MITIGATING THE EFFECTS OF RESERVOIR DEVELOPMENT ON BLACK-TAILED DEER IN TRINITY COUNTY, CALIFORNIA

John G. Kie, John W. Menke
James R. David & William M. Longhurst
Dept. of Agromony and Range Science
University of California
Davis, California 95616

ABSTRACT.

When Trinity and Lewiston Reservoirs were filled between 1960 and 1963, 17,250 acres of prime winter deer range and an estimated 4,000 to 7,500 deer, or about 1,000,000 annual deer days of use (DDU), were lost. The Shasta-Trinity National Forest recently began a habitat improvement program of prescribed burning (4,500 acres thus far) after earlier mitigation attempts (1965-1970) met with limited success. A preliminary goal programming model, based on land near Trinity and Lewiston Reservoirs, was built to estimate the potential of the habitat improvement program and to explore trade-offs between deer and timber production.

Assuming all brush-covered areas adjacent to the reservoirs were treated periodically with fire, only about 332,000 DDU could be regained. Even by foregoing some 12,400,000 board feet of timber production annually and converting all the land adjacent to the reservoirs to deer habitat, only 813,000 DDU could be regained. Under more realistic ecological and managerial constraints only about 38,000 DDU will be regained, and by also foregoing about 1,000,000 board feet of timber growth, only about 100,000 DDU would be regained. Estimates of the cost of a deer day of use or a deer bagged by a hunter are extremely high in this analysis, yet they include only the cost of timber foregone. The lack of an antlerless harvest would result in few of the increased deer being utilized by sport hunters. Additional potential for mitigation exists on other Forest Service, BLM, and private land in Trinity County.

INTRODUCTION

Between 1960 and 1963, about 17,250 acres in Trinity County were inundated by the filling of Trinity (Clair Engle) and Lewiston Reservoirs. Much of this area was prime winter range for black-tailed deer (*Odocoileus hemionus columbianus*). The U.S. Forest Service (USFS 1960) estimated that 4,000 to 6,000 deer from the Weaverville herd would be affected directly by loss of habitat within the project's "zone of influence." In addition, it was believed that the reservoirs would block several deer migration routes. The Weaverville deer herd occupies about 1,400 square miles in northern Trinity County. Summer ranges generally occur above 4,000 feet in the Salmon-Trinity Alps Primitve Area, and comprise about 70 percent of the total area. Vegetation consists mostly of coniferous forest and scattered alpine meadows and brushfields (Burton 1976).

Transitional ranges make up about 20 percent of the total area and occur at elevations between 3,000 and 4,000 feet. These consist of coniferous forest interspersed with hardwood stands and brushfields. Winter range occurs primarily below 3,000 feet. Critical winter range is limited to south-facing slopes with adequate amount of preferred browse species (Burton 1976).

A few resident deer are found on the winter range throughout the year. However, most of the migratory population arrives at the lower elevations in mid-October and remains through March. The degree to which the deer concentrate on the winter range depends on the severity of the weather. In mild winters, many deer can still be found at 4,000 to 5,000 feet, dispersed over a much larger area. Some of the deer that summer in Trinity County migrate north to Siskiyou County or east to Shasta County in the winter (T. Burton, pers. comm.).

Post-project estimates of deer lost as a result of reservoir construction generally have confirmed the original predicted impact on 4,000 to 6,000 deer. The U.S. Fish and Wildlife Service (USFWS 1975) found that deer use adjacent to the project area, as measured by pellet-group counts, increased from 30 deer-days use (DDU) per acre annually in 1960, to 89 DDU per acre in 1963. Using the difference as a measure of the deer displaced from the flooded areas, and assuming that the deer were displaced from the 17,250 acres inundated to a surrounding area of similar size, it was estimated that about 5,000 migratory deer and 550 resident deer had been affected (USFWS 1975).

If it is assumed that the increase of 59 DDU per acre occurred only on areas designated as key winter range (12,700 acres, after Dunaway 1964) adjacent to the reservoirs, the estimate of deer loss is reduced to 3,600 migratory and 400 resident deer. This is likely an underestimate, as some lesser increase in deer use probably occurred on other, non-key winter ranges.

Unpublished data from the California Department of Fish and Game documented deer use downstream from Trinity and Lewiston Reservoirs at the site of the proposed Helena Reservoir. This area was similar to that flooded by the reservoirs upstream. Applying those data to the acreages involved in the Trinity and Lewiston Reservoirs yield an estimated loss of 6,000 migratory deer and 1,500 resident deer (USFWS 1975). This estimate is probably high because it is based in part on data gathered during the severe winter of 1968-69, when most deer were highly concentrated on the winter range. The California Department of Fish and Game (CDFG 1970) reported that deer kill within the project zone of influence declined by 27 percent following the filling of the reservoirs. Data on reported buck kill from the Weaverville herd, along with post-season herd composition counts, can be used to reconstruct the pre-season population sizes, given certain assumptions about harvest percentages, unreported kill, and crippling losses (Kie et al., ms. in prep.). These data are consistent with a total loss of 4,000 to 5,000 deer from the Weaverville deer herd.

Once a loss of deer had been established, federal funds became available under various legislative acts (Rappoport et al. 1977) to mitigate (in part) or compensate for (in total) the loss. Several attempts were made between 1965 and 1970 to improve winter deer range for the Weaverville herd by a variety of methods including mechanical and chemical rejuvenation of old, decadent brush and the planting of preferred browse and herbaecous plant species. Of 10 areas manipulated (1,429 acres) for which evaluations are available, four showed a decrease in deer use, two remained stable, and only four exhibited an increase in deer use (USFWS 1975). Factors that likely reduced the effectiveness of the mitigation efforts were: location of mitigation sites on marginal land, lack of use of prescribed fire, inability to control both livestock and deer numbers, poor seed catch and survival, no attempts to reseed, and small size and number of mitigation sites (USFWS 1975:15).

Currently, the Shasta-Trinity National Forest is attempting to improve winter deer habitat on the Weaverville, Big Bar, Hayfork, and Yolla Bolla Ranger Districts through prescribed burning. About 3,000 acres were burned in 1978 and another 1,500 acres in 1979. Additional acreage is designated for burning in the future.

It is thought that the amount and quality of winter range are the main factors regulating the size of the Weaverville herd. Trinity and Lewiston Reservoirs flooded only winter range and the subsequent deer loss can be attributed directly to that loss of winter habitat. However, sizes of the Weaverville and other deer herds in Trinity County have fluctuated over the past 20 years, and the county-wide deer population has gradually declined during the past 10 years or more (Kie et al., ms. in prep.). The effects of changes in quality of summer and transitional ranges cannot be ruled out at this time.

The purpose of the current study is to investigate deer response to past mitigation efforts, to evaluate the potential for success of the proposed mitigation measures on the Shasta-Trinity National Forest and elsewhere in Trinity County, and to explore conflicts between providing deer habitat and other natural resource values. Goal programming methods were used (Bartlett et al. 1976) to define trade-offs between deer and timber production in the area adjacent to Trinity and Lewiston Reservoirs. We thank Hugh Black, Jr., from the Shasta-Trinity National Forest, for providing support for this study. Tim Burton, of the California Department of Fish and Game as been exceptionally helpful in all phases of this

study. Keith Crummer, of the USFS Weaverville Ranger District, and George Belden, of Southern Pacific Land Company, critiqued an earlier version of the model presented here and were helpful in providing valuable suggestions. However, we take full responsibility for the views presented and any errors contained herein.

A PRELIMINARY GOAL MODEL

Goal programming is a static, deterministic, mathematical technique suitable for exploring trade-offs and optimizing mixes of conflicting natural resource management alternatives. It is a variation of linear programming, and as such, it shares the same basic assumptions of proportionality, additivity, and divisibility (Bare and Anholt 1976). Unlike linear programming, which requires an objective function expressed in common terms for all resources (usually dollars), goal programming is a multi-objective technique. It will allow the use of an objective function expressed in different terms, such as board feet of timber and deer days of use, given that the terms are ranked and weighted in some order of priority, which may be arbitrarily specified. The use of goal programming in natural resource management has been demonstrated by Field (1973), Bell (1976), Bartlett et al. (1976) among others.

THE RESOURCE BASE:

The preliminary model was limited geographically to the Clair Engle-Lewiston Unit of the Whiskeytown-Shasta-Trinity National Recreation Area (Figure 1). This area had been mapped and divided into response units by Johnson et al. (N.D.), with each unit being given a relative suitability rating for conifer production and winter deer range.

In addition, the National Recreasion Area (NRA) includes most of the winter deer range adjacent to Trinity and Lewiston Reservoirs. It might be argued that attempts at mitigating deer loss close to where the loss occurred should have first priority. However, there are sound ecological reasons for concentrating efforts outside the NRA. First, much of the remaining winter range in the NRA has less potential for supporting increased deer densities than do other areas used by the Weaverville herd. Second, during severe winters, deer may be trapped adjacent to the reservoirs by deep snows, resulting in high mortality. This occurred during the winter of 1968-69, when several hundred deer died, some of which walked out onto the ice, broke through, and drowned (T. Burton, pers. comm.).

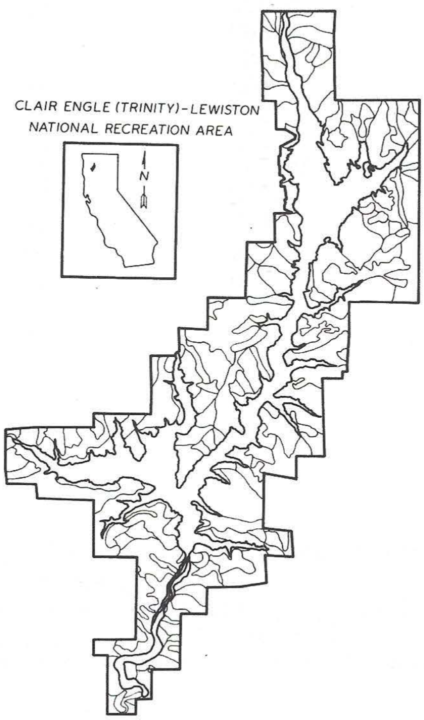

FIGURE 1. Response units in the Clair Engle-Lewiston unit, Whiskeytown-Shasta-Trinity National Recreation Area.

Additional modeling efforts will be directed toward other winter ranges used by the Weaverville herd. Potential for increasing wintering deer numbers exists in the adjacent Hayfork herd and this will also be explored. The mapping necessary to extend the model to these areas has been completed by the U.S. Forest Service and will be available soon.

The area within the NRA has been divided into 183 response units totaling 60,441 acres (Figure 1). About 80 percent of the area is administered by the U.S. Forest Service, the remainder is owned by private concerns, primarily Southern Pacific Land Company. The effects of land ownership patterns will be discussed later.

Each of the 183 response units were classified as brush, forest, or other types according to existing vegetation. Those classified as other types (such as riparian-rock, riparian-tillable, and borrow pits) were omitted from the model, eliminating 13 response units (1,451 acres). Those response units averaging over 60 percent slope were also omitted, because their susceptibility to erosion precludes intensive deer habitat manipulation (USFWS 1975), as were areas considered not to be winter deer range (Dunaway 1964). These restrictions eliminated an additional 56 response units (14,401 acres). The final area considered in the model then consisted of 114 response units totaling 44,589 acres (36 units or 15,076 acres of brush types, and 78 units or 29,513 acres of forest). The remaining response units were grouped into similar types (Table 1) based on their suitability for conifer production (Johnson et al. N.D.) and whether they are key winter range or other winter range (Dunaway 1964).

TABLE 1. Response unit types in the National Recreation Area included in the preliminary GOAL model. Deer winter range type 1 = key winter range, 2 = other winter range.

Response unit type	Vegetation	Acres	Timber class	Deer Winter range type
1	brush	7,041	--	1
2	brush	8,035	--	2
3	forest	200	1	1
4	forest	5,081	1	2
5	forest	602	2+	1
6	forest	3,057	2+	2
7	forest	642	2	1
8	forest	10,531	2	2
9	forest	1,828	2-	1
10	forest	2,870	2-	2
11	forest	20	3+	2
12	forest	930	3	1
13	forest	2,129	3	2
14	forest	1,623	3-	2
Total		44,589		

MANAGEMENT ALTERNATIVES - BRUSH TYPES:

Common brush species in the NRA include wedgeleaf ceanothus (*Ceanothus cuneatus*), lemon ceanothus (*C. lemonii*), deerbrush (*C. integerrimus*), greenleaf manzanita (*Arctostaphylos patula*), whiteleaf manzanita (*A. viscida*), silktassel (*Garrya fremontii*), mountain mahogany (*Cercocarpus betuloides*), and interior live oak (*Quercus wixlizenii*). Black oaks (*Q. kelloggii*) and scattered digger pines (*Pinus sabiniana*) occur in some areas classified as brush.

The management alternatives for brush response units included no action, and prescribed burning (stragegy B, for burn) at periodic, unspecified rotation intervals. It was assumed that brush response units would produce no timber regardless of management alternative. It was further assumed that these units supported some deer under the no-action alternative and some higher deer density under strategy B. To avoid having to estimate the former, it was decided to model the increase, or difference, in deer numbers (expressed as DDU/acre/year) under a prescribed burning program. This also allowed a direct comparison of predicted increases in deer use with the estimates of deer lost as a result of reservoir construction. Therefore the no-action alternative for brush units produced no timber and no additional deer days of use, while strategy B produced no timber but did produce some additional deer use.

It was estimated that on the four successful mitigation sites on Forest Service land (Helena-Logan Gulch) and BLM land (Junction City-Teepee Burner, Indian Creek, and Jesse Gulch) manipulated in the mid-1960's, deer use increased by an average of 44 DDU/acre (USFWS 1975: 13-14). However, many of these areas are better winter range than the bulk of that in the NRA.

The results of pellet group counts on the Frethy Burn (a 1959 wildfire) conducted in 1971, 12 years after the fire, revealed that total deer use averaged about 30 DDU/acre (T. Burton, pers. comm.). It is likely that deer use peaked before 1971, and that this figure represents somewhat less than the maximum number of deer utilizing the burn at that peak. Also, only about 25 percent of the 2,600 acre burn was rated as key winter range by Dunaway (1964), the remainder being classified as other winter range. Based on these previous evaluations, it was assumed that a program of prescribed burning at repeated intervals in the NRA would increase deer use by 30 DDU/acre on key winter range and 15 DDU/acre on other winter range (Table 2). Periodic reburns would presumably maintain these increases over the no-action alternative indefinitely (Figure 2). For comparison, these increases correspond to winter deer densities of an additional 116 and 58 deer per square mile, respectively, assuming a 165-day winter period. Current plans call for additional data acquisition to verify or modify these assumptions.

TABLE 2. Additional annual deer days use (DDU) per acre by winter range type and management strategy (B = burned brush, N = no change in forest management, K = lengthen forest rotation, S = shorten forest rotation, C = convert forest to brush).

Deer winter range type	Brush	Forest		
	B	K	S	C
Key winter range	30	0.468	0.238	28.571
Other winter range	15	0.234	0.119	14.286
Non-winter range	0	0	0	0

MANAGEMENT ALTERNATIVES - FOREST:

Commercial conifer species in the NRA include ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and incense cedar (*Libocedrus decurrens*). Black oaks are often present in mixed conifer stands and deer brush and lemon ceanothus occur as understory species.

Forest management alternatives considered in the model assume that all harvesting occurs in regeneration cuts (clearcutting, shelterwood, or seed-tree silvicultural systems). The effects of this assumption on timber yields will be discussed later.

The management alternatives for forest response units include no action (i.e., no harvest), no change in current forest management practices (strategy N, for no change), lengthening

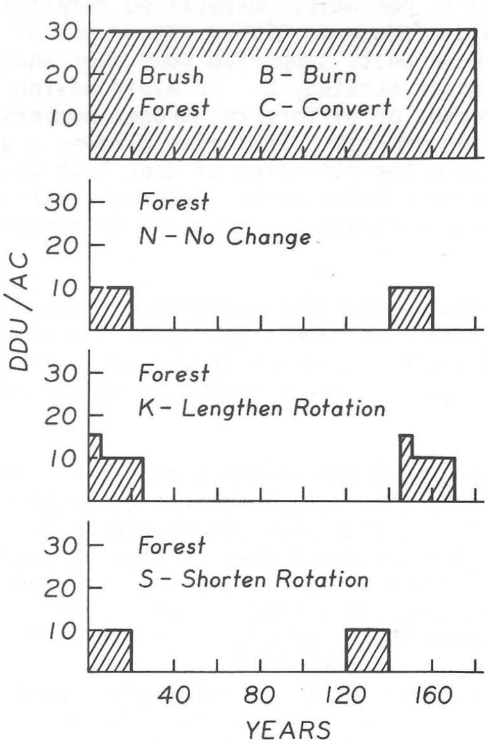

FIGURE 2. Predicted deer response under various brush and forest management alternatives on key winter range.

rotation age (strategy K, explained below), shortening rotation age (strategy S, for shorten), and coverting forest to brush (strategy C, for convert).

The no-action alternative produced no timber. The N, K, and S strategies produce varying amounts of timber, while the C strategy, although producing timber during the conversion cut, is assumed to add nothing to total timber production.

The no-action alternative produced no additional deer use. The N strategy assumes that deer use will increase for several years following a regeneration cut and then return to the level of the no-action alternative (Figure 2). The K and S strategies also produce increases in deer use following regeneration cuts, but over different time scales (Figure 2). The conversion of forest to brush (strategy C), essentially produces the same increase in deer use as prescribed burning of brush types (both assuming periodic reburning), with the exception noted below.

Increases in deer use following clearcutting in the NRA have not yet been measured. Brown (1961:104) hypothesized a pattern of increased black-tailed deer use following clearcutting in western Washington. Brown's hypothetical response curve applied to non-migratory deer and was expressed in terms of deer per square mile. By assuming equal densities of migratory deer on a winter range for 165 days, the response curve in Figure 3A was generated.

Crouch (1974:136) measured black-tailed deer use in western Oregon following clearcutting. Dividing his pellet group/acre by 13 pellet groups/deer/day yielded the response curve in Figure 3B.

Based on these studies, it was assumed that clearcutting in the NRA increased deer use by 10 DDU/acre on key winter range (Figure 3C), and by 5 DDU/acre on other winter range. It was also assumed that these increases continued for 20 years, at which time they dropped to the no-action management alternative levels. Because the deer use levels here represent

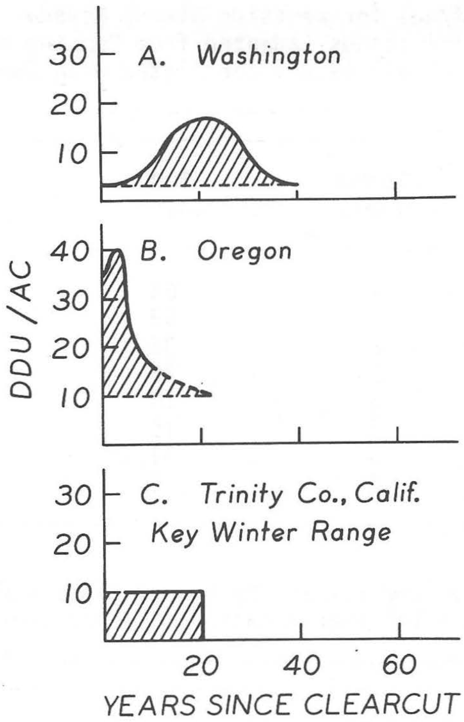

FIGURE 3. Deer response to clearcutting in Washington and Oregon, and predicted average response in Trinity County, California.

increases over the no-action alternative, it is appropriate to compare the total area under the curve in Figure 3C with the shaded areas in Figures 3A and 3B.

Strategy N assumes a 140-year timber rotation which closely approximates the average rotation for Forest Service land in the NRA (K. Crummer, pers. comm.). Timber volumes at the end of a rotation were approximated from the tables of Dunning and Reineke (1933) for westside Sierra Nevada, unmanaged, young-growth, even-aged, mixed conifer stands (Table 3). Annual timber production per acre was estimated by dividing the volume at the end of the rotation by the length of the rotation (Table 4). In the case of a 140-year rotation on timber class 2+ land, the annual timber production would equal 69,000 board feet (BF)/acre divided by 140 years, or an average of 493/BF/acre/year (all digits carried so this estimate can be used as a multiplier).

Deer use under strategy N on key winter range would increase by 10 DDU/acre for 20 years and then drop to the no-action management alternative level for the remaining 120 years of the rotation, as discussed previously. Annual increase in deer use would then equal 10 DDU/acre, multiplied by 20 years, divided by 140 years, or 1.429 DDU/acre/year. Again, while this represents an annual increase over no action, it is considered baseline under status quo management (strategy N) and represents no additional annual deer use.

Strategy K assumes a 145-year total rotation, delaying attempts at artificial regeneration until five years after harvesting. By encouraging growth of favorable deer browse species, such as *Ceanothus* spp., it assumes that some additional deer use can be realized during that time. Originally, a longer delay in regeneration was considered (designated strategy L, for lengthened rotation) but because of conflicts with the National Forest Management Act of 1976 and the California Forest Practices Act of 1973, this delay was shortened to the current 145-year total rotation.

Annual timber production under strategy K was estimated by dividing the volume at the end of a 140-year timber rotation (Table 3) by the total length of the rotation at 145 years (Table 4). Assumptions implicit in this approach is that growing a five year rotation

TABLE 3. Scribner volumes (mbf/ac) for westside Sierra Nevada, unmanaged, young-growth, even-aged mixed conifer stands (adapted from Dunning and Reineke 1933). Timber classes from Johnson et al. (N.D.) correlated with Dunning site classes.

Timber class	Site class	Timber class	100 years	120 years	140 years
1	I	1	63	80	95
	II	2+	43	57	69
2		2	35	47	58
	III	2-	26	37	46
	IV	3+	18	28	33
3		3	15	23	26
	V	3-	11	18	19
4	NC	4	0	0	0

TABLE 4. Annual increment in volume (bf/ac) by timber class and management strategy (N = 140 year rotation, K = 145 year rotation, S = 120 year rotation).

Timber class	Site class	Timber class	N	K	S
1	I	1	679	655	667
	II	2+	493	476	475
2		2	414	400	392
	III	2-	329	317	308
	IV	3+	236	228	233
3		3	186	179	192
	V	3-	136	131	150
4	NC	4	0	0	0

of deer browse, such as deerbrush or lemon ceanothus, neither reduced conifer seedling establishment and survival (after necessary site preparation) through competition nor increases establishment and survival because of the nitrogen-fixing benefits of a ceanothus nursery crop.

Deer production under strategy K, during the first five years following harvesting, was assumed to be greater than would normally be the case because favorable browse species would be encouraged. However, browse would probably not reach maximum productivity until 2 to 4 years after manipulation. Therefore, the model arbitrarily assumes an increase over no action of 15 DDU/acre on key winter range and 7.5 DDU/acre on other winter range annually for five years (50 percent of the annual response expected from burning the brush-response units), followed by the same response as under strategy N for 20 years (Figure 2). Because these increases represent additional deer use over strategy N when expressed on an annual basis, only the annual difference between strategies N and K is entered into the model (Table 2).

Strategy S assumes a 120-year rotation period. Annual timber production is calculated by dividing volume at 120 years (Table 3) by 120 years (Table 4). Increases in deer use following regeneration cutting are assumed to be equal to those under strategy N (Figure 2), but as they occur every 120 years instead of every 140 years, the difference between the strategies expressed on an annual basis represents additional deer use and is entered into the model (Table 2).

Strategy C removes forest response units from timber production. Response units are then assumed to be managed in a way similar to strategy B for the brush units by periodic use of prescribed fire. Deer use is assumed to be the same, but only the additional deer use beyond what would occur under strategy N is entered into the model (Table 2).

In summary, Figure 2 portrays total increases in deer use under various forest management strategies over the no-action alternative. The N strategy is considered the baseline of no additional deer use, and must be subtracted from the other forest management alternatives (K, S, C). The increased deer use under brush management strategy B represents an increase over the no-action alternative, all of which is considered additional deer use. Additional levels of deer use are then expressed on an annual basis (DDU/acre/year) and listed in Table 2.

RESULTS OF THE PRELIMINARY MODEL:

Once the response units have been delimited (Figure 1) and categorized (Table 1), and the production of resources (in this case, total timber production and additional deer days use) under various management alternatives estimated (Tables 2 and 4), it is simple to use a prepared computer package to formulate and solve a goal program (e.g. Bartlett et al. 1976).

The preliminary model described here was formulated in the following manner: if 1 million DDU (about 6,000 migratory deer on the winter range for 165 days) were lost as a result of the construction of Trinity and Lewiston Reservoirs, how much of that loss can be mitigated by prescribed burning of brush within the NRA and how much more of that loss can be recouped at the expense of timber production?

Simple calculations based on data in Tables 1, 2, and 4 reveal that if all of the 78 forest response units included in this model are managed to maximize timber production, they would produce about 12,400,000 BF of timber annually. Similarly, if all 36 brush response units were burned periodically, about 332,000 additional DDU would result annually.

These results were also obtained in run 1 of this preliminary model by setting the timber goal unreasonably high at 13 million BF with a priority of 1, and setting the deer goal at 1 million DDU with a priority of 2 (Figure 4).

By keeping timber production as the first priority, but sequentially reducing the goal from 13 million BF by 1 million BF increments to zero (using the parametric programming option), addition DDU can be produced. For example, at 6 million BF of timber produced annually, about 660,000 additional DDU can be achieved, while at zero timber production, about 813,000 additional DDU would be realized (Figure 4).

At maximum timber production of about 12,400,000 BF annually, all forest response units down to and including timber class 3+ (site classes IV and above) are managed under no change in management (strategy N, 140 year rotation), while those rated at timber class 3 or less (below site class IV) are managed under shortened rotation ages (strategy S, 120 years). This could have been predicted by careful examination of annual volume increments (Table 4) under strategies N and K in the poorer timber classes. It reflects no great insight produced by the goal programming model but simply the reality that timber volume curves level off more rapidly on poorer sites than on good sites.

As the timber goal is stepped down by 1 million BF increments, more forest response units are converted to brush, until, at a level of zero timber production, all 29,513 acres of forest are converted. As currently formulated, the model does not choose strategy K but rather maximizes each acre either for timber production (strategy N for good sites, strategy S for poor sites) or increase in deer use (strategy C). Regardless of the timber production goal, all brush response units are managed under a prescribed burning program (strategy B), because this maximizes deer use without loss of timber production.

Run 1 of the preliminary model, formulated as described above, ignores several ecological and managerial realities for purposes of simplification. Consideration of these realities leads to run 2, which further constrains the model and results in a more conservative model.

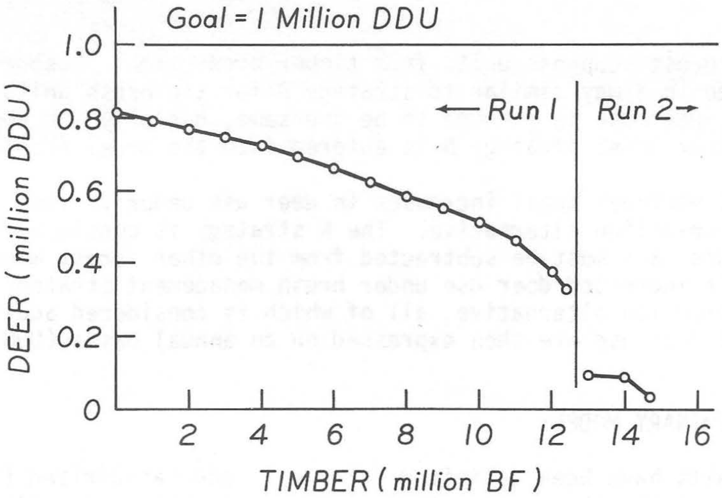

FIGURE 4. Results of the preliminary goal programming model, showing the relationship between deer and timber production.

In run 1, it was assumed that the conversion of forest to brush was possible on all timber class lands. Run 2 restricts strategy C to only those timber class response units rated 3 or less (site class less than IV).

Run 1 also assumes the 100 percent of any forest response unit can be converted to brush. However, assuming that such conversion provides forage areas for deer, but no thermal and hiding cover, and assuming further that the response units are so large that both forage and cover requirements must be met in each unit, a percentage of forest response units should be left in timber to provide necessary cover for deer. Thomas et al. (1979) state that a ratio of 60 percent forage areas to 40 percent cover areas, of proper size and arrangement, approximates an optimum mix for deer and elk in the Blue Mountains of Oregon and Washington. Run 2 limits the conversion of any single forest response unit to 70 percent of the total area (Longhurst and Connolly 1970), reflecting a slightly lower need for cover areas in Trinity County than in the Blue Mountains. It is believed that less thermal and hiding cover is necessary because of a normally milder climate and the presence of migratory deer on the winter range only during the last few weeks of the hunting season.

Brush response units are defined in run 1 based on existing vegetation, and may be the result of either edaphic and climatic influences (shallow soils on south facing slopes) or disturbance (wildfire). In the latter case, a brush unit may be defined as existing on a relatively good timber production site. Both the Forest Service (K. Crummer, pers. comm.) and Southern Pacific (G. Belden, pers. comm.) are attemtping to reforest some of those brush units on timber classes 3+ and above (site classes equal to or greater than IV). Run 2 reclassifies six brush response units, totaling 5,642 acres, as forest response units (one unit or 60 acres in key winter range, and five units or 5,582 acres in other winter range). The largest single response unit reclassified (4,157 acres) contains most of the 2,600 acre Frethy burn, which has been planted with conifer seedlings.

Run 1 assumes that 100 percent of any brush response unit can be managed by prescribed burning. However, lack of preferred deer browse species, lack of fuel to carry a fire, location of north facing slopes, and other factors tend to reduce the acreage of brush that can be burned successfully to increase winter deer use. Personnel on the Weaverville Ranger District have designated some 76 separate areas within the NRA as having potential for manipulation through prescribed burning (1,051 acres in key winter range, 2,453 acres in other winter range). These represent 15 percent of the modified brush unit acreages in run 2. Therefore, stratey B was limited to 15 percent of any one brush response unit.

Finally, 20 percent of the land within the NRA is privately owned. Silvicultural systems permissible on these areas are limited to individual tree selection, ruling out any type of regeneration harvest (G. Belden, pers. comm.). It is assumed that this restriction does not appreciably affect timber production on private land within the NRA, but that it eliminates any possible benefit of regeneration cutting on deer use. In run 2, then, deer response was reduced by 20 percent under strategies K and S to reflect land ownership patterns and resulting harvest restrictions. It still assumes that poor site classes can be declared non-timber producing areas and converted to brush (strategy C).

Results from run 2 indicate that realistic expectations for mitigating deer loss are much lower than indicated by the less restrictive assumptions in run 1 (Figure 4). Under status quo management, about 14,600,000 BF of timber was produced annually and about 38,000 DDU can be realized. Reducing the timber goal to about 13,600,000 BF results in the production of about 100,000 additional DDU annually. Further timber reductions in run 2 yield no additional increases in deer use because of the added constraints.

Similar to run 1, at maximum timber production, run 2 places all of the good timber sites into strategy N (140-year rotation) and the poor sites into strategy S (120-year rotation). Unlike run 1, at maximum increase in deer use, run 2 places all of the good timber sites into K strategy (145-year rotation), converts 70 percent of the poorer sites into brush (C strategy) and manages the other 30 percent under K strategy.

DISCUSSION

The purpose of this preliminary goal programming model was to explore, in general terms, possible trade-offs between timber and deer production. It was not meant to present decision-making criteria at the project level, i.e., the manner in which a specific stand of brush or trees should be managed. In that context, the assumptions of the technique appear to have been at least partially satisified, particularly in run 2. Assumptions listed by Bell (1976) are discussed here.

The first assumption deals with the homogeneity of response units. By classifying units by timber site class and deer winter range quality (Table 1), it is believed that the units are as homogeneous as is justified by the preliminary input data. As additional deer use data are gathered, the model can be divided into more and smaller response unit types. For example, it is likely that the browse species present in a brush field will influence deer response following prescribed burning. When those data become available, it might be possible to define several brush series or sub-series (in sensu Parker and Matyas 1979), such as ceanothus-grass or manzanita-silktassel, each with a different deer response to burning within a given winter range class.

Secondly, management activities are assumed to be independent, and action taken on one acre does not affect resource response on an adjacent acre. This is probably true in the case of timber production. For this to be true with deer response, the manager at the project level would have to consider a wide variety of criteria including optimum sizes and shapes of openings and cover patches, proximity of forage and cover areas, and other aspects of deer habitat management in coniferous forests (Thomas et al. 1979). This goal programming model does not address those requirements directly.

Third, goal programming assumes that coefficients are linear, and that burning an additional acre of brush or converting an additional acre of forest would result in the same response as would burning or converting the previous acre. These assumptions of proportionality, additivity, and divisibility appear to be met with respect to timber production for both run 1 and run 2, although they are probably true for deer response only over the smaller range of values in run 2. As long as small proportions of the areas are manipulated each additional acre manipulated would likely produce the same marginal response. However, if large acreages of forest were converted to brush, or large brush areas were prescribed burns , there would likely be less increase in deer use per acre treated.

Finally, goal programming is a static optimization technique, not a simulation model. Changes over time can only be handled indirectly. An example of this is the manner in which deer response for several years following a clearcut has to be divided by the total length of rotation to arrive at an average annual deer response. The resulting implication in this model is that management activities must be spaced equally over the entire rotation period. If, for example, the optimum brush burning rotation was once every 10 years, then 10 percent of the total brush area designated for burning in a given response unit should be burned each year. Similarly, timber management activities are assumed to occur with constancy from year to year, with equal acreages being clearcut.

A basic weakness with this model, and the reason that it should be considered a preliminary attempt only, is the uncertainity of the deer response data. Such problems are common to all optimization and simulation models and are, in fact, one of the benefits of a modeling approach. Through pointing out such weaknesses, models result in better organized and directed efforts toward acquiring additional data.

By nature, this goal programming model is not a timber yield simulator. Timber volumes were taken from Dunning and Reineke (1933) for unmanaged mixed conifer stands. Keith Crummer (pers. comm.) has pointed out that, as a general rule within the NRA, the Forest Service will enter a stand once every 10 or 20 years, remove about 45 percent of the basal area, and allow the stand to grow to 90 percent of the basal area on an unmanaged stand before entering again. This intensive management can double the timber yield as presented in this model. Also, response units with slopes greater than 60 percent were omitted from the model because of the risk of soil erosion when attemtping deer habitat manipulation (USFWS 1975). However, timber is harvested on these steep slopes, usually by skyline cable.

Conversely, timber harvesting is prohibited within buffer strips along free-flowing streams, and all silvicultural systems except individual tree selection are prohibited within 1/4 mile of the reservoirs. Additional land is removed from potential harvest around several active eagle nests. These withdrawals reduce timber yields from the NRA and will be incorporated into refinements of the current model.

Recent forest management legislation at both the federal and state levels has been considered in formulating the model. The Forest Service is bound by the National Forest Management Act (NFMA) of 1976, while Southern Pacific, as a private timberland owner in California, is bound by the Z'berg-Nejedly Forest Practice Act (FPA) of 1973.

The NFMA limits the Forest Service to harvesting only areas that can be adequately restocked within five years. The initial lengthened rotation period in the goal model (strategy L, 160-year rotation) was shortened (strategy K, 145-year rotation) to comply with this restriction. The NFMA also limits clearcutting to those areas where it is the optimum silvicultural method, thereby possibly constraining the goal further. The FPA constrains Southern Pacific to an even greater extent with respect to stocking levels by specifying exactly what is considered adequate stocking five years after harvesting.

Conversely, the NFMA allows areas to be declared unsuitable for timber production and prohibits timber harvesting for 10-year periods except for salvage sales and sales to protect other resource values. Conversion of poor timber sites to brush for deer habitat would be permitted under these provisions. Similar provisions exist within the FPA. Also, the NFMA allows the use of Knutson-Vandenberg deposits (K-V funds, resulting directly from timber sales), for wildlife habitat improvement. Both the NFMA and FPA provide for the protection of streams and associated riparian vegetation.

Despite the inadequacies of this model as discussed above, it is enlightening to compare the value of the timber growing potential foregone with the realized increase in deer use. Last year, timber stumpage prices for all species of conifers on the Weaverville Ranger District averaged about $300 per MBF. Taking the value of the difference in timber produced at either end of the curve of run 1 (Figure 4, about 12,400,000 BF) and dividing by increase in DDU (about 481,000 DDU), it can be estimated that the cost per DDU is $7.73. Similar analysis using the end points of the curve for run 2 yields an estimate of $5.22 per DDU. Expression of these deer costs on a per-deer-harvested basis is even more enlightening. Assuming about 30 to 35 deer are carried on the range for each buck killed, and an average 165-day winter range residence, the estimated cost of timber foregone for each buck killed is between $38,000 and $45,000 under run 1 conditions and $26,000 and $30,000 under run 2 conditions. These estimates of the cost of a deer day of use or a deer bagged by a hunter are extremely high yet they include only the cost of timber foregone. Not included are the costs of conversion and maintenance (e.g. periodic reburning), or the cost of the loss of habitat for other wildlife species.

This preliminary goal program indicates that within the National Recreation Area, status quo management will result in the mitigation of less than 4 percent of an estimated 1 million DDU (6,000 migratory deer) that were lost as a result of the construction of Trinity and Lewiston Reservoirs. Realistically, an additional 60,000 DDU can be gained (a total of 10 percent of the loss), but only by giving up over $300,000 annually in timber growth, plus the cost of more intensive deer management. It is necessary to judge this cost of providing habitat for additional deer at the expense of timber production in light of current California deer harvest restrictions. The lack of an extensive antlerless harvest would result in few of the increased deer being utilized by sport hunters. Conversely, not all use of deer is consumptive. Policy decisions dictate whether mitigation should be directed at replacing lost habitat acreage, declines in harvest levels, or decreases in total deer numbers. Furthermore, conflicts between deer and timber cannot be resolved solely on an economic basis.

LITERATURE CITED

Bare, B.B. and B.F. Anholt. 1976. Selecting forest residue treatment alternatives using goal programming. USDA Forest Service. Gen. Tech. Rep. PNW-43. 25 pp.

Bartlett, E.T., K.E. Bottoms, and R.P. Pope. 1976. Goal - multiple objective programming. Colorado St. Univ. Range Sci. Ser. No. 21. 157 pp.

Bell, E.F. 1976. Goal programming for land use planning. USDA Forest Service Gen. Tech. Rep. PNW-53. 12 pp.

Brown, E.R. 1961. The black-tailed deer of western Washington. Wash. St. Game Dept. Biol. Bull. No. 13. 124 pp.

Burton, T. 1976. Weaverville deer herd plan. draft copy. 25 pp.

CDFG. 1970. Preliminary report on impact of Trinity River water development on fish and wildlife resources. Calif. Dept. Fish & Game Environ. Serv. Admin. Rep. 70-2. 58 pp.

Crouch, G.L. 1974. Interaction of deer and forest succession on clearcuttings in the coast range of Oregon. Pp. 133-138 in: H.C. Black (ed.), Wildl. & forest mgt. in the Pacific Northwest. Sch. of Forestry, Ore. St. Univ. 236 pp.

Dunaway, D. 1964. A habitat management plan for the Weaverville deer herd unit. USDA Forest Service, Shasta-Trinity Natl. Forest. 12 pp.

Dunning, D. and L.H. Reineke. 1933. Preliminary yield table for second-growth stands in the California pine region. USDA Tech. Bull. No. 354. 23 pp.

Field, D.B. 1973. Goal programming for forest management. For. Sci. 19(2):125-135.

Johnson, K.E., et al. No date. Soil resource inventory report, reconnaissance level, Clare Engle-Lewiston Unit, Whiskeytown-Shasta-Trinity National Recreation Area. USDA Forest Service, Shasta-Trinity Natl. Forest. 77 pp.

Longhurst, W.M. and G.E. Connolly. 1970. The effects of brush burning on deer. Cal-Neva Wildl. Trans. pp. 129-148.

Parker, I. and W.J. Matyas. 1979. Calveg-vegetation classification and mapping of California. USDA Forest Service, Region 5. 158 pp.

Rappoport, A.G., J.M. Mitchell, and J.G. Nagy. 1977. Mitigating the impacts of water resource developments on wildlife. Proc. Intl. Gong. Game Biol. 13:327-334.

Thomas, J.W., et al. 1979 Deer and elk. Pp. 104-127 in: J.W. Thomas (ed.) Wildl. Habitats in Managed Forests, the Blue Mtns. of Ore. and Wash. USDA Forest Service Agric. Handbook No. 533. 512 pp.

USFWS. 1975. Deer loss compensation program resulting from Trinity River Division, Central Valley Project, California. USDI Fish and Wildlife Service, Portland, 30 pp.

USFS. 1960. Impact of Trinity River Project on Shasta-Trinity National Forests, summary report. USDA Forest Service, Region 5. 54 pp.