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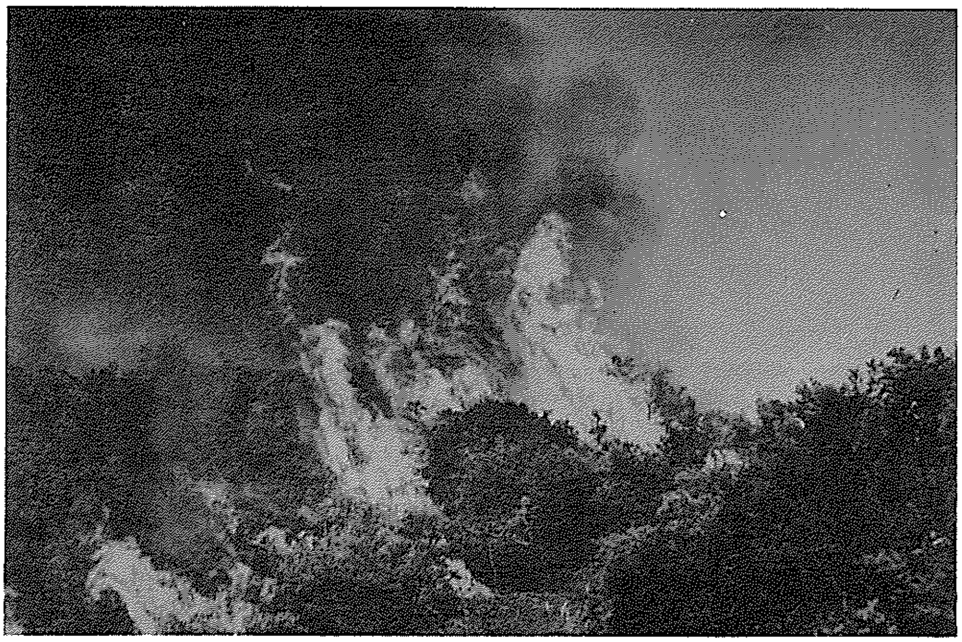
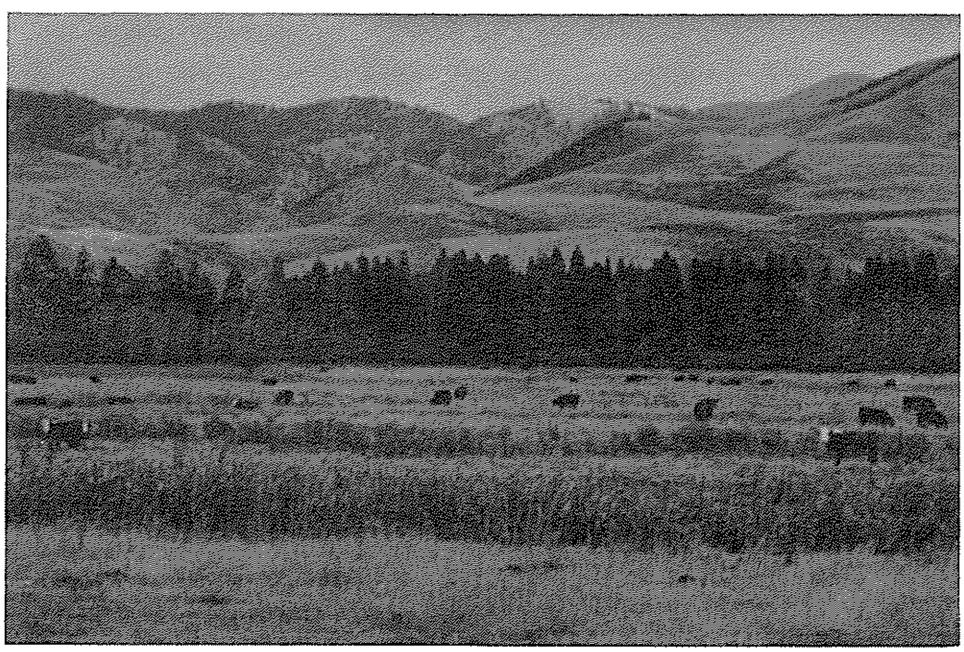
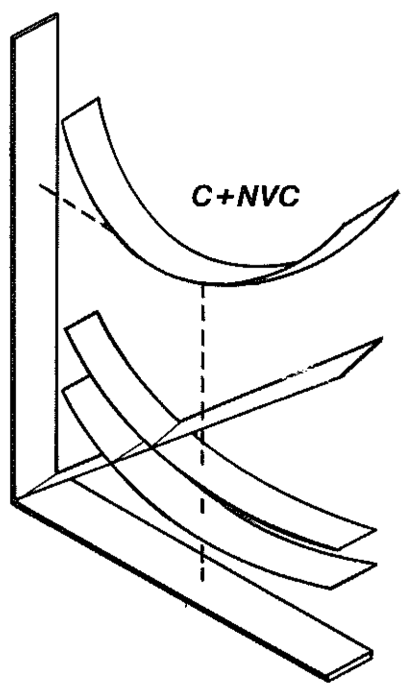
Estimating Postfire Changes in Production and Value of Northern Rocky Mountain-Intermountain Rangelands

David L. Peterson   Patrick J. Flowers







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IN BRIEF ...

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A simulation model was used to estimate expected postfire changes in the production and value of grazing lands in the Northern Rocky Mountain–Intermountain region. Ecological information and management policy decisions were used to simulate expected changes in range production following wildfire. An investment analysis procedure was used to calculate the net value change (NVC) of postfire range outputs. Physical output and economic changes were determined by subtracting "with fire" values from "without fire" values for a simulated postfire time stream.

Six major rangeland types were evaluated: permanent forested range (ponderosa pine), transitory range (Douglas-fir, larch, lodgepole pine, western white pine), mountain grassland, sagebrush, pinyon–juniper, and western hardwoods.

The magnitude and duration of postfire changes in production varied widely among these different range types. Transitory rangeland can be grazed for approximately 20 years after a stand replacement fire, with a substantial gain in grass and shrub production during this time. Losses occur later in the postfire time stream because of harvests that occur in the "without fire" situation (that is, harvests that would normally occur in the absence of fire). The early gains weigh heavily in the financial return calculation, however, and NVC is highly negative (that is, a gain in net value) for most situations. Net value change for a seedling–sapling stand utilized at 40 percent of total production and discounted at a rate of 4 percent is -$26.69 per acre. Small losses in net value are found only for recently cutover stands.

In most situations, the production of ponderosa pine range increases immediately postfire. These increases are especially large for older age classes that have high mortality. Removal of the overstory allows understory production to increase. Initial postfire gains again outweigh any subsequent losses in the financial return calculation. A maximum NVC of -$35.96 per acre was calculated for a sawtimber stand with 100 percent mortality (40 percent utilization, 4 percent discount rate). Seedling–sapling and recently cutover stands have small to moderate losses of production and value because the loss of production resulting from grazing deferral is greater than subsequent gains in yield.

Fire effects are shortlived for mountain grassland. Losses in production result from decreased forage and deferred grazing. A maximum decrease in net value of $7.06 per acre was calculated for mountain grassland range that burned in late summer (40 percent utilization, 4 percent discount rate).

Fire produces a substantial increase in forage production of sagebrush range for about 20 years. Removal of the shrub overstory allows grasses to dominate until sagebrush reinvades the site. A maximum NVC of -$16.61 was calculated for sagebrush range (40 percent utilization, 4 percent discount rate).

Long-term increase in production is common for pinyon–juniper range after fire, although annual increases are relatively small. Removal of the overstory allows forage production to remain above prefire levels for about 90 years. A maximum NVC of -$10.87 was calculated for pinyon–juniper range (40 percent utilization, 4 percent discount rate).

A small increase in forage production is common on western hardwoods rangeland after a fire that removes the overstory. Postfire increases last for about 7 years, but are small compared with losses from deferred grazing. As a result, small overall losses occur in production and value. A maximum decrease in net value of $1.38 was calculated for western hardwoods range burned in summer (40 percent utilization, 10 percent discount rate).

The estimates generated in this study allow decision-making on the basis of changes in production, changes in value, or a combination of both. They can be used in fire management planning in the Northern Rocky Mountains and for other aspects of resource management that require estimates of changes in postfire range production and value.

The National Forest Management Act of 1976 requires Forest Service managers to analyze their land management planning activities, formulate and evaluate management alternatives, and select an alternative on the basis of explicit criteria (U.S. Dep. Agric., Forest Serv. 1982). Fire management programs for the National Forests are required to be part of integrated land management and to be economically efficient (U.S. Dep. Agric., Forest Serv. 1979). Agency resource planners, therefore, need data and analytical procedures that will enable them to estimate long-term changes in resource yields and values. And they need to predict accurately any changes in resource outputs and values resulting from wildfire.

Range is one of the major resource categories for which the effects of wildfire must be estimated. In the northern Rocky Mountain–Intermountain area—Idaho, western Montana, western Wyoming, eastern Oregon, eastern Washington—several grassland, shrub, and forest ecosystems are used by cattle for grazing. Although site-specific information on fire effects is available for many rangeland types (for example, Wright and Bailey 1982), considerable time and effort are required to assimilate this information and translate it into a form that is meaningful for range management. Simulation techniques are now available to provide estimates of postfire changes in range production and value in a format compatible with the broad resolution applications required for land management planning (Mills and Bratten 1982). These estimates may also be useful for quantifying resource effects in analyzing escaped fires.

The difficulties associated with the identification and valuation of fire effects were first described by Flint (1924). Since this early review, numerous studies have addressed the theoretical and practical aspects of estimating the physical and financial effects of wildfire (for example, Crosby 1977, Lindenmuth and others 1951, Marty and Barney 1981). Few fire effects studies consider range effects in any detail. One study estimated range values-at-risk by multiplying total annual range production in animal-unit months (AUM), a fee per AUM, and a capitalization factor (U.S. Dep. Agric., Forest Serv. 1971). Another estimated range values-at-risk as the product of total annual range production (AUM) and a fee per AUM (Lewis and others 1979). This study was unique in applying no capitalization factor, and in distinguishing between annual production on wooded and improved pasture. Another study suggested that immediate forage value lost be estimated as the product of AUM destroyed and a fee per AUM (Marty and Barney 1981). The current value of future changes in forage revenues was added to immediate losses to obtain an estimate of the total change in forage revenues resulting from fire. In a study of six National Forests, 7 years of range effects were considered (Schweitzer and others 1982). The 7-year change in AUMs was multiplied by dollars per AUM. The analysis was simplified by assuming that the total 7-year change occurred in the third year, and this sum was then discounted to the present.

All of the studies described consider only the immediate and short-term (that is, less than 20 years) effects of fire on range. This approach is appropriate for only those range types in which timber is not found. In an optimization analysis, Ritters and others (1982) describe the interaction between the joint products of timber and range. This interaction should be considered in the valuation of fire effects. The cycle of range production in timbered areas depends upon the developmental stage of the timber. Forage production in a timbered area, for example, may be high in the seedling–sapling stage of stand development, but diminishes as the stand matures because of canopy closure and increased competition for light and moisture. If timber stand development is altered by fire, the cycle of forage availability is also interrupted. Interruptions in this forage cycle shift the timing of the perpetual series of forage cycles that follow. The shifting or long-term effect has been ignored in previous work of range fire effects and may significantly affect estimates of fire-caused net value change in the range resource.

Fire damage can be estimated as the difference in the value of affected resources before and after fire (Althaus and Mills 1982, Flint 1924). The value of a resource has been described as follows: "...the value of any productive resource equals the sum total of its future economic rents discounted back to the present" (Barlowe 1958, p. 169). Fire-caused value change in range, therefore, is estimated as the net present value of the time stream of economic rents found in the "without fire" situation, less the time stream found in the "with fire" situation.

This paper provides estimates of postfire changes in production and value of grazing lands in Northern Rocky Mountain–Intermountain rangelands. The estimates generated by computer simulation can aid resource managers in fire management planning and in integrating fire management with land management planning.

MODEL DESIGN

A simulation model was used to predict the effects of fire on range production *(fig. 1)*. A set of parameters describes some general features of the simulated rangeland and fire occurrence. The composite generated should be thought of as a generic fire site, or a kind of fire, because it does not describe an actual geographic location. All of the fire and site parameters are used by a fire behavior simulation system (Salazar and Bradshaw, in prep.). This system associates these parameters with historical weather records and calculates fire behavior characteristics such as scorch height (Van Wagner 1973) on the basis of the physical description of fuels and terrain.

Two basic submodels are included in the overall range model: the Timber Submodel simulates the effects of fire on forested areas for grazing, and the Nontimber Submodel simulates fire effects for grassland and shrubland range types. If the cover type parameter indicates a forested rangeland, fire-caused mortality is simulated before the data are used in the Timber Submodel. Percent basal area killed is determined for a simulated stand from the scorch height value generated by the fire behavior simulation (Peterson 1983). Subroutines that have been developed for each individual range type calculate forage production over time both with and without the presence of fire. Forage production is then adjusted on the basis of forage utilization level (in this study, 25 percent and 40 percent of total production are used in simulations). This adjustment can be related to a site parameter such as slope, elevation, or both, or can simply be a default value that is multiplied by forage production.

Range production over time can then be calculated in terms of animal-unit months for the "with fire" and "without fire" situations. The change in range production over time (ΔAUM) is calculated by subtracting "with fire" output from "without fire" output (Mills and Bratten 1982). As a result, *positive numbers represent a loss in grazing output, and negative numbers represent a gain.* After the point at which simulations indicate that "with fire" outputs stabilize at prefire levels, we assume that no change in outputs occurs for the balance of the 200-year analysis period and that no fires occur subsequently.

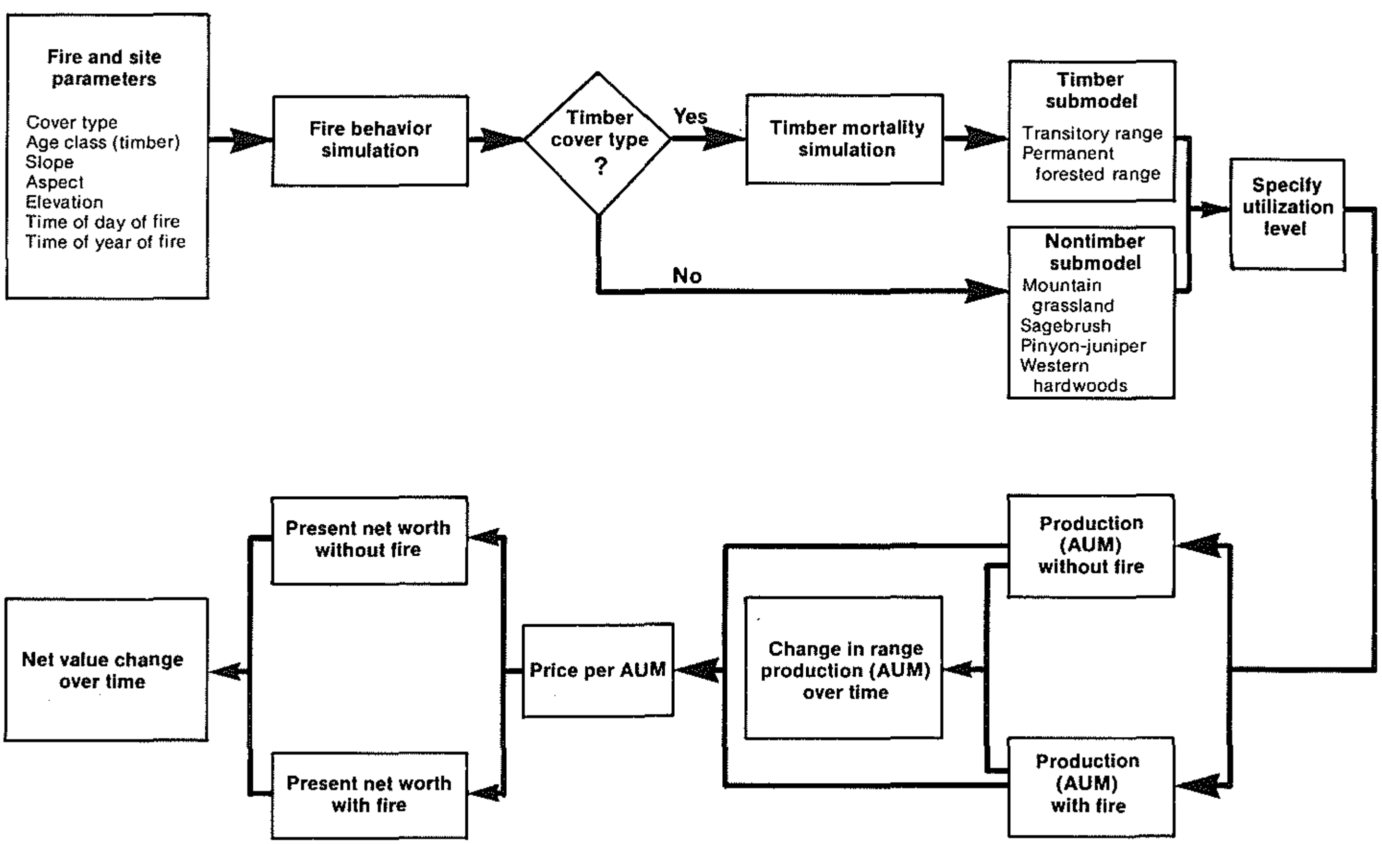

Figure 1—A simulation model was used to estimate the effects of wildfire on rangeland yield and values. The model includes two submodels: one for timber, and the other for nontimber range types.

The net value change of range output is determined through a straightforward financial return calculation. Prices are assigned to "with fire" and "without fire" AUM production values, and a given discount rate is used to calculate present net worth (PNW) for both series of values. Net value change (NVC) of range output is then calculated by subtracting the PNW of the "with fire" series from the PNW of the "without fire" series. Similar to the ΔAUM values, *positive NVC represents a loss in range value, and negative NVC represents a gain.*

Geographic Area and Range Types

The modeling procedures discussed were developed for the Northern Rocky Mountain–Intermountain fire climate zone (Schroeder and others 1964). This region has relatively homogeneous synoptic weather patterns with respect to conditions that affect fire occurrence. Pacific and Northwest Canadian high pressure systems are generally associated with periods of high fire occurrence in this region.

Cover types used to identify rangelands in the model are based on Forest and Range Ecosystem Study (FRES) ecosystem types (Garrison and others 1977). Eleven major ecosystem types are found in the Northern Rocky Mountain–Intermountain climate zone: ponderosa pine, Douglas-fir, lodgepole pine, larch, western white pine, fir–spruce, hemlock–Sitka spruce, mountain grassland, sagebrush, pinyon–juniper, and western hardwoods.

The hemlock–Sitka spruce (mainly western hemlock [*Tsuga heterophylla*] and western redcedar [*Thuja plicata*]), and fir–spruce (mainly subalpine fir [*Abies lasiocarpa*] and Engelmann spruce [*Picea engelmannii*]) timber types are generally not used for grazing (Mueggler 1962, Garrison and others 1977) and are not included in this analysis. Douglas-fir *(Pseudotsuga menziesii)*, lodgepole pine *(Pinus contorta)*, larch *(Larix occidentalis)*, and western white pine *(Pinus monticola)* rangelands are generally grazed only during a 20-year period after timber harvest or a stand replacement fire. These four timber types are grouped as transitory range and are modeled within a single subroutine. Ponderosa pine *(Pinus ponderosa)* rangeland is normally grazed for a much longer period of time than transitory rangeland types and is included in a discrete subroutine. Mountain grassland, sagebrush, pinyon–juniper, and western hardwoods are all modeled in discrete subroutines.

Definitions, Assumptions, Decisions

Most of the information and data sources used in the development of this model were derived from literature on the effects of fire on rangeland. A limited amount of reliable quantitative information on some range types was available, however, and literature sources sometimes offered conflicting results. Also, it was sometimes difficult to establish what "typical" range composition and conditions were and what "typical" responses to fire were. These problems were resolved through objective judgments on the relative value of information sources in consultation with experts on range management.

The unit of measure used to express range production is the animal-unit month (AUM), the amount of forage consumed per animal unit per month, with an animal unit defined as a 1000-lb (454-kg) cow. The daily production ration varies depending on type of forage and location. In this study, a daily production ration of 30 lb (14 kg) is assumed for all range types, so an AUM is equivalent to 900 lb (409 kg) of forage—that portion of vegetative production that is usable for consumption by cattle. Forage consumption by wildlife is not considered in the model, although it is recognized that cattle and wildlife interact on some rangelands.

Because it has not been demonstrated that consistent differences exist among most grazing systems with respect to long-term productivity (Currie 1978), grazing systems are not considered in simulations developed for this model. Length of grazing season varies depending on the elevation of the range and the cover type. Two elevation classes are used as values in the model: $\leq$4500 ft (1400 m) and > 4500 ft (1400 m). Grazing seasons were determined through consultation with range experts and are incorporated into individual subroutines for each cover type. We assumed that grazing is distributed equally throughout the grazing season rather than concentrated at any particular time.

In the model, the effects of fire on range are simulated for wildfire only. In the Timber Submodel, burn intensity (expressed as scorch height) determines the proportion of tree mortality, which is then used in the simulation of subsequent forage production. In the Nontimber Submodel, we assumed that wildfires occur only during years when fuels are dry enough to carry a fire, resulting in a high-intensity fire. This assumption is based on inferences from several literature sources and expert opinion. Fire occurrence data from the historical records of Forest Service Northern (R-1), Intermountain (R-4), and Pacific Northwest (R-6) Regions suggest that fires rarely occur in nontimber cover types unless weather and fuel conditions are conducive to high-intensity fires (Bratten 1982). As a result, burn intensity is not an input to the Nontimber Submodel.

Fire effects are simulated for two time-of-year classes: spring and late summer. The specific fire dates used in the model are May 15 and August 15, respectively. The effects of fire on variables such as nutritional value of forage and dispersal patterns of cattle on the range (for example, cattle may concentrate in certain areas) are difficult to simulate and are not considered in this model. Substitution of alternative range sites for grazing is not an option in the model; any loss of range production resulting from fire is considered an actual loss that cannot be compensated for through substitution.

MODELING POSTFIRE CHANGES

Six subroutines in the model simulate the effects of wildfire on the major rangeland types found in the Northern Rocky Mountain–Intermountain region. Ponderosa pine and transitory range—Douglas-fir, lodgepole pine, western white pine, and larch cover types—subroutines are contained in the Timber Submodel. Mountain grassland, sagebrush, pinyon–juniper, and western hardwoods subroutines are contained in the Nontimber Submodel *(fig. 1)*.

Transitory Range

Transitory ranges are forested ranges that are used for grazing for a limited period of time after harvest or a stand replacement fire. Transitory ranges are considered separately from permanent forest range (ponderosa pine) that can be grazed at any stand age.

Information on cover type and age class from the fire and site parameter list, and estimated scorch height from the fire behavior simulation process are inputs to the timber mortality simulation process *(fig. 1)*, which calculates proportion of basal area killed in the stand. Elevation, as it relates to length of grazing season, and time-of-year of fire, are not required inputs. Mortality is simulated for stands based on the Northern Region's timber inventory data, by cover type and age class. The proportion of timber killed determines if a stand is retained or if it is completely salvaged and regenerated. The stand retention decision is based on information obtained from the Northern Region's silviculture staff (Wulf 1982). Stands are retained for these age classes only:

Age class:	Proportion of basal area killed
Seedling–sapling	< 0.85
Pole	$< .70$
Sawtimber	$< .70$

The basal areas indicated are considered to be the maximum losses that can be incurred without reducing stocking below minimally acceptable levels. If the stand is not retained, range production is simulated for the regenerated stand. Also available is a recently cutover age class for which the stand retention decision rules are not used. Recently cutover is defined as 2 years postharvest.

Useful quantities of forage are produced on cutover or burned stands for about 20 years after tree removal (Basile and Jensen 1971, Davis 1982, Hardman 1982). Most studies to date on vegetal development after fire or harvest have evaluated percent cover only (Lyon 1971, Lyon 1976, Lyon and Stickney 1976, Stickney 1980). On the basis of one of the few studies done on forage production after clearcuts (Basile and Jensen 1971), peak understory production is estimated to be 900 lb per acre (1010 kg/ha) for a lodgepole pine stand. Peak understory production on Douglas-fir clearcuts was 1100 lb per acre (1240 kg/ha)(Lewis 1965). Production values are not available for other transitory range types. The value of 900 lb per acre is used in the model to represent lodgepole pine only, but 1100 lb per acre is used for Douglas-fir and for larch and western white pine. Of the understory production in this range type 70 percent is usable forage (Mueggler and Stewart 1980), so 630 lb per acre (710 kg/ha) and 770 lb per acre (860 kg/ha) are considered peak forage production values in this subroutine. Understory production may vary greatly depending on forest type and geographic location. It is reasonable to group transitory range types in this manner, however, because of the broad resolution of the model and the lack of production data.

The pattern of understory production after stand removal is described mathematically as (Basile and Jensen 1971):

$$p = (p_m) \exp [(-0.01667)(a_s - a_m)^2] \qquad (1)$$

in which

p = understory production
p_m = maximum understory production
a_s = stand age after harvest (years)
a_m = age of maximum understory production (years)

A consensus of the studies cited earlier indicates that peak production occurs approximately 10 years after stand removal, so a_m = 10. Because forage production (f) equals 0.7 p and p_m = 900, forage production for each year after stand removal is:

$$f = (0.7)(900) \exp [(-0.01667)(a_s - 10)^2], \qquad (2)$$

for the values a_s = 1, 2, 3, . . . 20. Because *year 1 of the model output is defined as the year of the fire*, f is calculated through year 21.

Grazing is not permitted in the year of the fire and is generally deferred for years 2 and 3 to permit seedling establishment (Davis 1982). The change in range production (ΔAUM) = 0 for years 1 to 3 because grazing would not have occurred in the absence of fire. For all age classes except the recently cutover class, a net gain in forage occurs for years 4 to 21. The one exception is lodgepole pine in the seedling–sapling age class. In this situation, grazing would have occurred in years 1 and 2 without fire because stand age = 20 for this cover type–age class combination. Consequently, a loss of AUMs occurs in years 1 and 2. Postharvest (or postfire) management actions are summarized as: (a) stand harvested (or salvaged) in year 1, (b) stand regenerated (planting or germination) in year 2, deferred from grazing, (c) stand deferred from grazing in year 3, (d) grazing begun in year 4.

In both the "with fire" and "without fire" situations, physical changes in grazing outputs are evaluated within the 200-year analysis period at appropriate points in time when harvest occurs. Forest planning documentation from the Northern Region indicates that average rotation age is about 125 years for Douglas-fir, western larch, and western white pine, and 100 years for lodgepole pine. The Northern Region's inventory data were used to determine the following mean ages for each age class:

Age class:	Lodgepole pine	Douglas-fir, western larch, western white pine
Seedling-sapling	20	30
Pole	50	60
Sawtimber	80	100

The presence of fire induces a sequence of discrete periods of gain and loss in AUMs for all age classes. In situations in which a stand is not retained, the range production that would have been realized after a future harvest is shifted to an earlier point in time. This shift affects the timing of all future timber harvests and associated grazing. Because the cutover age class is defined as 2 years postharvest, range production begins in the "without fire" situation in year 2, and continues through year 19. This production results in an initial loss in AUMs followed by a gain, because the "with fire" and "without fire" grazing sequences overlap.

Permanent Forested Range (Ponderosa Pine)

The ponderosa pine cover type can generally be used for grazing if canopy cover is less than 60 percent (Carson 1982). If canopy cover is greater, forage production in the understory is insufficient to support grazing (Jameson 1967, Pase 1958). Mathematical relationships between basal area and understory production, and between canopy cover and understory production have been developed for ponderosa pine by Pase (1958):

$$\log\ p=3.22-0.00936b \quad (3)$$
$$\log\ p=3.33-0.0247c \quad (4)$$

in which

p=understory production (lb/acre)
b=basal area (ft²/acre)
c=canopy cover (pct).

If equation 4 is solved for p in which c=60, and is substituted in equation 3, then basal area (b) is calculated to be 146 ft^2 per acre (33 m^2/ha). Forest inventory data from the Northern Region indicate that mean basal area of ponderosa pine is less than 146 ft^2 per acre even at rotation age. It is assumed for modeling purposes, therefore, that ponderosa pine can be used for grazing throughout the life of the stand.

Cover type, age class, and time-of-year of fire are required inputs for this subroutine. Mean basal area and stand age for each age class have been determined from forest inventory data from the Northern Region. The mean values are:

Age class:	Basal area (ft^2/acre)	Age (yrs)
Seedling-sapling	45	30
Pole	55	40
Sawtimber	96	90

Mean rotation age for ponderosa pine is about 125 years, on the basis of silvicultural practices currently used in the Northern Region. Mean basal area at harvest is 120 ft^2 per acre (27 m^2/ha). By using data on basal area and age, we developed a simple relationship:

$$b=12.7a^{0.5}-25.6 \qquad r^2=0.99 \quad (5)$$

in which

b = basal area (ft^2/acre)(if $b < 0$, the value of b is set equal to 0)
a = age (yrs).

This equation can be used to simulate basal area throughout the growth of the stand *(fig. 2).*

Similar to the decision process of the transitory range subroutine, stand retention depends upon the proportion of basal area killed. The decision rule is the same one used with the transitory range: the stand is retained if basal area killed is <85 percent for the seedling–sapling age class, or <70 percent for pole and sawtimber age classes. If the stand is retained, growth of the stand is simulated until the end of that rotation.

Understory production is estimated from the relationship developed by Pase (1958):

$$p=10^{3.22-0.00936b} \quad (6)$$

in which

p = understory production (lb/acre)
b = basal area (ft^2/acre).

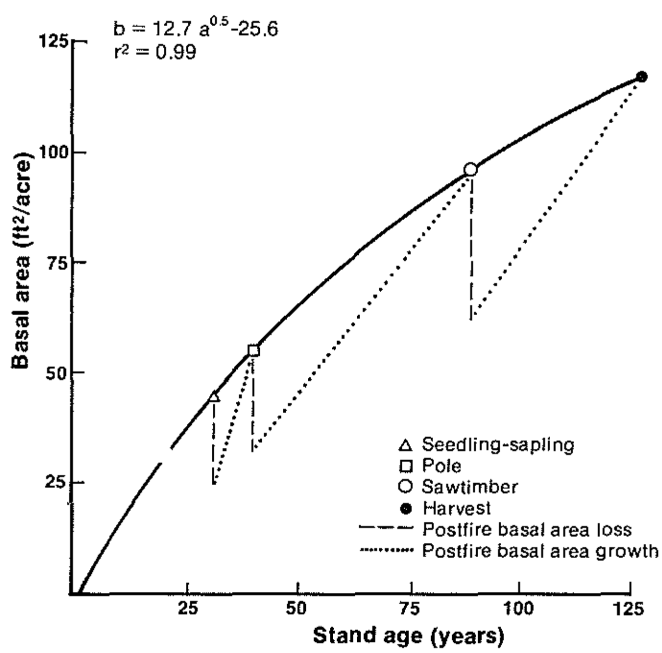

Figure 2—For ponderosa pine, basal area (b) reaches expected levels by the mean age of the next older age class or, if sawtimber, by the end of the rotation.

About 70 percent of understory production in this range type is available forage (Mueggler and Stewart 1980). Because forage production f = 0.7 p, forage production is calculated as:

$$f = (0.7)(10^{3.22-0.00936b}) \quad (7)$$

Basal area can be calculated for each year in the rotation with equation 5, so f can be determined throughout the growth of the stand.

The calculation of f is fairly simple in the "without fire" situation after harvest or a stand replacement fire. Forage production is determined for values of b along the basal area-age curve (*fig. 2,* eq. 5). The "with fire" situation in which the stand is retained requires an additional step in simulating regrowth. In this situation, some of the basal area of the stand has been lost. We assumed that because the stand still has adequate postfire stocking, basal area will reach expected levels along the basal area-age curve by the mean age of the next older age class or, if sawtimber, by the end of the rotation. Furthermore, we assumed that recovery is linear from the point of the fire to the point at which expected basal area is reached.

This pattern of basal area recovery after fire is illustrated in *figure 2,* in which a portion of stand basal area is lost after fire. In years subsequent to the fire, basal area is determined along straight lines until the basal area-age curve is reached at the mean age of the next older age class. Basal area is determined from the curve for the remainder of the rotation.

Forage production in the "without fire" situation is calculated from equation 7 with appropriate values of b from the basal area-age curve throughout the rotation. In situations in which a stand of ponderosa pine is not retained, the peak forage production realized after a future harvest is shifted to an earlier point in time. This shift affects the timing of all future harvests and the sequence of range outputs for the 200-year analysis period.

Ponderosa pine range is deferred for a short period of time after fire or harvest. After harvest, range is deferred for the year of the harvest and the next 2 years. After fire, range is deferred for the balance of that year and for the next 2 years. The grazing season is defined as June 1 to October 31 for elevations $\leq$4500 ft (1400m) and as June 1 to October 15 for elevations $>$ 4500 ft (1400 m) (Davis 1982, Hamner 1982, Hardman 1982). If fire occurs in spring (May 15), all of year 1 is lost for grazing. If fire occurs in late summer (August 15), 50 percent of the grazing season is lost in year 1 for range in either elevation class.

Mountain Grassland

The mountain grassland ecosystem consists mainly of open, untimbered areas, although it is often adjacent to or surrounded by ponderosa pine, Douglas-fir, or lodgepole pine at moderate elevations. This grassland cover type may include many grasses, especially those in the genera *Agropyron, Festuca, Muhlenbergia, Stipa, Poa,* and *Danthonia,* and forbs such as *Balsamorhiza sagittata.* The mountain meadows ecosystem is also dominated by perennial grasses, but tends to occur on more moist sites (Garrison and others 1977). Mountain meadows are relatively insignificant in terms of total land area in the Northern Rocky Mountains, and literature on fire effects in this range type is scant. It is included, therefore, with mountain grassland for the purpose of modeling the effects of wildfire.

In the mountain grassland type we assumed that *Agropyron spicatum* and *Festuca idahoensis* are the dominant species. Forage production is 1500 lb per acre (1680 kg/ha) based on the mean value for several mountain grassland sites (Paulsen 1975). Substantial literature is available on the effects of fire on *Agropyron* and *Festuca* for both wildfire and prescribed fire conditions (Bailey and Anderson 1978; Clarke and others 1943; Conrad and Poulton 1966; Uresk and others 1976, 1980; Willms and others 1980; Wright and Bailey 1980). Although the results of these studies are not in total agreement, some generalizations can be inferred: (a) *Agropyron spicatum* is resistant to fire and suffers low mortality; and (b) the effect of fire on overall production in mountain grasslands is relatively shortlived, and losses of *Festuca idahoensis* are generally compensated for by increases in production of *Agropyron spicatum* and other species.

Of the studies on fire effects on mountain grassland species, Clarke and others (1943), provide the best analysis of postfire changes in forage production. Because most of the other studies corroborate the results of this paper, it will be the basis for much of the modeling in this range type. With a spring fire (April-June), simulated loss of forage is 50 percent during the year of the fire (year 1) and 15 percent the year after the fire (year 2). Forage production returns to prefire levels in year 3. With a late summer fire (July-September), loss of forage is 30 percent in year 2, and forage production returns to prefire levels in year 3.

An additional loss of forage occurs depending on the time of fire. For a spring fire, the range is deferred from grazing in year 1 until after seed ripening (Davis 1982, Hardman 1982). The date of seed ripening is estimated to be August 1 at elevations $\leq$ 4500 ft, and August 15 to October 15 at elevations $>$ 4500 ft. The amount of grazing time that is lost depends on the length of the grazing season. Length of grazing season is defined as June 1 to October 31 at elevations $\leq$ 4500 ft, and June 15 to October 15 at elevations $>$ 4500 ft. Normal grazing patterns are resumed in year 2 after a spring fire. With a late summer fire, grazing is deferred until after seed ripening (August 1 or August 15, depending on elevation class) in year 2. Normal grazing patterns are resumed in year 3.

The effects of fire on mountain grassland are shortlived. Losses in range production in years 1 and 2 occur because of a decline in forage production and deferral of the range from grazing. Forage production reaches prefire levels by year 3, and the range can be fully utilized thereafter.

Sagebrush

Sagebrush is one of the most common range types in the Northern Rocky Mountain–Intermountain region. This range type contains primarily big sagebrush (*Artemisia tridentata*) and perennial grasses, of which *Agropyron* and *Festuca* are most common. The information used to simulate the effects of fire on sagebrush range is derived from long-term studies on sagebrush–grass range in Idaho (Blaisdell 1953, Harniss and Murray 1973, Mueggler and Blaisdell 1958) and Oregon (Hedrick and others 1966, Sneva 1972). Some of the general conclusions of the studies are these: (a) wildfire kills nearly all sagebrush plants; (b) most of the increased grass production after removal of sagebrush is because of *Agropyron* and *Calamagrostis;* (c) reinvasion of the range by sagebrush occurs by seed dispersal because big sagebrush does not sprout; and, as sagebrush increases on a site, perennial grasses decline.

Mean forage production on sagebrush range is 280 lb per acre (310 kg/ha) based on mean forage values for different productivity classes (Garrison and others 1977) and the percentage of existing rangeland that occurs in each class (U.S. Dep. Agric., Forest Serv. 1980). Sagebrush range is deferred from grazing for two growing seasons after fire under current management practice (Carson 1982, Wright 1982). Forage production need not be simulated during these years because no grazing occurs. Loss of range output in year 1 varies depending on elevation and time-of-year of the fire. Grazing season is defined as May 1 to October 31 at elevations $\leq$ 4500 ft, and June 15 to October 31 at elevations > 4500 ft (Carson 1982, Schultz 1982).

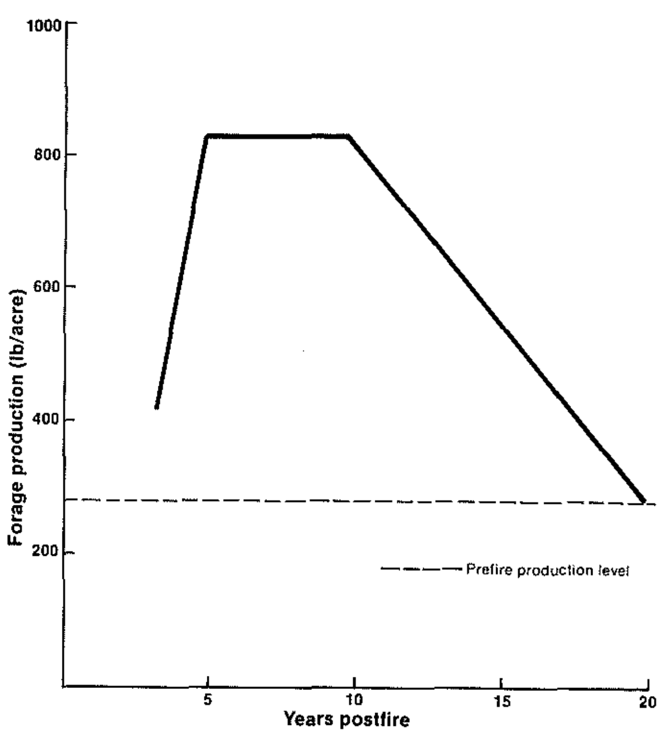

Figure 3—For sagebrush, peak forage production is maintained from years 5 through 10 and then declines until year 20 when it reaches prefire levels.

Forage production increases 50 percent over pretreatment levels 2 years after removal of sagebrush (year 3), 100 percent in year 4, and 200 percent in year 5 (Hedrick and others 1966, Sneva 1972). Peak forage production is maintained through year 10, and perennial grass production begins a gradual decline in year 11 because of the reinvasion of the range by the sagebrush (Blaisdell 1953, Harniss and Murray 1973, Mueggler and Blaisdell 1958). We assumed that this decline is linear from 200 percent greater than prefire production in year 10 to 0 percent in year 20. This decline is described by $p = -55.8y + 1390$, in which p = forage production (lb per acre), and y = years postfire ($10 \leq y \leq 20$). Postfire forage production is summarized (*fig. 3*).

Losses in range output in years 1 and 2 occur because of deferral from grazing. The range is deferred in year 3 in a late summer fire, resulting in an additional year of lost range production. The range can be grazed in year 3 in a spring fire, however, because two growing seasons have passed; a gain in range output occurs because forage production has increased in year 3. Time-of-year of fire has no effect on the gain in AUM in years 4 to 19.

Pinyon–Juniper

The pinyon–juniper ecosystem that is found in the Northern Rocky Mountain–Intermountain region contains only western juniper (*Juniperus occidentalis*) in the overstory. Dominant grasses in the understory are various species of *Agropyron* and *Festuca* and some *Stipa* and *Poa* (Wright and others 1979). In a discussion of the effects of fire on western juniper, Martin (1978) suggests that wildfire normally kills 80 percent of the overstory. Because juniper stands in Idaho have a mean canopy cover of 42 percent (Tueller and others 1979), less than 10 percent canopy cover would remain after wildfire. The best documentation of postfire changes over time in pinyon–juniper is a study of 28 different burns in west-central Utah (Barney and Frischknecht 1974).

Mean forage production for pinyon–juniper range is 130 lb per acre (150 kg/ha) based on mean forage values for four different productivity classes (Garrison and others 1977) and the proportion of land found in each productivity class (U.S. Dep. Agric., Forest Serv. 1980). Decision rules are the same as for mountain grassland because many of the grass species are the same (Davis 1982, Hardman 1982). Grazing is deferred until after seed ripening (August 1 at elevations $\leq$ 4500 ft, August 15 at elevations $>$ 4500 ft) of year 1 for spring fires. Grazing is deferred until these same dates in year 2 for a late summer fire, and the balance of the grazing season in year 1 is lost. Grazing season is defined as May 1 to October 31 at elevations $\leq$ 4500 ft, and

June 15 to October 15 at elevations > 4500 ft (Carson 1982, Schultz 1982).

The study on pinyon–juniper fire effects does not include information on forage production for the first few years after fire (Barney and Frischknecht 1974). Because the perennial grasses in pinyon–juniper are similar to those in mountain grassland range, effects in years 1 to 3 are simulated as for mountain grassland. Forage production is reduced by 50 percent for the balance of year 1 and by 15 percent in year 2 for a spring fire. Forage production during year 2 is reduced by 30 percent in a later summer fire. Forage production equals prefire levels in year 3 for both spring and summer fires. Forage production is 100 percent greater than prefire levels in year 5 (Barney and Frischknecht 1974). It is estimated that forage increases 50 percent (by interpolating between 0 percent and 100 percent) in year 4.

Reinvasion by juniper after fire is relatively slow, and canopy cover does not increase much until about 50 years after fire. During this period, forage production remains fairly stable (Barney and Frischknecht 1974), so forage production for years 5 to 50 is 100 percent greater than prefire levels (or 260 lb/acre). Juniper canopy cover increases steadily after year 50 until prefire levels are reached at about 90 years. During this period, a concurrent decrease in available forage occurs (Barney and Frischknecht 1974). We assumed that the decline in forage from year 50 to year 90 is linear. This decline is described by $p = 3.16y + 414$, in which p = forage production (lb/acre) and y = years postfire ($50 \leq y \leq 90$). Forage production remains at prefire levels for years 90 to 200. Postfire forage production is summarized (*fig. 4*).

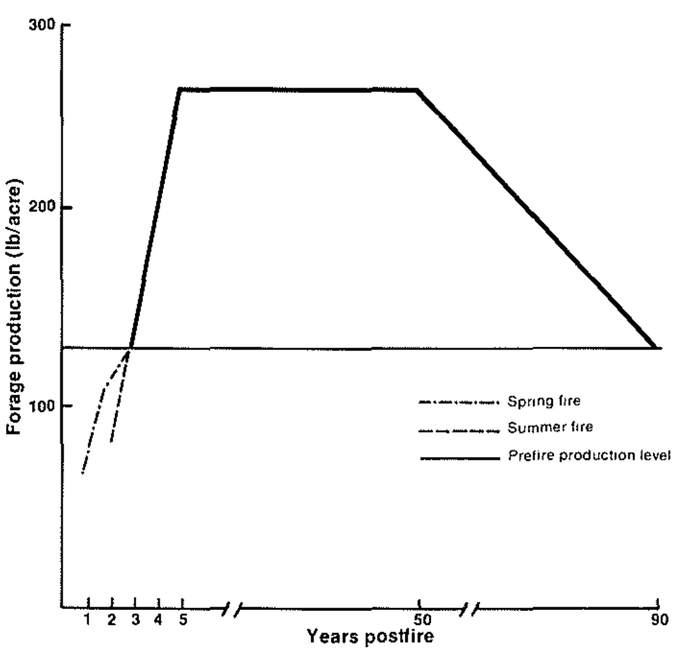

Figure 4—For pinyon-juniper, peak forage production is maintained from years 5 through 50 and then declines until year 90 when it reaches prefire levels. Season of fire affects early postfire production.

Western Hardwoods

The western hardwoods ecosystem in the Northern Rocky Mountains consists primarily of scattered stands of quaking aspen (*Populus tremuloides*) with an understory of grasses, forbs, and shrubs. This cover type is normally relatively open and meadow-like and may occur adjacent to grassland or conifer forest. Most of the information used to simulate the effects of wildfire on western hardwoods is drawn from a series of studies conducted on aspen stands in western Wyoming (Bartos 1978, 1979; Bartos and Mueggler 1979, 1981). These papers discuss the effects of prescribed fire, and classify burn intensity as low, moderate, and high. We assumed that the high burn intensity class can be used to simulate the effects of wildfire. Aspen sucker production increases initially after fire. Production of grasses and forbs increases in the second year after fire and gradually declines thereafter.

Decision rules for deferred grazing after fire are the same as those used for mountain grassland. Grazing is deferred until August 1 (for elevations ≤ 4500 ft) or August 15 (for elevations > 4500 ft) of year 1 in a spring fire. Grazing is deferred until the same dates of year 2 in a late summer fire. Grazing season is defined as June 1 to October 31 for elevations ≤ 4500 ft, and June 15 to October 15 for elevations > 4500 ft.

Mean understory production on aspen sites studied was1325 lb per acre (1480 kg/ha) and was dominated by various forbs (Bartos and Mueggler 1981). The value of this production for forage could not be determined directly from that study. Forage was estimated by multiplying palatability ratings by the production of each species.[1] Mean forage was calculated by this method to be 350 lb per acre (340 kg/ha), or 27 percent of total production. Understory production 3 years postfire was 2250 lb per acre (2520 kg/ha) on the severely burned sites, 66 percent of which was the unpalatable species fireweed (*Epilobium angustifolium*). Forage production calculated with the use of palatability ratings was 402 lb per acre (450 kg/ha), or only 18 percent of understory production.

Total understory production trends indicate that forage production (assuming the same forage–understory production ratio) was 22 percent of the 402 lb per acre, or 89 lb per acre (100 kg/ha) in the year after fire (Bartos and Mueggler 1981). This value is used for year 1 of a spring fire and for year 2 of a late summer fire. Peak forage production was estimated as 416 lb per acre (466 kg/ha) 2 years postfire (year 3). An interpolated value of 252 lb per acre (282 kg/ha) (the mean of years 1 and 3) was used to express forage production in year 2 for a spring fire. By extrapolating production trends into the future according to a constant linear decline, forage levels approach prefire levels 7 years after fire. This decline is described by

[1]Unpublished data by Lisle R. Green, on file at Pacific Southwest Forest and Range Experiment Station, Riverside, California.

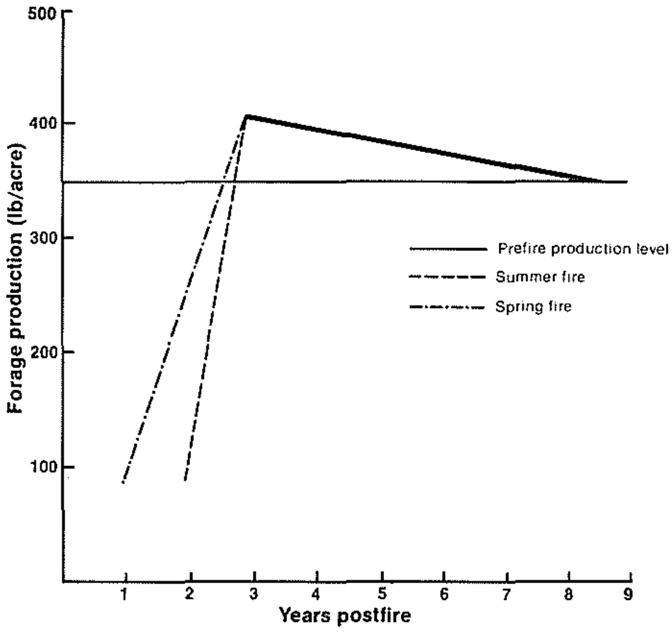

Figure 5—For western hardwoods, peak forage production is reached at year 3 and then declines until year 8 when it reaches prefire levels. Season of fire affects early postfire production.

$p = -12.6\ y + 450$, in which p = forage production (lb/acre) and y = years postfire ($3 \leq y \leq 8$). We assumed that forage production would remain constant thereafter (*fig. 5*).

Forage losses occur immediately postfire, and increases for several years after fire are relatively small. Although a substantial increase in understory production occurs after fire, the forage value of the vegetation is low and results in only a small gain in AUM.

CALCULATING NET VALUE CHANGE

The "with fire" and "without fire" approach to effects valuation is described by the following general form of the range effects valuation equation:

$$NVC = PNV_{w/o} - PNV_w \qquad (8)$$

in which

NVC = net value change

$PNV_{w/o}$ = present net value of all future range reventus in "without fire" situation

PNV_w = present net value of all future range revenues in "with fire" situation

Equation 8 accounts for long- and short-term effects by valuing changes in the infinite series of future revenues, rather than valuing changes in the revenue series for only a limited number of years. Management costs are omitted on the assumption that wildfire causes no significant variation in those costs. Although costs might be incurred in some situations for items such as fencing or watering facilities, it is difficult to estimate the frequency or magnitude of these costs. We assumed that fires occur only in areas currently managed for range, that required improvements are already in place, and that a fire does not create a new range that requires a high level of management costs. In equation 9, the range net value change calculation is expanded to its computational form.

$$NVC = \left[\sum_{s=o}^{n} \frac{PQ_{w/o,\,s_n}}{(1+i)^{s_n}} + \sum_{f=o}^{n} \frac{PQ'_{w/o,\,f_n}(1+i)^{t-f_n}}{(1+i)^{t}-1}\right] - \left[\sum_{s=o}^{n} \frac{PQ_{w,\,s_n}}{(1+i)^{s_n}} + \sum_{f=o}^{n} \frac{PQ'_{w,\,f_n}(1+i)^{t-f_n}}{(1+i)^{t}-1}\right] \qquad (9)$$

in which

NVC = net value change

P = price in 1978 dollars per AUM

$Q_{w/o,\,s_n}$ = single series annual or periodic forage yield at time s_n in the "without fire" situation

$Q'_{w/o,\,f_n}$ = infinite series annual or periodic forage yield at time f_n in the "without fire" situation

$Q_{w,\,s_n}$ = single series annual or periodic forage yield at time s_n in the "with fire" situation

$Q'_{w,\,f_n}$ = infinite series annual or periodic forage yield at time f_n in the " with fire" situation

i = policy provided discount rate (for example, i = 0.04)

s_n = the years after fire in which single series differences exist between "with fire" and "without fire" forage yields

f_n = the years after fire in which infinite series, cyclic, timber-associated forage yields first occur

t = the number of years between cyclic occurrences of timber-associated forage yields (that is, equivalent to rotation age of associated timber stand)

The first bracketed component of equation 9 represents $PNV_{w/o}$ and the second represents PNV_w. Long-term effects are estimated by subtracting the second term in the two bracketed components (that is, the infinite series difference). This long-term effect must be estimated in timber-associated range types because of the cyclical nature of these types. A fire may alter the development of a timber stand, and thereby alter the timing of forage yield cycles dependent on that development. The value of this shifting of the infinite series of forage yield cycles represents the long-term, fire-caused financial effect on the range resource.

Short-term effects are estimated by subtracting the first term in the second bracket from the first term in the first bracket (that is, the single series difference). These effects are characteristic of all nontimber range types and of some timber-associated types. Short-term effects are all those associated with fire-caused, single period changes in forage yields, rather than with simple shifts in the timing of postfire yields. Fire, for example, reduces mountain grassland forage yield for only 2 years after fire. Paired "with fire" and "without fire" sites show identical yield beyond that point. Mountain grassland range is subject to only short-term changes, with no infinite series forage cycle shifts occurring. The appropriate terms cancel in equation 9 when only long- or short-term effects occur.

To evaluate the fire effects on range types in this study, we used SASSY, an investment analysis computer package (Goforth and Mills 1975) that performs the equation 9 calculation, given the following information: (a) the timing or investment year of "with fire" and "without fire" forage yields; (b) the yield amount (AUM/acre); (c) a price per AUM; (d) discount rate(s); and (e) in some instances, a cycle or rotation length. The timing and magnitude of forage yields are output of the range simulation model discussed earlier, and the cycle or rotation age information was the same as that used in the simulation model.

A uniform price of $9.72 per AUM was used in the NVC calculations for all range types. This price is a weighted mean of the 1985 Resources Planning Act (RPA) Program prices for 26 National Forests in the Northern Rocky Mountains.[2] The forest-specific RPA Program prices were developed as shadow prices from a linear program developed by Gee (1981). These prices, where available, are being used in forest-level planning. The RPA prices were adjusted to 1978 dollars from the gross national product implicit price deflator. Actual range-use levels were used as weights in developing the mean Northern Rocky Mountain price. The AUM price was assumed to remain constant over time, as evidence was inadequate to justify a real price change assumption.

ESTIMATING POSTFIRE CHANGES

Estimates of changes in range production and value for the six range types were calculated for the postfire time stream during which range output is affected, up to 200 years postfire.[3] Some of the data in the tables are grouped by year, for convenience.

Changes in range production (ΔAUM) are based on the values used for forage production in the individual subroutines described earlier. These default values can be modified with an appropriate multiplier at the discretion of the user if it is determined that the values are too high or too low. The ΔAUM values in *tables 1, 3, 5, 7, 9,* and *11* are the entire change in AUM, that is ΔAUM at a theoretical 100 percent utilization. Although 100 percent utilization is not realistic in actual management, it serves as a reference point that can be modified by users according to the level they think is appropriate. Net ΔAUM (for the entire postfire time stream) for utilization levels of 25 percent and 40 percent of annual production is listed in *tables 2, 4, 6, 8, 10,* and *12.* Forty percent is the maximum utilization level for sustained range production, on the basis of various literature citations and a consensus of opinions from range management experts. Twenty-five percent represents a moderate level of range utilization. As discussed earlier, *positive numbers in the tables indicate a loss in range production and value, and negative numbers indicate a gain in production and value.*

Changes in range production and value are given for all possible situations within each range or cover type. Elevation and time-of year of fire were originally used to stratify some of these situations in the simulation model and are listed in odd-numbered tables. Values in even-numbered tables were aggregated for these parameters if the difference was less than 10 percent between range types for both net ΔAUM and NVC. As a result of the aggregation process, elevation is not listed in any of the even-numbered tables and is not a significant stratifier with respect to net ΔAUM or NVC. Age class and percent mortality are additional stratifiers for the timbered range types. In addition, NVC is calculated for two utilization levels at two different discount rates. The user should cautiously interpolate or extrapolate the data of these tables to fit individual purposes.

Transitory Range

Substantial changes in postfire range production for cover types are included in transitory range *(table 1).* This table should be used only for a stand replacement fire (defined here as > 70 percent of basal area removed) or if the entire stand is removed by salvage. The general effect of wildfire in these types is to shift the periods of grazing use that would have occurred after harvest to an earier point in the time sequence. The same sequence of values is repeated throughout the 200-year analysis period, with gains after fire and harvests in the "with fire" situation, and losses after harvests in the "without fire" situation. The magnitude of ΔAUM is relatively low for the cutover age class

[2]National Forests in Idaho were the Boise, Caribou, Challis, Clearwater, Idaho Panhandle, Nezperce, Payette, Salmon, Sawtooth, and Targhee. National Forests in Montana were the Beaverhead, Bitterroot, Deerlodge, Flathead, Kootenai, and Lolo. National Forests in Oregon were the Deschutes, Fremont, Malheur, Ochoco, Umatilla, and Wallowa-Whitman. National Forests in Washington were the Colville, Okanogan, and Wenatchee. National Forest in Wyoming was the Bridger-Teton.

[3]See *tables 1* to *12* in *appendix.*

because of the overlap of grazing sequences in the "with fire" and "without fire" situations.

The two examples (*table 1*) not only have different sequences of ΔAUM values, but have different sequence timing because lodgepole pine has different mean stand ages and rotation age than Douglas-fir, western larch, and western white pine. Net ΔAUM is large for some age classes but is equal to 0 in others (*table 2*). This demonstrates the effect of the shift of grazing sequences within the 200-year analysis period.

The NVC estimates for all size classes except cutover in the transitory range types show a net benefit resulting from fire (that is, negative NVC estimates). This beneficial effect results from a forward shift in the timing of future expected range yields. In a seedling–sapling stand (age 30), for example, range yields are not expected until the beginning of the next rotation (that is, a 95-year delay, given a 125-year rotation), but if fire destroys the timber stand the next rotation begins in year 1. The fire allows an almost immediate realization of range yields, which was not available for 95 years in the "without fire" situation. The beneficial effect of fire decreases as stand age at time of fire increases. This trend results from a less forward shift in the timing of range yields as fire occurs in older stands. The beneficial effect is more pronounced at a higher utilization level because larger values are differenced there than at the lower utilization level.

The beneficial effects in the transitory range types decrease at a higher discount rate. This result indicates that the "with fire" values are driving the NVC calculation in this instance. A higher absolute decrease occurs in out-year "with fire" range values at a higher discount rate than in out-year "without fire" values.

The losses in the cutover age class result from a fire-caused 2-year delay in range yields. Range yields expected in year 1 for the "without fire" situation are delayed until year 3 in the "with fire" situation. The losses in the cutover age class increase at a higher discount rate, because a higher absolute decrease occurs in the value of future "with fire" yields at a higher discount rate, than occurs in "without fire" values. Losses become more pronounced at higher utilization levels because larger values are being subtracted. This effect of higher utilization levels occurs in all range types.

Permanent Forested Range (Ponderosa Pine)

Change in postfire production of ponderosa pine range varies greatly depending on age class and percent timber mortality (*table 3*). The cutover age class and all seedling-sapling classes have overall losses in production except where mortality is 100 percent. Almost all pole and sawtimber classes have overall gains.

In the cutover age class, the initial losses from deferred grazing are large because the range is highly productive early in the rotation (*table 3*). After the initial loss, small increases occur until the mean seedling –sapling age is reached because the "with fire" rotation is 2 years behind the "without fire" rotation.

The effects of fire on the seedling–sapling age class (*table 3*), are relatively shortlived because the mean age of pole timber is reached in only 10 years. Initial losses from deferred grazing are substantial. Subsequent increases are large only if 100 percent of the stand is removed (this could result entirely from fire or postfire salvage). The 100 percent mortality class has a net gain in AUMs, while the other mortality classes have losses.

Long-term changes in range production are similar across all mortality classes for the pole (*table 3*) and sawtimber age classes. Gains in AUMs are large over a long period of time, especially in the 100 percent mortality class. In this class, the effect of the fire is to shift from a stand with relatively high basal area and low range output to a new rotation with high range output. Large losses in range output are incurred later in the postfire time stream. This results from the harvest of the stand at rotation age in the "without fire" situation, which results in higher range production than the "with fire" situation. The losses incurred later in the time stream tend to compensate for the earlier gains, and total ΔAUM production is about 0 for the 100 percent mortality class of pole and sawtimber (*table 4*).

The NVC estimates for ponderosa pine range follow the same general trend as the estimates of net change in physical output (AUMs). Net losses occur in all cutover classes and in all seedling–sapling classes except where there is 100 percent mortality. Net gains occur in all pole and sawtimber classes.

The net losses in the cutover age classes result from a fire-caused delay in range yields. The detrimental effect of the delay is greater at higher discount rates. The value of delayed future "with fire" yields decreases relative to "without fire" yields at higher rates.

Losses in the net value of seedling–sapling stands at 30 and 60 percent mortality result from a 2- or 3-year fire-caused deferral of grazing (*table 4*). The larger spring losses result from the loss of 3 years grazing as against 2 years for a summer fire. Evaluating NVC at a higher discount rate results in the same increase in losses that occurred in the cutover classes.

Net gains occurred at 100 percent mortality in seedling–sapling stands despite the 2- or 3-year grazing deferral. The "with fire" yields subsequent to the delay were sufficiently larger than "without fire" yields to offset the losses resulting from the delay. The fire-caused gains decrease at higher discount rates because early losses become relatively more significant than later gains at higher rates. Time-of-year of fire has a minimal effect on the NVC for all age classes.

The net gains in range values associated with fires in all pole and sawtimber age stands (*table 4*) results from fire-caused reductions in basal area. These reductions facilitate earlier increases in range production than would occur in the "without fire" situation. Future expected range yields are shifted forward in time and realized sooner in the "with fire" situation. Higher mortality levels are associated with greater net gains because of the range production response to removal of increasing amounts of basal area.

The gains in pole and sawtimber age stands decline at a higher discount rate for the same reason the decline took place in the transitory type. The early "with fire" yields are driving the the NVC calculation. The absolute decreases in annual range values that occur with the application of higher discount rates are larger in "with fire" values than in "without fire" values.

Mountain Grassland

The effects of wildfire on mountain grassland range are shortlived because production returns to prefire levels in year 3 (*table 5*). Losses are relatively high, however, because this range type is normally highly productive. A large proportion of the loss results from the deferral of the range from grazing after fire. Fires that occur in late summer result in slightly higher total ΔAUM losses than spring fires (*table 6*).

Mountain grasslands show the largest value losses of all the range types (*table 6*), along with the cutover and seedling–sapling age classes of ponderosa pine. The effect of time-of-year on NVC is generally the same as was described for physical output. NVC losses are smaller at a higher discount rate because of the relatively great magnitude of the "without fire" values.

Sagebrush

Sagebrush shows a substantial long-term gain in range production after fire (*table 7*). An initial loss of production occurs because the range is deferred from grazing, and elevation and time-of-year of fire affect range yield in years 1 to 3. Range production is maintained at 200 percent greater than prefire levels during years 5 to 10. Production gradually declines during the next decade as sagebrush increases and grass production decreases. The many years of gain in AUMs more than compensate for the initial years of loss. Elevation and time-of-year of fire have little effect on net ΔAUM (*table 8*) because of the long-term gain in range production.

The net value gains in the sagebrush type also vary slightly by time-of-year or elevation (*table 8*). The NVCs decline at a higher discount rate because of the great magnitude of the "with fire" values relative to the "without fire" values.

Pinyon–Juniper

The pattern of postfire range production for pinyon–juniper range is similar to that for sagebrush: an initial loss in production is followed by a long-term gain (*table 9*). Small losses of AUMs occur in years 1 to 2, with elevation and time-of-year of fire having only a minor effect. Range production is maintained at 100 percent greater than prefire levels during years 5 to 50. Although this increase is relatively small (0.14 AUM) on an annual basis, the long-term net ΔAUM is substantial (*table 10*). Production begins a gradual decline after year 50 as juniper increases and grass production decreases. Prefire conditions are not reached until year 90. Pinyon–juniper range is normally unproductive for range management. Wildfire can make it substantially more productive over a long period of time.

All NVC estimates represent net gains resulting from fire that are consistent with gains in physical output (*table 10*). NVC estimates vary slightly by elevation or time-of-year, and the NVC gains decrease at higher interest rates. This decrease results from the relatively large magnitude of the "with fire" values.

Western Hardwoods

The dominant influence on range production of western hardwoods is deferred grazing during years 1 to 2 (*table 11*). Losses of production in these years are substantial for all elevation and time-of-year classes, and yields in year 2 are affected to some extent by decreased forage production. Production increases in years 3 to 7 are small, and are not large enough to compensate for losses in years 1 to 2. Net ΔAUM indicates a small loss in range production (*table 12*). Although wildfire affects range production of western hardwoods for several years, the long-term effect is relatively small.

The net effect of fire on western hardwoods range values is also small (*table 12*). A slight difference in NVCs results from time-of-year. This difference occurs because the first year postfire value in the "with fire" situation is consistently smaller after a summer fire than after a spring fire. NVCs increase at a higher discount rate because early range output reductions in the "with fire" situation become relatively more significant than later increases.

APPLICATION

The estimates of postfire change in production and value that are provided represent a broad spectrum of possible situations for common range types in the Northern Rocky Mountain–Intermountain area (*tables 1-6*). Postfire changes range from substantial long-term gains to moderate losses in production and value. In addition, the duration of fire effects varies widely among range types.

The information provided here can be used for several different aspects of decisionmaking. The timestream of postfire outputs includes estimates of both long- and short-term changes in range production. In some situations, change in output in the first few years may be a major concern. In long-term land management planning, the entire analysis period during which effects can be measured should be considered. Net value change estimates are provided for use in economic assessments. These estimates can be used as the sole criterion for decisionmaking or can be used in combination with estimates of physical output change.

The estimates of fire effects on range production developed by this study have several potential applications. They summarize the effects of wildfire on several ecosystems that are managed for cattle grazing. They can be used in a broad resolution sense to predict increases or decreases in range production after fire, on the basis of ecological information and management policies. More valuable, however, is the use of these fire effects estimates within the context of land management planning. Until recently, it has been difficult to incorporate fire management programs in the planning process because of insufficient methods for estimating postfire changes in resource yields. Estimates provided in this study can help solve this problem and can facilitate the integration of fire management with land management planning for Northern Rocky Mountain rangelands. Net value change estimates may also be useful as part of escaped fire situation analyses if a NVC criterion is part of the decisionmaking process.

Because of the nature of the simulation process used to generate changes in range production after fire, several limitations of this study are evident. Information available for some range types on which to base relationships useful for modeling purposes was scant. Quantitative information from the literature was often poor or had to be extrapolated to fit the broad resolution design of the current study. In addition, some critical points in the simulations were provided by assumptions drawn from the literature or by a consensus from range management experts. Although these assumptions do not affect the overall design of the model, they may be significant if fire effects estimates are used in site-specific situations. The broad resolution categories for which values have been generated may be difficult to correlate with some of the existing classification systems used in planning and site-specific analysis.

The design of the model that was used to produce estimates of changes in range production and value after wildfire should be adequate for the broad resolution needs of fire management planning. Some refinements could improve estimates used for site-specific applications, however. The range types considered here are broadly defined and could be subdivided on the basis of discrete combinations of forage species. Different species groups have different production levels and different responses to wildfire. More research is needed to determine the effect of fire on production levels in different range ecosystems. The model could also be modified to have more flexibility with respect to management actions. Management decisions such as length of grazing deferral after fire, length of grazing season, and utilization level can have a major effect on range output in some situations. The availability of a wider range of options could increase the likelihood of identifying a range or cover type that is applicable to a site-specific situation.

APPENDIX

Table 1—*Estimated postfire change in animal-unit months (ΔA UM) in transitory range production over time for four age classes of (A) Douglas-fir, western larch, and western white pine, and (B) lodgepole pine cover types*[1]

Year	Age classes			
	Seedling-sapling	Pole	Sawtimber	Cutover
	ΔA UM/acre			
	(A) Douglas-fir, western larch, western white pine			
1	0	0	0	0
2	0	0	0	0.38
3	0	0	0	.46
4	-0.38	-0.38	-0.38	.18
5	- .46	- .46	- .46	.20
6	- .56	- .56	- .56	.17
7	- .66	- .66	- .66	.13
8	- .73	- .73	- .73	.11
9	- .79	- .79	- .79	.06
10	- .84	- .84	- .84	0
11	- .86	- .86	- .86	- .06
12	- .84	- .84	- .84	- .11
13	- .79	- .79	- .79	- .13
14	- .73	- .73	- .73	- .17
15	- .66	- .66	- .66	- .20
16	- .56	- .56	- .56	- .18
17	- .46	- .46	- .46	- .17
18	- .38	- .38	- .38	- .16
19	- .29	- .29	- .29	- .13
20	- .22	- .22	- .22	- .22
21	- .16	- .16	- .16	- .16
29 to 46			10.40	
69 to 86		10.40		
99 to 116	10.40			
127 to 146				10.40
129 to 146	-10.40	-10.40	-10.40	
154 to 171			10.40	
194 to 200		4.44		

Year	Age classes			
	Seedling-sapling	Pole	Sawtimber	Cutover
	ΔA UM/acre			
	(B) Lodgepole pine			
1	0.18	0	0	0
2	.13	0	0	0.31
3	0	0	0	.38
4	- .31	-0.31	-0.31	.15
5	- .38	- .38	- .38	.16
6	- .46	- .46	- .46	.14
7	- .54	- .54	- .54	.11
8	- .60	- .60	- .60	.09
9	- .65	- .65	- .65	.05
10	- .69	- .69	- .69	0
11	- .70	- .70	- .70	- .05
12	- .69	- .69	- .69	- .09
13	- .65	- .65	- .65	- .11
14	- .60	- .60	- .60	- .14
15	- .54	- .54	- .54	- .16
16	- .46	- .46	- .46	- .15
17	- .38	- .38	- .38	- .14
18	- .31	- .31	- .31	- .13
19	- .24	- .24	- .24	- .11
20	- .18	- .18	- .18	- .18
21	- .13	- .13	- .13	- .13
24 to 41			8.51	
54 to 71		8.51		
84 to 101	8.51			
102 to 109				1.39
104 to 121	-8.51	-8.51	-8.51	
110				0
111 to 121				-1.39
124 to 141			8.51	
154 to 171		8.51		
184 to 200	8.38			

[1] Δ AUM = 0 for years not listed. Time intervals not applicable for a particular age class are indicated by blanks.

Table 2—*Estimated postfire net value change (NVC) in transitory range production for (A) Douglas-fir, western larch, and western white pine, and (B) lodgepole pine cover types*

Age class	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
	pct	*ΔAUM/acre*	*4 pct*	*10 pct*
(A) Douglas-fir, western larch, and western white pine				
Seedling-sapling	25	-2.60	-16.68	-10.02
	40	-4.16	-26.69	-16.03
Pole	25	-1.49	-15.76	-10.00
	40	-2.38	-25.21	-16.00
Sawtimber	25	0	-10.68	-9.10
	40	0	-17.09	-14.55
Cutover	25	0	1.39	2.10
	40	0	2.23	3.37
(B) Lodgepole pine				
Seedling-sapling	25	0.04	-13.22	-7.87
	40	.07	-21.16	-12.60
Pole	25	0	-12.17	-8.13
	40	0	-19.47	-13.01
Sawtimber	25	0	-7.70	-7.64
	40	0	-12.32	-11.17
Cutover	25	0	1.15	1.72
	40	0	1.85	2.75

Table 3—*Estimated postfire change in ponderosa pine range production over time for (A) cutover, (B) seedling-sapling, (C) pole, and (D) sawtimber age classes*[1]

(A) Cutover age class

Year	ΔAUM/acre	Year	ΔAUM/acre
1	0	9	-0.09
2	1.29	10	- .08
3	1.29	11 to 20	- .68
4	- .08	21 to 30	- .50
5	- .15	31 to 40	- .30
6	- .13	41 to 50	- .12
7	- .11	51 to 100	- .10
8	- .10	101 to 150	- .42

Year and season of fire[2]		Mortality of . . . 30 pct	60 pct	100 pct
(B) Seedling-sapling age class				
1	Spring	0.49	0.49	0.49
	Summer	.24	.24	.24
2	Either	.48	.48	.48
3		.46	.46	.46
4		- .11	- .23	- .85
5		- .09	- .19	- .85
6		- .07	- .15	- .78
7		- .06	- .12	- .72
8		- .04	- .08	- .66
9		- .03	- .05	- .62
10		- .02	- .03	- .58
(C) Pole age class				
1	Spring	0.38	0.38	0.38
	Summer	.19	.19	.19
2	Either	.38	.38	.38
3		.37	.37	.37
4		- .15	- .36	- .93
5		- .15	- .35	- .92
6		- .14	- .34	- .86
7		- .14	- .32	- .80
8		- .13	- .30	- .74
9		- .13	- .29	- .70
10		- .13	- .28	- .66
11 to 20		-1.32	-2.45	-4.92
21 to 30		- .86	-1.48	-3.32
31 to 40		- .34	- .55	-2.40
41 to 50		- .12	- .20	-1.76
51 to 100		0	0	5.92
101 to 150		0	0	11.04
(D) Sawtimber age class				
1	Spring	0.16	0.16	0.16
	Summer	.08	.08	.08
2	Either	.16	.16	.16
3		.15	.15	.15
4		- .12	- .33	-1.14
5		- .11	- .31	-1.14
6		- .11	- .29	-1.06
7		- .10	- .27	- .99
8		- .10	- .25	- .93
9		- .09	- .24	- .88
10		- .09	- .22	- .84
11 to 20		- .61	-1.45	-6.51
21 to 30		- .26	- .56	-4.60
31 to 40		- .03	- .06	-3.88
41 to 50		0	0	5.72
51 to 100		0	0	10.84
101 to 150		0	0	1.96

[1]ΔAUM = 0 for years not listed.
[2]Season of fire for year 2 and all subsequent years is spring or summer.

Table 4—*Estimated postfire net value change (NVC) in ponderosa pine production for (A) cutover, (B) seedling-sapling, (C) pole, and (D) sawtimber age classes*

Mortality class (pct)	Season of fire	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
		pct	*ΔAUM/acre*	*4 pct*	*10 pct*
			(A) Cutover		
—	Either	25	0.10	3.13	3.88
—		40	.16	5.01	6.21
			(B) Seedling-sapling		
30	Spring	25	.25	2.52	2.54
		40	.40	4.03	4.06
	Summer	25	.19	1.92	1.94
		40	.30	3.08	3.11
60	Spring	25	.14	1.62	1.85
		40	.23	2.60	2.96
	Summer	25	.08	1.03	1.25
		40	.13	1.65	2.01
100	Either	25	- .94	-6.80	-4.37
		40	-1.50	-10.88	-6.98
			(C) Pole		
30	Spring	25	-0.62	-1.54	0.26
		40	- .99	-2.47	- .42
	Summer	25	- .68	-2.01	- .21
		40	-1.07	-3.22	- .33
60	Spring	25	-1.45	-6.41	-2.48
		40	-2.32	-8.47	-4.55
	Summer	25	-1.50	-6.88	-2.95
		40	-2.39	-11.01	-4.72
100	Either	25	0	-20.89	-10.17
		40	0	-33.42	-16.27
			(D) Sawtimber		
30	Spring	25	-0.29	-1.44	-0.46
		40	- .46	-2.30	- .74
	Summer	25	- .31	-1.63	- .66
		40	- .49	-2.61	-1.06
60	Spring	25	- .88	-5.30	-2.84
		40	-1.40	-8.47	-4.55
	Summer	25	- .90	-6.88	-2.95
		40	-1.44	-8.79	-4.86
100	Either	25	- .75	-22.48	-14.30
		40	-1.20	-35.96	-22.88

Table 5—*Estimated postfire change in mountain grassland range production over time*[1]

Year	Season of fire	Elevation (ft)	ΔAUM/acre
1	Spring	≤4500	1.16
2	Spring		.25
1	Summer		.83
2	Summer		.97
1	Spring	>4500	1.25
2	Spring		.25
1	Summer		.83
2	Summer		1.08

[1]ΔAUM = 0 for years not listed.

Table 6—*Estimated postfire net value change (NVC) in mountain grassland range production*

Season of fire	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
	pct	*ΔAUM/acre*	*4 pct*	*10 pct*
Spring	25	0.36	3.51	3.48
	40	.58	5.62	5.56
Summer	25	.46	4.41	4.28
	40	.74	7.06	6.85

Table 7—*Estimated postfire change in sagebrush range production over time*[1]

Year	Season of fire[2]	Elevation[3] (ft)	ΔAUM/acre
1	Spring	≤4500	0.29
1	Summer		.13
1	Spring	>4500	.31
1	Summer		.16
2	Spring	Either	.31
2	Summer		.31
3	Spring		- .15
3	Summer		.31
4	Either		- .31
5			- .62
6			- .62
7			- .62
8			- .62
9			- .62
10			- .62
11			- .56
12			- .50
13			- .43
14			- .37
15			- .31
16			- .25
17			- .19
18			- .12
19			- .06

[1]ΔAUM = 0 for years not listed.
[2]Season of fire for year 4 and all subsequent years is spring or summer.
[3]Elevation for year 2 and all subsequent years is ≤4500 or >4500 ft.

Table 8—*Estimated postfire net value change (NVC) in sagebrush range production*

Elevation	Season of fire	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
		pct	*ΔAUM/acre*	*4 pct*	*10 pct*
Either	Either	25	-1.56	-10.38	-6.18
		40	-2.48	-16.61	-9.88

Table 9—*Estimated postfire change in pinyon-juniper range production over time*[1]

Year	Season of fire[2]	Elevation[3] (ft)	ΔAUM/acre
1	Spring	≤4500	0.10
2	Spring		.02
1	Summer		.06
2	Summer		.09
1	Spring	>4500 ft	.11
2	Spring		.02
1	Summer		.07
2	Summer		.09
3	Either	Either	0
4			− .07
5			− .14
6			− .14
7			− .14
8			− .14
9			− .14
10			− .14
11 to 20			−1.40
21 to 30			−1.40
31 to 40			−1.40
41 to 50			−1.40
51 to 60			−1.21
61 to 70			−0.85
71 to 80			−0.52
81 to 89			−0.15

[1]ΔAUM = 0 for all years not listed.
[2]Season of fire for year 3 and all subsequent years is spring or summer.
[3]Elevation for year 3 and all subsequent years is ≤4500 ft or >4500 ft.

Table 10—*Estimated postfire net value change (NVC) in pinyon-juniper range production*

Elevation	Season of fire	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
		pct	*ΔAUM/acre*	*4 pct*	*10 pct*
Either	Either	25	−2.28	−6.79	−2.36
		40	−3.64	−10.87	−3.76

Table 11—*Estimated postfire change in western hardwoods range production over time*[1]

Year	Season of fire[2]	Elevation[3] (ft)	ΔAUM/acre
1	Spring	≤4500	0.32
2	Spring		.12
1	Summer		.19
2	Summer		.34
1	Spring	>4500	.34
2	Spring		.12
1	Summer		.19
2	Summer		.35
3	Either	Either	−.07
4			−.06
5			−.05
6			−.04
7			−.01

[1]ΔAUM = 0 for years not listed.
[2]Season of fire for year 3 and all subsequent years is spring or summer.
[3]Elevation for year 3 and all subsequent years is ≤4500 ft or >4500 ft.

Table 12—*Estimated postfire net value change (NVC) in western hardwoods range production*

Elevation	Season of fire	Utilization level	Net production change	NVC (1978 dollars/acre) (rate)	
		pct	*ΔAUM/acre*	*4 pct*	*10 pct*
Either	Spring	25	0.06	0.66	0.71
	Spring	40	.08	1.05	1.14
	Summer	25	.08	.84	.87
	Summer	40	.12	1.34	1.38

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A simulation model was developed to estimate postfire changes in the production and value of grazing lands in the Northern Rocky Mountain–Intermountain region. Ecological information and management decisions were used to simulate expected changes in production and value after wildfire in six major rangeland types: permanent forested range (ponderosa pine), transitory range (Douglas-fir, larch, lodgepole pine, western white pine), mountain grassland, sagebrush, pinyon–juniper, and western hardwoods. Changes varied widely in quantity and duration among the range types. The largest decrease in net value was calculated for mountain grassland ($7/acre for a 2-year period). The largest increase in net value was calculated for a ponderosa pine sawtimber stand with 100 percent basal area removal ($36/acre for a 150-year period). The estimates calculated in this study should be useful in land and fire management planning in the Northern Rocky Mountain–Intermountain area.

Retrieval Terms: fire economics, fire effects, net value change, range management, simulation model, transitory range