ENERGY BALANCE AS A CRITERION FOR ACQUIRING DEER MANAGEMENT AREAS

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ABSTRACT

A FORTRAN IV model of the inter- and intra-seasonal energy flow through deer populations was developed for evaluating the potential biological productivity of land for deer. The productivity per unit cost is suggested as a means for evaluating land being considered for acquisition for deer management areas.

The model uses the "Standard Deer Unit," an integration of climatic, behavior, and other factors. To characterize the energy dynamics of deer maintenance and production subjective probability estimations are made by the user of successional changes in cover and forage production. 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.

INTRODUCTION

Acquiring land for producing a wildland resource such as deer is a complex problem. There are many alternatives to fee simple acquisition such as acquiring access, leasing, forming cooperatives, encouraging private landowners to opening land for use, or increasing wildlife productivity on lands now open.

The question of whether to acquire a tract of land becomes increasingly difficult as land prices increase, land available for purchase decreases, and as public expressions about the desirability of state or federal land ownership become more clear but disparate. Criteria for wildlife land evaluation are needed and one of these should be a prediction of wildlife productivity on an area. By equating productivity with *benefits*, it is useful in comparing tracts and thereby allocating limited wildlife land acquisition funds more rationally. We present a methodology for estimating this long-term productivity of land for white-tailed deer *(Odocoileus virginianus)* and we suggest that similar analyses are feasible for other species and species groups. The method employs ecological bioenergetics (cf Moen 1968a) and computer modeling in a system to aid decision makers. The model was written in FORTRAN IV for the IBM 370 system and is described in detail in Rayburn (1972). A copy of the program is available.

Lobdell's (1972) MAST system allows a wildlife agency to maximize returns on investments based on wildlife production over the useful life of a project. His system is now used in several states on lands already owned to get better returns per dollar invested. Land acquisition as a general investment category can be included in his system. Once MAST specifies that approximately Z acres should be acquired, the method we outline can be employed to improve on that selection or to provide feedback to MAST estimates.

METHODS

Production of wildlife from wildland systems is biologically the same as production of domesticated stock from pasture systems. Its basis is that of the population-environment energy balance conceptualized as:

$$E_m + E_p = E_f - E_d \qquad (1)$$

where E_m = Energy for maintenance
E_p = Energy for production
E_f = Energy available from consumed forage, and
E_d = Energy drain to the environment.

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There are many variables which influence this energy balance. We developed a model which can be used to evaluate the relative potential productivity of different land areas. We established as design criteria that the model require only inputs which are relatively inexpensive to obtain or which are commonly available. We recognized that great expense could not be justified in the acquisition decision making process and that such decisions are usually made while an option is held, usually within a year.

The second modeling criterion was that the results be reflective of the likely successional changes in forage and wildlife production over the time the land was owned (e.g. at least 50 years) *if* it were purchased. Therefore, the concept of *potential* production was employed. Effects of possible management strategies on game production can be estimated by using Lobdell's MAST System on our model in a simulation model.

Table 1 presents a list of factors which influence the productivity of a deer heard. Those marked with a single asterisk are more easily quantified than the other factors, and were those used in the modeling of productivity. Those marked with a double asterisk can be included by slight modification of energy requirement or forage production once they are quantified by biologists.

Table 1. Major factors which affect the productivity of a deer population.

Habitat Factors	
Food production and seasonal distribution	*
Cover availability	*
Habitat interspersion	
Topography	**
Soil	**
Climate	*
Nuisance insects	**
Predators	**
Competitive species	**
Succession	*
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	*

* Factors which are considered in the model developed.
** Factors which can be used in the model with slight modification once quantified.

The model estimates the energy potentially available for productivity of the deer herd. This can be used either for maintenance of mature animals or growth of young animals depending on how the area is managed for the conversion of this energy to a product for man. The concept of the potential minimizes the influence of predators (human or quadruped), disease, and extremes of weather which can cause deviations of actual productivity from such a measure. However, it is well documented that animal populations tend to approach the potential of the habitat. Therefore, a model based on energy potentially available for production provides the best input for acquisition decisions to be used with other economic, social, and environmental considerations. For most acquisition purposes, knowledge of the *relative* potential response of the population to the habitat over the long run is sufficient.

Table 2 presents an outline of the basic model, the data source if computer supplied or if input from field inspections, and how the data are modified by other portions of the model. The basic calculations of energy requirement are based on the model proposed by Moen (1968a). The interaction of the animal-climate-habitat system has been described according to observation made and reported in the literature by Gieger (1965), Moen (1966, 1968a, 1968b), Moen and Evans (1971), Ozoga (1968), and Sellers (1965).

Table 2. Productivity components of a model to aid in wildlife land acquisition decisions.

Energy Balance Module (EBM)

$E_d = E_m$

$E_d = S_r E\sigma T_s^4 + S_t H_c \Delta T + I(T_b - T_a) + H_e S_t - S_r R_e$ — Moen (1968a, 1968b)

$E_m = H_b H_f H_a$ — Moen & Evans (1971)

E_d	= energy drain to the environment	I	= mass of food ingested
E_m	= energy released in body metabolism of deer	T_b	= 37.5°C, body temperature
S_r	= radiation profile	T_a	= air temperature
E	= emissivity of deer hair	H_e	= evaporative heat loss
σ	= 4.93×10^{-8} kcal $m^{-2}hr^{-1}K^{-1}$	H_b	= basal metabolic rate Silvers et al. (1969)
T_s	= surface temperature of deer	H_f	= heat increment of diet
S_t	= total surface area of deer	H_a	= heat increment of activity
H_c	= convection coefficient of deer	R_e	= environmental radiation to deer
ΔT	= $T_s - T_a$		

***Climatic-Environment Module* (CEM)**		
Temperature	data input	Modified for EBM by Ozoga (1968) and habitat use data input.
Radiation	Moen 1968b Lull and Relgner 1967	Night IR Daytime total radiation
Windspeed	data input	Modified for EBM by Ozoga (1963) and habitat use data input.
Snowpack	data input	Used to modify activity energy requirement on basis of Kelsall and Telfer (1971)
Season changes	data input	Used to change BMR (Silver et al. 1969) and forage utilization.
***Behavior Module* (BM)**		
Habitat use	summer	Proportional to forage production
	winter	data input
Subunit use	data input	
***Cover Module* (CM)**		
Cover availability by subunits	data input of cover succession	Used to modify CEM according to Gieger (1965). Sellers (1965) and Ozoga (1968).

***Forage Module* (FM)**	
Forage production availability	Data input by successional distribution modified by snow depth and forage consumption.
Forage consumption	Modified by snow depth and winter maximum intake (Ozoga and Verm 1970) for maintenance.
***Productivity Module* (PM)**	Productivity indices (I_s, I_h) Calculated at 5 yr. intervals over 50 yr. planning horizon w/cumulative summary and matrix of alternative I_s and I_h on basis of alternative management strategies for the summer and winter herd balances and harvest. (see text for discussion)

The consideration of habitat change due to succession is accomplished by the use of the Weibull distribution of Lobdell (1972). In this method the land evaluator needs only to estimate cover or forage production at present, the fastest change, and the maximum duration. The Weibull distribution function of the model then converts these estimates into a smoothed mathematical description of successional change of food and cover production.

There are many sections of the model. Most are based on well known concepts. The productivity module has aspects that have general application.

Production of recreational hunting is a complex function often reduced to "man days of recreation." For hunters it is composed of production subunits of animals bagged. The annual potential production of a wildlife population would be the integrated, quality-ranked opportunities or units available to users formed over the year. Quality ranking of any production unit is dependent on the recreationists involved. Animal size, sex, and activity will influence the quality of the experiences. Animal size will also affect the number of animals a habitat can support. For these reasons and since animal size, sex and age distribution are plastic to management, the energy balance model uses a standard deer for all calculations. This is a 50 Kg dry, open doe.

In the model, wildlife production is divided into two types, non-consumptive (sightings of deer or deer sign) and consumptive (harvestable deer). Non-consumptive production of a population (X_S) can be described as the function: $X_S = F(X,S)$ (2)

where X_S = total sightings made
X = wildlife population size
S = effect physical environment and human behavioral conditions have on deer sightings

Thus, the favorability of amounts of cover, weather, and human social conditions, will determine the *actual* production achieved from a given population, i.e. the portion of the potential actually experienced.

Consumptive production (X_h) of the wildlife population is the actual harvest. For stable population conditions this can at a maximum be equal to the net natality minus non-harvest mortality.

The total production of the herd can be expressed as:

$$QP_{total} = Q_s X_s + Q_h X_h \qquad (3)$$

where QP_{total} = total, quality-ranked production
Q_s = quality ranking of sighted animals
Q_h = quality ranking of harvested animals

Quality ranking of the harvest is not included here since it restricts the applicability of the model due to regional differences in quality ranking of production. In lieu of it, two indices are used to evaluate the potential non-consumptive and consumptive production from the habitat areas involved. The non-consumptive production index is calculated as:

$$I_S = ((SDP_S\ M_S) + (SDP_W\ M_W))/12 \qquad (4)$$

where I_S = potential non-consumptive production index
SDP_S = potential standard deer population size in summer
M_S = number of months in summer season
SDP_W = potential standard deer population size in winter
M_W = number of months in winter season
12 = the months of the year

The SDP_S and SDP_W are calculated by the Forage Module according to the following relation:

$$SDP_i = ME_i / \sum_{j=m}^{n} ERSD_j \qquad (5)$$

where SDP_i = potential standard deer population in season i
ME_i = metabolizable forage energy available in season i
m = first month of season i
n = last month of season i
$ERSD_j$ = energy requirement of a standard deer in month j

For the summer the calculation as *first* made is used. However for the winter conditions an intitial estimate is made with equation 5. This is then used to evaluate the interaction of monthly snow pack and forage consumption on the SDP which can be sustained on the area. This is done iteratively by the computer until the change in calculated SDP_W is less than 5 percent.

From equation 4, it can be seen that the influence of habitat and human factors on sightings is omitted. Therefore, equation 4 assumes equal effects of these factors in summer and winter. In using this index these assumptions should be kept in mind. Weights can be employed where differences can be estimated.

The index of potential consumptive production is calculated as:

$$I_h = SDP_s - SDP_w, \quad SDP_s \geq SDP_w \qquad (6)$$

$$\text{and } I_h = 0 \qquad\qquad , \quad SDP_s < SDP_w \qquad (7)$$

This index, I_h, does not include natural unharvested mortality. However, if we cannot assume that this mortality rate is the same for all areas being compared for purchase an estimate of the differences would have to be made.

Equation 6 is based on the assumption that the population is limited by the winter habitat-climate conditions. When a zero I_h is calculated it does not imply that no harvest can be expected from such an area. However, the potential non-consumptive production would have to be reduced in order to obtain a positive potential consumptive production. This compromising of I_s and I_h is discussed in detail by Rayburn (1972). This would be done by management plans for the SDP such that the SDP_w be kept sufficiently below the potential *size* to allow the SDP_s to utilize the summer forage supply for harvestable production. Thus, if an I_h of 25 is desired from the area when the SDP_s was 150 and SDP_w was 200 the allowable SDP_w would be 125. This is calculated by equation 6 as:

$$25 = 150 - SDP_w$$

$$SDP_w = 150 - 25$$

$$= 125$$

But I_s (equation 4) changes from 171 to 140 for an area with 7 months of summer and 5 months of winter. This concept is used in the model to construct and print a matrix of alternative I_s and I_h for the areas being evaluated.

A program was written to produce comparative reports for the areas under study.

RESULTS

Fig. 1 shows the general model development. Table 3 shows a computer-generated report from using the system. Table 4 presents the results of a sensitivity analysis of the model to various input data changes. Those variables which cause a large variation when slightly changed indicate the need for special care when gathering the information.

In the sensitivity analysis (Table 4) forage production estimates gave changes of the magnitude expected. However, when the season length was altered, larger differences than were expected occurred in the I_s and I_h indices. When forage supply is held constant for the season, as done herein, larger differences can be expected in the resulting productivity indices.

DISCUSSION

The goals of modeling are (1) to improve understanding of the system and (2) to improve decision making. Productivity models have previously been used for wildlife management decision making. Life equations and knowledge of a species reproductive success in a given year are used to set bag limits on waterfowl and upland game. The approach used in this model is to take data such as forage production and cover succession and data which are directly measurable such as monthly temperature and season initiation and integrate them to calculate potential productivity indices.

The model developed has aided in better understanding deer population responses, for example, the importance of forage supply in summer. It has produced reports by which a better informed choice can be made between alternative tracts of land available for purchase. It has emphasized that land "performance" in terms of potential human benefits produced per public dollar invested can, and, it seems to us, should be computed before land is acquired.

The concept of potential productivity does not detract from but can only enhance the managerial opportunities and responsibility. It provides a basis for managerial effectiveness and a means for assessing the impact of forces that tend to prevent full public benefits to be derived from wildlife lands.

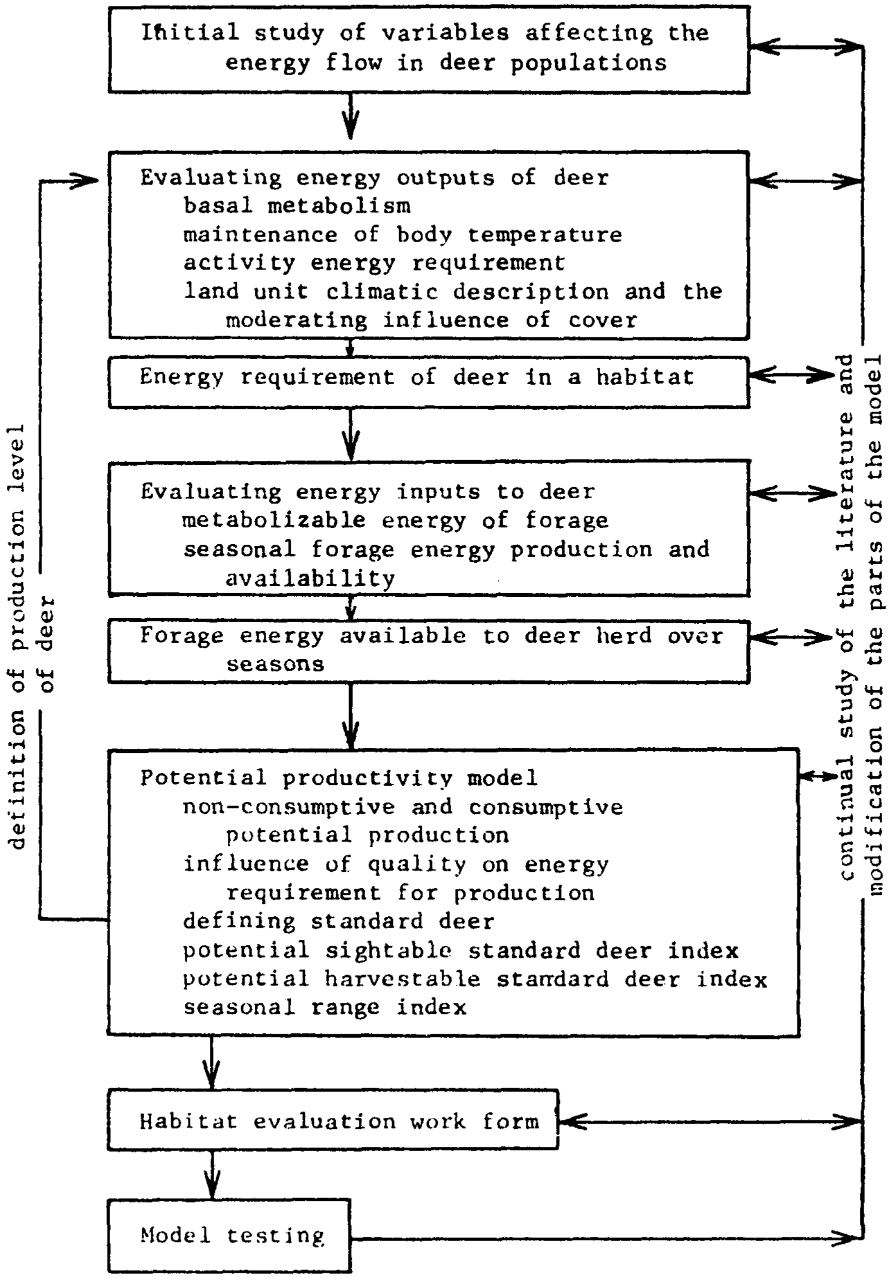

Figure 1. Flow chart of the development of the potential biological productivity land evaluation model.

Table 3. Computer evaluation printout for a hypothetical tract.

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			Mean Weather Station	Mean Monthly Snow-Pack
	Max.	Min. (F)	Mean	Wind Speed (MPH)	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.

Upland forests subunit is composed of approximately 1050. acres. The expected utilization of the subunit is as follows:

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

The subunit has been divided into 5 cover types.

Cover descripton 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

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.

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.

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.

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.

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.

A table of alternative indices is presented below for The Tompkins Tract for balance and eight levels of range utilization harvest rates.

Maximum Utilizable Range Balance

Range Utilization Harvest Rate	1.5 S	1.5 H	2.0 S	2.0 H	2.5 S	2.5 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.:

Table 4. Results of the sensitivity analysis of variables in the potential Productivity model.

Variable	*Change in variable* *Magnitude*	*Direction*	*Resulting change in productivity indices* *Cummulative indices* *Sightings* I_s	*Harvest* I_h
Normal*	—	—	19391.	4735.
Temperature	10°C	Increase	0.0	0.0
Snow Depth	10%	Increase	0.0	0.0
Spring Season	1 month	Earlier	24.4	−100.0
	1 month	Later	−14.5	54.2
Fall Season	1 month	Earlier	−2.0	−8.2
	1 month	Later	21.6	157.4
Spring Molt	1 month	Earlier	−20.2	77.7
	1 month	Later	0.0	0.0
Fall Molt	1 month	Earlier	23.3	174.0
	1 month	Later	0.0	0.0
All Habitat Use Based on Forage Production			7.7	−31.4
Forage Production Maximum				
All Types and Seasons	10%	Increase	10.0	9.9
All Winter Types	10%	Increase	3.9	−16.0
Winter Browse	10%	Increase	3.7	−15.0
Winter Succulents	10%	Increase	0.2	−1.0
All Summer Types	10%	Increase	5.6	28.0
Summer Browse	10%	Increase	1.7	21.8
Summer Succulents	10%	Increase	4.2	5.2
Forage Production Spans	10%	Increase	6.2	5.4
Basal Metabolic Rate	10%	Increase	−9.1	−9.0
Visible Solar Radiation	10%	Increase	0.0	0.0
Snow Depth on Activity Energy Requirement				
Regression Slope	10%	Increase	0.0	0.0
Regression Intercept	10%	Increase	0.0	0.0
Slope and Intercept	10%	Increase	0.0	0.0

* The Normal is the SDP calculated, all values after the Normal are percent change.

LITERATURE CITED

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