Gradient Modeling: A New Approach to Fire Modeling and Wilderness Resource Management

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ABSTRACT / Managers of wilderness resources must maintain, preserve, and sometimes restore pristine ecosystems while providing for public use and enjoyment of these areas. These managers require a resource information system that can store, retrieve and integrate basic data, synthesize components to solve particular problems, and provide simulations and predictions of natural processes and management actions. Traditional information systems based on land classification and type-mapping do not provide these capabilities.

Gradient modeling, a new approach to resource management and forest fire simulation, has been developed to meet these needs in Glacier National Park. The method links four major components: (1) a terrestrial site inventory coded from aerial photographs that offers 10-m resolution; (2) gradient models of vegetation and fuel that derive quantitative stand compositional data from the parameters stored in the coded inventory; (3) a fuel moisture and microclimate model that extrapolates base-station weather data to remote sites using the parameters stored in the inventory; and (4) fire behavior and fire ecology models that integrate the data from the inventory and models to calculate real-time fire behavior and ecological succession following a fire.

Introduction

At 2:55 p.m. MDT on July 25, 1975, the dispatch radio in Glacier National Park's Communications Center came to life: "720 Control, this is 739 Swiftcurrent Lookout, with a smoke report."

"739 Swiftcurrent, this is 720 Control, go ahead."

"720, I have smoke visible on West Flattop Mountain, base of smoke is below my line of sight. Approximate location 5412 North, 280 East."

"Roger, 739, smoke at 5412 North, 280 East. KOE 720 Control at 14:56."

A few minutes later the park's aerial observer was dispatched in a Cessna 182 to check out the report. At 3:41 p.m. MDT, he verified the presence of a fire at UTM (Universal Transverse Mercator) coordinates 5414.5 North, 282.6 East, just south of Redhorn Lake.

A few years ago, the park communicator would have notified the district ranger, chief ranger, and fire control officer, who would immediately have initiated an effort to suppress the fire. But research in the intervening years has shown that fire has a natural and often beneficial role in forests. Fires can threaten life, cause erosion, and burn commercial timber, but they also increase biotic diversity, provide browse for animals, and recycle dead fuels that accumulate in northern forests, which decreases the intensity of future fires. Thus, the old policy of complete fire control is both economically unrealistic and ecologically unsound. A "let-burn" policy that ignores other management contingencies is equally unrealistic. Fire managers need to know what a particular fire will do—what its short- and long-term effects on the ecosystem will be.

A system to provide that kind of information has been operating since early 1975. To see it in operation, let us return to the July 25, 1975, Redhorn fire, which was being monitored by Glacier's Fire Ecologist. At 3:42 p.m. MDT, he telephoned an IBM 370/168 digital computer located in McLean, Virginia, using a remote terminal located at park headquarters in West Glacier, Montana. He typed in the location of the fire and the latest weather report. Two minutes later, for a cost of less than $5.00, the information shown on the following page came off the terminal (Kessell 1975a)

This information was turned over to the Park's Fire Management Specialist, who realized he had a slow-spreading, low-intensity, easy-to-control fire. Four men were dispatched by helicopter—two regular fire guards and two members of the fire ecology staff. They verified the fire's low spread rate (0 to 2.5 cm/min measured, compared to 0 to 4 cm/min predicted). Since this particular fire was not beneficial, according to the management strategy of Glacier, it was decided to suppress it. The Redhorn fire was extinguished early the following

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Welcome to the Glacier National Park Basic Resource and Fire
Ecology Systems Model, activated for the square kilometer
located at UTM 5414 North, 282 East.

Inventory analysis for hectare at 5414.5 North, 282.6 East—
this hectare has uniform site conditions and therefore is not
blocked into subunits. This stand has an elevation of 1768
meters (5800 feet) MSL. It is a sheltered slope with southeast
aspect. The slope steepness is 5 degrees. Its vegetative cover
type is shrub, and its primary succession (soil development
condition) is code 70 (mixed meadow & shrub). The stand is
mature. No other disturbances are recorded. The stand is not
affected by the Alpine wind-snow gradient.

This stand includes localized cover types, including—typical
(upright) forest which covers 10% of the stand. It has a prim-
ary succession code of 99, which is typical forest. Its contagion
value (variance / mean ratio on a 20 × 20 m grid) is 1.0. This
stand has no recorded special features.

Grandient analysis of tree species for hectare at 5414.5 North,
282.6 East—(species with a relative density of less than 1% are
not printed). Localized forest covers 10% of the stand; species
include—

Picea Hybrid Complex           With a relative density of
(spruce)                       75–95%
Abies lasiocarpa (subalpine    With a relative density of
  Fir)                         1–5%
Pseudotsuga menziesii          With a relative density of
  (Douglas- Fir)               1–5%

Gradient analysis of fuel loadings for hectare at 5414.5 north,
282.6 east—the calculated average loadings include the effects
of all localized cover.

Litter                          10.20 metric tons per hectare
Grass & Forbs                   11.62 metric tons per hectare
1 hour dead & down               0.41 metric tons per hectare
10 hour dead & down              2.02 metric tons per hectare
100 hour dead & down             3.15 metric tons per hectare
Greater than 100 hour dead       6.70 metric tons per hectare
  & down

Fire Behavior predictions for hectare at 5414.5 north, 282.6
east—
  Wind at midflame   direction of  Rate of  Flame   Intensity
       Height            Spread    Spread   Length(KCAL/MIN/
(KPH = MPH = M/MIN)               (M/MIN)   (M)     METER)

  0.0   0.0    0.0  Upslope (NW)    0.01    0.01     0.35
                    Across (NE)     0.01    0.01     0.31
                    Downslope (SE)  0.00    0.01     0.26
                    Across (SW)     0.01    0.01     0.31

  8.0   5.0 134.09  Upslope (NW)    0.04    0.03     2.23
                    Across (NE)     0.04    0.03     2.19
                    Downslope (SE)  0.00    0.00     0.00
                    Across (SW)     0.00    0.00     0.00
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day at a total size of 0.6 hectares. However, other fires may be left burning.

Glacier National Park is currently the only large wilderness area where real-time fire behavior predictions can be made (Kessell 1975a). But the kind of data retrieval, synthesis, and integration provided by the *Glacier National Park Basic Resource and Fire Ecology Systems Model* will become increasingly important to resource managers.

In order to preserve, maintain and often restore pristine ecosystems managers must have a good general knowledge of the areas, an accurate and quantitative inventory of the biota, an understanding of the interaction among the various components of the dominant ecosystems, and the ability to predict or simulate changes to the system resulting from management action.

Daily a manager must face questions such as these:

What is the distribution and relative abundance of rare or endangered species in an area proposed for recreational development?

What buildings or trails in a national park are in areas subjected to frequent flooding?

What predictions can be made for the behavior of a prescribed or natural fire? Can these predictions be generated quickly enough if fire control decisions must be reached in a few minutes? What could the fire destroy? How much fuel is present? What will be the post-fire successional communities? What is the anticipated natural fuel build-up if the fire is suppressed?

Where can stands with abundant huckleberries or other prime grizzly bear habitat be found?

Inventory and modeling systems that attempt to answer these questions must be comprehensive, flexible, and accurate. They must draw together diverse kinds of information to make predictions and they must permit selective retrieval to solve a particular problem. Finally, they must be accessible to the manager and they must be economical.

Type-mapping and land classification are the traditional approaches to resource inventories. They are usually presented in graphic form as overlay maps (reviewed in Kessell 1976; see Whittaker 1973a). But even when such maps are digitized and stored in a computer, they do not meet the requirements of a broad-based resource information system. There are several reasons why they do not:

Insufficient resolution. Overlay maps on a scale of 1:24,000 (standard 7½-minute topographic maps) do not offer the detailed resolution needed for many management purposes. Inventories often require a resolution of 20 m or better.

Incomprehensible graphic complexity. Mapping systems that have detailed resolution offer it at the expense of clarity. The old Glacier National Park vegetation map shows 21 colors and 114 special symbols. It is virtually unusable.

Inappropriate classification criteria. Habitat-type classification of vegetation must divide natural communities into discrete units. Actually, most communities vary continuously in space and time. Moreover, even the best vegetative classification is inadequate to portray fuel loadings, fuel moisture, wildlife ranges, or land use conflicts. In addition, habitat classifications do not let us make environment-biota correlations or integrate several kinds of data to solve a particular problem.

The Gradient Modeling Approach

Gradient modeling applies the techniques of gradient analysis and ordination developed over the past two decades by Whittaker, a group at the University of Wisconsin led by Bray and Curtis, and many others (Whittaker 1956, 1960, 1967, 1970a, 1970b, 1973b, 1973c; Whittaker and Niering 1965; Bray 1956, 1960, 1961; Bray and Curtis 1957; for a review of techniques see Whittaker 1973b, Whittaker and Gauch 1973). Rather than dealing with the landscape and its vegetation as sharp, discontinuous units, gradient analysis describes and quantifies continous variation in the landscape and its biota.

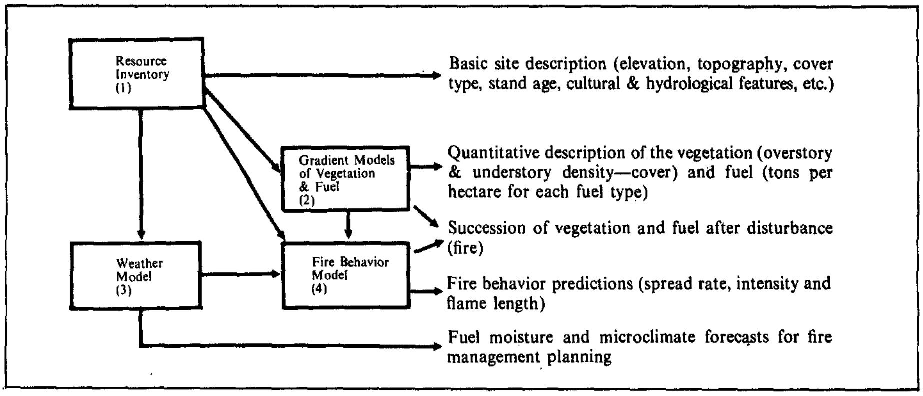


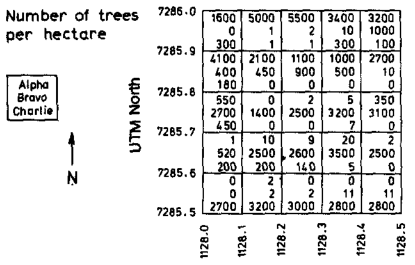
Figure 1. Flowchart of Glacier Park systems model.

The *Glacier National Park Basic Resource and Fire Ecology Systems Model* combines (1) a hectare-by-hectare resource inventory coded from aerial photographs, (2) gradient models of vegetation and fuel derived from field sampling, (3) a microclimate model, and (4) a fire behavior model (Kessell 1973, 1975b, 1976). This unique combination provides capabilities unavailable from any other resource management system. A simplified flow chart is shown as Figure 1.

Perhaps the best way to visualize the system is to consider a simplified, hypothetical ecosystem (based on Kessell 1976). A 25-hectare area of this hypothetical ecosystem is shown in Figure 2.

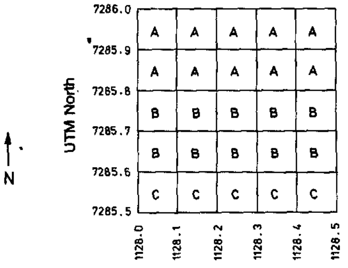
The 25 individual hectares are referenced by the Universal Transverse Mercator (UTM) coordinates at the southwest corner of each square. The land is forested, and the canopy is composed of three tree species. We will call these three species Alpha, Bravo, and Charlie. The numbers plotted in each hectare indicate the estimated number of individuals of each species.

A traditional classification by predominant overstory species, and its resulting type map, is shown in Figure 3. By introducing this classification, we lose detail and information, but if we try to show actual species diversity,



1600 0 300	5000 1 1	5500 2 1	3400 10 300	3200 1000 100
4100 400 180	2100 450 0	1100 900 0	1000 500 0	2700 10 0
550 2700 450	0 1400 0	2 2500 0	5 3200 7	350 3100 0
1 520 200	10 2500 200	9 2600 140	20 3500 5	2 2500 0
0 0 2700	2 2 3200	0 2 3000	0 11 2800	0 11 2800

Figure 2. Hypothetical forest ecosystem. Each square is one hectare (100 m = 100 m). Plotted numbers are absolute densities of each species—Alpha, Bravo, or Charlie.



A	A	A	A	A
A	A	A	A	A
B	B	B	B	B
B	B	B	B	B
C	C	C	C	C

Figure 3. Type map from classification by overstory species.

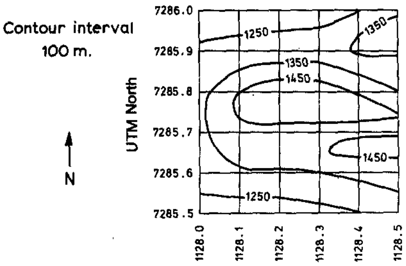


Figure 4. Topographic map of hypothetical ecosystem.

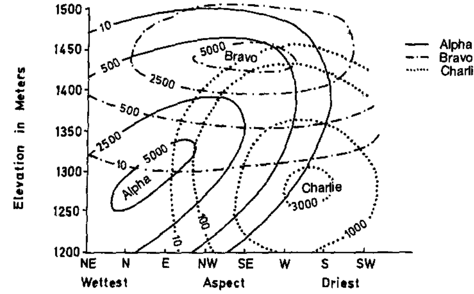


Figure 5. Gradient model for species Alpha, Bravo, and Charlie. Densities are functions of elevation and aspect. Contour lines (isodens) connect areas of equal species density. Plotted numbers give densities in trees per hectare.

we shall produce an unreadable mosaic of squiggles and quirks plotted on a topographic overlay.

As an alternative, we might classify according to underlying environmental causes of species distribution. A logical starting point would be a topographic map of the area (Fig. 4). Two environmental variables that might influence biotic communities—elevation and aspect—may be determined from this simplified map for each 1-hectare plot.

Let us use these two variables as the basis of a hectare inventory system, and record elevation and aspect for each hectare, as shown in Table 1. We shall assume that, for this simplified scheme, these two continuous environmental variables determine the biotic composition of the stands; that is, the presence or absence of each different tree species is due to some response of that species to aspect and elevation.

We now perform a gradient analysis on the area by sampling 0.1 hectare plots within the study area and recording the density of the three tree species. From this sample, we construct the population nomogram shown as Figure 5. Aspect, arranged from the wettest northeast slopes to the driest southwest slopes, is plotted on the abcissa of this nomogram, and elevation on the ordinate. Having plotted the individual field samples, we construct isodens, or lines connecting areas of equal species density. The result is a gradient model for the three species. We see, for example, that species Bravo is most abundant at higher elevations, while Alpha is most abundant at lower, wetter sites.

If we now link the gradient model to the inventory, we can predict the density of the three species in unsampled stands by using only the data presented in Table 1.

Using the hectare located at 7285.7 North, 1128.0 East as an example, the inventory in Table 1 gives an elevation of 1410 meters and west aspect. Turning to Figure 5, we find the intersection of these two points on the graph and estimate the following densities: 500 trees per hectare for Alpha, 2800 for Bravo, and 400 for Charlie. Compare these results with actual measurements given in Figure 2.

Suppose we also desire quantitative information on

Table 1 Hectare Inventory for the Hypothetical Ecosystem

UTM North	UTM East	Elevation (m)	Aspect
7285.5	1128.0	1250	S
7285.5	1128.1	1275	S
7285.5	1128.2	1290	SW
7285.5	1128.3	1310	SW
7285.5	1128.4	1340	SW
7285.6	1128.0	1370	SW
7285.6	1128.1	1400	S
7285.6	1128.2	1410	S
7285.6	1128.3	1470	W
7285.6	1128.4	1500	S
7285.7	1128.0	1410	W
7285.7	1128.1	1430	SW
7285.7	1128.2	1500	S
7285.7	1128.3	1470	S
7285.7	1128.4	1460	E
7285.8	1128.0	1330	NW
7285.8	1128.1	1360	N
7285.8	1128.2	1400	N
7285.8	1128.3	1390	NE
7285.8	1128.4	1320	NE
7285.9	1128.0	1240	NW
7285.9	1128.1	1250	N
7285.9	1128.2	1260	N
7285.9	1128.3	1290	NW
7285.9	1128.4	1370	NW

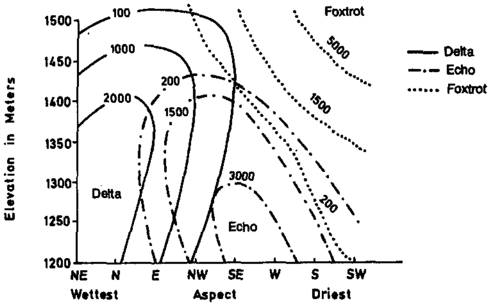


Figure 6. Gradient model for shrub species Delta, Echo, and Foxtrot.

three shrub species Delta, Echo, and Foxtrot. We construct a gradient model for them based on field sampling as shown in Figure 6. We can now use the same inventory (Table 1) to predict their species composition. For hectare 7285.7 North, 1128.0 East, we predict a density of less than 100 shrubs per hectare for Delta, 150 for Echo, and 1,000 for Foxtrot.

The above examples, with only two environmental gradients and three species, need considerable expansion and refinement for application to a real wilderness system. Yet the reader will see that the actual Glacier National Park model is simply a logical expansion of this basic approach.

The Glacier National Park Model

Situated along the continental divide in northwestern Montana, Glacier National Park is an area of spectacular alpine scenery and diverse habitat. Over 1,000 species of vascular plants are present (Kessell 1974). Communities range from xeric prairie intrusions and remnants to alpine tundra, from ponderosa pine savanna to mesophytic cedar-hemlock (*Thuja plicata-Tsuga heterophylla*) forests. They are further complicated by such natural disturbances as fires, slides, fellfields, and avalanches, and by patterns resulting from hydric, glacial, and floodplain successions.

Fire played a critical role in shaping the forests of the lower elevations and drier sites; man's suppression of fire over the past several decades has led to vegetation changes and unnatural fuel buildups (Kessell 1976; Habeck 1970a, 1970b). Heavy fuel buildups following many years of fire suppression may result in more destructive fires later. An immediate effort must be undertaken to restore natural fire to the park.

It is obvious to many managers that some fires should be allowed to burn while others should not. But which fires should be suppressed? As we have seen, computer models can be quite helpful in deciding this question, but first we need to develop background information.

Gradient Models of the Vegetation and Fuel

The gradient models of Glacier's vegetation and fuel are derived from more than 2,000 field samples taken between 1972 and 1975 (Kessell, Dwyer and Colony 1975). Overstory species are recorded by density and basal area, understory species by total cover, and fuel loadings by dry weight per unit area for each category—live or dead—and size class. An expansion of the planar intersect method was used. Detailed site descriptions and UTM coordinates are recorded for each sample.

Analyses of the field data revealed ten major environmental influences on the Glacier Park communities. They are:

1. elevation
2. topographic-moisture (topography and aspect)

3. primary succession (soil development following glacial retreat and rock weathering)
4. watershed (drainage) area
5. alpine wind exposure and snow accumulation
6. secondary fire succession (time since the last burn)
7. intensity of the last burn
8. slide, fellfield and avalanche areas
9. hydric successions
10. heavy ungulate winter use.

If our computer inventory was to have at least as much accuracy as normal within-stand variation found from field sampling, the first six effects would have to be treated as continuous, environmental gradients, while the latter four could be treated as discrete categories. Knowledge of a stand's location on each gradient and within each category would then allow prediction of its vegetational and fuel composition without an actual visit. As it turned out, predictions are within sampling error for about 93 percent of the several hundred stands test-predicted by the model.

It is difficult to plot a six-dimensional diagram on two-dimensional paper. However, we may hold several gradients constant and view the effects of varying any two at a time. Some real examples are shown in Figure 7 for the McDonald drainage (from Kessell 1976). Figure 7a shows a mosaic classification of mature forest communities in terms of the first two gradients, elevation and topographic moisture. Figure 7b plots the distribution of *Abies lasiocarpa* (subalpine fir) in mature stands on these same two gradients; the isodens connect areas of equal relative density.

Figure 7c holds elevation constant and plots time-since-burn against topographic-moisture for *Pinus contorta* (lodgepole pine). The seral nature of *Pinus contorta* is clearly shown; its peak density occurs about 25 years after a fire on the driest sites. Its short lifespan is shown by its total replacement within 150 years after the burn. By contrast, Figure 7d plots the relative density of *Tsuga heterophylla* (western hemlock) on the same two gradients as 7c. Here we see a "climax" species that first enters a stand about 50 years after a fire, and does not reach peak density until nearly 200 years after the burn.

Figure 8 plots the loadings in metric tons dry weight per hectare of two fuel types in mature forested stands along moisture gradients. (Fuels are classified by their time-lag in responding to a humidity change. One-hour fuels are sticks less than 0.64 cm diameter; 10-hour sticks range from 0.64 to 2.54 cm diameter. Dead and down refers to dead material that has dropped to the

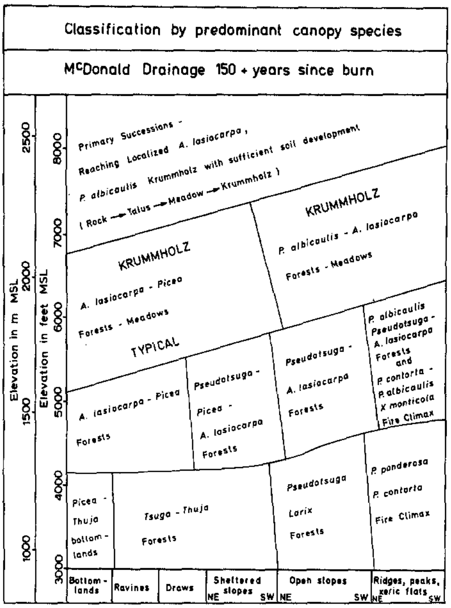


Figure 7a. Classification mosaic of mature, forested stands plotted on elevation and topographic-moisture gradients.

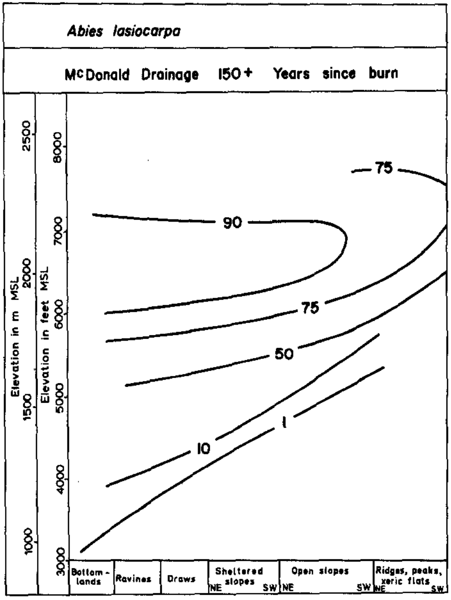


Figure 7b. Gradient model for mature, subalpine fir.

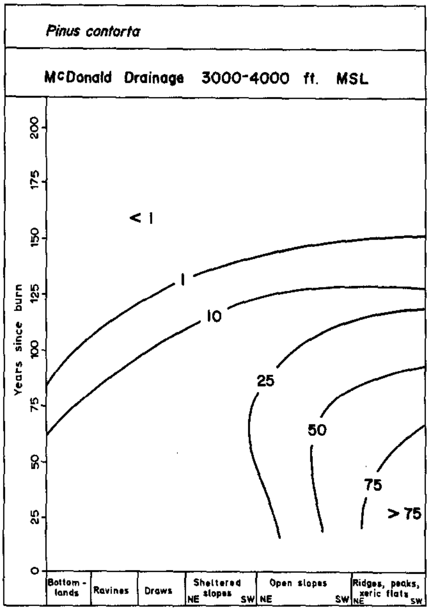


Figure 7c. Gradient model for lodgepole pine.

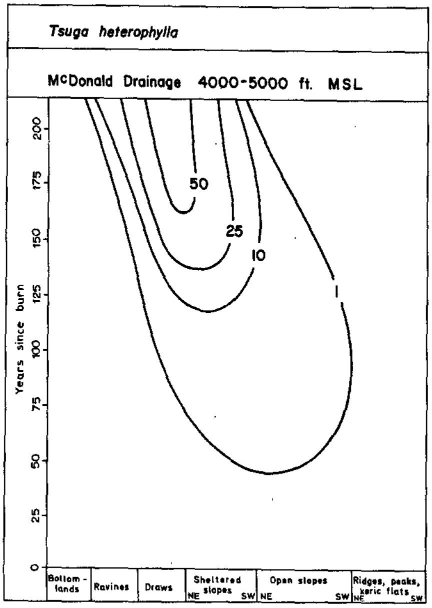


Figure 7d. Gradient model for western hemlock.

forest floor.) We observe peak loading of the 1-hour fuels on slopes in forests between 1,700–1,900 m in altitude and again below 1300 m. Ten-hour fuels peak on the 1,400–1,600 m slopes.

Figure 9 shows the response of six fuel types to the time-since-burn gradient for slopes at 1,000 m. Note that after 100 years of age, a stand's fuel continues to increase at the rate of about 1 ton/hectare/year indefinitely. Suppression of natural fires allows this build-up to continue unchecked, leading to fires with higher intensities and greater destructive potential in the future.

Several hundred illustrations would be required to show the response of all species and fuels to all gradients. It is hoped that these samples convey a feeling for the distribution of plants and fuels along gradients.

As noted above, the gradient models can predict quantitative plant and fuel composition for each stand if one knows the stand's location along each gradient and within each category. We designed an inventory system to determine location by using aerial photos (false color infrared obliques and vertical black and white), topographic maps, and fire history maps (Dwyer and Kessell 1975). The system permits 10-m resolution within each hectare, and also records hydrological or cultural features.

Within-hectare resolution is provided by two methods. For major discontinuities along any gradient, such as ravine-slope in topography, or forest-meadow in cover types, a separate record is used for each portion of the hectare. If the discontinuities are under 20 m, a scattering of rock outcrop or shrubs on a meadow, for example, the percentage of overall cover occupied by these localized types is recorded, along with a measure of their "clumpedness" (variance/mean cover ratio on a 20 × 20 m grid). See the reference to localized trees in the computer readout on the Redhorn fire given earlier.

By combining the inventory and gradient models we can also predict the succession of plants and fuels following a fire (Kessell, Dwyer and Colony 1975). When a stand burns, its age in the computer inventory reverts to zero. The model may solve for different values along the time-since-last burn gradient, and thus predict composition at any age after the fire.

As examples, compare Figure 7c (lodgepole pine) and Figure 9 (slopes/fuels). For a 1,000 m elevation, south aspect open slope, we predict that 30 years after a burn lodgepole pine density will be 60 percent, litter loading will be 1.4 tons/hectare, 100 hour dead-and-down loading will be 28 tons/hectare, and so on. Stochastic ele-

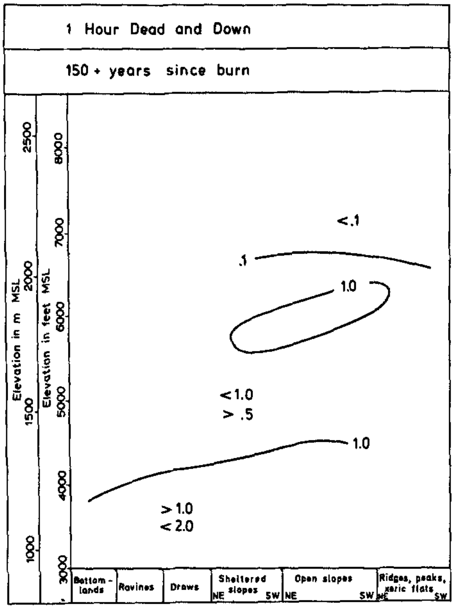


Figure 8a 1-hour fuel loadings on elevation and topographic moisture gradients. Loadings in metric tons dry weight per hectare. Isodens connect areas of equal fuel loadings.

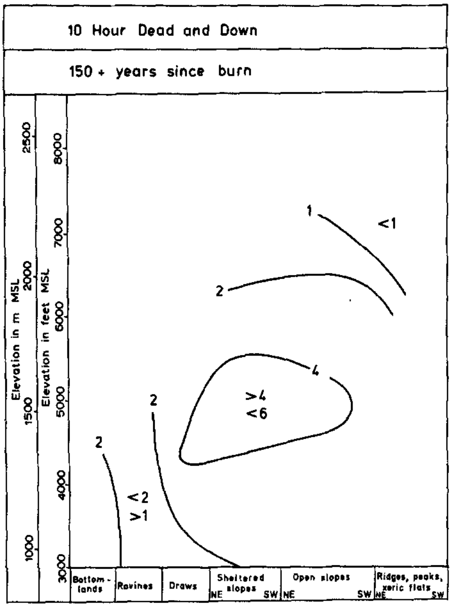


Figure 8b 10-hour fuel loadings.

ments influencing succession are being considered but have not yet been incorporated into the model.

Fire Behavior Models

Recent advances in modeling the behavior of forest fires enable us to predict the spread rate and intensity of fires if we know certain properties of the fuel and the conditions under which it will burn (Rothermel 1972). For example, it is necessary to know the total dry weight, the degree of compaction for each combustion and size category, and the mineral and moisture content. It is also necessary to know the wind speed and direction, and the steepness of slope. All of the required parameters have either been derived by empirical studies (e.g., Rothermel 1972) or may be retrieved from the gradient models.

If we now take slope steepness derived from the inventory, solve for fuel loadings and packing ratio by linking the inventory with the fuel gradient models, enter current measured wind speed and fuel moisture from the nearest weather station, we can calculate fire spread rate and intensity, hectare by hectare. We may also calculate flame length (FL) by

$$FL = a\ IB^{b}$$

where IB is the intensity per unit length (not area) of fireline per unit time, and a and b are constants. From here we may calculate scorch height (height above the ground where living foliage will be killed), probability of a fire igniting the forest crown, and other parameters.

A major limitation of the Rothermel fire behavior model is its necessary assumption of a uniform horizontal and vertical spatial distribution of fuels. However, the Glacier group, in cooperation with William Frandsen and Richard Rothermel at the Northern Forest Fire Laboratory, is circumventing this problem in the following way. A system of grids 2 m across is mathematically imposed on the fuel array. It is assumed that the fuel is uniformly distributed within each grid cell. But one may assign, stochastically, different quantities of fuel and different packing ratios, to each cell. This assignment is based on the actual measured contagion of localized cover (from the inventory) and the field measurements of fuel loadings by category and size class.

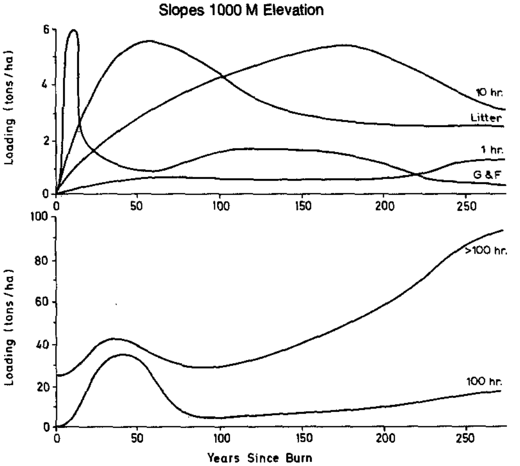


Figure 9. Distribution of six fuels along the time-since-burn gradient at 1,000 ms. Fuels are 1-hour and 10-hour dead-and-down; 100-hour dead-and-down (sticks between 2.54 and 7.62 cm diameter); greater than 100-hour (sticks over 7.62 cm), standing grass and forbs, and litter.

In this fashion, one may calculate the spread rate and heat flux for each grid cell and simulate the behavior of a fire through a nonuniform fuel array. The limiting assumption of a uniform, vertical fuel distribution is being solved at Glacier by developing a multistrata fuel model. Each stratum has an individual fuel loading, packing ratio, and moisture content (Bevins, personal communication).

A new addition to the Glacier package is a microclimate and fuel moisture model (Mason and Kessell 1975). It is designed to extrapolate base-station fuel moisture and weather information to remote sites having different elevations, topographies, aspects, and cover types, through empirical regressions using the site parameters recorded in the resource inventory. It is currently operational for one large drainage area in the park.

Work is currently underway to develop gradient models of important mammal species in Glacier, including grizzly and black bears, white-tailed and mule deer, elk, moose, mountain goats and bighorn sheep. Results show that the vegetation-fuel gradient, supplemented by slope steepness and winter snow depth, may be used to quantify winter ungulate ranges (Singer, Kessell, and Ackerman, in preparation). This information is being integrated with the fire model to predict animal populations in a given region following a real or projected burn.

The entire model is written as a single FORTRAN IV G1 program using numerous computational and input/output subroutines. With subroutines, its length is about 4,500 lines. It is currently being run on an IBM 370/168 VS system under IBM 370 JCL.

Execution of the program, entry of all specifications and options, job submission, and output retrieval are accomplished through a series of instructions that closely simulate interactive FORTRAN. The user gives English language commands, answers "yes" or "no" to various options, enters UTM coordinates and weather parameters, and sets job priority. Personnel with no computer training can be taught to use the system in a few hours. A *User's Manual* is available (Kessell 1975a).

The cost of implementing the model for an area over 250,000 hectares is about $1 per hectare. This cost is comparable to many type-mapping systems that offer considerably less capability, flexibility, and precision. The money saved by not suppressing a single, major fire that would have been suppressed previously but need not have been, would pay for our entire model development program. The Glacier National Park model is a prototype. Currently, the National Park Service is evaluating its application to other areas.

Copies of programs, data files and documentation, and a *Systems Manual* are available.

Conclusions

New modeling methodology and the availability of computer services to remote natural and wilderness areas are revolutionizing traditional wilderness resource management. Data retrieval, simulation, and modeling capabilities are now available that were undreamed of by ranger and management personnel even a decade ago.

Some managers welcome the new systems and are excited by their applications. Others are interested but skeptical. Still others see computer modeling as anathema to wilderness.

Yet our nations must preserve our wilderness heritage. To do this, we cannot lock the public out of national parks and wilderness areas. The never-ending conflict between preservation and use demands ever more competent managers. New modeling methods are invaluable tools for improving the quality of natural resource management.

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