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Human ecological intervention and the role of forest fires in human ecology

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Abstract

The present text is a summary of research on the relationship between forest fires and human activities. Numerous theories have been created to explain changes in forests during the late Pleistocene and early Holocene, and a general understanding has developed in the past 50 years regarding natural fire regimes. The present summary is directed to assess the validity of these theories. A re-analysis of the literature argues that the intense forest fires we experience today are an artifact of human intervention in forest ecology, especially by the reduction of herbivores and are relatively recent, approximately 100 000–250 000 BP. The history of fire, especially in the context of the increased dominance of humans, has produced a progressively fire-adapted ecology, which argues for human-free wildlife areas and against prescribed burns under many circumstances. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

1.1. Dominant paradigm of forest fire

Over the past 20 years or so the view has developed that forest fires, as they occur today, are natural events which are good for forests, animals and everyone in general. Nearly 40 years ago Helm (1964) defined the ecological approach in Anthropology as one which stressed, ‘...the adaptive and exploitive relations, through the agency of technology, of the human group to its habitat, and the demographic and sociocultural consequences of those relations’. Anthropologists who

take this approach tend to take a long-term view of human history and establish frameworks by which human relations to the environment can be charted to causes and consequences of human behavior. Humans exist within the flora and fauna of any locality and, in a general sense, humans are in a co-evolutionary sequence, caught within the effects of this biota and climate. While these concepts are the result of work in other fields and long established among biologists, for example in the work of Wallace (1880) and Matthew (1939), they are seldom applied to humans outside of evolutionary considerations (Potts, 1996). This is the approach I have taken to the subject of forest fires, both regarding the history of the phenomenon

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of forest fires and to the attitudes applied to their occurrence in recent years.

Some of these attitudes, especially after extensive loss of acreage and the destruction of property, are based on sound biological evidence — forests do grow back after fires, and certain species of trees and brush depend on fires to sustain or allow them to regenerate themselves (Sweeney, 1956; Komarek, 1964, 1974). Pyne and Goldammer (1997) have referred to these behaviors as a 'culture of fire'. These behaviors have evolved in the context of human evolution and transformations in human environmental exploitation. The understanding of this 'culture of fire' is central to regarding the consequences of an increasingly fire-adapted biota. Since fighting forest fires is a dangerous and expensive enterprise, and larger more devastating fires seem to be associated with the affects of fire suppression over decades, the idea that forest fires are good has become a policy for some forest management entities (Hartesveldt, 1964) and become a popular belief (Anon, 2000; Malamud et al., 1998; Pyne, 1997). This view was strongly set forth recently during the May 2000 wildfire near Los Alamos, New Mexico (see Jehl, 2000). We now have a 'let it burn' policy in some National Parks in the USA. Part of this program is prescribed fires, which have become so prevalent that the US Forest Service recently asked for an exemption from EPA restrictions on air pollution to allow more of them.

All those people who suffer the effects of fires can, with some explanation, feel that their loss is a part of a natural process over which no one has any control. This argument is made with the acknowledgement that more than 90% of all forest fires were reported as human-caused in the US in regional surveys (California Division of Forestry, 1953; Holbrook, 1943; UNECE Timber Committee, 2001; FAO, European Forestry Commission, 2001), although recent local surveys in some regions report a nearly reversed relationship with lightning causing between 70 and 86% of fires (Touchan et al., 1994; Allen, 1994). However, lightning was not considered a cause of forest fires until 1900 in some locales (Burke, 1980). Also, most lightning strikes do not cause fires, those that do are from 'hot' lightning which make up approx-

imately 20% of all cloud-to-ground discharges in the Northern Rockies (Pyne, 1982). According to data cited by Lewis (1989) from the Alberta Forest Service, the ratio of strikes to fires can vary as much as 1:1 to 1:1000 or none depending on the object struck, the fuel conditions and the weather. Finally, lightning-caused grass fires are rare (Rowe, 1969). We also know that 90% of all forest fires in Siberia (Zhukov, 1976) and 97% of the fires in Mexico (Stolzenburg, 2001) are human-caused. There is evidence that the number of lightning strikes may be increasing with global warming (Williams, 1991), so lightning and fires may be related to climate cycles. Nevertheless, when human-caused fires were plotted against lightning-caused fires, the distribution did not overlap and human fires clustered distinctly (see Figs. 1 and 2). Furthermore, at least in this location, while almost 60% of the fires were lightning-caused, these were usually small and limited to mid-summer. Human-caused fires were larger and occurred throughout the fire season (Burke, 1980). Finally, there is evidence that forest fires can actually enhance the number and intensity of lightning strikes (Lyons et al., 1998).

It is evident that there is an excess of biomass, which builds up in forests, grasslands and intermediate zones. This biomass is responsible for the intensity and duration of fires as well as the spread and difficulty in putting such fires out. The question which needs to be addressed, however, is how does this biomass become so abundant, why is it not consumed by wildlife and if not, has fire and this build up of biomass been consistent throughout history and into prehistory? The evidence is contradictory, studies of carbon in the soil indicate that cores from fire-prone regions in North America show nearly as much charcoal in the fire suppression era as previously (Swain, 1973, 1978, 1980; Foster, 1976; Patterson, 1978; Waddington, 1978; Bradbury, 1986). Clark (1988a) has remarked that study of the Lake of Clouds, often used as evidence for the importance of fire in virgin forests, shows instead that the charcoal diagram displays no significant changes since 1 500 AD. A central limiting factor is discussed by Pyne and Goldammer (1997) that, 'environments that burn frequently do so because they are at least

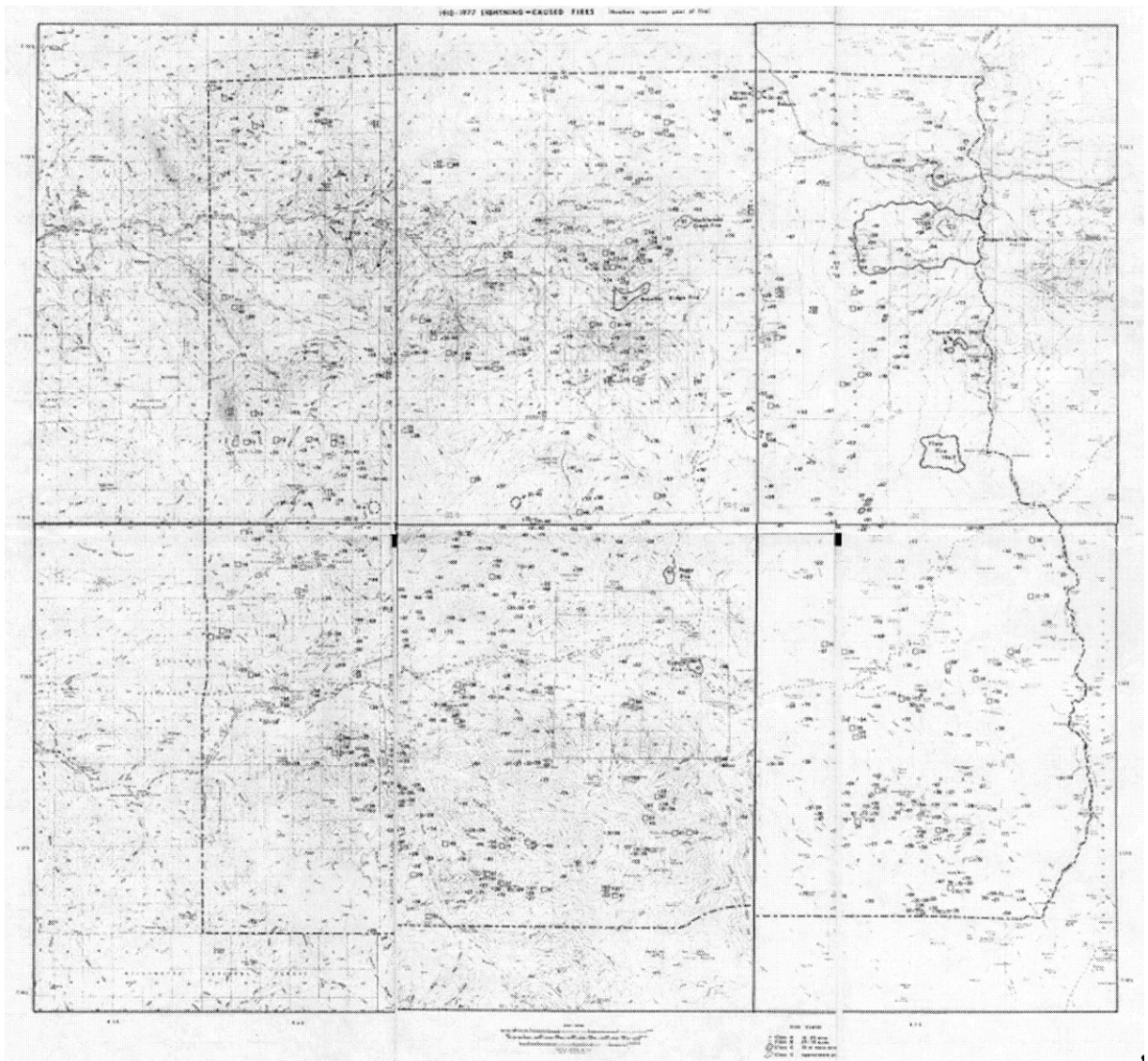


Fig. 1. 1910–1977 lightning-caused fire (Burke, 1980).

seasonally or episodically dry; environments that preserve charcoal do so because they are normally wet'. While this is not entirely true, that is, many dry environments do not frequently burn and also have fairly good preservation opportunities for organic materials, e.g. western Peru and Egypt, it does frame an important problem in reconstructing fire history.

There is evidence that various kinds of human activities exploiting forest resources leads to increased biomass, for example, logging (Vayda, 1999). Strauss et al. (1989), report that one percent of all fires are responsible for 98% of the area burned in the Western USA, although this is contradicted by Malamud et al. (1998). It has been argued, however, that the data support a conclusion

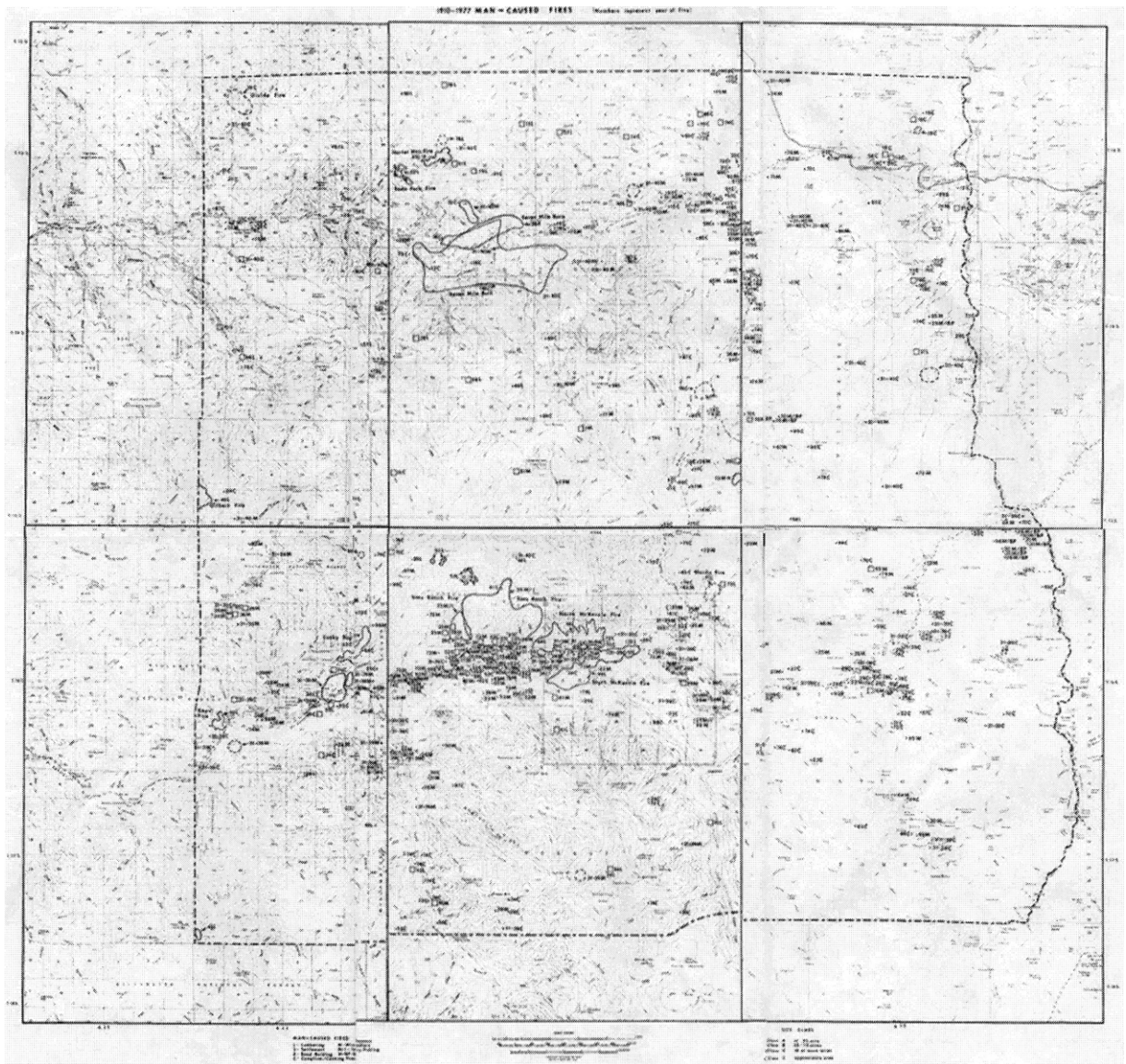


Fig. 2. 1910–1977 human-caused fire (Burke, 1980).

that there have been more fires in the USA in the past 500 years but that the cause is the change in land use (Leenhouts, 1998). We do know that fires can produce large increases in the total quantities of forage available, in some cases of over 400% (Dills, 1970). In one area of mixed oak forest in Pennsylvania the forage increased by 10 times that available in unburned areas (Ribinski, 1958). It

seems clear that burning, even low intensity and controlled burns (Lay, 1957), can increase the danger of fire and make our forests more susceptible to fire. The greatest concentration of growth appears within 11 months of a fire (Leege and Hicky, 1971), so that any benefit in fire control is very short-lived, requiring continuous burning. Without fire, forests proceed to a succession of

type of plant growth with an eventual succession, which reduces light to the forest floor limiting plant growth.

While the public generally views forests as wild areas apart from human control, scientific studies increasingly show them to be human-dominated ecosystems (Noble and Dirzo, 1997). Forest management has for several decades used fire to control density of deer and elk populations (Mellars, 1976). The greatest increase in biomass occurs after both burning and logging (Longhurst, 1961). Human land conversions greatly increase fire fuel consumption and logging is one important process in preconditioning forests for high-intensity fire (Stocks and Kauffman, 1997).

1.2. Ethnographic theory of forest fires

Behind the fire role argument is an understanding that forest fires were both frequent and general prior to Western settlement of the Americas (Lutz, 1959; Komarek, 1964, 1968, 1974; Mellars, 1976) and that the main effect of historic human occupation has been a reduction of these natural events by our civilized desire to fight fires and save forests (Komarek, 1983). The result is more intense forest fires than in the past (Malamud et al., 1998; Pyne, 1997). Several pollen/charcoal studies have supported this thesis and we assume that particle analysis has differentiated forest fire charcoals from industrial soot, while others have shown that forest fires have increased since colonial times (Patterson and Backman, 1988). Tree scar studies are generally supportive (Barrett and Arno, 1982), while ethnohistorical studies can be contradictory (Russell, 1983), and the subtext here is often that preserving forests and fighting fires is counterproductive and just leads to bigger and more destructive fires.

While this scenario is attractive in that it seems to be a reasonable explanation of what we see happening today, archaeological and ethnographic evidence is either confusing, contradictory or inconsistent. This is borne out by the studies which have correlated changes in forest flora by analysis of pollen in strata with charcoal from fires, as Tolonen accomplished in Finland (Tolonen, 1978). Human interaction with forests seems to be asso-

ciated with the burning of the forests (Mellars, 1976). This is clearly the case historically, both in the Americas after European contact, but also in Europe beginning at approximately 10 000 BP, according to the radiocarbon data used by Ammerman and Cavalli-sforza (1984) for their estimations of population changes. This idea was detailed by Clark (1945) in the 1940s as a preadaptation for agriculture and Simmons (1969) summarized the evidence supporting the theory that Mesolithic inhabitants of Britain burned forests to clear hunting areas (Edwards, 1996; Tipping, 1996). However, Brown notes that regional pollen diagrams lack sufficient resolution to resolve the contradiction between pollen evidence of Neolithic impact and the archaeological record (Brown, 1997; Tipping, 1996). Simmons and others (Moore, 1996) have added to this data recently. Clark and Harris (1985) have described the role of fire in terms of hominid survival. The idea being that by burning the forests, grasslands were produced which resulted in increased game due to increased forage (Mellars, 1976). Wedel (1952) completed geoclimatological and pollen studies on the origin of North American grasslands, and argues forcefully against this theory. The grasslands existed before human arrival and varied by the climate and especially the periods of glaciation and fluvial influences.

In his summary of the evolution of grasslands and grasses, Anderson (1982) pointed out that several important factors are necessary for the establishment and maintenance of grasslands, fire alone is not sufficient. Droughts retard tree invasion (Fig. 3); soils and drainage limit types and extent of tree and grassland distribution; tree disease and parasites, (e.g. oak wilt) control tree species distribution; and grazing plays an important role in both limiting forest spread and in reducing biomass below fire-fuel levels. Grazing can improve yearly growth by managing light and heat at ground level, fertilize and control grass distribution. It is recognized, however, that Pre-Columbian grazing patterns differed significantly from present-day commercial grazing methods. Thomasson (1986) in reviewing fossil grass data notes that there is evidence of fossil grass plant remains from every continent and stratigraphic

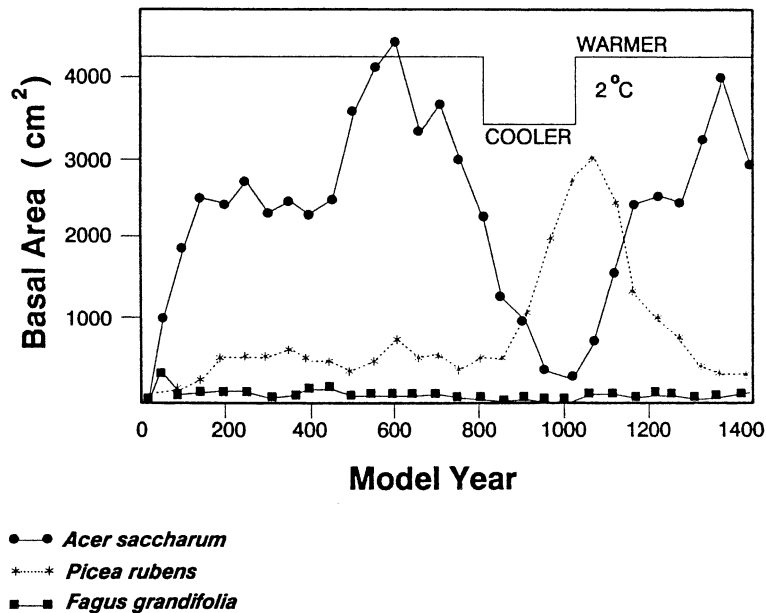


Fig. 3. The results of stand simulation modeling depicting the response of three tree species from eastern North America to a decline in annual temperature of 2 °C (adapted from Davis and Botkin, 1985, by MacDonald et al., 1995). The simulation shows how minor climatic changes may cause reciprocal changes in plant populations that could be misconstrued as resulting solely from interspecific competition if the period of invasion coincided with a change in climate.

level since the Mesozoic. However, the oldest unequivocal remains of grasses are very limited and do not appear until the Oligocene of central North America. Probable grass leaf fragments are also claimed from the Eocene and Oligocene of Germany. Grassland fires, therefore, could be no older than 50 million years BP.

1.3. Climate vs. human intervention

Whyte (1977) presents evidence for 50 000 years of human-set fires on grasslands in Eurasia which is supported by Blydenstein (1967) for the Americas. Looman (1983) develops a more complex picture of grassland genesis, which supports Wedel's climate and pollen studies in many respects. But the main issue is really focus — since fire and human intervention did shape forests and grasslands — and this is obvious from major surveys of the data (Komarek, 1983). The major difference is that these effects are recent. Simmons (1993) has summarized the pollen, radiocarbon, archaeological and ethnographic data in an attempt

to determine the difference between forest fires before humans enter an area and those after. He notes that pollen analysis of two English sites, Hoxne and Mark's Tey in East Anglia (long cited as evidence of a human-induced change from dry forest to grassland) could as easily be explained by natural fires, climatic change or high density of browsing animals. The evidence for a natural fire seems clear from a new study by Mullenders, (1993). It seems that Acheulian tools and charcoal were found in association only at Hoxne (James, 1989). He and other researchers feel that the world's vegetation has been so shaped by human caused fire that it can now be characterized and distinguished from pre-human disturbed vegetation by this fire adaptation. While *Homo erectus* fossils have been found in what are rain forest zones today, debate continues over the success of human subsistence in forest environments (Bailey, et al., 1989; Gamble, 1993; Cosgrove, 1996; Roosevelt, 1996).

Our understanding of the nature of forest fires is aided by comparison of fire records in National

Parks and charcoal/pollen data which has shown that fires in the 20th century differ by type of forest, (e.g. pine and spruce vs. hardwood) and are influenced by wind patterns. But these factors do not seem to apply clearly prior to this period (Patterson and Backman, 1988). This research is hampered by the lack of good historical records on fire frequency and extent. Fire occurrence samples cannot be consistently assembled for pre-historic locations without expensive soil coring correlated with tree-ring analysis (Johnson and Gutsell, 1994).

1.4. Antiquity of anthropogenic fire

The earliest evidence of human created or direct fire is controversial (James, 1989) and is limited by a number of taphonomic processes (Binford, 1981; Dennell, 1989; Gilbert, 1989). There is little agreement on the earliest claims surrounding fire features at Chesowanja in Kenya at 1.4 mya (Growlett, et al., 1981, 1982; Isaac, 1982) or Yuanmou in China (Jia, 1985) (initial date at 1.7 mya, later dating at 0.5 and 0.6 mya). The once widely accepted date for early fire at Zhoukoudian is under question (Binford and Ho, 1985). Binford and Stone (1986) have pointed out the lack of rigor involved in claims for the antiquity of human agency in fire at Zhoukoudian and suggest natural causes as more likely. Perles (1975) has outlined the difficulties involved in identifying convincing evidence for human agency in fire. Pope (1989) rigorously disputes this assessment and argues that not only is the Zhoukoudian site evidence for human-controlled fire, but he adds a Middle Pleistocene site in Thailand. James' critique has sharpened the problem, though some disagree fundamentally with his conclusions (Lewis, 1989), taking a direct historical approach based on contemporary foragers. Lewis (1989) argues that the ability to make tools presupposes the ability to control fire. The issue has remained unresolved since Oakley's extensive reviews (Oakley, 1956a,b, 1961).

Brain (1993a,b) has presented evidence of burned bone at Swartkrans as indicating hominid use or control of fire. Clark (1991, 1993), however, and James (1996), suggest that there is no direct

association between the tools and bones at Swartkrans, and thus hominid activities with fire may only be an artifact of deposition. Other claims for hominid-controlled fire before 1 mya rest on the supposition of a difference between human-controlled fire and natural fires in temperature (Sillen and Brain, 1990). James (1996) shows that this assumption may be false.

The most convincing and least controversial examples of anthropogenic fire in the fossil record are common after 200 000 BP, with sites in Europe like St. Esteve (Howell, 1966; Barbetti et al., 1980) and Abri Vaufrey (Binford, n.d.), though Terra Amata is dated between 400 000 and 250 000 BP with fairly convincing evidence of hearths and controlled fire (De Lumley, 1969; Villa, 1983). This corresponds with evidence for the transition to Anatomically Modern Humans (AMH) by many authorities including Wolpoff (1996) and some of the biochemical data (Caldararo and Guthrie, 1998). Lewis (1989) has argued that forms of habitat burning that are distinct from natural fire patterns can be ascribed to AMH, although he believes that earlier hominids were capable of some degree of fire manipulation. Clark and Harris (1985) and McGrew (1989) hold similar positions. McGrew (1989) presses this case to the chimpanzee use of cigarettes in the Johannesburg zoo (Brink, 1957) and reports of chimpanzees being returned to the wild in Senegal who 'managed campfires' for cooking and warmth (Brewer, 1978). Wrangham et al. (1999) argue for early fire as a significant factor driving several trends in hominid evolution, basing their evidence on work by Barbetti (1986), Bellomo, (1991), Bellomo (1994), Rowlett (1986, 1990), Rowlett and Peters (n.d.). The arguments put by Wrangham et al. (1999) and supporting work are questioned by Brace (1999) and Bunn (1999) among others. Difficulties with the archaeomagnetic methods used by Barbetti (1986) are acknowledged, less so with some other applications to later sites (Barbetti et al., 1980), while the spread of results published by Bellomo (1993) does not argue for a reliable feature of this method. An approach by multiple means of analysis seems to provide a potential for recognition of hominid-controlled fire. The use of thermoluminescence, mineral and pol-

len analysis by Rowlett and Peters (n.d.) and siliceous aggregates (Schiegl et al., 1996) may also provide methods of identifying hominid-controlled fire, but these methods must be standardized and applied to a variety of sites and conditions to establish confidence.

Forest fires have been recently associated with the appearance of aboriginal occupation of Australia, at approximately 50 000 BP (Alroy, 2001). Paleoecologists found remains of vast forest fires in Australia, which resulted in the elimination of conifer forests and the spread of eucalyptus forests as long ago as 100 000–150 000 years BP (Dayton, 1992; Hopkins et al., 1990) (see Fig. 4). Other studies, however, (e.g. Singh et al., 1981) found evidence of fire associated with warming trends over the last 400 000 years. This new information, however, would push hominid occupation of Australia back more than 40 000 years, given the 60 000 BP date for the Kakadu National Park site (Rhys Jones, 1985), and is consistent with recent archaeological evidence of *Homo* in Australia (Adcock et al., 2001). The evidence is from ocean sediment cores and the association with human occupation is very weak, based entirely on the expectation that these fires are only known from locations occupied by humans. Pyne (1991) sets the transition to eucalyptus forest later, ending at approximately 38 000–26 000 BP. Cosgrove (1996) reviews the literature on this subject and the archaeological evidence. The variation in dating may be due to local transport and deposition of pollen and charcoal in the cores examined by the Australian researchers. However, a similar coincident relationship seems to occur in New Zealand, with a steep increase in fires in the last millennium and the arrival of humans (Ogdon et al., 1998). Since the present Australian biota is now fire-adapted, the ability of lightning to create forest fires may reflect this adaptation and date from it.

We know that forest fires occurred in Eastern Borneo during the late Pleistocene and Holocene, but it is not clear if these can be associated with human arrival as reported by Goldammer and Seibert (1989). Their evidence indicates that the earliest date for these fires is approximately 18 000 BP, which coincides with the arrival of humans

(Watson and Cole, 1978). The idea that green wood tropical forests will burn and produce typical forest fires which consume substantial areas has been challenged (Walsby, 1993) and supported by Fearnside (1990), but the idea is generally accepted that under the right conditions these forests will burn (Goldammer, 1993). If this is true, then a two stage human intervention would be necessary for the phenomena we recognize as ‘forest fires’ to occur. First, a human group must establish an exploitative relationship with the forest fauna as a hunting niche. This results in increased human population and increased predation by the humans to the end of a reduction of forest fauna below replacement (Mellars, 1976). The fauna which controlled undergrowth and grasses is extinguished and the forest flora increases annual biomass to fire fuel levels, although biomass replacement seems to vary under certain conditions of forest composition (Hely et al., 2000). This is combined with human fire activity. It is possible that this second stage is not absolutely necessary for forest fires to occur, simply the only condition may be the extinction of herbivorous animal life, and Mellars (1976) argues that fire is a part of this hunting process. Hot fires of long duration will eliminate many soil nutrients and nutrients produced in the fire are easily washed away in the exposed soils. Erosion also follows reducing former forest soils and depleting them (Hobbs and Gimingham, 1987).

Kershaw et al. (1997) and Dayton (1992) proposed a change related to the burning of forests in Australia by examination of cores extracted from an oil-drilling program. While thousands of such cores have been taken all over the world for both archeological purposes (Stein, 1986) and geological prospecting (Tarling and Tarling, 1975), they could be examined for other evidence of forest fires. Cores and auger samples have been collected by archaeologists for over 60 years in the Americas (Stein, 1986) and could be used to chart the relation of fire to forest growth, although many of these cores were taken using methods that were not free of contamination and may not be useful for scientific examination (Reed et al., 1968). Examination and analysis of cores has now been automated, so a large-scale study could be under-

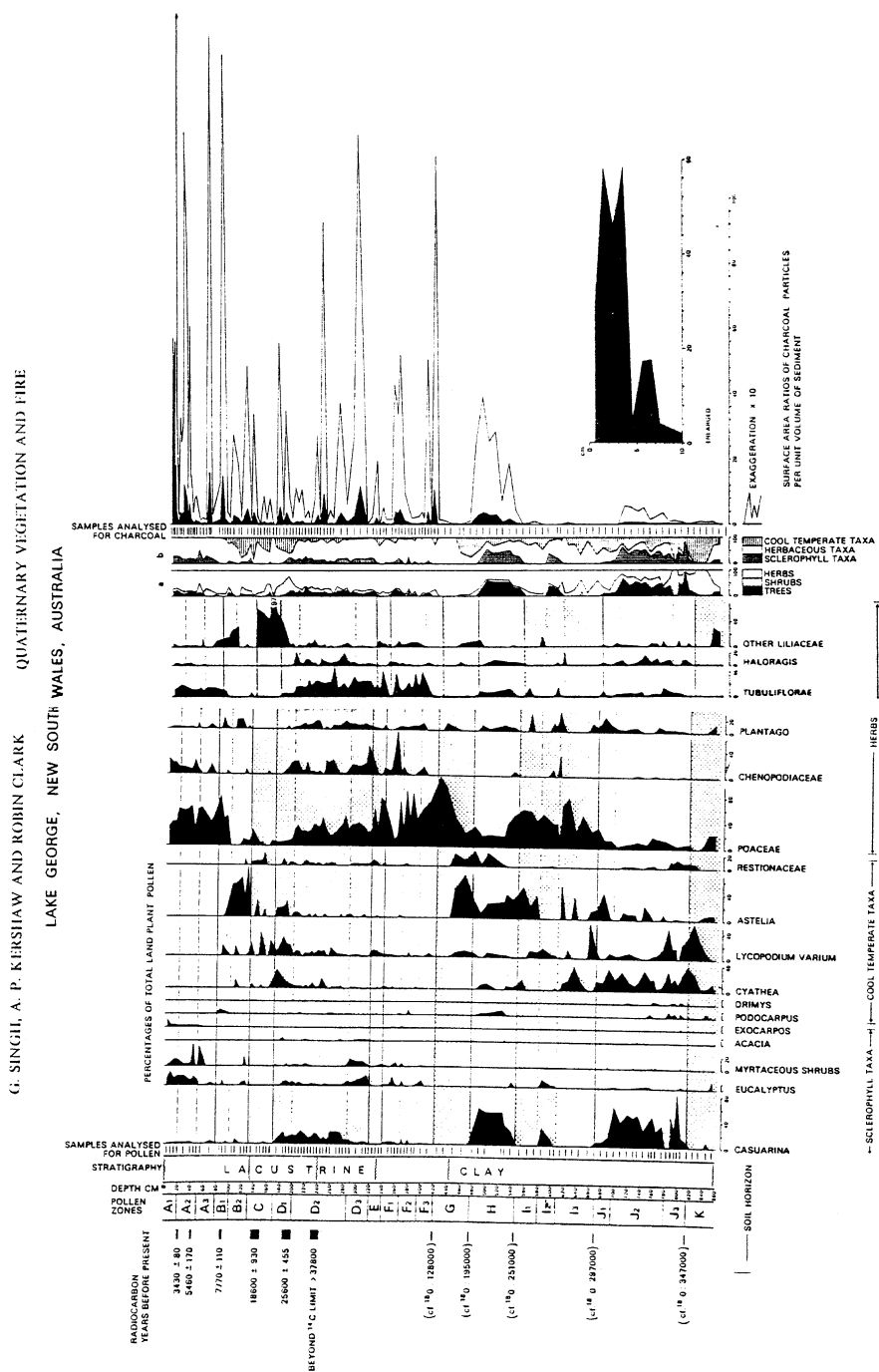


Fig. 4. Summary pollen diagram from Lake George. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. Charcoal values are expressed as two-dimensional surface area ratios of all visible charcoal particles per unit volume of sediment. The ¹⁸O dates beyond ¹⁴C dating limit in the pollen diagram are purely notional and have been transferred directly from the ocean palaeotemperature sequence of Shackleton and Opdyke (1973) for general guidance. The inset diagram shows an enlarged view of the charcoal values in the 0–10 cm section of the main diagram. The stippled zones represent cool–cold periods. Some fossil pollen of Chenopodiaceae and Tubuliflorae belong to shrub taxa.

taken (Spain et al., 1992). However, according to Tolonen (1986), peat deposits are a more reliable source of data. This opinion is supported by work reviewed by Lim and Renberg (1997). The main problem with peat deposits is the lack of precise dating.

Stahl (1989) has argued convincingly that hominid associations with evidence of fire are only a basis for interpreting behavior, e.g. control of fire and its uses. The earliest occurrence of fire and hominids tells us nothing about the potential significance of that event, frequency and association can. Association can tell us about cognitive abilities and purposeful behavior: warmth, cooking, clearing, etc. Frequency tells us that after a certain period of time hominids are associated with fire but not before. The identification of systematic features of fire evidence allows for such interpretation (James, 1989).

1.5. Forest management as an ancient adaptation

The arrival of Europeans to the Canary Islands, long populated by a people with an Upper Paleolithic stone tool technology (Hooton, 1925), resulted in the destruction of the forests by burning (Fernandez-Armesto, 1982). When Europeans discovered the Madeira Islands in the 15th century, the islands were covered with old growth forests and devoid of human occupation. The settlers set fire to these forests and the fires were kept burning for 7 years. The same situation occurred when the ancient forests on St. Helena were discovered in 1501. The island was left a barren landscape (Wallace, 1880). Human colonization required clearing of forests given the new forms of ecological exploitation humans invented during the transition from purely hunter-gather activities to that of the Neolithic and the development of horticulture and pastoralism (Mellars, 1976). However, the extent and history of these ancient forests on islands like St. Helena, the Madeiras, New Zealand (Kershaw, 1988) and Madagascar (Schule, 1990) argue against fire as a primary force in pre-human forest ecology. Since we have contrasting evidence between the Aboriginal occupation of Australia and the Canary Islanders, we cannot say if the propensity to burn forests has been a necessary

consequence of human occupation since the invention of fire. The Canary Islanders seem to have co-existed with their forests like many peoples with hunter-gather and horticultural ecological adaptations (Turnbull, 1962).

Our evidence for the Australian experience is indirect, we may have both a transitional *Homo erectus* and Anatomically Modern Human remains in Australian locations (Mulvaney, 1991) and it would appear, therefore, that they could have inhabited the continent at the same time, although their relationship is uncertain (Adcock et al., 2001; Wolpoff et al., 2001). However, we know that the long existence of *Homo erectus* was characterized by a wide dispersal over Africa and Eurasia, possibly into Australia and by a slow elaboration in tool kit (Schick and Toth, 1994) but a long stability in relation to its environment, and a varied ecological approach with regard to stone tools, (e.g. the Acheulian vs. bamboo). Its ecological adaptation was in balance for a considerable period (Wolpoff, 1996). Some questions have been raised about *Homo erectus* being considered one species (Rightmire, 1990), but these are insubstantial, at best, as regards the environmental impact of hominid history which I am considering.

1.6. Environmental degradation as a new adaptation

The various Archaic *Homo sapiens* seem to also have had a low population growth and a relatively stable ecological adaptation, though major changes in the toolkit occurred during this period. The appearance of Anatomically Modern Humans begins a new process in hominid ecology, one of environmental degradation by over exploitation and increased population growth. Neandertal and other Archaic Human populations seem to have followed the advance and retreat of forests during the Middle Pleistocene, but do not appear to have initiated dramatic environmental changes (Howell, 1952; Stiner, 1994; Gore, 1996). This may be due to the still low population density of the Middle Paleolithic groups as opposed to the general population increase of the Upper Paleolithic (Kennedy, 1980). Klein (1992) has identified two distinct ecological adaptations, which co-existed during the

transition to Anatomically Modern Humans. One which we can associate with a more intense environmental exploitation adaptation and rapid population increase, and the other a continuation of the less intense, low population trend which was prevalent through the Early and Middle Pleistocene. Examples of over-hunting which led to extinction of game and cultural entities are found in North America with the big game hunters of the Paleo-Indian cultures (Martin and Mehringer, 1965; Krantz, 1970; Simmons, 1993). Cohen (1977) described this process as leading to disastrous food shortages prior to the invention of agriculture. Interestingly, megafauna and humans survived for 7000 years in Australia, quite unusual when compared to other continents (Simmons, 1993).

A recent re-examination of the effects of humans on environmental extinction has been developed by Marx, McPhee and Lackner (Zimmer, 1995; Dayton, 2001). They have focused on habitat destruction and hunting. One other interesting aspect of human intervention, which they have brought up, is the introduction into new environments by humans and their animals (mainly dogs) of new infectious agents which increase the mortality of local animal life. The end result of an anthropogenic fire-adapted flora is the elimination of all animal life, which cannot survive such fire. A selective pressure assures the success of only those who can adapt.

Some peoples do appear to have lived within or near forests without resorting to forest destruction and this condition seems to have been rather general in the Americas prior to contact. As Russell (1983) noted from his review of the ethnographic literature, fires when set were local and in the minority of reports (approx. 17%). His sources are for the Northeast part of the USA and other authorities I have cited for different regions report more frequent use of fire, (e.g. Barrett and Arno, 1982). Burning grasslands, and some fires in woodlands and forest margins, seems to be a general characteristic of human enterprise (Stewart, 1956). We do have some exceptions to this idea, however, especially in Mesoamerica, where archaeological evidence and historical records show that large-scale harvesting of forests was underway in the late 15th century for fuel and

fiber, especially for clothing and paper manufacture (Hagen, 1944; O'Hara et al., 1993). The environmental degradation resulting from these activities did not reach the extent of the old world which, even by 6000 BP, caused collapse of civilized centers (Rollefson and Kohler, 1992; Redman, 1999). Similar events seem to have been underway in the Peruvian area prior to contact (Moore, 1998).

Fire in the Amazon in the period 7000 to approximately 1000 BP indicates human presence (Fearnside, 1990). Data on the extent of slash and burn agriculture in the Americas and its antiquity must be considered carefully in light of new work like that of Roosevelt (1980, 1991) and Roosevelt (1996), which support Lathrop's theories of long-established and stable complex societies in the Amazon and other regions formerly thought to be areas of slash and burn agriculture. These concepts of population stability must be viewed in the context of the limiting factors of population growth within the biological concepts of carrying capacity of the environment, seasonal variations and resulting steady state adaptation (Murdoch and Oaten, 1975; Keeton, 1980). Earlier ethnographic evidence and historical reports appear to be based on hunters and gatherers (using fire in hunting) who were driven to the peripheries of their range and were surviving in marginal areas. This is certainly true of such peoples in Africa as the Kung! (Diamond, 1994).

The Eastern Woodlands of America, however, has good evidence supporting traditions of forest management using fire (Patterson and Sussaman, 1988; Pyne, 1982). Sediment core analysis in Japan shows destruction of natural laurel-leaved forest at approximately the 12th century and replacement with pine, which corresponds with the building and expansion of a Buddhist temple in the area (Miyoshi and Itow, 1980). Other pollen analysis in Japan shows destruction of forests and replacement with rice (Nakamura and Hatanaka, 1976). On the other hand, Yll et al. (1997) find that pollen diagrams indicate that changes in forestation coincided with human arrival in the Balearic Islands and significant climate change is also noted by Magri (1995) in other areas of Europe. But the character of fires produced by climate

change must be considered, since drought — the assumed major factor — would result in less plant growth and less biomass. Faunal consumption of these decreased resources would result in reduced fire fuel. It would be logical then, to expect that without man to reduce forest and grassland fauna fire would be limited.

1.7. *Co-evolutionary aspects*

So what is the ecological relationship of humans to forests, what is the evolutionary history? And what are the recent trends based on? We know that most Hominoids are restricted in their present ranges to tropical forests, the gorilla, the chimpanzee, orangutan, gibbon and siamang. Evidence from the Miocene shows that our Dryopithecine-like ancestors were most likely forest-dwelling, but the Mid-Miocene climate introduced a long drying period associated with forest decline. By the Pliocene we find creatures like *Ardipithecus ramidus* and the Lothagam finds, which appear to be adapted to a savanna or woodland environment. More recent finds of hominids in the 4 million year range show a variation, but in general our ancestors still appear to be forest or near forest inhabitants (Harris, et al., 1988; Schrenk et al., 1993; Teaford and Ungar, 2000). The australopithecines and early *Homo* types appear to be adapted to more open environments, while *Homo erectus* seems to have gained an ability with its cultural aids to survive in many ecological settings and climates. But *Homo erectus* also most likely invented fire.

Since we have no real evidence of forest fires associated with *Homo erectus*, does this mean that we can assign to the kind of being which became Anatomically Modern Humans the tendency to destroy the forests? Was this an ecological need? A psychological need? One author has stated that humans 'instinctively' prefer a savanna landscape (Whitford, 1983). The general view is that fire increased game, which resulted in increased human population, but as Cohen (1977) has noted, this could only be a temporary relationship with a finite increase in game and the inevitable result of human overpopulation. Is it possible that because fire is such a dramatic and destructive event in

our era, we are influenced to believe that it must have been as powerful a selective pressure on forests in the past? The geoclimatological evidence argues against fire having this major role (Lewin, 1984).

1.8. *Human arrival in Australia and fire*

Our first evidence of forest fires in Australia, then, may be associated with the arrival of AMH, say 60 000–100 000 BP, although there is some evidence of fire prior to this period (Kemp, 1981; Singh and Geissler, 1985). Nevertheless, charcoal studies conducted by Singh and Geissler (1985) demonstrate a regular pattern of fire after 120 000 BP (see Fig. 4) and suggest that present fire-adapted species could not maintain their present extent without human fire intervention. If so, this fits a general pattern with other continents, although Bowman (1998) argues for a transition to 'fire resistant' species given charcoal/pollen sampling for other Australian sites at 1 mya, before any evidence of human arrival. Whelan (1995) also cautions, following Gould and Lewontin (1979) and Harper (1982), that one should not make broad assumptions concerning evolutionary trends using ultimate explanations. However, the natural agency so often associated with non-human-caused fires is lightning, although volcanic sources and spontaneous combustion are other possible sources, especially when drought and disease have pre-conditioned a locale for fire. We do have some evidence that Australia has some local lightning conditions, which result in considerably higher naturally created fire (Pyne, 1991). Still, we do know that Australian aborigines have historically caused a great number of fires and they did so with seasonal regularity (Pyne, 1991). But other human groups have not reproduced this relationship. Thus, what is the main feature operating here? It could be argued that *Homo erectus* might be responsible for the Australian fires, given the intermediate features of the Kow Swamp remains (Mulvaney, 1991), but the sample of Australian hominids is overwhelmingly weighted to *Homo sapiens sapiens* (Thorne, 1980). Also, recent mtDNA analysis shows that the Kow Swamp population cluster with living Australians



Fig. 5. Carbon in soil 1 year after Mt. Vision fire.

and indeed (Adcock et al., 2001), when considering ancient mtDNA and living mtDNA ‘...the deepest branch is Australian’ (Relethford, 2001).

1.9. Makeup and nature of forests: fire-adapted species vs. ‘old growth’

We hear today that our forests require fires to clear the build-up of years of biomass accumulation, of old trees and undergrowth that old growth forests are weaker than new forests and therefore are regenerated by fires. Yet there is no evidence that old growth forests burn more often or produce more acres lost than younger forests. Certainly, some species of trees need fires to maintain their dominance in various ecosystems. This is true of the pine forests of the southwestern coastal plains of the US. These forests require periodic fires to keep out competing broad-leafed trees (Bates, 1960). The slow-growing, long-leafed pine seedling is covered by a bushy canopy of needles and is always in danger of being shaded out of the necessary light for survival by rapidly growing shrubs. These pine seedlings are also susceptible to a fungus growth on its needles. Fire destroys the competing shrubs and the fungus as well. This helps the pine maintain its control and furthers its dominance. The pine seedlings are protected during fires by a dense cover of needles and they grow rapidly for 2 or 3 years after a fire, clearly establishing themselves. In the same way, fires are a help to the Jack Pine of Michigan and the Knob Pine of California. These trees require the heat of

a fire to open their cones. The cones open after a fire and the seeds fall on a fertile bed of ash to germinate (Nelson et al., 1974) (see Figs. 5 and 6).

The fact that some trees have adapted to fire conditions does not mean that fires are good for all trees or all forests. Forest fires aid some species of trees at the expense of others. Such trees are opportunists who take advantage of disasters (storms, fires, etc.) to expand and establish themselves when the climax canopy is broken. Their success is short-lived unless fires are periodic and general (Patterson and Backman, 1988). In one of the comprehensive surveys of studies of the effects of fire on specific localities Sweeney (1956) reviewed the effects of fire on a spectrum of species. The effects of fire on local populations of plants were found to vary due to soil type and a variety of other factors including germination due to light and heat levels, soil pH and drainage. While herbaceous plants increase in number after recent burns and are generally absent under continuous woody cover, annuals generally replace perennials. However, there are transition areas of shade-tolerant perennials in broken areas of woody cover and the peripheral areas. Ultimately, after 4 or 5 years herbaceous plants become rare and burn areas come to be dominated by grasses, although this was not true in all cases. In fact, it was the combination of fire and cold that resulted in the greatest increase in population densities, which adds support to the idea that these ‘fire-adapted’

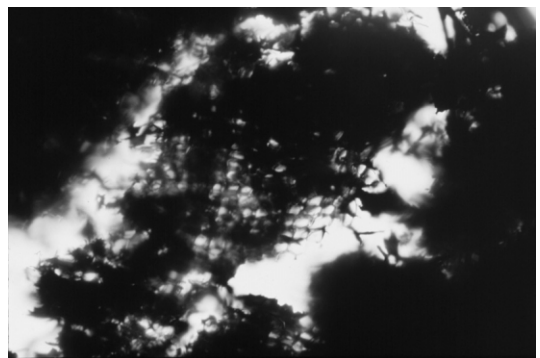


Fig. 6. Carbon and plant fragment in soil 1 year after Mt. Vision fire.

species are really opportunists. Their transient status on burn areas lends further evidence to this view. However, the effects of fire depend on the type of forest or grassland, the type of soil and the climate compounded by local variations in drainage and microenvironmental conditions (see papers in Kozlowski and Ahlgren, 1974).

1.10. Fire and native Americans

Often, as in the case of the Malibu fires, and those in recent years in Florida, Northern California's Mt. Vision fire in Marin and the Los Alamos fire in New Mexico, ethnographic evidence of Native Americans burning brush and forests is used to support the idea of the antiquity of forest fires (Barrett, 1935). Much of this information is indirect and is questionable in interpretation (see Blackburn and Anderson, 1993). Some examples are clearer in this regard than others, for example the Dobyns (1981) report on the Sonoran Desert or the Oak savanna in Northeastern Wisconsin (Dorney and Dorney, 1989). Nevertheless, in some cases, we can associate burning of brush in some cases to the needs of cattle ranging and economic pressures brought on by Western contact (Gayton, 1948; Walton, 1992).

Most reports of early immigrants to North American forests tell of mature forests which lacked undergrowth (Matthiessen, 1959; Bates, 1960). How do we explain this lack of undergrowth? Partly by a great population of animals, which consumed what biomass that accumulated, but also in the nature of mature, climax forests. They have little in the way of brush. Second growth forests are choked with undergrowth until the canopy develops and the light is restricted, allowing only shade resistant plants to survive (Alaback, 1988). Such forests are unstable and only maintained by logging or periodic fires (Bates, 1960). How do we reconcile this lack of undergrowth with the knowledge that Native Americans engaged in hunting as a major dietary source? The answer lies in both a broad reliance on a variety of food resources and a relatively stable population (Caldwell, 1958). The population history of Native American populations is the subject of considerable debate (Salzano and Cal-

legari-Jacques, 1988; Thornton et al., 1991). Birds, mammals and shellfish and fish were utilized (Carlson, 1988). While changes in population density from Paleo-Indian through Archaic to pre-European contact resulted from a generally greater reliance on plant food collection, at least in the western portions of North America (Chartkoff and Chartkoff, 1984), methods of environmental exploitation did not spread continuously even among peoples in contact through trade. All these wildlife resources have been vastly reduced since European contact.

We do know that even these mature forests were not stable or static over the millennia, they shrank and expanded in response to climate change (Prance, 1982; Walker, 1990) and due to the action of 100–400 million beavers which once populated North America (Luoma, 1996). The main culprits of forest and wildfires are non-native plants, especially grasses and brush. The lack of fauna generally, allows for the build-up of native plants, but the lack of animals that feed on non-native plants is a real problem. In Europe this 'silence of the forests' was emphasized by reference to the lack of danger of the spread of hoof and mouth disease to wildlife, there is none.

1.11. Archaeological evidence

So what of the archaeological record for the Americas, what does it tell us of forest fires? One drawback to the various sources of evidence of fire is summarized by Peters (1989), 'expert opinions based on visual inspection appear to be assigned the same factual status as the results of laboratory tests.' Of the thousands of archaeological reports written since Thomas Jefferson (Caldararo, 1984), few have noted evidence of forest fires, but few investigators were looking for them. The evidence is to be found in the auger remains and cores often taken at sites as preliminaries to trenching. Thus far there is little information available.

One unavoidable fact, however, is that Late Quaternary sediments characteristically contain inclusions of microscopic carbon particles resulting from the burning of wood, grass or other vegetation (Patterson et al., 1987). While some research-

ers argue that some of these must result from natural fires (Tolonen, 1986; Terasmae and Weeks, 1979), the correlation of this carbon and the appearance of Anatomically Modern Humans is certainly significant. Indications of paleofire prior to the Pleistocene is uncertain due to contradictory results and interpretation of fossil charcoals, soot, features (see Figs. 4 and 5), which appear to be chars and the presence of a substance resembling charcoal in strata — fusain (Goldberg, 1985; Robinson, 1987; Harris, 1957, 1958; Scott, 1989; Jones and Chaloner, 1991; Beeston, 1987; Taylor et al., 1989). It is thought that fossil charcoals — fusain — may accumulate over time and concentrate in strata due to its greater resistance to degradation and other properties that give it greater durability (Harris, 1958). This would skew our understanding of fire in the past, as this accumulation would give us a false impression of fire frequency and intensity. Also, due to the higher concentration of oxygen in some past environments (Monastersky, 1995), oxidative decomposition may represent some of the ‘burned’ features of fusain, especially those noted by Harris (1958) and attributed by him to fast fires of short duration in the Mesozoic. However, other mechanisms for fusain preservation have been proposed and are reviewed in Robinson et al. (1997). The vast stores of coal and petroleum found in the earth prior to industrial age represent good evidence for a lack of fire in the distant past as these stores are unburned vegetation. The general lack of seasons and high humidity would act to reduce the occurrence and extent of fires through the Carboniferous (Berner et al., 2000).

There is evidence that there were few dense woods until the Paleocene or late Cretaceous due to the feeding of herbivorous dinosaurs and their crushing locomotion (Schule, 1990). Evidence from paleosols with fossil root traces give us an idea of the antiquity of rain forests and other forests (Retallack and German-Heins, 1994). Fossil trees and forested paleosols are known from the Middle Devonian, but the earliest paleosols with characteristics like that of rain forest soils date only from the Carboniferous (Retallack, 1997).

Clark and Robinson (1993) have recently summarized the available global data. They note, for example, with regard to North America, that most fossil charcoal in New England occurs most abundantly in coastal areas where Native American populations were concentrated. Other points of disagreement regarding the charcoal evidence for Indian set fires have been addressed by Campbell and McAndrews (1995). However, as Tolonen (1986) has pointed out, very little is known of the relationship of charred particles and the intensity and/or extent of fires. Tests using charred particle analysis to pollen ratios have identified historic fires that were not noted using charred particle analysis alone (Swain, 1973). Nevertheless, the question of the proximity of the fires is in doubt and only a comparison of many sites over widely separated regions can distinguish many local fires from one large regional fire. Recent work has improved the ability to make this distinction (Clark and Patterson, 1997), but clear patterns are still difficult to distinguish (Pyne and Goldammer, 1997). Disturbingly, charred particle peaks and pollen influx peaks do not correspond over geographic areas, e.g. results from eastern Finland (Tolonen, 1983) and Ontario (Cwynar, 1978) are not similar. See Fig. 10 for an example of the confounding affects of soil mixing.

1.12. Other methods: fire scars, fire histories and thermal alteration

Reference to fire histories (fire regimes) based on tree-ring analysis (Swetnam and Baisan, 1996) are also unreliable because they are constructed from variable evidence. The feature utilized to identify fire chars in tree-rings (Swetnam, 1993) can be the result of any injury to the tree which initiates vascular repair (see Figs. 7 and 8). Most of the evidence is circumstantial and based on anecdotal reports and not scientific testing (Baisan and Swetnam, 1990; Lachmund, 1921; Arno and Sneek, 1977; Hepting and Hegecock, 1937). This can include insect infection, physical trauma of any type, pathogen attack or stress, all of which can bring on necrosis of tissue. Until the physical structure, which is called a fire char, can be characterized scientifically, tree-ring data for fire



Fig. 7. Oak tissue damaged by fungus producing dark line (necrotic border).

histories must be regarded with some caution. Note Fig. 7, which illustrates tissue damage caused by extensive fungus attack. Pyne and Goldammer (1997) illustrates tissue damage believed to have been caused by fire on page 72 of their article and Hepting and Hegecock (1937) describe in detail features of various post-fire damage believed to be associated with fire scars. A catalog of reference photographs and microscopic photographs of tissue damage would be helpful in determining precisely what types of tissue damage are specifically caused by fire.

Comprehensive, multi-dimensional approaches have been developed recently, relying on a number of information sources and methodologies including charcoal and pollen, but placing these different

data in an ecological context (MacDonald et al., 1991; Bellomo, 1993, 1994).

2. Tentative conclusions

I think we can deduce from our discussion that the large-scale forest fires we experience today are modern creations of human habitation, made worse recently by suburban sprawl. We must conclude that human occupation, at least in the Old World, results in forest destruction, and that this trend has its roots in the late Pleistocene due to the few Native American parallels, the evidence from the Canary Islands, and the general lack of forest clearance by hunter-gatherers. We do not have a good database for understanding the history of forest fires, pre and post hominid presence.



Fig. 8. Section of tree exposing dark mass in tissue (lower left edge of grayish heartwood at center).

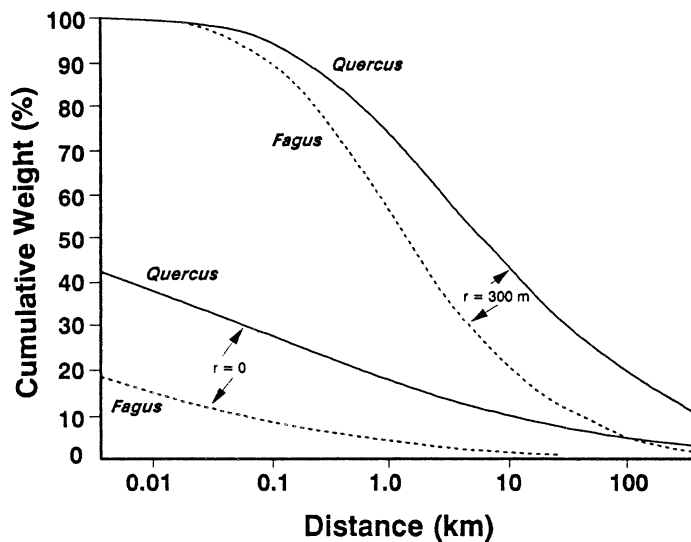


Fig. 9. The cumulative weight of airborne pollen from different radial distances from the center of a small lake ($r=300$ m) and from a deposition such as a moss hollow ($r=0$ m) [from Fig. 1]. *Quercus* is a relatively small and light pollen type ($b_r=0.73$), while *Fagus* is larger and heavier type ($b=1.4$) (adapted from Prentice, 1988 by MacDonald et al., 1996). The spatial resolution of the lakes usually used for fossil pollen analysis ($r=100$ – 500 m) will vary considerably for pollen taxa that have different settling velocities.

The desire or willingness to burn the forest may reflect the process of successive environmental depletion, which appears to be a consequence of the behavior and technology of Anatomically Modern Humans to some extent. We do have evidence, however, that many human groups did not resort to such behavior and we cannot conclude, as Jared Diamond has in his analysis of the collapse of Easter Island society, that modern humans are driven to environmental destruction (Diamond, 1995). We may simply be pre-adapted for it. One positive note is the change Sweden has made from an anthropogenic fire regime in its biota to one controlled for commercial and recreational timber growth using other means (Pyne, 1995). These efforts are being reviewed by scientists of the US National Park Service to determine if such silviculture could be a more effective means of fire management (Allen, 1994). This is especially important since prescribed burns in the National Parks have been found to destroy evidence of past fire-scars (Swetnam and Baisan, 1996). The affect of the presence of humans in the present fire-adapted flora seems to argue forcefully for the

establishment of wildlife preserves from which humans are excluded.

Some procedures used in the past, like the identification of fire scars and the creation of fire histories, have been applied without rigorous scientific methods. Other methods like charcoal analysis and pollen studies were considered only in the context of fire regimes. Today these methods are being applied to study climate and its affects on flora transitions (Hu and Brubaker, 1996; Markgraf and Anderson, 1994). Still, problems exist in some studies that have not considered the effects of differential transport of pollen of different species (see Fig. 9) and the impact of sediment mixing by worms on the age composition of pollen grains (see Fig. 10). Other factors related to taphonomy of pollen and charcoal need to be studied. Problems in associating pollen data and charcoal often result in contrasting results (Clark, 1988a), though some improvement in associating transport and local fire has been made (Clark and Patterson, 1997). Efforts to reduce variations due to particle size variation have been made, (e.g. Clark, 1988b) have assumed that methods used to

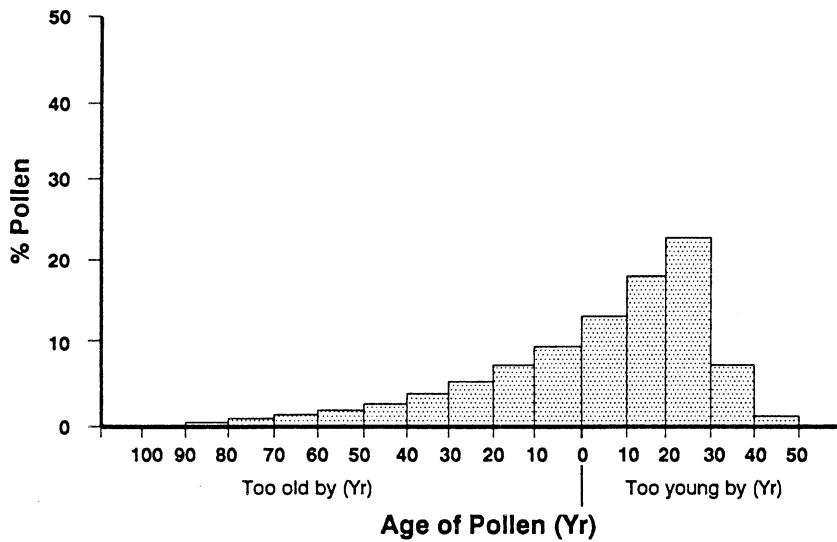


Fig. 10. The impact of sediment mixing by common tubificid worms on the age composition of pollen grains in the sediments of a small lake in eastern North America (adapted from Davis, 1973 by MacDonald et al., 1995). Due to bioturbation by tubificids, the sediment sample contains pollen grains that are both younger and older than the calculated time of deposition, and the temporal resolution of the pollen record is reduced.

compensate, namely fire scars, were uniform phenomenon which is open to question as here discussed.

Correlation of pollen and charcoal data with 'fire scars' and fire histories should be applied to archaeological evidence of faunal succession and archaeomagnetism as well as climate change. Other potential causes and factors like plant disease need to be considered as well. Riggen et al. (1988) noted this for chapparel. Large-scale mass death of trees would have the same effect as fire and climate in changing patterns of tree composition and other flora, and would drastically change the pollen profile. This would be similar to the epidemic of Sudden Death Oak Disease seen now in California. An epidemic which killed many trees quickly could add to fire potential (especially one like the California epidemic which appears to be spreading to other species than Oak), but one which progressed slowly (as well as insect infestations) could have the same effect on pollen diagrams as fire. Improvements in the specificity of the data will allow for more confidence in understanding both the antiquity of human-con-

trolled fire and in the mechanisms of fire regimes in the past, present and future.

In terms of present forest management policies, one can see from the data provided in this paper that controlled burns would tend to increase biomass, fire burden and fire frequency. A study by Keeley et al. (1999) found that prescribed burns do not always reduce brushland fire intensity. However, intensive silviculture as seen in Sweden, may result in a too agricultural forest system with detrimental effects on some wildlife and the public's conception of how a forest should look. Variations in the effects of prescribed burns have been described by Riggen et al. (1988). A balance would seem to be possible with management of wildlife, which would reduce biomass and arrival at climax forest stage, which tends to prevent biomass growth. The combination of burning and logging are the most apt to predispose a forest to fire and present forest practices that rely on this should be ended.

However, substantial changes in grasslands and woodlands are underway, which compound their transformation into periodic infernos and have

advanced the process of fire adaptation. These changes have arrived with every new species of non-native plant that has made a successful invasion. Recently, Wilkinson (2001) described how these exotic plants have spread into desert areas making them a subject of periodic fire where there is little evidence of fire.

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