Lightning and Fire Ecology in Africa

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MORE than a decade has passed since our first conference on fire which my associates and I had decided to call the Tall Timbers Fire Ecology Conferences, with emphasis on the ecological aspects of this phenomenon. I can recall, even now, the remarks of one of our first speakers:

> "... I can't help but comment on the fact that woods burning two years ago was something like a dirty word, and woods burners were treated accordingly. Here today so-called woods burners are meeting in convention under the name fire ecologists," (Lotti, 1962).

In the past decade we have progressed to the extent that a recent speaker remarked:

> "Many ecologists have been afraid to experiment and merely describe what they see. Any of us who were afraid in this way will from now on be changed in their outlook. The enthusiasm of . . . (those) dedicated eco-pyrologist(s)* (have) lit a spark in all of us. . ."

Today fire ecology, or eco-pyrology, is an accepted branch of ecology and investigations in this science are growing in profusion. However, even so, there are many persons that still believe that fire

*"Note the clear distinction between an eco-pyrologist and a pyro-ecologist. The latter is the sort of idiot that burns his house down," (Varley, 1970).

in nature is nothing more than a "human artifact"; not a universal natural force on earth long before man. My basic thesis is that climatic factors, not man, are the foundations of fire ecology. All that is necessary for natural fires to occur anywhere on earth is to have (1) lightning as the primary ignition source, and (2) a fire climate conducive for the burning and spread of the fires resultant from the lightning strike. Fire is the same rapid process of oxidation wherever it occurs.

Lightning is but an expression of an intregal part of the earth, its electrical field, and a visual manifestation of a universal force, electricity. These are over-looked fields of ecological study which I have pointed out in other papers.

Certain weather ingredients are necessary for the production of thunderstorms and lightning. They are hot air, cold air, and humid air. Wherever they meet and mix, in all their possible variable quantities all over the world, thunderstorms and lightning are generated. Most of these come from globe encircling "air masses" which are driven around the earth in a westerly direction by its rotation. These may be affected by the physiography of the various continents but their essential characteristics are not eliminated or greatly changed. Some continents are apparently more lightning and thunderstorm prone than others, i.e. Africa.

The other ingredient for natural fires is a fire climate or what foresters sometimes call "fire weather." A fire climate must be provided with dry periods in which to burn fuel that is grown in the wetter times. The wetter the growing season and the longer and hotter the dry season the more chance of fires. Some tropical countries, as Africa, have two wet and two dry seasons so can and do actually burn two times a year provided that these coincide with lightning activity. These fire climates, although they vary from one continent to another, are and have been global in both space and time.

In "Lightning and Lightning Fires as Ecological Forces" (1968) and eight other papers (Komarek, 1962–1968) I have discussed these ecological forces as essential components, which began early in its geological history, of the earth's environment. The relationship of both lightning and lightning fires to the past history of plant and animal communities has been a continuing field of study. New lines of investigation have developed into the past geological history of fire that is pertinent to our understanding of African fire ecology. No continent, even Africa the fire continent, can be studied as an isolated entity. Its fire ecology can only be properly understood in relation to fire wherever it occurs or has occurred.

ANCIENT FIRES

Prehistoric Fire Scars and Lightning Strikes

In recent years many studies have been made in the dating of past fires in many of the western trees of the United States. Techniques and methods have been developed that have resulted in much information on recurring fires in Sequoia (Biswell, 1961), Ponderosa Pine (Weaver, 1964 and Biswell, 1963), Douglas Fir (Isaac, 1963), and White Spruce (Heinselman, 1970). As a result, I made a cursory visit to some of the many petrified forests in the western States. At Florisant, Colorado, one of the large stumps of sequoia-like trees which grew in the Miocene period contains an obvious and typical fire scar and consequent regrowth similar to those discussed by the above mentioned authors. What appeared to be fire scars were also noted in a petrified forest near the Black Hills, North Dakota. Cursory examination at many other such areas has led me to believe that this would be an excellent field for future investigation for individuals equipped with the necessary materials and knowledge to section petrified woods.

Another field of investigation in such regions of petrified forests would be the search for lightning strikes. Lightning makes certain recognizable streaks, particularly on conifers, and is a major "predator" of such trees as the pines, hemlock, firs, and sequoia (Komarek, 1964, 1966, 1967).

In 1965, the Florida Geological Survey uncovered a large petrified cypress tree (*Taxodium* sp.) of Miocene age with a typical lightning streak from top to bottom. I believe that the reason we have so little information on ancient fire scars or lightning streaks is that apparently no one has searched for them.

Ancient Lightning—Fulgurites

When lightning strikes dry ground the heat of discharge fuses the sand, etc. into a configuration at times resembling the pattern of discharges as we see in the sky, but on a much smaller scale, or sometimes they are similar to the root systems of a plant. These are called fulgurites and are produced in many parts of the world. They are more common in sandy ground or sand. As these are essentially made up of fused inorganic material they can remain in the ground for a long time. Schonoland (1950) mentions that some are more than eight feet long and with a diameter of two inches. He writes:

> ". . . In one sand-dune patch of 5,000 acres at Witsands, on the southeastern border of the Kalahari Desert, Lewis estimated that there were not less than 2,000 fulgurites. Since lightning is at the present time infrequent in this area, some of these tubes must have been formed by lightning flashes many thousands of years ago."

A similar condition, in what one might call a "mirror-image" on the other side of the equator, has been reported in a desert area in the Chad (Setzer, pers. comm.). These fulgurites were said to be so abundant as to present difficulties in travel. The wind had blown the sand from around them and they projected from the ground somewhat like petrified stakes.

Fires in the Geological Past

Abundant evidence of ancient fires in the geological past is found in the coal beds of Paleozoic, Mesozoic, and Tertiary periods in the form of fossil charcoal, called fusain by coal petrologists. Fusain is found in nearly all, if not all, coal formations but is most abundant in bituminous coals or "brown coals," and is the material that makes one's hands dirty when handling coal. It is formed in bands throughout the coal seams as well as in pockets and is in many forms, ranging from dust to sizeable pieces of charred wood and even stumps.

There is general agreement among coal petrologists that fusain and related materials were formed by lightning started forest fires in all the coal formation periods—Paleozoic, Mesozoic, Tertiary, and Quarternary (White, 1913; Moore, 1922; Jeffrey, 1925; Thom, Jr.. 1929; Bergstrom, 1932; Terres, 1932; Stutzer and Noe, 1940; Harris, 1958; Kreveln, 1961; Francis, 1961; Williamson, 1967; Mackowsky, 1968; Teichmuller and Teichmuller, 1968).

Harris (1958) in "Forest Fire in the Mesozoic" found that this material is indeed fossil charcoal. He conducted laboratory and field experiments and compared fusain fragments "from an extinct conifer, *Cheirolepis muensteri,* with those of burnt *Pinus sylvestris* wood" ". . . and found them similar chemically and physically." He also similarly compared fusain fragments of the fossil fern *Phlebopteris woodwardi* with a recently burnt *Pteridium* sp. leaf, and fire cracks in fossil wood material with that in recently burned *Sequoia* sp. and *Cedrus* sp. He concludes his paper with the following summary:

> ". . . The objection usually used against accepting fusain as charcoal produced by fire is that there is too much of it and in too many layers. It would make the past a 'nightmare'. I believe over-presentation fully accounts for that. . .
>
> "There is, indeed, nothing to show how many fires occurred in the Greenland and Yorkshire deltas, but from changes in botanical composition of the fusain layers I think the number must have been considerable.
>
> "The ecological significance of early forest fire: I doubt whether fire in the Mesozoic would have much effect (on the plants of) today, but the ecologist would be concerned if fire were widespread and recurrent in the Tertiary. Fusain has been described from the Tertiary brown coals, and has indeed been taken as evidence of fire. . .
>
> "Let us then imagine the same sort of evidence exists in the Tertiary as in the three Mesozoic floras dealt with here. We would conclude that widespread fires occurred at varying intervals according to local conditions. . . *It would help us to understand the origin of the vast number of species which today seem to depend on fire; they may have already evolved in strength and have been ready to seize the increased opportunities offered by man.*" (Italics Komarek).

There is a great abundance of fossil charcoal, fusain or related material in coal fields all over the world and from the Carboniferous to the Pleistocene and many studies have been made in this regard. Further discussion of ancient fires, particularly of the Tertiary period, will not be given here but a paper is in preparation that will review this entire subject of fires in the geological past. The meteorological conditions that were responsible for the formation of coal beds and fusain were determined by global weather and atmospheric circulations. Global atmospheric conditions likewise determine the lightning patterns and fire climate today, as they have in the past.

GLOBAL WEATHER PATTERNS

Africa can be designated as the "fire continent" on climatological grounds. This large land mass, the second largest of the continents, is ideally located and designed for the development and occurrence of thunderstorms and lightning and certainly no one will argue that it does not have a fire climate. For a proper understanding of African fire ecology of today we will have to review the climate of this continent, its relation to global weather patterns, and in more detail the conditions and occurrence of thunderstorm and lightning as well as its characteristic fire climates.

Atmospheric Circulation

> "The ultimate cause of the movements of the atmosphere and the formation of the associated pressure-systems is the differential heating of the globe by solar radiation . . . [and] the climatological importance of the distribution of pressure lies in its control of the winds. . ." (Kendrew, 1957).

The cold air from both the north and south poles, being heavier, flows towards the equator whereas the hot equatorial air, being lighter, flows upward and poleward in a vast global circulation pattern. This circulation is in turn greatly affected by the rotation of the earth, which deflects this circulation eastward as the westerlies.

> "This remarkable distribution is an effect of the Coriolis force acting on the meridional currents which would form the circulation without it. Poleward currents from the equator suffer eastward deflexion . . . and form a vast system of westerlies, a great circumpolar whirl, throughout most of each hemisphere. . .
>
> "The circumpolar whirls are driven by two forces. The thermal tends to maintain an upper circulation from equator to pole and a

> return surface-movement, . . . and the centrifugal force developed in the circling westerlies . . . tends to give a strong equatorward component to the whole system. A result is the piling up of air in the sub-tropics to form high-pressure ridges; . . . [the] *major control of the climates* over the globe. . ." (Kendrew, 1957). (Italics Komarek).

Wherever broad and globe encircling atmospheric circulation patterns bring together hot, cold and moist air, we have the ingredient of thunderstorm development. I have shown, in a series of papers, (Komarek, 1964, 1966, 1967) that as a result of such widespread "air-mass" circulation the North American continent is literally bathed in lightning and thunderstorm development from the far Arctic north to the tropical south. I discussed the thesis then that the resulting fires are also a part of climate. This resulted in provisionally dividing the North American continent into "lightning-fire bioclimatic divisions" (Komarek, 1968) dependent upon not only continental patterns but global "air-mass" phenomena as well. Africa appears to likewise have "lightning-fire bioclimatic divisions" as well.

Flint (1959) discussed Africa's climate in relation to world atmospheric circulation patterns as follows:

> "Africa is the world's warmest continent. It is divided by the equator and lies mainly between two subtropical belts of high pressure, which strongly influence its climates. Local topographic influences on climate are less important than in Eurasia and the Americas . . . *African climates depend chiefly on the broad atmospheric-circulation pattern* and have relatively few local variations." (Italics Komarek).

AFRICAN CLIMATOLOGICAL PATTERNS

Climatologically the African continent is quite unique in many respects. The location of the equator just south of the bulge in the continent divides Africa into what may be likened to mirror images of climate and vegetation bands north and south of the equatorial zone.

> "Africa, alone of the continents, extends to almost equal distances north and south of the equator. In the south it projects far into the ocean remote from other lands, but in the northeast it joins

Asia, and its climate is controlled largely from Asia. Yet in spite of this external control similar series of climates can be traced northward from the equatorial belt of heat and moisture to the Mediterranean Sea, and southward to the Cape of Good Hope. The Sudan has its counterpart in Rhodesia, the Sahara in the arid tracts of the Kalahari and south-west Africa, the Mediterranean coast in the southwest of the Cape Provinces.

"The continent lacks those extensive mountain-ranges that are effective elsewhere as climatic barriers. Gradual transitions take the place of . . . abrupt changes. . ." (Kendrew, 1953).

The thunderstorm-day maps and data collected by the World Meteorological Organization (WMO) clearly shows the movement of the thunderstorm pattern from north to south, synchronized with the northern and southern movements of the intertropical convergence zone or front (ITC). This regular wand-like movement across the equator regulates the pattern of precipitation, temperature as well as thunderstorm activity. If we begin with the month of January, we find that most of the thunderstorm activity is south of the equator and in fact, reaches southerly to the end of the continent. North of the equator there is virtually no such activity then. As the months progress the entire thunderstorm processes move northerly so that by June the activity is located north of the equator. By September the ITC begins to move southerly and so do the thunderstorms so that by October the thunderstorm activity lies astraddle the equator. At times thunderstorms may even occur in the Sahara or the Kahalari, at opposite seasons of the year, however, always synchronized to the ITC which in turn is in tune with the movement of global air masses.

Thunderstorms in East Africa

The East African Meteorological Department has furnished me the following pertinent data on thunderstorm activity in East Africa.

"East Africa has a high occurrence of thunderstorms. The frequency distribution curve for most areas of Kenya and Uganda (excluding the Lake Victoria Basin), show a double peak. One occurring in March–April and other in October–November. These periods are also generally the wettest months in the year.

"The occurrence of thunder in East Africa can very broadly be attributed to five main synoptics and geographical features.

1) Inter-Tropical Convergence Zone (ITCZ);
2) Lake Victoria;
3) Orography;
4) East Disturbance;
5) Frontal Disturbance."

(East African Meteorological Dept., 1971)

All five of these features are responsible for most of the numerous thunderstorms which occur over most of East Africa.

Thunderstorms in Rhodesia

The Rhodesian Department of Meteorological Services has furnished me a recent detailed summary of thunderstorm activity in that country. The data have been mapped (Fig. 1).

Seccombe (1970) in a description of climatological conditions in southern Rhodesia shows that the frequency of thunderstorms in that region are due to four different air mass conditions. One such condition is as follows:

"Under the influence for the greater part of the year, of the Sub-Tropical High Pressure Belt, the movement of anticyclones from west to east across Southern Africa and their positions relative to Rhodesia are critical. . .

". . . Little significant rain is recorded but, during the rainy season, convergence between this flow and warm, moist air of northerly origin triggers off outbreaks of thunder activity. These storms tend to form in lines and march across Matabeleland. . ."

A second condition is location of the Intertropical Convergence Zone:

"The large fluctuations of seasonal rainfall are the direct result of the relative positions of the I.T.C.Z. and the belt of high pressure to the south."

A third condition is the movement of Congo air:

"With persistent low pressure over the southeast of South Africa this air (Congo air) advances into the west and northwest

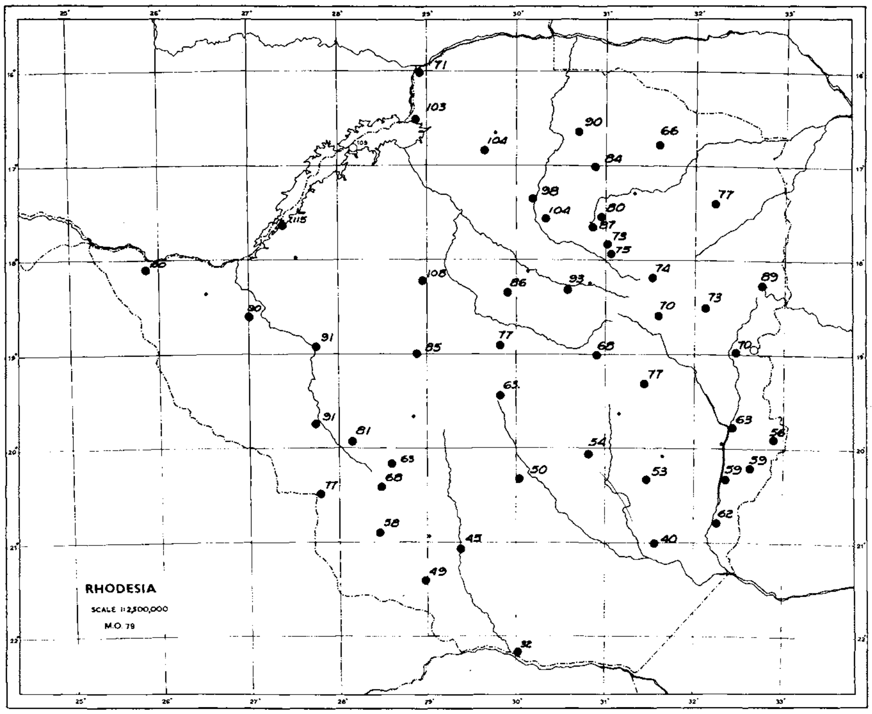

FIG. 1. Thunderstorm days in Rhodesia (from data furnished by the Rhodesian Department of Meteorological Services).

> of Rhodesia. . . Considerable moisture and surface heating combine to produce convective thunderstorms and showers."

A fourth condition is the activity of the airstreams called the Upper Westerly Waves:

> "During the periods covered by the pre- and post-rainy seasons (September–October to March–April) occasional outbreaks of unseasonable thunderstorms occur over the southwestern parts of Matabeleland."

THUNDERSTORMS IN SOUTH AFRICA

The tapering shape of southern Africa (Fig. 2), the warm Moçambique and Agulhas Sea currents on the south and east coasts and the

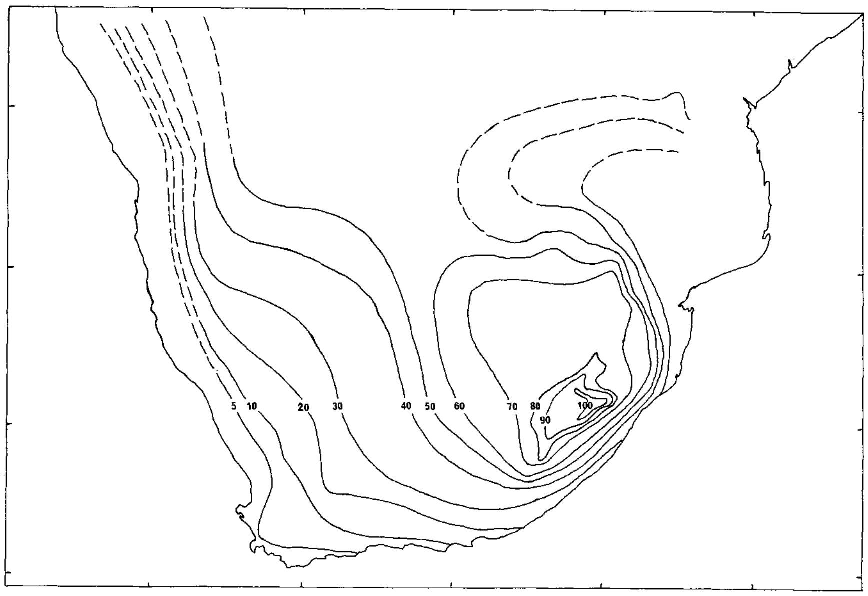

FIG. 2. Thunderstorm days in South Africa (from Climate of South Africa, Weather Bureau, Pretoria, South Africa, 1957).

Benguella Sea current on the west coast all tend to condition the climate so as to produce thunderstorms as well as does the elevation of most of South Africa into an interior plateau.

> "The weather and climate of South Africa are dominated by the more or less stable subtropical high-pressure belt and a succession of cyclonic and anti-cyclonic disturbances emanating from the South Atlantic Ocean and approaching from some westerly point of the compass.
>
> "In certain circumstances in summer, wave development in the upper westerly air circulation causes influx of tropical conditionally unstable, air from equatorial regions, which whilst converging on flowing southwards, gives rise to the summer rains over the greater part of South Africa. . .
>
> "One would in these circumstances expect precipitation in the summer rainfall zone to be largely due to instability showers, more often than not accompanied by thunderstorms which are often of great severity" (South Africa, Official Year Book, 1960).

South Africa, as with most of the continent, is subject to long and severe droughts. In fact, except in a few relatively small regions this is the rule, not the exception. Droughts like the dry periods usually end by a series of thundershowers which at the beginning are apt to be "dry lightning storms".

THUNDERSTORMS MISCELLANY

The thunderstorm patterns north of the equator resemble in many respects those just discussed south of the equator. Along the west coast of Africa and at and near the equator are many thunderstorm regions similar in some respects to that of Uganda and the Congo.

LIGHTNING COMMENTS

The lightning flash that we see is the result of a primary mechanism of the earth's atmosphere for the thundercloud not only produces precipitation and circulates the atmosphere but is also the electrical pump or generator that replenishes the earth's electrons.

> "The earth is like a big battery, continuously losing electrons to the atmosphere. . . Linss in 1887 estimated that the earth would lose almost all of its charge in less than an hour if the supply were not replenished (and) Scrase computed in 1933 that the world would lose its charge in about 48 minutes" (Viemeister, 1961).

That thunderstorms were the main mechanism in replenishing the earth's electrons was first proposed over a half century ago (Wilson, 1920). Today nearly all investigators agree that the thousands of daily thunderstorms with their consequent lightning activity balance the loss of electrons from the earth to the atmosphere.

Various estimates on the number of lightning strikes to the ground have been made. Viemeister (1961) estimates that ground strikes to the earth as a whole occur about 100 times every second. In a study of 2,610 flashes in three thunderstorms in western United States, 548 struck the ground or about 21 percent (Fuqua, 1959). The conversion of thunderstorm days to the potential lightning is very difficult for several reasons. First, the thunderstorm data itself is not accurate for the globe as a whole; secondly, the number of lightning flashes per unit of thunderstorm is difficult to count, and lastly, the thundercloud along with its lightning is constantly moving and changing internally as well, as it marches across the sky.

Recently a study was conducted from a satellite equipped with four telescopes focused on earth to which were attached photometers (Vorphal and Sparrow, 1970). The map of Africa (Fig. 3) which resulted from this investigation show a rather even distribution of lightning flashes over the continent, with the exception of the Sahara, from February to October 1965. All were, however, recorded at night when the thunderstorm activity is relatively low as compared to midday. Lightning counters are being used in many places. With data from these more accurate and sophisticated instruments, much new knowledge will be made available about the lightning activity that surrounds the earth.

FIG. 3. Satellite Observations of lightning (reprinted by permission of Science, and authors; Science, v. 169, 1970) (J. A. Vorphal, J. G. Sparrow, and E. P. Ney, 1970).

Mr. J. Kreft, Rhodesian representative on the Electrical Research Association's Research Advisory Committee on Lightning (Central Africa) has furnished me with the following very interesting discussion:

> "The conversion of thunderstorm days to lightning strokes to the ground is not simple. The Lightning Committee co-ordinates the results from about 25 lightning stroke counters operated by various interested authorities in Rhodesia. These counters, the design of which is continually being improved, are still in the development stage and vary in sensitivity. The latest report from the Secretary gives an average of about 160 registrations per thunderstorm day. An attempt has been made to compute the probable ground stroke density per square mile per annum. The results vary over one order of magnitude from about three to 30, and while some spread might be expected, this seems to me to be excessive. The mean works out at about 20 strokes per annum over a square mile, computed for the country as a whole. This figure should be higher in areas of high thunderstorm frequency and vice versa, but the varying counter sensitivity makes it difficult to arrive at any accurate result. (The assumed operating range of the instruments is 17.5 km)."

LIGHTNING FIRES

I have stated that the basic ingredients for fire in nature (lightning, dry weather, and fuel) have been present on the African continent for a long time, long before the advent of man. These basic ingredients and associated climatological patterns, global in essence, continue to be a part of the African environment. The original or primeval natural fire mosaic has been changed in many ways by the activities of man. I wish to emphasize, however, that the major natural ecological forces and processes are still present and very active. Man has only changed the effects and occurrence of these to a certain degree. He has not destroyed or abolished them. When the activity of man is removed, such as farming, pasturing, fire exclusion, etc., the lightning mosaic begins to re-assert itself as plant succession recovers and fuel is developed by the natural process of dying. It is quite often forgotten that no vegetative leaf or blade of grass lives forever, and that in reality its life is short. That this lightning fire mosaic will re-assert itself has been proven abundantly wherever fire has been excluded in Africa for any length of time.

Native peoples, early farmers, pastoralists, and pioneers, being close to the physical environment, have long witnessed the natural phenomena of lightning effects and lightning fires so that both lightning and fire are woven throughout early religions and cultures. One of the uses of fire by these peoples has been to protect themselves and their material possessions from such natural fires. It is, however, difficult for mankind removed from his natural environment not only to recognize the fact that there are lightning fires but that there was a lightning fire mosaic in nature long before man. The frequency and extent of such fires has just recently been recognized and the extent and number of these can, in the terms of some, create natural "nightmares."

In several studies (Komarek, 1967–69) on lightning fires in the U.S. National Forests, (perhaps the best kept and longest record) data on the frequency of such fires as related to acreage have been presented. The following table and graph is from those studies (Table 1a and 1b and Fig. 4).

The figures from the Arizona National Forests are particularly pertinent because they show the high incidence of lightning fires in a semi-arid and mountainous climate, similar to some areas in Africa. It would appear, from these studies, that many regions must have burned over with a monotonous regularity that is hardly conceivable. Civilized men might think that this must have been a "nightmare" to native peoples living in a fire environment but they were adapted to such a condition.

In a continuing study of fires in arid or semi-arid environments I have received data on the effect of lightning on Sahuaro cacti in Arizona in which the strike has actually set fire to the cactus spines (Woodin, pers. comm.). Data has also come to hand on fires in the Sonoran Desert, two of which were ignited by lightning. Examination of fires in such a region has shown that even though the area may be desert, annual grasses and forbs will create more than enough fuel to carry fire following unusually wet summers and winters. The fires in such semi-arid or arid regions also produce a differential effect on the vegetative components of such areas. One fire in 25 or

TABLE 1a. INCIDENCE OF LIGHTNING FIRES FOR ENTIRE 22-YEAR PERIOD—1945–66.

All National Forests:	107,160 fires on 186,487,010 acres—Avg. of 1 fire per	38,297 acres
California N.F.	25,055 fires on 19,370,383 acres—Avg. of 1 fire per	24,927 acres
Ariz.-New Mex. N.F.	33,965 fires on 20,407,885 acres—Avg. of 1 fire per	601 acres
Arizona N.F. only	22,334 fires on 11,410,808 acres—Avg. of 1 fire per	511 acres
New Mexico N.F. only	11,631 fires on 8,997,079 acres—Avg. of 1 fire per	774 acres

TABLE 1b. INCIDENCE OF LIGHTNING FIRES FOR HIGH AND LOW YEARS ONLY—WITHIN THE 22-YEAR PERIOD

All National Forests:	1948	1 fire per 76,276 acres	1961	1 fire per 19,958 acres
California N.F.	1948	1 fire per 92,239 acres	1961	1 fire per 10,981 acres
Arizona-New Mex. N.F.	1955	1 fire per 27,129 acres	1961	1 fire per 7,449 acres
Arizona N.F. only	1955	1 fire per 23,822 acres	1961	1 fire per 6,447 acres
New Mexico N.F. only	1955	1 fire per 33,951 acres	1961	1 fire per 9,381 acres

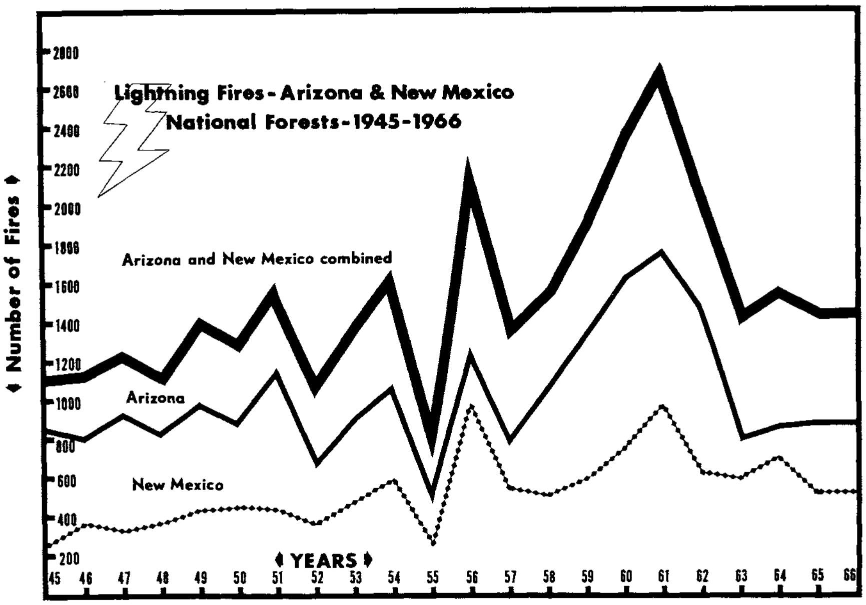

FIG. 4. Lightning fires—Arizona and New Mexico National Forests, 1945–1966 (from Komarek, 1969).

more years may be sufficient to retard the invasion of certain brush species for a long time. These studies show that even an extremely light stocking of domestic livestock (one cow per square mile) is enough to inhibit such fires, however.

Africa has a unique fire climate, as compared to North America, that accentuates the possibility and occurrence of lightning fires. Much of the continent, as we have already discussed, has a climatic pattern of extensive dry periods and in some regions results in two dry and two wet periods. The fluctuating changes in the weather at the beginning and ending of different kinds of climatic weather patterns is sometimes called the "persistence of weather patterns." This means that certain prevalent weather patterns tend to persist. Thus at the beginning of a dry period there is a period of considerable thunderstorms but less and less rain falls. Likewise, at the end of a dry period or drought, thunderstorms will form and march across the sky in seemingly endless profusion, at least to the long suffering farmer or pastoralist, and although they create much lightning, produce little rain that falls to the ground. These are generally called dry lightning storms and after a long dry period or drought, ignite many fires. From the limited data on African lightning fires available, it would appear that more fires, and also more extensive fires, occur towards the end of the long dry spells although they do occur at the beginning as well. The fires at the beginning of the dry spells are most likely to be "cooler" or more feeble and less intense than those that occur when no rainfall has occurred for an extended time and all the vegetation is parched and dry. It must also be remembered that the lightning strike does not necessarily occur in the rain pattern but can, and very often does, occur off to one side or where the rain does not fall. Africa has very extensive and widespread scattered and randomized patterns of thunderstorms along with extensive long dry periods, some places 6 months or more, and this makes much of the continent conducive to lightning fires. In the wet regions of Africa, that have little dry weather, thunderstorms are abundant but fires are not frequent unless extensive and repeated drought occurs, or man replaces the original wet tropical evergreen forest with derived grasslands. The lightning ignition, however, is always present and some of these regions have the most lightning occurrence.

Mr. J. Kreft of the Rhodesian Meteorological Service has written me (1971):

> "As a generalization grass and forest fires are most likely to be started by lightning in our 'hot season'. This runs from late August or early September to late October or early November. During this period the average temperature rises until the start of the main rains in November while the relative humidity falls. The vegetation is drying out steadily after our normally dry winter months. Rainfall accompanying thunderstorms may be light or patchy so that the 'sprinkler' effect is often insufficient to quench a fire. (Our climate is similar to that of the Mexican plateau region—obviously six months out of phase.)"

West (1969) reported that:

> "In Rhodesia where rainfall is seasonal and confined to a comparatively short period during the summer months and where ground frosts occur at night over most of the land surface during the dry winter months, conditions particularly suitable

> for widespread fires develop annually during the dry season, and often during dry periods in the rainy season. Because of this lightning fires are not uncommon in Rhodesia."

The Secretary for Forestry, Republic of South Africa has informed me that (pers. comm., 1967):

> "Most of the fires of any consequence that are started by lightning, usually occur during the early summer months—October and November—before the summer rains have started or before the rains have set in properly. During this period when the vegetation is extremely inflammable after the dry winter months, dry electric storms occur and frequently lightning strikes set the veld and plantations alight."

Data on the actual occurrence of lightning fires in Africa is sparse and rather widely scattered. The following information is presented with the hope that it will encourage Africans to study, collect and evaluate lightning effects and lightning fires in the various regions of that continent.

For Liberia, Johnston (1906) stated that he frequently witnessed the ignition of African veld by flashes of lightning (in West, 1969). Staples (1926) reported that an experimental burning plot was ignited and burned off by lightning at Cedara, Natal, South Africa. (It is interesting to note in this regard that three experimental U.S. Forest Service watershed projects have been burned out after several years of study, in southern California, southern Arizona, and Oregon). Lightning fires have been recorded in Rhodesia by Whiteside (1962 in West, 1969) and in the Inyanga National Park (West, 1969). Phillips (1930) stated that many lightning fires are witnessed in East and South Africa and in 1935 reported them in the Transvaal, South Africa. Jeffrey (1952) records several lightning fires to native thatched huts in the Cameroons and Nigeria. South African farm literature has many such references.

Cowles (pers. comm. 1967) witnessed multiple lightning fires from one storm in the Natal veld. Pienar (1968) has reported on a lightning fire in the Kruger National Park that burned nearly 300 square miles there, which I visited about one week after the fire. Another lightning fire burned about 70 square miles a short time afterwards nearby. Wardens at Serengeti National Park, Tanzania, (Miles Turner), Tsavo National Park, Kenya (David Sheldrick), and Wankie National Park, Rhodesia (Bruce Austen) have all witnessed lightning started fires viewed from aircraft (pers. comm.). Nanni (1969) records seeing lightning fires started in the grasslands in the Natal Drakensburg on several occasions.

The following comments "From a Park Warden's Notebook" in the September, 1968, *African Wildlife News* is of interest:

> "January, 1968, was a most unusual month in the Serengeti. Instead of the clear skies and strong northeast wind of former years, a westerly wind started in early January which brought smoke and smog from the Uganda and Congo grass burning for days on end. There were frequent afternoon build-ups and very violent electric storms throughout the Park. On 31st January at 12 noon an enormous clap of thunder galvanized the Deputy Chief Warden's camp at Barafu and lightning struck the ground half a mile away in a cloud of dust and smoke. On the evening of 29th January while flying with Dr. Schaller amongst evening storms, another lightning strike was seen two miles south of Barafu. A large cloud of smoke rose in the air and gradually disappeared."

The following information in lightning fires furnished by the Secretary for Forestry, Republic of South Africa in 1968 and updated through the efforts of Mr. Banie Penzhorn (1971) is the most complete record I have found on Africa's lightning fires. The Secretary, however, also has written that:

> "It must be stressed that the number of lightning fires shown. . . are only those that necessitated suppression operations by the field staff. Such fires that are put out are reported as plantation or catchement reserve fires, but fires started by lightning and immediately extinguished by the accompanying rain are not mentioned. As a matter of fact, a considerable number of such fires are never even noticed. Evidence of such small fires that were not able to spread can be found in most plantations in the summer rainfall area. Dead trees, either single or in small groups, killed by lightning are also frequently encountered in plantations in this region."

The following table represents the lightning caused fires on the forest plantations in South Africa:

	No. of lightning fires	% started by lightning of total fires
1957	35	17
1958	22	13
1959	36	13
1960	24	16
1961	24	15
1962	20	11
1963	25	7
1964	16	6
1965	13	3
1966	38	8
1967	46	12
1968	39	13
1969	46	15
1970	24	15

Lightning caused fires have averaged 11.08 percent with a low incidence in 1965 of only three percent and a high incidence in 1957 of 17 percent. When this is related to the rather artificial condition of plantations in South Africa as well as their locations, it would appear that the natural incidence of lightning fires in some of these areas when the region was covered by natural grasslands must have been high indeed.

AFRICAN FIRE ENVIRONMENT

Plant Adjustment to a Fire Environment

The global aspects of a fire environment have been discussed as they pertain to the African continent; the climatic conditions for a fire climate, the ancientness of fire as evident from fossil charcoal, and lightning as the primary natural ignition agent for fire. There is still another expression of a fire environment particularly pertinent to Africa, but global in scope as well. This is the necessary response or adjustment that plants and animals have had to make to be able to live in a fire environment. It seems to me no mere coincidence that some of the most ancient of plant groups consist of species that have those necessary characteristics that permit them to live and thrive in fire habitats. Among these are such early vegetations as the cycads, tree ferns, ferns, etc., many of which not only trace their ancestry back as far as the Carboniferous time but have changed but little comparatively speaking since that long distant period. Today many of these species exist in habitats that are subjected to intense fires. This does not mean, however, that they cannot be killed by fire of the wrong kind and at the wrong time, for they, like all plants, have an "achilles heel" to stress.

The impact of natural fires, by a process of natural selection, has developed species that have the necessary "genes" or characteristics to withstand burning (Komarek, 1965). The concept that fires are ancient and were particularly prevalent in the Tertiary does ". . . help us to understand the origin of the vast number of species which today depend upon fire." (Harris, 1958). It is interesting to note that most of these "fire species" will not thrive in dense shade. It is sometimes very dramatic to see the reaction of such species where they are barely existing, crowded and shaded by other non-fire species, when the area is burned over. The competing species are destroyed or badly damaged and the "fire species" spread spectacularly. Because of the spectacular response many different plants are called "fire-weeds" in various parts of the world and apparently occur on all continents. One of the most striking is the fireweed of the boreal forest region, *Epilobium* sp., which after forest fires in northern circumpolar evergreen conifer forests, literally clothe entire mountainsides in a cloak of pink color.

As most of the many different kinds of responses to fire are well known to those interested in African fire ecology, there is no need to dwell upon this subject. However, I do wish to point out that there are responses of which we are only dimly aware. One of these is the fact that many grass species will start to grow after being burned even though no rain has fallen for several months. This appears to be a physiological response that certainly needs to be investigated. I have noted green shoots of *Hyparrhenia* sp. over 12 inches high where burned, whereas at the edge of the fire in the unburned grass the green shoots were barely visible among the dead grass leaves. In this area no rain had fallen for over five months. Vesey-Fitzgerald (1970) has written that . . . "After burning, the growth of ground shoots takes place without the incidence of rain" . . . in the sporobolus grasslands in the Valley Grasslands of East Africa. Buechner

(1963) also mentions growth of green grass after burning after long, dry periods.

Fire Ecology—And Early Man

Man evolved in a fire environment. He had to become a fire ecologist and not a "pyro-ecologist" that burned his house down, although no doubt this did occur before he became a successful "eco-pyrologist." In "Fire—and the Ecology of Man" (Komarek, 1967) I briefly discussed my ideas on some of these early adjustments to a fire environment by *Homo sapiens* and his immediate ancesters. Of more importance to us at present, however, is the impact on the vegetative cover of Africa by native tribes by their use of fire. The Stone Age man would have had very little permanent effect, simply because of his small numbers and the continent of Africa is vast. He was replaced by the Iron Age peoples who, because of smelting and the use of charcoal, may have had at least a temporary effect on wooded areas. Here again, their numbers were small in relation to the size of the land area and most of their habitations were more or less localized.

With the advent of pastoralism and farming, the impact grew greater (see West, 1969) and in localized regions these people certainly changed the local plant communities. However, all too often modern man, particularly the European and the American, with roots in the early development of forestry based on ideas developed in a very unique European environment, has looked with disdain upon the fire knowledge and fire use of native tribes wherever found. The modern science of fire ecology has shown that many of their ideas and uses were based on sound principles. What has confused this early use of fire by man is the reaction of local peoples to recent regulations and prohibition on the use of fire. It is interesting to note that the reaction of such local pastoralists and farmers to such laws was the development of many kinds of incendiary devices that would set fire long after the "arsonist" was gone. The development of such devices would be an interesting study in itself, both in Africa and America. Jeffreys (1945) has written about one such device in Africa:

> "Especially where authorities have given instructions that grass-burning is an offence, it is a favorite trick. . . to throw a piece of smouldering dung among dry grass some distance off a path so that by the time the surrounding grasses have caught alight. . . he may be perhaps three miles away from the scene. A more elaborate plan is to take an old hollow nut of the dum palm, stuffed with dung pressed in through the opening and plugged with a piece of rag. To this a light is applied, and the nut placed among dry grasses; the dung ignited by the rag, gives off great heat which smouldering, and the nut, glowing as a tinder for a considerable period, acts as a good delayed action fuse, often used when regulations, against grass-burning are rigorously pressed."

Much of the early opinions expressed on the effects of fire have been based on these kinds of fires caused by local peoples in retaliation against what they considered ignorant and unfair police action. The period following the early Europeanization of Africa is not the kind and types of fire the native peoples used before such influence or impact on their culture occurred.

I digress to point out that in the United States early propaganda by the forestry profession based on European forest fire exclusion philosophy discounted all the beneficial aspects of fire use and in retaliation local peoples also went to indiscriminate burning with many kinds of incendiary devices. None of these devices were necessary, either in Africa or America, before fire supression was forced upon the population. The resulting fires deliberately set when they could cause the greatest damage were then used as evidence as to the harmful effect of burning by foresters.

Some aspects of this policy have been documented in the United States in "Fire and Water, Scientific Heresy in the Forest Service" (Schiff, 1962) and by several papers in the first Tall Timbers Fire Ecology Conference (Stoddard, 1962; Beadel, 1962; Harper, 1962; Bonninghausen, 1962, and Komarek, 1962). One of the reasons that the Tall Timbers Research Station was started in 1958 was that the force of propaganda on fire exclusion had so indoctrinated not only the general public but the university systems as well, that the beneficial and necessary aspects of fire would be lost. The Charter of Tall Timbers Research, Inc., in Article II, states the following:

"Object: The general nature and object of this corporation shall be to acquire, own, operate, lease and control, and cause to be operated and controlled, any and all manner of biological stations, research and experiments, including particularly, without in any manner limiting the generality of the foregoing, the operation and use of a "fire type" nature preserve, the the conduct thereon of research on the effects of fire on quail, turkey, and other wildlife, as well as on vegetation of value as cover and food for wildlife, and the conduct of experiments on controlled burning for those objectives. . . to manage and conduct ecological research. . . including the carrying on of demonstrations or educational work in such fields as wildlife management tool. . .

"By "fire type" there is meant the maintenance, by controlled burning, of pine forest in an open and parklike condition, with herbaceous vegetation. . ."

The first Tall Timbers Fire Ecology Conference was called to bring together the scientific data on fire ecology so as to make a realistic base for proper forest, wildlife, and range lands. In the preface to that conference it was stated:

". . . the differences of opinion on the place of fire in nature and its use by man are no longer so apparent among those who actually manage or direct the management of our forest, grasslands, and wildlife. But now the public at large, the conservation groups, and the leaders of our educational systems must be reeducated to the concept that fire has a useful place and may even be a necessity in the conservation of some of our natural resources.

"Tall Timbers Research Station is dedicated to that concept and has as one of its primary interests the ecology of fire, both basic research on the influence of fire on the environment and the application of fire in land management. . . It. . . recognizes the right of the public to be adequately and honestly informed as to usefulness of fire in land management as well as to its destructiveness. This conference seeks to provide a common meeting ground where the results of research and experimentation may provide a more intelligent course to follow regarding the use of fire in the production of forest, grassland, and wildlife not only for the benefit of those professionally or privately engaged in land management but for the enlightenment of conservation groups whose energies have so frequently been wasted in a crossfire of misleading and opinionated information."

As some of the anti-fire specialists, or as Harper (1962) called them "fire-fundamentalists" are constantly being exported to all parts of the globe by various government aid programs of the United States, it is perhaps pertinent to point out that as recent as 1959 the late Dr. John T. Curtis, Plant Ecology Laboratory of the University of Wisconsin, wrote that the prairies and savannas of that State:

> ". . . have become victims of the bureaucratic dictum, that since most forest fires are the source of economic loss, therefore all fires are bad and must be prevented at any cost. This dogma has been supported by such an intensive propaganda campaign that there is danger of its being accepted as truth."

I have digressed simply to show that because of divergent opinions and the force of bureaucratic policies the long acquired knowledge of fire ecology by so-called primitive peoples or pioneers has largely been lost. In North America the fire ecology that was part of the Indian culture has long since disappeared. In Africa, some native fire ecology still exists and should be recorded before it is lost, preferably by individuals that are members of the tribe or group.

In Africa if fire had not been properly used before Europeanization the native tribes themselves would have suffered. They developed methods and techniques of using fire, some of which are still used today that show a remarkable knowledge of fire ecology. My wife and I have seen small areas of only a few acres along the border of Murchison National Park, Uganda burned out as holes in tall grasslands. These had been fired primarily to attract game out of the park in to such small areas so that the snares of the local people would be efficient. To burn out such small areas without firebreaks in these vast grasslands bespeaks a fundamental knowledge of fire ecology. In the Annual Reports of the Uganda Park Service (Wheater, 1969) the effectiveness of this method of poaching for the snaring of game is mentioned. Likewise, we had noted in many parts of Kenya and Tanzania, that in spite of all we had heard to the contrary, the Masai and other pastoral tribes were conducting their burning in many regions just as carefully and knowledgeably as the cattleman used to in Florida (Stoddard, 1962). To one not versed in fire ecology, some of this may appear haphazard or careless, but if the pastoralist had burned off too great an area, particularly at the wrong time, he and his grazing would have suffered. This burning is condemned by individuals that see the gradual disappearance in some areas of the tropical or semi-tropical forest vegetation. However, it should be pointed out that such vegetative communities furnish little in the way of food or other materials for the pastoralist and he is doing only what the European cattleman does when he clears or de-brushes his range.

Jeffreys (1945) points out that in Nigeria and the Cameroons the local people gave the following reasons for burning: "for good grass for thatching," for food production, for protection from leopards, to kill snakes, insects, etc.

He also mentions that the natives had a set time of burning: "We always know the time from a certain insect which comes out of the ground (Negemba)"; "we burn the grass after the following trees have produced flowers: Uko, Amba, Mbun and Ifiridin which shows the time of burning" (Ngi).

Jeffreys (1945) also remarks that native tribes had various rules, laws, or taboos on conducting fires and gives the following account on one such instant:

> "*Native attitude to grass-burning*. Njoya, Sultan of Fumban, French Cameroons wrote in a script invented by him about 1900 a history of his people, the Bamum, their laws and customs. His rules on grass-burning are reproduced here for the first time.
>
> "Chapt. XLII.–*Concerning bush fires*. 'If a man fires the bush or grass after the chiefs has decreed that no burning is to be done and that man is discovered, he will pay a fine of a slave to the chief: 3,000 cowries to the head of the Ngu Society and 600 cowries to the next senior of this Society.'
>
> "Chapt. XLII.–*Concerning bush fires*. 'If a man fires the bush piece of grass-land or bush to be fired for hunting and another man sets fire to it to catch the animals therein and the owner of the grass-land finds the man, and demands all the game thus captured, and the man refuses to comply, and the owner of the grass-land hails him before the chief, the chief will not order the man to hand over the game to the owner of the grass-land.' Njoya thus recognized not only the practice of grass-burning but the right to do so."

The Experimental Method

The literature, particularly the farm journals and papers of the early 1920's in Africa vehemently show the attitudes that sprung from the anti-fire attitudes of European forestry. It is remarkable how world-wide this philosophy became. However, also throughout the world during that period there was an awakening by foresters, scientists, and range managers that felt this was not true and had the courage to try and stem this wave of propaganda. It is well summarized by Greswell (1926) a forester in India but his comments were pertinent world-wide. They are as follows:

> ". . . statements. . . by writers on the Himalayan conifers. . . have forced me to the conclusion that our management has hitherto been based on pussyfoot principles. Excessive indulgence in alcohol is no argument for total prohibition. The same applies to fire and grazing and perhaps other natural phenomena to which our forests have been subjected for centuries. We talk glibly about following nature and forget that the nature we are visualizing may be an European nature inherited from our training and not an Indian nature. We, therefore, intuitively welcome the proof provided by the few cases in which they are so and by inductive reasoning arrive at general conclusions which may be incorrect if not dangerous."

Each continent seems to have had its "pioneers" in the science of fire ecology and so had Africa. These early scientists looked to the experimental method regardless of which continent they were on. This was not the approach used by the European and American foresters and those they had converted to an anti-fire philosphy. The earliest record of this approach in Africa which I have found is the experimental plots that were developed at the School of Agriculture at Cedara, Natal, South Africa, 1921. The results of these were first published in 1926 (Staples, 1926) and summarized and brought up to date by the same author in 1930. Because this paper has long been out of print and not readily accessible the opening paragraphs are quoted for it shows the kind of "climate" in which early experimental studies had to be conducted.

> "Studies in Veld Management. Introduction. It is hardly necessary, in view of the publicity which has been recently given to

these matters, to stress the importance of obtaining reliable information on the effects of veld burning and other factors affecting the management of our vast areas of grassland.

"The practice of veld burning in particular has aroused a considerable amount of controversy both amongst farmers and those advising the farmer. Is burning necessary and if so, what is the best time of year to burn and how often, are questions which are often asked.

"In order to obtain reliable answers to these and other questions affecting the management of the grassveld in the more humid areas, a comprehensive system of experiments was laid down in 1921 at the School of Agriculture, Cedara" (Staples, 1930).

I had intended for this paper to bring together at least a list of the experimental studies on fire in Africa but this has not been feasible, for there was literally an "explosion" of such studies shortly thereafter. This needs to be done, however, for Africa certainly leads the world in the number, quality, and length of experiments in fire ecology and I will be grateful for any references to any such experiments. Many experiments were conducted and results only filed away in main offices, although often the results were put to use. There was no need to "publish or perish" and few funds for publication were available.

The "explosion" in such studies I believe leads very clearly to one individual who not only encouraged the experimental method but added to it the "holistic" approach which means that the entire environment or eco-system must be considered—the forest as well as the trees. This is Dr. John Phillips, to whom we have dedicated this conference, who:

". . . was appointed Professor of Botany at the University of the Witwatersrand in July 1931. He found to his joy that the University had a large piece of land some fourteen miles from Johannesburg. . .

". . . Phillips, in 1931, at once initiated experiments on grasses at Frankenwald. . .

"It is the continuity of experiments, many of them maintained for decades, which gives a particular flavor and significance to the work carried out at Frankenwald. It is for this reason that Frankenwald has sometimes been described as 'the Rothamstead of South Africa'" (Roux, 1969).

The students that studied at Frankenwald spread the experimental methods and holistic philosphies in future years all over East, West, and Southern Africa. It is virtually impossible to investigate the ecological literature on Africa south of the Sahara without having to study data and information that had their roots in Frankenwald and the teaching of Dr. John Phillips. This conference on African Fire Ecology has been the first attempt to bring together all this vast amount of information on fire ecology from these as well as many other investigators. It is no coincidence that most of the speakers at this conference are the former students, and in one case, a "grand-student" of this remarkable man and the ecological experiment station that began in 1931. Many of the experiments there, as at Cedara and elsewhere, continue to function, producing more valuable results as they grow in years in spite of changes in governments. Most of these experiments, however, have been related to the grazing by domestic livestock but nevertheless, they show certain basic principles in relation to fire ecology and fire use. There are a few generalities that may be pointed out from a perusal of many of these experiments that were and are being conducted from East Africa to South Africa.

1) Fire is a controlling agent in the constant fight between grasslands and forest or bush land.
2) Grasslands, in the absence of fire, become moribund, the grasses die of old age and much bare ground results.
3) That fire at the end of the wet periods and when the grasses are still relatively green is fairly cool, or less intensive, and thus a savanna or mixture of grassland and open parkland of trees develops.
4) Fire at the end of the long dry period, and before rains begin, is hot, more intense and widespread, and the result is largely a grassland with the "bush" or trees remaining only suckers within the sward.

These generalities apply only when there is no intensive or excessive grazing by either domestic livestock or the many wild large mammals for which Africa is so famous. In some respects, the impact of wild animals on the vegetation creates conditions that resemble that caused by fires.

Experimental studies in other parts of the world, including North America, South America, and Asia also appear to bear out these general statements. Thus, I conclude that these are general principles of worldwide application, not just something that occurs in any one place. Certainly there are exceptions because of soils, topography, and other conditions, but these are *exceptions* and not the general rule.

Only in relatively recent years have experimental methods been designed for fire use in relation to the management of the large wild animals of Africa. The most complete and oldest of such experiments are those at Kruger National Park which were put into operation after a period of attempted fire exclusion. It is interesting to note that the effects of past fire exclusion in some areas have resulted in changes in habitat that are "problems." The area around Pretoriuskop was once famous for its large abundance of herbivores. The exclusion of fire for seven years was enough to change the grassland into a bushland. Today the trees are of such size that they are virtually "fireproof" and shade the ground to such an extent, along with the grazing of the sparse grass, that fire alone can no longer change the area back to grassland. Many observers do not realize that with fire exclusion, as with over-burning, there can come a point of "no return." The policy of fire exclusion in many parts of the world has created such conditions that now it takes expensive methods and chemicals to make the region productive of economic grass, forest, or wildlife. The problem of "brush" invasion caused by over-grazing and fire exclusion has become a worldwide problem.

CONSERVATION AND FIRE ECOLOGY

Darling (1962) in "Conservation and Ecological Theory" wrote that

> "Conservation is quite definitely the applied science of ecology, ecology in action, but it is not a mere technology. It does not twist natural laws to economic ends, but aligns land use—involving the whole plant and animal biome—with ecological principles of climatic influences, succession, habitat, community, niche-structure, behaviour and the maintenance of conversion

cycles. This last item of *conversion cycles of matter* is at the very root of modern ecological research. . . ." (Italics Komarek).

Fire ecology and its proper application concerns itself with all of the above mentioned items; climatic influences, succession, habitat, community, niche-structure, behaviour and the maintenance of conversion cycles. Fire is a natural and basic component in the "*conversion cycles of matter*". The fact that fire affects in varying degree every one of the items mentioned by Darling makes fire ecology and management pertinent and necessary in the conservation and management of the National Parks in Africa. These parks, are for the most part, devoted to the preservation of the many large and small and varied animals so unique to Africa. At the very base of this conservation and management however is the maintenance and re-cycling of plant succession, as well as the proper operation of these "conversion cycles of matter".

Professor Russell (1968) in a report to the Tanzania National Parks Board in a paper titled "Management Policy in the Tanzania National Parks" wrote:

> "A very important research problem . . . (to) investigate as a matter of urgency is the exact conditions required for the regeneration or maintenance of the open acacia woodlands and grasslands, that are such a characteristic feature of many areas in the National Parks, and which contain a characteristic assemblage of mammals and birds. This is a habitat that may be unstable in the sense that it is only a part of a natural vegetation cycle which goes from open grassland through young acacia thicket to mature trees in open parkland back to grass-land as the trees die. *The time scale of the cycle is probably strongly affected by the frequency of fire. . . .*" (Italics Komarek).

He also mentioned that another very important phase of management research should be to develop

> ". . . improved methods for fire control, both in the preventing of fire at different periods in the dry season, and in the efficient use of fire at different periods in the dry season. This kind of research is difficult and costly to organize and to find the right staff to carry it out; but "it is very important that these

methods be developed *because the controlled use of fire is the most powerful tool of habitat management available* to the Trustees." (Italics Komarek).

The afore-mentioned African experimental studies have shown that fire does indeed re-cycle the plant succession from grasslands to bush and to trees and vice versa under many varying climatic and soil conditions. However, from a management viewpoint the National Park administrators have yet to obtain from the research biologists some of the more pertinent data needed for the proper use of this valuable tool, fire. The large animals of Africa have attracted much research attention and many excellent investigations have been conducted but in the main these have failed to take into consideration the management methods needed to maintain the animals habitat without which it cannot exist. The needs of Park management have apparently been unrecognised or found less interesting than other studies. One Park director expressed this view succinctly when he remarked that it is interesting to know the gestation period of an animal or to conduct census's but what use is such research to management if the frequency of fire necessary to maintain the habitat is not known and under what conditions fire should, or should not be used. It is my personal opinion that entirely too much emphasis has been put on what are largely zoological and life history studies, as interesting as these maybe, when what are needed are thorough ecological investigations that will give the needed information for practical management, and not theoretical studies. Many of these lack what Professor Phillips constantly exhorted his students at Frankenwald—the holistic approach. Many excellent investigations have been conducted on the large African animals with little or no reference to fire though the effects of fire may have been an obvious ecological factor present.

Today great concern is expressed, and rightly so, because of the disappearance of the park-like acacia landscape of several species and its grassland component. And yet I have been unable to find a single thorough study of a single acacia species and the necessary requirements for its cycle of life and relationship to fire.

Likewise many studies lack the comprehension of the variability of fire and treat it as if fire is always the same. No attention is focused on the fact that different kinds of fires create different effects: a head-fire versus a backing-fire for example. There is not only an extreme variability of the effects of different kinds of fire but the conditions under which the fire burns may make such diversity depending upon such variable factors as winds, soils, moisture, temperature, etc. All of these variable factors occur with fire in nature and provide an exceedingly large amount of variation and diversity in the wildlife landscape (in this term meaning both plants and animals). The holistic approach however has not been applied to the the fire itself. This is partly due to the fact that the burns are usually set by hired personnel, not by the investigator, so that the researcher never really becomes quite familar with the fire as does the native burner. However this is the kind of information the Park administrator must have if he is to use effectively "the controlled use of fire . . . the most powerful tool of habitat management".

The impact of the large and small grazing and browsing animals, from harvester termites to elephants, on the fire environment has been studied only cursorily and then by only a few investigators. The interactions of the different, and differing, populations of these animals on their, and other animal, habitats as well as their impact on fire ecology is necessary for the proper ecological management of such Parks. The management must know at least the general trends or knowledge of such variable interactions between plants, animals, and fire. I cannot help but wonder whether the "elephant problem" of too many elephants isn't to a large degree caused by improper habitat management and in particular improper fire management. Certainly in many regions the vast herds of African herbivores and other large mammals lived in virtual harmony with the native human populations and their mosaic burning or fire management and in fact with both fire policies as well as fire methods. However in recent years the impact of European culture, expanding native culture is rapidly destroying this commensal harmony. Proper management by the Park officials will have to replace this former method of "native fire management" on most, if not all Park areas.

Of first importance is the necessity of retrieving knowledge of the fire uses and fire methods of the native people before this age old wisdom is lost forever. The medical profession and its pharmacopoeia is heavily indebted to the "native lore" and usages of many native peoples and I believe a like search for knowledge of fire ecology and fire management among native peoples of Africa would likewise be rewarding and useful.

Perhaps secondly would be the necessity of a better knowledge of the fire relationships, ecology or aute-ecology of the important tree and bush species and their relation to the "fire cycle". More attention needs also be placed on studies of the major grass and forb species necessary for a wide diversity of wild animal and plant species. Most of the fire research has been towards improving the range for domestic cattle and sheep with habits and needs quite different from the variety of animals that inhabit the African wildlife landscape.

Study likewise needs to be focused on the interactions of the wild animal grazing or browsing impact on vegetations and this relationship to fire. It would appear to me that this grazing and browsing impact in conjunction with fire produces even greater diversity than either alone and this may be one of the reasons that the large grazing and browsing herds of Africa are so unique.

More attention must be paid to the study of animal relationships to the fire induced habitat, instead of only their behaviour, which seems to be the prevailing fad, so that we can learn where in the "fire cycle" populations prosper or decline.

Let me emphasize that the necessary investigations on the relationship between African large mammals, and their plant and other animal associates to fire ecology and fire management must be conducted soon, particularly in East and Central Africa, if future generations of man are to view these unique animal and plant assemblages. Time is of the essence in these studies if we are to use fire, this—"most powerful tool of habitat management." Without the proper habitat the African wildlife landscape will become "historic."

In conclusion I wish to acknowledge the excellent cooperation and interest shown in our studies of fire ecology in Africa, as well as this Conference, by so many individuals and organizations on that continent. The National Parks Boards and Forestry Departments of Republic of South Africa, Rhodesia, Tanzania, Kenya, Uganda all have spared no effort and have been most helpful. The Natal Parks Board of South Africa was also of great assistance. Neither our studies or this conference could have been conducted without the

friendly cooperation of so many people in Africa, much too numerous in number to mention and so to all we say "thank you".

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