USING OBJECTIVE FUNCTION PENALTIES TO ELICIT OWL AND LATE SERAL CAPABILITIES

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ABSTRACT.—This paper addresses the issues of modeling northern spotted owl (*Strix occidentalis caurina*) habitat and late seral conditions within the long-term forest ecosystem management plan. The results presented here are from management plans constructed for several large northern California management units using the ecosystem planning express, or **Ep(x)** analysis process developed by VESTRA Resources. Before incorporation of the owl and seral policy constraints into the final preferred alternative linear program run, we first developed a set of strategies and objective function formulations designed to elicit owl and late seral acres for various periods in the planning horizon, primarily to see what the model was capable of producing in those periods or groups of periods. Final policy constraints were then revised based on this knowledge. The results of this strategy were that the landowner and wildlife policy analysts were able to more efficiently converge on the objectives of timber harvest and wildlife protection, and to save countless hours of linear programming run time.

INTRODUCTION

Forest planning has progressed through the years from managing for timber production, to managing for multiple use, to managing for the total forest ecosystem with wildlife habitat preservation and enhancement progressing to the top of the forest output priorities (Fletcher 1997). Timber harvesting is now more a byproduct of the forest ecosystem plan, especially on public lands. And, this planning process is not peculiar just to public lands. American society is increasingly viewing forests as a public trust resource regardless of ownership (Davis and Barrett 1992).

The forest planning models have also transitioned along with these changes in planning priorities. They have progressed from the classical fully regulated, continuous yearly flow models of area regulation (Davis and Johnson 1987) prior to the 1960s, to the mathematical programming/optimal harvest schedule models (Johnson and Sheurman 1977, Davis and Johnson 1987) from the 60s to mid-80s, to the current strategy available in the Spreadsheet Assisted Resource Analysis (SARA) model (Davis *et al.* 1991) of prescribing specific ecological health prescriptions to specific land areas and evaluating the resultant schedules of total forest outputs including vegetation structure, wildlife suitability, timber harvest, water quality and recreation. FORPLAN (Johnson *et al*. 1986) and Spectrum (Sleavin 1994) also provide similar levels of model input and output analysis.

The enhancement and maintenance of wildlife habitat and late seral conditions in the forest ecosystem environment have been perplexing issues for those in both the public and private sectors who are charged with the stewardship of forest lands. To model these often enigmatic goals, one must first define in algebraic terms the relevant parameters that define the particular habitat types and conditions. Thus model output, typically a linear programming (LP) solution, are only as valid and as useful as the input formulations from which they are generated. In addition, a high level of validation in the form of ground-truthing needs to be done prior to issuing this final definition set. And assuming that the definition set is valid, how does the wildlife analyst then determine what percentages of each of the nesting, roosting and foraging habitats will be required throughout the management unit? This latter determination probably has the greatest effect on the landowner in terms of harvest flow or present net worth of the land, and in this litigious area of natural resource planning, these determinations must often be justified in a court of law.

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In California, the timber industry has been quick to respond to increasing demands on their lands by both regulatory bodies and environmental groups (Fletcher 1997). Specifically, the California Department of Forestry's sustained yield plan (SYP) option for private timber holdings greater than 50,000 acres, if selected requires that a long-term plan be submitted by each landowner which addresses, among many others considerations, the specific issues of wildlife habitat and late seral protection and enhancement. These issues must be addressed at both the individual watershed and management unit levels. In response to this total ecological and economic planning environment, the ecosystem planning express, or **Ep(x)**, modeling process was developed by VESTRA Resources (VESTRA 1997, Olson *et al.* 1997). The **Ep(x)** process utilizes geographic information systems (GIS), data base, and linear programming technologies to formulate a long-term management plan while addressing the various goals of the landowner, regulatory agencies and the public trust. One of the key features afforded by the **Ep(x)** technology in dealing with these complex and multi-level constraint sets is the ability to perform high volume, multiple run set, post-optimality sensitivity analyses which do not involve reformulation of the entire problem.

METHODOLOGY

Many of the long-term planning projects at VESTRA involve sizeable management areas, some exceeding 200,000 acres. Although large area does not, by itself, pose problems for LP size, the large number or areal units singled out for special concern and additional constraint development results in a large number of land type/silvicultural prescription combinations (decision variables)-- one recent project involving constraints over 25 watersheds resulted in an LP with over 350,000 columns and 15,000 rows. Ultimately, this project precipitated development of much of the technology presented in this paper, primarily as a response to limits on computational feasibility-- a problem of this size can take over 5 hours of LP run time on an Intel Pentium Pro 200 PC with 128mb RAM.

After defining vegetation types, size classes and crown closures which best characterize owl[2] and/or late seral habitat, the wildlife analyst(s) then specifies the desired percentages of each to be attained for each watershed in the management unit and for the unit as a whole. These constraints, occasionally accompanied by existing watershed acres in these habitat types, are then presented to the operations research analyst for inclusion into the LP model. As alluded to earlier, it is generally these types of constraints that almost always render the LP problem infeasible, and generally in such a massive way that it is often impossible to detect the real underlying causes of those infeasibilities. And at 5 hours per LP run, it could take weeks to sort out just what is achievable in each watershed and at what time period. And, of course, the customer wants the results the next day. The solution to this dilemma is to develop a set of pre-processing algorithms and routines that will better identify the behavior of these habitats as they progress through the long-term planning horizon. These results are then conveyed back to the wildlife analyst(s) and/or planner(s), and after a number of such iterations a final set of feasible habitat constraints can then be finalized for the preferred LP run. We have developed such a module as part of our overall planning model **Ep(x)**. This module, called REVISE, contains a number of subroutines which allow for batch processing of multiple alternative LP runs. These specific subroutines allow us to quickly develop and solve the following types of LP run sets:

1. Goal programming where both present net worth (PNW) and minimum habitat variances are maximized simultaneously,
2. Maximize owl and/or late seral habitat types either discounted or non-discounted,
3. Sequential linear programming (SLP) maximizing owl and/or late seral habitat types, and
4. Run LPs at different percentages of habitat retention to show effect on PNW and/or harvest.

In addition, we can execute database queries on maximum habitat achievable per period not conditional on the maximum habitat achievable in the previous period.

[2] Throughout this paper the owl habitat type referred to is nesting, and does not include roosting or foraging.

EP(X) POST-OPTIMIZATION SENSITIVITY ANALYSIS

The **Ep(x)** process from the initial problem development through the first LP run is explained in detail in the literature (VESTRA 1997, Olson *et al.* 1997). One of many differences between **Ep(x)** and other long-term planning models is that, in **Ep(x)**, the LP output is not the "final" or "preferred" scenario optimization solution. Rather it is the beginning of a process that uses an initial solution of a LP, which has been formulated to include all relevant constraint sets and special concerns (wildlife, seral stage, viewshed, etc.), along with the **Ep(x)** routine REVISE which allows the analyst to then select the ranges and increments over which the constraint set(s) are to be varied. These changes are all applied directly to the final tableau of the initial LP run (VESTRA Resources uses the C-WHIZ solver from Ketron Management Science, and their final tableau is called the Actfile). In addition to varying the constraint sets, the REVISE routine is also capable of selecting single or multiple objective functions. The **Ep(x)** MPS generator (MPS is the input format required by C-WHIZ) also allows inclusion of all possible objective functions as well as the constraint sets. It is irrelevant for the initial LP run which objective function is selected.

The graphical user interfaces used in the REVISE routine for varying the constraint and objective settings are depicted in Figures 1 and 2 respectively. Figure 3 shows the flow through the REVISE routine. Briefly, in Figure 1 a constraint value setting can be constant, vary/constant or vary/vary. If constant is checked then the constraint value is always set at the default value. The vary/const option varies the constraint value between the LO and UP range at the specified increment, with all other constraint settings held at their default values. A vary/vary selection (only one such selection allowed per run set) varies that constraint setting as with the vary/const check, however these settings will continue to vary over all other constraint sets for which the constant or vary/const options are selected. Thus, for example, if the boxes are checked as in Figure 1, there will be a total of 75 run changes generated by REVISE which will be output to a database table having 75 record sets, each of which will then be converted to a separate MPSIN file (MPSIN is the C-WHIZ routine which makes changes directly to the Actfile and then reruns the LP without having to reformulate the problem). **Max. hvst dec. percent** is varied between .5-.7 (3 values), **Min. net rev** is varied between 20-25 (6 values), and **Min. owl hab percent** is varied between 0-.5 (6 values). This is a total of 15 changes, however with the **Min. late seral percent** varied between 0-.2 (5 values) each of these 15 vary/const changes is also varied 5 times over the ranges of **Min. late seral percent**, since it is checked vary/vary, for a total of 75 changes.

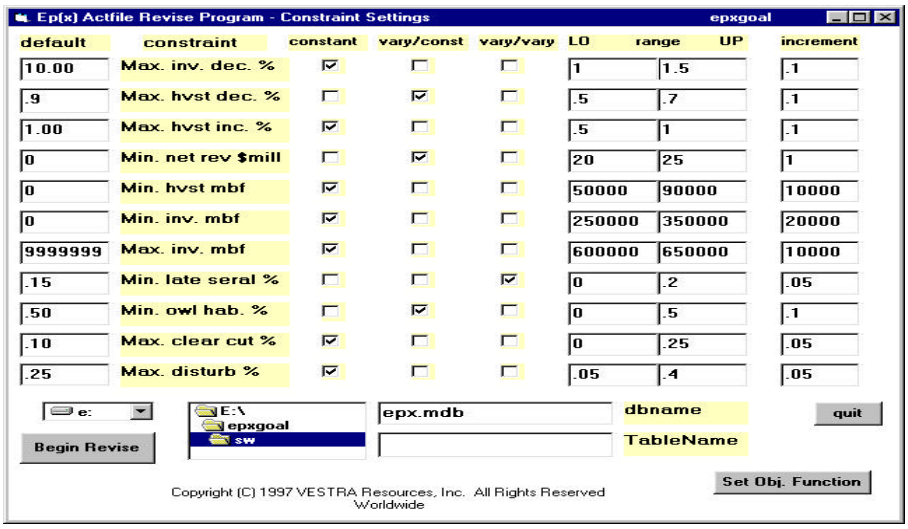


Figure 1.—**Ep(x)** REVISE constraint range setting interface.

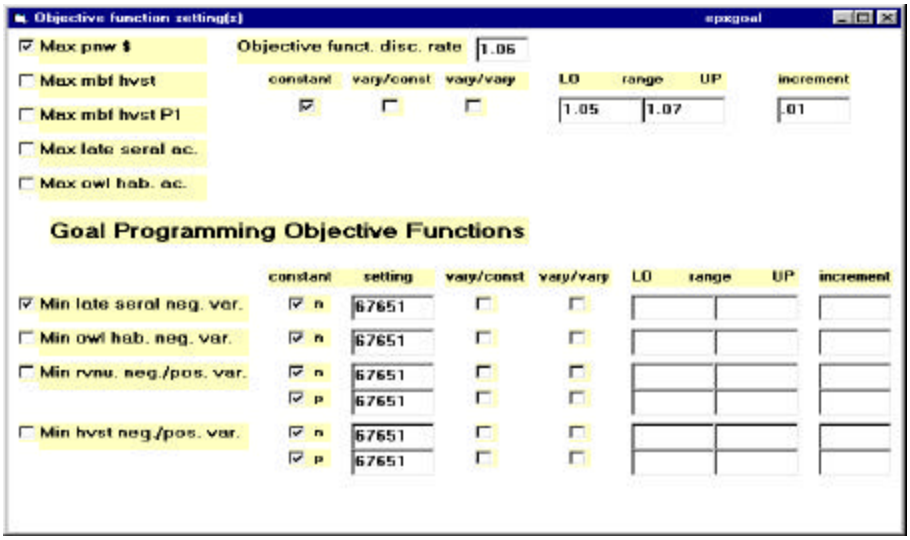


Figure 2.—**Ep(x)** REVISE objective function selection interface.

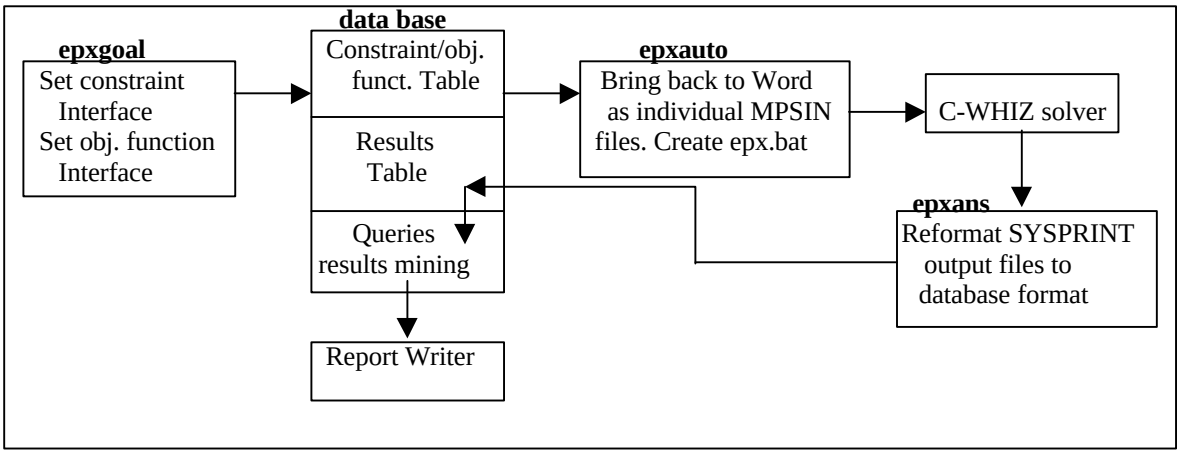


Figure 3.—**Ep(x)** REVISE post-optimization sensitivity analysis routine.

GOAL PROGRAMMING APPROACH

In the objective function setting interface depicted in Figure 2, individual and/or simultaneous goal and standard objective function selection can be accommodated, along with a discount rate selection. Often omitted in the literature on goal programming is that standard (top of Fig. 2) objective functions can still be optimized along with the goal programming objectives (bottom of Fig. 2) if the analyst is careful in selecting the goal weights. For instance, one might want to minimize late seral and/or owl habitat variance from a desired level. If these are the only decision variables in the objective function, then the LP will terminate when this variance has been minimized. There is no reason that we cannot also and simultaneously maximize profit. Simply setting the goal weight(s) greater than the highest revenue contribution per acre of any combination land type and silvicultural prescription does this.

In the example from Figure 2, the goal weights begin at 67651 for this management unit because the largest contribution to net revenue from any acre in any period is $67,650. This objective function is formulated as follows:

Maximize $Z = \sum_{i=1}^{n} d_i R_i - \sum_{i=1}^{n} PD_i$ where

n= number of periods in planning horizon

$d_i =$ discount in period i

$R_i =$ net revenue in period i = $\sum_{j=1}^{m} \sum_{k=1}^{p} a_{jk} L_j S_k$

m = number of land types in management unit

p = number of silvicultural prescriptions available to each land type

$a_{jk} =$ net revenue contribution per acre of land type L_j using silvicultural prescription S_k

P = penalty weight per acre of late seral below desired level

$D_i =$ dummy late seral acres in solution to achieve desired level in period i, and

$P > a_{ijk} L_j S_k \forall i$

Thus in the LP it will always be most optimal to achieve all the late seral acres desired, if they exist, throughout the range of land type/prescription combinations and subject to the limitations of other constraint. The accounting variable PNW is then set:

$$PNW = Z + \sum_{i=1}^{n} PD_i \text{, or} = \sum_{i=1}^{n} d_i R_i$$

to retrieve the maximized PNW since the objective function value Z is not very useful.

MAXIMUM TEMPORAL HABITAT QUERY SETS

The quickest way to discern what levels of habitat will be potentially available over the planning horizon, is to do a database query by period of the maximum available habitat acres achievable by all land types over all prescriptions designed to produce those specific habitat types. This is done independent of the prescriptions selected by the query for those land types in the preceding period. In this manner the results will never be achievable since only a single prescription can be assigned for the entire planning horizon for each land type, however they do show the potential for habitat acres in any particular period as well as uncovering any arithmetical modeling problems within the database. Figures 4 and 5 show the results of one such query for owl and late seral acres. These queries can be done at both management unit and watershed levels, and are some of the first quality control steps in the **Ep(x)** modeling process. Figure 4 illustrates the typical response one would expect in this type of planning environment. Figure 5, however, shows a potential decline in late seral acres in periods 9 and 10. This anomaly is not supported by the silvicultural prescriptions set up in the growth and yield modeling process, which were designed to produce late seral acres. In this instance we were using the California Wildlife Habitat Relationships System (WHR) (Airola 1988, Mayer and Laudenslayer 1988, Zeiner et al. 1990) to determine late seral acres, and specifically the classes 5D, 5M and 6. These are stands with trees >24 inches dbh and => 40 percent canopy closure or multi-layered stands with size class 5 trees over a distinct layer of size class 3 or 4 trees and a total canopy closure ≥ 60 percent. In the growth and yield modeling process, it is the latter size class 6 which, due in part to the influx of new growth, can vacillate between a size class 6 and size class 4 which then takes the acreage out of the late seral category. This is, in fact, what had occurred and we were able to correct the problem at this early stage of the planning process.

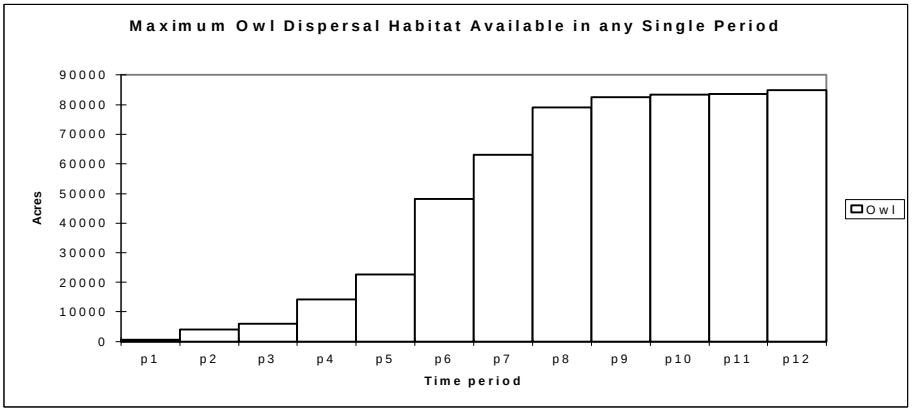


Figure 4.—Temporal availability of unconditional owl habitat acres.

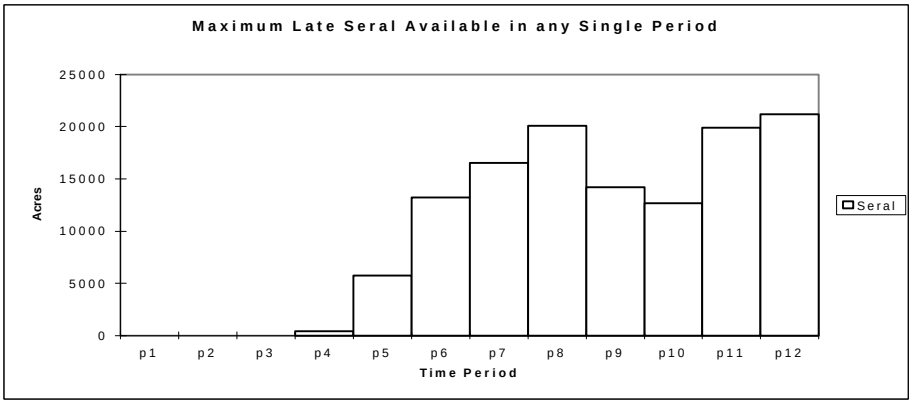


Figure 5.—Temporal availability of unconditional late seral habitat acres.

SENSITIVITY OF PNW AND HARVEST LEVELS TO CHANGES IN HABITAT REQUIREMENT

The sensitivity of PNW and harvest percentage changes (which follow PNW closely) to minimum percentage late seral retention can be seen in Figure 6. As expected, the change in PNW is dramatic up to about 25 percent late seral at which point the problem usually becomes infeasible. For any number of large timber holders, this reduction in PNW can reach well into the hundreds of millions of dollars. This is also one of the first charts we feed back to the wildlife analyst(s), not for purposes of affecting any changes in habitat retention, but rather to drive home the point that there is little room for arbitrariness in their determinations.

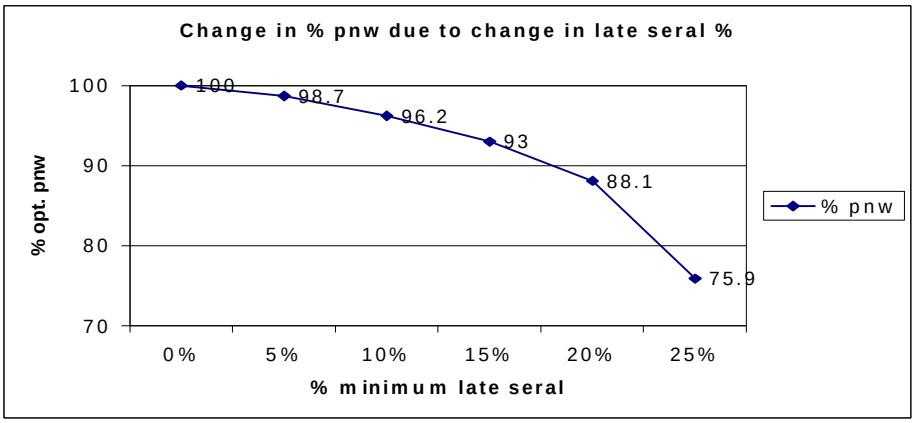
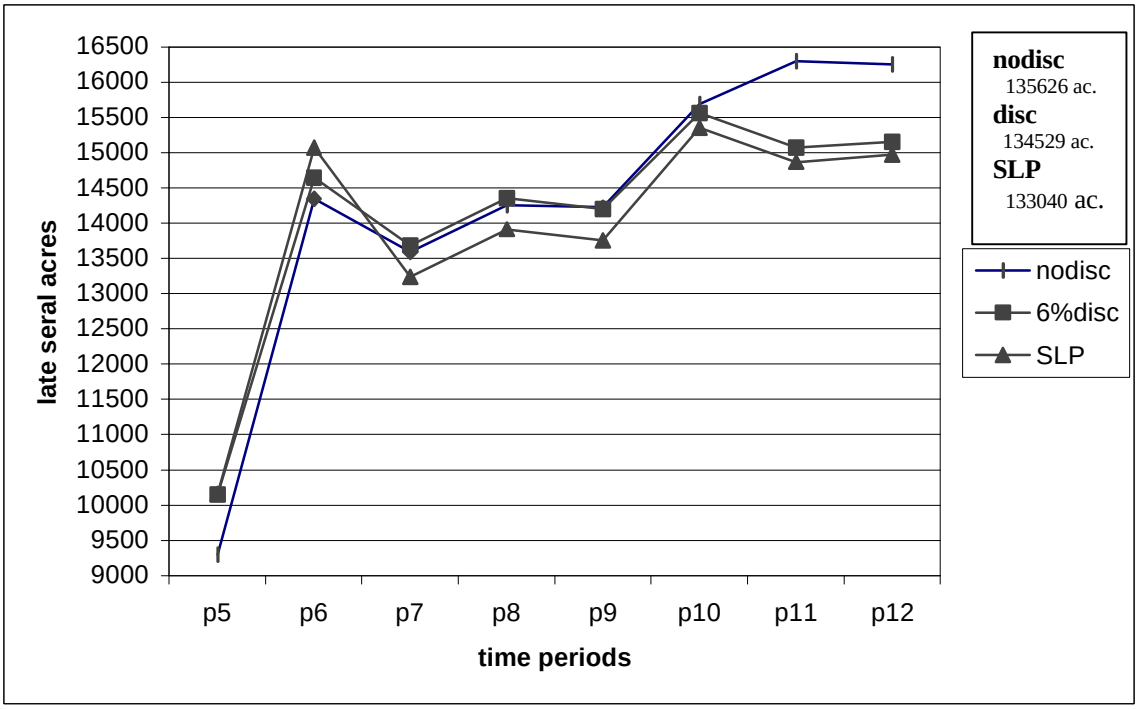


Figure 6.—Change in percent PNW due to change in late seral percent.

Figure 6 is also derived using the **Ep(x)** REVISE routine. Referring back to Figure 1, we would have checked the **Min. late seral percent** vary/const box and specified a LO/UP range of 0-.25 with an increment of .01, for a total of 26 runs. The original formulation of this problem for any given late seral percentage would have taken approximately one hour and fifteen minutes to solve, with the MPS file already having been generated. Using the REVISE routine, however, and solving from the most to least restrictive late seral percentages, each REVISE run took approximately fifteen minutes of solution time with no set up time between runs (REVISE generates it's own batch file for continuous processing through C-WHIZ).

MAXIMIZING OWL AND LATE SERAL HABITAT

In addition to querying the database for maximum habitat achievable for single periods, it is also useful to maximize total habitat acres conditional on the habitat acres of previous periods. This can be done in several ways: maximizing discounted and non-discounted habitat or using SLP to maximize 1st through final period habitat separately, holding prior period solution habitats constant for subsequent period optimization. These runs are generally set up with all other constraints relaxed. Figure 7 shows the results of these three run sets. As expected the non-discounted run produced the most late seral acres overall, however the discounted run brought those acres up faster through period 8. The SLP run brought late seral acres up the fastest through period 6 and then fell below the others for the rest of the planning horizon. The wildlife analyst(s) and policy maker(s) could use this information along with results from other sensitivity runs to develop the final resource and policy constraint sets.



	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12
nodisc	1387	5567	6185	8530	9306	14345	13588	14256	14223	15690	16296	16253
disc	1387	5598	6185	8530	10154	14650	13687	14355	14199	15565	15068	15151
SLP	1387	5598	6185	8530	10167	15068	13245	13913	13757	15351	14866	14973

Figure 7.—LP maximization of late seral acres.

CONCLUSIONS

Using the strategies developed in this paper, along with the **Ep(x)** sensitivity routine REVISE, we were able to perform many such analyses both as a quality control technique and subsequently, as a wildlife and policy strategy setting tool. These types of analyses are also used to look at many other critical LP constraint sets such as maximum disturbance index percent allowed, maximum clear cut area as a percentage of total area, maximum period harvest decrease percentages, inventory levels and many others.

The automated generation and subsequent processing of the MPSIN files on the Actfile, and subsequent output of these LP's directly to the database, create a new environment in LP modeling. The analyst can now generate hundreds or thousands of LP runs in batch mode, and analyze the outputs through a series of database queries, selecting an appropriate subset of LP results for subsequent manual perusal. As an example, on one such REVISE run set, we were able to generate and solve 819 LP runs in just less than 12 hours. The actual time to generate the MPSIN files and batch file from interface through the database and back to Word for input to the C-WHIZ solver (see Fig. 3) took less than 2 minutes. The analyst then initiated the epx.bat file, left for the evening and returned the next morning to begin the database queries on the completed 819 LP runs. This type of LP batch processing and sensitivity analyses on critical and controversial forest ecosystem parameters becomes more relevant as more and more special interest groups attempt to influence the decision-making process.

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