harvested. The actual production of a wildlife population would be the integration of all the quality-ranked production units formed over a period of time. The potential productivity of the population would be the summation of all the quality-ranked production units which could be produced from the population without detriment to the achievement of long-term managerial goals.

There are two classes of production interactions: consumptive and non-consumptive. For deer, the main non-consumptive production units are the sightings of deer or deer signs. The consumptive production unit for this species is a harvested deer.

The energy expended by a wildlife population in the actual formation of a unit of production is variable. Non-consumptive interactions may or may not cause energy losses from the population above those required for normal maintenance. Watching deer from a blind without disturbing the animals would cause no additional energy drain. However, unsuccessful shots at deer would cause increased energy drain from the population by increasing the activity of the animals. The consumptive man-animal interaction of harvesting deer would reduce the population's standing biomass energy. A large animal harvested removes more energy than a small animal.

Measures of the instantaneous energy expense to a wildlife population in forming production units, are important for understanding the impact which various forms of harvesting have on the population energy requirement. However, they are not too meaningful by themselves for determining energy potentially available for forming production units of sightable or harvestable deer.

Index To Potential Productivity

Non-consumptive Production

The energy potentially available to a population of deer for production, is a function of the normal energy requirement of the population living in a habitat energy system, and the additional energy requirement placed on the population by man in harvesting or obtaining production units. The energy available from a habitat for forming non-consumptive production may best be measured as the number of animals which can be maintained in the habitat. The favorability of the habitat (cover and access conditions), weather, and human social conditions will determine the actual production achieved by influencing deer utilization by man. However, once these conditions are set, the production achieved should be proportional to the size of the deer herd conceptualized as:

$$X_s = F(X,S) \qquad (16)$$

Where X_s = the total sightings made

X = the population size

S = the effect that the physical environment and human behavioral conditions have on deer sightings.

Equation 16 could be used to predict the non-consumptive production of a deer herd if the number of deer were known and the function F(S) quantified. It is not the purpose here to try to quantify F(S), which is dependent on the resource-user population characteristics, the habitat characteristics which affect sightings and use, and variables which fluctuate yearly, such as weather, leisure time, and the reputation of an area for recreationist success. This function is being studied by E. F. Bell at Virginia Polytechnic Institute and State University (pers.

comm.). Equation 16 provides a concept of the measurement of potential non-consumptive production of deer. The concept is discussed later.

Consumptive Production

The energy potentially available to a wildlife population for the production of harvestable animals is a measure of the energy available for forming consumptive recreation. This is the energy available to the deer herd for the development of fetuses and for the maintenance and growth of young.

Herein, the energy potentially available for forming consumable production is studied only for stable population-habitat conditions (i.e., stable grazing pressure). This limitation was made because, in the natural condition, the actual desired harvest in a year may differ from the potentially consumable harvest due to changes from stability. In a habitat which has fewer deer than can be readily maintained by a forage supply increasing with succession, the manager may prefer to leave some of the produced young to increase the size of the herd. In the case of a herd which is larger than that which can be maintained, the manager may try to crop more deer than can be produced by the energy available in that year.

For the stable carrying capacity condition, the energy usable from the habitat for the production of fawn deer is the difference between the energy available for sustaining a population through the critical season of the area and that available during the fawn growing season. The utilization of this potential harvestable energy is dependent on a variety of factors, such as fawns needed as replacements for natural mortality, herd management, and nutritive factors of the forage.

Ullrey et al. (1967) have shown that fawn growth rate is dependent on protein level as well as energy. Though protein cannot be ignored, in many cases the forages available to deer contain levels of crude protein (12%) sufficient to maintain active, though not maximal, growth. This is especially so in the summer and early fall (when mast is available). Protein is not here considered to be a major limiting factor to growth. As more is learned about the growth requirements of fawns, factors, such as protein, may be reconsidered and if appropriate, added to the model.

Total Production

From the above discussion and equations, it can be seen that the total quality-ranked productivity of a wildlife population can be expressed as:

$$QP_{total} = Q_s X_s + Q_h X_h \tag{17}$$

Where QP_{total} = total, quality-ranked production

Q_s = the quality ranking of sighted animals

Q_h = the quality ranking of harvested animals

X_s = the number of sighted animals

X_h = the number of harvested animals.

The quality ranking factors Q_s and Q_h need to be in units such that the quality-ranked production of the two production types are in the same or equatable units. Lobdell (1972) provides a methodology for such quantification.

The production provided by a deer population is a function of quantity and quality of animals interacting with man. Each human population will have a different utility associated with young or old, does or well-antlered bucks. Thus the value of Q_s and Q_h will usually differ for each population of deer and resource-users.

It is not the purpose of this thesis to quantify the quality-ranking of the different sexes and ages of deer. However, a model containing a factor of quality-ranking is needed to emphasize the fact that there exists a conversion of energy for quality. Thus for a given forage supply and thermal energy requirement, there will be a balance between the quantity and quality of animals that may be grown in the habitat. The manager may adjust that balance to suit the needs of the people he serves.

Mott (1960) developed a model for livestock which shows the three-way balance which exists between stocking rate of animals (quantity), production per animal (quality), and production per acre of pasture habitat (total production). This is presented graphically in Fig. 4. The three axes are represented on a ratio scale as follows: X is the ratio of observed stocking rate to the stocking rate at the optimum grazing pressure; Y is the ratio of the product per animal actually obtained to the product per animal obtained at the optimum grazing pressure; and Z is the ratio of the product per acre actually obtained to the product per acre obtained at the optimum grazing pressure.

When the axes are in such units, the products per animal (Y) can be expressed as:

$$Y = K - AB^X \qquad (18)$$

Mott (1960) stated that the product per acre (Z) is simply the stocking rate (X), multiplied by the product per animal. Mott, therefore, expressed the product per acre as:

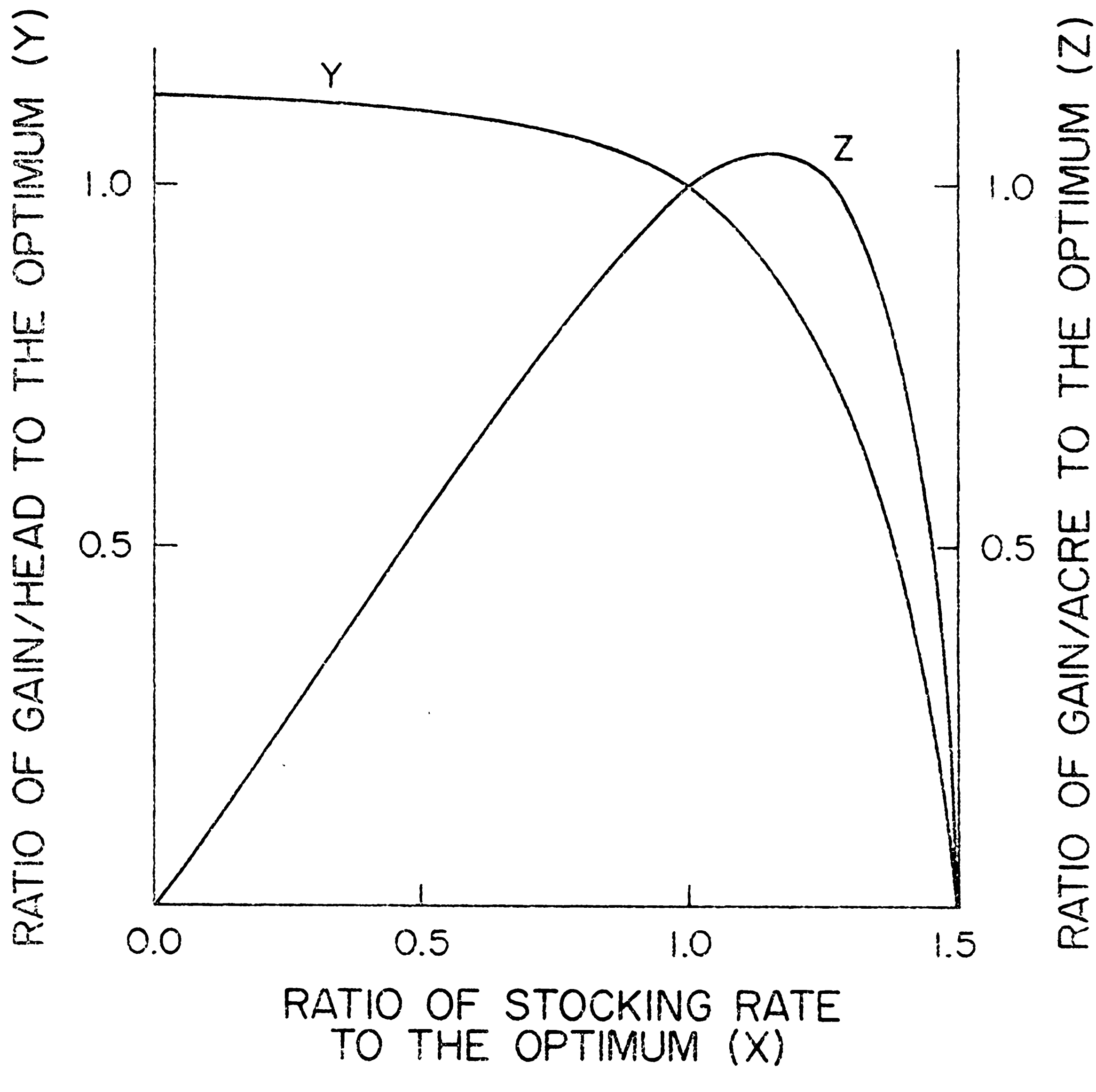

Fig. 4. Relationship between the ratios of stocking rate (X), gains per head (Y). and gains per acre (Z) to the values at which "optimum" production is reached (Adapted from Mott 1960).

$$Z = X(K-AB^X) \quad (19)$$

For meat-type livestock, quality is closely correlated with the product per animal (Y) or rate of gain. The total dollar value of a crop of grazing calves is the price received for a given quality times the number of calves sold at that quality. This is the case in deer production, although the social value of the production is not reducible to dollars and the quality per deer may not be as closely related to the rate of gain as in cattle. As with livestock, the rate of gain of deer will be inversely related to the grazing pressure. Petersen et al. (1965) discussed the theoretical consideration of this relation. The reader interested in further development of this relation is referred to the papers by Mott (1960) and Petersen et al. (1965).

Standard Deer

Since the total production from a wildlife population is dependent on the population characteristics, size, the number of harvestable animals, and the quality of the animals (Equation 17), it is necessary to hold these variables stable if comparisons of different areas are to be made. If this were not done, but rather the measures of these variables (such as sex and age ratios and population size) were used for different populations, in different habitats, the environmental complex determining the potential productivity would be masked. Until the quality-weighting factors of Equation 17 are available, an estimate of the potential productivity of a habitat can be made only by an index of some standard population.

When the comparison between the potential productivity of two or more habitats is desired, the population variables may be eliminated from consideration. The population variables can be managed to develop different balances between quantity and quality in the harvest. That is, a new balance may be developed between the two to give a higher quality of, or a more desired type of production.

For these reasons, a "standard deer" is used in modeling the deer-environment energy system. This deer is defined as a 50 kg, female deer which is maintaining a constant body weight, and is not pregnant or lactating. These characteristics define the quality of the animal. For the purposes of estimating the energy required by a standard deer in a given habitat, calculation of the thermal-energy requirement (Equation 6) is made on the basis of a standing deer. This definition allows the calculation of an index of animals supportable by a habitat. This index is not the number of animals one will find in the habitat. Rather, the standard deer unit is a measure of the energy potentially available for maintaining and growing deer. This unit reduces the energy variations in climate, cover, and forage production to a unit of energy available for the production of wildlife biomass and recreation. The standard deer unit can be converted into potential deer of natural characteristics, if the energy requirements of those deer are shown.

Potential Productivity Index

Energy in Biological Production

The system of energy inputs and outputs is important in evaluating the productivity of animals. The balance between the inputs and outputs are rarely constant. Fluctuations are caused in the inputs by seasonal changes of forage supply and quality. Energy output fluctuations are caused by seasonal changes in climate, activity, stage of pregnancy or lactation, and growth rate of young.

For the wildlife population, three conditions of the energy input-output balance may exist. When energy input is less than energy output in a population for a significant part of the year, individuals will lose weight. If the condition is more severe, the population mortality will increase, bringing the energy input and output into balance.

When, over the year, energy input is equal to the energy output needed to maintain a stable population condition, the population will maintain itself with possible fluctuations in the body condition of the individuals but will not produce a harvestable surplus of animals. An exception to this would occur if all natural mortality could be replaced by the harvest. However, such a case is unlikely. The population existing under such a stable energy balance could be used to produce some harvestable production, but it would only be at the expense of the stable population conditions. If a harvest were to be made, the population being reduced, an energy imbalance of inputs exceeding outputs required for population stability would probably occur. The excess energy will result in increased body vigor of individuals and increased production or survival of fawns. These animals will either increase the population or will be available for harvest.

Only when energy inputs are greater than the energy outputs required for maintaining population stability will there be sufficient energy available for producing a harvestable surplus. Under these conditions, young can be produced, which are available for harvest without detriment to population stability. If natural mortality were limited to death from old age and the requirements for energy were those of basal metabolism, general activity, and the climatic-thermal energy loss, the energy in excess of the output requirement and available to the wildlife, would be the energy potentially available for harvestable production. The energy available for non-consumptive production would be the energy used in maintaining the base population. However, the harvestable animals can also supply potential non-consumptive production prior to their harvest.

This model evaluates the energy potentially available for production by means of the standard deer unit. The estimation of the energy potentially available for production is composed of three considerations:

1) estimating the standard deer population sustainable by the habitat through the winter;
2) estimating the standard deer population sustainable by the habitat during the summer; and
3) interrelating 1 and 2.

Seasonal Standard Deer Population

The energy available for sustaining a standard deer population (hereafter abbreviated SDP) in either season is a function of the balance between the energy required for maintaining the basal metabolism, body temperature, and activity requirements of the population, and the metabolizable energy available from the forage. The energy requirement for living in a habitat is calculated from the evaluator-supplied climatic and habitat data. The climatic data used in Equation 6 is the climatic data furnished, modified by the habitat and behavior as discussed previously. The metabolizable energy available over the season is the metabolizable forage production available in the fall, as influenced by consumption and snow conditions.

The availability of forage in any given month depends on the initial forage supply and the rate of consumption of the various forage types. The rate of consumption depends on the size of the deer population. To account for this, an iterative process is used for calculating the SDP stocking rate for the winter season.

The first estimate of the SDP which can be sustained over the winter season is expressed by the ratio of the metabolizable forage energy available in the fall to the summation of monthly energy requirement of one standard deer, assuming that the total forage supply is utilized. For a given set of habitat and climatic conditions, the winter SDP will be maximal only when the utilization of forage is maximal. However, due to snow accumulation and the unequal use of the different forage types, it is not always possible to have complete utilization. The winter SDP was first estimated by:

$$SDP_w = \frac{ME_w}{\sum_{j=m}^{n} ERSD_j} \qquad (20)$$

Where SDP_w = standard deer population sustainable in winter (w)

ME_w = metabolizable forage energy available in the fall

m = the first month of the winter season

n = the last month of the winter season

$ERSD_j$ = energy requirement of a standard deer in month j.

This estimate of the potential winter SDP is then used to assess the interaction of snow and animal foraging on the availability of forage through the season. Monthly calculations of the SDP energy requirement are made over the season. The energy needed to maintain the energy balance of the population for the month is then subtracted from the metabolizable forage energy available. This reduction of available forage energy is made by forage type, proportional to the expected consumption. The availability of forage in any month then, is determined by the snow depth and previous calculated utilization.

Under mild climatic conditions and little or no snow, a calculation such as the above should result in no remaining forage at the end of the winter season. However, as mentioned previously, deer will not always consume sufficient forage to meet their requirement, due to a behaviorally limited intake or due to the unavailability of forage. If the energy requirement is greater than the energy that can be consumed by the SDP due to behaviorally limited intake, the energy deficit (difference between the energy which will be ingested and the energy requirement) is summed over the season as a negative energy balance (NEB1). If the energy requirement is greater than what can be supplied by the available forage to the SDP, then the deficit is similarly summed as a separate negative energy balance (NEB2). These two indices describe the relationship between the SDP, the climatic severity, and the forage production by forage type.

The successive estimate of the winter SDP is made, using the information obtained on the effects which show and utilization had on forage availability. An estimate is made of the number of standard deer which could have been supported at the calculated energy requirement on an amount of energy equivalent to the energy deficit accumulated due to lack of forage (NEB2). This estimate is calculated as:

$$SDP' = SDP - \frac{NEB2}{\frac{\sum_{j=m}^{n} ERSDP_j}{SDP}} \qquad (21)$$

Where SDP' = the new estimate of the sustainable SDP

SDP = the previous estimate of the SDP

NEB2 = absolute value of the portion of the energy requirement of the SDP which was not satisfied due to the lack of available forage

ERSDP = energy requirement of the SDP in month j

m = first month of winter season

n = last month of winter season.

This iterative procedure can be carried on to any length. As used herein, it was repeated until an estimate of the winter SDP is within 5% of the previous estimate.

Climatic Severity Index

An index of the severity of a set of climatic and habitat conditions can be expressed as a relation between the seasonal energy requirement and behavioral limitations to forage consumption. This relation has been estimated by the energy deficit due to behaviorally-limited forage intake (NEB1). The relative magnitude of this index is more meaningful if it is converted into an index of the proportion of expected body weight loss of the standard deer. This index is developed by assuming that all the body tissue catabolized to furnish this energy is fat and that all the body weight change is due to the loss of fat tissue. The constant used for the energy furnished by a unit of catabolized fat is 9.0 Kcal/g. Equation 22 represents this conversion for a 50 kg deer. Equation 23 makes the desired calculation for the SDP, and is the reduced form of Equation 22.

$$BWL = ((NEB1/9000)/50) \quad 100 \tag{22}$$

$$BWL = NEB1/(4500\ SDP) \tag{23}$$

Where BWL = the percent of body weight loss, for an individual or population

NEB1 = the energy deficit due to behaviorally limited forage intake

9000 = Kcal of energy supplied per kg of fat catabolized

50 = weight of a standard deer (kg).

Summer SDP Index

The summer sustainable SDP is calculated as was the first estimate of the winter SDP. However, the iterative procedure is not used. The limitations to be considered when evaluating the availability of summer forage have been discussed previously.

Sightable Deer Index

The calculated seasonal SDP's are used to estimate the energy potentially available for productivity in a habitat. One index to the potential production of sightable deer is the mean seasonal SDP's, that is:

$$X_s = \frac{(SDP_s\ M_s) + (SDP_w\ M_w)}{12} \tag{24}$$

Where X_s = index to the yearly mean potential SDP

SDP_s = potential summer SDP

SDP_w = potential winter SDP

M_s = number of months in summer season

M_w = number of months in winter season.

Poux (1972) observed that fawns were sighted more frequently in the population as they grew older. The peak was reached in December, at which time they were observed proportionally to their number. For this reason, the index as calculated in Equation 24 is not a direct representation of sightable animals. The winter SDP index may be more appropriate for this use. For this reason, the winter SDP is reported as the sightable deer index.

The potential sightable standard deer index should be proportional to the potential natural deer population if maintenance energy requirements are linear, which they do appear to approximate.

Harvestable Deer Index

Once a portion of the available input energy has been assigned to the maintenance of potential sightable production, the energy remaining is available for the potential harvestable production. In the case of wild animals which give birth to the young in the spring, this energy used in the production of harvestable animals must occur as an excess during the summer season. For this reason, the index of energy available for the potential production of harvestable deer is defined as the difference between the two seasonal SDP's, where the winter standard deer population is the index of energy used for sightable productivity (Equation 25).

$$X_h = SDP_s - SDP_w, \quad SDP_s \geq SDP_w \qquad (25)$$
$$= 0.0 \qquad , \quad SDP_s < SDP_w$$

Where X_h = index to the yearly harvestable energy production in standard deer units (Equation 17).

This definition of the harvestable productivity index makes it possible to calculate a zero productivity index when the winter SDP is greater than the summer SDP. Such a condition can occur in the field when a large mast supply is regularly available over the winter, or it may occur only theoretically if the estimates of summer forage production are too low, or winter forage too high. It is here assumed that the relative estimates of seasonal forage availability will be correct. For the natural case of a winter range sustaining more deer than the summer range, the winter population is the population level which the range can support. This would be so unless the natural mortality occurred in the summer and fawning occurred after the critical season. Since this case of mortality and fawning is unlikely, the definition of energy available for harvestable productivity is assumed. Under conditions of winter SDP being greater than summer SDP, the winter SDP is assumed to be limited to the summer SDP.

Range Balance Index

The relative availability of energy for deer in the two seasons can be expressed as the ratio of the summer SDP to the winter SDP, and is termed the range balance index (RBI). This is expressed in Equation 26.

$$RBI = \frac{SDP_s}{SDP_w} \qquad (26)$$

This ratio gives an expression readily useful for analyzing the above consideration of a zero harvestable deer index. In the previous discussion, the condition of equal summer and winter SDP's (RBI of 1.0) at first appears to imply that there is no energy available for harvestable production. Such might be the case if management attempted to use all the energy available for maintaining a maximum stable population. Thus, this is an example of the second case of energy input-output balance discussed earlier (p. 72). By reducing the energy used for maintaining the stable population, decreasing the sightable deer index (X_s or SDP_w), the energy available for the potential harvestable production may be increased.

The rate at which management objectives dictate deer should be harvested, is termed the range utilization harvest rate. This is an expression of the level at which energy, in standard deer units, is to be harvested from the population. The range utilization harvest rate is analogous to managing a fawn production level which will be utilized by man through a managed harvest. Thus, if a RBI for an area calculates at 0.9 but a range utilization harvest rate of 1.2 is needed to meet hunter demand, the wintering population needs to be decreased to be proportional to the summer population and production in a ratio of 1.2. The assumption is that the quality of forage and other factors are such that this rate of fawning and fawn growth can be attained.

If it is assumed that a fawn growing up to the hunting season requires the same energy as does its dam for maintenance, a range utilization harvest rate of 1.2 would be comparable to harvesting about 17% of the pre-season population (0.2/1.2). The concept of range utilization harvest rate is used to construct a matrix of alternative production indices, for which a forage base can be managed. This is limited by the maximum RBI which a population can utilize, due to its maximum fawning rate, the requirements of the fawns, and the increase in body condition of the adults over the summer.

The limit to which the summer range can be utilized can be expressed as the ratio of the summer and winter requirements of a hypothetical population. This concept is expressed as:

$$R = \frac{SDP_w + (F\ N\ SDP_w)}{SPD_w} \qquad (27)$$

Where R = the index expressing the maximum utilizable difference between summer and winter range conditions expressed in units of supportable standard deer

F = a conversion factor relating the mean energy requirements of a fawn to that of an adult or the relative number of adult deer which are supported by the energy requirement for a fawn

N = the ratio of fawns to the total adult population (R_a).

Equation 27 can be reduced by factoring out the potential winter SDP, thus:

$$R = 1.0 + (F\ N) \qquad (28)$$

The factor F can be estimated from literature on deer and sheep. Table 13 expresses the relative energy requirement of lambs and fawns at a given rate of gain in terms of their dams' energy requirement. The young's weight is expressed as a percentage of the dam's weight. This table was developed from data presented by Crampton and Harris (1969: 434-435) on sheep and by Ullrey et al. (1967 and 1970) on deer.

In using Equation 28 and factors (F) from Table 13 for predictive purposes, it must be remembered that the seasonal means are less than the values tabulated. This is so since only post-weaning weight lambs and fawns are included in Table 13. To obtain an estimate of the F factor before weaning, this factor was calculated for pregnant and

Table 13. Relative energy requirements, in terms of the dam's energy requirement, of lambs and fawns at a given rate of gain, when body weight is expressed as a percent of the dam's weight.

Body weight as percent of dam's weight	Rate of gain (kg/day)	Number of * females maintained on the energy required by one young
	Lambs	
38.	0.14	0.78
43.	0.14	0.87
50.	0.09	0.84
	0.14	0.99
	0.18	1.04
57.	0.09	0.94
	0.18	1.17
60.	0.14	1.14
62.	0.06	0.90
	0.14	1.11
67.	0.09	1.07
	0.18	1.32
71.	0.06	1.00
	0.14	1.24
	Fawns**	
43.6	0.14	0.94
47.4	0.15	1.03
49.6	0.18	1.02

* This value used for F in Equation 27.

** Calculated for 93 day mean weight and weight gain.

lactating ewes.

Fig. 5 shows the relative energy required by ewe sheep at different stages of pregnancy and lactation. This is expressed as the ratio of the energy required at a given stage to that required by a dry ewe of the same weight. This can be converted to an approximation of F by assuming one lamb per ewe and the applicability of these data to deer. Such an approximation is made and presented in Fig. 5 by the right-hand axis. The population proportionality factor, N, is the percent of pregnant does in the population. The conversion of the data was made using Equation 27.

For the biological maximum, this ratio can be expressed for a population of all females having an average of two fawns per doe. If a seasonal mean fawn weight of 43% of the doe's weight is assumed, and a mean daily gain of 0.14 kg is assumed, by substituting in Equation 28, then:

$$R = 0.94\ (2.0 + 1.0)$$

$$R = 2.82$$

Poux (1972) reported the population composition of a confined deer herd in Virginia which can be used to evaluate this ratio for a wild population. Poux found that in the population under his observation, does constituted 65% of the adults and each doe averaged 0.58 fawns, giving 0.38 fawns per adult. Using 0.94 again for F and substituting in Equation 28, the value of R is:

$$R = 0.94\ (0.38 + 1.0)$$

$$R = 1.30$$

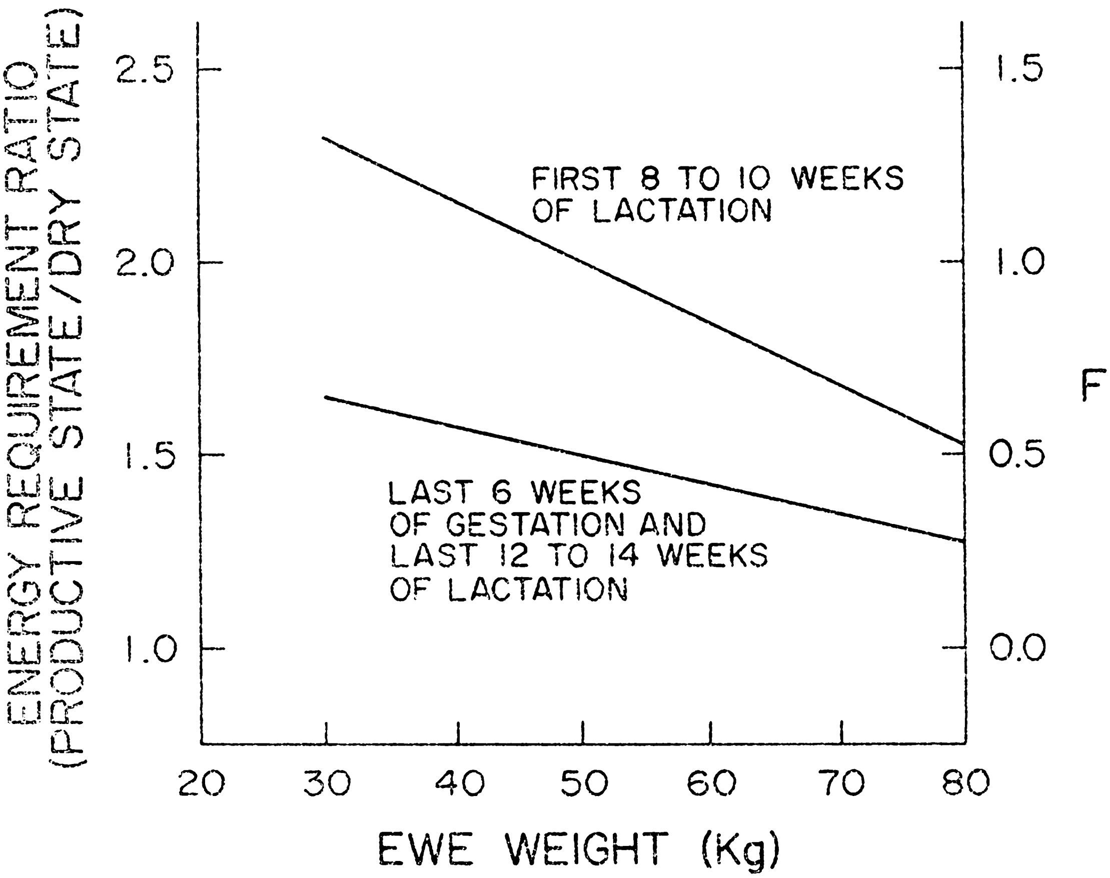

Fig. 5. Ratio of the energy requirement of pregnant or lactating sheep to that of the dry sheep, and the corresponding F value.

There are several factors to be remembered in interpreting the maximum seasonal difference calculated using the values of F in Table 13 and Fig. 5. These are: when a doe is lactating and feeding one fawn, she does not require as much energy as when she feeds two fawns. The doe feeding two fawns will be more efficient; therefore, the value of F (Fig. 5) will be overestimated. During the latter half of lactation, the fawn will consume forage energy in addition to the energy obtained from the milk, so using values only from Fig. 5 will underestimate the value of F. However, the values of F presented in Table 13 and Fig. 5 can be used to estimate a mean F for a given set of conditions. This can then be used in Equation 28 to estimate the desired balance between summer and winter range conditions for deer, expressed as the ratio of the two seasons' SDP carrying capacity.

Habitat Evaluation Work Form

The work form presented in Table 14 was developed for collecting and keypunching data required by the program discussed in the text. The form is composed of two main sections. The first is a general description of the tract of land being evaluated. The second is a more detailed description of the various subunits into which the tract is divided for evaluation.

General Tract Description

On the form, some of the questions are followed by the card number and spaces on the card in which the data are to be punches. In a series of similar data, the card spacing appears only under the first set of data. The remaining data are to be punched on different cards at the same spacing.

Table 14. Habitat evaluation work form.

HABITAT EVALUATION FORM FOR
ESTIMATING THE ENERGY POTENTIALLY
AVAILABLE FOR DEER PRODUCTION

		(CARD	COLUMN)
1. TRACT NAME	______________________.	1	1-40
2. TRACT LOCATION			
A. STATE	______________________.	2	1-40
B. COUNTY	______________________.	3	1-40
C. TOWNSHIP	______________________.	4	1-40
D. LATITUDE	______________________.	4	41-45
E. LONGITUDE	______________________.	4	46-50
3. SIZE OF TRACT (ACRES)	____________.	4	51-60

4. CLIMATIC DISCRIPTION OF AREA

	MEAN MONTHLY TEMPERATURE MAX. (F)	MEAN MONTHLY TEMPERATURE MIN. (F)	MEAN WEATHER STATION WIND SPEED (MPH)	MEAN MONTHLY SNOW-PACK ACCUMULATION (INCHES)	
JAN	__._ (1-5)	__._ (6-10)	___._ (11-15)	___._ (16-21)	5
FEB	__._	__._	___._	___._	6
MAR	__._	__._	___._	___._	7
APR	__._	__._	___._	___._	8
MAY	__._	__._	___._	___._	9
JUN	__._	__._	___._	___._	10
JUL	__._	__._	___._	___._	11
AUG	__._	__._	___._	___._	12
SEP	__._	__._	___._	___._	13
OCT	__._	__._	___._	___._	14
NOV	__._	__._	___._	___._	15
DEC	__._	__._	___._	___._	16

Table 14. (continued)

5. MAJOR SEASONAL EVENTS
(CODE THE MONTH IN WHICH THE EVENT OCCURS IN THE AREA BEING EVALUATED.)
(JAN=01,FEB=02,ETC.)

A.	FIRST MONTH OF SUMMER SEASON	____	17	1-2
B.	FIRST MONTH OF WINTER SEASON	____	17	3-4
C.	INITIATION OF MAST FALL	____	17	5-6
D.	DEER'S SPRING MOLT	____	17	7-8
E.	DEER'S FALL MOLT	____	17	9-10

6. HOW MANY IDENTIFIED FUNCTIONAL SUBUNITS ARE THERE ON THE TRACT ____ 17 11-12

7. PROPORTION OF CONSUMPTION OF THE THREE FORAGE CLASSES.

	WOODY BROWSE	SUCCULENTS	FRUITS	
SUMMER SEASON	____ 1-5	____ 6-10	____ 11-15	18
WINTER SEASON	____ 16-20	____ 21-25	____ 26-30	18

8. HABITAT USE IN WINTER WHEN SNOW DEPTHS ARE GREATER THAN _____ INCHES: 18 31-35

EFFECTIVE COVER

	OPEN	SAPLINGS	POLEWOODS	TREES		
			DAY		19	1-60
HARDWOODS	____ 1-5	____ 6-10	____ 11-15	____ 16-20		
MIXED WOODS	____ 21-25	____ 26-30	____ 31-35	____ 36-40		
CONIFERS	____ 41-45	____ 46-50	____ 51-55	____ 56-60		
			NIGHT		20	1-60
HARDWOODS	____	____	____	____		
MIXED WOODS	____	____	____	____		
CONIFERS	____	____	____	____		

Table 14. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE ____________________.
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS
SUBUNIT. ____________________.
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

___	___	___	___	___	___	___	___	___	___	___	___
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS
SUBUNIT ____________________.
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
1	____ 1-4	____ 5-8	____ 9-12	____ 13-16	____ 17-20	__ 21
2	____	____	____	____	____	__
3	____	____	____	____	____	__
4	____	____	____	____	____	__
5	____	____	____	____	____	__
6	____	____	____	____	____	__
7	____	____	____	____	____	__
8	____	____	____	____	____	__
9	____	____	____	____	____	__
10	____	____	____	____	____	__

Table 14. (continued)

FORAGE PRODUCTION

		MAXIMUM EXPECTED SUMMER PRODUCTION	MAXIMUM EXPECTED WINTER PRODUCTION	PRODUCTION: AGE OF STAND S	PRODUCTION: AGE OF STAND W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF PRODUCTIVE LIFE REMAINING S	YEARS OF PRODUCTIVE LIFE REMAINING W
1	WB	____	____	____	____	____	____	____	____
		6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
2	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
3	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
4	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
5	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
6	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
7	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
8	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
9	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____
10	WB	____	____	____	____	____	____	____	____
	SC	____	____	____	____	____	____	____	____
	FR	____	____	____	____	____	____	____	____

Questions 1 through 3 are self-explanatory. Only data in Question 3 are used in calculations, while the others are strictly for identification purposes.

Question 4: Climatic description of the area. The mean monthly maximum and minimum temperatures and the mean monthly weather station wind speed are obtainable from local weather station records. The snowpack accumulation data are not often available from weather station records. However, an approximation of this can be made by using estimates representative of the average snow accumulation during the most severe winter likely to occur in a given time span. Such an interval might be 5 or 10 years.

Question 5: Major seasonal events. The information obtained from this question is used to set the calendar of phenological events for the standard deer in this area.

Answers to sub-questions A and B define the summer and winter seasons on the tract. The first month of the summer season (growing season) is defined as the first spring month in which forage production has increased to the point at which deer are no longer dependent on forage produced during the preceding year. The first month of the winter season is defined as the month in which forage production (other than mast) has declined to the point at which no further significant production of forage available to the deer in winter can be expected.

An answer to sub-question C defines the fall month in which mast begins to become available to deer.

Sub-questions D and E are used to define the period during which the deer are undergoing a high summer basal metabolic rate or the lower winter metabolic rate. The months in which the average deer has shed the coat of the previous season should be used in these sub-questions.

Question 6: The number of subunits into which the evaluator divides the tract for habitat evaluation is recorded here. It is assumed that these subunits are of sufficient size to furnish complete home ranges to deer during the months in which they are used. An evaluation form will be filled out for each subunit.

Question 7: An estimate of the rate of forage type consumption by deer in the area being evaluated should be entered here. If none is available, the data presented in Table 12 of the text can be used for an estimate. This value should be expressed as a decimal.

Question 8: The snow depth, in inches, beyond which habitat use by deer changes significantly, is entered here. Following this is a table for entering the percent of time (expressed as a decimal proportion) deer will spend in the different cover types. These cover types are defined by stand composition and cover quality. If a given cover type is not found in the habitat evaluated, cover use is proportional to the percentages given for those cover types present.

Subunit Evaluation Form

A form must be filled out for each subunit, the number of forms corresponding to the number entered in Question 6 of the general tract description form.

Question 1: A name or code to identify the subunit and to distinguish it from other subunits.

Question 2: The percent of the tract area covered by this subunit (expressed as a decimal) is entered here.

Question 3: The expected use of the subunit by deer is the answer to this question. Some subunits may not be used at all during the year due to weather or forage conditions. If the subunit is not used in a given month, code 0 (zero) is entered in the space for that month. For those months in which the subunit will be used, a 1 (one) should be coded.

Question 4: The number of habitat cover types which are in this subunit, evaluated as forage- and cover-producing areas distinctly different from other cover types, is entered here. The number coded here will correspond to the number of units evaluated in the following sections and must be less than or equal to 10. If there are more cover types than 10, the unit may be divided into two separate subunits.

Cover Availability

The availability of cover in the subunit is characterized by the area covered by the different habitat types, the dominant stand successional change parameters, and a species composition code. The area covered by a cover type should be expressed as the porportion of the subunit area covered by the type. Areas in a subunit which are seldom entered by deer, such as ponds or rock fields, and which do not supply significant forage or cover should be excluded.

The successional-change parameters are used to construct the probable successional curve of the cover type. These parameters should be given for the dominant cover type which is present or most likely to occur and have the greatest influence on deer. These parameters are: stand age, maximum expected attainable height, years to the maximum height, and age at which most active growth occurs.

Stand age is the age of the dominant stand in years. If the cover type most likely to exert the greatest influence over the next 50 years has not begun development (such as brush and tree development in old pasture land), the age should be given as a negative number whose value is equal to the most likely number of years before the dominant stand will begin its entrance on the area.

Maximum expected attainable height is the potential height to which the given dominant cover will grow on the site.

Years to maximum height is the number of years from the present, required by the dominant stand to reach the maximum height. If the maximum height is zero, as in the case of grasslands, place a 20 in the space.

Maximum growth activity is the number of years in the future in which the dominant canopy will attain its most vigorous growth. If this point has passed, the number of years in the past should be entered as a negative number. If the maximum height is zero, place a 10 in this space.

Species Composition is the code used to designate the prominant tree types in the dominant canopy. This code is as follows:

1 = hardwoods

2 = mixed hardwoods and conifers

3 = conifers

Forage Production

The forage production data of a cover type must be opposite the same cover type identification (ID) number as was that cover type's cover availability data. The data required are by forage type and season. The abbreviations WB, SC, and FR respectively, stand for woody browse, succulents, and fruit forage types. The successional parameters of forage production are comparable to those of the cover successional parameters. These parameters need to be evaluated on the basis of summer and winter season availability, and be listed in the proper column. The forage production successional parameters are the maximum expected production, the production age of the stand, the year in which maximum production is reached, and the years of productive life remaining.

Maximum expected production is the maximum number of pounds of available forage (for the season and forage type in consideration) which will be or has been produced by the cover type.

Production age of the stand is the number of years over which this cover type has probably been producing the forage type. If production has not yet started, this should be given as the negative of the years in which production should begin.

Year of maximum production (except for fruits) is the year in which maximum production will be reached. If this point has passed, express it as a negative number. For mast, this is the year in which maximum increase in production is reached. This can be estimated by the mean of the production age of the stand and the years in which the maximum mast crop will be reached. If there will be no production of a forage type in a cover type enter a 10 in the space.

Years of productive life remaining is the number of years into the future that production of this forage type from this habitat will probably remain at managerially significant levels. For the case of no production enter a 20 in the space.

Model Testing

Sensitivity Analysis

The potential productivity model was tested for its sensitivity to model-supplied parameters and to evaluator-supplied data. The sensitivity analysis was conducted for a hypothetical tract of land, described in the work form presented in Table 15. The area is typical of the Northeast climate, having moderately severe winters and is composed of a mix of overgrown pasture land, early second growth hardwoods, and conifer reforestation projects. Table 16 presents the parameters tested, the change made in a given parameter, and the resulting change in the calculated cumulative potential productivity indices over a 50-year planning horizon, when all other parameters were held constant.

The results of the sensitivity analysis point out the limitations of the model and the relative importance of the various parameters. The best indicators of the sensitivity of the modeled deer-environment energy system for the short-term, are the forage-based SDP's. These SDP's are determined only by the energy system within a season. The cumulative 50-year productivity indices are related to the energy balance of the population over the entire year rather than either season alone. Therefore, the sensitivity of the productivity indices indicate the sensitivity of this model for the predictive purposes for which it was developed.

The insensitivity of the model to variables related to temperature and the effect of snow depth on activity energy requirement indicates

Table 15. Evaluation work form for the first hypothetical tract.

HABITAT EVALUATION FORM FOR
ESTIMATING THE ENERGY POTENTIALLY
AVAILABLE FOR DEER PRODUCTION

		(CARD	COLUMN)
1. TRACT NAME	Vandermark .	1	1-40
2. TRACT LOCATION			
A. STATE	New York .	2	1-40
B. COUNTY	Allegany .	3	1-40
C. TOWNSHIP	Ward .	4	1-40
D. LATITUDE	41. .	4	41-45
E. LONGITUDE	80. .	4	46-50
3. SIZE OF TRACT (ACRES)	1200 .	4	51-60

4. CLIMATIC DISCRIPTION OF AREA

	MEAN MONTHLY TEMPERATURE MAX. (F)	MIN. (F)	MEAN WEATHER STATION WIND SPEED (MPH)	MEAN MONTHLY SNOW-PACK ACCUMULATION (INCHES)	
JAN	35.5	11.5	3.5	15.4	5
	1-5	6-10	11-15	16-21	
FEB	35.5	11.5	3.8	18.7	6
MAR	42.5	18.5	4.0	10.5	7
APR	53.5	25.5	4.1	4.0	8
MAY	65.0	33.0	3.8	0.0	9
JUN	23.0	45.0	3.5	0.0	10
JUL	75.0	51.0	3.4	0.0	11
AUG	75.5	51.5	3.5	0.0	12
SEP	74.5	46.0	3.6	0.0	13
OCT	72.0	30.0	3.8	0.0	14
NOV	58.0	24.0	3.9	0.0	15
DEC	46.0	16.0	3.7	6.7	16

Table 15. (continued)

5. MAJOR SEASONAL EVENTS
(CODE THE MONTH IN WHICH THE EVENT OCCURS IN THE AREA BEING EVALUATED.)
(JAN=01,FEB=02,ETC.)

A.	FIRST MONTH OF SUMMER SEASON	05	17	1-2
B.	FIRST MONTH OF WINTER SEASON	10	17	3-4
C.	INITIATION OF MAST FALL	10	17	5-6
D.	DEER'S SPRING MOLT	05	17	7-8
E.	DEER'S FALL MOLT	10	17	9-10

6. HOW MANY IDENTIFIED FUNCTIONAL SUBUNITS ARE THERE ON THE TRACT 3 17 11-12

7. PROPORTION OF CONSUMPTION OF THE THREE FORAGE CLASSES.

	WOODY BROWSE	SUCCULENTS	FRUITS	
SUMMER SEASON	.094	.793	.109	18
	1-5	6-10	11-15	
WINTER SEASON	.039	.697	.214	18
	16-20	21-25	26-30	

8. HABITAT USE IN WINTER WHEN SNOW DEPTHS ARE GREATER THAN 15 INCHES: 18 31-35

	EFFECTIVE COVER					
	OPEN	SAPLINGS	POLEWOODS	TREES		
		DAY			19	1-60
HARDWOODS	.01	.02	.02	.01		
	1-5	6-10	11-15	16-20		
MIXED WOODS	.02	.05	.08	.06		
	21-25	26-30	31-35	36-40		
CONIFERS	.02	.06	.32	.33		
	41-45	46-50	51-55	56-60		
		NIGHT			20	1-60
HARDWOODS	.02	.03	.03	.02		
MIXED WOODS	.02	.05	.08	.05		
CONIFERS	.02	.05	.31	.31		

Table 15. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE Pine plantations.
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS SUBUNIT. .45.
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)
1	1	1	1	1	1	1	1	1	1	1	1

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS SUBUNIT 7.
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
	1-4	5-8	9-12	13-16	17-20	21
1	.20	35.	100.	65.	10.	3
2	.10	35.	100.	65.	15.	3
3	.20	50.	100.	100.	25.	1
4	.10	50.	100.	75.	10.	2
5	.20	10.	120.	80.	35.	3
6	.10	10.	120.	90.	45.	3
7	.10	15.	70.	45.	15.	1
8						
9						
10						

Table 15. (continued)

FORAGE PRODUCTION

		MAXIMUM EXPECTED SUMMER PRODUCTION	MAXIMUM EXPECTED WINTER PRODUCTION	PRODUCTION: AGE OF STAND S	PRODUCTION: AGE OF STAND W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF PRODUCTIVE LIFE REMAINING S	YEARS OF PRODUCTIVE LIFE REMAINING W
1	WB	80.	500.	35.	35.	-15.	-15.	55.	55.
		6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
	SC	400.	5.	35.	35.	-30.	-30.	55.	55.
	FR	0.	5.	0.	-25.	50.	50.	75.	75.
2	WB	80.	500.	35.	35.	-15.	-15.	55.	55.
	SC	400.	5.	35.	35.	-30.	-30.	55.	55.
	FR	0.	5.	0.	-25.	50.	50.	75.	75.
3	WB	144.	45.	70.	70.	-50.	-50.	45.	45.
	SC	32.	5.	70.	70.	-65.	-65.	45.	45.
	FR	0.	50.	0.	10.	15.	15.	40.	40.
4	WB	144.	80.	50.	50.	-30.	-30.	45.	45.
	SC	32.	5.	50.	50.	-30.	-30.	45.	45.
	FR	0.	25.	0.	5.	20.	20.	45.	45.
5	WB	80.	500.	10.	10.	14.	14.	100.	100.
	SC	400.	5.	10.	10.	-4.	-4.	100.	100.
	FR	0.	5.	0.	-35.	45.	45.	70.	70.
6	WB	80.	500.	10.	10.	14.	14.	100.	100.
	SC	400.	5.	10.	10.	-4.	4.	100.	100.
	FR	0.	5.	0.	-35.	45.	45.	70.	70.
7	WB	144.	45.	15.	15.	9.	9.	70.	70.
	SC	32.	5.	15.	15.	-9.	-9.	70.	70.
	FR	0.	50.	0.	-30.	40.	40.	65.	65.
8	WB								
	SC								
	FR								
9	WB								
	SC								
	FR								
10	WB								
	SC								
	FR								

Table 15. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE Hardwood hills .
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS SUBUNIT. .25 .
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

JAN (26)	FEB (27)	MAR (28)	APR (29)	MAY (30)	JUN (31)	JUL (32)	AUG (33)	SEP (34)	OCT (35)	NOV (36)	DEC (37)
1	1	1	1	1	1	1	1	1	1	1	1

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS SUBUNIT 5 .
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
1	.25	50.	100.	100.	25.	1
	1-4	5-8	9-12	13-16	17-20	21
2	.30	50.	100.	100.	25.	1
3	.25	35.	100.	150.	75.	2
4	.10	35.	100.	150.	75.	1
5	.10	20.	100.	150.	80.	1
6						
7						
8						
9						
10						

Table 15. (continued)

FORAGE PRODUCTION

		MAXIMUM EXPECTED SUMMER PRODUCTION	MAXIMUM EXPECTED WINTER PRODUCTION	PRODUCTION: AGE OF STAND S	PRODUCTION: AGE OF STAND W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF PRODUCTIVE LIFE REMAINING S	YEARS OF PRODUCTIVE LIFE REMAINING W
1	WB	144.	45.	50.	50.	-20.	-20.	85.	85.
		6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
	SC	32.	5.	50.	50.	-43.	-43.	85.	85.
	FR	0.	50.	0.	10.	25.	25.	50.	40.
2	WB	144.	45.	50.	50.	-20.	-20.	85.	85.
	SC	32.	5.	50.	50.	-43.	-43.	85.	85.
	FR	0.	50.	0.	10.	25.	25.	50.	40.
3	WB	144.	85.	35.	35.	1.	1.	120.	120.
	SC	32.	5.	35.	35.	-27.	-27.	120.	120.
	FR	0.	25.	0.	-5.	40.	40.	50.	55.
4	WB	144.	45.	35.	35.	1.	1.	120.	120.
	SC	32.	5.	35.	35.	-27.	-27.	120.	120.
	FR	0.	50.	0.	-5.	20.	40.	50.	55.
5	WB	144.	45.	20.	20.	15.	15.	130.	130.
	SC	32.	5.	20.	20.	-12.	-12.	130.	130.
	FR	0.	50.	0.	-15.	20.	55.	50.	65.
6	WB								
	SC								
	FR								
7	WB								
	SC								
	FR								
8	WB								
	SC								
	FR								
9	WB								
	SC								
	FR								
10	WB								
	SC								
	FR								

Table 15. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE Old farm Lands.
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS SUBUNIT. .30.
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

JAN (26)	FEB (27)	MAR (28)	APR (29)	MAY (30)	JUN (31)	JUL (32)	AUG (33)	SEP (34)	OCT (35)	NOV (36)	DEC (37)
1	1	1	1	1	1	1	1	1	1	1	1

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS SUBUNIT 6.
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
1	.35	0.	100.	180.	100.	2
	1-4	5-8	9-12	13-16	17-20	21
2	.20	0.	100.	150.	80.	1
3	.10	0.	100.	180.	100.	1
4	.15	0.	100.	180.	100.	2
5	.15	75.	100.	50.	10.	2
6	.05	75.	100.	50.	10.	1
7						
8						
9						
10						

Table 15. (continued)

FORAGE PRODUCTION

		MAXIMUM EXPECTED SUMMER PRODUCTION	MAXIMUM EXPECTED WINTER PRODUCTION	PRODUCTION: AGE OF STAND S	PRODUCTION: AGE OF STAND W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF PRODUCTIVE LIFE REMAINING S	YEARS OF PRODUCTIVE LIFE REMAINING W
1	WB	144.	80.	0.	0.	36.	36.	162.	162.
		6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
	SC	32.	5.	0.	0.	9.	9.	135.	135.
	FR	0.	25.	0.	-70.	45.	85.	50.	100.
2	WB	144.	45.	20.	20.	10.	10.	130.	130.
	SC	32.	5.	20.	20.	-12.	-12.	85.	85.
	FR	0.	50.	0.	-50.	25.	65.	50.	80.
3	WB	144.	45.	0.	0.	36.	36.	162.	162.
	SC	32.	5.	0.	0.	9.	9.	135.	135.
	FR	0.	50.	0.	-70.	45.	85.	50.	100.
4	WB	144.	80.	0.	0.	36.	36.	162.	162.
	SC	32.	5.	0.	0.	9.	9.	135.	135.
	FR	0.	25.	0.	-70.	20.	85.	50.	100.
5	WB	144.	80.	75.	75.	-50.	-50.	40.	40.
	SC	32.	5.	75.	75.	-69.	-69.	20.	20.
	FR	0.	25.	0.	5.	20.	20.	50.	45.
6	WB	144.	45.	75.	75.	-50.	-50.	40.	40.
	SC	32.	5.	75.	75.	-69.	-69.	20.	20.
	FR	0.	50.	0.	5.	20.	20.	50.	45.
7	WB								
	SC								
	FR								
8	WB								
	SC								
	FR								
9	WB								
	SC								
	FR								
10	WB								
	SC								
	FR								

Table 16. Results of the sensitivity analysis of variables in the potential productivity model.

Variable	Change in variable		Resulting change in productivity indices			
			Forage Based SDP		Cummulative indices	
	Magnitude	Direction	Winter	Summer	Sightings	Harvest
Normal*	-	-	29901.	24126.	19391.	4735.
Temperature	10°C	Increase	0.0**	0.0	0.0	0.0
Snow Depth	10%	Increase	0.0	0.0	0.0	0.0
Spring Season	1 month	Earlier	141.2	0.0	24.4	-100.0
	1 month	Later	-22.1	0.0	-14.5	54.2
Fall Season	1 month	Earlier	0.0	-3.2	-2.0	-8.2
	1 month	Later	0.0	49.5	21.6	157.4
Spring Molt	1 month	Earlier	-35.3	0.0	-20.2	77.7
	1 month	Later	0.0	0.0	0.0	0.0
Fall Molt	1 month	Earlier	0.0	54.4	23.3	174.0
	1 month	Later	0.0	0.0	0.0	0.0
All Habitat Use Based on Forage Production			24.3	0.0	7.7	-31.4
Forage Production Maximum						
All Types and Seasons	10%	Increase	10.0	10.0	10.0	9.9
All Winter Types	10%	Increase	10.0	0.0	3.9	-16.0
Winter Browse	10%	Increase	9.8	0.0	3.7	-15.0
Winter Succulents	10%	Increase	0.2	0.0	0.2	-1.0
All Summer Types	10%	Increase	0.0	10.0	5.6	28.0
Summer Browse	10%	Increase	0.0	5.6	1.7	21.8
Summer Succulents	10%	Increase	0.0	4.4	4.2	5.2
Forage Production Spans	10%	Increase	5.6	6.1	6.2	5.4

Table 16. (continued)

Basal Metabolic Rate	10%	Increase	-9.1	-9.1	-9.1	-9.0
Visible Solar Radiation	10%	Increase	0.0	0.0	0.0	0.0
Snow Depth on Activity Energy Requirement						
Regression Slope	10%	Increase	0.0	0.0	0.0	0.0
Regression Intercept	10%	Increase	0.0	0.0	0.0	0.0
Slope and Intercept	10%	Increase	0.0	0.0	0.0	0.0

* The Normal is the SDP calculated when the variables were left as reported in the text and Table 15.

** All reported values after the Normal are in precent, increasing if positive and decreasing if negative that these variables add little to the predictive ability of the developed model. However, the model's sensitivity to basal metabolic rate is great. It may be that for the conditions set herein, the model deer are approximating a thermal-neutral condition. Under such a situation the energy requirement would be related to basal metabolic rate rather than thermal conditions.

The sensitivity of the model to forage supply is as would be expected. The differences in the sensitivity to different forage types is dependent on the relative proportion that the different forages are in the model deer population's total diet.

The evaluator-supplies data of most importance in the model are: seasonal forage production; initiation of the seasons; and the periods of molt of the deer.

Land Evaluation Test

The model was further examined by using it to evaluate the potential productivity of two hypothetical tracts of land. The first tract is the one used in the sensitivity analysis, and described in Table 15. The second tract has a similar climate and is composed of second-growth hardwoods and old pastures and hay fields. The second tract is described by the work form in Table 17. The evaluation printout forms are presented for the two tracts in Tables 18 and 19, respectively.

Table 17. Evaluation work form for the second hypothetical tract.

HABITAT EVALUATION FORM FOR
ESTIMATING THE ENERGY POTENTIALLY
AVAILABLE FOR DEER PRODUCTION

			(CARD	COLUMN)
1.	TRACT NAME	Tompkins	1	1-40
2.	TRACT LOCATION			
A.	STATE	New York	2	1-40
B.	COUNTY		3	1-40
C.	TOWNSHIP		4	1-40
D.	LATITUDE	41.5	4	41-45
E.	LONGITUDE	79.	4	46-50
3.	SIZE OF TRACT (ACRES)	1500	4	51-60

4. CLIMATIC DISCRIPTION OF AREA

	MEAN MONTHLY TEMPERATURE MAX. (F)	MEAN MONTHLY TEMPERATURE MIN. (F)	MEAN WEATHER STATION WIND SPEED (MPH)	MEAN MONTHLY SNOW-PACK ACCUMULATION (INCHES)	
JAN	37.5	13.5	3.7	12.8	5
	1-5	6-10	11-15	16-21	
FEB	37.5	13.5	3.8	23.2	6
MAR	46.0	22.0	4.0	10.8	7
APR	56.0	28.0	4.1	4.2	8
MAY	69.0	37.0	3.8	0.0	9
JUN	76.5	43.5	3.5	0.0	10
JUL	77.5	53.5	3.4	0.0	11
AUG	77.5	53.5	3.5	0.0	12
SEP	76.5	50.5	3.6	0.0	13
OCT	76.0	33.0	3.8	0.0	14
NOV	62.5	26.5	3.9	0.0	15
DEC	49.0	19.0	3.7	8.1	16

Table 17. (continued)

5. MAJOR SEASONAL EVENTS
(CODE THE MONTH IN WHICH THE EVENT OCCURS IN THE AREA BEING EVALUATED.)
(JAN=01,FEB=02,ETC.)

A.	FIRST MONTH OF SUMMER SEASON	04	17	1-2
B.	FIRST MONTH OF WINTER SEASON	10	17	3-4
C.	INITIATION OF MAST FALL	10	17	5-6
D.	DEER'S SPRING MOLT	05	17	7-8
E.	DEER'S FALL MOLT	10	17	9-10

6. HOW MANY IDENTIFIED FUNCTIONAL SUBUNITS ARE THERE ON THE TRACT 2 17 11-12

7. PROPORTION OF CONSUMPTION OF THE THREE FORAGE CLASSES.

	WOODY BROWSE	SUCCULENTS	FRUITS	
SUMMER SEASON	.094	.793	.109	18
	1-5	6-10	11-15	
WINTER SEASON	.084	.697	.214	18
	16-20	21-25	26-30	

8. HABITAT USE IN WINTER WHEN SNOW DEPTHS ARE GREATER THAN 15. INCHES: 18 31-35

EFFECTIVE COVER

	OPEN	SAPLINGS	POLEWOODS	TREES		
		DAY			19	1-60
HARDWOODS	.01	.02	.02	.01		
	1-5	6-10	11-15	16-20		
MIXED WOODS	.02	.05	.08	.06		
	21-25	26-30	31-35	36-40		
CONIFERS	.02	.06	.32	.33		
	41-45	46-50	51-55	56-60		
		NIGHT			20	1-60
HARDWOODS	.02	.03	.03	.02		
MIXED WOODS	.02	.05	.08	.05		
CONIFERS	.02	.05	.31	.31		

Table 17. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE Upland forest.
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS SUBUNIT. .70.
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

JAN (26)	FEB (27)	MAR (28)	APR (29)	MAY (30)	JUN (31)	JUL (32)	AUG (33)	SEP (34)	OCT (35)	NOV (36)	DEC (37)
1	1	1	1	1	1	1	1	1	1	1	1

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS SUBUNIT 5.
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
1	.35	60.	90.	90.	15.	1
	1-4	5-8	9-12	13-16	17-20	21
2	.25	60.	100.	90.	15.	1
3	.20	60.	100.	90.	15.	2
4	.10	0.	100.	180	100.	2
5	.10	20.	70.	40.	10.	1
6						
7						
8						
9						
10						

Table 17. (continued)

FORAGE PRODUCTION

		MAXIMUM EXPECTED PRODUCTION: SUMMER	MAXIMUM EXPECTED PRODUCTION: WINTER	PRODUCTION AGE OF STAND: S	PRODUCTION AGE OF STAND: W	YEARS TO MAXIMUM PRODUCTION: S	YEARS TO MAXIMUM PRODUCTION: W	YEARS OF PRODUCTIVE LIFE REMAINING: S	YEARS OF PRODUCTIVE LIFE REMAINING: W
1	WB	144.	45.	60.	60.	30.	30.	135.	135.
	SC	32.	5.	60.	60.	8.	8.	110.	110.
	FR	0.	100.	0.	10.	15.	10.	33.	33.
2	WB	144.	45.	60.	60.	30.	30.	135.	135.
	SC	32.	5.	60.	60.	8.	8.	110.	110.
	FR	0.	25.	0.	10.	15.	10.	33.	33.
3	WB	144.	80.	60.	60.	30.	30.	135.	135.
	SC	32.	5.	60.	60.	8.	8.	110.	110.
	FR	0.	25.	0.	10.	5.	10.	33.	33.
4	WB	144.	80.	0.	0.	36.	36.	162.	162.
	SC	32.	5.	0.	0.	9.	9.	135.	135.
	FR	0.	25.	0.	-70.	10.	85.	50.	100.
5	WB	144.	45.	20.	20.	-6.	-6.	70.	70.
	SC	32.	5.	20.	20.	-16.	-16.	75.	75.
	FR	0.	0.	0.	0.	10.	10.	20.	20.
6	WB								
	SC								
	FR								
7	WB								
	SC								
	FR								
8	WB								
	SC								
	FR								
9	WB								
	SC								
	FR								
10	WB								
	SC								
	FR								

Table 17. (continued)

SUBUNIT EVALUATION

1. SUBUNIT CODE Farm lands.
(1-20)

2. WHAT PERCENT OF THE TOTAL TRACT IS THIS SUBUNIT. .30.
(21-25)

3. USE OF THE SUBUNIT BY DEER, PROJECTED OVER THE YEAR.

JAN (26)	FEB (27)	MAR (28)	APR (29)	MAY (30)	JUN (31)	JUL (32)	AUG (33)	SEP (34)	OCT (35)	NOV (36)	DEC (37)
1	1	1	1	1	1	1	1	1	1	1	1

4. HOW MANY HABITAT COVER TYPES ARE THERE WITHIN THIS SUBUNIT 4.
(40-41)

COVER AVAILABILITY

	% OF SUBUNIT AREA	STAND AGE YEARS	MAXIMUM HEIGHT ATTAINABLE	YEARS TO REACH MAX HT	YEARS TO MAXIMUM GROWTH RATE	SPECIES MIX CODE
	1-4	5-8	9-12	13-16	17-20	21
1	.15	0.	120.	150.	75.	2
2	.20	0.	120.	175.	75.	1
3	.15	0.	120.	180	90.	1
4	.50	60.	120	100.	30	2
5						
6						
7						
8						
9						
10						

Table 17. (continued)

FORAGE PRODUCTION

	MAXIMUM EXPECTED PRODUCTION SUMMER	MAXIMUM EXPECTED PRODUCTION WINTER	PRODUCTION: AGE OF STAND S	PRODUCTION: AGE OF STAND W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF PRODUCTIVE LIFE REMAINING S	YEARS OF PRODUCTIVE LIFE REMAINING W
1 WB	240.	100.	0.	0.	30.	30.	135.	135.
	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
SC	800.	50.	0.	0.	8.	8.	135.	135.
FR	0.	25.	0.	-50.	20.	100.	150.	150.
2 WB	240.	100.	0.	0.	30.	30.	155.	155.
SC	800.	50.	0.	0.	8.	8.	155.	155.
FR	0.	50.	0.	-50.	21.	100.	175.	175.
3 WB	240.	100.	0.	0.	30.	30.	162.	162.
SC	800.	50.	0.	0.	8.	8.	162.	162.
FR	0.	50.	0.	-50.	21.	100.	180.	180.
4 WB	144.	45.	60.	60.	-30.	-30.	100.	100.
SC	32.	5.	60.	60.	-52.	-52.	100.	100.
FR	0.	25.	0.	10.	21.	20.	120.	120.
5 WB								
SC								
FR								
6 WB								
SC								
FR								
7 WB								
SC								
FR								
8 WB								
SC								
FR								
9 WB								
SC								
FR								
10 WB								
SC								
FR								

Table 18. Computer evaluation printout for the first of two hypothetical tracts.

A BIOENERGETIC EVALUATION OF DEER HABITAT, GIVING AN

INDEX TO THE ENERGY POTENTIALLY AVAILABLE FOR THE PRODUCTION

OF DEER ON VANDERMARK TRACT

IN THE STATE OF NEW YORK ,

ALLEGANY COUNTY,

WARD TOWNSHIP AT

41.0 LATITUDE, 80.0 LONGITUDE; BEING COMPOSED OF

1200.0 ACRES OF LAND.

THE GENERAL CLIMATIC DESCRIPTION OF THIS AREA OF THE

STATE IS AS FOLLOWS:

	MEAN MONTHLY TEMPERATURE (F) MAX.	MIN.	MEAN	MEAN WEATHER STATION WIND SPEED (MPH)	MEAN MONTHLY SNOW-PACK ACCUMULATION (INCHES)
JAN	35.5	11.5	23.5	3.5	15.4
FEB	35.5	11.5	23.5	3.8	18.7
MAR	42.5	18.5	30.5	4.0	10.5
APR	53.5	25.5	39.5	4.1	4.0
MAY	65.0	33.0	49.0	3.8	0.0
JUN	73.0	45.0	59.0	3.5	0.0
JUL	75.0	51.0	63.0	3.4	0.0
AUG	75.5	51.5	63.5	3.5	0.0
SEP	74.5	46.0	60.3	3.6	0.0
OCT	72.0	30.0	51.0	3.8	0.0
NOV	58.0	24.0	41.0	3.9	0.0
DEC	46.0	16.0	31.0	3.7	6.7

THE SUMMER SEASON BEGINS IN MONTH 5 AND THE WINTER SEASON BEGINS IN MONTH 10 .

THE SPRING MOLT OF DEER IN THIS AREA PEAKS IN MONTH 5 AND THE FALL MOLT PEAKS IN MONTH 10 .

FOR EVALUATION PURPOSES THE TRACT HAS BEEN DIVIDED INTO 3 SUBUNITS, THE DESCRIPTION OF WHICH FOLLOWS.

Table 18. (continued)

PINE PLANTATIONS SUBUNIT IS

COMPOSED OF APPROXIMATELY 540. ACRES. THE EXPECTED

UTILIZATION OF THE SUBUNIT IS AS FOLLOWS:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	1	1	1	1	1	1	1	1	1	1

THE SUBUNIT HAS BEEN DIVIDED INTO 7 COVER TYPES.

COVER DESCRIPTION OF THE SUBUNIT

COVER TYPE	% OF SUBUNIT	AGE OF DOMINANT COVER	MAXIMUM HEIGHT COVER WILL GROW	YEARS TO REACH MAX. HEIGHT	YEARS TO MOST VIGOROUS GROWTH	SPECIES MIXTURE INDEX OF COVER
1	0.20	35.	100.	65.	10.	3
2	0.10	35.	100.	65.	15.	3
3	0.20	50.	100.	100.	25.	1
4	0.10	50.	100.	75.	10.	2
5	0.20	10.	120.	80.	35.	3
6	0.10	10.	120.	90.	45.	3
7	0.10	15.	70.	45.	15.	1

Table 18. (continued)

FORAGE PRODUCTION, SUCCESSIONAL DESCRIPTION OF THE SUBUNIT

COVER TYPE	FORAGE TYPE	MAXIMUM YEARLY PRODUCTION TO EXPECT		PRODUCTION: AGE OF THE COVER FOR THIS FORAGE		YEARS TO MAXIMUM PRODUCTION		YEARS OF USEFUL PRODUCTIVE LIFE REMAINING	
		S	W	S	W	S	W	S	W
1	1	80.	500.	35.	35.	-15.	-15.	55.	55.
1	2	400.	5.	35.	35.	-30.	-30.	55.	55.
1	3	0.	5.	0.	-25.	50.	50.	75.	75.
2	1	80.	500.	35.	35.	-15.	-15.	55.	55.
2	2	400.	5.	35.	35.	-30.	-30.	55.	55.
2	3	0.	5.	0.	-25.	50.	50.	75.	75.
3	1	144.	45.	70.	70.	-50.	-50.	45.	45.
3	2	32.	5.	70.	70.	-65.	-65.	45.	45.
3	3	0.	50.	0.	10.	15.	15.	40.	40.
4	1	144.	80.	50.	50.	-30.	-30.	45.	45.
4	2	32.	5.	50.	50.	-30.	-30.	45.	45.
4	3	0.	25.	0.	5.	20.	20.	45.	45.
5	1	80.	500.	10.	10.	14.	14.	100.	100.
5	2	400.	5.	10.	10.	-4.	-4.	100.	100.
5	3	0.	5.	0.	-35.	45.	45.	70.	70.
6	1	80.	500.	10.	10.	14.	14.	100.	100.
6	2	400.	5.	10.	10.	-4.	-4.	100.	100.
6	3	0.	5.	0.	-35.	45.	45.	70.	70.
7	1	144.	45.	15.	15.	9.	9.	70.	70.
7	2	32.	5.	15.	15.	-9.	-9.	70.	70.
7	3	0.	50.	0.	-30.	40.	40.	65.	65.

Table 18. (continued)

PINE PLANTATIONS SUBUNIT

EVALUATION OF THE POTENTIAL SEASONAL STANDARD DEER POPULATIONS SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL" SUCCESSION.

YEAR	STANDARD DEER POPULATION: WINTER FIRST ESTIMATE	WINTER FORAGE BASED	SUMMER FORAGE BASED	CLIMATIC SEVERITY INDEX %	PRODUCTIVITY INDICES S*	H**	SEASONAL RANGE BALANCE
0	624.	624.	585.	0.	585.	0.	0.938
5	643.	643.	487.	0.	487.	0.	0.757
10	632.	632.	384.	0.	384.	0.	0.607
15	591.	591.	291.	0.	291.	0.	0.492
20	525.	525.	213.	0.	213.	0.	0.406
25	443.	442.	151.	0.	151.	0.	0.342
30	353.	353.	104.	0.	104.	0.	0.294
35	266.	266.	69.	0.	69.	0.	0.259
40	190.	189.	44.	0.	44.	0.	0.233
45	128.	128.	27.	0.	27.	0.	0.215
50	82.	81.	17.	0.	17.	0.	0.204

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 18. (continued)

HARDWOOD HILLS SUBUNIT IS

COMPOSED OF APPROXIMATELY 300. ACRES. THE EXPECTED

UTILIZATION OF THE SUBUNIT IS AS FOLLOWS:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	1	1	1	1	1	1	1	1	1	1

THE SUBUNIT HAS BEEN DIVIDED INTO 5 COVER TYPES.

COVER DESCRIPTION OF THE SUBUNIT

:COVER: :TYPE :	% OF :SUBUNIT:	: AGE : OF :DOMINANT: : COVER	: MAXIMUM : HEIGHT COVER :WILL GROW:	:YEARS TO: REACH : MAX. HEIGHT	:YEARS TO: MOST :VIGOROUS: GROWTH	:SPECIES : :MIXTURE : INDEX : :OF COVER:
1	0.25	50.	100.	100.	25.	1
2	0.30	50.	100.	100.	25.	1
3	0.25	35.	100.	150.	75.	2
4	0.10	35.	100.	150.	75.	1
5	0.10	20.	100.	150.	80.	1

Table 18. (continued)

FORAGE PRODUCTION, SUCCESSIONAL DESCRIPTION OF THE SUBUNIT

COVER TYPE	FORAGE TYPE	MAXIMUM YEARLY PRODUCTION TO EXPECT S	MAXIMUM YEARLY PRODUCTION TO EXPECT W	PRODUCTION AGE OF THE COVER FOR THIS FORAGE S	PRODUCTION AGE OF THE COVER FOR THIS FORAGE W	YEARS TO MAXIMUM PRODUCTION S	YEARS TO MAXIMUM PRODUCTION W	YEARS OF USEFUL PRODUCTIVE LIFE REMAINING S	YEARS OF USEFUL PRODUCTIVE LIFE REMAINING W
1	1	144.	45.	50.	50.	-20.	-20.	85.	85.
1	2	32.	5.	50.	50.	-43.	-43.	85.	85.
1	3	0.	50.	0.	10.	25.	25.	50.	40.
2	1	144.	45.	50.	50.	-20.	-20.	85.	85.
2	2	32.	5.	50.	50.	-43.	-43.	85.	85.
2	3	0.	50.	0.	10.	25.	25.	50.	40.
3	1	144.	85.	35.	35.	1.	1.	120.	120.
3	2	32.	5.	35.	35.	-27.	-27.	120.	120.
3	3	0.	25.	0.	-5.	40.	40.	50.	55.
4	1	144.	45.	35.	35.	1.	1.	120.	120.
4	2	32.	5.	35.	35.	-27.	-27.	120.	120.
4	3	0.	50.	0.	-5.	20.	40.	50.	55.
5	1	144.	45.	20.	20.	15.	15.	130.	130.
5	2	32.	5.	20.	20.	-12.	-12.	130.	130.
5	3	0.	50.	0.	-15.	20.	55.	50.	65.

Table 18. (continued)

HARDWOOD HILLS SUBUNIT

EVALUATION OF THE POTENTIAL SEASONAL STANDARD DEER POPULATIONS SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL" SUCCESSION.

YEAR	STANDARD DEER POPULATION: WINTER FIRST ESTIMATE	WINTER FORAGE BASED	SUMMER FORAGE BASED	CLIMATIC SEVERITY INDEX %	PRODUCTIVITY INDICES: S*	H**	SEASONAL RANGE BALANCE
0	88.	88.	154.	0.	88.	66.	1.749
5	82.	82.	139.	0.	82.	57.	1.702
10	74.	74.	123.	0.	74.	49.	1.663
15	65.	65.	105.	0.	65.	41.	1.632
20	55.	55.	89.	0.	55.	33.	1.607
25	46.	46.	73.	0.	46.	27.	1.589
30	37.	37.	58.	0.	37.	21.	1.577
35	29.	29.	46.	0.	29.	17.	1.570
40	23.	22.	35.	0.	22.	13.	1.570
45	17.	17.	26.	0.	17.	10.	1.575
50	12.	12.	19.	0.	12.	7.	1.587

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 18. (continued)

OLD FARM LANDS SUBUNIT IS

COMPOSED OF APPROXIMATELY 360. ACRES. THE EXPECTED

UTILIZATION OF THE SUBUNIT IS AS FOLLOWS:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	1	1	1	1	1	1	1	1	1	1

THE SUBUNIT HAS BEEN DIVIDED INTO 6 COVER TYPES.

COVER DESCRIPTION OF THE SUBUNIT

COVER TYPE	% OF SUBUNIT	AGE OF DOMINANT COVER	MAXIMUM HEIGHT COVER WILL GROW	YEARS TO REACH MAX. HEIGHT	YEARS TO MOST VIGOROUS GROWTH	SPECIES MIXTURE INDEX OF COVER
1	0.35	0.	100.	180.	100.	2
2	0.20	20.	100.	150.	80.	1
3	0.10	0.	100.	180.	99.	1
4	0.15	0.	100.	180.	99.	2
5	0.15	75.	100.	50.	10.	2
6	0.05	75.	100.	50.	10.	1

Table 18. (continued)

FORAGE PRODUCTION, SUCCESSIONAL DESCRIPTION OF THE SUBUNIT

COVER TYPE	FORAGE TYPE	MAXIMUM YEARLY PRODUCTION TO EXPECT S	W	PRODUCTION AGE OF THE COVER FOR THIS FORAGE S	W	YEARS TO MAXIMUM PRODUCTION S	W	YEARS OF USEFUL PRODUCTIVE LIFE REMAINING S	W
1	1	144.	80.	0.	0.	36.	36.	162.	162.
1	2	32.	5.	0.	0.	9.	9.	135.	135.
1	3	0.	25.	0.	-70.	45.	85.	50.	100.
2	1	144.	45.	20.	20.	10.	10.	130.	130.
2	2	32.	5.	20.	20.	-12.	-12.	85.	85.
2	3	0.	50.	0.	-50.	25.	65.	50.	80.
3	1	144.	45.	0.	0.	36.	36.	162.	162.
3	2	32.	5.	0.	0.	9.	9.	135.	135.
3	3	0.	50.	0.	-70.	45.	85.	50.	100.
4	1	144.	80.	0.	0.	36.	36.	162.	162.
4	2	32.	5.	0.	0.	9.	9.	135.	135.
4	3	0.	25.	0.	-70.	20.	85.	50.	100.
5	1	144.	80.	75.	75.	-50.	-50.	40.	40.
5	2	32.	5.	75.	75.	-69.	-69.	20.	20.
5	3	0.	25.	0.	5.	20.	20.	50.	45.
6	1	144.	45.	75.	75.	-50.	-50.	40.	40.
6	2	32.	5.	75.	75.	-69.	-69.	20.	20.
6	3	0.	50.	0.	5.	20.	20.	50.	45.

Table 18. (continued)

OLD FARM LANDS SUBUNIT

EVALUATION OF THE POTENTIAL SEASONAL STANDARD DEER POPULATIONS SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL" SUCCESSION.

YEAR	STANDARD DEER POPULATION: WINTER FIRST ESTIMATE	WINTER FORAGE BASED	SUMMER FORAGE BASED	CLIMATIC SEVERITY INDEX %	PRODUCTIVITY INDICES: S*	H**	SEASONAL RANGE BALANCE
0	21.	21.	49.	0.	21.	28.	2.301
5	51.	51.	117.	0.	51.	66.	2.290
10	72.	72.	145.	0.	72.	73.	2.012
15	89.	89.	163.	0.	89.	73.	1.821
20	102.	102.	172.	0.	102.	70.	1.686
25	111.	111.	176.	0.	111.	65.	1.588
30	115.	115.	174.	0.	115.	59.	1.515
35	114.	114.	167.	0.	114.	53.	1.460
40	110.	110.	156.	0.	110.	46.	1.419
45	102.	102.	142.	0.	102.	40.	1.387
50	93.	92.	126.	0.	92.	34.	1.363

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 18. (continued)

VANDERMARK TRACT
HABITAT EVALUATION SUMMARY FOR A 50 YEAR PLANNING PERIOD
ASSUMING NATURAL SUCCESSION

:YEAR:	ESTIMATE: OF : WINTER : SDP	FORAGE: BASED : WINTER: SDP	FORAGE: BASED : SUMMER: SDP	MEAN : SIGHTABLE: INDEX*	: HARVESTABLE: INDEX**	:SEASONAL: BALANCE : INDEX :
0	734.	733.	789.	695.	94.	1.076
5	776.	776.	743.	620.	123.	0.958
10	778.	778.	652.	530.	122.	0.838
15	745.	745.	559.	445.	114.	0.750
20	683.	682.	474.	371.	104.	0.695
25	599.	599.	400.	308.	92.	0.667
30	505.	504.	336.	255.	80.	0.666
35	410.	409.	281.	212.	69.	0.688
40	322.	322.	235.	176.	59.	0.731
45	247.	247.	196.	146.	49.	0.793
50	187.	186.	162.	121.	41.	0.870
50 YEAR TOTAL	29930.	29901.	24126.	19391.	4735.	0.807

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 18. (continued)

A TABLE OF ALTERNATIVE INDICES IS PRESENTED BELOW FOR THE VANDERMARK TRACT FOR THREE SELECTED LEVELS OF MAXIMUM UTILIZABLE RANGE BALANCE AND EIGHT LEVELS OF RANGE UTILIZATION HARVEST RATES.

RANGE UTILIZATION HARVEST RATE	MAXIMUM UTILIZABLE RANGE BALANCE 1.5		2.0		2.5	
	S	H	S	H	S	H
1.0:	24126.	0.:	24126.	0.:	24126.	0.:
1.2:	20105.	4021.:	20105.	4021.:	20105.	4021.:
1.4:	17233.	6893.:	17233.	6893.:	17233.	6893.:
1.6:	16084.	8042.:	15079.	9047.:	15079.	9047.:
1.8:	16084.	8042.:	13403.	10723.:	13403.	10723.:
2.0:	16084.	8042.:	12063.	12063.:	12063.	12063.:
2.2:	16084.	8042.:	12063.	12063.:	10966.	13160.:
2.4:	16084.	8042.:	12063.	12063.:	10052.	14073.:

Table 19. Computer evaluation printout for the second of two hypothetical tracts.

A BIOENERGETIC EVALUATION OF DEER HABITAT, GIVING AN

INDEX TO THE ENERGY POTENTIALLY AVAILABLE FOR THE PRODUCTION

OF DEER ON TOMPKINS TRACT

IN THE STATE OF NEW YORK ,

TOMPKINS COUNTY,

TOWNSHIP AT

41.5 LATITUDE, 79.0 LONGITUDE; BEING COMPOSED OF

1500.0 ACRES OF LAND.

THE GENERAL CLIMATIC DESCRIPTION OF THIS AREA OF THE

STATE IS AS FOLLOWS:

	MEAN MONTHLY TEMPERATURE (F) MAX.	MIN.	MEAN	MEAN WEATHER STATION WIND SPEED (MPH)	MEAN MONTHLY SNOW-PACK ACCUMULATION (INCHES)
JAN	37.5	13.5	25.5	3.7	17.8
FEB	37.5	13.5	25.5	3.8	23.2
MAR	46.0	22.0	34.0	4.0	10.8
APR	56.0	28.0	42.0	4.1	4.2
MAY	69.0	37.0	53.0	3.8	0.0
JUN	76.5	48.5	62.5	3.5	0.0
JUL	77.5	53.5	65.5	3.4	0.0
AUG	77.5	53.5	65.5	3.5	0.0
SEP	76.5	50.5	63.5	3.6	0.0
OCT	76.0	33.0	54.5	3.8	0.0
NOV	62.5	26.5	44.5	3.9	0.0
DEC	49.0	19.0	34.0	3.7	8.1

THE SUMMER SEASON BEGINS IN MONTH 4 AND THE WINTER SEASON BEGINS IN MONTH 10 .

THE SPRING MOLT OF DEER IN THIS AREA PEAKS IN MONTH 5 AND THE FALL MOLT PEAKS IN MONTH 10 .

FOR EVALUATION PURPOSES THE TRACT HAS BEEN DIVIDED INTO 2 SUBUNITS, THE DESCRIPTION OF WHICH FOLLOWS.

Table 19. (continued)

UPLAND FORESTS SUBUNIT IS COMPOSED OF APPROXIMATELY 1050. ACRES. THE EXPECTED UTILIZATION OF THE SUBUNIT IS AS FOLLOWS:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	1	1	1	1	1	1	1	1	1	1

THE SUBUNIT HAS BEEN DIVIDED INTO 5 COVER TYPES.

COVER DESCRIPTION OF THE SUBUNIT

COVER TYPE	% OF SUBUNIT	AGE OF DOMINANT COVER	MAXIMUM HEIGHT COVER WILL GROW	YEARS TO REACH MAX. HEIGHT	YEARS TO MOST VIGOROUS GROWTH	SPECIES MIXTURE INDEX OF COVER
1	0.35	60.	90.	90.	15.	1
2	0.25	60.	100.	90.	15.	1
3	0.20	60.	100.	90.	15.	2
4	0.10	0.	100.	180.	100.	2
5	0.10	20.	70.	40.	10.	1

Table 19. (continued)

FORAGE PRODUCTION, SUCCESSIONAL DESCRIPTION OF THE SUBUNIT

COVER TYPE	FORAGE TYPE	MAXIMUM YEARLY PRODUCTION TO EXPECT		PRODUCTION: AGE OF THE COVER FOR THIS FORAGE		YEARS TO MAXIMUM PRODUCTION		YEARS OF USEFUL PRODUCTIVE LIFE REMAINING	
		S	W	S	W	S	W	S	W
1	1	144.	45.	60.	60.	30.	30.	135.	135.
1	2	32.	5.	60.	60.	8.	8.	110.	110.
1	3	0.	100.	0.	10.	15.	10.	33.	33.
2	1	144.	45.	60.	60.	30.	30.	135.	135.
2	2	32.	5.	60.	60.	8.	8.	110.	110.
2	3	0.	25.	0.	10.	15.	10.	33.	33.
3	1	144.	80.	60.	60.	30.	30.	135.	135.
3	2	32.	5.	60.	60.	8.	8.	110.	110.
3	3	0.	25.	0.	10.	5.	10.	33.	33.
4	1	144.	80.	0.	0.	36.	36.	162.	162.
4	2	32.	5.	0.	0.	9.	9.	135.	135.
4	3	0.	25.	0.	-70.	10.	85.	50.	100.
5	1	144.	45.	20.	20.	-6.	-6.	70.	70.
5	2	32.	5.	20.	20.	-16.	-16.	75.	75.
5	3	0.	0.	0.	0.	10.	10.	20.	20.

Table 19. (continued)

UPLAND FORESTS SUBUNIT

EVALUATION OF THE POTENTIAL SEASONAL STANDARD DEER POPULATIONS SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL" SUCCESSION.

YEAR	STANDARD DEER POPULATION: WINTER FIRST ESTIMATE	WINTER FORAGE BASED	SUMMER FORAGE BASED	CLIMATIC SEVERITY INDEX %	PRODUCTIVITY INDICES S*	H**	SEASONAL RANGE BALANCE
0	566.	566.	539.	0.	539.	0.	0.952
5	654.	654.	612.	0.	612.	0.	0.936
10	726.	726.	658.	0.	658.	0.	0.906
15	784.	784.	688.	0.	688.	0.	0.878
20	827.	827.	705.	0.	705.	0.	0.853
25	851.	851.	706.	0.	706.	0.	0.830
30	853.	853.	691.	0.	691.	0.	0.810
35	834.	834.	661.	0.	661.	0.	0.793
40	792.	792.	616.	0.	616.	0.	0.777
45	731.	731.	558.	0.	558.	0.	0.764
50	655.	655.	493.	0.	493.	0.	0.752

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 19. (continued)

FARM LANDS SUBUNIT IS

COMPOSED OF APPROXIMATELY 450. ACRES. THE EXPECTED

UTILIZATION OF THE SUBUNIT IS AS FOLLOWS:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	1	1	1	1	1	1	1	1	1	1

THE SUBUNIT HAS BEEN DIVIDED INTO 4 COVER TYPES.

COVER DESCRIPTION OF THE SUBUNIT

COVER TYPE	% OF SUBUNIT	AGE OF DOMINANT COVER	MAXIMUM HEIGHT COVER WILL GROW	YEARS TO REACH MAX. HEIGHT	YEARS TO MOST VIGOROUS GROWTH	SPECIES MIXTURE INDEX OF COVER
1	0.15	0.	120.	150.	75.	2
2	0.20	0.	120.	175.	75.	1
3	0.15	0.	120.	180.	90.	1
4	0.50	60.	120.	100.	30.	2

FORAGE PRODUCTION, SUCCESSIONAL DESCRIPTION OF THE SUBUNIT

COVER TYPE	FORAGE TYPE	MAXIMUM YEARLY PRODUCTION TO EXPECT		PRODUCTION: AGE OF THE COVER FOR THIS FORAGE		YEARS TO MAXIMUM PRODUCTION		YEARS OF USEFUL PRODUCTIVE LIFE REMAINING	
		S	W	S	W	S	W	S	W
1	1	240.	100.	0.	0.	30.	30.	135.	135.
1	2	800.	50.	0.	0.	8.	8.	135.	135.
1	3	0.	25.	0.	-50.	20.	100.	150.	150.
2	1	240.	100.	0.	0.	30.	30.	155.	155.
2	2	800.	50.	0.	0.	8.	8.	155.	155.
2	3	0.	50.	0.	-50.	21.	100.	175.	175.
3	1	240.	100.	0.	0.	30.	30.	162.	162.
3	2	800.	50.	0.	0.	8.	8.	162.	162.
3	3	0.	50.	0.	-50.	21.	100.	180.	180.
4	1	144.	45.	60.	60.	-30.	-30.	100.	100.
4	2	32.	5.	60.	60.	-52.	-52.	100.	100.
4	3	0.	25.	0.	10.	21.	20.	120.	120.

Table 19. (continued)

FARM LANDS SUBUNIT

EVALUATION OF THE POTENTIAL SEASONAL STANDARD DEER POPULATIONS SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL" SUCCESSION.

YEAR	STANDARD DEER POPULATION: WINTER FIRST ESTIMATE	WINTER FORAGE BASED	SUMMER FORAGE BASED	CLIMATIC SEVERITY INDEX %	PRODUCTIVITY INDICES: S*	H**	SEASONAL RANGE BALANCE
0	78.	78.	72.	0.	72.	0.	0.921
5	424.	424.	1329.	0.	424.	771.	3.137
10	504.	504.	1430.	0.	504.	918.	2.836
15	534.	534.	1352.	0.	534.	818.	2.533
20	535.	535.	1206.	0.	535.	671.	2.255
25	516.	516.	1038.	0.	516.	522.	2.011
30	483.	483.	871.	0.	483.	388.	1.805
35	439.	439.	716.	0.	439.	278.	1.633
40	388.	388.	579.	0.	388.	191.	1.493
45	334.	334.	461.	0.	334.	127.	1.380
50	280.	280.	361.	0.	280.	81.	1.290

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 19. (continued)

TOMPKINS TRACT
HABITAT EVALUATION SUMMARY FOR A 50 YEAR PLANNING PERIOD
ASSUMING NATURAL SUCCESSION

YEAR	ESTIMATE OF WINTER SDP	FORAGE BASED WINTER SDP	FORAGE BASED SUMMER SDP	MEAN SIGHTABLE INDEX*	HARVESTABLE INDEX**	SEASONAL BALANCE INDEX
0	644.	644.	611.	611.	0.	0.949
5	1078.	1078.	1941.	1036.	771.	1.801
10	1230.	1230.	2088.	1162.	918.	1.697
15	1318.	1318.	2041.	1222.	818.	1.549
20	1362.	1361.	1911.	1240.	671.	1.404
25	1367.	1367.	1744.	1222.	522.	1.276
30	1336.	1336.	1562.	1174.	388.	1.169
35	1273.	1272.	1377.	1099.	278.	1.082
40	1180.	1180.	1195.	1004.	191.	1.012
45	1065.	1065.	1019.	892.	127.	0.957
50	935.	935.	853.	772.	81.	0.913
50 YEAR TOTAL	63938.	63926.	81707.	57169.	23827.	1.278

* POTENTIAL SIGHTABLE STANDARD DEER INDEX

** POTENTIAL HARVESTABLE STANDARD DEER INDEX - WHEN THIS INDEX IS ZERO, A POSITIVE PRODUCTIVITY INDEX IS ACHIEVED ONLY AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUCTIVITY INDEX; THE CONVERSION CAN BE MADE BY USING THE SEASONAL RANGE BALANCE INDEX AND EQUATIONS PRESENTED IN THE TEXT

Table 19. (continued)

A TABLE OF ALTERNATIVE INDICES IS PRESENTED BELOW FOR THE TOMPKINS TRACT FOR THREE SELECTED LEVELS OF MAXIMUM UTILIZABLE RANGE BALANCE AND EIGHT LEVELS OF RANGE UTILIZATION HARVEST RATES.

RANGE UTILIZATION HARVEST RATE	MAXIMUM UTILIZABLE RANGE BALANCE 1.5 S	H	2.0 S	H	2.5 S	H
1.0:	63926.	0.:	63926.	0.:	63926.	0.:
1.2:	63926.	12785.:	63926.	12785.:	63926.	12785.:
1.4:	58362.	23345.:	58362.	23345.:	58362.	23345.:
1.6:	54471.	27236.:	51067.	30640.:	51067.	30640.:
1.8:	54471.	27236.:	45393.	36314.:	45393.	36314.:
2.0:	54471.	27236.:	40853.	40853.:	40853.	40853.:
2.2:	54471.	27236.:	40853.	40853.:	37139.	44567.:
2.4:	54471.	27236.:	40853.	40853.:	34044.	47662.:

RESULTS

A bioenergetic-based land evaluation system of the potential productivity of deer habitat, was developed and programmed in Fortran IV for computer use. The card program, operated on the IBM 370 computer, required approximately 48 kilobytes and 2.3 seconds to compile. A work form was constructed for the tabulation and punching of data required by the program. Fig. 6 outlines the general procedure followed in using the model.

The result of the evaluation of a tract of land is a series of potential productivity indices given in terms of standard deer units. This unit is a measure of energy available for maintaining or growing deer under the environmental conditions specified for the land under study.

The two indices directly usable as criteria of potential productivity for use in decision-making, are the potential sightable standard deer index (X_s or SDP_w) and the potential harvestable standard deer index (X_h, Equation 25). These indices should be taken for the most likely range utilization harvest rate and maximum utilizable range balance. For an evaluation of the relative cost effectiveness of acquiring one of two tracts of land, the productivity of sightable and harvestable standard deer units can be considered two separate economic enterprises, managed at levels which will produce the greatest total quality production (Equation 17).

The cost effectiveness index of a tract of land being considered for acquisition can be calculated by dividing the purchase price of the land by the potential 50-year total quality productivity value (Equation

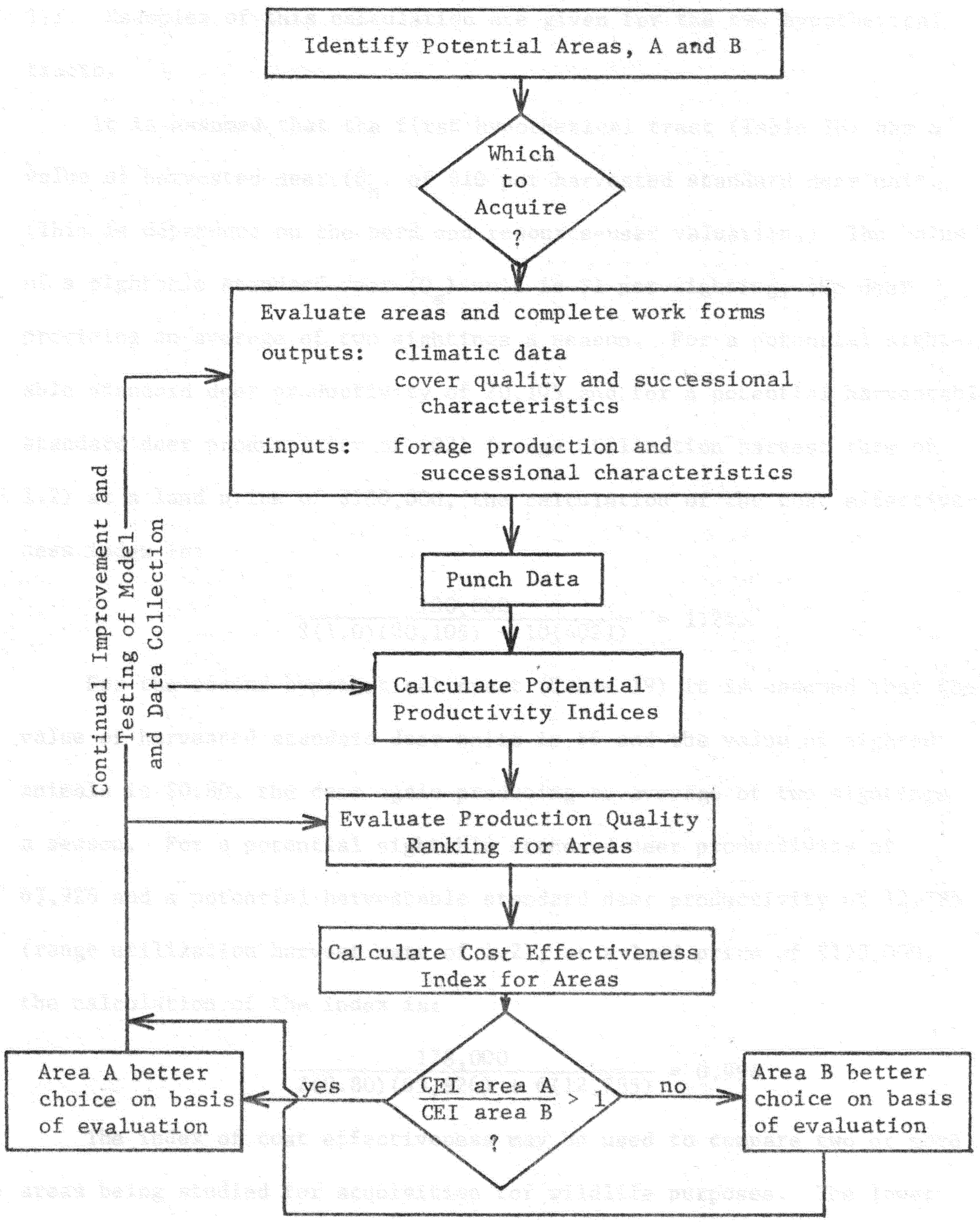

Fig. 6. Outline of the use of the potential productivity model.

17). Examples of this calculation are given for the two hypothetical tracts.

It is assumed that the first hypothetical tract (Table 18) has a value of harvested deer (Q_h) of $10 per harvested standard deer unit. (This is dependent on the herd and resource-user valuation.) The value of a sightable standard deer (Q_s) unit is $1 per sighting, the deer providing an average of two sightings a season. For a potential sightable standard deer productivity of 20,105 and for a potential harvestable standard deer productivity of 4021 (range utilization harvest rate of 1.2) at a land price of $100,000, the calculation of the cost effectiveness index is:

$$\frac{100,000}{2(1.0)(20,105) + 10(4021)} = 1.243$$

For the second hypothetical tract (Table 19) it is assumed that the value of harvested standard deer units is $6 and the value of sighted animals is $0.80, the deer again producing an average of two sightings a season. For a potential sightable standard deer productivity of 63,926 and a potential harvestable standard deer productivity of 12,785 (range utilization harvest rate of 1.2), at a land price of $178,000, the calculation of the index is:

$$\frac{178,000}{2(0.80)(63,926) + 6(12,785)} = 0.994$$

The index of cost effectiveness may be used to compare two or more areas being studied for acquisition for wildlife purposes. The lower number indicates the increased likelihood of greater return in energy available for wildlife production per dollar expended, if other considerations are equal. The index of cost-effectiveness is in units of dollars per energy unit (standard deer units), for maintaining sightable and/or harvestable deer.

This productivity model has been developed for evaluating the cost-effectiveness of acquiring land on the basis of its potential natural productivity. It is the author's opinion that a similar scheme can be developed for evaluating the cost-effectiveness of alternative management enterprises.

DISCUSSION

An aim of wildlife management is to understand the interactions of wild animal species, their habitat, and man, well enough to manipulate the species populations, habitat, and the resource-user to suit the needs of society. In order to accomplish this aim, modeling of the interplay of these three facets of wildlife production is needed.

Productivity models have been used for wildlife management decision-making in the past. Life equations of a species and knowledge of the species' reproductive success in the year have been used to set daily and seasonal bag limits on waterfowl and upland game. However, long-term management development requires more detailed evaluation than is accomplished by such models.

A wildlife productivity model based on the yearly nesting success uses data which integrates all variables affecting the population since the previous fall. Mott's (1960) empirical productivity model for domestic stock also uses data which integrates animal and pasture variables. A model of wildlife productivity useful for long-term management could use similar data, if the data were readily available. However, the model developed here takes an alternative approach. The approach used is to take data such as forage production and cover succession, which integrate many habitat factors affecting the plant community, and some data which are directly measurable and distinct, such as monthly temperatures and the initiation of seasons and integrate them to calculate the desired potential productivity indices.

The goal of the modeling effort was one of improved management decision-making. It was at once both for description and for application.

The former was only necessary for the latter. The goal was for large areas, over long periods, with the decision being a "play" (in the game theoretic sense) against the environment, the population, and the changing concepts of utility and their articulation by man. The methods were constrained by conditions requiring minimum periods of observation on unowned land, minimum investments in study of lands only a portion of which would be acquired, and maximum compatibility with an on-going system of land acquisition decision-making. The approach adopted was that of determining how to improve a decision that is going to be made anyway; how to provide the inputs and structure for reducing at least one major component of an extremely complex decision to an index or decision algorithm that would improve budget allocations for the wildlife resource.

The potential productivity indices are in terms of energy available for maintaining a standard deer. This calculated standard deer unit makes the model applicable over varied climatic and range conditions. The SDP is calculated for the summer and winter season so that both the potential sightable and harvestable productivity can be evaluated.

A prevalent idea is that the carrying capacity of winter range is so much lower than the carrying capacity of summer range that the summer range need not be considered. However, this may be a dangerous assumption. In many habitats, it is possible for the range conditions of the two seasons to be closer than anticipated. (A good example might be an extensive area of mixed oak forest having scant undergrowth.) If, under such conditions, management policies attempt to maintain winter deer populations near the maximum allowable stocking rate, the fawn crop may be jeopardized. To maintain and grow a healthy and vigorous fawn crop, sufficient energy is required in the summer range, beyond the energy for maintaining the standard requirements of the adults, to provide the energy for lactating does and growing fawns. When summer range has an SDP similar to the winter range, there will not be sufficient excess energy available for maintaining a growing fawn crop. Formulae and tables are presented for calculation of the differences in energy (in standard deer units) required by a given population in the two seasons. However, the distribution of vegetative growth over the summer and the relation of foraging to subsequent plant regrowth was not considered. Such factors may exert substantial influence on the use of the summer forage by the doe and fawn segment of the population. The degree of importance of these plant growth factors should be determined.

The energy basis of the potential productivity model affords an integrated result for making predictions. There are variables which have been omitted from consideration, such as topographic effect on the energy requirement for activity and topographic shading on radiation of habitat and its effect on behavior. Reasons for omitting these variables were discussed earlier. Consideration of topographic shadows was undertaken initially. However, due to lack of data, it was later omitted. Appendix II presents a system of measuring shadows cast by topographic features. This may be of value in some areas for delineating habitats which will not be used in winter months by deer.

A model of energy available for deer productivity including the major variables affecting the energy balance of deer could become an important wildlife management tool if accepted by wildlife biologists and managers. The results of proposed management projects could be specified in terms of energy made available for conversion into production of a game or non-game species. The model discussed here considers energy available to deer in habitats undergoing natural succession. The rationale is that, for acquisition purposes, the land providing the greatest energy for productivity (over natural succession) will also provide the greatest energy for productivity under managed conditions for the same investment. For example, of two areas, the area expected to have a lower productivity when no management is undertaken, will require the first portion of management investment, when managed, to bring its production up to the production level of the second area. This initial management investment needs to be added on to the purchase price of the first tract, if it will be managed, to evaluate the cost-effectiveness index of the area. Beyond the point at which equal productivity is achieved, if climate, soil, topography, and other external factors are the same, a management investment on either area should return the same energy for production per dollar expended.

The model can be adapted to evaluate the energy made available over time for production by different management projects which affect forage or cover production.

In its present form the model has several major, untested assumptions, and has based some parts on scant information. However, it is believed that the model in its present form can afford the manager and wildlife agency decision-maker an opportunity to familiarize themselves with some of the important aspects of energy conversion into wildlife production, to gain more understanding of the energy required by a population for the production of fawns, and to improve understanding of the conversion of a forage energy base into both consumptive and non-consumptive wildlife resources.

LITERATURE CITED

Aspinall, W. N. (ed.) 1970. One-third of the nation's land. Report of the Public Land Law Review Commission to the President. U. S. Government Printing Office. Washington, D. C. 342 p.

Blaxter, K. L., N. McC. Graham, F. W. Wainman, and D. G. Armstrong. 1959. Environmental temperature, energy metabolism, and heat regulation in sheep. II. The partition of heat losses in closely clipped sheep. J. Agric. Sci. 52:25-40.

_______ 1962. The energy metabolism of ruminants. Hutchinson and Co., Ltd. London. 329 p.

Bolte, J. R., J. A. Hair and J. Fletcher. 1970. White-tailed deer mortality following tissue destruction induced by lone star ticks. J. Wildl. Mgmt. 34(3):546-552.

Cain, S. A. (chairman) 1972. Predator control - 1971. Report to the Council on Environmental Quality and the Department of the Interior by the Advisory Committee on Predator Control. Univ. Michigan. Ann Arbor, Mich. 207 p.

Churchman, C. W., R. L. Ackoff, and E. L. Arnoff. 1957. Introduction to operations research. John Wiley and Sons, Inc. New York, N. Y. 645 p.

Coblentz, B. E. 1970. Food habits of George Reserve deer. J. Wildl. Mgmt. 34(3):535-540.

Crampton, E. W. and L. E. Harris. 1969. Applied animal nutrition. W. H. Freeman and Co. San Francisco, Calif. XXIV 753 p.

Dasmann, R. F. 1964. Wildlife biology. John Wiley and Sons, Inc. New York, N. Y. 231 p.

Duvendeck, J. P. 1964. The value and prediction of acorn crops for deer. Ph.D. thesis, unpubl. Michigan State Univ. Ann Arbor, Mich. 83 p.

Forbes, E. B., L. F. Marcy, A. L. Voris, and C. E. French. 1941. The digestive capacities of the white-tailed deer. J. Wildl. Mgmt. 5(1):108-114.

Gates, D. M. 1970. Animal climates (where animals must live). Envir. Res. 3(2):132-144.

Geiger, R. 1965. The climate near the ground. Harvard Univ. Press. Cambridge, Mass. XIV + 611 p.

Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. J. Wildl. Mgmt. 34(1):15-23.

Giles, R. H., Jr. and N. Snyder. 1970. Simulation techniques in wildlife habitat management, p. 23-50. In D. A. Jamison (ed.) Modeling and systems analysis in range science. Range Science Dept. Science Series #5. Colorado State Univ. Fort Collins, Colo. 134 p.

Grange, W. B. 1949. The way to game abundance. Charles Scribner's Sons. New York, N. Y. 365 p.

Harlow, R. F. 1971. Foods of white-tailed deer in the Southeast based on rumen analysis. M. S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. VIII + 72 p.

Hayne, H. N. 1969. The use of models in resource management, p. 119-122. In L. K. Halls (ed.) White-tailed deer in the southern forest habitat. Southern Forest Exp. Sta. Nacogdoches, Texas. 130p.

Heezer, K. L. and J. R. Tester. 1967. Evaluation of ratio tracking by triangulation with special reference to deer movements. J. Wildl. Mgmt. 31(1):124-141.

Hough, W. A. 1969. Caloric value of some forest fuels of the southern United States. U.S.D.A. For. Serv. Res. Note SE-120. S.E. Forest Exp. Sta. Asheville, N. C. 6 p.

Kelsall, J. P. and W. Prescott. 1971. Moose and deer behavior in snow. Canadian Wildlife Service Report Series No. 15. Ottawa, Canada. 27 p.

Kelsall, J. P. and E. S. Telfer. 1971. Studies of the physical adaptation of big game for snow, p. 134-146. In A. O. Haugen (ed.) Snow and ice in relation to wildlife and recreation symposium. Iowa State Univ. Ames, Iowa. 280 p.

Kirkpatrick, R. L., J. P. Fontenot, and R. F. Harlow. 1961. Seasonal changes in rumen chemical components as related to forages consumed by white-tailed deer of the Southeast. Trans. N. Amer. Wildl. and Nat. Res. Conf. 34:229-238.

Kruzan, J. C. and R. J. Harding. 1970. Controlled hunter access to private agricultural land in central New York. Trans. N. E. Fish and Wildl. Conf. 27:199-209.

Lime, D. W. and C. T. Cushwa. 1969. Wildlife esthetics and auto campers in the Superior National Forest. U.S.D.A. Forest Serv. Res. Pap. NC-32. N. Central Forest Exp. Sta. St. Paul, Minn. 8 p.

Lindeman, R. L. 1942. The trophic-dynamic aspect of ecology. Ecology. 23-399-418.

Lobdell, C. H. 1972. MAST: a budget allocation system for wildlife management. Ph.D. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. VII + 227 p.

Lull, H. W. and I. C. Relgner. 1967. Radiation measurements by various instruments in the open and in the forest. U.S.D.A. For. Serv. Res. Paper NE-84. N.E. Forest Exp. Sta. Upper Darby, Pa. 21 p.

Marchington, R. L. 1968. Telemetric study of white-tailed deer movement, ecology, and ethology in the Southeast. Ph.D. thesis, unpubl. Auburn Univ. Auburn, Ala. 138 p.

Mech, L. D. and L. D. Frenzel, Jr. 1971. An analysis of the age, sex and condition of deer killed by wolves in northeastern Minnesota, p. 35-50. In L. D. Mech and L. D. Frenzel (ed.) Ecological studies of the timber wolf in northeastern Minnesota. U.S.D.A. Forest Serv. Res. Pap. NC-52. N. Central Forest Exp. Sta. St. Paul, Minn. 62 p.

Mechler, J. L. 1970. Factors influencing the white-tailed deer harvest in Virginia. M.S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. VIII + 106 p.

Moen, A. N. 1966. Factors affecting the energy exchange and movements of white-tailed deer in western Minnesota. Ph.D. thesis, unpubl. Univ. of Minnesota. St. Paul, Minn. 121 p.

_______ 1968a. Energy Balance of white-tailed deer in the winter. Trans. N. Amer. Wildl. and Nat. Res. Conf. 33:224-236.

_______ 1968b. Surface temperatures and radiant heat loss from white-tailed deer. J. Wildl. Mgmt. 32(2):338-344.

_______ and K. E. Evans. 1971. The distribution of energy in realtion to snow cover in wildlife habitat, p. 147-162. In A. O. Haugen (ed.) Proc. snow and ice in relation to wildlife and recreation symposium. Iowa State Univ. Ames, Iowa. 280 p.

Morgan, E. F. 1971. Decisions under uncertainty by state fish and wildlife agencies. M.S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. V + 94 p.

Mott, G. O. 1960. Grazing pressure and the measurement of pasture production. Proc. Intern. Grassland Congr. 8:607-611.

Murphy, D. A. 1970. Deer range appraisal in the Midwest, p. 2-10. In L. J. Verme (chairman). White-tailed deer in the Midwest: A symposium. U.S.D.A. Forest Ser. Res. Pop. NC-39. N. Central Forest Exp. Sta. St. Paul, Minn. 34 p.

Murphy, D. A. and H. S. Crawford. 1970. Wildlife foods and understory vegetation in Missouri's national forests. Missouri Dept. of Conserv. Tech Bull. No. 4. 47 p.

Naylor, T. H., J. L. Balintfy, D. S. Burdick, and K. Chu. 1966. Computer simulation techniques. John Wiley and Sons, Inc. New York, N. Y. 352 p.

Odum, H. T. 1956. Primary production in flowing waters. Limnol. and Oceanogr. 1:102-117.

Ozoga, J. J. 1968. Variations in microclimate in a conifer swamp deer yard in northern Michigan. J. Wildl. Mgmt. 32(3):574-585.

_______ and L. J. Verme. 1970. Winter feeding patterns of penned white-tailed deer. J. Wildl. Mgmt. 34(2):431-439.

Perry, M. C. and R. H. Giles, Jr. 1970. Studies of deer-related dog activity in Virginia. Proc. Southeastern Ass. of Game and Fish Comm. 24:64-73.

Petersen, R. G., H. L. Lucas, and G. O. Mott. 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron. J. 57:27-30.

Petrides, G. A. 1941. Observations on the relative importance of winter deer browse species in central New York. J. Wildl. Mgmt. 5(4):416-422.

Poux, R. J., Jr. 1972. Deer behavior as it effects sex and age ratio counts. M. S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. VII + 42 p.

Rasmussen, D. I. and E. R. Doman. 1947. Planning of management programs for Western big-game herds. Trans. N. Amer. Wildl. Conf. 12:204-211.

Rayburn, Susan B. 1972. Analysis of major factors influencing decisions to acquire public lands for wildlife. M.S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va.

Riffe, J. E. 1970. Computer simulation of deer populations. M.S. thesis, unpubl. Penn. State Univ. University Park, Pa. 98 p.

Rongstad, O. J. and J. R. Tester. 1969. Movements and habitat use of white-tailed deer in Minnesota. J. Wildl. Mgmt. 33(2):366-379.

Ruhl, H. D. 1956. Hunting the white-tail. In W. P. Taylor (ed.) The deer of North America. Stockpole Co. Harrisburg, Pa. 668 p.

Sellers, W. D. 1965. Physical Climatology. Univ. Chicago Press. Chicago, Ill. VII + 272 p.

Short, H. L. 1966. Effects of cellulose levels on the apparent digestibility of feeds eaten by mule deer. J. Wildl. Mgmt. 30(1):163-167.

Silver, Helenette, N. F. Colovas, J. B. Holter, and H. H. Hayes. 1969. Fasting metabolism of white-tailed deer. J. Wildl. Mgmt. 33(3): 490-498.

_______, _______, _______, _______. 1971. Effect of falling temperature on heat production in fasting white-tail deer. J. Wildl. Mgmt. 35(1):37-46.

Slobodkin, L. B. 1960. Ecological energy relationships at the population level. Amer. Naturalist. 44:213-236.

Smart, C. W. 1970. A computer simulation of wildlife rabies epizootics and an analysis of incidence patterns. M.S. thesis, unpubl. Va. Polyt. Inst. and State Univ. Blacksburg, Va. IX + 126 p.

Snider, C. C. 1971. In vitro degestibility of 41 preferred Missouri deer foods and three unpalatable plants. M. A. thesis, unpubl. Univ. of Missouri. Columbia, Mo. 68 p.

Stevens, Deborah and A. N. Moen. 1970. Functional aspects of wind as an ecological and thermal force. Trans. N. Amer. Wildl. and Nat. Res. Conf. 35:106-114.

Swanson, G. A. 1970. Legislations and administration. In D. L. Allen (ed.) Land use and wildlife resources. Nat. Acad. Sci. Washington, D. C. 262 p.

Ullrey, D. E., W. G. Youatt, H. E. Johnson, P. K. Ku, and L. D. Fay. 1964. Digestibility of cedar and aspen browse for the white-tailed deer. J. Wildl. Mgmt. 28(4):791-797.

Ullrey, D. E., W. G. Youatt, H. E. Johnson, L. D. Fay, B. E. Brent, and K. E. Kemp. 1968. Digestibility of cedar and balsam fir browse for the white-tailed deer. J. Wildl. Mgmt. 32(1):162-171.

_______. 1970. Digestible and metabolizable energy requirements for winter maintenance of Michigan white-tailed does. J. Wildl. Mgmt. 34(4):863-869.

U.S. Department of Agriculture. 1941. Year book of agriculture: climate and man. U.S. Government Printing Office. Washington, D. C. XII + 1248 p.

U.S.D.I. 1968. Federal aid in fish and wildlife restoration; annual report on Dingell-Johnson and Pittman-Robertson programs. Wildlife Management Institute and Sport Fishing Institute. Washington, D.C. 114 p.

Usher, M. B. 1970. An algorithm for estimating the length and direction of shadows with reference to the shadows of shelter belts. J. Appl. Ecol. 7(1):141-145.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analyses and its application. J. Anim. Sci. 26:119-128.

Verme, L. J. 1968. An index of winter weather severity for northern deer. J. Wildl. Mgmt. 32(3):566-574.

Vilkitis, J. R. 1971. The violation simulation formula proves as reliable as field research in estimating closed-season illegal big game kill in Maine. Trans. N.E. Sect. Wildl. Soc. 28:141-144.

Walsch, J. W. T. 1961. The science of daylight. MacDonald, London. 285 p.

Watt, K. E. F. 1968. Ecology and resource management. McGraw-Hill Book Co. New York, N. Y. XII + 449 p.

Whelan, J. B., R. F. Harlow, and H. S. Crawford. 1971. Selectivity, quality, and _in vitro_ digestibility of deer foods: a tentative model. Release No. 72-3. Va. Coop. Wildl. Res. Unit. Va. Polyt. Inst. and State Univ. Blacksburg, Va. 22 p.

APPENDIX

Appendix Table 1. Definition of variables in the potential productivity model, listed in alphabetical order.

Variable Name	Variable Definition
AX(I)	Alpha numeric variable for the tract name
BX(I)	Alpha numeric variable for the subunit names
CLIM(J,I)	The climatic variables (J) for each month of the year (I); when J is 1 for the mean monthly maximum temperature, when J is 2 for mean monthly minimum temperature, when J is 3 for the mean montly mean temperature, when J is 4 for the mean weather station wind speed and when J is 5 for the mean monthly snow pack accumulation.
CFOOD(L,J,I)	Forage supply available to deer at the start of winter
CSI	Seasonal severity index
DHR	Desired harvest rate
E	Energy deficit in a month due to behaviorally limited intake
ED	Energy drain by thermal environment
EM	Energy metabolized by body
ENREQ	Energy requirement for part of the day
EREQ	Energy requirement for deer for an average day of the month
FCR(J,I)	Forage consumption rate by deer for the forage type I and for the season U
FDTOT(I)	Forage energy available in habitat type I
FOOD(L,J,I,)	Forage available to deer in a given month for habitat type I, forage type J and season L
FPM(L,J,I)	Maximum forage production which the habitat type I will achieve for forage type J in season L
FPMXC	Forage production maximum constant for multiplying the successional distribution function by to obtain production in any year
GRTHMX(I)	Years in the future in which the maximum growth rate of cover will be achieved in cover type I
HB	Seasonal fasting metabolic rate of deer
HNTINX	Harvestable deer index
HT	Height of dominant cover
HTMAX(I)	Maximum height attainable by cover type I
HTMXAG(I)	Years to when the maximum attainable height will be achieved by the cover of cover type I
HUNT(Z,X)	Function statement definition to calculate the potential S.D.U. of harvestable production
IDAYS	Numbers of days in the month

Appendix Table 1. (continued)

ISPC(I)	Species composition of habitat type I
IU	Month in which a subunit is used by deer, coded 1 if used
MSE(I)	The index of major seasonal events, I corresponding in order to the presentation in Table 14
NEB1	Energy deficiency due to behaviorally limited forage intake by deer
NEB2	Energy deficiency due to lack of available forage
NOHB	The number of habitat units within the subunit
NOSU	The number of subunits in the tract
PCTIM(I)	Percent of time spent in habitat type I
PCTM	The percent of the day that deer will spend in the cover types when snow depth exceed SNBEHA based on time of day (ID), height of cover (K) and species composition of cover (N)
PCTU	The proportion of the tract within the subunit
POUND(J,I)	Pounds of forage type J consumed from habitat type I
POUNDS	Pounds of available forage which is required to meet the energy requirement of the deer
PSI(L,J,I)	Age of the forage production of cover type I for forage type J, for season L
PSL(L,J,I)	Years to end of forage production in cover type I for forage type J, for season L
PSM(L,J,I)	Years to peak of forage production in cover type I for forage type J, for season L
PSU(I)	Portion of subunit which cover type I is
RANG(Z,X)	Function statement to calculate the range balance index
RANGNX	Range balance index
RBIMX	Range balance index maximum
REQ	Energy requirement of deer for the month
RIR	Infrared radiation
RLBMX	Maximum pounds of forage ingested by deer
RMET(J)	Metabolizable energy (Kcal/lb) of forage type J
SBC	Stefan-Boltzmann Constant
SDINDX	Sightable standard deer index
SDP(L)	Standard deer population maintainable in season
SNBEHA	Snow depth at which behavior of deer using the habitat changes
SUMTOT(I,J)	Accumulator of the potential productivity indices I over the 50 yr. planning horizon taken at 5 year intervals J
SURAD	Visable solar radiation

Appendix Table 1. (continued)

TOTFOD	Total Forage energy available in subunit
WIND	Wind speed in habitats
YR	Year in 50 year planning horizon

Appendix Table 2. Listing of the Fortran program.

```
C*****************************************************************
C*****************************************************************
C***                                                           ***
C***                                                           ***
C***                      MAIN PROGRAM                         ***
C***                                                           ***
C***                                                           ***
C*****************************************************************
C*****************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYP,
     / J,L,M,NOHB
C
C
      DIMENSION AX(10),BX(10),SUMTOT(5,12)
      RANG(Z,X)=X/Z
      HUNT(Z,X)=X-Z
C
C     KCAL MET. EN. PER LB INTAKE OF THE DIFFERENT FORAGE
C TYPES
      RMET(1)=371.87
      RMET(2)=669.37
      RMET(3)=669.37
C
      DO 990 I=1,5
      DO 989 J=1,12
      SUMTOT(I,J)=0.0
  989 CONTINUE
  990 CONTINUE
C READ TRACT NAME
    1 READ(5,51,END=999)(AX(I),I=1,10)
   51 FORMAT( 10A4)
      WRITE(6,61)( AX(I),I=1,10)
   61 FORMAT(1H1,//////,20X,'A BIOENERGETIC EVALUATION OF DE
     2,'ER HABITAT, GIVING AN',//,16X,'INDEX TO THE ENERGY',
     3' POTENTIALLY AVAILABLE FOR THE PRODUCTION',//,16X,
     4'OF DEER ON ',10A4,' TRACT')
C READ STATE NAME
      READ(5,51)(BX(I),I=1,10)
      WRITE(6,62)(BX(I),I=1,10)
   62 FORMAT( 1H0,15X,'IN THE STATE OF ',10A4,',')
```

Appendix Table 2. (continued)

```
C READ COUNTY NAME
      READ(5,51)(BX(I),I=1,10)
      WRITE(6,63)(BX(I),I=1,10)
   63 FORMAT( 1H0,15X,10A4,' COUNTY,')
C READ TOWNSHIP, LATITUDE, LONGITUDE AND ACRES IN TRACT
      READ(5,52)(BX(I),I=1,10), X, Y, ACRES
   52 FORMAT( 10A4,2F5.1,F10.1)
      WRITE(6,64)(BX(I),I=1,10),X, Y, ACRES
   64 FORMAT( 1H0,15X,10A4,' TOWNSHIP AT',//,16X,F5.1,
     2' LATITUDE,',F5.1,' LONGITUDE; BEING COMPOSED OF',//,
     316X,F10.1,' ACRES OF LAND.'//)
      WRITE(6,65)
   65 FORMAT( 1H0,20X,'THE GENERAL CLIMATIC DESCRIPTION OF',
     2' THIS AREA OF THE ',//,16X,'STATE IS AS FOLLOWS:',//,
     323X,': MEAN MONTHLY : MEAN WEATHER : MEAN MONTHLY :',/
     /,23X,': TEMPERATURE  :   STATION    :  SNOW-PACK   :',
     //,23X,':MAX. MIN. MEAN:  WIND SPEED  : ACCUMULATION :'
     /,/,23X,':     (F)      :    (MPH)     :   (INCHES)   :
     / ')
C
C READ MEAN MAXIMUM AND MINIMUM TEMP, WEATHER STATION WIND
C SPEED, AND EFFECTIVE SNOW DEPTH
      DO 3 I=1,12
      READ(5,53) CLIM(1,I),CLIM(2,I),CLIM(4,I),CLIM(5,I)
   53 FORMAT(3F5.1,F6.1)
C TO CALCULATE THE MONTHLY MEAN TEMPERATURE
      CLIM(3,I)=(CLIM(1,I)+CLIM(2,I))/2
C
      GO TO (511,512,513,514,515,516,517,518,519,5110,5111,
     / 5112),I
  511 WRITE(6,611)  (CLIM(J,I),J=1,5)
      GO TO 6113
  512 WRITE(6,612)  (CLIM(J,I),J=1,5)
      GO TO 6113
  513 WRITE(6,613)  (CLIM(J,I),J=1,5)
      GO TO 6113
  514 WRITE(6,614)  (CLIM(J,I),J=1,5)
      GO TO 6113
  515 WRITE(6,615)  (CLIM(J,I),J=1,5)
      GO TO 6113
  516 WRITE(6,616)  (CLIM(J,I),J=1,5)
      GO TO 6113
  517 WRITE(6,617)  (CLIM(J,I),J=1,5)
      GO TO 6113
  518 WRITE(6,618)  (CLIM(J,I),J=1,5)
      GO TO 6113
  519 WRITE(6,619)  (CLIM(J,I),J=1,5)
```

Appendix Table 2. (continued)

```
      GO TO 6113
 5110 WRITE(6,6110) (CLIM(J,I),J=1,5)
      GO TO 6113
 5111 WRITE(6,6111) (CLIM(J,I),J=1,5)
      GO TO 6113
 5112 WRITE(6,6112) (CLIM(J,I),J=1,5)
  611 FORMAT(19X,'JAN ',3F5.1,5X,F5.1,10X,F5.1)
  612 FORMAT(19X,'FEB ',3F5.1,5X,F5.1,10X,F5.1)
  613 FORMAT(19X,'MAR ',3F5.1,5X,F5.1,10X,F5.1)
  614 FORMAT(19X,'APR ',3F5.1,5X,F5.1,10X,F5.1)
  615 FORMAT(19X,'MAY ',3F5.1,5X,F5.1,10X,F5.1)
  616 FORMAT(19X,'JUN ',3F5.1,5X,F5.1,10X,F5.1)
  617 FORMAT(19X,'JUL ',3F5.1,5X,F5.1,10X,F5.1)
  618 FORMAT(19X,'AUG ',3F5.1,5X,F5.1,10X,F5.1)
  619 FORMAT(19X,'SEP ',3F5.1,5X,F5.1,10X,F5.1)
 6110 FORMAT(19X,'OCT ',3F5.1,5X,F5.1,10X,F5.1)
 6111 FORMAT(19X,'NOV ',3F5.1,5X,F5.1,10X,F5.1)
 6112 FORMAT(19X,'DEC ',3F5.1,5X,F5.1,10X,F5.1)
 6113 CONTINUE
      DO 2 J=1,3
C       CONVERSION OF TEMP. TO CENTIGRADE SCALE.
      CLIM(J,I)=.55555*(CLIM(J,I)-32.0)
    2 CONTINUE
    3 CONTINUE
C
C READ MONTHS OF MAJOR SEASONAL EVENTS
      READ(5,54)(MSE(I),I=1,5),NOSU
   54 FORMAT(6I2)
      WRITE(6,620)(MSE(I),I=1,2),(MSE(I),I=4,5),NOSU
  620 FORMAT(1H0,20X,'THE SUMMER SEASON BEGINS IN MONTH ',
     / I2,' AND THE WINTER',/,16X,'SEASON BEGINS IN MONTH ',
     / I2,' .',//,21X,'THE SPRING MOLT OF DEER IN THIS AREA'
     /,' PEAKS IN MONTH ',I2,/,16X,'AND THE FALL MOLT ',
     /'PEAKS IN MONTH ',I2,' .',//,21X,'FOR EVALUATION ',
     /'PURPOSES THE TRACT HAS BEEN DIVIDED',/,16X,'INTO ',
     / I2,' SUBUNITS, THE DESCRIPTION OF WHICH FOLLOWS.')
C
C READ FORAGE CONSUMPTION RATE INDICES AND THE SNOW DEPTH
C BEYOND WHICH HABITAT USE CHANGES
      READ(5,55)((FCR(J,I),I=1,3),J=1,2),SNBEHA
   55 FORMAT(7F5.1)
C
C READ THE HABITAT USE WHEN SNOW DEPTH IS GREATER THAN SNBEH
      READ(5,551)(((PCTM(ID,K,N),K=1,4),N=1,3),ID=1,2)
  551 FORMAT(12F5.3)
```

Appendix Table 2. (continued)

```
C
C        DO-LOOP FOR GOING THROUGH EACH OF THE SUBUNITS TO
C   CALCULATE THE INDICES FOR THAT SUBUNIT.
C
      DO 2000 IK=1,NOSU
C
C READ SUBUNIT NAME, THE PERCENT THE SUBUNIT IS OF THE TRACT
C MONTHS OF ACTIVE USE OF THE SUBUNIT AND THE NUMBER OF
C HABITAT TYPES IN THE SUBUNIT
      READ(5,56)(BX(I),I=1,10),PCTU,(IU(J),J=1,12),NOHB
   56 FORMAT( 10A4,F5.3,12I1,I2)
      X=PCTU*ACRES
      WRITE(6,601)(BX(I),I=1,10),X,(IU(J),J=1,12)
  601 FORMAT(1H1,//////,20X,10A4,' SUBUNIT IS',//,16X,
     /'COMPOSED OF APPROXIMATELY ',F8.0,' ACRES.  THE',
     /' EXPECTED   ',//,16X,'UTILIZATION OF THE SUBUNIT IS AS
     /,'FOLLOWS:',//,16X,I3,11I5)
      WRITE(6,602) NOHB
  602 FORMAT(1H+,16X,'___  ___  ___  ___  ___  ___  ___  ' ,
     /'___  ___  ___  ___  ___',/,17X,'JAN  FEB  MAR  APR  '
     /'MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC',
     ///,17X,'THE SUBUNIT HAS BEEN DIVIDED INTO',I4,
     /' COVER TYPES.',//)
      WRITE(6,621)
  621 FORMAT(1H0,29X,'COVER DESCRIPTION OF THE SUBUNIT ',//,
     / 16X,':COVER:  %  :  AGE  : MAXIMUM :YEARS TO:YEAR'
     /,'S TO:SPECIES :',/,16X,':TYPE :  OF  :  OF  : HE',
     /'IGHT  : REACH  :  MOST  :MIXTURE :',/,16X,':     :',
     /'SUBUNIT:DOMINANT:  COVER  :  MAX.  :VIGOROUS: INDEX',
     /'  :',/,16X,':     :        : COVER  :WILL GROW: HEIGH'
     /,'T : GROWTH :OF COVER:')
C
C FOR EACH HABITAT TYPE IN THE SUBUNIT READ THE PERCENT IT
C IS OF THE SUBUNIT, THE STAND AGE, THE MAXIMUM ATTAINABLE
C HEIGHT, THE YEARS TO THE MAXIMUM HEIGHT, THE YEARS TO THE
C MAXIMUM GROWTH RATE, AND THE SPECIES COMPOSITION OF THE
C TYPE
      DO 4 I=1,NOHB
      READ(5,57) PSU(I),STNDAG(I),HTMAX(I),HTMXAG(I),
     / GRTHMX(I),ISPC(I)
      WRITE(6,571) I,PSU(I),STNDAG(I),HTMAX(I),HTMXAG(I),
     / GRTHMX(I),ISPC(I)
   57 FORMAT(F4.3,4F4.0,I1)
  571 FORMAT(18X,I2,F8.2,4F9.0,I8)
    4 CONTINUE
C
C THIS STATEMENT ONLY CAUSES TABLES TO BE PRINTED ON
C SEPARATE PAGES IF THEY WILL BE TOO LONG FOR ONE PAGE
```

Appendix Table 2. (continued)

```
      IF(NOHB.GT.4) WRITE(6,624)
      WRITE(6,622)
  622 FORMAT(1H0,//,18X,'FORAGE PRODUCTION, SUCCESSIONAL ',
     /'DESCRIPTION OF THE SUBUNIT ',//,16X,':COVER:FORAGE: '
     /,'MAXIMUM  :PRODUCTION: YEARS TO :   YEARS OF    :',/,
     /16X,':TYPE : TYPE : YEARLY    :  AGE OF  : MAXIMUM  : '
     /,'  USEFUL     :',/,16X,':        :          :PRODUCTION:',
     /'THE COVER :PRODUCTION:  PRODUCTIVE  :',/,16X,':       '
     /,':      :TO EXPECT : FOR THIS :          :LIFE REM',
     /'AINING:',/16X,':      :         :          :  FORAGE  :',
     /'         :                  :',/,16X,':     :        :',
     /'  S    W  :  S    W  :  S    W  :  S      W   :')
C
C FOR EACH HABITAT TYPE READ THE FORAGE PRODUCTION
C CHARACTERISTICS WHICH DEFINE THE SUCCESSIONAL RATE AND
C STAGE OF THE FORAGE PRODUCTION
      DO 6 I=1,NOHB
      WRITE(6,623)
  623 FORMAT(1H+,/)
      DO 5 J=1,3
C
C        I  HABITAT TYPE
C        J  FORAGE TYPE
C        L  SUMMER OR WINTER SEASON FORAGE SUPPLY
C
      READ(5,58)FPM(2,J,I),FPM(1,J,I),PSI(2,J,I),PSI(1,J,I),
     /          PSM(2,J,I),PSM(1,J,I),PSL(2,J,I),PSL(1,J,I)
   58 FORMAT(5X,8F5.0)
      WRITE(6,581)I,J,FPM(2,J,I),FPM(1,J,I),PSI(2,J,I),
     /PSI(1,J,I),PSM(2,J,I),PSM(1,J,I),PSL(2,J,I),PSL(1,J,I)
  581 FORMAT(16X,I3,I6,4X,2F5.0,2X,2F5.0,2X,2F5.0,2X,2F6.0)
      IF(J.EQ.3)GO TO 5
      DO 41 L=1,2
C TO CALCULATE A SCALE FACTOR OF FORAGE PRODUCTION
      CALL FPMC
   41 CONTINUE
    5 CONTINUE
    6 CONTINUE
C
C
C
C********* DO-LOOP FOR 50 YR PLANNING HORIZON **********
C
C
      DO 99 ITERM=1,11
      IYR=(ITERM-1)*5
      YR=IYR
```

Appendix Table 2. (continued)

```
      DO 20 I=1,NOHB
      CALL SUCESN
   20 CONTINUE
      ICOUNT=0.0
      L=1
  201 CONTINUE
      NEB1=0.0
      NEB2=0.0
      IF(L.EQ.1) M=MSE(2)
      GO TO 22
   21 M=1
   22 CONTINUE
C
C THE BASAL METOBOLIC RATE IS CHOSEN ACCORDING TO THE COAT
C CONDITIONS OF THE NATURAL HERD
      IF(M.GE.MSE(4).AND.M.LT.MSE(5)) HB=2610.
      IF(M.LT.MSE(4).OR.M.GE.MSE(5)) HB=1690.
C
      REQ=0.0
      FREQ=0.0
      IF(L.EQ.1.AND.ICOUNT.GT.0) GO TO 7
      GO TO 10
C
C FOR THE ESTIMATION OF SUMMER SDP AND FOR SUBSEQUENT
C CALCULATION OF WINTER SEASON SDP THE FORAGE SUPPLY IS
C RE-INITIALIZED IN EACH HABITAT TYPE
    7 DO 9 I=1,NOHB
      DO 8 J=1,3
      FOOD(L,J,I)=CFOOD(J,I)
    8 CONTINUE
    9 CONTINUE
   10 CONTINUE
C
C
C DO-LOOP FOR THE ENERGY REQUIREMENT IN DAY AND NIGHT
C ASSUMING DAY AND NIGHT LENGTH EQUAL
C IDAY = 1 FOR DAY TIME
C IDAY = 2 FOR NIGHT TIME
C
      DO 24 IDAY=1,2
      CALL PCTIME
C SUBROUTINE TO ESTIMATE THE % OF TIME SPENT IN THE VARIOUS
C HABITAT TYPES.
C
C DO-LOOP FOR THE ENERGY REQUIREMENT OF DEER IN THE HABITAT
      DO 23 I=1,NOHB
      CALL MCROEN
```

Appendix Table 2. (continued)

```
C SUBROUTINE TO ESTIMATE THE MICROENVIRONMENT OF THE
C DIFFERENT HABITAT TYPES AND THE ENERGY REQUIREMENT OF
C THE STANDARD DEER THERE IN.
      EREQ=EREQ+(ENREQ*PCTIM(I))
   23 CONTINUE
C
   24 CONTINUE
C
      CALL MONTH
C TO CONVERT THE MEAN DAILY ENERGY REQUIREMENT TO THE MEAN
C MONTHLY ENERGY REQUIREMENT
      REQ=REQ+((EREQ/2)*IDAYS)
C
      IF(L.EQ.1.AND.ICOUNT.GT.0) CALL CONSUM
C CONSUM CAUSES THE FORAGE SUPPLY TO BE REDUCED PROPORTIONAL
C TO THE REQUIREMENTS OF THE DEER IF POSSIBLE; THE
C REQUIREMENT UNSATISFIED IS ACCUMULATED IN NEB1 AND NEB2
C
      M=M+1
C
C THE FOLLOWING 3 STATEMENTS DETERMINE THE MONTH AND SEASON;
C IF THE SEASON IS ENDED THE CALCULATION OF THE SEASONAL SDP
C IS COMMENCED AT 25, OTHERWISE THE NEXT MONTH OF THE SEASON
C IS CONSIDERED
      IF(L.EQ.1.AND.M.EQ.13) GO TO 21
      IF(L.EQ.1.AND.M.EQ.MSE(1)) GO TO 25
      IF(L.EQ.2.AND.M.EQ.MSE(2)) GO TO 25
C
      GO TO 22
   25 CONTINUE
C
C THE DEFINITION OF THE FIRST ESTIMATE OF THE WINTER SDP OR
C THE CALCULATION OF THE SUMMER SDP
      IF(L.EQ.2.OR.ICOUNT.EQ.0) SDP(L)=TOTFOD/REQ
C
C CALCULATION OF OTHER THAN THE FIRST ESTIMATE OF WINTER
C SDP, ONLY DONE WHEN NEB2 IS POSITIVE
      IF(L.EQ.1.AND.ICOUNT.GT.0.AND.NEB2.GT.0.)
     /          SDP(L)=SDP(L)-(NEB2/REQ)
C
      ICOUNT=ICOUNT+1
C
C TO GET OUT OF LOOP AT END OF SEASONAL CALCULATIONS AND TO
C GO TO 26 TO CALCULATE PRODUCTIVITY INDICES
      IF(L.EQ.2) GO TO 26
C
C FOR CUMULATING UNIT TOTAL OF 1ST EST OF SDP(1)
```

Appendix Table 2. (continued)

```
      IF(ICOUNT.EQ.1) SUMTOT(3,ITERM)=SUMTOT(3,ITERM)+SDP(L)
      IF(ITERM.EQ.1.AND.ICOUNT.EQ.1) WRITE(6,66)
     / (BX(I),I=1,10),IYR,SDP(L)
   66 FORMAT(1H1,//////,20X,10A4,' SUBUNIT',//,21X,'EVALUAT'
     /,'ION OF THE '
     /'POTENTIAL SEASONAL STANDARD DEER',/,16X,'POPULATION',
     /'S SUSTAINABLE ON THE SUBUNIT, ASSUMING "NORMAL"',/,
     /16X,'SUCCESSION.',////,16X,
     /':YEAR:STANDARD DEER POPULATION:CLIMATIC: PRODUCTIVITY
     /,' INDICES :',/,16X,':         :      WINTER        :SUMMER:',
     /'SEVERITY:          :        :SEASONAL:',/,16X,':      :      ',
     /'FIRST : FORAGE:FORAGE: INDEX   :  S* :    H** : RANGE',
     /'    :',/,16X,':       : ESTIMATE:  BASED:BASED :    %    '
     /,':       :        : BALANCE:',//,17X,I2,F11.0)
      IF(ITERM.GT.1.AND.ICOUNT.EQ.1) WRITE(6,661) IYR,SDP(L)
  661 FORMAT(17X,I2,F11.0 )
      IF(ICOUNT.EQ.1) GO TO 201
C
C TO DETERMINE IF THE ITERATIVE ESTIMATE OF THE WINTER SDP
C IS WITHIN 5% OF THE PREVIOUS ESTIMATE; IF NOT ANOTHER
C CALCULATION IS MADE
      XXH=1.05*SDP(L)
      XXL=.95*SDP(L)
      IF(SDP(L).GT.XXH.OR.SDP(L).LT.XXL) GO TO 201
C
      WRITE(6,67) SDP(L)
   67 FORMAT(1H+,30X,F8.0)
      L=2
      M=MSE(1)
      GO TO 201
   26 CONTINUE
C
C
C THE FOLLOWING EQUATIONS CALCULATE THE PRODUCTIVITY INDICES
C AS DESCRIBED IN THE THESIS
C
      SDPONE=SDP(1)
      SDPTWO=SDP(2)
      RANGNX=RANG(SDP(1),SDP(2))
      IF(RANGNX.LT.1.0) SDPONE=SDP(2)
      IF(RANGNX.GT.2.82) SDPTWO=2.82*SDP(1)
      SDINDX=SDPONE
      HNTINX=HUNT(SDPONE,SDPTWO)
      CSI=NEB1*(1./(SDP(1)*4500.))
C
      WRITE(6,68) SDP(2),CSI,SDINDX,HNTINX,RANGNX
```

Appendix Table 2. (continued)

```
   68 FORMAT(1H+,38X,F8.0,F5.0,2F9.0,F8.3)
C FOR CUMULATING 2ND EST OF SDP(1) AND EST OF SDP(2)
      DO 991 L=1,2
      SUMTOT(L,ITERM)=SUMTOT(L,ITERM)+SDP(L)
  991 CONTINUE
      SUMTOT(4,ITERM)=SUMTOT(4,ITERM)+SDINDX
      SUMTOT(5,ITERM)=SUMTOT(5,ITERM)+HNTINX
   99 CONTINUE
      WRITE(6,625)
  625 FORMAT(1H0,15X,'*  POTENTIAL SIGHTABLE STANDARD DEER'
     /,' INDEX',//,16X,'**  POTENTIAL HARVESTABLE STANDARD '
     /,'DEER INDEX - WHEN THIS',/,20X,'INDEX IS ZERO, A ',
     /'POSITIVE PRODUCTIVITY INDEX IS ACHIEVED',/,20X,'ONLY'
     /,' AT THE EXPENSE OF THE POTENTIAL SIGHTABLE PRODUC-',
     //,20X,'TIVITY INDEX; THE CONVERSION CAN BE MADE BY ',
     /,'USING THE',/,20X,'SEASONAL RANGE BALANCE INDEX AND'
     /,' EQUATIONS PRESENTED IN',/,20X,'THE TEXT')
 2000 CONTINUE
      WRITE(6,690)(AX(I),I=1,10)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C         THE FOLLOWING IS FOR CALCULATING AND PRINTING THE
C         50 YEAR SUMMARY FORM FOR A TRACT.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
  690 FORMAT(1H1,//////,20X,10A4,' TRACT',/,16X,'HABITAT EVA
     /,'LUATION SUMMARY FOR A 50 YEAR PLANNING PERIOD',/,16X
     /, 'ASSUMING NATURAL SUCCESSION',////,16X,
     /':YEAR:ESTIMATE:FORAGE:FORAGE:  MEAN    :            :'
     /,'SEASONAL:',/,16X,':     :    OF    :BASED :BASED :',
     /'SIGHTABLE:HARVESTABLE:BALANCE :',/,16X,':     : ',
     /'WINTER :WINTER:SUMMER:  INDEX* :   INDEX** : INDEX  '
     /,':',/,16X,':     :  SDP    : SDP  : SDP  :        :',
     /'    :             :',//,18X,I2,F10.0)
      DO 997 ITERM=1,11
      IYR=(ITERM-1)*5
      DO 998 L=1,5
      SUMTOT(L,12)=SUMTOT(L,12)+SUMTOT(L,ITERM)
  998 CONTINUE
      RANGNX=RANG(SUMTOT(1,ITERM),SUMTOT(2,ITERM))
      WRITE(6,69) IYR,SUMTOT(3,ITERM),(SUMTOT(L,ITERM),L=1,2
     /),(SUMTOT(L,ITERM),L=4,5),RANGNX
   69 FORMAT( 17X,I2,F10.0 ,F8.0,F7.0,F8.0,F11.0,F10.3)
  997 CONTINUE
```

Appendix Table 2. (continued)

```
      DO 992 I=1,5
C        TO ESTIMATE THE ACTUAL CUMULATIVE POTENTIAL
C        PRODUCTION FOR THE 50 YEAR SPAN FROM THE 5 YEAR
C        INTERVAL CALCULATIONS
      SUMTOT(I,12)=SUMTOT(I,12)*5.0
  992 CONTINUE
      RANGNX=RANG(SUMTOT(1,12),SUMTOT(2,12))
      WRITE(6,691) SUMTOT(3,12),(SUMTOT(L,12),L=1,2),
     /(SUMTOT(L,12),L=4,5),RANGNX
  691 FORMAT(1H0,15X,'50 YEAR',/,16X,'TOTAL',F9.0,F8.0,F7.0
     /,F8.0,F11.0,F10.3)
      WRITE(6,625)
      WRITE(6,6995) (AX(I),I=1,10)
 6995 FORMAT(1H1,//////,20X,'A TABLE OF ALTERNATIVE INDICES'
     /' IS PRESENTED BELOW FOR',/,20X,'THE ',10A4,' TRACT',
     /' FOR',/,20X,'THREE SELECTED LEVELS OF'
     /,' MAXIMUM UTILIZABLE RANGE',/,20X,'BALANCE AND EIGHT'
     /,' LEVELS OF RANGE UTILIZATION HARVEST',/,20X,'RATES.'
     /,//,30X,'MAXIMUM UTILIZABLE RANGE BALANCE',/,
     / 15X,'RANGE',/,15X,'UTILIZATION',/,15X,'HARVEST',6X,
     /'1.5',16X,'2.0',16X,'2.5',/,15X,'RATE      S',8X,'H',
     /9X,'S',8X,'H',9X,'S',8X,'H')
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C        THE FOLLOWING IS FOR CALCULATING THE TABLE OF
C          ALTERNATIVE POTENTIAL PRODUCTIVITY INDICES.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
      DHR=.80
      DO 96 I=1,8
      DHR=DHR+.2
      RBIMX=1.0
      DO 95 J=1,3
      RBIMX=RBIMX+.5
      IF(DHR.LE.1.0) GO TO 92
      X=RBIMX
      IF(RBIMX.GT.RANGNX) X=RANGNX
      IF(DHR.GT.X) GO TO 91
      SDPONE=SUMTOT(1,12)
      SDPTWO=SUMTOT(1,12)*DHR
      IF(DHR.GT.RBIMX) SDPTWO=SUMTOT(1,12)*RBIMX
      GO TO 94
```

Appendix Table 2. (continued)

```
   91 SDPONE=SUMTOT(2,12)/DHR
      IF(DHR.GT.RBIMX) SDPONE=SUMTOT(2,12)/RBIMX
      SDPTWO=SUMTOT(2,12)
      GO TO 94
C        WHEN NO HARVEST IS TO BE MADE
   92 IF(RANGNX.LT.1.0) GO TO 93
      SDPONE=SUMTOT(1,12)
      SDPTWO=SUMTOT(1,12)
      GO TO 94
   93 SDPONE=SUMTOT(2,12)
      SDPTWO=SUMTOT(2,12)
   94 CONTINUE
      SUMTOT(J,10)=SDPONE
      SUMTOT(J,11)=HUNT(SDPONE,SDPTWO)
   95 CONTINUE
      WRITE(6,6996)DHR,((SUMTOT(J,IK),IK=10,11),J=1,3)
 6996 FORMAT(15X,F3.1,':',2F9.0,':',2F9.0,':',2F9.0,':')
   96 CONTINUE
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
  999 CONTINUE
      WRITE(6,624)
  624 FORMAT(1H1,//)
 2001 CONTINUE
      STOP
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE SUCESN
C*****************************************************************
C*****************************************************************
C***                                                          ***
C***                                                          ***
C***                      SUCCESSION                          ***
C***                                                          ***
C***        THIS SUBROUTINE CALCULATES THE FORAGE             ***
C***       PRODUCTION AND COVER HEIGHT OF THE HABITAT         ***
C***       TYPES ON THE SUBUNITS.                             ***
C***                                                          ***
C***                                                          ***
C*****************************************************************
C*****************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,ECR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
C * * * * * * * * * * *        COVER        * * * * * * * * * * *
C
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C *                                                             *
C *                                                             *
C *                                                             *
C *                                                             *
C *                ISPC(I)=1          HARDWOOD                  *
C *                        2          MIXED WOOD                *
C *                        3          CONIFER                   *
C *                                                             *
C *                                                             *
C *                ISPA(I)=1          NO EFFECTIVE HEIGHT       *
C *                        2          LESS THAN 15'             *
C *                        3          15 TO 30'                 *
C *                        4          GREATER THAN 30'          *
C *                                                             *
C *                                                             *
C *                                                             *
C *                                                             *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Appendix Table 2. (continued)

```
      DO 1 I=1,NOHB
      IF(YR.LT.STNDAG(I)) GO TO 101
      XL=-STNDAG(I)
      XH=HTMXAG(I)
      XMODE=GRTHMX(I)
      CALL WEIBUL(XL,CUMXL,XMODE,XH,COMPXH,ZK,ZLAMDA,ZM,
     / XMEAN)
      CALL COMCDF(YR,ZK,XH,ZLAMDA,ZM,DISFNC)
      HT=DISFNC*HTMAX(I)
      GO TO 102
  101 HT=0.
  102 CONTINUE
      IF(HT.EQ.0.) ISPA(I)=1
      IF(HT.LE.15.0) ISPA(I)=2
      IF(HT.GT.15.0.AND.HT.LT.30.0) ISPA(I)=3
      IF(HT.GT.30.0) ISPA(I)=4
    1 CONTINUE
C
C
C * * * * * * * * * *      FORAGE      * * * * * * * * * * * *
C
C
      DO 4 I=1,NOHB
      DO 3 J=1,3
      DO 2 L=1,2
      XL=-PSI(L,J,I)
      IF(YR.LE.XL) GO TO 12
      XH= PSL(L,J,I)
      XMODE=PSM(L,J,I)
C
C     FOR MAST PSM IS FOR GROWTH RATE CHANGE NOT PRODUCTION
C
      CALL WEIBUL(XL,CUMXL,XMODE,XH,COMPXH,ZK,ZLAMDA,ZM,
     / XMEAN)
      CALL COMCDF(YR,ZK,XH,ZLAMDA,ZM,DISFNC)
      IF(J.EQ.3) GO TO 11
      X=DISFNC
      YR=YR-1.
      CALL COMCDF(YR,ZK,XH,ZLAMDA,ZM,DISFNC)
      YR=YR+1.
      DISFNC=X-DISFNC
      FOOD(L,J,I)=DISFNC*FPMXC(L,J,I)
      GO TO 13
   11 FOOD(L,J,I)=DISFNC*FPM(L,J,I)
      GO TO 13
   12 FOOD(L,J,I)=0.0
```

Appendix Table 2. (continued)

```
   13 IF(L.EQ.1) CFOOD(J,I)=FOOD(1,J,I)
    2 CONTINUE
C
C
    3 CONTINUE
    4 CONTINUE
C
C
      RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE PCTIME
C*****************************************************************
C*****************************************************************
C***                                                          ***
C***                                                          ***
C***                      PERCENT TIME                        ***
C***                                                          ***
C***           THIS SUBROUTINE CALCULATES THE PERCENT         ***
C***       TIME THE STANDARD DEER SPENDS IN THE VARIOUS       ***
C***       COVER TYPES.  THIS IS ACCOMPLISHED IN ONE OF       ***
C***       TWO MANNERS:                                       ***
C***       1.   IF THE SNOW DEPTH IS LESS THAN THE SNOW       ***
C***       DEPTH BEYOND WHICH HABITAT USE CHANGES DUE         ***
C***       TO SNOW, THE USE IS PROPORTIONED TO THE            ***
C***       HABITAT TYPE PRODUCTION OF METABOLIZABLE           ***
C***       ENERGY.                                            ***
C***       2.   FOR SNOW DEPTHS GREATER THAN THE BEHAVIOR-    ***
C***       CHANGING SNOW DEPTH, THE HABITAT USE IS            ***
C***       PROPORTIONED TO THE DATA SUPPLIED THE PROGRAM      ***
C***       BY QUESTION 8 OF THE WORK FORM.                    ***
C***                                                          ***
C***                                                          ***
C*****************************************************************
C*****************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
      DIMENSION FDTOT(10)
      TOTFOD=0.0
      DO 1 I=1,NOHB
      FDTOT(I)=0.0
    1 CONTINUE
   10 IF(CLIM(5,M).GT.3.0) GO TO 20
C
C  FOR SNOW CONDITIONS LESS THAN OR EQUAL TO 3 INCHES
C
      DO 12 I=1,NOHB
      DO 11 J=1,3
      IF(FOOD(L,J,I).EQ.0.0) GO TO 11
```

Appendix Table 2. (continued)

```
      FDTOT(I)=FDTOT(I)+(FOOD(L,J,I)*RMET(J)*
     / PSU(I)*PCTU*ACRES)
   11 CONTINUE
      TOTFOD=TOTFOD+FDTOT(I)
   12 CONTINUE
      GO TO 30
   20 IF(CLIM(5,M).GT.SNBEHA) GO TO 40
C
C
C * TO CALCULATE THE % TIME BY FORAGE ENERGY PRODUCTION * *
C
C
      DO 22 I=1,NOHB
      DO 21 J=1,2
      IF(FOOD(L,J,I).EQ.0.0) GO TO 21
      FDTOT(I)=FDTOT(I)+(FOOD(L,J,I)*RMET(J)*
     / PSU(I)*PCTU*ACRES)
   21 CONTINUE
      TOTFOD=TOTFOD+FDTOT(I)
   22 CONTINUE
C
C
C TO CALCULATE THE % TIME BY THE DATA FROM QUESTION 8 OF THE
C WORK FORM
C
C
   30 DO 31 I=1,NOHB
      PCTIM(I)=FDTOT(I)/TOTFOD
   31 CONTINUE
      GO TO 50
   40 DO 41 I=1,NOHB
      MS=ISPC(I)
      MA=ISPA(I)
      PCTIM(I)=PCTM(IDAY,MA,MS)
   41 CONTINUE
      T=0.
      DO 48 I=1,NOHB
      T=T+PCTIM(I)
   48 CONTINUE
      DO 49 I=1,NOHB
      PCTIM(I)=PCTIM(I)/T
   49 CONTINUE
   50 RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE MCROEN
C*****************************************************************
C*****************************************************************
C***                                                          ***
C***                                                          ***
C***                    MICROENVIRONMENT                      ***
C***                                                          ***
C***            THIS SUBROUTINE CALCULATES THE ENERGY         ***
C***        REQUIREMENT OF A STANDARD DEER USING A            ***
C***        SPECIFIED SET OF HABITAT TYPES AND HABITAT        ***
C***        USE, AND THE WEATHER CONDITIONS; SUPPLYING        ***
C***        VALUES FOR SOLAR RADIATION, MODIFIED WIND         ***
C***        FLOW, AND CONVECTION COEFICIENTS.                 ***
C***                                                          ***
C***                                                          ***
C*****************************************************************
C*****************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
      REAL LC,LW
      SBC=.0000000493
      MM=ISPC(I)
      SVRAD=0.0
C
C * * * * * * * * * *   TEMPERATURE   * * * * * * * * * * *
C
      IF(IDAY.EQ.1) TA=(CLIM(3,M)+CLIM(1,M))/2.
      IF(IDAY.EQ.2) TA=(CLIM(3,M)+CLIM(2,M))/2.
C
C * * * * * * * * * *    RADIATION    * * * * * * * * * * *
C
      IF(IDAY.EQ.2) GO TO 301
      IF(L.EQ.2) GO TO 201
C
C                          DAY TIME WINTER
C
      GO TO (11,12,13),MM
   11 SVRAD= 4750.
```

Appendix Table 2. (continued)

```
      IF (ISPA(I).EQ.1) SVRAD=7210.
      GO TO 301
   12 SVRAD= 4410.
      IF (ISPA(I).EQ.1) SVRAD=7210.
      GO TO 301
   13 SVRAD= 4070.
      IF (ISPA(I).EQ.1) SVRAD=7210.
      GO TO 301
C
C                          DAY TIME  SUMMER
C
  201 GO TO (21,22,23),MM
   21 SVRAD= 3070.
      IF(ISPA(I).EQ.1) SVRAD=10530.
      GO TO 301
   22 SVRAD= 4675.
      IF(ISPA(I).EQ.1) SVRAD=10530.
      GO TO 301
   23 SVRAD= 6280.
      IF(ISPA(I).EQ.1) SVRAD=10530.
C
C                        IR RADIATION
C
  301 GO TO (31,32,33),MM
   30 RIR=((TA+262.1)**4.)*SBC
      GO TO 40
   31 IF(ISPA(I).EQ.1) GO TO 30
      RIR=((TA+267.4)**4.)*SBC
      GO TO 40
   32 IF(ISPA(I).EQ.1) GO TO 30
      RIR=((TA+271.3)**4.)*SBC
      GO TO 40
   33 IF(ISPA(I).EQ.1) GO TO 30
      RIR=((TA+273.2)**4.)*SBC
   40 SSR=((TA+264.3)**4.)*SBC
      ER=(RIR+(0.8*SVRAD)+SSR)/2
C
C * * * * * * * * * * *        WIND        * * * * * * * * * * * *
C
      WIND=CLIM(4,M)
      MM=ISPC(I)
      GO TO (51,52,53),MM
C
C
C CALCULATING THE FRICTION VELOCITY AT WEATHER STATION
C
   50 UP=WIND/3.30738
```

Appendix Table 2. (continued)

```
C
C REDUCED FORM OF SELLERS EQUATION FOR A WIND SPEED
C MEASUREMENT AT 152 CM
C
C
C
C CALCULATING WIND AT DEER HEIGHT
C
      WIND=UP*2.95691
C
C REDUCED FORM OF SELLERS EQUATION FOR A DEER BODY CENTER
C HEIGHT OF 68 CM
C
C
      GO TO 60
   51 IF(ISPA(I).EQ.1) GO TO 50
      WIND=WIND*0.2772
      GO TO 60
   52 IF(ISPA(I).EQ.1) GO TO 50
      WIND=WIND*0.1386
      GO TO 60
   53 GO TO (50,54,55,56),MM
   54 WIND=WIND*0.0819
      GO TO 60
   55 WIND=WIND*0.0259
      GO TO 60
   56 WIND=WIND*0.0048
C
C * * * * * * * * CONVECTION COEFFICIENT * * * * * * * * * *
C
   60 IF(WIND.GT.0.5) GO TO 61
      HC= 45.0
      LC=  0.0
      HW=  0.5
      LW=  0.0
      GO TO 68
   61 IF(WIND.GT.1.0) GO TO 62
      HC= 67.0
      LC= 45.0
      HW=1.0
      LW=  0.5
      GO TO 68
   62 IF(WIND.GT.2.0) GO TO 63
      HC=135.0
      LC=67.0
      HW=2.0
      LW=1.0
```

Appendix Table 2. (continued)

```
      GO TO 68
   63 IF(WIND.GT.4.0) GO TO 64
      HC=225.0
      LC=135.0
      HW=4.0
      LW=2.0
      GO TO 68
   64 IF(WIND.GT.6.0) GO TO 65
      HC=288.0
      LC=225.0
      HW=6.0
      LW=4.0
      GO TO 68
   65 IF(WIND.GT.8.0) GO TO 66
      HC=351.0
      LC=288.0
      HW=8.0
      LW=6.0
      GO TO 68
   66 IF(WIND.GT.10.0) GO TO 67
      HC=413.0
      LC=351.0
      HW=10.0
      LW=8.0
      GO TO 68
   67 HC=468.
      LC=413.
      HW=12.0
      LW=10.0
   68 HC=LC+((WIND-LW)*(HC-LC)/(HW-LW))
C
C**CALCULATION OF THE ENERGY REQUIREMENT IN A HABITAT TYPE**
C
      TS=6.559+(0.944*TA)
      ED=(1.689*((TS+273.2)**4.)*SBC)+(1.679*HC*(TS-TA))+
     / (1.2*(37.5-TA))+416.3-(0.057*ER)
      EM=1.764*HB
C
C WHEN THERMAL ENERGY DRAIN IS LESS THAN ENERGY OF BASAL
C METABOLISM AND NO SNOW INCREASING ACTIVITY ENERGY
C REQUIREMENT
      IF(ED.LE.EM.AND.CLIM(5,M).LE.8.0) ENREQ=1.2*HB
C
C WHEN THERMAL ENERGY DRAIN IS LESS THAN ENERGY OF BASAL
C METABOLISM AND SNOW INCREASING ENERGY DRAIN DUE TO SNOW
C DEPTH
      IF(ED.LE.EM.AND.CLIM(5,M).GT.8.0) ENREQ=
     / (.8336+(.0458*CLIM(5,M))*HB)
```

Appendix Table 2. (continued)

```
C
C WHEN THE THERMAL DRAIN IS GREATER THAN THE ENERGY OF BASAL
C METABOLISM AND NO SNOW INCREASING ACTIVITY ENERGY
C REQUIREMENT
      IF(ED.GT.EM.AND.CLIM(5,M).LE.8.0) ENREQ=ED
C
C WHEN THE THERMAL DRAIN IS GREATER THAN THE ENERGY OF BASAL
C METABOLISM AND SNOW IS INCREASING ACTIVITY ENERGY
C REQUIREMENT
      IF(ED.GT.EM.AND.CLIM(5,M).GT.8.0) ENREQ=
     / ED+(((.0458*CLIM(5,M))-0.3664)*HB)
C
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE MONTH
C*****************************************************************
C*****************************************************************
C***                                                           ***
C***                                                           ***
C***                          MONTH                            ***
C***                                                           ***
C***             THIS SUBROUTINE DEFINES THE NUMBER OF         ***
C***        DAYS IN MONTH  M.                                  ***
C***                                                           ***
C***                                                           ***
C*****************************************************************
C*****************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
C
C A TABLE OF THE NUMBER OF DAYS IN EACH MONTH
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12),M
    1 IDAYS=31
      GO TO 14
    2 IDAYS=28
      GO TO 14
    3 IDAYS=31
      GO TO 14
    4 IDAYS=30
      GO TO 14
    5 IDAYS=31
      GO TO 14
    6 IDAYS=30
      GO TO 14
    7 IDAYS=31
      GO TO 14
    8 IDAYS=31
      GO TO 14
    9 IDAYS=30
      GO TO 14
   10 IDAYS=31
```

Appendix Table 2. (continued)

```
      GO TO 14
   11 IDAYS=30
      GO TO 14
   12 IDAYS=31
   14 RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE CONSUM
C*******************************************************************
C*******************************************************************
C***                                                             ***
C***                                                             ***
C***                  FORAGE CONSUMPTION                         ***
C***                                                             ***
C***        THIS SUBROUTINE CALCULATES THE DEPLETION             ***
C***     OF AVAILABLE FORAGE BY THE FEEDING SDP,                 ***
C***     CALCULATING NEB1 AND NEB2 WHEN APPROPRIATE.             ***
C***                                                             ***
C***                                                             ***
C*******************************************************************
C*******************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
      RLBMX=6.0
      IX=3
      IF(CLIM(5,M).GT.3.) IX=2
      X=0.0
      DO 1 J=1,IX
      X=X+(FCR(L,J)*RMET(J))
    1 CONTINUE
      POUNDS=EREQ/X
      X=POUNDS/SDP(L)
      IF(X.GT.RLBMX) GO TO 4
      DO 3 I=1,NOHB
      DO 2 J=1,IX
      POUND(J,I)=POUNDS*FCR(L,J)*PCTIM(I)
    2 CONTINUE
    3 CONTINUE
      GO TO 7
    4 E=0.0
      DO 6 I=1,NOHB
      DO 5 J=1,IX
      POUND(J,I)=RLBMX*FCR(L,J)*PCTIM(I)
      E=E+(POUND(J,I)*RMET(J))
    5 CONTINUE
```

Appendix Table 2. (continued)

```
    6 CONTINUE
      NEB1=NEB1+(EREQ-E)
    7 DO 10 I=1,NOHB
      DO 9 J=1,IX
      IF(POUND(J,I).GT.FOOD(L,J,I)) GO TO 8
      FOOD(L,J,I)=FOOD(L,J,I)-POUND(J,I)
      GO TO 9
    8 NEB2=NEB2+((POUND(J,I)-FOOD(L,J,I))*RMET(J))
      FOOD(L,J,I)=0.0
    9 CONTINUE
   10 CONTINUE
      RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE FPMC
C***************************************************************
C***************************************************************
C***                                                         ***
C***                                                         ***
C***         FORAGE PRODUCTION MAXIMUM CONSTANT              ***
C***                                                         ***
C***            THIS SUBROUTINE IS FOR CALCULATING A         ***
C***      FORAGE PRODUCTION CONSTANT, USED FOR SCALING       ***
C***      THE FORAGE SUCCESSIONAL DISTRIBUTION FUNCTION      ***
C***      TO ESTIMATE THE POUNDS OF FORAGE PRODUCED IN       ***
C***      A GIVEN YEAR.                                      ***
C***                                                         ***
C***                                                         ***
C***************************************************************
C***************************************************************
      COMMON ACRES,CFOOD(3,10),CLIM(5,12),COMPXH,CUMXL,ENREQ
     /,EREQ,FCR(2,3),FOOD(2,3,10),FPI(2,3,10),FPM(2,3,10),
     /FPMXC(2,2,10),GRTHMX(10),HB,HTMAX(10),HTMXAG(10),NEB1,
     /NEB2,PCTIM(10),PCTM(2,4,3),PCTU,POUND(3,10),MSE(5),
     /PSI(2,3,10),PSL(2,3,10),PSM(2,3,10),PSU(10),RMET(3),
     /SDP(2),SNBEHA,STNDAG(10),TOTFOD,YR
      COMMON I,IDAY,IDAYS,ISPA(10),ISPC(10),IU(12),IYR,
     / J,L,M,NOHB
C
C
      ICOUNT=0
      YR=PSM(L,J,I)+1.
      XL=-PSI(L,J,I)
      XH=PSL(L,J,I)
      XMODE=PSM(L,J,I)
    1 YR=YR-1.0
      ICOUNT=ICOUNT+1
      CALL WEIBUL(XL,CUMXL,XMODE,XH,COMPXH,ZK,ZLAMDA,ZM,
     / XMEAN)
      CALL COMCDF(YR,ZK,XH,ZLAMDA,ZM,DISFNC)
      IF(ICOUNT.EQ.1) X=DISFNC
      IF(ICOUNT.EQ.1) GO TO 1
      FPMXC(L,J,I)=FPM(L,J,I)/(X-DISFNC)
      RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE COMCDF(YR,ZK,XH,ZLAMDA,ZM,DISFNC)
C*********************************************************************
C*********************************************************************
C***                                                               ***
C***                                                               ***
C***                          COMCDF                               ***
C***                                                               ***
C***              THIS SUBROUTINE DEFINES THE HABITAT              ***
C***         SUCCESSION DISTRIBUTION FUNCTION.                     ***
C***                                                               ***
C***                                                               ***
C*********************************************************************
C*********************************************************************
      COMP(V,C,A,ZM)=EXP(-(((V-C)/A)**ZM))
      DISFNC=1.-COMP(YR,ZK,ZLAMDA,ZM)
      RETURN
      END
```

Appendix Table 2. (continued)

```
      SUBROUTINE WEIBUL(XL,CUMXL,XMODE,XH,COMPXH,ZK,ZLAMDA,
     / ZM,XMEAN)
C*****************************************************************
C*****************************************************************
C***                                                            ***
C***                                                            ***
C***                          WEIBUL                            ***
C***                                                            ***
C***            THIS SUBROUTINE DEFINES THE SHAPE AND           ***
C***        LOCATION OF THE HABITAT SUCCESSION                  ***
C***        DISTRIBUTION.  (DEVELOPED BY LOBDELL 1972)          ***
C***                                                            ***
C***                                                            ***
C*****************************************************************
C*****************************************************************
      A(ZM,Z)=((ZM/(ZM-1.))*(-ALOG(Z)))**(1./ZM)
      B(ZM,XH,Y,XMODE)=((ZM-1.)/ZM)*((XH-Y)/(XMODE-Y))**ZM
C*****************************************************************
C     SUBROUTINE WEIBUL CALCULATES THE LOCATION, SCALE, AND
C     SHAPE PARAMETERS OF THE WEIBULL DISTRIBUTION DESCRIBED
C     BY THE FOLLOWING CONSTRAINTS:
C                    (1)  THE FIRST DERIVATIVE OF THE DENSITY
C                         FUNCTION VANISHES WHEN EVALUATED AT
C                         THE MODE
C                    (2)  THE PROBABILITY OF A VALUE LESS THAN
C                         THE LOWER ESTIMATE IS EQUAL TO THE
C                         CDF EVALUATED AT THE LOW ESTIMATE
C                    (3)  THE PROBABILITY OF A VALUE LARGER
C                         THAN THE HIGH ESTIMATE IS EQUAL TO
C                         (1-CDF) EVALUATED AT THE HIGH VALUE
C       NOTE:  A RESOLUTION OF 0.00001 IS USED
C*****************************************************************
      CUMXL=.00001
      COMPXH=.00001
      G1=15.00001
      GINC=-1.
      ICOUNT=1
      COMPXL=1.-CUMXL
    1 ZM=G1
      IF(G1.EQ.50.) COMPXL=1.
      IF(G1.EQ.50.) GO TO 22
      ANSA=A(ZM,COMPXL)
      ZK=(XL-XMODE*ANSA)/(1.-ANSA)
      XCK=(XH-ZK)/(XMODE-ZK)
      IF(XCK.LT.0.) GO TO 2
      ANSB=B(ZM,XH,ZK,XMODE)
```

Appendix Table 2. (continued)

```
      P1=0.
      IF(ANSB.GT.180.) GO TO 100
      P1=EXP(-ANSB)
  100 CONTINUE
      IF(P1.GT.COMPXH) GO TO 2
      ICOUNT=ICOUNT+1
      G1=G1 + GINC
      GO TO 1
    2 G1=G1-GINC
      IF(ICOUNT.EQ.1) GO TO 1
      GINC=GINC/10.
      IF(ABS(GINC).LT.0.00001) GO TO 22
      GO TO 1
   22 IF(G1.EQ.50) ZLAMDA=10.**75.
      IF(G1.EQ.50.) GO TO 21
      ZLAMDA=(XL-ZK)/((-(ALOG(COMPXL)))**(1./ZM))
   21 CONTINUE
      XARG=(1./ZM) + 1.
      XMEAN=ZK+ZLAMDA*GAMMA(XARG)
      RETURN
      END
```

A System of Measuring Shadows Cast by Habitat and Topographic Features

Ecologists, foresters, agronomists, and regional planners are all well aware of the influences solar radiation exerts on the results of their decisions. For this reason this set of tables has been developed for ease and rapidity of determining the angle of incident solar radiation, shadow direction, and shadow length.

These tables are of aid for the following problems as well as for many others in which knowledge of the sun's altitude, azimuth and shadow are of importance:

1. finding shadowed areas from topographic maps;
2. finding length of shadows cast by forest edges, shelter belts, buildings, etc.;
3. finding what part of the day or year an area will be in or out of shadow; and
4. finding the incident angle of radiation on a horizontal surface.

For the person interested in only a few measurements of these factors, the use of solar almanacs and appropriate formulae is no trouble. However, when many such calculations are needed much time will be spent in making the calculations. These tables provide the altitude and azimuth of the sun at weekly and hourly intervals for the latitude and longitude printed at the top of the tables. Included is a set of tables of shadow lengths cast by objects of different heights. These tables eliminate the necessity of time-consuming calculations necessary for extensive use of this information.

The tables are divided into three parts; solar altitude, solar azimuth, and object height-shadow length ratios.

Solar Altitude

Solar altitude, the angle of the sun above the horizon, was calculated from the equations of Usher (1970) and Walsh (1961). Usher presented equations for expressing the sun's declination (D) in degrees and the equation of time (E) in minutes as trigonometrical polynomials of the angle Y, representing the time before or after the vernal equinox. The angle Y is 360° for a complete year of 364.24 days.

$$\begin{aligned} D = {} & 0.38092 - 0.76996 \cos Y - 1.84002 \sin Y - 0.68841 \cos 2Y \\ & + 9.92299 \sin 2Y + 0.30260 \cos 3Y + 0.10635 \sin 3Y \\ & + 0.03508 \cos 4Y - 0.21211 \sin 4Y - 0.00895 \cos 5Y \\ & - 0.00773 \sin 5Y + 0.0061 \cos 6Y \end{aligned}$$

$$\begin{aligned} E = {} & -0.00198 - 7.12965 \cos Y - 1.84002 \sin Y - 0.68841 \cos 2Y \\ & + 9.92299 \sin 2Y + 0.30260 \cos 3Y + 0.10635 \sin 3Y \\ & + 0.03508 \cos 4Y - 0.21211 \sin 4Y - 0.00895 \cos 5Y \\ & - 0.00773 \sin 5Y + 0.00061 \cos 6Y \end{aligned}$$

Walsh presented equations for determining solar altitude (θ) from declination, latitude (L), and hour angle (H). The hour angle is the time, expressed as an angle, before or after apparent noon. When the calculations are done in hours and minutes, H (in degrees) is as follows:

$$H = ((MN - E) + (long \times 4.0) - hr)/4.0$$

where mn = mean noon or 12:00
long = longitude west of the mean time meridian
hr = local time of interest for solar data.

Appendix Table 3 is an example of a table of solar altitudes at a latitude of 40° north on a mean time meridian.

Solar Azimuth

The azimuth of the sun (ϕ), the direction in which the sun lies as measured in degrees clockwise from North, was derived from the equation

Appendix Table 3. Solar altitude table for 40° north latitude, on a mean time meridian.

TABULATION OF SOLAR ALTITUDE

40.00 DEGREES NORTH LATITUDE AND 0.0 DEGREES LONGITUDE WEST OF THE MEAN TIME MERIDIAN

DATE	MEAN SOLAR TIME														
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
7	0.0	0.0	0.0	5.2	13.9	20.8	25.5	27.3	26.0	21.9	15.3	6.9	0.0	0.0	0.0
14	0.0	0.0	0.0	5.4	14.3	21.4	26.2	28.2	27.1	23.0	16.4	8.0	0.0	0.0	0.0
21	0.0	0.0	0.0	6.0	15.0	22.3	27.3	29.5	28.5	24.4	17.8	9.4	0.0	0.0	0.0
28	0.0	0.0	0.0	6.8	16.0	23.5	28.7	31.1	30.1	26.0	19.4	10.9	1.1	0.0	0.0
35	0.0	0.0	0.0	8.0	17.3	25.0	30.5	32.9	32.0	27.9	21.1	12.5	2.6	0.0	0.0
42	0.0	0.0	0.0	9.4	18.9	26.8	32.4	35.0	34.1	29.9	23.0	14.2	4.1	0.0	0.0
49	0.0	0.0	0.5	11.1	20.8	28.9	34.7	37.3	36.4	32.0	24.9	15.9	5.7	0.0	0.0
56	0.0	0.0	2.2	13.0	22.8	31.1	37.1	39.8	38.8	34.2	26.9	17.7	7.3	0.0	0.0
63	0.0	0.0	4.2	15.1	25.1	33.6	39.7	42.5	41.3	36.5	28.8	19.4	6.8	0.0	0.0
70	0.0	0.0	6.3	17.3	27.4	36.1	42.4	45.2	43.9	38.7	30.8	21.1	10.3	0.0	0.0
77	0.0	0.0	8.4	19.5	29.8	38.7	45.2	48.0	46.4	41.0	32.7	22.7	11.8	0.5	0.0
84	0.0	0.0	10.6	21.8	32.3	41.3	47.9	50.8	49.0	43.1	34.5	24.3	13.3	1.8	0.0
91	0.0	1.4	12.8	24.1	34.7	43.9	50.7	53.5	51.5	45.2	36.3	25.8	14.7	3.2	0.0
98	0.0	3.5	15.0	26.3	37.0	46.5	53.4	56.2	53.9	47.2	37.9	27.3	16.0	4.5	0.0
105	0.0	5.5	17.0	28.4	39.2	48.9	56.0	58.8	56.2	49.1	39.5	28.6	17.3	5.8	0.0
112	0.0	7.4	18.9	30.3	41.3	51.1	58.5	61.3	58.3	50.8	40.9	29.9	18.5	7.1	0.0
119	0.0	9.2	20.6	32.0	43.1	53.1	60.8	63.6	60.3	52.4	42.3	31.2	19.7	8.3	0.0
126	0.0	10.7	22.1	33.5	44.7	54.9	62.8	65.8	62.2	53.9	43.5	32.3	20.8	9.5	0.0
133	1.1	12.0	23.3	34.8	46.1	56.5	64.6	67.7	63.8	55.2	44.7	33.4	21.9	10.6	0.0
140	2.2	13.0	24.3	35.8	47.1	57.7	66.2	69.4	65.3	56.5	45.7	34.4	22.9	11.6	0.9
147	3.1	13.8	25.1	36.6	47.9	58.6	67.4	70.8	66.6	57.5	46.7	35.3	23.8	12.6	1.9
154	3.7	14.4	25.6	37.1	48.5	59.3	68.2	72.0	67.6	58.4	47.5	36.1	24.6	13.5	2.8
161	4.0	14.7	25.8	37.3	48.7	59.6	68.8	72.8	68.5	59.2	48.2	36.8	25.3	14.2	3.6
168	4.1	14.7	25.9	37.3	48.7	59.7	69.0	73.3	69.0	59.7	48.7	37.3	25.9	14.7	4.1
175	4.0	14.5	25.7	37.1	48.5	59.5	69.0	73.5	69.4	60.1	49.1	37.7	26.3	15.1	4.5
182	3.6	14.2	25.3	36.7	48.2	59.2	68.6	73.3	69.4	60.2	49.3	37.9	26.4	15.3	4.6
189	3.0	13.6	24.7	36.2	47.6	58.6	68.0	72.8	69.1	60.1	49.3	37.8	26.4	15.2	4.5
196	2.3	12.9	24.1	35.5	46.9	57.9	67.2	71.9	68.5	59.7	49.0	37.6	26.1	14.9	4.2
203	1.4	12.1	23.3	34.7	46.1	57.0	66.2	70.8	67.6	59.1	48.4	37.1	25.6	14.3	3.5
210	0.4	11.1	22.4	33.9	45.2	56.0	64.9	69.3	66.4	58.1	47.6	36.3	24.8	13.5	2.6
217	0.0	10.1	21.4	32.9	44.2	54.8	63.5	67.7	64.8	56.8	46.5	35.2	23.8	12.4	1.4
224	0.0	9.1	20.4	31.9	43.1	53.6	61.9	65.7	63.0	55.2	45.1	33.9	22.5	11.1	0.0
231	0.0	7.9	19.3	30.8	41.9	52.1	60.1	63.6	60.9	53.4	43.4	32.4	20.9	9.5	0.0
238	0.0	6.8	18.2	29.7	40.7	50.6	58.2	61.3	58.6	51.3	41.5	30.6	19.2	7.7	0.0
245	0.0	5.6	17.1	28.4	39.3	48.9	56.1	58.9	56.2	49.1	39.5	28.6	17.3	5.8	0.0
252	0.0	4.4	15.9	27.2	37.8	47.1	53.9	56.3	53.6	46.7	37.2	26.5	15.2	3.7	0.0
259	0.0	3.2	14.6	25.8	36.3	45.2	51.6	53.7	50.9	44.1	34.9	24.3	13.0	1.6	0.0
266	0.0	1.9	13.3	24.4	34.6	43.2	49.1	51.0	48.1	41.5	32.5	22.0	10.8	0.0	0.0
273	0.0	0.6	12.0	22.9	32.9	41.2	46.7	48.2	45.4	38.9	30.0	19.7	8.6	0.0	0.0
280	0.0	0.0	10.6	21.3	31.0	39.0	44.1	45.5	42.6	36.3	27.6	17.4	6.4	0.0	0.0
287	0.0	0.0	9.1	19.7	29.2	36.8	41.6	42.8	39.9	33.7	25.2	15.2	4.3	0.0	0.0
294	0.0	0.0	7.6	18.1	27.3	34.6	39.2	40.1	37.3	31.3	22.9	13.1	2.3	0.0	0.0
301	0.0	0.0	6.1	16.4	25.4	32.4	36.8	37.6	34.9	29.0	20.8	11.1	0.4	0.0	0.0
308	0.0	0.0	4.6	14.7	23.5	30.3	34.5	35.3	32.6	26.9	18.9	9.4	0.0	0.0	0.0
315	0.0	0.0	3.1	13.1	21.7	28.4	32.4	33.2	30.6	25.1	17.3	7.9	0.0	0.0	0.0
322	0.0	0.0	1.7	11.5	20.0	26.5	30.5	31.3	28.9	23.5	15.9	6.7	0.0	0.0	0.0
329	0.0	0.0	0.3	10.0	18.4	24.9	28.8	29.7	27.4	22.2	14.8	5.7	0.0	0.0	0.0
336	0.0	0.0	0.0	8.6	17.0	23.4	27.4	28.4	26.2	21.2	14.0	5.1	0.0	0.0	0.0
343	0.0	0.0	0.0	7.5	15.8	22.3	26.3	27.4	25.5	20.7	13.6	4.8	0.0	0.0	0.0
350	0.0	0.0	0.0	6.5	14.9	21.4	25.6	26.8	25.0	20.4	13.5	4.9	0.0	0.0	0.0
357	0.0	0.0	0.0	5.8	14.2	20.9	25.1	26.6	24.9	20.5	13.7	5.2	0.0	0.0	0.0
364	0.0	0.0	0.0	5.4	13.9	20.7	25.1	26.7	25.2	20.9	14.3	5.8	0.0	0.0	0.0

of Walsh (1961:52),

$$\sin \phi = (\sin H)(\cos D)(\sec \theta).$$

The direction a shadow is cast from the base of an object is

$$\phi \pm 180°$$

Appendix Table 4 is a table of solar azimuths paired to the solar altitude table in Appendix Table 3.

Object Height-Shadow Length Ratios

These tables are composed of selected values of object heights and the lengths of the shadows cast when the sun is at tabulated altitude. When the height of the object is HT, and the length of its shadow is LNTH, the shadow length is:

$$LNTH = HT(\text{ctn } \phi)$$

Appendix Table 5 is an example of an object height-shadow length ratio table for a solar altitude of 32°.

Use of Tables

For most problems where these tables will be of use, fine accuracy in determining altitude and azimuth is not essential. Rounding off to the nearest weekly interval will be accurate enough in most cases though linear interpolation between weeks can be used. Except for angles less than 10°, the ratio tables are at altitude intervals such that rounding to the nearest tabulated value will give shadow lengths within five percent of the true length of the shadow. In the case of the angles less than 10°, it is most likely that the angle is changing so rapidly that the error will have little effect on the outcome of the work. The exception to this is at high latitudes during the winter.

Appendix Table 4. Solar azimuth table for 40° north latitude, on a mean time meridian.

TABULATION OF SOLAR AZIMUTH

40.00 DEGREES NORTH LATITUDE AND 0.0 DEGREES LONGITUDE WEST OF THE MEAN TIME MERIDIAN

DATE	MEAN SOLAR TIME														
	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
7	0.0	0.0	0.0	125.6	136.5	149.1	163.3	178.6	194.0	208.5	221.3	232.5	0.0	0.0	0.0
14	0.0	0.0	0.0	124.5	135.4	148.0	162.3	177.8	193.5	208.2	221.3	232.6	0.0	0.0	0.0
21	0.0	0.0	0.0	123.1	134.2	146.8	161.3	177.1	193.1	208.1	221.5	233.0	0.0	0.0	0.0
28	0.0	0.0	0.0	121.7	132.8	145.6	160.3	176.5	192.9	208.4	222.0	233.8	244.0	0.0	0.0
35	0.0	0.0	0.0	120.2	131.4	144.4	159.4	176.0	193.0	208.9	222.8	234.8	245.2	0.0	0.0
42	0.0	0.0	0.0	118.6	129.9	143.1	158.5	175.7	193.3	209.7	223.9	236.1	246.7	0.0	0.0
49	0.0	0.0	106.9	117.0	128.4	141.9	157.7	175.6	193.9	210.8	225.4	237.7	248.4	0.0	0.0
56	0.0	0.0	105.1	115.3	126.9	140.7	157.0	175.6	194.7	212.2	227.1	239.6	250.3	0.0	0.0
63	0.0	0.0	103.3	113.6	125.4	139.4	156.4	175.8	195.7	213.9	229.1	241.7	252.5	0.0	0.0
70	0.0	0.0	101.6	111.9	123.8	138.2	155.7	176.1	197.1	215.8	231.3	244.0	254.8	0.0	0.0
77	0.0	0.0	99.8	110.2	122.2	136.9	155.1	176.6	198.7	218.0	233.7	246.4	257.2	267.0	0.0
84	0.0	0.0	98.0	108.4	120.6	135.5	154.5	177.3	200.5	220.4	236.3	248.9	259.7	269.5	0.0
91	0.0	86.5	96.2	106.7	118.8	134.1	153.9	178.0	202.5	223.0	239.0	251.5	262.2	268.1	0.0
98	0.0	84.8	85.6	104.8	117.1	132.6	153.2	178.8	204.7	225.8	241.7	254.1	264.7	265.6	0.0
105	0.0	83.1	87.3	103.0	115.2	131.0	152.4	179.6	207.0	228.6	244.5	256.7	267.1	276.7	0.0
112	0.0	81.4	89.1	101.2	113.3	129.2	151.4	180.5	209.4	231.4	247.1	259.2	269.4	278.9	0.0
119	0.0	79.8	89.2	99.3	111.3	127.3	150.3	181.3	211.8	234.2	249.7	261.5	268.5	280.9	0.0
126	0.0	78.3	87.5	97.5	109.3	125.2	148.9	181.9	214.2	236.8	252.1	263.7	266.5	282.7	0.0
133	67.5	76.8	85.9	95.7	107.3	123.1	147.3	182.4	216.4	239.2	254.3	265.6	275.2	284.3	0.0
140	66.3	75.4	84.4	86.0	105.4	121.0	145.5	182.5	218.3	241.3	256.2	267.3	276.7	285.7	294.9
147	65.2	74.2	83.1	87.5	103.7	118.9	143.6	182.4	219.9	243.1	257.7	268.6	277.9	286.8	295.9
154	64.2	73.2	82.0	88.8	102.1	117.1	141.6	181.9	221.0	244.4	258.9	269.6	278.8	287.6	296.6
161	63.4	72.3	81.0	89.8	100.9	115.5	139.8	181.0	221.6	245.3	259.7	269.7	279.4	288.0	297.0
168	62.8	71.7	80.4	89.4	100.0	114.4	138.3	180.0	221.6	245.6	260.0	269.4	279.6	288.2	297.2
175	62.5	71.4	80.0	89.0	99.5	113.7	137.3	178.7	221.1	245.4	259.9	269.5	279.5	288.2	297.1
182	62.4	71.3	80.0	89.0	99.4	113.5	136.8	177.6	220.0	244.7	259.4	269.9	279.2	287.8	296.7
189	62.5	71.5	90.2	89.3	99.8	113.9	136.9	176.6	218.5	243.5	258.5	269.3	278.5	287.2	296.1
196	63.0	72.1	80.8	89.9	100.6	114.8	137.6	175.9	216.7	242.0	257.2	268.3	277.6	286.4	295.3
203	63.7	72.9	81.7	89.0	101.8	116.2	138.8	175.7	214.9	240.1	255.7	267.0	276.4	285.3	294.4
210	64.7	74.0	82.9	87.6	103.3	118.0	140.5	175.8	213.1	238.1	254.0	265.5	275.1	284.1	293.3
217	0.0	75.3	84.4	86.0	105.3	120.1	142.6	176.2	211.5	236.1	252.1	263.9	266.3	282.8	292.1
224	0.0	77.0	86.2	96.0	107.5	122.6	144.9	176.9	210.1	234.1	250.2	262.1	267.9	281.4	290.7
231	0.0	78.8	88.2	98.2	109.9	125.3	147.4	177.7	208.9	232.1	248.3	260.4	269.5	279.9	0.0
238	0.0	80.9	89.6	100.5	112.5	128.1	149.9	178.7	207.9	230.4	246.4	258.6	268.8	278.3	0.0
245	0.0	83.1	87.3	103.0	115.2	131.0	152.5	179.8	207.1	228.7	244.6	256.8	267.2	276.7	0.0
252	0.0	85.4	95.1	105.6	118.0	133.8	154.9	180.8	206.5	227.2	242.8	255.1	265.5	275.1	0.0
259	0.0	87.8	97.6	108.2	120.8	136.6	157.2	181.7	205.9	225.8	241.1	253.3	263.8	266.5	0.0
266	0.0	89.7	100.1	110.8	123.5	139.3	159.3	182.6	205.4	224.5	239.5	251.6	262.1	0.0	0.0
273	0.0	87.2	102.6	113.4	126.1	141.8	161.3	183.4	205.0	223.3	238.0	250.0	260.4	0.0	0.0
280	0.0	0.0	105.1	115.9	128.6	144.1	162.9	184.0	204.5	222.1	236.4	248.3	258.7	0.0	0.0
287	0.0	0.0	107.4	118.2	130.9	146.2	164.4	184.5	204.0	220.9	234.9	246.7	257.0	0.0	0.0
294	0.0	0.0	109.6	120.4	132.9	147.9	165.6	184.7	203.4	219.8	233.5	245.1	255.3	0.0	0.0
301	0.0	0.0	111.6	122.3	134.7	149.4	166.5	184.9	202.8	218.6	232.0	243.5	253.6	0.0	0.0
308	0.0	0.0	113.4	124.0	136.2	150.6	167.1	184.8	202.0	217.4	230.6	241.9	0.0	0.0	0.0
315	0.0	0.0	114.9	125.4	137.4	151.5	167.5	184.6	201.2	216.3	229.2	240.4	0.0	0.0	0.0
322	0.0	0.0	116.1	126.5	138.4	152.1	167.6	184.2	200.4	215.1	227.8	238.9	0.0	0.0	0.0
329	0.0	0.0	117.1	127.3	138.9	152.4	167.5	183.7	199.5	213.9	226.5	237.5	0.0	0.0	0.0
336	0.0	0.0	0.0	127.8	139.2	152.4	167.2	183.0	198.5	212.8	225.3	236.2	0.0	0.0	0.0
343	0.0	0.0	0.0	127.9	139.2	152.2	166.7	182.2	197.5	211.7	224.1	235.0	0.0	0.0	0.0
350	0.0	0.0	0.0	127.8	139.0	151.7	166.1	181.4	196.6	210.7	223.2	234.1	0.0	0.0	0.0
357	0.0	0.0	0.0	127.4	138.4	151.1	165.3	180.5	195.7	209.8	222.3	233.3	0.0	0.0	0.0
364	0.0	0.0	0.0	126.7	137.7	150.2	164.4	179.6	194.9	209.1	221.7	232.8	0.0	0.0	0.0

Appendix Table 5. Object height-shadow length ratio table for a solar altitude of 32°.

SOLAR ALTITUDE: 32. DEGREES

20.:	32.	40.:	64.	60.:	96.	80.:	128.	100.:	160.
120.:	192.	140.:	224.	160.:	256.	180.:	288.	200.:	320.
220.:	352.	240.:	384.	260.:	416.	280.:	448.	300.:	480.
320.:	512.	340.:	544.	360.:	576.	380.:	608.	400.:	640.
420.:	672.	440.:	704.	460.:	736.	480.:	768.	500.:	800.
520.:	832.	540.:	864.	560.:	896.	580.:	928.	600.:	960.
620.:	992.	640.:	1024.	660.:	1056.	680.:	1088.	700.:	1120.
720.:	1152.	740.:	1184.	760.:	1216.	780.:	1248.	800.:	1280.
820.:	1312.	840.:	1344.	860.:	1376.	880.:	1408.	900.:	1440.
920.:	1472.	940.:	1504.	960.:	1536.	980.:	1568.	1000.:	1600.
1020.:	1632.	1040.:	1664.	1060.:	1696.	1080.:	1728.	1100.:	1760.
1120.:	1792.	1140.:	1824.	1160.:	1856.	1180.:	1888.	1200.:	1920.
1220.:	1952.	1240.:	1984.	1260.:	2016.	1280.:	2048.	1300.:	2080.
1320.:	2112.	1340.:	2144.	1360.:	2176.	1380.:	2208.	1400.:	2240.
1420.:	2272.	1440.:	2304.	1460.:	2336.	1480.:	2368.	1500.:	2401.
1520.:	2433.	1540.:	2465.	1560.:	2497.	1580.:	2529.	1600.:	2561.
1620.:	2593.	1640.:	2625.	1660.:	2657.	1680.:	2689.	1700.:	2721.
1720.:	2753.	1740.:	2785.	1760.:	2817.	1780.:	2849.	1800.:	2881.
1820.:	2913.	1840.:	2945.	1860.:	2977.	1880.:	3009.	1900.:	3041.
1920.:	3073.	1940.:	3105.	1960.:	3137.	1980.:	3169.	2000.:	3201.

To use these tables, proceed to the table of solar altitutde headed by the latitude of the area of interest. The table is divided into columns by local mean solar time from 05:00 to 19:00 hours. Along the left side the table is divided into rows at seven-day intervals. The date given is the last three digits of the julian calendar or the day of the year. To convert a day of the month to this julian day of the year simply add the date of the month to the number found by that month in Appendix Table 6.

The solar altitude or azimuth is found in the appropriate table at the intersection of the date row and mean time column at which it will be observed at the latitude and longitude heading the table. If the point of interest is to the west of the table's longitude the solar altitude will occur four minutes later per degree west of the tabulated longitude. Conversely it will occur four minutes earlier per degree east that the point lies from the tabulated longitude.

Once the sun's altitude and azimuth are known, if shadow lengths are needed proceed to the tables of object height-shadow length ratios. These tables give ratios of the height of an object to the length of its horizontal shadow for different altitudes of the sun. Each table has the solar altitude for which it is applicable printed at its top. The height of the object is the number to the left of the colon while the length of the shadow cast by that height object is to the right of the colon.

The ratio at the top of the far right-hand column is the shadow scale for the solar altitude of that table. This ratio is 100.:N, N being the number of feet of shadow cast per 100 ft of object height.

Appendix Table 6. Factors to add to the day of the month for converting to the Julian day of the year.

Cumulative date (day of the year) to the end of the preceding month

Jan.	0	July	181
Feb.	31	Aug.	212
March*	59	Sep.	243
April	90	Oct.	273
May	120	Nov.	304
June	151	Dec.	334

* In leap years add 1 to these numbers after Feb. 28.

The right hand column of these tables gives the ratios for 1 to 10 ft intervals from 1 to 20 ft or 10 to 200 ft if the decimals of both numerator and denominator are moved to the right one or two places respectively. The ratios can be read across rows at 20 ft height intervals for ease of use of these tables with contour maps.

Topographic Shadows

The ratio tables can be used for establishing shadow lengths for objects on flat terrain or for determining the location and extent of topographic shadows. To use these tables for topographic shadow measurement from topographic maps, first make a scale out of the finest scale graph paper available. The paper should be cut along one of the graph lines to expose the graph scale along the edge. Mark a spot at one end as zero. From the zero end, mark off intervals from the map scale in the units of measure of the contour interval such as feet or meters.

To establish the location of a topographic shadow first locate the ridge or ridges of interest on the map. On acetate secured to the map or on the map draw the azimuth of the shadow cast. To determine if a ridge will cast a shadow at a given solar altitude determine the height difference and horizontal distance between the ridge top and the valley bottom where the shadow azimuth crosses it. Convert this to horizontal distance per 100 ft height different. If this distance per 100 ft of height is less than the corresponding distance on the shadow scale (the ratio in the upper right corner of the table) there is definitely going to be a shadow cast. However, if this value is greater than the shadow scale distance there may be a shadow cast if the hill is adequately convex or concave. Determining the shadow length per 100 ft for the steepest portion of the slope will give the shadow scale for the solar altitude below which the hill will start casting a shadow.

The shadow cast by a topographic feature can be estimated by the determination of the shadow length cast by that feature from several points along the crest of the feature. The end points of these shadows are connected for the estimation of the topographic shadow. Using the table of ratios for the sun's altitude, obtained from the previous tables, a system as outlined in Appendix Table 7 may be used to determine the shadow length along lines parallel to the shadow azimuth.

The shadow cast by a topographic feature will lie wholly between the solar crest of a feature and the measured end of the shadow. The more lines used along the shadow azimuth for determining the shadow length the more precise will be the delineation of the edge of the topographic shadow. However, for determining areas in shadows, three to five lines may suffice.

On maps that have very close contour lines it may be most expedient to use 100 ft contour units (5 contour lines on a 20 ft contour interval map) rather than the 20 ft units for which the tables are prepared. The right hand column gives the 100 ft interval ratios from 100 ft to 2000 ft.

When the tabulated distance and the measured distance are the same and remain the same for several contour lines the shadow end may be considered to be toward the distal end of this interval since effectively the sun's rays are parallel to the surface and usually ineffective in an ecological sense.

Appendix Table 7. A method for determining topographic shadows from contour maps.

1. Move from the crest along the line extending toward the shadow azimuth to the first contour line. Here place the zero end of the prepared scale with the marked end extending toward the shadow azimuth.

2. Determine the tabulated shadow length associated with the height of the zero point above the next contour line in the direction of the shadow azimuth. This is (N x contour interval), where N is the number of contour lines below the zero point contour line. If a drainage is crossed N will decrease in magnitude.

3.A. If the tabulated shadow length is greater than the length measured from the zero point to this contour line this line is within shadow. Progress to the next contour line. Return to Step 2.

B. If the tabulated shadow length is less than the length measured from the zero point to this contour line this line is not within shadow. Go to Step 4.

4.A. If this was the first contour line below the zero point then the sun is at an angle such that there is light directly on the 'shadow side' at this point. Move the zero point to the lower contour line. Go to Step 2 and continue the process until a point within shadow (3.A.) is obtained. When you do, the contour at the zero point is near the solar crest of the hill at this solar altitude. (The solar crest is the area of the feature that has shadow to one side and direct sunlight on the other.

B. If this was not the first contour line below the zero point then you have passed out of the shadow cast by this formation. Mark this point and go to the next line along which shadow length is to be measured. Start at Step 1.

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Measure of the Natural Potential of

Land for Supporting Deer Populations

Edward Barrow Rayburn

ABSTRACT

A model of the inter- and intra-seasonal energy flow through deer populations was developed through the use of the existing literature. The model was programmed in Fortran IV for computer-based use in evaluating the potential biological productivity of land for deer. The model was developed specifically for evaluating land being considered for acquisition for deer-management areas.

The model uses "Standard Deer Units" (an integration of climatic, behavior, and range characteristics affecting the energy dynamics of the deer) as a measure of the energy available for the production and maintenance of deer. Estimation of successional changes in cover and forage production are made by use of a flexible statistical distribution model known as a Weibull distribution. Indices of the potential sightable and harvestable deer production are calculated in standard deer units at 5-year intervals over a 50-year planning horizon.