Integrating timber and wildlife management planning

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Fusion entre plan d'aménagement et conservation de la faune. *La planification de l'usage polyvalent peut être biaisée par un manque de connaissances des interrelations entre les divers rendements de la forêt. L'article en question décrit la méthodologie susceptible de fournir l'information nécessaire entre les relations commerciales impliquées dans la production commune de deux produits de la forêt: le bois et la faune. Comme ces produits ne peuvent être évalués sur une base analogue (dollars) la méthodologie présentée étalonne le "coût" d'un aménagement faunique accru, considéré en tant que récolte forestière prévue.*

Most publicly owned forests, and many private forests, are managed with multiple-use as a primary objective. It is generally recognized that forests produce multiple outputs (e.g. wood, water, wildlife, and recreation). However, effective multiple-use planning can be hampered by lack of knowledge in several areas. For example, production functions (input-output relationships) are not known for all forest outputs and even when the individual production functions are known, the joint production functions or trade-off relationships between outputs are frequently not known.

This paper reports on a study undertaken to overcome the above difficulty and thereby aid multiple-use planning for two forest outputs: timber and wildlife. The study was a cooperative effort between the Maryland Wildlife Administration, Maryland Forest Service (both agencies of the Maryland Department of Natural Resources), and the Division of Forestry and Wildlife Resources at Virginia Polytechnic Institute and State University. Maryland's Pocomoke State Forest was used as a case study area to implement the planning approach. The specific results do apply to the Pocomoke. The methodology, however, should have wider application in multiple-use planning.

The problem

To completely integrate planning for timber and wildlife management, a knowledge of the individual and joint production functions for the two outputs is required. For example, if the level of wildlife management is increased on an area, the resulting changes in wildlife and timber outputs should be known. Although timber production functions, in the form of growth and yield data, are either known or can be obtained, those for wildlife, in terms of either man-days of recreation or changes in animal population levels, are less available. For the study area, discussion with Maryland personnel revealed that data necessary to develop production functions for either man-days of recreation or animal population levels were not available. For some areas, such data may be available. However, we feel that the study area situation is typical of the level of wildlife information available for forest resource management planning.

In the absence of a more satisfactory measure of the output accruing to wildlife management, this study's objective was to evaluate the interrelationships, or trade-offs, between timber output and intensity of wildlife management. That is, how much timber output must be foregone, over a specified time period, as increasingly intensive levels of wildlife management are practised on an area.

Procedures

The Pocomoke State Forest is comprised of approximately 12,000 acres and is located on Maryland's Eastern Shore. The Forest is composed of 10 separate tracts ranging in size from 110 to 3,870 acres. Approximately 2,400 acres are in river bottom or dedicated to parks or other recreational uses, leaving 9,600 acres available for multiple-use planning.

The tracts are dispersed among land which produces both agricultural and timber crops. The principal timber species on the Forest is loblolly pine (*Pinus taeda* L.). Eighty-five percent of the Forest is covered with either pure loblolly or mixed loblolly-hardwood stands. The remaining 15% is covered with mixed hardwood stands. White tail deer *(Odocoileus virginianus)* is the primary wildlife species, but bobwhite quail *(Colinus virginianus)*, cottontail rabbits *(Sylvilagus floridanus)*, and gray squirrels *(Sciurus carolinensis)* are also found on the Forest.

The Maryland Department of Natural Resources' goal in managing the Forest is to obtain a maximum, even-flow of sawtimber consistent with sound management for other outputs, primarily wildlife. In addition to the even-flow of timber volume, an approximately equal annual area cut is considered desirable. All harvest cutting is accom-

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[1]At the time the study was conducted, Thompson and Halterman were at the Division of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University.

plished by clear-cutting. Subsequently, regeneration preparation and planting, depending on local conditions.

The procedure used to achieve the study's objective was to develop a timber harvesting schedule which maximized potential timber harvest and was constrained by the requirements for an even-flow of timber, an equal annual area cut, and various wildlife management considerations. Linear programming[2] was the technique used to develop the harvesting schedule. Linear programming has been used for timber harvest scheduling (Curtis 1962, Kidd *et al.* 1966, Ware and Clutter 1971); the extension made in this study, to include wildlife management considerations, appeared reasonable and compatible with the general linear programming format.

The initial linear program was set up to maximize the even-flow of sawtimber and to provide an equal annual area cut over one 60 year timber rotation. Various levels of wildlife management were then included in the model as constraints and the solutions were compared to the initial program solution. The differences were the "cost" of the wildlife management practices, in terms of timber foregone.

To implement the linear programming model, the Forest was divided into 66 separate and essentially homogenous stands using data from a recent inventory of the Pocomoke's timber resources. Timber growth for existing stands was also obtained from the inventory data. The 60 year period was divided into 12 sub-periods of 5 years each. The basic management activity, then, was defined as cutting a specific stand in a specific sub-period.

Quantitatively, the model is:

$X_{i,j}$ = number of acres cut in stand i in sub-period j; $i = 1, 2, \ldots, 66; j = 1, 2, \ldots, 12$

$V_{i,j}$ = average timber volume per uncut acre in stand i in sub-period j; $i = 1, 2, \ldots, 66; j = 1, 2, \ldots, 12$

The objective function maximizes the total volume available for harvest during the 60 year period. That is,

$$\text{Maximize: } \sum_{i=1}^{66} \sum_{j=1}^{12} (V_{i,j})(X_{i,j})$$

subject to the following technical, Forest Service, and Wildlife Administration constraints.

Stand size. The number of acres harvested in a stand during the 60 year period cannot exceed the total stand size. That is,

$$\sum_{j=1}^{12} X_{1,j} \leq \text{acres in stand 1}$$

$$\sum_{j=1}^{12} X_{2,j} \leq \text{acres in stand 2}$$

$$\vdots$$

$$\sum_{j=1}^{12} X_{66,j} \leq \text{acres in stand 66}$$

One of the assumptions of linear programming is divisibility. That is, the optimum solution could indicate an uneconomically small acreage (e.g. 2.5 acres) should be cut in a given time period. There are various ways of handling this problem. One way is to place minimum as well as maximum bounds on size of cut, another is to simply allow management to decide whether to cut small areas and/or accumulate small areas over time periods. Timber harvest scheduling is at best an inexact science and any schedule should be reconsidered at fairly frequent intervals. For this reason, the latter approach was taken with no apparent serious consequences.

Even-flow of sawtimber. An even-flow of sawtimber may be obtained by setting the volume cut from all stands in a sub-period less than or equal to some upper limit. With a maximizing objective function, there is a natural tendency to achieve the upper limit. To determine the maximum upper limit, the linear program is solved with increasing levels of maximum allowable cut, very easily done with parametric programming techniques, until the level cannot be met in all sub-periods. The highest level which can be achieved in all sub-periods is the maximum even-flow. The constraining equations are:

$$\sum_{i=1}^{66} (V_{i,1})(X_{i,1}) \leq \text{Maximum allowable timber cut in sub-period 1}$$

$$\sum_{i=1}^{66} (V_{i,2})(X_{i,2}) \leq \text{Maximum allowable timber cut in sub-period 2}$$

$$\vdots$$

$$\sum_{i=1}^{66} (V_{i,12})(X_{i,12}) \leq \text{Maximum allowable timber cut in sub-period 12}$$

Equal annual acreage cut. As indicated, the Maryland Forest Service considered an approximately equal annual acreage cut desirable. This is achieved in a manner very similar to the even-flow of volume. The specific equations are:

$$\sum_{i=1}^{66} X_{i,1} \leq \text{Maximum allowable acreage cut in sub-period 1}$$

$$\sum_{i=1}^{66} X_{i,2} \leq \text{Maximum allowable acreage cut in sub-period 2}$$

$$\vdots$$

$$\sum_{i=1}^{66} X_{i,12} \leq \text{Maximum allowable acreage cut in sub-period 12}$$

[2]Linear programming is a mathematical technique for optimizing a linear objective function subject to a set of linear constraints. No attempt is made to develop linear programming in detail in this article. Readers interested in a detailed development and explanation are referred to Wagner (1969).

The above problem resulted in an initial linear programming matrix containing 90 rows and 792 columns.

A series of discussions with Wildlife Administration personnel led to the conclusion that their primary concern on the Forest was 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 a diversity of vegetative cover, hence good wildlife habitat, over the Forest. To achieve this diversity, the wildlife personnel recommended the following practices.

1/ Limit clear-cuts in hardwood stands to 25 acres.
2/ a Limit clear-cuts in pine and pine-hardwood stands to 150 acres, or
   b Limit clear-cuts in pine and pine-hardwood stands to 100 acres.
3/ Distribute timber cutting over the entire Forest.
4/ Carry the approximately 1,900 acres of currently bare land at less than one-half regular timber stocking (specifically, 40 ft^2 basal area per acre). This practice was included with the hope of developing improved quail habitat. Yield estimates for these stands were developed from Brender and Clutter (1970).

The constraints represented by the above practices were used in various combinations and not all constraints were employed at the same time. It should be noted, the wildlife management practices considered were limited to those which are competitive with timber production. For example, a promotional program to inform hunters of the hunting opportunities on the Pocomoke might lead to large increases in man-days of hunting. Such a program, which does not compete with timber production, could not be included in the study. The above wildlife recommendations resulted in the following constraining equations.

Limit clear-cuts. The general equation to limit the size of individual clear-cuts was:

$$X_{i,j} \leq \text{Maximum clear-cut size (i.e., 25, 100, or 150 acres)}: i = 1, 2, \ldots 66; j = 1, 2, \ldots 12$$

Distribute cuts. Limiting cut size in a given stand does not prevent concurrent cutting in adjacent stands. To overcome this difficulty, pairs of stands with common boundaries were identified. Then, a series of equations was constructed which limited the cutting in each pair to the upper limit on a single clear-cut over at least a 10 year period. Ten equations are required for each common boundary to insure that over-size clear-cuts do not occur within a 10 year period. For example, assume that stand 1 and stand 2 have a common boundary. Three of the required 10 equations are:

Equation for sub-periods 1-3;

$$X_{1,1} + X_{1,2} + X_{1,3} + X_{2,1} + X_{2,2} + X_{2,3} \leq \text{Maximum size of clear-cut}$$

Equation for sub-periods 2-4:

$$X_{1,2} + X_{1,3} + X_{1,4} + X_{2,2} + X_{2,3} + X_{2,4} \leq \text{Maximum size of clear-cut}$$

Equation for sub-periods 10-12:

$$X_{1,10} + X_{1,11} + X_{1,12} + X_{2,10} + X_{2,11} + X_{2,12} \leq \text{Maximum size of clear-cut}$$

Fifty-three common boundaries were identified on the Pocomoke. Therefore, 530 equations were added to the original matrix resulting in a final matrix dimension of 630 x 792. These equations also effectively limit the size of individual clear-cuts throughout the Forest; therefore, the previous constraint is unnecessary when these are used.

Results and discussion

The linear program, described in the previous sections, was solved for the following problem foundations.

1/ Maximum even-flow of timber and equal area cut per sub-period.
2/ Maximum even-flow of timber, equal area cut, and 25 acre limit on hardwood cuts and 150 acre limit on cuts in pine and pine-hardwood.
3/ Same as 2, except cuts were distributed over the Forest.
4/ Maximum even-flow of timber, equal area cut, and 25 acre limit on hardwood cuts and 150 acre limit on cuts in pine and pine-hardwoods.
5/ Same as 4, except cuts were distributed over the Forest.
6/ Same as 5, except 1,900 acres carried at reduced stocking for quail habitat improvement.

Each solution indicated which stands, or parts of stands, to cut each sub-period as well as the volume to be expected. The total cut, over the 60 year period, decreased between solutions as the solutions became increasingly constrained (Table 1). This decrease in total cut, as the problem formulation is more constrained, is to be expected. For example, if there is no limit on size of cut, a 130 acre stand may be scheduled to be completely cut during a sub-period. But, with a 100 acre limit on size of cut, the volume in the uncut 30 acres must be made up from volume in stands which are younger or more lightly stocked. With no restriction on size of cut, these latter stands would have been scheduled for cut in subsequent sub-periods when they could contribute more to the total cut over the planning period.

While the specific results apply only to the Pocomoke Forest, their implications have general application for multiple-use planning. With respect to the Pocomoke, the most valuable results apply to answering the question: "What does it cost, in terms of timber foregone, to institute specific wildlife management practices?" To answer this question, it appears that the recommended wildlife management practices can be instituted at very reasonable costs.

From Table 1, it can be seen that limiting the size of clear-cuts to 25 acres in hardwoods and 150 acres in pine and pine-hardwood reduces the potential cut only 3 million board feet over the 60 year planning period. Distributing these cuts over the Forest reduces the potential harvest an additional 7 million board feet.

TABLE 1. Total volume available for harvest over 60 year period, by problem formulation

Problem formulation	Volume available for harvest (million board feet)
1. Maximum even-flow of timber and equal area cut per sub-period.........	170
2. Same as 1, except hardwood cuts were limited to 25 acres and pine and pine-hardwood cuts to 150 acres...........	167
3. Same as 2 except cuts were distributed over the Forest.....................	160
4. Same as 2, except pine and pine-hardwood cuts limited to 100 acres.........	166
5. Same as 4, except cuts distributed over the Forest.........................	156
6. Same as 5, except 1,900 acres carried at reduced stocking for quail habitat improvement.........................	148

When the limit on pine and pine-hardwood cuts is decreased from 150 to 100 acres, the total potential cut is reduced one million board feet. Distributing these cuts over the forest reduces the total another 10 million board feet. When the 1,900 acres are carried at reduced stocking for improved quail habitat, the total potential cut is 22 million board feet below the maximum. It should be pointed out, however, that this is not a currently accepted quail management practice in Maryland and, therefore, should be considered experimental. The costs of maintaining suitable quail habitat under the sparse overstory could be quite high.

The above reductions are less than we expected. We anticipated that any "tampering" with a maximum timber production schedule would lead to more significant reductions in potential harvest. It would seem extremely difficult to argue against the wildlife management recommendations solely on the basis of reduced timber harvest. For example, using the 25 and 100 acre cutting limits and distributing the cuts, at a timber value of $60 per thousand board feet, the average annual revenue foregone would be $14,000. Of course, whether or not the indicated wildlife management practices are worth an average of $14,000 per year to Maryland is a question to be decided by Department of Natural Resources personnel.

The important point is that without a linear programming type solution, the amount of timber reduction corresponding to the specific wildlife management practices would be unknown. Once the specific model formulation is available, the effects of other practices on timber production can be easily determined. For example, other wildlife related activities such as different size limits on clearcuts, no clear-cutting in specific areas, increased accessibility, food plots, and water holes, could be evaluated. Also, in this model the objective function was formulated in volume terms. Had the Maryland Forest Service desired, the objective function could have been expressed in dollars, either current value at harvest or in discounted present value, and the timber value foregone due to the wildlife management practices determined directly.

The model developed in this study is preliminary because the ultimate multiple-use planning model should evaluate inputs and outputs in the same units. Relevant economic models are available if all inputs and outputs can be converted to dollars. However, wildlife and many other forest outputs, particularly on public-owned forests, cannot presently be expressed in dollar terms.

The linear programming model is a good substitute for the ultimate model because it does allow the manager to evaluate alternative plans in terms of their output mixes. In the absence of a common unit for evaluating outputs, however, the manager must still decide which mix is preferable. The value of the model is that the manager can identify and evaluate (in this case, in terms of foregone timber) the specific output mixes available.

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