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Use of Fire in Land Management

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I. Introduction

Preceding chapters have documented in detail the physical, chemical, physiological, ecological, meteorological, and other environmental effects of fire on biomes of the world. The reader has been made aware that fires ignited by natural forces or sources have exerted a profound influence on vegetation (or fuel) types of the world. Wherever or whenever suitable combinations of fuels, burning conditions, and ignition sources have existed concomitantly, vegetation has burned. The corollary is that plants and animals must be adapted in various ways to fire (since they would not exist today if not adapted), and the question arises: "Has man, either ancient or modern, been able to adapt or utilize effects of fire on vegetation to his advantage?" Obviously, "Yes," but asking unqualified questions and obtaining unqualified answers may not produce much new information. The more difficult question becomes: "Has man been able to use fire for his purposes without degrading the particular ecosystem he is trying to manage?" Here the answer equivocates, "Yes and no," depending on objectives of management and burning techniques employed.

Ancient man of course was not concerned with management objectives. If the fire he lit to facilitate gathering of honey contributed to his survival, then concomitant forest destruction was irrelevant. The need by modern man for limited (versus unconstrained) management objectives gave rise to the concept of using controlled or "prescribed" fires to attain the beneficial effects of fire, while avoiding the harm of uncontrolled conflagrations. Prescribed burning has been defined by the Society of American Foresters (1958) as: "Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc., that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc." As such, this definition includes "controlled burning" as used in North America, "control burning" in Australia (Hodgson, 1968), "veld burning" in Africa (Phillips, 1965), "muirburn" in Scotland (Gimingham, 1956), or "swaling" in Finland (Viro, 1969). The definition is sufficiently broad to cover all aspects of land management with fire, and the terms are used interchangeably throughout the text.

Since the ecosystems man wishes to manage or manipulate are exceedingly complex, it follows that prescriptions for wise and intelligent use of fire will also be complex, utilizing a host of interacting factors which are not well understood singly, let alone collectively. This understanding will undoubtedly increase with appearance of articles on the utility of properly managed fire in popular magazines (cf. Cooper, 1961; Kilgore and Briggs, 1972; Ternes, 1970) and the commissioning of reports by municipal governments (Boughton, 1970).

In technical journals, a different circumstance exists. As observed by Smith (1970): ". . . There is no shortage of literature on controlled or prescribed burning. . . ." Comprehensive documents or lists have been prepared by many authors for various geographical locations or management objectives. In North America literature on the effects of forest and range fires has been assembled by the Canadian Forestry Service (1950–1972, 1969), Cushwa (1968), Hostetter (1966), Ramsey (1966–1971), and Shipman (1970). Many symposia on fire, including prescribed fire, have been held recently, including "The Role of Fire in the Intermountain West" (Intermountain Fire Research Council, 1970), the "Prescribed Burning Symposium" (U.S.D.A. Forest Service, 1971), "Fire in the Northern Environment" (Slaughter *et al.*, 1971), and "Fire in the Environment" (U.S.D.A. Forest Service, 1972).

Proceedings of the eleven Tall Timbers Fire Ecology Conferences have contributed much to the understanding and use of prescribed fire in American ecosystems, and lately, in Canadian (1970) and African (1971) contexts. In Africa, literature has been collated and reviewed by Phillips (1965) and West (1965, 1971), in Australia by Hodgson (1967), McArthur (1962), and Vines (1968), in tropical ecosystems by Bartlett (1955, 1957, 1961), and in Europe, with particular reference to the management of *Calluna* heathland, by Gimingham (1972). Obviously the foregoing is incomplete: both for the areas or management objectives listed and more particularly, for the areas not mentioned, Asia and South America where no doubt fires occur and are used. Shostakovitch (1925) outlined some forest conflagrations in Siberia in 1915 and mentioned the use of fire for manipulating grass meadows and driving game, and Batchelder (1967) remarks on the ubiquity of fire in South America.

Similarities in the nature and use of fire in various fuel types of the world enable general descriptions and evaluations to be made, but the reader is cautioned against taking the general and applying it to the specific without first thoroughly analyzing local conditions and objectives.

II. Historical Uses of Fire

Anthropologists differ slightly on their estimates of when man first started to use fire. Ardrey (1961) reported some inconclusive evidence from Central Africa indicating that man used fire 800,000 years ago, while Stewart (1963) and Johnston (1970) indicated that man probably used, "kept," and controlled fire for more than 500,000 years. The differences may not be too significant because, more importantly, primitive man did not exert his maximum influence on the vegetation of the world until he learned to produce and use fire 10 to 20 thousand years ago (Johnston, 1970; Phillips, 1965; Stewart, 1963; West, 1971). Stewart (1963) suggested there is a massive amount of evidence that primitive man, with fire as a tool, has been the deciding factor in determining and maintaining the fire subclimax types of vegetation covering one-quarter of the globe. Komarek (1967) disagreed, stating that lightning fires over long periods of time created vegetation "fire mosaics" that man undoubtedly changed by his activities, but such mosaics existed before the advent of man and would continue to exist in his absence. Of course, ancient or aboriginal man was not concerned with, nor interested in, vegetational mosaics. His task immediately at hand was to provide fire for warmth, cooking, attracting game, improving pasture for wild and domestic animals, improving visibility, and aiding travel in grassland, savanna, and forest, hunting and safety, and for promoting growth of nuts, berries, seeds, etc., for food. Fire was also an indispensable adjunct to shifting tropical agriculture, and occasionally fire was used in warfare.

Accounts of early explorers frequently describe the prevalence of vegetation which had been or was being burned by native peoples. In eastern North America, various accounts are available on the openness of eastern forests and the existence of prairie islands surrounded by forest cover (Johnston, 1970). Stoddard (1962) stated that native peoples and early settlers alike used fire liberally and had no doubts as to its necessity and effectiveness for raising livestock and farming activities. Komarek (1965), in support of his thesis that man is a grassland hominid, drew attention to the "popping" characteristic of certain grasses, the popped kernel of *Tripsacum* spp. being almost indistinguishable from open pollinated strawberry popcorn (Komarek, 1965, p. 216). This characteristic could not have gone unnoticed to primitive peoples. On the Gulf of Mexico coast, a Spanish soldier who survived shipwreck in 1528, told of the Indians firing the plains to destroy mosquitoes and to compel deer and other animals to forage within range of hunters (Johnston, 1970). Indians also set large circular fires in flat grassy spots, letting the fires burn slowly toward the center where a hole had been dug to catch the roasted grasshoppers (Johnston, 1970).

In Africa, West (1965) found the earliest reference on occurrence and use of fire to be apparently the "Periplus," an account of a voyage by Hanna the Carthaginian along the west coast in 600 B.C. West (1965) continued with an interesting account of observations by various early explorers, missionaries, and hunters. In the latter part of the nineteenth century, almost every country which was visited and described by the many explorers of the "dark continent" showed evidence of deliberate burning by the natives.

Stokes (1846) in "The Voyage of H.M.S. Beagle" gave this description of aborigines intentionally firing the country near Albany, western Australia:

> . . . we met . . . natives engaged in burning the bush, which they do in sections every year. The dexterity with which they manage so proverbially a dangerous agent as fire is indeed astonishing. Those to whom this duty is especially entrusted, and who guide or stop the running flame, are armed with large green boughs with which, if it moves in a wrong direction, they beat it out . . . I can conceive no finer subject for a picture than a party of the swarthy beings engaged in kindling, *moderating*, and *directing* the destructive element, which under their care seems almost to change its nature, acquiring, as it were, complete docility, instead of the ungovernable fury we are accustomed to ascribe to it . . . [italics by A. J. K.].

Wharton (1966) wrote of Cambodia:

> . . . About 500 years ago a civilization . . . said to dwarf the wonders of Egypt, Greece and Rome laid down its arms and entered a non-martial and non-material period . . . much of the environment that once supported immense cities and armies was abandoned to a few scattered villagers who, with the aid of the agency of fire, have since maintained . . . one of the last great refuges for herbivorous mammals in all of southeast Asia . . . .

Techniques of slash and burn used in Cambodia are similar to those used in the Central Americas as described by Budowski (1966) and covered exhaustively for all the tropics by Bartlett (1955, 1957, 1961).

It is apparent that fire has been used by primitive man whenever and wherever natural fuels would burn and firing techniques must have been simple. The relatively low intensity single purpose grassland and bushland fires would have required little preparation, and if the fires became intense or burned into adjacent forest, the effects may have been considered beneficial, albeit unplanned. But with advent of modern multiple-use and multiple-value concepts, and the increased pressures of man on a limited, finite resource, it has become essential not only to employ fire, but also to do so in a controlled fashion on a predetermined area for one or more specified objectives.

III. Current Uses of Fire

In applying fire as a management tool in complex biological systems, increasing attention has been given to analyzing the various components of the system, evaluating the consequences of invoking steps to achieve management goals, and then devising procedures to attain those goals. The analogy has been drawn with a patient being diagnosed for an illness and having the ingredients of a cure being put together in the form of a prescription. Prescribed burning has been used in an attempt to encompass all of the factors involved in using fire effectively, efficiently, and safely in the management of natural ecosystems.

A. Purposes of Prescribed Burning

Reasons for using prescribed burning are almost as varied as the fuel types in which fire may be a suitable management tool, but in the elaboration of these reasons by various authors (Campbell, 1960; Davis, 1959; Foster *et al.*, 1967; McArthur, 1962; Scott, 1947; West, 1965; Whyte, 1957) there is a marked thread of similarity which is almost independent of fuel type or geographical location. These purposes can be related to the various fuel types being considered, i.e., natural pastures, grasslands, savannas, shrublands, tropical or temperate forests, etc., and include the following:

1. To remove unpalatable growth remaining from previous seasons
2. In some limited instances, to stimulate growth during seasons when there is little green grazing (a practice strongly criticized by Scott, 1947)
3. To control or destroy insects and diseases
4. To control the encroachment or development of undesirable plants and encourage desirable food plants such as legumes for both forage and soil improvement, or shrubs for berry production
5. To aid in the better distribution of animals on a range or management unit, including bird habitat
6. To remove accumulated fuels occurring naturally or as a consequence of logging or cultivation
7. To stimulate seed production or opening of cones and prepare seedbeds for seeding, either naturally or artificially
8. To establish fire breaks in a system of protection from wildfire
9. To provide training for fire fighters and fire researchers

B. Techniques of Prescribed Burning

Techniques of prescribed burning or "fire management" (the title of this chapter is something of a misnomer in that it is application of fire to manage what is on the land, rather than the land itself) vary tremendously depending on the purposes of management and the many factors considered prior to actually igniting a blaze. The necessity for planning is emphasized by all authors (Beaufait, 1966; Davis, 1959; Bonninghausen, 1962; Haddon, 1967; Hodgson, 1967; McArthur, 1962; Vines, 1968; West, 1965). The amount of planning required may be roughly proportional to the intensity of fire expected. Thus a knowledge of fire behavior is intrinsic to developing and applying prescribed burning techniques. Included are data on available fuels, their size and spatial distribution, meteorological controls, use of head-fires (burning with the wind,) or back-fires (burning against the wind), and data on the physical, physiological, and ecological effects of fire. For example, use of fire in Africa to manage a mixed forest–grassland for grazing and browsing by domestic or wild animals could be at the expense of the forest (West, 1965), and must be recognized in the burning prescription.

1. *Grasslands and Savannas*

Although there is not a balanced amount of world literature on the subject, fire has been used in the management of grasslands and savannas in all tropical and temperate regions of the world (Batchelder and Hirt, 1966; Budowski, 1966; Daubenmire, 1968; Humphrey, 1963; Phillips, 1965; Smith, 1960; Vogl, 1965; Wharton, 1966; West, 1965, 1971). Batchelder (1967) pointed out ". . . in South America, so unbiquitous is fire, that very few specific references describe in detail the times or purposes of burning. . . ." Detailed descriptions of burning techniques are almost equally scarce, but the following outline is representative.

Using suitable ignition sources, including matches, fire brands, or diesel oil burners (pressurized or gravity feed), areas are lit at suitable intervals (annual, biannual, half-decade) during the dormant season. Burning late or early in the season will depend on management objectives. For example, in Zambia where rainfall is high (40–50 inches/year), annual, late, high-intensity burning near the end of the dry season has transformed well-developed woodland and coppice woodland into grassland with the woody species persisting below the level of grasses. Annual, early, low intensity burning as early as possible in the dry season has maintained the woodlands in a slightly thickened condition (West, 1965) and similar effects have been noted in Nigeria (West, 1965). This type of burning removes the top layer of litter but heat does not penetrate into the ground to any appreciable depth to kill the roots. However, burning too frequently can engender depletion of root reserves, leading to death of the desirable grasses and invasion of the site by less palatable, but more fire-resistant or heat-tolerant species. Both backfiring and head-firing techniques are used, the latter probably being more common because burning of a specific area can be accomplished more quickly. Where graziers or ranchers are apprehensive about controlling rapidly advancing high intensity head-fires, nighttime ignition may be used.

In tropical American lowlands fire is used in management of natural grassland and in "slash and burn" agriculture, but little information on techniques is available (Budowski, 1966). Similar circumstances exist for such areas as Cambodia (Wharton, 1966) and northern Australia (Smith, 1960). Burning techniques similar to those employed in Africa are likely used for various stated or implied objectives.

Grasslands in the United States have been extensively investigated (cf. Chapter 5). Daubenmire (1968) reviewed characteristics of grassland fires and their effects on the ecosystem, but the simple nature of grassland-burning techniques understandably has not sponsored a similar review. Despite careful definition of grassland-burning objectives, detailed plans and procedures are not as common as with prescribed burning of forest lands. This lack is probably a reflection of the relatively lower intensity of grassland and shrubland fires and the ease with which they may be lit and controlled. However, more planning and research would help preclude "excursions" by prescribed fires. Furthermore, research is needed not only on the effects and use of fire, but also on techniques of burning, i.e., management *of* fire as well as management *with* fire.

2. *Shrublands*

Burning techniques in dwarf shrub communities are similar to those employed in grasslands and have been briefly described by Kayll (1967) and Miller (1964). An estate gamekeeper, using a diesel oil burner to start the fire and a traditional "broom" (usually a birch stem about 10 ft long, weighing up to 20 lb with a loop of chicken wire at one end) to control its edge, attempts to burn on a cycle of 12 to 15 years. Head-fires are commonly used with previous burns, woods, trails, waterways, etc., serving as firebreaks. The management objective is to obtain a patchwork quilt effect of regenerating (recently burned) and maturing heather. Where stands become older than 20 to 25 years, back-burning may be needed to consume the somewhat clumped and discontinuous fuels. Similar burning is practiced by commercial blueberry growers, but the cycle is shorter. Ocassionally straw is scattered to facilitate fire spread.

3. *Forest Lands*

The greater significance attached to forest fires is reflected in the number and scope of publications dealing generally with the subject and dealing specifically with planning and use of prescribed fires. In the United States Bonninghausen (1962), Beaufait (1966), and Davis (1959) gave detailed descriptions. Similar works have been produced in Canada by the British Columbia Forest Service (1969) and Haddon (1967), and in Australia by McArthur (1962) and Vines (1968). All emphasize the necessity of coupling good planning with experience and sound common sense in order to achieve effective and efficient prescribed fires.

a. SOUTHEASTERN UNITED STATES. In the United States, prescribed burning may have had its start in the Southeast (Riebold, 1971). Over the years, the practice has produced many detailed but flexible plans for implementing burning prescriptions. Assuming management objectives can be achieved by using fire, existing barriers such as roads, waterways, and significant fuel discontinuities (e.g., a recently plowed field) are utilized in preparing an area for burning. Some areas may require parallel fire breaks (plowed or existing lines) within the compartment to facilitate ignition (Bonninghausen, 1962; Davis, 1959). Deciding when to burn, including time of day, season of year, and frequency, depends on the stated management objectives, fuel characteristics (e.g., grass under a forest overstory versus slash on a cutover), and meteorological factors. For example, burning for wildfire control (hazard reduction) purposes may be done at 3- to 6-year intervals (sometimes longer), back-fires or head-fires may be used alone or in combination, and winter burning may be preferred to take advantage of the prevailing lower ambient air temperatures (Wade, 1969).

Using simple drip torches for ignition from established fire lines or occasionally spotted at intervals by walking into a steady wind of 5 to 10 mph, small crews of 3 to 6 experienced men can burn 300 to 1000 acres in one day. For control, water backpacks and hand tools are usually immediately available with heavier mechanical equipment on local standby.

b. Eastern Canada. With superficially similar forests, but distinctly different climatic and silvicultural conditions, prescribed burning in jack pine (*Pinus banksiana*) management in Canada has the following characteristics (Adams, 1966; Foster *et al.*, 1967). Burns are on cutover compartments subdivided by plowed furrows into blocks of 6 to 20 acres. Preburn planning includes preparing guidelines, preparing sketch maps showing existing roads and water courses ("safe edges"), locating new 10-ft-wide fire lines, and felling of all trees up to 100 ft inside the perimeter. Fuels should be more or less continuous and have a moisture content of less than 20%. Burning in midafternoon with a relative humidity less than 40% and a wind of 8 to 10 mph is preferable. Ignition procedures are similar to those used in the southeastern United States, but rather more men and equipment are utilized because of the generally higher fuel loadings and relative infrequency of burning, perhaps once every 30 to 50 years. (As a general rule, the higher one's latitude, the less frequent is the occurence of natural fire on any given area, the less frequent should prescribed fire be used, and days suitable for prescribed fires are also less frequent.) Where a mineral seedbed is desired, an intense fire is needed, which in turn requires a lengthy drying period. Thus fuels outside the perimeter of a prescribed burn may be hazardous to the point of needing wetting down. Crews of 16 to 20 men, with two-way radio communication and equipped as torchmen, patrol-men, and tanker crews, may burn 200 to 300 acres in a day.

c. Western United States and Canada. Where fuel concentrations become heavy and slopes steep, comprehensive planning for the use of fire becomes critical, especially if benefits are to be commensurate with costs. Burning in the mountainous regions of the western United States and Canada has been largely for reduction of wildfire hazard and site preparation after the merchantable timber has been removed. Removal of residual logging debris (slash) by prescribed burning (slash burning) has been used in western North America since 1910 (LeBarron, 1957), has been recommended in the Vancouver Forest District of British Columbia since 1912 (Smith, 1970), and has been required by law in the District since 1939 (Haddon, 1967). Although first used for hazard reduction purposes, prescribed fire is being increasingly used in silviculture, in habitat manipulation, and in maintenance of wilderness and parklands. Details on burning in western North America have been provided by Beaufait (1966), British Columbia Forest Service (1969), Davis (1959), Emrick (1967), Murphy (1967), and Zwolinski and Ehrenreich (1967).

Slash is usually "broadcast" burned, i.e., burned where felled or lying on the ground after logging. Occasionally, in particularly difficult circumstances, slash may be machine piled or windrowed before burning. Burns are usually conducted in the autumn while the slash still has needles, with compartments laid out prior to logging to take advantage, where practicable, of natural barriers. These barriers are supplemented by bulldozed fire lines one or two blade-widths wide to create blocks of 10 to 400 acres, with an optimum of 100 to 200 acres. Detailed maps and plans are prepared and all crewmen instructed prior to ignition. Ignition times ". . . should be determined by the job, not the clock . . ." (Beaufait, 1966; Beaufait and Fischer, 1969), and thus according to localities and fuel types, ignition time may range from early morning to late afternoon. Desirable winds range from calm to 10 mph, depending on ignition techniques and devices being used, the latter being selected for speed and flexibility. Strip and center ignition patterns are used, the latter providing a strong central convection column which draws air to the center of the fire, enables area ignition (lighting up the area more or less at once), and lifts the smoke to high elevations. Plans are made such that compartments may be burned in one day. Mop-up and patrol after the fire are essential.

d. Australia. Burning techniques similar to those used in western North America have developed in Australia and are thoroughly described by McArthur (1965), although the emphasis in this case is on the use of prescribed burning for reduction of wildfire hazard on a broad area basis. Developing techniques have led to the use of low flying aircraft and small cheap incendiary capsules to ignite up to 10 thousand to 15 thousand acres in one afternoon (Vines, 1968). The object is to reduce the amount of flammable fuel over a broad area and thus lessen the intensity of a wildfire burning during hot, dry, windy weather. On the flat terrain of western Australia, grid flight patterns are flown, but over more mountainous areas, aircraft fly along contours, igniting the ridgetops first in the sequence (a pattern often used in North American forests). Properly executed, the resulting low intensity fires do little damage to the overstory, protection against damaging wildfires is effective, and costs are commensurate with benefits: about 10 cents per acre, including total costs of preparation of fire guards, burning plans, mobile radio beacons, and aircraft time. Each area is burned on a rotation of about 5 years.

IV. Examples of Use of Prescribed Burning

In eucalypts and in other fuel types of the world, it is more difficult to begin controlled burning than to continue the practice. But irrespective of fuel type, as more is learned about managing fire, increasingly sophisticated and subtle burning techniques are being employed to manage natural resources. But as several authors (Austen, 1971; Hodgson and Heislers, 1972; Scotter, 1971) pointed out, fires are not equally useful for all species and the choice of using fire infers disadvantage as well as advantage (as does any other management technique).

The underlying principle in the use of fire in land management is the manipulation of a biological system on a particular land form. Management of grasslands, savannas, and shrublands with fire is usually for a secondary purpose, i.e., to provide browse and cover for domestic or wild animals. Using fire in the management of a forest for fiber or wood production differs basically because of the intrinsic value of the wood. Obviously, the integration of all interactions cannot be achieved with single purpose management concepts. It is only for ease of discussion (or administrative reasons) that we categorize types of prescribed fire use. But just as fire crosses all the artificial and somewhat arbitrary disciplinary boundaries we sometimes establish, so must its uses and implications be examined in what Phillips (1965) has termed a "holistic" approach. Advocates of the wise use of fire as a management tool maximize the advantages and keep the disadvantages at a level tolerable to the ecosystem in question. Unacceptable disadvantages, or alternatives which maximize advantages better, may preclude the use of prescribed fire. On the other hand, fire should not be rejected as a suitable management tool without thorough, comprehensive analysis.

A. Grasslands and Savannas

Whether in the Northern or Southern Hemisphere, most authors agree that late spring is the most beneficial time to burn for stimulation of grass production. In the United States in Kansas, Anderson (1964) makes the following general recommendations:

1. Burn only in late spring (when plants are best able to recover quickly).
2. Burn only when the soil and plant crowns are damp after a rain (to minimize heat penetration to protected growing points).
3. Burn when there is a breeze to move the fire along quickly.
4. Avoid close and early grazing after burning (to allow plant stocks to establish food reserves).

The last point is particularly important because the interaction of fire and grazing can have a profound effect on the health and vigor of rangeland or "veld." Clements (1949) stated most clearly ". . . If not too frequent, it [fire] affects grassland little, but the reaction value of grass may be seriously reduced or almost destroyed by overgrazing . . ."

In Wisconsin, Vogl (1965) recommended spring burning of the tall grass brush–prairie savanna. The resultant green herbage with its higher moisture content is more productive, palatable, and desirable to herbivores. Periodic burning, up to once every other year, prevents the prairie savanna from becoming decadent, helps maintain maximum productivity, and is important in retarding the woody growth which otherwise enables the savanna to succeed to forest.

In Oregon, Hardison (1957) described the use of fire in sanitation of fields used for commercial production of grass seeds. Following combining, burning the straw and stubble destroys old dry leaves together with the spore bodies capable of producing the countless spores which would otherwise be disseminated to reinfect new leaves and plants. Burning has also given good control of several seed disorders by destroying those seeds which have been modified into galls, sclerotia, or other aberrations. In Canada, similar practice (spring burning) in Saskatchewan gives good control of black stem disease in alfalfa fields.

In the less pronounced seasonal changes of Louisiana, Duvall and Whitaker (1964) recommended a system of rotationally burning one-third of the longleaf pine (*Pinus palustris*)–bluestem (*Andropogon tener* and *A. divergens*) ranges in the winter or early spring, both on cutover and timbered lands. By integrating range- and forest-burning programs, economies of operation as well as desired management objectives are achieved. Wildfire hazard in the forest is reduced, range vegetation and grazing distribution are improved, scrub hardwoods are top killed, and unpalatable perennials are curtailed.

In California, Burma (1967) discussed controlled burning in the "public domain" where general rules and detailed procedures have been developed to ensure that not only is burning safe and efficient, but also that due attention is paid to integrating all uses of a particular parcel of land. The provisions made for legal and technical authority to burn and to minimize escape risks are followed by considerations of potential erosion, of aesthetic, habitat, or watershed qualities, and of subsequent land use. For example, constraints on burning may be accompanied by requirements for seeding, spraying, and grazing. Thus burning becomes one step in implementing a management plan. Emrick (1967) provided detailed steps for successful brush-control burning in California. To some readers the amount of planning and organizing considered essential may seem excessive, but such requirements may in part be a function of increasingly high population densities in California and concomitant splintered ownership patterns.

The role of fire in desert grassland is in part determined by the intensity of domestic livestock grazing (Humphrey, 1963). Where grazing has been too heavy, residual, weakened grasses may not have the density or volume to carry a fire. Thus, where in former times hot fires precluded shrub invasion, the mature treelike shrubs which have now grown up are not killed by weak fires. Building up suitable fuel quantities through grazing control seems mandatory if fire is to be a practical and effective tool.

West (1965, 1971) described the effects and uses of fire in Africa. In areas where forest would be the "climax" cover in the absence of fire, controlled burning may be employed to convert the forest to savanna (open woodland and grass understory), and with continued application, perhaps ultimately to grassland. Van Rensburg (1971) outlined characteristics of burning early or late in the seasons in various fuel types. In southern, central, and eastern Africa, the best time for burning to promote vigorous grass growth is the end of the dry season, i.e., as late as possible in the dormant season, just before the grasses begin to grow. Burning in early or mid-dry season encourages brush encroachment at the expense of grasses and causes exposure that may further damage and weaken the sward. In discussing burning as a management practice, West (1965) noted the strong interaction between the intensity of grazing and the efficiency of fires in controlling the encroachment of woody species (cf. Humphrey, 1963). Because late season hot fires are required to suppress and control bush encroachment, it follows that on heavily grazed land efficacious fires can be obtained only after resting. Some postburn resting may also be necessary to enable the grasses to recuperate. The interval between burns depends on management objectives, rates of litter accumulation, and grazing intensities, and may range from annually to every fourth year or more (West, 1965). Scott (1970) commented on the pros and cons of eliminating veld burning and substituting mowing (not practicable over large areas) or "complete utilization" (high grazing pressure). Scott (1970) recounted that the ill effects of veld burning are mainly due to exposure of the soil to insolation and wind, and the "complete utilization" may do the same damage and more, because of heavy trampling. Greater utilization of grass would no doubt be beneficial, but not at the expense of weakening the sward and subsequent site deterioration. Integrated rotational grazing and burning management is suggested by West (1971) in Africa, but because of the different vegetation types, does not include the forest management component suggested by Duvall and Whitaker (1964) for southeastern United States.

B. Shrublands

Integration of management objectives is an essential feature of all effective burning programs. Just as in grasslands and savannas, the use of fire in the more limited "shrubland" fuel type has its interacting effects on wildlife, vegetation, watersheds, aesthetics, and domestic animal husbandry.

In Europe, fire is used extensively in management of dwarf shrub heath communities and has its attendant effects on grass and forest communities (Gimingham, 1970; Kayll and Gimingham, 1965; Grant *et al.*, 1963; Hansen, 1964; Uggla, 1958). Although the effects of large uncontrolled fires may be detrimental (Radley, 1965), the prevailing advocacy is the use of properly controlled fires of suitable intensity on a 10- to 15-year rotation (Allen, 1964; Robertson, 1957; McVean, 1959). Ward (1972) outlined the uses of prescribed fire by farmers and gamekeepers in management of heather, grass, and gorse. Essentially the objectives are the same: provision of food and cover for grouse and sheep. In England and Wales, heather is not as well regarded for sheep grazing as in Scotland, and thus fire management practices tend to favor grass at the expense of heather.

In the United States, brush control and encouragement of grass with prescribed fire are topics of both technical and popular writings, but the operational constraints are distinctly different from the European case. Raymond (1967) showed that the complexity of the problem did not relate merely to the physical and ecological effects of prescribed fire, but also involved questions of legal constraints (complex land tenure) and liabilities associated with fire escapes. Nevertheless, prescribed fire is used as an effective tool in range improvement for both wild and domestic animals, and in reduction of wildfire hazard. Baldwin (1968), Doman (1967), Murphy (1967), and Pase and Glendening (1965) outlined brush conversion programs which include crushing with a tractor, ignition in late fall through to early spring, seeding with grass and/or legumes, control of brush sprouts and seedlings with chemical herbicides, and continued active management (grazing control) of the treated area. Costs are high ($40 to $70 per acre) but may be commensurate with resultant benefits to wildfire control, wildlife habitat, domestic livestock grazing, and watershed management.

C. Forest Lands

Well-developed prescribed burning techniques for major forest types usually exist if the relationship of fire to the commercially valuable species is pronounced, if safe burning is achieved relatively easily, or if the wildfire hazard associated with cutting practices is so high as to make fuel-reduction burning almost mandatory. Thus, in many parts of North America, prescribed burning has been extensively developed and applied.

In the southeastern United States, as in other areas, details of prescribed burning in forest management vary according to species, site, and management objectives. Riebold (1964, 1971) outlined its history of use and other authors (Bonninghausen, 1962; R. W. Cooper, 1963; Lotti, 1959, 1962; Neel, 1965; Stoddard, 1962) presented details. It is dangerous to generalize, but low intensity head- or back-fires are prescribed, principally in the dormant or winter season. Dieterich (1971) estimated that 2.5 million acres are burned annually, with costs ranging from a few cents to $1.00 per acre (Neel, 1965), depending on area burned, time since last burn (fuel accumulation), proximity of structures or areas requiring special fire guards or precautions, and other factors related to controlling and executing the burn.

Little and Somes (1961) summarized the extensive use and effects of prescribed burning in the pine region of southern New Jersey, but in the north central part of the continent, prescribed burning has not been as common. Recommendations for the Lake States by Dieterich in 1963 included using fire for site preparation on clear-cut jack pine and black spruce (*Picea mariana*) areas, on areas of jack pine–hardwood mixtures, and under mature red pine (*Pinus resinosa*). Costs at that time ranged as high as $43 per acre. Sando (1969) summarized the status in 1968 with about 15,000 acres being treated at costs ranging from $0.15 to $19.00 per acre. For northeastern Minnesota, Ahlgren (1970) did not include costs of burning in his experimental studies, but he did elaborate on the efficiency of prescribed burning in removing slash, reducing humus, retarding competing shrubs, and establishing a new jack pine stand. Ahlgren (1970) also highlighted the necessity of allowing for natural cycles (time) when evaluating the success or failure of prescribed burning. After fire, at least 2 or 3 years are needed because survival of germinants depends not only on the nature and extent of the fire, but also on a good seedbed, adequate rainfall, seed supply, rodent activity, shrub competition, etc. (Some indications that poplar was not reduced by fire, but occupied about the same position as in a cut, unburned stand, were based on 9-year results.)

Although several researchers have explored the utility of fire in the silviculture of jack pine in Canada (Cayford, 1963, 1970; Chrosciewicz, 1967, 1968; VanWagner, 1966; Williams, 1960) and the results have been promising, prescribed burning nevertheless plays a relatively small role on an operational basis (Cayford, 1970). The few days in each year when prescribed burning can be safely undertaken and the mechanical site treatment techniques available at comparable costs (ca. $20 per acre) militate against initiating burning programs. A psychological reluctance to burn on the part of foresters is aggravated by the relatively high fuel loadings extant initially, and as has been pointed out, it is more difficult to begin controlled burning than to continue the practice.

To obtain the mineral soil essential for germination and survival of conifer seedlings, high intensity, high hazard summer fires are needed. Spring hazard-reduction burns on cutover areas do not consume the wet or perhaps still frozen organic layer (Foster *et al.*, 1967). A sequence of low intensity fires coupled with mechanical scarification may be needed to attain the desired seedbeds (Jarvis and Tucker, 1968). Use of fire in northern hardwood silviculture is in the experimental stages only, but some applications seem possible (Niering *et al.*, 1970; Sykes, 1964).

In Scandinavia, prescribed burning is used to release immobile nitrogen in the cold moist soils, care being taken to remove only the slash and upper portions of the humus layer. Fire is not used on dry sites with thin humus layers (Weetman and Nykvist, 1963). Cutovers of 200 acres or more are burned all through the summer period whenever conditions of settled weather, light winds, and dry surface humus exist. As well as activating the humus, planting and seeding are facilitated by burning (Uggla, 1958). Viro (1969) suggested that prescribed burning in Finland was best utilized on sites with thick humus accumulations, cold soils, and bound nutrients. After burning, pines should be established on such sites.

Certain parallels have been drawn with the Scandinavian experience by Hardy and Franks (1963) in Alaska by their suggesting that prescribed fire had yet to be effectively used as a forest management tool. Experience subsequently gained through research (Slaughter *et al.*, 1971) and long-term studies such as Viro's (1969) in Finland will aid in clarifying the role and potential uses of pescribed fire in the far north. For instance, slash burning may have aided sitka spruce (*Picea sitchensis*) regeneration in southeast Alaska (Harris, 1966), but advantages over burned areas seemed marginal.

In western North America, intentional burning probably was conducted in one form or another since the beginning of the twentieth century. LeBarron (1957) reported that slash burning has been conducted in the intermountain west since 1910. From 1920 onwards, burning of hand-piled logging slash and debris gradually extended to include preparation of sites for regeneration, range improvement, wildlife habitat improvement, and reduction of natural hazards (DeSilvia, 1965). In the rough mountainous country of Montana and Idaho, much of the burning is on cutovers ranging from 10 to 500 acres with practically all burning done in the autumn after rains have broken the fire season. Piling and burning may adversely affect conifer reproduction (Vogl and Ryder, 1969) and it is suggested that broadcast burning, in more closely simulating wildfire, may lead to more uniform restocking of cutovers.

Use of fire in management of ponderosa pine (*Pinus ponderosa*) has been extensively covered (cf. Lindenmuth, 1960; see also Chapter 9 of this volume). Briefly, management should be directed toward achieving a mosaic of even-aged groups (maximum area 1.5 acres) of trees with the debris being burned following cutting. Following regeneration, areas should be periodically burned to thin the stands and maintain vigorous growth. Burning should be done when trees are dormant, soils are moist, and winds are low. As elsewhere, first fires in heavy fuels are most difficult, but easier conditions follow (Biswell, 1970).

In Alberta, effects of prescribed fire in subalpine spruce-fir slash have been described by Kiil (1970, 1971). In partially cut stands, low intensity fires are not effective in creating site conditions suitable for survival of conifer seedlings, but do show promise for hazard reduction and improvement of wildlife habitat. Single fires on clear-cut areas are not effective in exposing mineral soil because of deep organic layer accumulations. With late September or early October being the periods of safe burning, smoldering fires, a sequence of burns, or mechanical scarification in conjunction with burning, may be required to achieve satisfactory conifer regeneration.

The use of fire in the Douglas-fir (*Pseudotsuga menziesii*) region of western North America has been extensive for half a century. However, Isaac (1963) pointed out that fire is a tool and not a blanket rule in Douglas-fir ecology and he listed the times to burn as (a) when slash and weather conditions are safe, (b) when slash areas become so large or continuous that fire control is impracticable, (c) when slash accumulations are extremely heavy, (d) when competing, undesirable species invade, (e) when it is necessary to prepare sites for seeding or planting, (f) when insect or disease infestations threaten, or (g) when there are neither seeds nor seedlings on a cutover area and there is a seed crop in prospect on nearby seed sources. Times when not to burn include: (a) when fire cannot be safely controlled, (b) when cutting has left a good residual stand, or one has become established, (c) when slash is light and unlikely to be dangerous even during periods of high hazard or the slash provides cover on exposed slopes, or (d) when burning conditions will produce an extremely intense fire that may seriously affect the soil or the habitat generally. Long-term studies are altering some of the details of burning (Morris, 1970), but its role in wildfire hazard abatement has been clearly shown (Smith, 1970). In other forest types of western North America, Muraro (1968, 1971) has shown hazard reduction in cedar–hemlock logging slash can be successful within narrow constraints, but continuing use of fire is expected.

Perhaps one of the narrowest sets of burning constraints is the special circumstance where a "let-burn" policy is being developed and applied to high elevation, low intensity, lightning started fires (Kilgore, 1971b, 1972). In giant sequoia (*Sequoiadendron giganteum*) and red fir (*Abies magnifica*) forests where other economic values are not threatened, fires are being allowed to follow their natural course in maintaining the appearance and substance of the forest complex prior to the advent of fire exclusion policies. The management implications are far reaching; similar plans are being considered for other areas of western North America (e.g., Prasil, 1971) and implementation of such policies will require effective and continued dialogue between resource scientists, managers, administrators, and the general public.

In Australia, a good public understanding has been one of the contributing factors to the widespread success of the hazard reduction control burning program, which utilizes low intensity fires (<100 BTU/sec-ft) to remove fuel accumulations and facilitate wildfire control (Hodgson, 1968, 1970). As mentioned, large areas are treated annually using aerial incendiaries, but ground ignition techniques are also used, for example, in Tasmanian eucalypt forests (Mount, 1965). The use of fire in radiata pine (*Pinus radiata*) plantations has been explored experimentally by Gilmour and Cheney (1968) and used operationally as a hazard reduction tool. With an upper limit of 100 BTU/sec-ft, 25 to 50 BTU/sec-ft is considered an optimum intensity.

D. Wildlife

In North America, the first principal work on use of fire in management of wildlife populations was that of Stoddard (1931) for bobwhite quail. Since that time, many researchers and managers (Komarek, 1963) have developed and used techniques for manipulating forests, grasslands, and savannas for the benefit of wildlife. Miller (1963) has described fire as a tool for maintaining the subclimax vegetation (the usual preferred habitat of most species) in vigorous and proper condition, density, and composition. Komarek (1971), in summarizing the effects of fire on wildlife habitats in southeastern United States, pointed out that grasslands and early stages of brushland, maintained by controlled burning, provide the diversity of flora necessary for healthy wildlife populations. Czuhai and Cushwa (1968) found similar evidence for the more upland areas of the Southeast. Miller (1963) was referring largely to "upland" game, but his statement is applicable to many other forms of wildlife. Thus habitat maintenance with knowledgeably applied fire has benefitted various species of grouse, prairie chicken, pheasant, turkey, quail, woodcock, snipe, ducks, geese, songbirds, birds of prey, deer, elk, moose, muskrats, and others (Vogl, 1967). The use of fire for habitat manipulation for both wild and domestic animals is common, e.g., deer and cattle in California (Hendricks, 1968) and sheep and grouse in Britain (Ward, 1972).

Marsh burning is an accepted management practice in most waterfowl refuges on the East Coast of the United States (Givens, 1962; Zontec, 1966) and burning on inland, freshwater wildfowl habitats has been undertaken both in Canada (Ward, 1968) and the United States (Schlichtemeier, 1967). The dual benefits on wildfowl and muskrat populations have also been described (Perkins, 1968). In the giant sequoia forests of California, Kilgore (1971a) recorded the effects of habitat manipulation, including cutting and burning of brush and saplings on breeding bird populations. As he expected, habitat requirements of the various species engendered varying responses to the treatments, but changes were not substantial because of the limited areas and degree of change. Small mammals likely have similar responses, e.g., burning of jack pine areas in Minnesota gave rise to increases in seed-eating mouse species while other species with a more varied diet remained relatively constant in number (Ahlgren, 1966). Studies in Australia are exploring the effects of the widespread control-burning policies on vegetation (C. F. Cooper, 1963), wildlife populations (Butcher and Dempster, 1970), and on small mammals (Leonard, 1970), but definitive statements are not yet available.

Management of big game animal habitats with fire is common in Africa and becoming so in North America. In the former, Brynard (1964, 1971), Austen (1971), Owen (1971), and others have outlined the use of "veld" and savanna burning for management of various animals in African national parks. Under the premise that grass should be eaten, mowed, or burned (Austen, 1971), fire management plans have been developed which incorporate not only burning regimes favorable to wildlife (i.e., promotion of grasslands), but also incorporate long-term principles of management related to forest production (early versus late burning), watershed protection, and aesthetics. Integration of management objectives is clearly demonstrated.

In the United States, Leege (1968) outlined burning procedures favoring elk habitats in northern Idaho. Spring fires after the snow recedes, but before sprouting of new growth occurs, seem most efficient in reducing height of existing browse and stimulating seed germination, both of which are beneficial to the elk habitat. In northern Canada, limited controlled burning may favor moose populations (Spencer and Hakala, 1964) but be detrimental to barren-ground caribou (Scotter, 1970, 1971). Since the effects of fire in the slowly cycling northern environment can be profound and long lasting, an intensification of research and development effort seems imperative, and suggestions for a northern research center have been made (Slaughter *et al.*, 1971).

E. Watersheds, Air Quality, and Recreation

Public concern and awareness of ecological subjects have prompted the writer to clump the uses of fire on watershed, air quality, and recreation management because of their "political" visibility, rather than intrinsic relationships. The use of fire in manipulation of watershed areas in Arizona has had the multiple-use objectives of increasing yield of water, timber products, forage for livestock and game, improving conditions for recreation, reducing the adverse effects of wildfires, and reducing soil erosion (Arnold, 1963; Kallander, 1969). Burning practices have been applied in watersheds with cover types of spruce-fir, ponderosa pine, pinyon-juniper, chaparral, and desert grassland (Zwolinski and Ehrenreich, 1967). Conversion from brush to grass has increased water yields in California (Burma, 1967), but in smog-sensitive California, the use of broadcast burning in watershed management may be restricted for aesthetic, atmospheric, and economic reasons (Zivnuska, 1968). More intensive and carefully controlled environmental management may preclude use of prescribed fire in certain circumstances, but alternatives will need to be developed.

In the Douglas-fir region of western North America, multidisciplinary studies have been initiated to determine prescribed fire smoke constituents (Fritschen *et al.*, 1970) as well as effective smoke dispersal in burning for forest, grassland, and watershed management (Beaufait, 1968; Dell and Green, 1968). Vines *et al.* (1971) have undertaken similar studies in Australia. It is interesting to note that seven individuals cooperated with Fritschen and six with Vines, indicating perhaps not only a diversity of interests but also of the effects engendered by prescribed burning.

Intentional burning on campgrounds and intensively used recreation areas has not been widely applied, but the finesse required for this type of operation is being developed (Cumming, 1969) with low intensity, carefully controlled fires being prescribed to lower wildfire hazards. Secondary benefits have accrued in the form of additional wildlife and improved aesthetics. The latter has been partly brought about by the creation of "edges," considered a prime requisite by Meskimen (1971) in the production of forest landscapes. The creation of edge leads to diversity and variety, and Meskimen (1971) presents the thesis that, irrespective of geographical or vegetational location, only three building blocks provide all the characteristic landscapes, viz., meadow, shrub thicket, and forest stand. Perkins (1971) has indicated several forms of outdoor recreation that are compatible with use of prescribed fire, including hunting, camping, picnicking, hiking, bird watching, and outdoor photography.

According to Hoffman (1971), one purpose of natural parks is to enable people to enjoy the features of a natural environment and this environment must include fire. Robinson (1970) summarized the future direction of fire management by identifying the following trends: an increasing use of fire in managing natural resources, an increasing requirement for demonstration of favorable benefit/cost ratios, a recognition of the role of fire as a natural component of wilderness, and an allowance for fire to follow its natural course under carefully specified conditions.

Prescribed fire will never become a management tool to the total exclusion of other techniques, but it will continue to be effective and its uses will diversify in management of the world's natural resources for the benefit of man.

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