Methodology for Assessing Timber and White-tailed Deer Habitat Tradeoffs

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Abstract: A linear programming model was used to evaluate trade-offs between timber returns and white-tailed deer (*Odocoileus virginianus*) habitat in East-Central Mississippi. The model was designed to maximize capitalized present net worth of a sample forest subject to white-tailed deer habitat, wood flow, and acreage regenerated restrictions. Four levels of habitat diversity were evaluated. Enhancing habitat diversity will cost, in terms of timber revenue foregone, between $2.08 and $30.71/hectare per year. These cost estimates are not applicable to all loblolly pine (*Pinus taeda*) forests. However, the methodology is applicable for other forests when appropriate forest inventory data and wildlife habitat restrictions are specified.

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In recent years, intensive forest management (even-age management) has received considerable attention from sportsmen and concerned conservationists. Some contend that the conversion of large tracts of mixed pine-hardwood stands to intensively-managed, short-rotation pine plantations will have a detrimental effect on wildlife populations. Others contend that diversity created by age-class distribution of pine plantations, streamside management zones (Section 208, Public Law 92-500) and use of silvicultural tools such as prescribed burning and thinning will enhance certain wildlife populations.

Price information for land use alternatives in agriculture and forestry and most other economic activities are readily discernible. Benefits that accrue from wildlife or other recreational activities are more difficult to measure. These measurement difficulties arise from the non-market nature of the good; the market place is the normal determinant of price and value for most other goods. Most previous investigations have attempted to handle the price problem through the use of a proxy for price (Clawson 1959, Gibbs 1975, Knetsch 1963, Lundgren 1973, Martin et al. 1974).

In the absence of the traditional media of comparison (real dollars), the investigator must resort to other economic tools to help clarify the relative demand for non-market goods and services, i.e. wildlife. The basic procedure most frequently used in this regard is the maximum value the resources could produce in any other feasible use (i.e. the opportunity cost method). That is, the investigator must determine how much timber revenue must be foregone as deer habitat management is intensified.

The purpose of this study was to provide a methodology by which forest landowners and/or managers can assess the tradeoffs between timber returns and white-tailed deer habitat. Application of the model to a typical loblolly-shortleaf pine (*P. echinata*) hardwood forest is demonstrated.

Methods

A timber harvesting schedule which maximized capitalized present net worth subject to wood flow, acreage regenerated, and deer habitat restrictions was developed. Discounting models and a linear programming model were used to develop the harvesting schedule.

Data Requirements

Timber growth and yield estimates, current prices for timber products, forest management cost estimates, and a selected discount rate are data required for discounting models to assess the relative profitabilities of alternative rotations and thinning schedules.

Silvicultural activities of an intensively-managed forest include brush control, fertilizing, pre-commercial thinning, control burning, and commercial thinning. Each of these affect deer habitat, i.e. forage production. Incorporation of habitat restrictions into the linear programming model was based on discussions with wildlife professionals and previous research (Hurst and Warren 1980, Warren 1980, Hurst and Warren 1981). Wildlife professionals were concerned with the pattern of timber harvesting activity. Specifically, they were concerned that harvest cutting be done in relatively small blocks and dispersed throughout the forest to insure diversity of habitat types over the forest. Discussions with professional wildlife personnel and research results were instrumental in helping quantify 4 habitat diversity levels. Habitat diversity levels are defined as: (1) very poor (1 deer/40 ha), (2) poor (1 deer/24 ha), (3) good (1 deer/12 ha), and (4) excellent (1 deer/6 ha).

Discounting Models

The most acceptable method for the appraisal of long-term projects such as forestry is discounted cash flow or present net worth (PNW) analysis (Holmes and Waldrop 1971). The superiority of the technique and the characteristics which distinguishes it from others is its recognition that money has a time value.

Quantitatively, the present net worth model for a single rotation is:

$$PNW = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+1)^t} - A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad (1)$$

where:

PNW = The present net worth of a single rotation,
R_t = Revenue received at time t,
C_t = Silvicultural cost occurring at time t,
A = Annual cost,
n = The rotation age,
t = The number of years until revenue or costs occur,
i = The discount rate expressed as a decimal number.

The present net worth of an infinite series of rotations, sometimes referred to as the capitalized value or land expectation value, is a relevant measure of the value of any timber growing enterprise which is expected to produce revenues for many years.

The calculation for adjusting the present net worth of 1 rotation to the present net worth of an infinite series of such rotations, the capitalized value, is given by the model:

$$PNW_p = (\text{Present Net Worth of one rotation}) \left[1 + \frac{1}{(1+i)^n - 1}\right] \quad (2)$$

where:

PNW_p = The present net worth of an infinite series of single rotations, other variables as previously defined.

An "annual equivalent" may be defined as the amount of an annual payment, which will just pay off the present net worth of an asset during its remaining lifetime. It provides a means of comparing the timber enterprise with shorter term uses of the land, for it gives the discounted expected annual income from leaving the timber in place for "N" years in the future.

The annual equivalent values for a single rotation can be calculated as follows:

$$AE_{SR} = [PNW] \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (3)$$

where:

AE_{SR} = The annual equivalent for a single timber rotation,
PNW = Present net worth of a single rotation as given in equation (1),
i = The discount rate as a decimal, and
n = The length of the rotation.

Annual equivalent values of timber rotations in perpetuity are obtained by multiplying the rate of discount by the capitalized present net worth of such rotations. Algebraically,

$$AE_{IR} = [PNW_p]\,[i]$$

where:

AE_{IR} = The annual equivalent for an infinite number of timber rotations,
PNW_p = Capitalized present net worth as given in equation (2),
i = The discount rate as a decimal.

Linear Programming Model

Linear programming is a mathematical model for maximizing or minimizing a linear objective function (such as capitalized present net worth) subject to a set of linear constraints and/or requirements. Linear programming is an iterative procedure that selects 1 combination from a set of production possibilities that satisfies the operational constraints and determines whether profit can be increased by selecting some other combination. The iterative procedure continues until the objective function specified is maximized. The basic assumptions and methods of linear programming are well-documented and need not be presented here (Dantzig 1963). Formulation of the model developed in this study is presented as follows.

Consider the problem of scheduling "s" cutting units through a planning period of 'nt' years with "n" cutting periods of "t" years each. The following management restrictions are imposed:

1. Total pulpwood requirements in period $j (j = 1, \ldots, n)$ must be at least b_j but not greater than c_j.

2. Total sawtimber requirements in period $j (j = 1, \ldots, n)$ must be at least g_j but not greater than h_j.

3. Total acreage regenerated in period $j (j = 1, \ldots, n)$ must be at least e_j but not greater than f_j.

There are "m" alternative cutting regimes available for harvesting each cutting unit with each regime producing a distinctive pattern of wood flow and possessing an associated capitalized present net worth. To mathematically represent the variables involved in the model the following notation is defined.

Y_{ijk} = yield of cutting unit "i" in period "j" under management regime "k", where:
i = 1, . . . , s (s = no. of cutting units),
j = 1, . . . , n (n = no. of cutting periods),
k = 1, . . . , m (m = no. of management regimes).

C_{ijk} = 1 cutting unit "i" is regenerated in period "j" under management regime "k"; = 0 otherwise; "i", "j", "k" as previously defined.

X_{ik} = proportion of cutting unit "i" managed under management regime "k"; "i", "k", as previously defined.

D_{ik} = capitalized present net worth of stand "i" managed under management regime "k"; "i", "k", as previously defined.

Z_{ijk} = acres of cutting unit "i" regenerated in period "j" under management regime "k"; "i", "j", "k", as previously defined.

W_{ij} = 1 natural stand "i" is harvested in period "j", where: i = 1, . . . , s (s=2; adjacent natural stands),
j = 1, . . . , n.

R_{ik} = 1 plantation "i" harvested under management regime "k", where:
i = 1, . . . , s (s=2; adjacent plantations),
k = 1, . . . , m.

WI_{ik} = 1 all of cutting unit "i" is managed under management regime "k", where:
i = 1, . . . , s (s=2; adjacent cutting units),
k = 1, . . . , m.

Using the above notation, the cutting schedule problem can be stated. The objective is maximization of capitalized present net worth Q, when Q is defined as:

$$\text{Maximize } Q = \sum_{i=1}^{s} \sum_{k=1}^{m} X_{ik} D_{ik} \quad (1)$$

Subject to the set of restrictions

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Z_{ijk} X_{ik} \geq e_j \quad (j = 1, \ldots, n) \quad (2)$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Z_{ijk} X_{ik} \leq f_j \quad (j = 1, \ldots, n) \quad (3)$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Y_{ijk} X_{ik} \geq b_j \quad (j = 1, \ldots, n) \quad (4)$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Y_{ijk} X_{ik} \leq c_j \quad (j = 1, \ldots, n) \tag{5}$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Y_{ijk} X_{ik} \geq g_j \quad (j = 1, \ldots, n) \tag{6}$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} Y_{ijk} X_{ik} \leq h_j \quad (j = 1, \ldots, n) \tag{7}$$

$$\sum_{i=1}^{s} \sum_{j=1}^{m} W_{ij} = 1 \tag{8}$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} R_{ik} \leq 1 \tag{9}$$

$$\sum_{i=1}^{s} \sum_{k=1}^{m} WI_{ik} \leq 1 \tag{10}$$

$$\sum_{k=1}^{m} X_{ik} = 1 \tag{11}$$

$$X_{ik} \geq 0 \tag{12}$$

The inequalities (2) and (3) express the restrictions imposed on regeneration acreages while expressions (4) and (5) state the restrictions regarding pulpwood requirements. Expressions (6) and (7) state the restrictions regarding sawtimber requirements. Equations (8) and (9) enhance deer habitat diversity by preventing cutting of adjacent stands in the same cutting period. Equation (10) forces adjacent stands to select 1 single management regime. Equation (11) requires that for each cutting unit the proportions of the cutting unit harvested under all regimes must sum to 1 (i.e., for each cutting unit, the number of hectares harvested under all regimes must equal total hectares in the cutting unit). Inequality (12) states the non-negativity constraint.

Equations (8), (9), and (10) were added to the original linear program matrix to insure that the minimum habitat level was achieved. Some discretion should be used when using these equations. In most cases, preventing concurrent cutting of all combinations of adjacent cutting units would require a large number of additional equations to be added to the original matrix. By plotting initial solution results on a map, the investigator can visualize spatial arrangement of the harvest schedule. Harvest of adjacent cutting units in the same cutting period can be prevented by adding the deer habitat equations above to the original matrix.

Application and Results

Application of the model to a 7,255-ha loblolly-shortleaf pine hardwood forest is presented in this section. The purpose was to illustrate the use of the model and to derive estimates of tradeoffs between timber production and selected levels of deer habitat diversity. This example should serve as a guide for users who wish to make timber and deer assessments for their forest holdings.

Data

Stand data, price, and cost information used in this study were provided by an organization which has requested anonymity. Age class of cutting units on the study area are presented in Table 1.

Estimates of yields for natural loblolly-shortleaf pine hardwood stands for this study were based on a growth model developed by Killcreas (1976). Yields for planted loblolly pine were based on a model developed by Strub (1978).

Opinions concerning specification of the discount rate diverge considerably among users. An informal survey of forest industry managers indicated that a 10% discount rate would be appropriate; therefore, it was selected for this study. For other applications of the model, the user should choose the rate that reflects the restriction and conditions applicable at the time.

Table 1. Area and number of cutting units on the sample forest by age class of the dominant pine crown class.

Age class (Years)	Cutting units[a] (*N*)	Forest area[b] (Ha)	% of total area
0– 5	29	1,533	21.1
6–10	18	1,110	15.3
11–15	2	153	2.1
16–20			
21–25	1	30	.4
26–30	1	54	.8
31–35	6	205	2.8
36–40	11	668	9.2
41–45	25	1,487	20.5
46+	43	2,015	27.8
Total	136	7,255	100.0

[a] Average cutting unit size for loblolly pine plantations and natural loblolly-shortleaf pine hardwood cutting units was 57 and 51 ha respectively.
[b] To convert hectares to acres multiply hectares by 2.471.

Alternative Management Regimes

When an existing cutting unit is harvested, a continuing series of planted loblolly pine stands will be grown on the unit. A computer program was used to evaluate alternative management regimes for loblolly pine plantations. Yield estimates and subsequent capitalized present net values were calculated for combinations of site index, planting rate, rotation length, number, and age of thinnings and residual basal area after thinning.

Conversion of natural stands to plantations during the first 3 cutting periods generated a total of 15 alternative management regimes, 5 for each cutting period. Existing plantations were 1 to 11 years old. Five alternative management regimes were generated for age classes 1–5, 6–10, and 11–15 (i.e. a total of 15 plantation activities). These activities, alternative management regimes, were the basic variables for application of the linear programming model developed in this study (Table 2).

Cutting Schedules

Cutting schedules for the study area were calculated over a 60-year planning period (12 5-year cutting periods) for each deer habitat level. Practices formulated for each habitat level are presented in Table 3. Wood flow and hectares-regenerated restrictions were formulated for each habitat level. The agency providing the stand data was instrumental in determining realistic restrictions.

The absence of wood flow and hectares-regenerated requirements resulted in a solution comparable to the carrying capacity requirements outlined earlier for habitat level I. Wood flow and hectares-regenerated restrictions for habitat level II was focused on stabilizing hectares-regenerated per period and volume removed per period. Wood flow and hectares-regenerated restrictions for habitat level III and IV were the same as habitat level II. The only difference being that deer habitat diversity was enhanced by preventing concurrent cutting of adjacent cutting units and installation of hardwood leave strips.

Cutting unit age class distribution, percentage of total forest acreage, for each habitat level is presented in Table 4. Diversity at habitat level I is virtually nil. For example, 61% of the forest is harvested and regenerated in period 1 while the remaining 39% is in 1-11 year old loblolly pine plantations. Distribution is more uniform for habitat levels II, III and IV. Spatial arrangement for each habitat level is presented in McKee (1982).

Opportunity Cost of Providing White-tailed Deer Habitat Diversity

Each cutting schedule solution indicated that the objective function value, capitalized present net worth, of the study area decreased as the solutions became increasingly constrained. Elimination of regeneration, wood flow, and deer habitat diversity requirements, habitat level I, resulted in an objective function value of $23,329,187. After imposing deer habitat diversity

Table 2. Alternative cutting regimes for study area natural stands and existing plantations (T = thin, CC = clearcut).

			Cutting periods											
	ACR[a]	Rotation	1	2	3	4	5	6	7	8	9	10	11	12
Natural stands:														
Clearcut	1	20	CC			T	CC			T	CC			T
Sub-period 1	2	25	CC			T		CC			T		CC	
	3	30	CC			T			CC			T		
	4	35	CC			T		T		CC			T	
	5	40	CC			T		T	T		CC			T
Clearcut	6	20		CC			T	CC			T	CC		
Sub-period 2	7	25		CC			T		CC			T		CC
	8	30		CC			T			CC			T	
	9	35		CC			T		T		CC			T
	10	40		CC			T		T	T		CC		
Clearcut	11	20			CC			T	CC			T	CC	
Sub-period 3	12	25			CC			T		CC			T	
	13	30			CC			T			CC			T
	14	35			CC			T		T		CC		
	15	40			CC			T		T	T		CC	
Plantations:														
Age 1– 5	16	20			T	CC			T	CC			T	CC
	17	25			T		CC			T		CC		
	18	30			T			CC			T			CC
	19	35			T		T		CC			T		
	20	40			T		T	T		CC			T	

Table 2. Continued.

	ACR[a]	Rotation	Cutting periods 1	2	3	4	5	6	7	8	9	10	11	12
Age 6–10	21	20		T	CC			T	CC			T	CC	
	22	25		T		CC			T		CC			T
	23	30		T			CC			T			CC	
	24	35		T		T		CC			T		T	
	25	40		T		T	T		CC			T		
Age 11–15	26	20	T	CC			T	CC			T	CC		
	27	25	T		CC			T		CC			T	
	28	30	T			CC			T			CC		
	29	35	T		T		CC			T		T		CC
	30	40	T		T	T		CC			T	T		

[a] Alternative cutting regime.

Table 3. Practices formulated for each habitat level.

Habitat level	Wood flow requirements	Hectares-regenerated requirements	Hardwood strip acreage (Ha)	Existing hardwood strips converted to pine	Adjacent cutting of natural stands prohibited	Adjacent cutting of plantations prohibited
I	No	No	90	Yes	No	No
II	Yes	Yes	90	Yes	No	No
III	Yes	Yes	90	No	Yes	Yes
IV	Yes	Yes	155	No	Yes	Yes

constraints objective function values for habitat levels II, III, and IV were $21,681,265.00, $21,531,393.00, and $21,100,495.00, respectively.

Proper planning of harvest operations and consideration of deer habitat has an opportunity cost associated with it (timber revenue foregone). The magnitude of the cost is determined by the level of habitat diversity the forest enterprise desires. The opportunity cost of providing various levels of deer habitat diversity on the study area is presented in Table 5. If the firm chooses to improve habitat diversity from habitat level I to habitat levels II, III, or IV, the associated costs will be $1,647,922.00, $1,797,794.00, $2,228,692.00, respectively with annual equivalents of $22.71, $24.78 and $30.71/ha. The opportunity cost of improving habitat diversity from habitat level II to habitat levels III or IV is $149,872.00 and $580,770.00, respectively. On a per hectare-per year basis, this operation will cost the firm $2.08 and $8.01, respectively. The last option available to the firm is improving habitat diversity from habitat level III to habitat level IV. Capitalized value foregone under this option is $430,898.00 which equates to an annual equivalent of $5.93/ha.

Conclusions

In general, the analytical approach used in this study has the attributes needed to assess the timber-deer tradeoff problem. The approach is flexible. It can be used for large problems and should be reasonable in cost in terms of computational time on large computers.

The model developed in this study is strongly dependent on reliable data inputs. Data required for the use of the model consists of standard forest inventory information, growth and yield estimates, current price and cost information, a discount rate, and an understanding of deer habitat diversity requirements.

Some habitat diversity can be achieved by imposing wood flow and hectares-regenerated requirements. Enhancing deer habitat to a higher degree can only be achieved by imposing habitat restrictions (i.e., preventing concurrent cutting of adjacent stands and installation of hardwood leave strips).

Table 4. Sub-period age class distribution for each habitat level.

Age class	1	2	3	4	5	6	7	8	9	10	11	12	Mean	One standard deviation[b]
	% of total forest acreage													
	Habitat Level I													
1– 5	21	61		3	15	32	50		3	24	22	49	23	21
6–10	15	21	61		3	15	32	50		2	26	22	21	20
11–15	3	15	21	61		3	15	32	50		3	26	19	20
16–20		3	15	21	61		3	15	32	45		3	16	20
21–25			3	15	21	50		3	15	29	49		15	18
NS–H[a]	61													
NS														
	Habitat Level II													
1– 5	22	22	21	18	14	19	19	22	18	17	19	19	19	2
6–10	15	22	22	21	18	14	17	22	22	18	17	19	19	3
11–15	2	15	22	22	21	18	12	19	22	22	18	17	18	6
16–20		2	15	22	22	21	18	14	19	22	22	18	16	8
21–25			2	15	19	22	17	18	11	17	19	20	13	8
26–30				2	6	6	17	5	8	4	5	7	5	5
NS–H	22	21	18											
NS	39	18												

Table 4. Continued.

Age class	1	2	3	4	5	6	7	8	9	10	11	12	Mean	One standard deviation[b]
	% of total forest acreage													
	Habitat Level III													
1–5	22	21	21	20	13	19	23	23	16	18	20	20	20	3
6–10	14	22	21	21	20	13	19	23	23	16	18	20	19	3
11–15	2	14	22	21	21	20	13	19	23	23	16	18	18	6
16–20		2	14	22	21	21	20	13	19	23	23	16	16	8
21–25			2	14	17	21	18	13	9	15	18	19	12	8
26–30				2	8	6	7	12	10	5	5	7	5	4
NS–H	21	21	20											
NS	41	17												
	Habitat Level IV													
1–5	22	24	19	19	16	21	22	21	13	22	18	17	20	3
6–10	16	22	24	19	19	16	21	22	21	13	22	20	20	3
11–15	1	16	22	24	19	19	16	21	22	21	13	22	18	6
16–20		1	16	22	24	19	19	16	21	22	21	13	16	8
21–25			1	16	18	19	19	10	11	16	18	19	12	8
26–30					4	6	3	10	12	6	8	9	5	4
NS–H	24	19	18											
NS	37	18												

[a] "NS" denotes natural stands. "H" denotes natural stand harvesting.

[b] $s = \sqrt{\frac{X^2 - (X)^2/n}{n-1}}$

Table 5. Opportunity cost of providing white-tailed deer habitat diversity on the study area.[a]

From–to (habitat level)	Capitalized value foregone ($)	Per hectare annual equivalent[b] ($)
I– II	1,647,922	22.71
I–III	1,797,794	24.78
I–IV	2,228,692	30.71
II–III	149,872	2.08
II–IV	580,770	8.01
III–IV	430,898	5.93

[a] A 10% discount rate was used to obtain the revenue and annual equivalent values.
[b] To convert per hectare annual equivalent to a per acre annual equivalent multiply the per hectare equivalent by .4047.

These restrictions have a cost associated with them: timber revenue foregone.

Results from this study should benefit timberland owners and/or managers and consumers. Forests produce multiple outputs and are often managed on a multiple-use basis. This study should help quantify the public relations cost associated with deer habitat diversity. Timber agencies would be better equipped to determine an appropriate lease fee for deer hunting. Conversely, consumer groups would be able to assess if the lease fee is actually buying the type of deer habitat they desire.

The approach presented in this study can be used to assess tradeoffs between timber returns and other selected game species as habitat data for these species are made available.

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