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Controlled Burning and Air Pollution: An Ecological Review

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MANKIND IS only a part of the great ecosystem which surrounds the planet earth as a thin envelope—and this earth is but a minute fragment in a much larger system, the universe. All, however, are subjected to the same forces and governed by the same basic laws. Man, from his beginning has consistently challenged and directed many of the natural forces in the earth's ecosystem. But unexpectedly, he has now been compelled to recognize that certain fundamental and basic principles that govern these forces cannot be changed; that *nature to be commanded must also be obeyed.* These basic laws can no longer be violated with impunity or be disregarded.

Much of the current discussion on pollution, in particular control burning and air pollution, reveals little understanding of the complexities of these basic and fundamental principles or of the intricate relationships of fire ecology to the ecology of the whole atmosphere, "this great, swirling envelope of gases that surrounds the earth" that "extends outward for hundreds of miles to form a tough, transparent shield against the cold immensity of space; and . . . accompanies our planet in its annual 600-million-mile journey around the sun" (Simpson, 1969). Certainly a comprehension of the complex inter-relationships between that of nature's ecosystems and that of man's highly complicated societal ecosystem is not apparent. Much more ecological investigation with a holistic or over-all view is needed as well as the current excellent specialized studies, primarily on emissions at the source of the pollution. We cannot understand, of course, the "whole" without information of its "parts", but neither can we comprehend the "parts" without a knowledge of the "whole." Lack of time as well as the complexities of these inter-locking ecosystems, man and nature, will permit only a generalized, elementary discussion in this ecological review. However, I would like to consider some of the basic laws and ecological principles that govern man, earth and the universe and thus try to place control burning effects in regard to air pollution in their proper ecological perspective.

BASIC UNIVERSAL LAWS

One of the basic universal laws is the *conservation of mass or matter* which is "the principle that the total mass of any material system is neither increased nor diminished by reactions between the parts." (Webster, 1946). Thus, man does not destroy matter, he simply *changes* its form according to certain other basic laws.

However, all living things exist by a process of converting one form of energy into another. Energy also is needed to operate any system and man's civilization is a system, an ecosystem by itself. Thus, man again must govern his activities by another basic law, the *conservation of energy*. This law states that "energy can neither be created nor destroyed, but it can be changed from one form to another." (Beiser, 1965). This has been called the first law of thermodynamics. The second such law is stated as follows: "No process involving an energy transformation will spontaneously occur unless there is a degradation of energy *from a concentrated form into a dispersed form.*" (Odum, 1954) (*Italics mine*). Thus, man, in operating his civilization does not *create energy*, he simply transforms energy from a concentrated form to a more dispersed form. This, then, is the essence of pollution problems; the dispersal of what are generally called "wastes."

These basic *universal* laws govern man in his actions when he transforms matter to obtain energy to operate his civilization. If this transformation is not properly regulated and the alteration of matter to produce energy is either too rapid or of too great a magnitude, the earth's natural self-cleansing systems are overloaded and do not function properly. When this occurs the ecosystem becomes polluted.

The earth's ecosystem, or the biosphere, consists of the thin outer envelope of the earth from a few feet below the surface to the limits of the atmosphere. This biosphere consists of many diverse, complex, inter-reacting and interlocking systems. These systems are part of an organization dependant upon many fundamental natural and universal principles for Nature is not a disorganized entity.

The Life System

Living things have certain properties that separate them from the non-living. Of paramount interest is the fact that they create and dispose of wastes. The AAAS Air conservation Commission (1965) has pointed out that:

> Every living thing contaminates its environment. To live, it must react with its environment, and in the process of reacting—by the very fact of living and reacting—it produces and casts off wastes.

Another basic ecological law for living things can be stated as follows: *Living things cannot continue their life processes in their own wastes*, unless those are changed considerably by physical, chemical or biological actions. Mankind is no exception. However, the earth's ecosystems, including land, water and air have remarkable self-cleansing properties. The life systems contain very cooperative programs in which essentially the waste products of one living organism become the very existence of other living things. This, in conjunction with many chemical and physical processes, is a very integral part of the earth's housekeeping. If environments did not have such "built-in" mechanisms they could not sustain life. They do not operate independently but cooperate and in a sense reinforce each other to keep the ecosystems from being overwhelmed with waste products.

The habitat of man and every other living thing is intimately intertwined with land, water, and air. When wastes are produced too rapidly and not dispersed properly the concentrations of such materials do not allow the several self-cleansing mechanisms to work. In such events the land, water, and air become polluted, and eventually the environment cannot support life. Man by his immense concentration in urban developments which necessitates the removal of vast quantities of "wastes" can destroy his own environment as well as that of other living things. Thus, pollution control, or management, becomes imperative.

One of the easiest and most economic ways of disposing of many of mankind's wastes has been by burning, dispersing the ashes on the land and remains into the atmosphere. In fact, fire was the foundation for man's evolution and the rise and development of his cultures (Komarek, 1967). It now is the basis for his civilization. Air appeared to be an unlimited resource but now man has found that this waste disposal system is limited indeed, particularly if not managed properly. As long as its capabilities are understood, it can be used constantly. To understand these capabilities the "ecology of the atmosphere" must be studied.

THE AIR ECOSYSTEM: THE ATMOSPHERE

In 1941 J. B. A. Dumas, the great French chemist, concluded his lecture on "The Chemical and Physiological Balance of Organic Nature" with the following remarks:

> The atmosphere, . . . , is the mysterious link that connects the animal with the vegetable, the vegetable with the animal kingdom. (Hutchinson, 1944)

Unfortunately the holistic approach to a study of the atmosphere is seldom used. We attempt to put together some "parts" and hope to understand part of the atmosphere's ecology. Byers (1959) has pointed out that the atmosphere:

> . . . is a huge thermodynamic engine, driven by the energy re-

> ceived from the sun. The general circulation over the earth, all winds, storms, and clouds result from the differences in the amount and utilization of this energy.

This circulation in turn is modified by the coriolis force of the earth's rotation, topography, etc.

The atmosphere of the earth has changed throughout time and will continue to do so. A basic and universal ecological law is "*always there is change*" and changing conditions must be accepted as the normal state of the air system. Chambers (1968) has written:

> . . . most certainly air composition has undergone great qualitative changes in the two billion years or more since the first anaeorbic self-producing units of matter came into being.
> . . . the primeavel gaseous environment probably contained almost no free oxygen; indeed all existing evidence indicates that the oxygen in more recent air has accumulated as a result of photosynthetic processes . . .

The Oxygen Cycle, and Carbon Dioxide Cycle

Note the interdependence of the oxygen producing plants and the atmosphere of today. Some 21 percent of the air mixture consists of oxygen that has been primarily produced by plants in water, air and on the land. Forests, green belts, grasslands, etc. that cover the land and the plants that live in the sea and fresh water are in the ecological sense a vital part of the atmosphere. Note too, as with our atmospheric engine, that the oxygen, this important ingredient for living things, is produced by the energy of the sun through a photosynthetic process in keeping with theories of dynamics.

Remembering the basic theories of the conservation of matter and energy as well as those of thermodynamics, imagine that the vast vegetative cover of the earth, like the atmosphere, is a vast thermodynamic engine. The energy required to make plants live and grow is received in a concentrated form from the sun and since they are alive they must produce and cast off wastes. Most of the oxygen (a little is used in its own respiration) is thus dispersed to the air as waste. Without this waste the animal world could not exist. It in turn uses this oxygen to oxidize or burn up food to release the energy that the plant captured from the sun. The animals in turn give off carbon dioxide back to the atmosphere as their waste. This is the oxygen-carbon dioxide cycle: essentially waste products which man cannot see, smell or feel. This is the great interdependence of plants and animals. However, these are not the only waste products being cast off. No living thing produces only one waste product.

Miscellaneous but Important Cyclic Systems

There are many cycles or systems in nature besides that of oxygen and carbon-dioxide in the atmosphere. The understanding of these, such as nitrogen, sulfur, ozone and others is necessary for the proper management of our air resources but time and space will permit only the inclusion of the following self-explanatory diagrams. However, a knowledgeable insight into the hydrologic, particulate and the carbon cycles is necessary in a review of control burning and air pollution so they will be discussed in some detail.

The Hydrologic Cycle

Only about 3 percent of the atmosphere consists of water vapor, but it is an extremely important and necessary part of our air ecosystem. Byers (1959) writes that:

> Although the percentage of water vapor in the atmosphere is quite small compared with the other gases, about six times more water is transported in the atmosphere of North America, for example, than is transported by all the rivers combined.

It is primarily a physical phenomena of evaporation but plants and animals do add considerable moisture to the air. Next to gravity it is probably the most important cleansing mechanism in the atmosphere; rainfall literally washes the air and removes from it chemicals, particles, pollen and other foreign material. This material is brought down to the surface of the earth, with the assistance of gravity, where the soil and water continue the cleansing process. This self-cleansing mechanism of the atmosphere works quite efficiently except when overloaded by catastrophic amounts of matter.

Overloading seldom occurs in nature, but man regularly and repeatedly exceeds the natural limits so that these cleansing functions cannot operate with maximum efficiency. However in most instances if this dumping of concentrated matter in overwhelming amounts is stopped or slowed down the atmosphere will cleanse itself if given sufficient time.

The hydrologic cycle generally relies on particles in the air called condensation nuclei for its precipitation. For increased emphasis I have separated the particulate cycle from the hydrologic cycle, for it is a cycle within a cycle.

The Particulate Cycle

Our atmosphere as well as outer space contains many small particles of various kinds of matter. Some of these are so minute that they can be seen only by the scattering of light rays microscopically; others so large as to be easily seen with the unaided eye. Some writers have even included flying birds, insects, mammals, and other large organisms as particles in the earth's atmosphere. We will however be only concerned with relatively small particles which appear to be cyclic in nature; that is, they originate on land or water, become airborne for varying lengths of time, and then return to the surface of the earth. However, I do wish to emphasize that particle "pollution" is not only an earth or atmospheric condition. In "Particles in the atmosphere and space", Cadle (1966) writes under the heading of "Galactic Dust":

> The galaxy in which we live, the Milky Way, contains large amounts of interstellar dust, and galaxies in general are probably very dusty systems. The dust in our own galaxy can be observed as dark patches in the Milky Way . . .
> The clouds are largely found in the spiral arms where they are a great nuisance to astronomers since they prevent observations of distant parts of the galaxy, such as its nucleus.

Thus even in outer space there are "nuisances" to mankind, a term that seems to be used by pollution experts regularly. However, some of these so-called "nuisances" in our atmosphere play a great part in the proper functioning of many of our ecosystems. Thus

Green and Lane (1957) in their "Particulate clouds: dusts, smokes and mists" under the heading of "Physcis of natural clouds" write:

Condensation Nuclei

> It is generally agreed among meteorologists that all natural cloud droplets formed from the vapour commence their growth around minute particles known as nuclei. From the time of the pioneering researches of Aitken (1923) it has been known that without nuclei there would be no fog, no cloud and probably no rain.

Cadle (*ibid*) writes:

> The particles in the troposphere are both "natural" and man-made although it is often difficult and rather arbitrary to try and distinguish between them. For example, numerous of man's operations dump tremendous quantities of particles produced by combustion into the atmosphere. But numerous forest, brush, and grass fires do the same thing, and *many of these are started by lightning.* (italics mine).

He separates the particles in the troposphere into seven main categories, sea salt; forest fires, rocks, and soil; volcanoes; meteroritic dust; biological material; air pollution; chemical reactions. The following discussion is concerned largely with the particles from forest fires, biological material, air pollution and chemical reactions as atmospheric pollutant materials.

Byers (1959) writes that, "Given a variety of particles in an atmosphere containing water vapor, one finds that, as saturation is approached, condensation will occur first on those nuclei that are large and *hydroscopic*, or at least not hydrophobic."

Byers then asserts that smoke, dust, and haze are quite similar in respect to particles but that, "Most atmospheric condensation appears to occur on what are classed as 'large' condensation nuclei."

Mason (1957) has suggested that of the condensation nuclei which produce clouds, about one-tenth are sea salt, and the rest are mixed nuclei and the products of natural and man-made fires. "Even a small fire introduces vast numbers of small particles into the atmosphere. It has been estimated that an average grass fire, extending over one acre, produces about 20,000 billion-billion (2.10^{22}) fine particles:" (Neuberger, 1948, by Cadle, 1966).

Certainly forest and grass fires were and are an important source of particles in worldwide weather patterns. Long before man, there had to be condensation nuclei and most of these came from the natural forces such as volcanoes, dust storms, salt spray and natural lightning-caused fires. The earth is, and has been bombarded with lightning discharges with an intensity and regularity that is just beginning to be recognized. This widespread action resulted in fire environments for both plants and animals with many adaptations that allow these to live in such environments. In many cases fire has become necessary for their existence and such natural fires have been called the "fire of life."

Dust from volcanoes, from wind storms over deserts or cultivated regions, and the activities of man are also a source of particles in the atmosphere. Wind erosion, a natural process, contributes a great deal to the dust load as it sculptures rock, seashore, desert, and sand. Mason (*ibid*) has stated that, "A single dustfall in 1901 deposited an estimated two million tons of dust on the African desert and on Europe (Hellmann and Meinardus, 1902)" and "An estimated ten million tons of red dust from northwest Africa was deposited on England in 1903 (Shaw, 1936)."

Another source of particles are various biological materials such as viruses, fungi spores, molds, marine bacteria, pollen and many such plant and animal materials. Mason quotes Darwin as follows: "Of five little packets which I sent him, he has ascertained no less than sixty-seven different organic forms! The infusoria, with the exception of two marine species, are all inhabitants of fresh-water."

This was dust that had settled on the Beagle and Darwin had sent it to a friend for examination.

Of special importance to this discussion of air pollution and controlled burning are the carbon particulates and the carbon cycles.

THE CARBON CYCLES

There are at least three cycles concerned with carbon particulates; Went's Natural Carbon Cycle, Lightning Fire Natural Carbon Cycle, and the man-made Pollution Carbon Cycle. The first two are *natural* carbon cycles. They have rarely caused problems to any living organisms. The latter is created by man fouling not only his environment but others as well. This man-made carbon cycle should not be confused with the first two for they are not the culprits in our modern air pollution problems.

Went's Natural Carbon Cycle

At the same time the vegetation "engine" of the earth is producing and casting off oxygen it is also producing and casting off vapors that can be sensed; the natural hazes over the vegetatively covered mountains, the jungles of the tropics, and the seashore. Went (1955, 1960a, 1960b, 1952, 1955, 1962) in a very interesting series of papers of utmost importance to ecologists and air pollution control specialists, discussed a natural carbon cycle that has been operating since the beginning of plant life. He wrote (1955) that:

> Summer heat haze is a mysterious special phenomena. It covers large areas of the world free from dust, fires or human habitation. A more or less dense haze hangs the year around over such areas as the Amazon basin, the vast jungles of northern Colombia and the highlands of southeastern Mexico. During the summer the heat haze covers most of the U.S. except the desert of the Southwest. It is so dense that in summer the open country is almost as hazy as our cities. The heat haze has nothing to do with dust, smoke or even moisture . . .
>
> . . . What is its source? For an explanation of such a blue haze in the air we can turn to the famous discovery concerning the blueness of the sky that was made in the 1860's by the well known English physicist and lecturer John Tyndall. He demonstrated experimentally that when a strong beam of light was passed through air containing small amounts of organic vapors, a "blue cloud" formed . . . He concluded that most of the sky's blue color had to be attributed to the reflection of sunlight by minute particles in the sky . . .
>
> . . . we can draw the conclusion that summer haze or natural smog, is caused by organic emanations from plants. They release vast quantities of material into the air. Most of the aromatic substances emitted by flowers are hydrocarbons or slightly oxidized hydrocarbons belonging to the general group of essential oils. Many plants contain terpenes, which after evaporation into the air produce the pungent odors of the deserts, the chaparrals, the dunes

or the pine forests. There is hardly any type of vegetation which does not emit volatile organic compounds. Haagen-Smit (1964) has estimated that the sagebrush vegetation of the Southwest releases approximately 570 pounds per square mile per day.

Went demonstrated that this is a "*natural carbon cycle*" and that these organic atmospheric gases and particles are eventually brought back to the earth by wind, rain, gravity, etc. as the atmosphere itself cleanses naturally.

> How does the air clear itself of this natural pollution. We might consider the theory that the organic emanations from plants are ultimately oxidized to carbon dioxide and water, but the particles responsible for the bluish haze are hardly likely to disappear in that manner; they are large, complex molcules and presumably inert chemically. They must leave the air by settling . . . it was found that even in remote areas about five per cent of the residue was organic and of a black tarlike consistency. . . . I also suggest that this inert material, consisting largely of hydrocarbons, might be the parent material for petroleum. The amounts of terpenes given off by plants are certainly sufficient to account for all the petroleum formed in previous geological periods.

Went also compares this natural carbon cycle with the man-made cycle when petroleum is used in combustion engines and creates what is called urban smog; what I call the Pollution Carbon Cycle. He also speculated about

> . . . the autumn haze, so common in countries with deciduous forests and with much dying vegetation. Who does not remember the typical smell of the autumn woods and of decaying leaves? This smell must be due to volatile organic substances arising from the dying material. In decaying leaves we find considerable amounts of terpenes, in the form of the yellow pigments, or carotenoids. . . . Even more familiar are those beautiful days in late autumn when the sun filters weakly through a bluish haze which baths the fields, forests and hills.

This then is Went's Carbon Cycle, a natural event that began with the first vegetation covering of the earth.

The Lightning Fire Natural Carbon Cycle

There is, in addition to Went's cycle, another natural carbon cycle. This I have termed the *Lightning Fire Natural Carbon Cycle* because it receives its initial energy primarily from lightning and secondarily from vegetation or organic matter. This is a natural particulate cycle initiated by fire in forest, grassland and other similar organic material. It has been an integral part of the earth's ecosystem since there was sufficient organic matter that would burn. There are also other less common fires of similar nature caused by other agents such as spontaneous combustion, sparks from rolling stones, friction, and vulcanism. However, the primary source of ignition energy for this cycle is received from lightning. This obvious and impressive electrical discharge is a complex mechanism (Taylor, 1969: Komarek, 1964, 1966, 1968; Arnold, 1964) which assists in stabilizing the earth's electrical field. Human beings too, are electrical mechanisms and thus kin, so to speak, to the lightning bolt. Every living thing is an electrical device, a live multicell battery that only remains alive as long as it is not discharged. Our ecosystem is an electrical system of which biologically we know little and practically nothing of its implications. I mention this, not as a matter of digression, but simply to stress the importance of understanding the impact of lightning and lightning fires upon our environment.

In the pre-man period lightning fires were a widespread yearly phenomena and this resulted in a fire mosaic of vegetation and animals. Man, however, has interfered and changed this mosaic but, even so, widespread fires occur. In October, 1968, one lightning fire burned over 281 square miles of Kruger National Park in South Africa, according to Dr. U. de V. Pienaar, the Park's chief biologist (Anon., 1968). This occurred in a region that had been controlled burned on a 3-year rotation for the most part and no great amount of litter or debris had accumulated. This fire spread over this region in spite of roads, fire-breaks, and the efforts of the fire fighters. Part of the area had been burned over by another lightning fire some 8 years previously.

The numbers of lightning fires in some of our national forests are nearly unbelievable. Arnold (1964) wrote in connection with USFS lightning research project "Skyfire" as follows:

> What *is* the lightning fire problem? Consider this: at this very moment some 1,800 thunderstroms are in progress over the earth's surface. During the next 20 minutes these storms will produce

> 60,000 cloud-to-ground lightning discharges. Some of them will start fires. This sequence of events occurs 9,000 times each summer in America's forests and grasslands (including Alaska and Hawaii). During the period 1946-1962, the United States experienced more than 140,000 lightning-caused fires. Eighty-five percent of them occurred in the western United States, causing severe losses of timber, wildlife, watershed, and recreation resources. We believe that the magnitude of the lightning fire problem calls for intensive research on lightning phenomena.

In 1967 I reported on all fires on all the U.S. National Forests for the 22-year period 1945-1966. This showed that on the 186,497,010 acres of such lands there had been 168,632 wildfires, and of these, 64 percent or 107,160 were ignited by lightning. In 1969 I showed that many national forests would be completely burned over every few years in the absence of man-made barriers or interference by man's fire-fighting.

In 1969 Taylor wrote that in the Western States:

> . . . a single thunderstorm can start tens of fires in minutes over miles of virtually inaccessible terrain. In August, 1961, lightning started nearly 600 fires in one 3-day period on the National Forests in Montana, Idaho, Oregon, and Washington (USDA, Forest Service, 1962). *This characteristic consequence of lightning—many fires in a short time*—taxes fire suppression agencies . . . (italics mine)

In "Lightning and Lightning Fires as Ecological Forces" (Komarek, 1968) I divided, in a preliminary manner, the North American continent into seven lightning fire bio-climatic regions on the basis of fire weather, fire climate, and fire plant and animal environments. Additional data now being accumulated show that both Australia and Africa can also apparently be divided into lightning-fire bio-climatic regions on a similar basis (Phillips, 1965; Hodgson, 1967; Mount, 1969a, 1969b). These natural organic fires have been a part of the earth's ecosystem for many millions of years long before man evolved. Since man learned how to use fire he has changed the vegetation surface of the earth but he has not changed the basic principles that govern the *Natural Lightning Fire Carbon Cycle*. Man cannot change the basic properties of the earth's ecosystem.

It comes as a shock to many people to learn that fires in forest and grassland were and are of natural origin; by lightning. For more than two generations the populace in the United States has been subjected to one of the most deliberate propaganda programs that this nation has ever been subjected to. This has included censorship under the guise of editorship to the extent that no one can evaluate much of the early American studies in this field. The "history" of most of the propaganda is covered by Stoddard, Harper, Beadel and Komarek in the first Tall Timbers Fire Ecology Conferences (1962). It has also been documented in a book "Fire and Water, Scientific Heresy in the Forest Service" by Dr. Ashley Schiff, a professor of public administration. Today certain divisions still continue their false advertising. Smoky Bear marches on in spite of the fact that other divisions in those same agencies are the largest control burners of forest land in the Southeast, acreage-wise! No wonder science, educators and the public are bewildered when they ride through a national or state forest "afire" while the radio blares "Only you can prevent forest fires." It is time that Smokey was re-educated to distinguish between careless, accidental wildfires and controlled burning. After daily bombardment on TV and radio it is no wonder that smoke from burning forest and grassland is considered a man-made pollutant of our atmosphere by pollution experts as well as the public.

It is because of this continuing fire propaganda I re-emphasize that forest and grassland fires are an integral part of the global atmosphere, of the earth's ecosystem. The ecological reasons why fires are so important has been well covered in more than 2300 pages in ten Fire Ecology Conferences by over 200 speakers. In addition, there has been a tremendous increase in fine scientific studies on fire ecology in the past decade or more, published in many scientific journals. There is no need in this paper to defend the use of fire in forest, grassland, marsh and other vegetative types for many purposes including the management of a great variety of major and important animals and plants. Man by fire-exclusion policies in the United States has indeed tampered with a natural system without consideration of the ecological effects of such action.

The action of natural fire by lightning can vary from the blinding intensity of the burning matter in the lightning channel to the "cold" fire ignited in a wet marsh or bog. In doing so it "re-cycles" organic matter and on land it develops fire environments. These are environments that if not "disturbed" in some manner would develop into old and senescent vegetations covering the globe. Birth, growth, age, and death are the natural components of all living things. And they create wastes which must be removed or changed by some agency. Fire is one such agency that changes wastes. It also sets succession back to an earlier stage with great benefit to many animals, flowers, grasslands and forests.

Information on what might be termed the ecology of the particulates in forest or grassland fires is meager. No serious studies appear to have been made as to the composition, character, size, shape, hygroscopic and other absorbing qualities, comparable to what has been investigated in regard to particulates from fossil fuels created by modern combustion processes. Certainly there must be considerable difference in the cleansing qualities of such particulates. Cadle (1966) points out that:

> Even a small fire introduces vast numbers of small particles into the atmosphere. It has been estimated that an average grass fire, extending over one acre, produces about 20,000 billion-billion (2.10^{22}) fine particles. These particles range in composition from inorganic ash through carbon to complex tars and resins.

He mentions that this is about two billion per cm but that the "concentration of condensation nuclei in a ventilated kitchen was found to exceed 5.10^5 nuclei per cm."

Some excellent studies, both field and laboratory, have been made on the emissions primarily from the control burning of grass seed fields in Oregon, Washington and California.

Darley *et al.* (1966) reported that studies conducted in a "burning tower" at Riverside, California showed:

> Pounds of carbon per ton of waste burned varied from approximately two to a high of 27. Carbon yields from barley were consistently higher than those from rice, and this is probably due to the fact that the rice fires burned hotter than barley. . . . It is interesting to note that dry native brush had a relatively low carbon yield, but as green material was added to it the carbon count went up. When totally green native brush was burned, the highest yields of carbon were obtained.

From their data we find a range of differences in amount from various plants. Their data showed the following amounts of saturates (except methane, olefins, acetylenes).

fruit tree pruning	14 lb per ton
rice straw	9 lb " "
barley straw	18 lb " "
dry native brush	7 lb " "
green brush	36 lb " "

The brush consisted of 10 native species and one native digger pine.

They compared the above figures with the amount produced from the automobile which was 130 lb per ton of fuel. The average for their studies was 15.6 lb per ton of fuel from agricultural wastes. That is, one ton of fuel burned in an automobile produces over eight times as many pounds of particulates. There certainly must be some difference in the particulates from the two sources but this was not pointed out.

Boubel, Darley and Schuck (1969) in an excellent investigation of both field and laboratory studies found that their results agreed with that from the previous tower burning study. They found 15.55 lb per ton of fuel (from blue grass, annual ryegrass, and orchard grass) in comparison with the tower studies of 15.6.

I have been unable to find studies or investigations, except much speculation and theorizing, on the differences in particles or particulates from such natural combustion processes as forest or natural grassland compared to those created by man-made combustion engines or fossil fuels such as coal or petroleum. These are all burned under much higher temperatures than occur in forest or field. The "ecology of the atmosphere" as it pertains to the particles from forest and grassland fires certainly is in need of intensive study if we are to understand the natural processes of the earth's ecosystems.

It is time that we consider the natural fire carbon cycle of lightning and lightning fires as a very vital part of the earth's ecosystems of land, water and the atmosphere.

Pollution Man-Made Carbon Cycle

The difference in degree between the natural carbon cycles and the man-made pollution carbon cycle is staggering. It is true that at times natural particles from lightning fires, dust storms, volcanoes, can be extremely large, remain suspended in the air for a relatively long time and literally travel around the world. However, these natural producers of particles are infrequent and irregular. Furthermore, I can find no evidence that these particulates, in the amount and manner in which they are emitted, have ever been found to be harmful to living things. In contrast, man in his large cities pours particles into the atmosphere in great quantities in a steady daily cycle 365 days a year, and year in and year out. In some cities . . . "the fall of combined soot, dust, and other particulate materials on a single square foot of horizontal surface may exceed a pound a year" (Air Cons. 1970).

The industrial revolution precipitated this to such an extent that the accumulation of soot from coal, primarily, on buildings in Great Britain was so great that a melanistic strain of the Miller moth was developed by natural selection by nature to fit this environment. In the rural areas the population of this insect remained light colored.

> Both organic and inorganic particles emanate from a number of sources; industrial operations, modern transportation facilities, and domestic combustion processes. Major sources of dust include coal and oil-burning power plants, iron and steel mills, cement mills, and oil refineries. In addition, small sources, such as automobiles and incinerators, contribute significantly to the dust load of the atmosphere because they are so numerous. Smoke (dust and droplets) is produced during combustion or destructive distillation, and fume (dust) is formed by high temperature volatilization or by chemical reaction (Air Cons. 1970).

The pollution load of particulates dumped into the atmosphere by man is extremely large. So far the atmosphere has been able to disperse the material and cleanse the air given enough time and space. However, under certain meteorological conditions inversions occur, and this particulate load contributes to urban pollution. Air turbulence, air movements, and rainfall either disperses or washes out the particulates in time. There appears to be, at present, no general "overloading" of the global atmosphere and the overloading seems to be primarily a local problem.

TABLE 1. TONS OF PARTICULATES PER ONE SQUARE MILE PER MONTH.

Man produced	
	Tons
Industrial city (Great Britain)	16.7–166.7
Rural, small town (Great Britain)	0.8– 8.3
New Haven, Conn.	5.0– 62.0
Large cities (U.S.)	10.0–100.0
New York (1961)	68.4
Pittsburgh (maximum)	291.0
(Air. Cons. 1970)	
From natural sources	Tons
Organic materials (vegetation)	3.4
Salt (within 200 miles of ocean)	4.2
(Marchesani, et al 1970)	
Tons of particles per day per 1,000,000 people	
	Tons
dust	430.
rubber tires	4.3
spray cans, aerosols, etc.	5.4
cigarettes	3.2
cosmetics, perfumes, etc.	0.5
(Marchesani, et al 1970)	
Million tons per year for continental United States	
	Million Tons
natural fog	15
pollen	1
natural dust (some caused by man)	30
smoke (man)	5
industrial ash, dust	7
sulfur oxides	19
vapors (hydrocarbons, largely man)	42

TABLE 2. THE U. S. FOREST SERVICE CALCULATED THE FOLLOWING DATA. FROM WILDFIRES IN THE UNITED STATES:

	East	*West*	*Total*
Particulate matter (MM tons)	11	26	37
From controlled burning			
Particulate matter	6	11	17

GLOBAL AIR POLLUTION

I have discussed, from an ecological point of view, and in a very generalized manner, some of the universal laws, ecological principles and the natural gaseous and particulate cycles. Now I would like to discuss the ecology of the atmosphere from a holistic or over-all manner with particular emphasis, first on man's activities as a source of global air pollution, and secondly on his impact upon local air pollution.

I believe that *the global atmosphere has not as yet been materially affected by man-made or created pollutants*, with only a few possible exceptions. These are the carbon dioxide content of the atmosphere and the possible temporary contamination by chemical pesticides, and man-created radiation.

Carbon Dioxide

Although many materials are emitted in large quantities by pollution sources, none, other than CO_2, has been clearly identified as significant on a worldwide scale or over a long enough period to show a secular increase. (Robinson, 1970)

That the carbon dioxide content of the earth's atmosphere has been changing, or at least varying, is well substantiated. However, the statment that man has been responsible for these changes certainly has not been proven and has been proposed purely on theoretical grounds.

Both biological and geochemical processes provide a natural system for disposal, as well as replenishment of carbon dioxide. Green plants use carbon dioxide in photosynthesis, but most of the plant material formed is reoxidized within a few years, returning carbon dioxide to the atmosphere. (Berkner and Marshall, 1964)

In "The Origin and Evolution of the Atmospheres and Oceans" (Brancazio and Cameron, 1964) have pointed out that the carbon dioxide content of the earth's atmosphere must have had very wide variations in the geologic past. Eriksson (1963) writes:

> Because the CO_2 in the ocean is in some kind of equilibrium with the CO_2 of the atmosphere, the latter may be influenced by changes in the properties of the sea which affect the equilibrium of sea to atmosphere. One property which certainly affects it is the temperature of the sea surface; another is the volume of the sea. A third possibility is a change in the vertical circulation of the sea, because the present equilibrium is, no doubt, dynamical in nature.

He concludes, however;

> The general conclusion from this study is that neither temperature nor volume changes of the sea can have been large enough

> to cause any appreciable change in the atmospheric CO_2 concentration, at least not of any climatic importance. It is, however, pointed out that there is a considerable excess of CO_2 in the ocean, owing to a combination of biological and gravitational processes, which, if released, would increase the atmospheric concentration by a factor of 5. Serious disturbances in the biological circulation of carbon in the sea in the past may have caused wide fluctuations in the atmospheric CO_2.

And Moller (1963) in "On the Influences of Changes in the CO_2 Concentration in Air in the Radiation Balance of the Earth's Surface and on the Climate" writes:

> The entire theory of climatic changes by CO_2 variations is becoming questionable.

The AAAS Air Conservation Commission in its report concluded:

> However, the hypothesis that an increase in carbon dioxide will increase global temperatures is by no means proved. Moller (1963) recently examined the best available mathematical analyses of the total heat balance, and he has shown that depending upon the assumed dependence of the atmospheric water content on the temperature, *any answer*, from an actual temperature decrease to an infinite increase, can be obtained. (Air Cons. 1970) (italics mine)

It is apparent from the above statements that the so-called "greenhouse effect" which *might* develop by accumulations of carbon dioxide in the earth's atmosphere has been unduly emphasized by popular journals and other news media. Until the preparation of this paper and the necessary reading of technical journals and books, I had assumed that this "greenhouse effect" had a more *proven basis*.

Carbon Monoxide

Most of the carbon monoxide in the atmosphere along with carbon dioxide and water vapor, is the product of incomplete combustion of fossil fuels. The automobile produces on an average of 5 pounds per vehicle per day but remarkably there is no apparent accumulation in the earth's global atmosphere. The Air Conservation Commission (1970) reported:

> Global implications: From a long-range point of view, it is not likely that the accumulation of carbon monoxide will seriously change the composition of the atmosphere. The global emissions of carbon monoxide per year may be somewhat less than twice that of the United States. This would be about 200 million tons which, evenly spread over the lower atmosphere, would result in an increase of 0.03 ppm of carbon monoxide per year if it were not oxidized. It is generally assumed that carbon monoxide is oxidized in the atmosphere, although at a slow rate, and accumulation seems improbable. However, there are no measurements of the rate of conversion of carbon monoxide to carbon dioxide, and it therefore cannot be stated with absolute certainty that there is no increase.

There certainly seems to be little reason for alarm over the latter statement and there does not appear to be much concern among interested scientists that carbon monoxide is, or will, accumulate in the earth's atmosphere to any important extent.

Chemical Pesticides

Although such pesticides as DDT are carried around the world by atmospheric circulation the various self-cleansing mechanisms of the air apparently do a very good job of removing them from the air. They, of course, can accumulate on land and water where other problems arise. I have been unable to find any references that these pesticides remain in the atmosphere any longer than some of the following chemicals:

Sulphur and Its Chemical Compounds:—Sulfur and its chemical compounds, because of their role in plant and animal nutrition as well as their importance in air pollution, have received a great deal of attention and study. Eriksson (1963) writes:

> In the past it has been more or less tacitly assumed that most of the S compounds in the atmosphere were due to combustion of fossil fuels, smelting of iron ores, etc. Recent investigations in atmospheric chemistry, however, have revealed geographic distribution patterns that are not compatible with such origin alone. The circulation of S in nature seems to be more intricate.
>
> The yearly circulation of S seems to form a complicated and quantitatively impressive pattern. The total amount passing

> through the atmosphere is . . . 365 million tons per year. The industrial emission at present makes up only 11 per cent of the total.

The AAAS Air Conservation Commission (1970) reported that:

> Sulfur occurs in trace quantities as an element in the atmosphere, and in its reduced form as unpleasant-smelling hydrogen sulphide and mercaptans. Most of the sulphur in the atmosphere is in an oxidized form: Sulphur dioxide is probably the most widespread of the man-made air pollutants and is the one most intensively studied. (Air Cons. 1970).

This report also stated

> . . . sulfur dioxide does not remain in the air. It may last an average of 43 days, probably less . . . sulphur oxides may, therefore, be of little global concern from a long-range point of view. However, without systematic study, it is not certain whether or not there is a global increase in sulphur dioxide or sulfate. . . . More than 75 per cent of the total airborne sulphur enters the atmosphere as hydrogen sulfide from natural sources. This amounts to about 300 million tons of hydrogen sulfide per year. These sources are so diffuse, and the lifetime of hydrogen sulfide in the air so short, that perceptible concentrations are seldom encountered.

Junge and Warby (1958) write that SO_2 is washed out of the global atmosphere by rainfall and that the

> . . . small values . . . indicate how efficiently the natural cleansing process works. Only one or a few turnovers of the water content in the atmosphere are necessary to remove all pollution. The importance of this fact for the global aspects of air pollution cannot be overemphasized.

In a provacative paper by Deevey, Jr. (1970) titled "In Defense of Mud" the author discusses some of the intricate relationships between water, land and air as well as complex ecological processes, biological in nature, that play an important part in global atmospheric ecology:

> As long as the sun shines, and the plants are green, it seems that animals, and people, have nothing to worry about. The truth, of course, is that no living system is ever balanced without microbes . . . Or . . . not all oxygen in the atmosphere is made by green plants. Some is necessarily made by nigrogen-fixing plants and *sulfate-reducing bacteria* in soil, lakes, swamps, and the sea.

> *Sulfate and nitrate, in particular, are mainly reduced in mud,* where free oxygen (poisonous to such bacteria) is absent. *Linkage between mud and air, is the escape of gaseous hydrogen sulfide, H_2S, and ammonia, NH_3.* By the time these compounds are washed out of the atmosphere, however, they have been oxidized back to sulfate and nitrate. (italics mine)

Nitrogen and Nitrogen Compounds:—The global air system consists of 78 percent nitrogen, a relatively inert gas. Its importance to air pollution, however, is due primarily to two of its compounds neither of which have relatively long lives in the atmosphere. Of the oxides of nitrogen:

> . . . only two are normally considered as pollutants; nitric oxide and nitrogen dioxide. These are what might be called "status symbol" pollutants. Only a highly mechanized and motorized community is likely to suffer pollution from them. Nitric oxide, the primary product, is formed when combustion takes place at a sufficiently high temperature to cause a reaction between the nitrogen and oxygen of the air. Such temperatures are reached only in highly efficient combustion processes or when combustion takes place at high pressure. (Air Cons., 1970).

Through a series of complex processes, chemical and photochemical nitric oxide can be changed by energy from the sun to nitrogen dioxide. These along with various other compounds produce the Los Angeles type of smog. In some respects, the processes resemble the photochemical actions of the emanations from plants as discussed under Went's natural Carbon Cycle.

The AAAS Air Conservation Commission reported (1970):

> Global implications: The accumulation of products from photochemical air pollution is not likely to be important for a number of years. The oxidation of organic material of low molecular weight is completed in the upper atmosphere and eventually water and carbon dioxide will be the main products. The objectionable substances are products of the first steps in the oxidative destruction of the primary pollutants. However, the carbon chain of the organic compounds will oxidize gradually, and it is possible that the more resistant substances, such as methane, will persist for a very long time. The ozone formed does not accumulate, and the high level observed during the daytime returns to normal during the night.

TABLE 3. FIVE TYPES OF POLLUTANTS ACCOUNT FOR MORE THAN 90% OF THE NATIONWIDE AIR POLLUTION PROBLEM

Source	CO	Hydro-carbons	NO_x	SO_x	Partic-ulates	Total by source
			Millions of tons			
Transportation	64.5	17.6	7.6	0.4	1.2	91.3
Fuel combustion, stationary sources	1.9	0.7	6.7	22.9	9.2	41.4
Industrial processes	10.7	3.5	0.2	7.2	7.6	29.2
Garbage incineration	7.6	1.5	0.5	0.1	1.0	10.7
Miscellaneous[a]	16.9	8.2	1.7	0.6	9.6	37.0
Total by type	101.6	31.5	16.7	31.2	28.6	209.6

[a] Includes emissions from forest fires.
Source: NAPCA, 1966 data.

Thus, nitric oxide and nitrogen dioxide are man-developed pollutants that are primarily urban or city phenomena of our highly industrialized society. Although these build up to extreme concentrations over urban regions, the atmosphere on a global scale, breaks down, recycles, and washes out the pollutants in a remarkable manner. In fact, it does so to the extent that urban pollution has been called a meteorological condition caused by lack of ventilation. The air system within the city is simply overloaded until the pollutant material is dispersed. Heavy rains and strong winds at times clear the air miraculously in city environs.

REMARKS ON GLOBAL POLLUTION

The evidence confirms my early statement that *the global atmosphere has not as yet been materially affected by man's pollutants, with a few possible exceptions.* The air pollution problem is primarily a city problem due to the intense concentration of people and their so-called "necessities" in a highly affluent society. To me as a biologist, this problem is only one of many that not only beset urban areas but will do so in a much greater magnitude in the future. Man's nature, and his evolution, has not prepared him to live in crowded populations.

URBAN AIR POLLUTION

It is generally recognized that air pollution is primarily a problem of cities and industrial regions. Recently during the early part of

August weather conditions precipitated a severe polluted atmosphere over eastern seaboard cities. However according to *Time* magazine, even the "people on the street" realized that the smog was essentially of their own doing.

The bulk of the pollutant problems are due to accumulations of sulfur dioxide, carbon monoxide, photochemical smog (the reaction of sunlight on certain chemical compounds) and other materials ranging from asbestos to zinc. Table 3 shows the five major types of pollutants accounting for over 90 percent of the nationwide air pollution problems.

A recent article (Lorang, 1970) quotes Middleton, Director of the National Center for Air Pollution as follows:

> . . . he estimates that of the 142 million tons of pollutants released into the air over the nation each year, 86 million tons comes from motor vehicles. Other sources include manufacturing, 23 million tons; generating electric power, 20 million tons; heating, 8 million tons; and refuse disposal, 5 million tons.

Lorang also writes that:

> Some of the damage to plants comes from stack gases which contain sulfur dioxide, fluorides, lead and hydrogen sulfide. *But the main source of air pollution is the gasoline-burning engine.* Just one automobile consumes more than 1000 times as much oxygen as does a person. Says Phillip Leighton, Emeritus Professor of Chemistry, Stanford University: "To dilute an automobile's exhaust gases to harmless concentrations requires from 5 to 10 *million* times as much air as does the driver. In other words, just one automobile along a Los Angeles County freeway, needs as much air to disperse its waste as do all the people in the County for breathing."

Landsberg (1970) has pointed out that:

> . . . the increase of some 35 million vehicles in the last decade has obviously overtaxed the assimiliative capacity of the air, especially over metropolitan areas.

He likewise points out that electric power generation has increased terrifically:

> . . . ninety per cent of the growth in power generation in the last thirty years has been caused by higher per capita consumption and only 10 per cent by population growth.

Bockel (1969) writes that:

> More than 94 million tons of carbon monoxide are emitted annually in the United States alone, with 50 parts per million in the air of most cities. It is a product of incomplete combustion and 78 per cent of the load is from motor vehicle exhaust. . . . At the level of concentration in the cities, carbon monoxide affects function and behavior primarily. Dr. Robert E. Forster of the University of Pennsylvania Medical School says this syndrome is characterized by fatigue, headache, confusion, irritability, dizziness and disturbed sleep. This could even occur at fairly low levels.

Controlled Burning and Air Pollution

The foregoing discussion certainly indicates that although air pollution is severe, the global atmosphere, because of its large volume, self-cleansing characteristics, and other factors is essentially clean. Also, air pollution without question is a problem created by cities and industrial areas, and must be corrected there. The following statement has been made in reference to smoke from agricultural burning in Oregon:

> . . . The air pollution burden from field burning is imposed upon all the residents of the valley, whether they be permanent, transient, or tourist. (Boubel, 1969).

Let me point out that the pollution from the cities *"is imposed" upon forest, agriculture,* and people that do no live in urban areas. The damages that have occurred from pollution on forests and agriculture in the western states has not come from field or forest burning, but almost entirely from urban and industrial pollutants. Boubel goes on to say after a series of scientific tests that showed that the particulates in these studies were less than in a former investigation:

> . . . The fact that the emission values reported are somewhat lower than those used in previous studies does not lessen the magnitude of the problems associated with field burning. The visibility reduction, soiling and nusiance problems are just as severe to those downwind from the burn whether the particulate emitted is 22 lb. per ton of fuel or 16 lb. per ton. The problems

> are the direct result of the burn itself, not some value reported in a paper.

My first reaction to this statement is that if that is so, why waste money and effort on any further investigations on air pollution anywhere? However, Boubel, by lack of inference, must mean that the emissions from field burning are not toxic to human health, do not appreciably effect the particulate or other pollutant emissions in the cities. He limits his remarks to visibility reduction, soiling and nusiance so let us take these problems up in that order.

That the smoke from controlled burns of field burning lowers the visibility is certainly true but only under certain specific kinds of weather conditions. Any field or forest is not burned more than once each year so that the emissions from any one acre only occur once each year—not every day in the year as is true with pollutants in the cities and towns. Darley, *et al.* (1966) reported on the following study in California as follows:

> Two field studies, one conducted on range lands and grain stubble in 1959 and the other on rice stubble in 1960 indicated that the concentrations of photochemically active hydrocarbons were rather negligible at a mile from the fire when more than 1000 acres of wastes were being burned. In the second study it was concluded that most of the hydrocarbon burden downwind from Sacremento originated in the urban community and that burning of stubble upwind from the city did not add significantly to the hydrocarbon level.

Darley *et al.* also stated that:

> . . . if total yields of hydrocarbons are compared in the Bay Area, agriculture contributes about 1014 tons of hydrocarbons per day from the daily consumption of about 12,000 tons of gasoline, whereas annual burning of 151,000 tons of the three principle agricultural wastes produces a maximum of 950 tons of hydrocarbons. Thus, the *annual* yield from agriculture approximates the *daily* yield from automobiles in this area.

They also say:

> . . . The emissions of CO and oxides of nitrogen also indicate that the burning of agricultural wastes is a relatively less important source of photochemically related pollution than is the automo-

bile . . . the emissions of this pollutant from the burning of most wastes was between 40 and 80 lb/ton of material burned. Again, this is considerably less than 850-900/lb of CO per ton of fuel emitted from auto exhausts.

They give the following amounts of emissions from field burning there per ton of material:

	Field Burning	Fossil Fuels
Hydrocarbons	7–36 lb	130 lb
Olefins	2.7 lb	7.8 lb
Etene from tree prunings	4.1 lb	10.8 lb

The air pollution problem from controlled burning in the southern pine forests or from the improved pastures of the Southeast is a minor one. Unfortunately, we know little about the emmissions from these fires but from somewhat similar materials in western states it would appear that none of these are toxic. Very little is known about the particulates from controlled burns, or even from wildfires and nothing seems to be known about their absorbing or adsorbing qualities. That they are a mechanism that assists in cleansing the air can be safely assumed. That they also play a part in atmospheric weather patterns seems probable. It would appear from Cooper (1969) that the effluents from the vehicles, stationary engines, and industrial plants from the Miami region alone would be more than from all the controlled burning in the coastal plains pine forests. Certainly no known concentrations have been reported from controlled burning that are harmful to health.

CONCLUSION

An ecological review on air pollution as a whole, and in particular the relationship of control burning to such possible pollution warrants the following conclusions:

1. In spite of the tremendous amounts of pollutant materials released into the atmosphere, mankind as yet has not materially affected air quality on a global basis. This is largely due to the excellent self-cleansing properties of the atmosphere as well as the extremely large volume of the air envelope of the earth.

2. The air pollution problem, presently, is primarily one of urban areas and the consequent concentration of pollutants from combustion engines, industrial processes, and the burning of fossil fuels (coal, oil, gasoline, etc.). Over 95 percent of the pollution problem is a city problem; not of rural areas or of forest and field.

3. Smoke particles from lightning fires have always been a part of our atmosphere long before man. These particles play an important part in our atmosphere as condensation nuclei for rainfall and are a vital part of our atmosphere.

4. There is no evidence that materials resulting from controlled burning in forestry, agriculture or wildlife management are hazardous to human health.

5. The problems of such controlled burning are primarily one of visibility. However, such burning is not a daily activity and any one acre is only burned one time within any one year, or even longer intervals. That visibility can be an important problem is certain but this can be handled by proper management, particularly with due regard for meteorological conditions. It is weather that primarily creates such conditions.

6. I find that control burning as a source of air pollution is rarely if anything but a purely local matter. The past history of fire exclusion abundantly demonstrates that wildfires would sweep large areas and in fact, would produce much larger problems of air pollution. These wildfires occur under the worst possible conditions and only come under control when weather patterns or fuel conditions change.

7. And in final conclusion I wish to state that there is no ecological alternative to control burning for its many important uses in wildlife, forest and farm management. These past ten Fire Ecology Conferences, where over 200 speakers have presented their studies and their conclusions, cannot be over-looked. The work of these leading ecologists, foresters, wildlife managers, and other land managers must be recognized by the specialists in air pollution or drastic effects on nature's ecosystems will result.

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