Fire—and the Ecology of Man

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AS I review the past six Annual Tall Timbers Fire Ecology Conferences, the 77 very competent papers presented, representing a diversity of disciplines from a large segment of the globe and the many stimulating, inspiring and mind-searching discussions generated thereby, I am reminded of the following statement from Dobzhansky's Mankind Evolving (1962):

> Science is cumulative knowledge. This makes scientific theories relatively impermanent, especially during the epochs when knowledge piles up something like geometric progression. Scientists should be conscious of the provisional and transient nature of their attainments. Any scientist worth his salt labors to bring about the obsolescence of his own work.

Certainly our efforts have added to "cumulative knowledge" in "something like geometric progression." Many of our ideas have grown, changed and continue to evolve, and we all labor to bring about the obsolescence of our own work.

Dobzhansky states additionally:

> Two rival trends vie constantly for influence in science—specialization and synthesis. The former usually predominates. Scientists are specialists; a good specialist is able to master only some fraction of human knowledge. . . . Attempts to synthesis knowl-

> edge are, however, indispensible. The need is more keenly felt the more knowledge becomes splintered. Failure of synthesis would vindicate Albert Schweitzer's remark: "Our age has discovered how to divorce knowledge from thought, with the result that we have, indeed, a science which is free, but hardly any science which reflects."

With the above in mind I am compelled to cross the frontiers of, and into, scientific disciplines somewhat new to me and to cross the rough seas of the human behavior we call "the arts." In this way I hope to bring to you the synthesis of which Dobzhansky speaks and reflect upon the nature of fire as an agent in the evolution and culture of man.

To accomplish this, we must first look into the basic nature of fire, and to those natural laws which govern its behavior in physics, chemistry, and biology: Secondly, into the evolution and the nature of man and his natural environment.

WHAT IS FIRE?

Fire was regarded by the ancient man as a tenuous material substance classed with air, water and earth as one of the four basic elements. Today, however, we consider fire as a principle of combustion manifested by light and heat. The physicist looks upon it as a manifestation of one of the basic sources of energy—heat; the chemist as a process of rapid oxidation.

The nature of heat baffled investigators for many years, until 1798, when Count Rumford (Benjamin Thompson) of Massachusetts concluded that heat was a form of energy (Beiser, 1956):

> This belief has stood the test of time and is now universally accepted by scientists. It has the merit of obeying the law of conservation of energy; energy can neither be created nor destroyed, but it can be changed from one form to another.

Thus fires in the true scientific sense do not "destroy" but change one form of energy into another.

Fire has been called "the oldest chemical manipulation in man's history" (Vaczek, 1964) but an understanding of this type of reaction is credited to Antoine Lavoisier, the father of modern chemistry.

He reported on a series of detailed experiments in a paper titled, *Of the Decomposition of Vegetable and Animal Substances by the Action of Fire* (Traite' Elementaire de Chimie, 1789) in which he demonstrated the reaction of fire and named the process, oxidation and the active gas, oxygen.

It is interesting to note that the knowledge of this basic chemical reaction was first demonstrated and understood by the action of fire on plant and animal substances.

HOW DO FIRES START?

Several basic forces are involved in the ignition of fires, such as, compression (volcanoes), chemical action (spontaneous combustion), motion (friction), and nuclear (fission and fusion). All of these occur in nature except the latter, and all have been reported as ignition factors in natural fires on earth. The nuclear explosions induced by man, do, however, create vast fires in forest and grassland.

Friction appears to be the basis of most natural fires as well as those ignited by man. The most common in a state of nature is lightning which is believed to be caused by the friction of moving raindrops. The recent development of apparatus that records the electrical discharges within and around thunderstorms shows a nearly unbelievable amount of such activity. There should no longer be any doubt, particularly because of the information presented at these conferences, that lightning was, before the evolution of man, the major source of natural fires.

Lightning fires, over long periods of time, in fact, have produced a "fire mosaic" of vegetations of seral nature which we commonly call fire environments. The North American continent as an example is literally swept with what appears to be waves of electrical energy in more or less regular periods throughout the summer months (Komarek, 1965). This electrical activity continues to ignite a very large number of fires in spite of the landscape, greatly man-altered. There is no question that man has changed the natural "fire mosaic" and the natural fire environments by his activities, including his use or non-use of fire. However, to state that he is the major responsible agent, as some have, of the American grasslands is false in the light

of the evidence at hand. In fact, it now appears that the major plant and animal associations of this continent appear to be a vast "fire mosaic" interrelated and interwoven very closely with other climatic forces as well as with other factors such as climate, topography, soils, etc.

WHAT DOES FIRE DO?

Chemical Effects.—As Lavosier noted, the elements, when plant and animal substances are burned are not destroyed but *changed*. The changed material that concerns us here is the residue left after burning—the ash. Combustion of organic materials in the field are never as complete as in the laboratory, but the oxidation process is nevertheless identical. Repeated experiments have shown that fire *changes* organic material, in which nutrients are not readily available, to ash. In ash the nutrients are made more soluble and more quickly available to plants. The resulting use by plants then makes this burned organic material more useful to animal life through higher concentrations of minerals and protein. Much study needs to be given as to the effect of fire on minor elements and other chemical compounds necessary for living things.

Much nitrogen is released into the air by burning but burned soils do not necessarily, in fact rarely, show a decrease in this important element. The action of the soluble nutrients in the ash influence the decomposition of the remaining organic matter and the nitrifying bacteria are increased in both number and activity. The living roots readily utilize the soluble nutrients from the ash at the first rain. A common component of many fire plant communities is legumes whose nitrifying bacteria are likewise enhanced.

Physical Effects.—There are some well known physical aspects of fire, usually forgotten, that need to be considered. One of these is that the greatest amount of heat from any fire is *above the burning material*. Likewise, repeated studies have shown that soil, particularly damp soil, is a very good insulator and only in unusually severe or intense fires where a *great amount of fuel is burned* is the soil heated appreciably. Thus, the primary living parts of many plants are well protected by a very small amount of soil covering. Similarily, only

very shallow and meager burrows, are needed to protect animal life as the fire sweeps overhead.

Another important physical character of burned over ground is the dark color of the ash and other residues of incomplete combustion. This in turn absorbs more heat from the sun. In northern climates this additional warmth may be the difference between the establishment of a spruce forest or a muskeg. Under the accumulation of more and deeper mosses in the absence of fire, the permafrost develops nearer the surface of the ground prohibiting the establishment of trees. Upon burning, the dark ground absorbs sufficient radiant heat from the sun so that permafrost is forced to retreat deeper into the ground. In more southern climates, this same effect can have a decided influence upon the living things inhabiting some areas. The increased warmth can also speed up the chemical and physical processes in the soil as briefly mentioned earlier in relation to nitrifying bacteria.

Biological Effects.—Before discussing the biological effects of fire in detail, I wish to point out that there are differences between lightning ignited fires which generally occur during *the reproductive stages or periods of plants and animals* and man-caused fires.

Secondly, I wish to call attention to the possibility that most, if not all, so called catastrophic or "famous" historical fires given as the "proof" for fire exclusion policies resulted from *man-caused unnatural accumulations of large quantities of highly flammable plant material.* In nature, except in very rare instances, a "build-up" of such large amounts of fuel does not occur.

This is not to say that fires of high intensity did not, and do not occur in nature. Studies of these kinds of fires and their effects on plant and animal life, soils, water-sheds should not be confused with the more usual fires and should be considered the exceptional and not the general rule.

The impact of fire on the environment and the plants and animals that live therein is very great and time will permit only a small selection to be presented now.

Natural selection.—Fire as it sweeps over the ground removing various amounts of the vegetation certainly changes living conditions for both plants and animals drastically. Those with the necessary

characteristics (or genes) that protect them from the fire continue to live and in most instances thrive while others not so protected are eliminated or reduced. Thus, recurring fire acts as a natural selective agent. It is striking to me that the most ancient groups of plants, in general, exhibit characteristics which have better fire survival value.

Dyer (1965) in *The Cycads of Southern Africa* writes,

> For Cycads to have propagated themselves for over 50 million years, with little change in basic character, is something to be marvelled at. One may speculate on the reasons for this phenomenon. On the basis that the strength of a chain is the strength of the weakest link, it is obvious that the ancestors of modern Cycads had no really weak link, or, if they did, it was compensated for in another direction. This does not imply that there has been no change in the species from one era to another, but that new forms or species have evolved as and when environmental changes created a sufficiently strong stimulus. The stock possessed the genetic factors required for adaptation to the changing environment throughout the long period of survival.
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> Temperature fluctuations was probably the most testing factor in the earlier phase of survival and species today suffer less permanent damage than most other plants under wide fluctuations of temperature. After the evolution and spread of grasses and the advent of generally drier conditions within the environment Cycads were put to the critical test of fire.

Among conifers many species exhibit a wide range of "pre-adaptations" to fire, such as serotinous cones which require heat to open them, need of mineral soil for germination and early survival, ability to sprout when above ground portions are killed back, thick bark, the ability of some wood to dissipate heat rapidly, thus protecting the cambium or living layer, and many others.

Fire as it sweeps over the ground quickly creates considerable stress and relief on both plant and animal life. This stress and relief is not only on the individual plants and animals but on the entire community or association as well. Sudden changes occur in availability of food or nutrient, shelter or competition, and in regard to light, predation, territoriality, reproduction, heat radiation, and others. I ask the fol-

lowing questions of the *bio*-scientist in whatever division of science he may be:

1. Is the *bio-mass* changed by fire, and if so, how?
2. Is the *energy flow* changed by fire, and if so, how?
3. Is the *feed-back* changed by fire, and if so, how?
4. How do these changes relate to the evolution of living things?

Time will not allow me to even list the many reactions that occur in a fire environment but I do wish to mention a few of the more obvious ones.

Food.—The regrowth from burnt grasses and shrubs is higher in protein, calcium, potash, phosphorus and other elements necessary for the development and maintenance of life. What is the mechanism that makes many grasses produce more quantities of seed of better quality when burned at the right time? Is this due to better control of disease or insects, to fertilization by more quickly available nutrients, to release from competition of other plants, to the removal of the dead grass material as a mulch or to some other factors unknown?

Is the apparent proliferation of animal life, such as the vast herds of mammals that have, and still do, inhabit grasslands where fire has always been a factor due to the same causes? In Africa, such animals are still found in abundance in environments where the effect of fire on grasslands is now more pronounced due to man's indiscriminate use of fire. The regrowth of those "fire-selected" plants is always higher in protein, in calcium, in phosphorus and in potash, and perhaps other necessary elements.

Reproduction.—We have already noted that the effect of fire increases seed production in "fire-selected" grasses. Can this same reaction of the "re-cycling" of necessary elements by fire also play a part in animal reproduction, as well as in plant production? Most over-production of animal life seems to occur where man has altered the vegetational succession to a great extent from what were probably pre-man conditions. In connection with deer irruptions or over-production in fire-excluded regions in the United States, Aldo Leopold (1937) states that over-production was not known in the Chihuahua section of Mexico where the Sierras "burn over every few years" and that overgrazing by deer seemed to be unknown. Al-

though the relationship of fire to deer is clouded with the grazing of livestock in areas protected from fire, I cannot help but wonder if some deeper factor is involved. Is it possible that this highly nutritious regrowth of burned grass or shrubs is also higher in some chemical or other component that might even assist in "regulating" reproduction and consequent over populations? In the light of the studies on chemical contraceptives this may well be possible. Certain Indian tribes are presumed to have oral contraceptives of vegetable origin and if this is so fire might be a "recycling agent" as it is with the other afore-mentioned minerals. The experimentation and study of the possible relationship of the regrowth of burned vegetations in connection with vitamins, hormones, population regulating chemicals as well as the so-called "minor elements" should be very fruitful and could have far-reaching effects in our understanding of both animal and plant populations.

Fire Environments.—The foregoing synthesis, as well as our past five fire ecology conferences certainly demonstrate that

1. We have many "fire-environments" wherever fire occurs in nature and that the basic properties and principles that under-lie these environments are the same.
2. We have shown that the basic laws of the sciences of physics, chemistry as well as biology apply and are concerned in these "fire environments." We have had time only to point out a few of the natural processes that apply; oxidation, heat, electricity, mutations, and natural selection.

Thus the differences that arise when comparing the effects of fire are local and variable in nature and are often confused or obliterated by activities of man such as over-grazing, fire-exclusion, and the over-use or mis-use of fire. We must not lose sight of the fact that man, in a great many ways, has altered the earth upon which he lives. I seriously doubt if we can say that there is a single square mile on this planet that has not been in some way affected by this relatively new agent—man.

Historical.—On the North American continent primates once flourished and then disappeared rather suddenly about 35,000,000 years ago. At about the same time our grassland—the largest continuous grassland in the world—appeared along with the formation

of the vast mountain chain that extends from the northern to the southern end. Man came here much later, well developed as man and with a knowledge of the use of fire. Thus to study fire as an agent in the ecology of man we must go to Africa and Asia but let us not forget that the basic principles of fire are the same wherever they occur.

Through the many studies, excavations, and observations of investigators such as Dart, Leakey, Pei, and others, we are beginning to develop a comprehensive outline of man's early evolution from earlier primates, dating back perhaps as much as 1,500,000 years. To me the following things are of great interest in the discoveries of pre-man or early man's bones:

1. *Wherever* other bones are associated with these remains they are *predominately of grassland or shrub-land mammals.*
2. *The descendants of these species* if they are still in existence *inhabit fire environments.*
3. And so it follows both the *pre-man primates as well as early man inhabited fire environments* and had to be "fire-selected" to be able to continue to live in such environments.

I must digress for a moment to point out that animal life does not "fear" fire except in catastrophic fires and then it reacts only in the same manner as to any other catastrophe. The "fear" of ordinary fires in nature is in direct relation to man's *culture*, not to his nature. We who work with and study fire often observe animals unconcerned about fire, and we fail to report such observations because they are so common. However, let me cite just a few examples out of personal experience. Deer, cattle, and horses often watch the fire, and somtimes seek it for warmth, or for relief from flying insects. Quail will fly up ahead of a fire and land on a smoking burn. This is quite common and was pointed out by H. L. Stoddard, Sr., the dean of quail managers, many years ago. Our labrador retriever Prince hunts around, both ahead of the fire and on the burn behind, as well as through the flames. At times we have been concerned about the safety of not only Prince but of our cows and horses by their seeming nonchalance about the dangers of fire.

Three weeks ago (January 18, 1967) while burning just before dark, I observed a robin (*Turdus migratorius*) feeding in front of a

fire. I watched the bird's behavior for 32 minutes and during this time it fed within three inches of flames that varied from one to two feet high. When the fire "crackled" after a gust of wind the robin hopped out of the way and when the flames lowered it came close to them. The robin fed on the smoking burn and had an uncanny ability of side-stepping smouldering and smoking brands, as had our dog Prince. Seven times during the 32 minutes it hopped onto fence posts, as I was burning through a "rough" fence line; sometimes ahead of the fire but mainly over the smoking burn. However, three times it sat upon the fence posts and the fire burned directly under it, once the flames were nearly half the height of the posts or about 2 feet. The last I observed the robin it was getting quite dark. He sat upon a fence post and sang as the flames passed beneath him.

Paintin (1965) in a letter to the Editor, African Wild Life writes:

> Sir: Recently in the Sebungwe area of Rhodesia where we were doing a research project, some honey-hunters started a bush fire on the banks of the Lutopi river.
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> I arrived on the scene some time afterwards to find the perimeter of the fire swarming with hundreds of Drongoes (*Picurus adsimilis*) and a few Grey Hornbills (*Lophoceros nasutus*) and Lilac-breasted Rollers (*Coracias caudata*).
>
> The Drongoes seemed to favour the crosswind sides of the fire rather than the downwind side while the Hornbills and Rollers favoured the downwind side.
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> The Drongoes showed no fear of the fire and frequently sat on branches and grasses two or three feet from the flames, five or six feet high. How they managed to withstand the heat I do not know.
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> As the insects were flushed from the grass by the fire the Drongoes would pick them out of the air or off the ground as they landed, and would then return to a perch near to the fire once more.
>
> As I had travelled through this area frequently and had never before noticed this dense populations of Drongoes I assume that they had been attracted by the smoke column from far afield.
>
> I had noticed this behaviour on several occasions in the past but never to such a great degree.
>
> The Hornbills and Rollers played a very minor part in the insect slaughter. Bulawayo, S. Rhodesia

In the literature, field or laboratory observations on the reactions of primates to fires are nearly non-existent.

Dr. Irven DeVore has written me (1967) as follows in regard to baboons:

> I do not know of anything in print which refers to baboons and their reactions to fire, but it is certainly true that baboons live in a fire environment over much of savanna Africa. I have seen them in close proximity to fires on a number of occasions, and they are likely to move into a burned-over area just as soon as the ashes are cool enough to be tolerable. Various predators, especially jackals and raptorial birds, also move into such areas looking for insects and carrion. Ungulates move in to browse on the new grass shoots that are fostered by the burning. We have taken some film of fires in Nairobi Park where we were studying baboons; I believe this film shows fire burning right down to the river's edge, under the trees where the baboon have gathered for the night.
>
> In any case, my observations would certainly confirm your impression that baboons have no "irrational" fear of fire. The heat and smoke are unpleasant, obviously, so they avoid it, but certainly do not flee in panic, and often turn the burned-over areas to their advantage very quickly.

Kenneth P. Oakley in On Man's Use of Fire (1961), with comments on tool-making and hunting writes:

> The fact, mentioned in discussion by Professor Schultz, that the Philippine tarsier has been named *Tarsier carbonarius* (Heude, 1898), on account of its propensity for picking up hot embers from campfire sites, suggests that man's ancestors far below hominid level of evolution may have been attracted to natural fires and toyed with burning matter just as rooks and some other birds exhibiting "anting behavior" seek fire and smoke (Burton, 1959, pp. 99-109. . . .
>
> These considerations lead one to bear in mind that man's ancestors may have become familiar with burning matter plucked from natural conflagrations long before such activity became *purposively* fire-using.

Wharton (1960) reported that the natives in Malaysia have told him that the Tarsiers (*Tarsius carbonarius*) will come and sit around a lone campfire "like little old men." He wrote (1958):

> Fires, and lamps blinked by hand, hold a powerful attraction for

> the tarsier. I was told that in the higher mountains on a cold night during the rainy season, the natives often build a fire and then withdraw. The *amas*, as the Manobos call them, then gather around the fire. Sometimes there will be three or four, hopping about like miniature kangaroos and warming themselves before the blaze. . . .
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> The Manobos insist that the tarsier eats charcoal. So persistent is this belief that the specific name of the Mindanao tarsier is *carbonarius*. The fact that it is often found in burned over areas may have something to do with this legend. Although I placed charcoal in every cage for weeks, I never saw an indication of a liking for this material.

Hough (1926) in *Fire as an Agent of Human Culture* wrote as follows:

> There is some data, more or less reliable, on the psychology of the higher primates in respect to fire. Purchas quaintly says; "The people of the countrie, when they travaile in the woods make fire when they sleep at night; and in the morning when they are gone the Pongoes will come and sit about the fire till it goeth out; for they have no understanding to lay the wood together." (Pongidae = Gibbons, chimpanzees, gorillas)

Certainly this field should be explored by primate biologists. There probably is a considerable amount of information on the behavior of animals and fire that has not been recorded in the literature because it is so common-place. Certainly many a woods burner has noted the concentration of hawks, etc., over burning lands but few ornithologists have recorded such observations.

I believe, then, that our pre-man ancestor was a product of "fire environments" as well as the other assemblages of plants and animals that we place in this category, and that he was "attracted" to fires and their consequent burns for food of both plant and animal nature. He likewise came to the natural fires, largely ignited by lightning, for warmth and protection from insects and that fire was no more nor less frightful than it is to those creatures that now live in such environments. That he, by *nature*, was also attracted by fires and probably sat around them for many thousands of years "like little old men" seems probable. Thus it follows that early man and his nearest relatives were "fire-selected" in the same manner and by the

same natural processes as were the other animals in fire environments.

FIRE AS A HUMAN AGENT

Regarding fire as cultural development, Hough (1926) states,

> Man has possessed fire so long that the inquiry as to whether it is a human characteristic has some point. And the question is: Shall we then extend the use of fire to other primates than man? It is evident that of all animals primates are the only species who could undertake the task of caring for fire. As a deduction from the leverage of fire possession shall we say that here began the elevation of primates toward man.

When this early primate *knowingly* and *purposely* reached forward, picked up a flaming stick, set afire some fuel, and communicated this to another the "elevation of primates toward man" began. Already inherent in this early primate must have been a sense of educability. The actual use, *knowingly* and *purposely*, of fire sets man apart from the rest of the animal kingdom. He then had to learn how to control this wild and powerful agency—to domesticate it. The species or race that accomplished this acquired a very decided "adaptive" advantage over all others, following a long period of trial and error in its use. Fire gave man the necessary "tool" not only to change his habitat but to create more livable habitats out of unfavorable environments. This one tool gave man the power to inherit the earth. No other animal has so completely occupied the reaches of the earth and no other animal has so completely dominated its environment. Fire must have been his first and primary "tool," the *first control* of a major natural force or agency, and by its use he had already occupied much of the earth before he acquired other tools and other controls. For these reasons he has become not only man from a taxonomic viewpoint but man as a very dominant, probably the most dominant, *ecological and cultural species*. Because of this primary "tool," the use of fire and its control, he developed "culture" and "art." This early beginning started a chain of circumstances depending on the use and control of the major forces in the universe such as have never before occurred on earth and of which as yet we can see no end.

Man has accomplished this because he learned to work with the major natural forces instead of "adapting" to them. He then started a process he is still continuing and that is of "adapting" the various environments of the universe to him. This has only been possible because of what one may call the mixing of his genes with what we call man's culture—the mixing of biological and cultural evolution. Dobzhansky (1962) has very succinctly pointed this out as follows,

> The path of evolution leading to the emergence of mankind may . . . be sketched as follows. One of the species of *Australopithecus* (if, indeed, there were several contemporaneous ones) became dependent for survival on tool-making and tool-using. It adopted, thereby, a way of life that no other species ever led. The new way of life created a challenge to which the species responded by becoming even more dependent on the invention of better tools that could be used in new ways. The successful response to the challenge, via natural selection accelerated the tempo of evolutionary change. The species became classifiable as *Homo*, no longer *Australopithecus*.

He also says,

> Suppose, however, that a favorable mutation or an important invention such as the use of fire appeared in or was made by *Homo erectus pekinensis* somewhere in China. It probably would have conferred an adaptive advantage on the clan, tribe, or race in which it arose, and these favoured populations, increased in number, probably over-flowed into the territory of neighboring populations. They did not necessarily keep their genes or their inventions for themselves alone because populations of the same species usually mate when they meet.

Later in his book *Mankind Evolving* he says,

> . . . The human species is biologically an extraordinary success, precisely because its culture can change ever so much faster than its gene pool. This is the reason cultural evolution has become adaptively the most potent extension of biological evolution. For at least 10,000 and perhaps 1,000,000 years man *has been adapting his environments to his genes more often than his genes to his environments*. And the supremacy of culture in adaptation will continue in the foreseeable future. In this sense, but in this sense only, it may be said that man has escaped from the clutches of his biological past and has become to some extent master, rather than a slave, of his genes.

FIRE AND HUMAN CULTURE

The meaning of culture is as difficult to define as are the various aspects of fire. Keesing (1958) in his *Cultural Anthropology* points out that there are "over one hundred and sixty different delineations of the term "culture" by anthropologists and others." He defines culture as ". . . the totality of learned, socially transmitted behavior, or "custom." He also delineates the following traits that may be considered cultural,

> Culture is concerned with actions, ideas, and artifacts which individuals in the tradition concerned learn, share, and value.
>
> Elements of a culture have a function. They *do* something, have *meaning*, for the people concerned, within the total context of their culture.
>
> Any break in the learning chain would lead to their disappearance. Broadly considered, all of human culture from its beginnings has a continuity in trained human minds.
>
> Biological tendencies in modern men are seen by the anthropologist as intricately bound up with cultural factors. Even separating them conceptually involves an often difficult exercise in thought.

Note how the use of fire fits into these various expressions of culture. Using fire is an *action*, it *does* something, has *meaning* for the people concerned. It can be *communicated* to others of his species, it consists of *learned habits*, it has *value*, and it is a *socially transmitted* behavior of "custom." The use of fire and its relationship to the ecology of man is likewise a "difficult exercise in thought." Years ago, Dr. Keesing, an old friend, and I had many such a difficult exercise in relation to the question: What are the traits of rodent populations as compared with those of human populations? The relationship of fire and man is even more difficult.

As Keesing (1958) points out, there appears to be a universal patterning of culture, but it is very difficult to delineate the many human customs and to separate these from animal traits. However, he gives a rather simplified scheme which meets the three basic problems of human existence and which I shall use in a very general way.

1. Man to habitat: especially the technological and economic dimensions.
2. Man to man: especially the dimensions of social organizations

and inter-personal relations.

3. Man to the unknown: that is, the "world" of symbolic thought within which knowledge, religion, and other conceptual dimensions of culture build up.

THE FIRE RELATIONSHIP TO HABITAT

We have already discussed the relationship of fire to the animal or biological environment and that early man and his ancestors were "fire-selected" and lived in a "fire environment." However, man has also had a decided effect on his habitat. He has, with the use of fire and other cultural attainments, "*shaped the habitat into a "secondary environment" which is culturally defined.*" This "shaping" of the habitat only can be briefly considered now and then in only a few categories.

Food.—Early man, as man does now, obtained nearly all of his food from grasslands, shrublands, and water but not from forest lands. The seeds or fruits of grass and herbivorous animals make up most of man's diet. From all indications man's early progenitors were omnivorus. Anthropologists divided his food gathering or food producing abilities or evolutionary cultural habits into three major elements; "food gatherer" who depends on wild products, "food producer" who depends on the cultivation or domestication of plants and animals, and the "industrial revolution."

The "food gatherer" had much opportunity to observe the amount, the quality, the ease of harvest, and many other characters of the plants he ate. As this "food gatherer" lived in a fire environment he certainly observed many of the chemical, physical, and biological aspects of these environments or habitats as we have noted earlier in our discussion. It is also very pertinent to me that apparently all, or nearly all, of the progenitors, or near relatives of *all of our major cereal grains* (i.e. rice, maize, sorghum, millet, wheat, rye, and other such grains) appear to be very highly "fire-selected." *Tripsacum* and *Teosinte* (very closely allied to maize) responded with more vigor and health to burning in experimental studies at Tall Timbers as did some of the possible perennial progenitors of rice.

Was gathering of food on the burns the incipient beginning of

farming and modern agriculture? Certainly these semi-wild to wild individuals with their keen senses noted, as have I with my senses dulled with modern culture, that these and other food grasses grew more profusely on burned land and were more easily gathered on a burn. All of the early progenitors of cereal crops drop their seeds one by one, as they mature, into the grass below. Likewise these early people must have noted that these burned plants were healthier, more vigorous, and that the seed was more easily gathered wherever the fire burned logs and other accumulations of fuel, particularly along the edges of forests or in park-like forests. It is no surprise then that the earliest practice of farming was the type that goes under many names but usually as "slash-and-burn" and this is still a very common sort of agriculture in many parts of the world.

Primitive peoples soon learned the value of ash as a fertilizer. Until quite recently our relatively modern agriculture likewise used tremendous amounts of it for this purpose. In fact, the use of this material in the United States is so recent that the "official analysis" of various kinds of wood-ashes and regulations pertaining to them are still on our law books. Less than fifty years ago we still had a very large wood-ash fertilizer industry.

The burning of stubble or crop refuse was discouraged for a number of years in this country in spite of the fact that no honest scientific studies were conducted on whether or not it was a good farm practice. It was simply stopped by bureaucratic policy. However, the use of fire for this purpose has now had renewed interest and for many crops has again become an accepted practice recommended by agricultural experiment stations.

The same history applies to the field of animal industry which began when early man first hunted on the "burn." Here again the progenitors of most of our major domestic animals, appear to have been inhabitants of natural fire environments and again of grass or shrublands—not forests. First the hunter, and later the pastoralist, noted that the animals he fed upon were attracted to the burned lands. He observed likewise that both the wild animals and domestic stock grew fat, were healthy, reproduced well, and could be "managed" by the proper use of fire. Fire was perhaps what might be called the first "fence." By the proper use of fire, movements of

livestock, and even game, can be controlled to a considerable extent. The pastoralist knew by the age of the burns where his livestock would be and rotated the fire accordingly. Today we know *why* the animals are so attracted. After being condemned for a period of time in this country, fire has come back into use as an established practice not only on range lands but on intensely managed and highly developed "improved pastures."

Other food materials such as insects, rodents, and birds were also attracted to the burns and were gathered as food by early man. The use of heat for roasting, popping, parching, preservation, etc., are all well known and go back into the early beginnings of man's use of fire.

Shelter.—Hough (1926) points out that the beginning of man's shelter and architecture may have been due to the necessity of keeping the fire going and protected from the "elements." He speculates that this development may have started by providing a wind break for the fire, and roof to protect it from the rain. However, when man began to build houses and bring his fire into them, new problems arose. As he acquired more material goods and better shelter, fire became both a demon as well as a god to him. This perhaps was the beginning of the conditioning of the human mind to "fear" fire and the human infant is scarcely able to talk when he learns that fire is "hot." It appears to me that the more man's culture and civilization depends on material goods, and the more he personally acquires, the greater his fear of fire becomes. Certainly the city dweller "fears" fires of all kinds more than the farmer who uses it in his fields, pastures, and forests. The latter respects fire but does not fear it in the sense of most city dwellers. And yet the urbanite cannot refrain from "running" to burning buildings in considerable numbers. Man's fear of fire then appears to be in proportion to his culture.

FIRE AND THE "MAN TO MAN" RELATIONSHIP

With the acquisition of fire from natural sources, man was surely faced with the problem of keeping it, for he could not always go out and find a new source of natural fire. This meant that someone

either had to carry the fire around with him or stay in one place to protect it. This business of "keeping the home fires burning" must have been of great importance to early man. Without fire, it meant less food, less warmth, and loss of his "adaptive" advantage over others. Man truly had to become a "social" animal in this early period before he knew how to make fire. Also, fires became a meeting place for friends, as campfires still are, when the problems and events of the day could be discussed. It still surprises me to see how modern humans, adapted to a modern city type culture, react to a campfire. Barbecue and a campfire will bring on more friendly discussions, talk, song, philosophy and bring peace among opposing forces more easily than any other kind of meeting with which I am familiar. Much of the success of developing the type of thought we have had at these fire ecology conferences goes to our evening meetings when opposing participants find out they are not as far apart as they thought—fire certainly has a mellowing effect.

Surely there is no argument of the place of fire in our cultural heritage. It is still a part of our modern civilizations. Most assuredly, fires have assisted in the development of this social being we call man.

Fire Keeper.—Hough (1926) has pointed out that,

> The role played by fire in the development of the artificial social organization has been given great attention by many writers. The thesis is briefly that the care of the fire was exiguous in earliest times, and therefore enforced the delegation of an individual to its services. Thus the first delegated office, that of fire keeper, had its inception. From this beginning are traced institutions and the governing fabric of society.

Law.—Hough also has pointed out the part fire has played in our early relations between humans.

> Ordeal in general is a primitive substitute for law. In the ordeal of fire it is a reference of a case to the magic power of this institution, whose mysterious properties, not of this world, shall by burning or not burning adjudicate the cause. It is a form of divination by which the will of the superior powers is made known through an agency thought infallible.

Habits.—Many of our expressions and habits in regard to fire go

back in time to our early attempts at keeping our fires burning. Hough (1926) goes on to say that,

> There were good reasons for using the word borrowing in respect to fire. Fire was the property of a particular class, and could not be sequestered by gift but could be loaned. It was a violation of primitive morals both to ask for the gift of a portion or to give a portion. Speech has preserved the idea, though the meaning is lost when one man asks another, "May I borrow a light?" The Hopi Indian understands it, however, when he asks for "some of your fire." There is much data to show that this custom harks back to the time when the house fire was regarded as sacred and the life and well-being of the family were involved in its care and worship.

FIRE—"MAN TO THE UNKNOWN"—THE WORLD OF SYMBOLIC THOUGHT

Man must have been impressed very early in his history by the fires ignited from the sky by lightning. Likewise the fire itself must have filled him with awe. It is thus not surprising that he worshipped both the fire and the lightning.

It also is quite interesting that wherever there are traces of early religions in early peoples the place of fire and lightning is always an integral part of religion. Tyler (1871) points out that,

> . . . the real and absolute worship of fire falls into two great divisions . . . the first is the rude, barbarous adoration of the actual flames which he watches writhing, devouring, roaring like a wild animal; the second belongs to an advanced generalization that any individual fire is a manifestation of one general elemental being, the fire god.

The necessity of maintaining fire must have developed a privileged person very early in human culture who could be called the "fire-keeper." In time this would take on a position of authority probably first as some sort of religious leader and then as virtually the main authority. Early religions are filled with the necessary duties of taking care of the sacred fire, the perpetual fire and to the eternal flame. Our modern use of candles for many religious events apparently stem back to these early days. In some of these early religions

such afore-mentioned fires could not be relit except by fire coming directly from the sky and such fire was most highly esteemed. In Persia the fire worshippers held that the "purest fire" was caused and came from lightning.

In Japan the "sacred mountain" at the Festival of Nara has been burned over annually in January for more than 400 years: This perhaps is the longest record for a regular and periodic "controlled burn." The fire festival of Kyoto has been particularly concerned with the perpetuation of a sacred fire that is thought to have been kept burning for over 2,500 years.

Symbolism, representing the religious aspects of fire, lightning, and thunderstorms, occurs throughout the ancient as well as the modern world for fire is part of our being.

There are many other interesting relationships between man and fire but time will only allow but a brief mention of a few. The light from fires, torches, etc., surely changed the habits of man by extending the length of his period of activity. Hough (1926) says,

> The most ancient torch known is from the old Stone Age in France, about 100,000 years ago.

The word fire is the source of much of our vocabulary and 300 or more combinations are listed in some large dictionaries. Fire plays a large part in our literature, music, and arts, such as metallurgy and pottery-making. Fire split stones may have been man's first stone tools. However, perhaps the most important art has been that of the art of fire management.

Art of Fire Management.—After man set his first fires he learned how to manage and/or control it in order to accomplish the desired result. Because fire has always been a danger as well as a blessing, early man had to acquire by experience, study, or observation the knowledge of fire behavior to be able to tame those fires he kindled. He had to develop skill and dexterity in its management so he could domesticate this wild force. With all of these, which define art, fire would have been of more danger than use to man.

As man's culture developed into more complex societies, the need for a better understanding of the place of fire in his world increased, because man's use of fire always involved an element of

compromise between its benefits and its dangers. Fire has been rightly called a "two-edged sword" which can cut both ways. Thus we can consider that the use of fire is an art—the art of fire management—and fits this definition of art (of which there are many) the "Systematic application of knowledge or skill in effecting a desired result."

Our conferences have been particularly concerned with the knowledge about fire, the development of the necessary skills, the systematic application, and in obtaining the desired result. Man has not always used his knowledge nor developed his skills in this art and, therefore, has not accomplished the desired results. There are several reasons for this: The lack of correct knowledge, the lack of skill, and the lack of systematic application. Whenever any one of these factors are missing he does not practice the art of fire management. However, we must also look upon the values of fire management, particularly in the past, in the light of his requirements in both space and time. When he wants food he may not be interested in trees and conversely when he wants to produce trees he may not be interested in food production. When new uses evolve, the old benefits or dangers have to be reviewed. As an example, Odum (1963) states concerning nuclear contamination, that the

> . . . shielding capacity of mineral soil could also reduce dose. It might even be desirable to burn badly contaminated vegetation or crops as a recovery measure.

However, a more immediate review of fire and fire management is particularly pertinent today. Our hunters have increased, but the numbers of bird-watchers will shortly be greater than the numbers of hunters. Outdoor recreation, plus the greater interest in all the plants, animals, and life processes that occur in nature, has likewise increased. I sense in this complex world of ours today a need, one might even say a craving, for field and stream, for forest and grassland and desert, and for wilderness. How can we best meet this need? Man must again review and compromise the place of fire in nature. These conferences, without a doubt, are pertinent to man's decision of when, how, where, why, what kind and how often fire should, or should not be used.

These decisions sometimes will be difficult and much re-education is necessary. Cain (1966) points out that,

> . . . should an extensive wildfire (an act of God) reduce the forest and allow again for young growth the moose can browse; or a controlled burn (an act of man and a difficult decision for the National Park Service) can accomplish the same end.

Roy Komarek (1966) has pointed out the need for the re-evaluation of the goal of wildlife management—the art of creating "wildlife landscape," which is the skillful manipulation of native vegetation.

We have these conferences because of the complex decisions that have to be made and some of which in turn are based upon the fundamental force—fire. I have tried to bring to you in this synthesis, reflections on the exceedingly close relationship of fire and the ecology of man because science and art are so closely interwoven in this subject as to be inseparable. Man has used both the science and the art. The two are so closely entwined that those of us who use fire must be both scientist and then artist, or artist and then scientist. In bringing you this synthesis and reflection I have not only drawn freely upon our conferences but I have also searched the "minds of men" through literature as well as otherwise. I hope that I have impressed upon you that fire is no superficial thing in the lives of mankind but that it is a very fundamental part of our very being.

BIBLIOGRAPHY

Allan, William. 1965. The African husbandman. Barnes & Noble, Inc. N. Y. 505 p.

Ardrey, Robert. 1961. African Genesis. 11th printing. Dell Publ. Co., N. Y. 380 p.

Boule, M., and H. V. Vallois. 1957. Fossil men. Dryden, N. Y. 535 p.

Benedict, R. 1952. Patterns of culture. Houghton Mifflin, Boston, 272 p.

Birdsell, J. B. 1951. The problem of the early peopling of the Americas as viewed from Asia. Phys. Anthropology of the Am. Indian. Viking Fund. N. Y.

———. 1957. Some population problems involving Pleistocene man. Cold Spring Harbor Symp. Quant. Biol., 22:47-69.

Bingham, Harold C. 1932. Gorillas in a native habitat. Publ. No. 426 Carnegie Inst. of Washington. pp. 10-11.

Black, Davidson. 1925. Asia and the dispersal of the primates. Bull. Geol. Soc. China, 4(2):133-183 pp.

———. 1931. Evidence of the use of fire by Sinanthropus. Bull. Geol. Soc. of China, Peiping. 11(2):108 pp.

———. 1934. On the discovery, morphology, and environment of Sinanthropis pikinensis. The Croonian lecture. Phil. Trans. Roy. Soc. London. Series B. 223:57-120 pp.

Bonin, G. Von. 1935. European races of the upper Plaeolithic. Hum Biol. 7, 196-221.
Boyd, W. 1953. The contributions of genetics to anthropolgy. *In* Anthropology today. *Ed.* A. Kroeber. Univ. of Chicago Press, Chicago. p. 488-506.
Broom, R., and G. W. H. Schepers. 1946. The South African fossil ape-man, the Australopithecinae. Transv. Mus. Mem. 2, 272 p.
Burton, M. 1959. Phoenix re-born. Hutchinson & Co., London.
Clark, Grahame. 1963. Hunter-Fishers of Yorkshire. *In* The world of the past. *Ed.* J. Hawkes pp. 230-241.
——. 1963. The beginning of farming: Jericho and Jarmo. *In* The world of the past. *Ed.* J. Hawkes pp. 249-251.
Clark, W. E. Le Gros. 1955. The fossil evidence for human evolution. Chicago Univ. Press, Chicago. 201 p.
Cooke, H. B. S. 1964. Pleistocene mammal faunas of Africa with particular reference to Southern Africa. *In* African ecology and human evolution. *Eds.* F. C. Howell and F. Bourliere. Methuen and Co. Ltd., London. pp. 65-116.
Coon, C. S. 1939. The races of Europe. Macmillan, N. Y. 399 p.
——. 1954. Climate and race. Smithsonian Report for 1953: pp. 277-298.
——. 1955. Some problems of human variability in climate and culture. Am. Nat., 89:257-259 pp.
——. 1959. Race and ecology of man. Cold Spring Harbor Symp. Quant. Biol., 24:153-159 pp.
——. 1962a. The story of man. Knopf, N. Y. 438 p.
——. 1962b. The origin of races. Knopf, New York. 724 p.
——. 1963. Belt cave and the first domestic animals. *In* The world of the past. *Ed.* J. Hawkes.
——, and Edward E. Hunt, Jr. 1965 The living races of man. Alfred A. Knoff publ. N. Y. 344 p.
Darling, F. Fraser and John P. Milton. 1966. Future environments of North America. Nat. Hist. Press, Garden City, N. Y. 767 p.
Dart, R. A. 1925. Australopithecus africanus; the man-ape of South Africa. Nature 115, 195-199 pp.
——, and Dennis Craig. 1959. Adventures with the missing link. Harper & Bros., N. Y. 255 p.
——. 1960. The status of Gigantopithecus. Anthrop. Anz. 24, 139-145 pp.
Davis, D. H. S. Editor. 1964. Ecological studies in southern Africa. Dr. W. Junk Publ. The Hague. 415 p.
Day, Michael H. 1965. Guide to fossil man, a handbook of human palaeontology. The World Publ. Co., Clevelad, Ohio. 289 p.
Devore, Irven. Editor. 1965. Primate behavior, field studies of monkeys and apes. Holt, Rinehart and Winston, N. Y.
——, and K. R. L. Hall. 1965. Baboon ecology. *In* Primate behavior. *Ed.* Irven DeVore.
Dobzhansky, T. 1944. On the species and races of living and fossil men. Am. J. Phys. Anthrop. 2, 251-265 pp.
——. 1948a. Genetics of natural populations XVI. Genetics, 33:158-176.
——. 1948b. Genetics of natural populations XVIII. Genetics, 33:588-602 pp.
——. 1951a. Genetics and the origin of species. Columbia Univ. Press, N. Y. 364 p.
——. 1952. Genetics of natural populations XX. Evolution, 6:234-243 pp.
——. 1955. A review of some fundamental concepts and problems of population genetics. Cold Spring Harbor Symp. Quant. Biol. 20:1-15 pp.
——. 1956. What is an adaptive trait? Am. Nat. 90:337-347 pp.
——, and O. Pavlovsky. 1957. An experimental study of interaction between genetic drift and natural selection. Evolution 11:311-319 pp.

——. 1958. Evolution at work. Science, 127:1091-1098 pp.
——, and M. F. Ashley Montagu. 1947. Natural selection and the mental capacities of mankind. Science, 106:587-590 pp.
——. 1964. Mankind evolving. 5th printing. Yale Univ. Press, New Haven, Conn. 381 p.
Dyer, R. A. 1965. The cycads of Southern Africa. Botalia—a record of contributions from the National Herbarium. Rep. of So. Africa, Pretoria. 8:(4)411, 450, 476-77, 485-86.
Eiseley, L. 1955. Fossil man and human evolution. Yearbook of Anthropol. Wenner-Gren Foundation, New York. 61-78 pp.
Frazer, Sir James G. 1926. The golden bough. Edinburgh, Scotland. 13 v.
——. 1931. Garnered sheaves. Macmillan & Co., London. 537 p.
Gregory, William K. 1916. Studies on the evolution of the primates. Bull. Am. Mus. of Nat. Hist. 19:239-355 pp.
——. 1921. The origin and evolution of the human dentition. J. Dental Res. 2(1):2-4 pp. and 3(1)
——, and Henry C. Raven. 1937. In quest of gorillas. Darwin Press, New Bedford, Mass. 231 p.
Haldane, J. B. S. 1932. The causes of evolution. Harper & Brothers, London. 234 p.
——. 1959. Natural selection. *In* P. R. Bell, Darwin's biological work; some aspects reconsidered. Cambridge Univ. Press.
Hallowell, A. I. 1953. Culture, personality, and society. *In Ed.* A. L. Kroeber, Anthropolgy today. Univ. of Chicago Press, Chicago 597-620 pp.
——. 1956. The structural and functional dimensions of a human culture. Quart. Rev. Biol., 31:88-101 pp.
——. 1960. Self, society, and culture in phylogenetic perspective. *In* S. Tax, Evolution after Darwin. Univ. of Chicago Press, Chicago, 2:309-371 pp.
Hardin, G. 1959. Nature and man's fate. Rinehart, New York.
Harlow, H. F. 1958. The evolution of learning. *In* G. G. Simpson and A. Roe, Behavior and evolution. Yale Univ. Press, New Haven, Conn. 269-290 pp.
Hawkes, Jacquetta. 1963. The world of the past. 2 v.
Hough, Walter. 1926. Fire as an agent in human culture. Smithsonian Inst. Bull. 139. Washington. 270 p.
Howell, F. C. 1951. The place of Neanderthal man in human evolution. Am. J. Phys. Anthropol. 9:379-416 pp.
——. 1957. The evolutionary significance of variation and varieties of Neanderthal man. Quart. Rev. Biol. 32:330-347 pp.
——.1959. The Vallafranchian and human origins. Science. 130:831-844 pp.
——.1960. European and northwest African middle Pleistocene hominids. Curr. Anthrop. 1:195-232 pp.
Howells, William. 1944. Mankind so far. Am. Museum of Nat. Hist. Science Series. Doubleday, Doran and Co. Garden City, N. Y. 319 p.
Hrdlicka, Alex. 1930. The skeletal remains of early man. Smithsonian Misc. Coll. Publ. 3033. Smithsonian Inst., Washington, D. C.
Huede, Pierre Marie. 1898. Memoires concernant l'histoire naturelle de l'Empire Chinois, par des peres de la com pagnie de Jesus: Etudes Odontologiques, Lemuriens, Tarsiens, Galeopithec et Cebiens. Mem. Hist. Nat. Chinois. 4:155-181 pp.
Huntington, Ellsworth. 1929. The human habitat. 2nd printing. D. vonNostrand Co., N. Y. 293 p.
James, Preston E. 1966. A geography of man. 3rd edition. Blaisdell Publ. Co. Waltham, Mass. 656 p.

Johnston, W. A. 1933. Quaternary geology of North American in relation to the migration of man. *In* The American Aborigines, D. Jenness *Ed.*
Keast, A., R. L. Crocker and C. S. Christian. 1959. Editors. Biogeography and ecology of Australia. Dr. W. J. Junk, Publ. The Hague. 640 p.
Keesing, F. M. 1958. Cultural anthropology; the science of custom. Rinehart, N. Y. 477 p.
Keith, A. 1949. A new theory of human evolution. Philosophical Library. New York. 451 p.
Kluckhohn, C., and W. H. Kelly. 1945. The concept of culture. *In* R. Linton, The science of man in the world crisis. Columbia Univ. Press, N. Y. 78-106 pp.
Koenigswald, G. H. R. Von 1949. The discovery of early man in Java and Southern China. *In* Early man in the Far East. *Ed.* W. W. Howells. Stud. Phys. Anthrop. Philadelphia, Pa. 1:83-98 pp.
Kohler, W. 1925. The mentality of apes. Harcourt Brace, N. Y. 336 p.
Komarek, E. V., Sr. 1962. The use of fire: an historical background. Proc. First Ann. Tall Timbers Fire Ecol. Conf. pp. 7-10. Tall Timbers Res. Sta. Tallahassee, Fla.
———. 1962. Fire ecology. Proc. First Ann. Tall Timbers Fire Ecol. Conf. pp. 95-107. Tall Timbers Res. Sta. Tallahassee, Fla.
———. 1963. Fire, research and education. Proc. Second Ann. Tall Timbers Fire Ecol. Conf. pp. 181-187 Tall Timbers Res. Sta. Tallahassee, Fla.
———. 1964. The natural history of lightning. Proc. Third Ann. Tall Timbers Fire Ecol. Conf. pp. 139-183. Tall Timbers Res. Sta. Tallahassee, Fla.
———. 1965. Fire ecology—grasslands and man. Proc. Fourth Ann. Tall Timbers Fire Ecol. Conf. pp. 169-220. Tall Timbers Res. Sta., Tallahassee, Fla.
———. 1966. The meteorological basis for fire ecology. Proc. Fifth Ann. Tall Timbers Fire Ecol. Conf. pp. 85-125. Tall Timbers Res. Sta. Tallahassee, Fla.
Komarek, Roy. 1963. Fire and the changing wildlife habitat. Proc. Second Ann. Tall Timbers Fire Ecol. Conf. pp. 35-43. Tall Timbers Res. Sta. Tallahassee, Fla.
———. 1966. A discussion of wildlife management, fire and the wildlife landscape. Proc. Fifth Ann Tall Timbers Fire Ecol. Conf. pp. 177-194. Tall Timbers Res. Sta. Tallahassee, Fla.
Krieger, Alex D. 1963. The earliest cultures in the western United States. *In* The world of the past. *Ed.* J. Hawkes. 693-698 pp.
Kroeber, A. L. 1960. Evolution, history and culture. *In* S. Tax Evolution after Darwin. 2:1-16 pp. Univ. of Chicago Press, Chicago.
Leakey, L. S. B. 1935. Stone age races of Kenya. Oxford Univ. Press, London.
———. 1959. A preliminary re-assessment of the fossil fauna from Broken Hill, No. Rhodesia. J. R. Anthrop. Inst. 89:225-231 pp.
———. 1960. The origin of the genus Homo. *In* S. Tax, Evolution after Darwin. Univ. of Chicago Press, Chicago. 2:17-32 pp.
———. 1960. Recent discoveries at Olduvai Gorge. Nature 188:1050-1052 pp.
———, J. F. Evernden, and G. H. Curtis. 1961. Age of Bed I, Olduvai Gorge, Tanganyika. Nature 191:478-479 pp.
———. 1961a. New finds at Olduvai Gorge. Nature 189:649-650 pp.
———, and M. D. Leakey, 1964. Recent discoveries of fossil hominids in Tanganyika; at Olduvai and near Lake Natron. Nature 202:5-7 pp.
———, P. V. Tobias, and J. R. Napier, 1964. A new species of the genus Homo from Olduvai Gorge. Nature 202:7-9 pp.
———. 1965. Olduvai Gorge 1951-61. Cambridge Univ. Press, Cambridge.
Leeper, G. W., Editor. 1962. The evolution of living organisms. Melbourne Univ. Press, Melbourne, Australia. 459 p.

Leopold, Aldo. 1937. Conservationist in Mexico. Am. For 43:118-120+
Lovejoy, A. O. 1936. 1960. The great chain of being: a study of the history of an idea. Harvard Univ. Press, Cambridge, and Harper Torchbooks, New York. 382 p.
Mason, K. E. 1939. Relation of the vitamins to the sex glands. *In* E. Allen, C. H. Danforth, and E. A. Doisy, Sex and internal secretions. 2nd Ed. Williams and Wilkins Co., Baltimore. 1149-1212 pp.
Matthew, W. D. 1915. Climate and evolution. Ann. N. Y. Acad. Sci. 24:171-318 pp.
Montelius, Oscar. 1963. Swedish Prehistory. *In* The world of the past. *Ed.* J. Hawkes p. 476.
Movius, H. L. 1948. The lower Palaeolithic cultures of Southern and Eastern Asia. Trans. Am. Philos. Soc. 38:329-420 pp.
——. 1953. Old world prehistory; Palaeolithic. *In* A. L. Kreober Anthropology today. Univ. of Chicago Press, Chicago. 163-192 pp.
Muller, Herbert J. 1957. The uses of the past. Oxford Univ. Press, New York.
Murray, R. W. 1943. Man's unknown ancestors. Bruce Publ. Co., Milwaukee, Wisc. p. 66 and p. 74.
Napier, J. R., and J. S. Weiner, 1962. Olduvai Gorge and Human Origins. Antiquity 36:41-47 pp.
Obermaier, Hugo. 1924. Fossil man in Spain. Yale Univ. Press for the Hispanic Society of America.
Oakley, K. P. 1954. Skill as a human possession. *In* C. J. Singer, History of technology. Oxford Univ. Press, New York. 1:1-37 pp.
——. 1956a. The earliest tool-makers. Antiquity, 31:4-8 pp.
——. 1956b. The earliest fire-makers. Antiquity, 30:102-107 pp.
——. 1957. Tools maketh man. Antiquity, 31:199-209 pp.
——. 1958. Use of fire by Neanderthal man and his percursors. *In* In Neanderthal centenary. 267-269 pp.
——. 1961. On man's use of fire, with comments on tool-making and hunting. *In* Social life of early man. *Ed.* S. L. Washburn. Viking Fund Publ. in Anthropology. 31:176-193 pp.
Odum, Eugene P. 1963. Summary. *In* Ecological effects of nuclean war. *Ed.* G. M. Woodwell. Brookhaven Natl. Lab. Upton, N. Y. 69-72 pp.
Osborn, Henry Fairfield. 1915. Men of the old stone age; their environment, life and art. New York, 559 p.
Paintin, E. H. Drongoes gather prey at fire. African Wild Life 19:(4) Dec. 1965.
Pei, W. C. 1931. Notice of the discovery of quartz and other stone artifacts in the Lower Pleistocene hominid-bearing sediments of the Choukoutien cave deposit. Bull. Geol. Soc. China 11:(2).
——. 1934. A preliminary report on the late-Palaeolithic cave of Choukoutien. Bull. Geol. Soc. China 13:327-358 pp.
——. 1939. On the upper cave industry. Peking Nat. Hist. Bull. 13, 175-179 pp.
——. 1939. The upper cave industry of Choukoutien. Palaeont. Sinica, New Ser. D, 9:1-56 pp.
Phillips, John. 1959. Agriculture and ecology in Africa. Faber and Faber, London. 412 p.
——. 1965. Fire—as master and servant: its influence in the bioclimatic regions of Trans-Sahara Africa. Proc. Fourth Ann. Tall Timbers Fire Ecol. Conf. Tall Timbers Res. Sta., Tallahassee, Fla. 7-109 pp.
Rogers, David J. 1966. Plants used by man. Science 153(3743):1514.
Sahlins, M. D. and E. R. Service. 1960. Evolution and culture. Univ. of Michigan Press, Ann Arbor, Mich.
Schaller, George B. 1964. The year of the gorilla. Univ. of Chicago Press, Chicago, Ill. 260 p.

Scholander, P. F. 1955. Evolution of climatic adaptations in homeotherms. Evolution, 9:15-26 pp.
——, R. Hock, W. Waters, L. Irving, and F. Johnson. 1950. Body insulation, heat regulation, and adaptation to cold in arctic and tropical mammals and birds. Biol. Bull. 99:225-271 pp.
Selye, H. 1956. The stress of life. McGraw-Hill, New York.
Shapiro, Harry L. 1956. Editor, Man, culture and society. Oxford Univ. Press, New York. 380 p.
Simpson, G. G. 1944. Tempo and mode in evolution. Columbia Univ. Press, New York. 237 p.
——. 1949. The meaning of evolution. Yale Univ. Press, New Haven, Conn. 364 p.
——. 1953. The major features of evolution. Columbia Univ. Press, New York. 434 p.
Sinnott, E. W., L. C. Dunn, and Th. Dobzhansky. 1958. Principles of genetics. 5th Ed. McGraw Hill, New York.
Steward, J. N. 1953. Evolution and process. *In* A. L. Kroeber, Anthropology today. Univ. of Chicago Press, Chicago, Ill. 313-326 pp.
Stewart, Omer C. 1963. Barriers to understanding the influence of use of fire by Aborigines on vegetation. Proc. Second Ann. Tall Timbers Fire Ecol. Conf. Tall Timbers Res. Sta., Tallahassee, Fla. 117-126 pp.
Thorpe, W. H. 1963. Learning and instinct in animals. Methuen, London. 558 p.
Tinbergen, N. 1951. The study of instinct. Clarendon, Oxford, 228 p.
——. 1959. Behaviour, systematics, and natural selection. Ibis. 101:318-330 pp.
Vaczek, Louis C. 1964. The enjoyment of chemistry. Viking Press, N. Y. 243 p.
Washburn, S. L. 1950. The analysis of primate evolution with particular reference to the origin of man. Cold Spring Harbor Symp. Quant. Biol., 15:67-78 pp.
——. Speculations of the interrelations of the history of tools and biological evolution. Human Biol. 31:21-31 pp.
——, and V. Avis. 1958. Evolution of human behavior. *In* A. Roe and G. G. Simpson, Behavior and evolution. Yale Univ. Press. New Haven, Conn. 421-436 pp.
——, and F. C. Howell. 1960. Human evolution and culture. *In* S. Tax, Evolution after Darwin. Univ. of Chicago Press, Chicago, Ill. 2:33-56 pp.
——. 1960. Tools and human evolution. Sci. Amer. 203(3):3,7,9,11,13.
Wedel, Waldo R. 1961. Prehistoric man on the great plains. Univ of Oklahoma Press, Norman, Okla. 355 p.
Weckler, J. E. 1954. The relationship between Neanderthal man and Homo sapiens. Am. Anthropol., 56:1003-1025 pp.
Weekler, J. E. 1957. Neanderthal man. Sci. Amer. 3-4 pp.
Weidenreich, F. 1939. On the earliest representatives of modern mankind recovered on the soil of East Asia. Peking Nat. Hist. Bull. 13. 161-174 pp.
——. 1940. Some problems dealing with ancient man. Amer. Anthrop. 42:375-383 pp.
Wharton, Charles H. 1948. Seeking Mindanao's strangest creatures. Natl. Geographic Mag. (Sept. 1948) 94:389-408 pp.
——. 1965. (personal communication)
Woolley, Sir Leonard. 1965. The beginnings of civilization. History of mankind, cultural and scientific development. 1(2):49, 67, 227-231 pp.
Yerkes, R. M., and A. W. Yerkes, 1929. The great apes. Yale Univ. Press, New Haven, Conn. 652 p.
Zeuner, F. E. 1958. The replacement of Neanderthal man by Homo sapiens. *In* Neanderthal centenary, Utrecht, Kemink. 312-315 pp.