FORESTS AND CLIMATE CHANGE IN AMERICA: SOME EARLY VIEWS

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Abstract. Supposed connections between forests and climate are long established in Western tradition and were the subject of speculation in the New World even from the time of Christopher Columbus. The luxuriant forest growth and unusual climate of America early invited conjecture on the climatic effects of the forests and the consequences of their removal. Pioneer settlers in America thought that forest clearing was producing a warming trend and affecting the climate in other ways. By the nineteenth century there was wide, but not entirely unanimous, belief that deforestation had caused significant climate changes, especially higher temperatures and lower precipitation. It was also believed that tree planting might increase precipitation in the semi-arid West. Later in the nineteenth century, mainly as a result of increasing availability of climatic data, the possibility of a positive or negative macroscale climatic influence for forests was largely dismissed. Modern scientists now attribute an important microscale climatic influence to forests and are reconsidering the macroscale effects, especially as related to atmospheric carbon dioxide and albedo changes.

> The effect of forests upon the total amount of rainfall is a question upon which writers are not agreed, some denying their influence altogether.
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> A. Bryant, *Forest Trees*, New York: Henry T. Williams, 1871, p. 18.

Christopher Columbus, according to his son Ferdinand, knew "from experience" that removal of the forests that once covered the Canary, Madeira, and Azores islands had reduced their mist and rain. Thus Columbus was led to believe that the afternoon rains of Jamaica and elsewhere in the West Indies were produced by the islands' luxuriant forests.[1] Attribution of a cause and effect relationship between vegetation and climate certainly did not begin with Columbus but his opinion probably represents the first documented assertion of this type to apply to the New World.[2] Such notions about forests, or their removal, as having significant macroscale climatic influences persisted in America and elsewhere until modern times. A climax of concern over the forest–climate issue was reached in the latter part of the nineteenth century when it was feared that the large-scale deforestation occurring in the United States would adversely affect climate. This paper examines some of the ideas surrounding the supposed connection between forests and climate in America prior to the modern period. The term climate is used in a broad sense, mainly at the regional scale, and especially in regard to precipitation and temperature.

As Columbus's response to West Indian rainfall patterns suggests, there was at this time an established Western tradition connecting vegetation and weather. Both the vegetation and weather of the new lands being settled greatly impressed the American colonists. Both were markedly different from northwestern Europe. But the forests were, of course, an obstacle to development and the colonists early began to attack the luxuriant forest

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cover. The colonists' war against the forests was at first a matter of simple necessity. The trees had to be removed to make way for the farmers' fields. Reduction of the forests also provided benefits by eliminating barriers to travel and communications as well as depriving hostile Indians, dangerous predators, and destructive vermin of protective cover. In addition, it was widely believed that forest clearing improved public health conditions by reducing disease-causing atmospheric toxins.[3] The result was, of course, the wholesale destruction of great virgin forests at a scale and speed never equalled elsewhere in the annals of environmental history.

Under such circumstances it was hardly surprising that speculation developed early in America regarding the climatic significance of the luxuriant forests and their increasing destruction. The earliest statement on the topic appears to have been made by the English scientist-clergyman John Clayton, in letters describing Virginia, written in 1688. The Reverend Clayton, who depicted the colony as "thick grown all over with massy timber"[4], wondered if the frequency of thunder there resulted "from the Air's being more stagnant, the motion of the Winds being impeded by the Trees, or whether the Motion of the Winds being obstructed by them below, the Motion might not be more violent aloft."[5]

Further consideration was given to forest–climate relationships in colonial America by Dr. John Woodward, a London physician, in 1708 in an article entitled 'Some Thoughts and Experiments concerning Vegetation'. Woodward concluded that the "emission and detachment" of abundant moisture from plants provided a "manifest reason" why countries that "abound with Trees, and the larger Vegetables" should experience "great Humidity in the Air, and more frequent Rains, than others that are more open and free." This same writer went on to point out that this "great Moisture in the Air, was a mighty inconvenience and annoyance to those who first settled in America; which at that time was much overgrown with Woods and Groves. But as these were burnt and destroy'd, to make way for Habitation and Culture of the Earth, the Air mended and clear'd up apace, changing into a Temper much more dry and serene than before."[6]

Others who came later also took the view that forest clearing in America was producing a warming trend. Another physician,[7] a Dr. Hugh Williamson, read a paper at a meeting of the American Philosophical Society in 1770 under the title 'An Attempt to account for the Change of Climate, which has been observed in the Middle Colonies in North-America'. This author noted that it was general belief among long-time residents of the Pennsylvania region that during the 40 or 50 years prior to 1770 there had occurred a "very observable Change of Climate" involving milder winters and cooler summers. Williamson ascribed these climatic changes to the wholesale clearing of trees, which he believed favored winter heating of the land and diminished "winter blasts, which are the general origin of cold." Dr. Williamson optimistically predicted that as cultivation led to the clearing of the "interior part of this country, we shall seldom be visited by frosts or snows, but may enjoy such a temperature in the midst of winter, as shall hardly destroy the most tender plants." This writer denied that forest clearing would increase summer temperatures but rather that the clearing would increase atmospheric mixing, leading to cooler summer conditions. The convoluted reasoning of Dr. Williamson is both difficult to follow and unconvincing, but an attribution of a macroscale moderation of temperatures to deforestation is evident.[8]

Somewhat similar to Williamson's ideas are the often-quoted views of Thomas Jefferson on the subject of climate change which were first aired at this period. In his *Notes on Virginia* (first published in 1784, dated 1782) Jefferson observed that a moderating trend in the climate seemed to be occurring, with reduced extremes of heat and cold.[9] At this time, Jefferson did not specify any possible causality for the supposed climate change but that vegetation change was perhaps believed to be involved is suggested in a proposal made later, in 1824, that "the effect of clearing and culture towards changes of climate be investigated."[10]

Deforestation was reported in 1798 by B. Henry Latrobe, an engineer, to produce climatic consequences of a somewhat different type to the preceding. Speaking also to the American Philosophical Society, Latrobe declared that forest clearing in Virginia was permitting easterly ocean breezes to extend progressively farther inland each year thus improving the climate by moderating temperatures, especially in summer.[11] On the other hand, one year later Noah Webster denied that trees "obstruct the free circulation of air." According to the pioneer lexicographer and man of science, in calm summer weather trees "very much increase a light breeze, by partly obstructing the upper current with their branches, and throwing more air below, thus augmenting the under current on the surface of the earth, where it is wanted." Webster also claimed that the movement of the leaves and branches of trees "agitate the air . . . and give velocity to the air that finds its way through their interstices."[12]

Webster again differed from some of his predecessors in views expressed before the Connecticut Academy of Arts and Sciences in 1799 and 1806 regarding supposed changes in winter temperatures. Webster acknowledged that it was a popular opinion that in northern latitudes, on both sides of the Atlantic, the winters were becoming warmer.[13] However, he averred that the winter weather in the United States, far from improving, was actually worsening and was "more inconstant, than when the earth was covered with wood." Deforestation was claimed by Webster to be producing a deferral of winters and more variable winters with a shorter duration of snow cover. These developments were attributed to the "greater quantity of heat accumulated in the earth in summer, since the ground has been cleared of wood, and exposed to the rays of the sun; and to the greater depth of frost in the earth in winter, by the exposure of its uncovered surface to the cold atmosphere."[14]

By the end of the eighteenth century, the question of regional climate change, mainly involving temperature and precipitation, as a result of deforestation was not just a debate in intellectual circles. The broad base of belief in such changes is attested to by the Comte de Volney, the French traveller and scientist who spent three years in eastern North America and wrote an informative volume on the American environment that was translated into English and published in the United States in 1804.[16] Volney's book included one of the earliest, if not the earliest, detailed treatment of the climatology of the United States and it reported that "An opinion has, of late years, gained ground in the United States, that partial changes have taken place in the climate of the country, which have shown themselves in proportion as the land has been cleared."[17] Volney cited several authorities in support of the climate-change hypothesis (including Thomas Jefferson) indicating its acceptance not only in what is now the eastern United States but also in

Canada. Volney wrote that he had "collected similar testimonies, (*regarding climate change*) in the whole course of my journies (sic), in the western as well as through the maritime country . . . Longer summers, later autumns, shorter winters, lighter and less lasting snows, and colds less violent, were talked of by every body . . . ". This writer went on to state that the climate changes were always reported "in the newly settled districts, not as gradual and slow, but as quick and sudden, in proportion to the extent of cultivation." Volney ascribed the changing weather to the warming and drying of the ground that resulted from forest clearing and glumly doubted if the changes represented an improvement.[18]

Presenting a striking contradiction to the conclusions of Volney, were the views of another European savant, Alexander von Humboldt. Humboldt had visited the United States in the same year that the American edition of Volney's book appeared and evidently took a very different impression of the forest-climate issue. In his *Ansichten der Natur* (*Views of Nature*) (first published in 1807 and revised in 1849) Humboldt noted that:

> The statements so frequently advanced, although unsupported by measurements, that since the first European settlements in New England, Pennsylvania, and Virginia, the destruction of many forests on both sides of the Alleghanys (sic), has rendered the climate more equable, – making the winters milder and the summers cooler, – are now generally discredited.[19]

In taking note of the American concerns over climate change supposedly caused by deforestation, Volney was reporting on a subject in which his countrymen became the pioneer scientific investigators. Scientific research on the forest–climate issue expanded rapidly in the nineteenth century, as did the everyday speculations. Heightening interest in the issue was the increasing pace of deforestation in North America which intensified the old fears that a deteriorating situation was being worsened.

French scientists, including some major figures, were especially prominent in the early investigations of the forest–climate question. Most seemed to assume the existence of an important forest influence on climate and they attempted to elucidate the mechanisms involved. These pioneer investigators included the well-known agricultural chemist, Jean Baptiste Boussingault,[20] and the noted physicist and chemist, Antoine César Becquerel. Most influential in gaining support for belief in a substantial forest influence on climate was Becquerel. Publication of his book in 1853 *Des climats et de l'influence qu'exercent les sols boisés et non boisés* (*Climate and the Influence of Wooded and Non-Wooded Lands*) was a landmark in the evolution of the forest–climate issue and constituted the first thorough and systematic treatment of the subject.[21] It was followed a few years later by *Mémoire sur les forêts et leur influence climatérique* (*Memoir on Forests and Their Climatic Influence*).[22] These publications, together with others coauthored with his son Edmond, reinforced belief and stimulated interest in the matter of forest influences on climate. Becquerel's 1866 article was translated into English and appeared in the annual report of the Smithsonian Institution of 1871.[23] The same article was republished in 1878, but in a different and clumsier translation, as part of F. W. Hough's monumental *Report upon Forestry*.[24]

Becquerel believed in the significant climatic role of forests. His Smithsonian Report

article was a thorough and plausible review of the forest–climate issue from an advocates standpoint. According to Becquerel, seven questions on the forest-climate issue "arise for consideration":

1. What is the part which forests fulfill as a shelter against the winds or in retarding the evaporation of the rain-water?
2. What is the influence of trees on the water imbibed by the roots and on that which exudes by the leaves, as modifying the hygrometric state of the ambient air?
3. How do they modify the calorific state of a country?
4. Do forests exert an influence on the quantity of water which falls, and on the distribution of rains in the course of the year, as well as on the system of running waters and those of springs?
5. How do they intervene for the preservation of mountains and of slopes?
6. Do forests serve to withdraw from storm-clouds their electricity, and thus to moderate their effect on neighboring and unwooded regions?
7. What is the nature of the influence which they are capable of exerting as regards the public health?[25]

Strictly speaking, these questions went beyond the issue of climate since they involved erosion, ground and surface water, and public health. With the erosion and water supply matters, Becquerel presented clear and convincing arguments. For the purely climatic questions the case was expectably rather less substantial and inclined more to assertion. Becquerel thought that in the rainfall inducing process of forests, an air current rises, and meets a "colder stratum of air, yields its vapor to precipitation, and a fall of rain ensues." Forests were also seen by Becquerel as exerting a screening influence on wind flows.[26] The ways in which trees husbanded soil moisture and also transpired copious amounts of moisture into the lower atmosphere, together with the moderating temperature influence of trees, were considered by Becquerel in some detail. Only once in the review did Bequerel cite a distinctly negative opinion in regard to a forest influence on climate.[27]

After the middle of the century, doubtless influenced by the work of Becquerel and other Europeans, American scientists became increasingly involved in the forest–climate issue.[28] Continuing the adversative traditions that had marked the debate from its early days, opinion remained sharply divided. Typical of one point of view were the prefatory remarks in R. U. Piper's pioneering botanical work *The Trees of America* published in 1855 which testified that:

> Forest trees should be preserved for their beneficial influence upon the climate. It is universally conceded that the winters of the northern states are colder than they were thirty or forty years ago, and that the weather is more windy, fluctuating, and disagreable. We are also subject to severer droughts. Peaches once grew in abundance throughout Central New York; now it is almost impossible to raise them. The wheat and some other crops are more uncertain. These facts are to be ascribed not so much to the deterioration of the soil as to the destruction of our forests.[29]

An opposing view of the forest–climate issue at mid-century was represented by Lorin Blodget in his authoritative *Climatology of the United States*, published in 1857.

Blodget devoted a whole chapter to the "permanence of climate" and reviewed a wide array of historical and theoretic evidence on the subject of climate change. He concluded that in the United States and elsewhere, the evidence did not support the numerous hypotheses of climate change. According to Blodget, the mechanisms supposedly underlying these changes were "circumstances affecting the surface within our control, such as the removal of forests, draining, and cultivation" but were in fact incapable of exerting the climatic influence attributed to them.[30]

Acceptance of belief in a significant forest influence on climate was, of course, fully consistent with belief in the need for forest preservation. However, apprehensions about the destruction of woodlands, depletion of natural resources, or the integrity of nature, had not been prime concerns in early America, and the subject of conservation received scant attention. Forest conservation was especially neglected as forests were commonly considered to be in inexhaustible supply in America. As the nineteenth century advanced, however, increasing interest in conservation developed and the subject of man's destructive impact on the environment was broached by George Perkins Marsh in his seminal book *Man and Nature*, first published in 1864.[31]

Marsh's book dealt with various aspects of man's tampering with nature, and there were some major omissions, but man's impact on the forests was not among these and actually represented the major (over one-third) and most authoritative section of the book.[32] In this section, subtitled 'The Woods', Marsh examined in some detail the major consequences of deforestation – fluctuation of stream flows, reduced water supplies, accelerated erosion, soil desiccation, and damage to flora and fauna. Rather surprisingly, however, considering the tenor of contemporary opinion, Marsh assigned only minor climatic significance to forests, although he showed full recognition of the works of Becquerel and others on this topic. Marsh acknowledged that trees exerted a moderating influence on air temperatures, but expressed dubiety about a significant influence on precipitation. It was, however, noted that "it has long been a popularly settled belief that vegetation and the condensation and fall of atmospheric moisture are reciprocally necessary to each other." Marsh also acknowledged that a "majority of the foresters and physicists who have studied the question are of the opinion that in many, if not all cases, the destruction of the woods has been followed by a diminution in the annual quantity of rain and dew."[33]

Marsh's skepticism regarding a forest influence on rainfall derived from his belief that the matter was too complicated for certitude and the evidence struck him as both conflicting and unreliable.[34] Elsewhere in *Man and Nature*, in a short section on the influence of forests on temperature, Marsh quoted the famous French scientist Joseph Louis Gay-Lussac as stating "In my opinion we have not yet any positive proof that the forest has, in itself, any real influence on the climate of a great country, or of a particular locality." However, Marsh also quoted Becquerel in support of the view that forest clearing exerts a moderate, and generally cooling, influence on temperatures.[35]

While Marsh assigned considerable significance to deforestation in general, but little in terms of specific climatic effects, most other writers of the period thought otherwise. Thus in 1865, one year after the publication of *Man and Nature*, a paper with the title

'Forests – their influence, uses and reproduction' appeared in the *Transactions of the New York State Agricultural Society* in which was discussed a range of forest influences on climate in New York and elsewhere. The definite conclusion reached was that an adverse climatic influence was in operation as a result of deforestation.[36]

The developing concern in the first part of the nineteenth century that deforestation and regional climatic deterioration, especially reduction of precipitation, were connected was paralleled by a cognate concern over the aridity of the treeless Great Plains. Thus, as the century advanced, there was increasing acceptance of the view that the paucity of trees in the Great Plains was the cause of the region's meager precipitation and that tree planting would provide a remedy.[37] There is, of course, consistency in this view. If deforestation caused decreased precipitation then forestation would increase precipitation.

The important related question as to whether trees could be induced to grow in the Great Plains was answered affirmatively. The Report of the Commissioner of the General Land Office in 1867 confidently asserted "that sufficiently numerous experiments have been made to demonstrate the fact that forests, in comparatively brief periods, may be restored to the almost treeless prairies of the west."[38] Developing this argument later in the same report, the U.S. Geologist F. V. Hayden declared that such tree planting in the West would have "a most important effect on the climate, equalizing and increasing the moisture . . . ". Hayden went on to cite European scientific support for the rain-making effectiveness of forestation.[39]

Belief that planting trees would increase precipitation in the semi-arid West burgeoned after mid-century, thanks to the efforts of numerous propagandists, some of whom were major American scientists. Joseph Henry, the physicist and first secretary and director of the Smithsonian Institution, was among the notables who urged the planting of trees in the West because "Many parts, even of our own country, which now exhibit a surface of uninterupted sand, may be rendered productive, or covered with trees and herbage."[40] Such support for tree planting for the purposes of climatic modification led to the passage in 1873 of federal legislation designed to promote forestation for rain-making ends.[41] This congressional encouragement of rain-making received the approbation of the scientific community, as indicated by an 1874 formal congratulatory report signed by numerous American scientists under the auspices of the American Association for the Advancement of Science.[42]

Meanwhile another noteworthy official involvement in the widening concern over the forest–climate issue occurred in Wisconsin in 1867. That year the Wisconsin legislature appointed a commission to investigate and report on various forestry matters, of which the first-mentioned was a call for "facts and opinions relating to the injurious effects of clearing the land of forests upon the climate." The commissioners' findings were submitted under the less-than-neutral title of *Report on the Disastrous Effects of the Destruction of Forest Trees now going on so rapidly in the State of Wisconsin.*[43] This report, prepared by I. A. Lapham, J. G. Knapp, and H. Crocker, borrows on Marsh's work acknowledging the debt with a quotation from *Man and Nature* on the title page. Unlike Marsh, however, Lapham *et al.* were quite convinced of the existence of an effective link between climate and forests. In this, and other respects, the report was similar to

numerous other reports prepared for state and federal agencies and submitted between the 1860s and World War I.

While much of the Lapham report was devoted to such matters as reforestation, forestry economics, and hydrography, the supposed climatic consequences of deforestation were given priority in the discussion. Two major direct consequences were identified involving temperature and humidity. Because of the relative simplicity of the factors involved, the effects of forest clearing on temperatures were correctly assessed for both winter and summer seasons.[44] The authors were distinctly less successful in dealing with the consequences of deforestation as far as humidity was concerned. They prudently admitted an imperfect understanding of "aqueous vapor" in "atmospheric air", but nevertheless assigned trees an important role as transmitters of moisture from ground to air and as agents for the retention of ground moisture, propositions that contain some contradictions. Lapham *et al.* also recognized that soil moisture was increased by trees through their capacity to promote the deposition of dew.[45]

Especially unacceptable to modern scientists was the attempt by Lapham *et al.* to explain the processes whereby trees supposedly augment precipitation. Beginning with the canonical assertion that "Forest growths are regarded by many of our ablest physicists as exerting a marked influence over the amount of rainfall in such a region", they proceeded to the dubious statement that:

> . . . all countries abundantly clothed with forests are also well supplied with rain and rain is equally distributed through the season of vegetable growth, would naturally lead to the conclusion that forest growths have some agency in determining this rainfall.[46]

Lapham and his coauthors explained that this forest influence on precipitation was believed by some meteorologists to be due to the fact that "trees attract clouds from a distance, and cause them to discharge their watery contents in places over which they would otherwise have been wafted . . . ".[41] However, Lapham *et al.* believed it improbable that "this is so to any considerable extent". Rather these writers thought that the "coldness of the air in and about forests" produced the same effect "as do mountains in condensing the vapors." Indeed, such was their conviction regarding the rain-producing powers of forests that they speculated that a forest, if it could be established in the "hot and dry plains of our south-western territories" would "so cool the surface as to cause . . . showers of rain to reach the ground and thus render such forest permanent."[48]

Other climatic influences ascribed to forests by Lapham *et al.* included effects on winds which were presented in a detailed and reasonable manner. A more obscure climate effect from trees in the Lapham report concerned atmospheric electricity, a weather factor that was then little understood but which held considerable interest and was believed to be of possibly high significance. Lapham *et al.* asserted that trees tended to maintain an electrical equilibrium in the air, thereby diminishing the "liability to storms with thunder, hail or dry winds." The final forest influence, according to Lapham *et al.*, was that trees "purified" the air and destroyed that "unknown something that we call miasm in the air, and thus prevent sickness."[49]

In addition to the scientific and pseudo-scientific discussion of the supposed climatic

consequences of deforestation, Lapham *et al.* gave consideration to the commonplace indicator of climate change – the fruit crop. In the popular mind, fruit trees were of high significance to the deforestation–climate change issue because their well-known frost sensitivities were taken as reliable criteria of climatic change.[50] When freezing conditions killed or damaged established fruit trees or vines, it was commonly interpreted as evidence of climatic deterioration (rather than normal cyclical variation), and in America the deterioration was often blamed on the malign influence of forest clearing. Thus Lapham *et al.* quoted from a speech made by Horace Greeley, the journalist and politician, delivered in the 1860s to an agricultural society in New York, which doubtless struck a responsive chord by touching on the popular concerns with fruit trees. Greeley declared that:

> Taking the forest off has left our lands exposed to the bleak and driving winds, and has aggravated the disadvantages of our hot, dry summers, and bleak, cold winters. Lack of forests has narrowed the fruit region, and is constantly narrowing it. More forests must be raised, and those of the best kinds.[51]

Lapham *et al.* also reported the example of migrants to Wisconsin, who on returning to their former homes in New York and Pennsylvania, where in the past they had enjoyed "peaches and plumbs (sic)", found "the primeval forests cut away and destroyed, and those (*fruit*) trees dead", further learning that such fruit could no longer be grown except in the most sheltered places. Michigan was reported to have the same problem, and a "veteran pomologist" of that state was cited as observing in 1864 that as the result of forest destruction the peach crop, which "once was almost as sure throughout our state as the apple," could only be raised now "under the lee of Lake Michigan."[52]

Other crop declines were noted in the Lapham report as bearing witness to an adverse climatic trend supposedly caused by deforestation. The Michigan wheat crop was reported to be diminished "from want of the usual covering of snow, and general lack of shelter from wind and sun."[53] A Michigan legislative committee corroborated these views, and attributed a four-year reduction in wheat and other crops in the southern part of the state as due to the exposure of the fields to that "scourge of God, the southwest wind" which was the result of the "wholesale destruction . . . forests." This committee was quoted as denying that such a climatic disaster was the result of "causes evanescent in their nature, and destined speedily to pass away, to return nevermore" and the fear was expressed that these agricultural losses were "the beginning of sorrow."[54]

Evidence that concern regarding the climatic effects of deforestation was felt in the highest councils of the land is provided by a resolution that was introduced into the United States Congress in 1872 requesting an inquiry into the need for forest preservation or replanting in order to prevent or remedy drought. The Timber Culture Act previously referred to was passed in 1873, and, three years later in 1876, the Agricultural Appropriation Act provided for an official investigation into the influence of forests on climate and for a review of measures taken in foreign countries. A Dr. F. B. Hough was appointed to conduct this investigation and produced a two volume *Report Upon Forestry*, the first volume of which appeared in 1878.[55]

Like the Lapham *et al.* report, Hough's monumental work provided much insight into the status of the deforestation–climate issue. Hough documentated the hydrographic and

erosional evils of deforestation, but took a moderate position on the broad subject of forest influences on climate. He noted that "unseasonable and prolonged droughts, with other vicissitudes of climate" are "alleged" to be the result of deforestation. Displaying a commendably open approach to the subject, Hough acknowledged that scientists differed in their opinions on the forest-climate connections and suggested that "the advocates of extreme theories may have erred on both sides."[56]

Even so, Hough was cautiously inclined to accept the idea of a forest influence on precipitation and temperature, but it was noted in his report that European investigators had for years been unsuccessfully attempting to settle the debate by actual field measurements. Because there were no similar American field data on the subject, Hough included a review of the European research (mainly involving temperature, humidity, and precipitation) that had been conducted in Bavaria, Prussia, Switzerland, and France.[57] As mentioned earlier, the review article by the French scientist Becquerel, 'Memoir upon Forests, and their Climatic Influence' was included in English translation as part of the *Report Upon Forestry*.[58]

Again, displaying prudence, Hough declared that the American data on the deforestation–climate change question were too meager and imprecise to permit any definite answers. While admitting the limitations of the American data, Hough did allow that factors tending to increase humidity and decrease temperatures (such as was stated to be the case with forests) predispose to the formation of precipitation. Without claiming that such a connection exists between forests and precipitation, Hough did suggest that this was indeed the case.[59]

As Hough had pointed out, there was a dearth of American climate data suitable for application to the forest influence problem. Data of a sort were not, however, entirely lacking, since the Smithsonian Institution had published compilations of relatively long-term weather statistics for locations in the United States in 1860,[60] 1870[61] and in more detail in 1872[62] and 1876.[63] The 1872 publication consisted of a lengthy monograph with extensive data on precipitation, and the author, Charles A. Schott, acknowledged that the "question of whether the annual rainfall is gradually increasing or diminishing, stationary, of a periodic character, or apparently irregular, is one of great interest, scientifically as well as practically."[64] Of course, a stable or unstable annual precipitation involved factors besides deforestation but this question was a key portion of the forest–climate issue. Schott concluded, however, that the data were too incomplete and discontinuous to provide a final answer to this intriguing question but, after grouping the precipitation records into nine categories of weather stations "where the annual rain-fall appears subject to the same laws", this writer concluded that the figures *implied* "that no sensible change has taken place in the law of the annual distribution (*of precipitation*) within the period of observation."[65] Schott ended his monograph with an expression of hope that his efforts might "stimulate to more extended observations and serve as a basis of more detailed investigations hereafter."[66]

The other key portion of the forest–climate issue concerned temperature change; Schott addressed this topic with the publication in 1876 of the second part of his compilation of climate data. Data were presented on temperatures throughout the United

States, and elsewhere in the New World, from the earliest to the latest available (1870). Once more, on the basis of an unprecedented array of data, Schott was able to deny the existence of any discernable trends. He declared categorically that there was nothing "to countenance the idea of any permanent change in the climate having taken place, or being about to take place; in the last 90 years of thermometric records, the mean temperatures showing no indication whatever of a sustained rise or fall."[67] Schott emphasized his position further by the following reiteration "The same conclusion was reached in the discussion of the secular change in the Rain-Fall, which appears also to have remained permanent in amount as well as in annual distribution."[68]

Aided by the huge compilations of weather observations assembled under the auspices of the Smithsonian Institution, Charles Schott was thus able to refute the antique opinion that precipitation receipts and temperature averages were subject to distinct trends. With some small qualifications, Schott claimed that the Smithsonian data indicated stability in both temperature and precipitation. Many modern climatologists would take issue with this claim but given the information available to Schott his conclusions seem reasonable.[69]

After Charles Schott's important work, there was increasing attention paid to the expanding quantities of climatic data. Nevertheless support continued to be meager for the idea of secular trends in climate, especially for precipitation, or even for the idea of connections between forests and climate. Notable among these investigations was the contribution of Henry Gannett in 1888 who analyzed regional precipitation trends and detected no relationship between precipitation receipts in areas that had either been subjected to deforestation or where trees had been widely planted.[70]

While Schott, and most of those who followed, clearly believed that the climate data supported the view that neither deforestation nor any other factor had significantly influenced temperature averages or precipitation receipts in almost a hundred years, debate and speculation on the matter continued. Although not exactly representing the "extended observations" or "detailed investigations" urged by Schott, a major examination of the problem of forests and precipitation was made in 1892 with the completion of *Forest Influences* by Fernow *et al.* Bernhard E. Fernow was the Chief of the United States Department of Agriculture Forestry Division and intended his report to be:

> . . . a review of the meteorological observations which have been made, mostly in foreign countries, for the purpose of determining whether and to what extent forests influence climate, together with a discussion of the manner in which forests affect the water conditions of the earth and other matter elucidating the question of forest influences in general.[71]

Unfortunately, and inevitably, *Forest Influences* fell far short of its goals, especially in regard to the climate matter. It did, however, provide a useful summary of much material on erosion and hydrography as related to forests, as well as a fairly detailed review of what was termed 'forest meteorology'. Apart from revealing a bias in favor of a forest influence on precipitation (and acknowledging that such beliefs were firmly held among both laity and scientists), Fernow's book was essentially an inconclusive review and failed to answer the important questions of the climate–forest issue due to a lack of suitable and reliable data.

What Fernow had attempted for the pro-forest influence position was undertaken for

the opposing view in 1910, in a short report to a congressional committee by the chief of the United States Weather Bureau, Willis L. Moore.[72] Moore not only denied that forests had significant climatic influence, a position we now know to be essentially correct, but went so far as to deny also that forests had a significant influence on flooding. The latter incorrect proposition must surely have weakened the credibility of the former. Moore declared categorically that, "Precipitation controls forestation, but forestation has little or no effect upon precipitation."[73] Although Moore strongly endorsed the principle of forest conservation he would not concede (as was then currently popular) that the beneficial climatic influence of forests was an argument in favor of forest conservation.

Moore's anti-forest influence position was based mainly on his analysis of precipitation data which he claimed lent no support for the forest influence arguments. This writer admitted that climate change has been a feature of the earth's history but denied that vegetation destruction played an effectual role. Several examples were cited in support of this view, including an observation by the well-known geographer Ellsworth Huntington to the effect that there was no good evidence that forests have an appreciable effect upon rainfall.[74]

Twenty years after the preparation of Fernow's *Forest Influences*, in 1912, a further attempt to settle the forest–climate question was made by another member of the Forest Service, United States Department of Agriculture, Raphael Zon, with the publication of *Forests and Water in the Light of Scientific Investigation.*[75] The objective of the author is clear from the title, and the work is indeed quite illuminating, if perhaps overly disposed to accept the idea of a forest influence on precipitation. Zon reviewed a wide range of research of forest influences and concluded that:

> Accurate observations, continued for many years in different parts of the world, establish with certainty ... forest lowers the temperature of the air inside and above it ... Forests increase both the abundance and frequency of local precipitation over the areas they occupy, the excess of precipitation, as compared with that over adjoining unforested areas, amounting in some cases to more than 25 per cent.[76]

Zon further concluded that "the influence of mountains upon precipitation is increased by the presence of forests. The influence of forests upon local precipitation is more marked in the mountains than in the plains." In addition, Zon believed that forests in "broad continental valleys" supply significant quantities of moisture to prevailing air currents and thus increase moisture supplies to continental interiors. The destruction of such continental forests, according to Zon, especially if they are replaced by "weak, herbaceous vegetation or complete baring of the ground" would affect the climate "not necessarily of the locality where the forests are destroyed, but of the drier regions into which the air currents flow". These are strong statements and appear only weakly supported by the evidence adduced.[77]

Raphael Zon's 1912 monograph may be regarded as the penultimate chapter in the long chronicle of the supposed influences of forests on climate. The final chapter, still unfinished, is being written by modern meteorologists and climatologists. It includes no mention of forests 'attracting' rain clouds but it does ascribe a significant influence at microscale. More modern investigators see this microscale influence mainly in terms of

wind currents, barrier effects, and increased condensation. Thus C. E. P. Brooks in 1928 calculated that the combined effects of friction on air flows and the height of trees in forests could cause a two or three percent maximum increase in the precipitation of temperate regions, with the greatest effects on hill crests and upper windward slopes.[78] Joseph Kittredge in 1948 confirmed Brooks's figures and suggested that forests may increase rainfall only between one and three percent in temperate climates.[79] Molchanov, writing in 1960, reviewed a wide range of modern research and concluded that forests do increase precipitation receipts, but only very slightly. However, Molchanov maintained that if the forest's part in the condensation of water vapor during rains is taken into account, the precipitation increase may reach 10 percent.[80] Another Russian scientist, Rakhmanov, in 1962, reviewed a variety of research and judged that forests do play a complex and variable climatic role that is capable of producing only relatively small augmentations of precipitation.[81,82]

Although one well-known modern climatologist, C. W. Thornthwaite, in 1956, went so far as to exclude a macroscale deforestational influence on climate because man's activities were "incapable of making any significant change in the climate pattern on the earth", few would now support that position.[83] For example, Landsberg has attributed a significant climate influence to the changeover from forest to field, especially as regards temperatures and winds.[84] More recently, Sagan *et al.* suggest that quite substantial climate impacts may have resulted from past deforestation for both local and global climates, especially in winter albedos. In a modern echo of the old forest–climate debate, Sagan raises the possibility of a connection between the Little Ice Age, roughly AD 1200 to 1900, and the extensive European and North American deforestation of this period.[85] Yet another echo of the old debate has to do with the significance of forest destruction in contributing carbon dioxide to the atmosphere. It has been suggested that the appreciable increase in atmospheric carbon dioxide that has occurred in modern times has been substantially caused by the release of this gas from destroyed forest vegetation.[86] The increase in the carbon dioxide content of the atmosphere raises some large questions about future land use and energy policies and to some extent revives the forest–climate issue at macroscale.[87]

Although in the past the forest–climate issue was for a long time merely an inconclusive scientific discussion, with opinion sharply divided, the majority view favored belief in a major forest influence on temperature and precipitation, especially in its negative aspects as related to deforestation. Because of the wide currency of these views there developed some important practical and political overtones to what had hitherto been essentially an abstract debate. These overtones mainly involved the nineteenth century crusade for forest conservation which, after mid-century, drew increasing support to the cause of forest preservation and replanting. George Perkins Marsh's book was, of course, partly responsible for this development. The forest preservation cause gained further momentum after 1871 when the worst forest fire in American history destroyed well over one million acres of forest and cost 1500 lives at Peshtigo, Wisconsin. Perturbed by such calamitous fires, and the dwindling reserves of forest, various organizations and numerous individuals urged the state and federal governments to initiate policies of forest

conservation. The American Forestry Association was established in 1875 to promote forest conservation and in 1886 the Division of Forestry was created in the United States Department of Agriculture. In 1891, the United States Congress laid the foundations for what was to become the National Forest system.

This crusade for forest conservation in nineteenth century America involved a wide variety of participants, including many with non-commercial or indirect interests such as nature lovers, health advocates, farmers, and users of inland waterways. There was a convergence of interest groups around the concern that adverse climatic effects were supposedly occurring as a result of extensive deforestation. In countless speeches and articles urging forest conservation, the tocsin of climatic deterioration was sounded repeatedly. Such warnings must have formed effective propaganda with a broad appeal because of their seemingly widespread significance. Further, warnings of this type were commonly compatible with local observations and folklore concerning trends in the yields of fruits and other crops. It should also be noted that the explanations advanced in support of forest influences on climate were highly plausible and sustained by long tradition. A cynic might have noted too that decades of research on the complex issues involved had produced only ambiguous results so that use of the deforestation–climatic change argument seemed secure from speedy refutation.

The persistency of the ancient belief in a major connection between climate and forests is a remarkable theme in the history of man's attempts to comprehend his environment and his place within it. As has been known for a long time, forests have considerable hydrographic significance as controllers of ground and surface water, in erosion prevention, and in other ways, but our forebears misinterpreted the climatic role of forests. Furthermore, the scanty evidence available at the time was unrelated to the fervor with which the cause of climate protection through forest conservation was upheld. Even with its false assumptions, however, this issue was significant in stimulating much climatological and meteorological research and encouraging the large-scale compilation of weather statistics. Perhaps most important was the part the forest–climate beliefs played in raising environmental consciousness and in furnishing an effective weapon for use in the belated struggle to preserve the remnants of America's forest patrimony.

Notes

[1] The reference occurs in connection with Christopher Columbus's revisit to Jamaica on his second voyage, in 1494, B. Keen trans. *The Life of the Admiral Christopher Columbus by his son Ferdinand*, (New Brunswick, N.J.: Rutgers University Press, 1959), pp. 142–143.

[2] Quite possibly the matter of linkages between vegetation and climate, especially in regard to forest clearing and its climatic impact, represents mankind's earliest major environmental debate.

[3] For further discussion of this topic see K. Thompson, 'Trees as a Theme in Medical Geography and Public Health', *Bull. New York Acad. Medicine*. 54, 1978, pp. 517–531.

[4] E. Berkeley, and D. S. Berkeley, eds., *The Reverend John Clayton His Scientific Writings and Other Related Papers*, (Charlottesville: The Virginia Historical Society, 1965), p. 80.

[5] *Ibid*. p. 49.

[6] J. Woodward, 'Some Thoughts and Experiments concerning Vegetation', *Miscellanea Curiosa*, Royal Society of London, Vol. 1, 1708, p. 220.

[7] The involvement of physicians in climatological debate is not to be wondered at, since medicine at this period was a rather wide field, embracing most of science. Further, climatic influences were believed to be highly significant in disease causation.

[8] H. Williamson, M.D., 'An Attempt to account for the Change of Climate, which has been observed in the Middle Colonies of North-America', *Transactions of the American Philosophical Society*, Vol. I, Philadelphia, 1771, pp. 272–278.

[9] *The Writings of Thomas Jefferson*, Vol. II, (Washington D.C.: The Thomas Jefferson Memorial Association, 1907), p. 114.

[10] *Ibid.*, Vol. XVI, Letter to Lewis E. Beck, p. 72.

[11] B. H. Latrobe, 'Memoir on the Sand-hills of Cape Henry in Virginia', *Transactions of the American Philosophical Society*, Vol. IV, Philadelphia, 1779, p. 440.

[12] N. Webster, *A Brief History of Epidemic and Pestilential Diseases*; etc., Vol. II, originally published Hartford: Hudson and Goodwin, 1799, (reprinted New York: Burt Franklin, 1970). p. 235.

[13] N. Webster, 'On the Supposed Change in the Temperature of Winter', paper read before the Connecticut Academy of Arts and Sciences, 1799, in N. Webster, *A Collection of Papers on Political, Literary and Moral Subjects*, Originally published New York, 1843, (reprinted New York: Burt Franklin, 1968) p. 119.

[14] *Ibid.*, in supplementary remarks read before the Academy in 1806, p. 162.

[15] For a full treatment of this reverse aspect of the forest–climate issue see the article by Walter Kollmorgen and Johanna Kollmorgen, 'Landscape Meteorology in the Plains Area', *Annal. Assoc. Amer. Geographers*, **63**, 1973, pp. 424–441.

[16] C. F. Volney, *A View of the Soil and Climate of the United States of America* etc. trans. by C. B. Brown, Philadelphia: 1804, (reprinted New York: Hafner Publishing Company, 1968).

[17] *Ibid.*, p. 213.

[18] *Ibid.*, pp. 215–222.

[19] A. von Humboldt, *Views of Nature: or contemplations on the sublime phenomena of creation; with scientific illustrations*, trans. by E. C. Otté and H. G. Bohn, London: H. G. Bohn, 1850, (reprinted New York: Arno Press, 1975) p. 103. This is a translation of the third edition published in 1849.

[20] Jean Baptiste Boussingault published on the subject as early as 1837. J. B. Boussingault, 'Memoire sur l'influence des defrichements dans la diminution des cours d'eau', *Annales de chimie*, **64**, 1837, pp. 113–141. Boussingault's major work was translated into several languages and published in English (first edition in 1845) as *Rural Economy, in its relations with Chemistry, Physics, and Meteorology* and the very last sentence of one of the several American editions (published by Orange Judd and Company, New York, in 1865) on page 507 was "... it may be presumed that clearing off the forests does actually diminish the mean annual quantity of rain which falls."

[21] A. C. Becquerel, *Des climats et de l'influence qu'exercent les sols boisés et non boisés*, Paris, 1853.

[22] A. C. Becquerel, 'Mémoire sur les forêts et leur influence climatérique', *Memoires de l'Académie des sciences de l'Institut Impérial de France*, Vol. XXXV, 1866.

[23] M. Becquerel, (sic) 'Forests and their climatic influence', *Annual Report of the Board of Regents of the Smithsonian Institution*, for the year 1869, (Washington D.C.: Government Printing Office 1871), pp. 394–416.

[24] M. A. C. Becquerel, (sic), 'Memoir upon Forests, and their climatic influence', in F. B. Hough, *Report upon Forestry*, Vol. I, (Washington D.C.: Government Printing Office, 1878), pp. 310–333.

[25] Becquerel, *Annual Report of the Smithsonian Institution. op cit.*, p. 394.

[26] *Ibid.*, p. 396–397. The possibility of ameliorating the climate of Normandy and Brittany by the removal of coastal forests, thereby admitting mild marine winter winds to the interior, was mentioned by Becquerel.

[27] *Ibid.*, p. 397.

[28] It should be noted that supposed deterioration of climate caused by tree cutting was not just a European and North American concern. It had global ramifications and extended far into areas of European influence such as, for example, British India where as early as 1849 a British surgeon, Dr Edward Balfour, published a lengthy essay (heavily derivative of Boussingault and others) entitled 'Notes on the Influence exercised by Trees on Climate', *The Madras Journal of Literature and Science*, **XV**, 1849, pp. 401–476. Even more distant echoes of the debate came from

Australia and a British newspaper reported that "attention is being drawn in different parts of Australia to the alterations which the climate is undergoing in consequence of the systematic denudation of tree-covering which the surface of the country is being subjected to." *The Times*, November 3, 1869.

[29] R. U. Piper. *The Trees of America*, (Boston, Mass.: William White, Printer to the Commonwealth, 1855), p. 51.

[30] L. Blodget, *Climatology of the United States, and of the temperate latitudes of the North American continent*, (Philadelphia: J. B. Lippincott and Co., 1857), pp. 481–492.

[31] G. P. Marsh, *Man and Nature; or physical Geography as Modified by Human Action*, (New York: Charles Scribner, 1864).

[32] For a discussion of this and other aspects of Marsh's *Man and Nature* see the excellent introduction in David Lowenthal Ed. *Man and Nature*, by George Perkins Marsh, (Cambridge, Mass.: Harvard University Press, 1965).

[33] *Ibid.*, p. 158.

[34] *Ibid.*, p. 158. However, a decade later Marsh had moved from his position of neutrality and, in the second edition of *Man and Nature*, declared that a direct relationship existed between forests and precipitation receipts. G. P. Marsh, *The Earth as Modified by Human Action*: a *New Edition of Man and Nature*, (Charles Scribner: New York, 1874), p. 193.

[35] *Ibid.*, p. 140.

[36] W. C. Watson, 'Forests – their influence, uses and reproduction', *Trans. New York State Agric. Soc.*, **XXV**, 1865. pp. 288–291.

[37] Another dimension to the controversy regarding forests as sources of rain was added by the pioneer American meteorologist James Pollard Espy who, in U.S. Senate hearings in 1857, actually advocated the systematic *burning* of portions of the western forests on the grounds that this would increase rainfall in the eastern part of the country. The actual recommendation of this fearsome hypothesist was as follows:

> Now, if masses of timber, to the amount of forty acres for every twenty miles, should be prepared and fired simultaneously every seven days in the summer, on the west of the United States, in a line of six or seven hundred miles long from north to south, then it appears highly probable from the theory, though not certain until the experiments are made, that a rain of great length, north and south, will commence on or near the line of fires; that this rain would travel towards the east side foremost; that it would not break up until it reaches far into the Atlantic ocean; that it would rain over the whole country east of the place of beginning; that it would rain only a few hours at any one place; . . . that it would rain enough and not too much in any one place; . . . and the health and happiness of the citizens much promoted.

That the making of this holocaust was actually proposed tells us much about mid-nineteenth century attitudes towards forest conservation and the understanding of precipitation processes. J. P. Espy, *Message from the President of the United States, communications, in compliance with a resolution of the Senate of July 24, 1854, the Fourth Meteorological Report of Prof. James. P. Espy*, 34th Congress, 3rd Session, Ex. Doc. No. 65, Washington, 1857, pp. 36–37.

[38] Report of the Commissioner of the General Land Office, for the year 1867 (Washington: Government Printing Office, 1867), p. 106.

[39] F. V. Hayden. *Ibid*, pp. 135–136.

[40] J. Henry, 'meteorology in its connection with agriculture', *Scientific Writings of Joseph Henry*, 2 vols., (Washington: Smithsonian Institution, 1886), p. 20. This paper was first published in 1855.

[41] This was the Timber Culture Act of 1873; it was repealed in 1891. The subject of this legislation is well treated in D. M. Emmons, 'Theories of Increased Rainfall and the Timber Culture Act of 1873', *Forest History*, **15**, 1971, pp. 6–14, and C. R. Kutzleb, 'Can Forests Bring Rain to the Plains?', *Forest History*, **15**, 1971, pp. 14–21.

[42] F. B. Hough, 'On the Duty of Governments in the Preservation of Forests', *Proc. A.A.A.S.*, (Washington D.C., 1875), pp. 1–10.

[43] I. A. Lapham, J. G. Knapp and H. Crocker, *Report on the Disastrous Effects of the Destruction of Forest Trees, now going on so rapidly in the State of Wisconsin*, (Madison, Wis.: Atwood and Rublee, State Printers, 1867), p. 3.

[44] *Ibid.*, p. 9.
[45] *Ibid.*, p. 12.
[46] *Ibid.*, p. 12.
[47] *Ibid.*, p. 17. The attractive force that forests supposedly exerted on rain clouds was a persistent widely-held belief. In a book on forestry published in 1900 it was noted that "It is a well established fact that wooded mountains have a greater power to attract the clouds saturated with water and cause precipitation of the same." A. Kinney, *Forest and Water*, (Los Angeles: Post Publishing Company, 1900), p. 235.
[48] Lapham, *op. cit.*, p. 17.
[49] *Ibid.*, pp. 22–23.
[50] Theophrastus, some 2000 years earlier, had concluded that climatic change had occurred in regions of ancient Greece because of observed variations in the growth and yields of olives and grape vines.
[51] Lapham, *op. cit*, p. 6.
[52] *Ibid.*, pp. 5–6.
[53] *Ibid.*, p. 6.
[54] *Ibid.*, p. 6–7.
[55] F. B. Hough, *Report Upon Forestry*, Vol. I, (Washington D.C.: Government Printing Office, 1878).
[56] *Ibid.*, p. 221.
[57] *Ibid.*, *passim.*
[58] *Ibid.*, pp. 310–333.
[59] *Ibid.*, pp. 285–286.
[60] A. Caswell, 'Meteorological observations made at Providence, R.I.', *Smithsonian Contributions to Knowledge*, Vol. XII, (Washington D.C.: The Smithsonian Institution, 1860).
[61] S. P. Hildreth, 'Results of Meteorological Observations made at Marietta, Ohio, between 1826 and 1859, inclusive', reduced and discussed by C. A. Schott, *Smithsonian Contributions to Knowledge 120*, Vol. XVI, (Washington D.C.: The Smithsonian Institution, 1870).
P. Cleaveland, 'Results of Meteorological Observations made at Brunswick, Maine, between 1807 and 1859', reduced and discussed by C. A. Schott, *Smithsonian Contributions to Knowledge 204*, Vol. XVI, (Washington D.C.: The Smithsonian Institution, 1870).
[62] C. A. Schott, 'Tables and Results of the Precipitation, in Rain and Snow, in the United States: and at some stations in adjacent parts of North America, and in Central and South America', *Smithsonian Contributions to Knowledge* 222, Vol. XVIII, (Washington D.C.: The Smithsonian Institution, 1872).
[63] C. A. Schott, 'Tables, Distribution, and Variations of the Atmospheric Temperatures in the United States, and some adjacent parts of America', *Smithsonian Contributions to Knowledge* 277, Vol. XXI, (Washington D.C.: The Smithsonian Institution, 1876).
[64] *Ibid.*, p. 142.
[65] *Ibid.*, p. 136
[66] *Ibid.*, p. 159.
[67] Schott, *op. cit.*, p. 311.
[68] *Ibid.*, p. 311.
[69] For a discussion of ideas concerning the stability, or otherwise, of the American climate see K. Thompson, 'The Question of Climatic Stability in America, 1770–1870', in preparation.
[70] H. Gannett, 'Do Forests Influence Rainfall?', *Science*, **XI**, 1888, pp. 3–5.
[71] B. E. Fernow, *Forest Influences*, United States Department of Agriculture, Forestry Division, Bulletin No. 7, (Washington D.C.: Government Printing Office, 1902) p. 3.
[72] W. L. Moore, A Report on 'The Influence of Forests on Climate and on Floods', House of Representatives, United States Committee on Agriculture, (Washington D.C.: Government Printing Office, 1910).
[73] *Ibid.*, p. 37–38.
[74] *Ibid.* p. 6.
[75] R. Zon, *Forests and Water in the Light of Scientific Investigation*, first published as Appendix V of the Final Report of the National Waterways Commission, Senate Document No. 469, 62nd. Congress, 2nd. Session, 1912, reprinted (Washington, D.C.: Government Printing Office, 1927).
[76] *Ibid.*, p. 23.

[77] *Ibid.*, p.23.

[78] C. E. P. Brooks, 'The Influence of Forests on Rainfall and Run-off', *Quart. J. Royal Meteorol. Soc.*, **54**, 1928, pp. 1–13.

[79] J. Kittredge, *Forest Influences*, (New York: McGraw-Hill Book Co., 1948), p. 11.

[80] A. A. Molchanov, *The Hydrological Role of Forests*, (Jerusalem: Israel Program for Scientific Translations, 1963). Originally published in Russian in 1960, p. 13.

[81] V. V. Rakhmanov, *Role of Forests in Water Conservation*, (Jerusalem: Israel Program for Scientific Translations, 1966). Originally published in Russian in 1962, p. 97. Speaking of the U.S.S.R., Rakhmanov suggests that on the average each 10 percent of additional forestation produces about a 2 percent increase in precipitation, pp. 97–100.

[82] For an up-to-date review of forest meteorology see A. Baumgartner, *Proceedings of the World Climate Conference: A Conference of Experts on Climate and Mankind*, World Meteorological Organization, (Geneva, Switzerland), 1979.

For a general discussion of climatic change, see S. H. Schneider, *The Genesis Strategy*, New York, Plenum Press, 1976, and W. W. Kellogg, *Effects of Human Activities on Global Climate*, World Meteorological Organization (Geneva, Switzerland), 1977. A short examination of the possible long-term implications of climate change for human institutions is in C. F. Cooper, 'What might man-induced climate change mean?', *Foreign Affairs*, **56**, 1978, pp. 500–520.

[83] C. W. Thornthwaite, in W. L. Thomas (Ed.), *Man's Role in Changing the Face of the Earth*, (Chicago: University of Chicago Press, 1956), p. 582.

[84] H. E. Landsberg, 'Man-Made Climatic Changes', *Science*, **170**, 1970, p. 1265–1274.

[85] C. Sagan, O. B. Toon, J. B. Pollack, 'Anthropogenic Albedo Changes and the Earth's Climate', *Science*, **206**, 1979, pp. 1363–1368.

[86] M. Stuiver, 'Atmospheric Carbon Dioxide and Carbon Reservoir Changes', *Science*, **199**, 1978, pp. 253–258.

[87] G. M. Woodwell, 'The Carbon Dioxide Question', *Scientific American*, **238**, 1978, pp. 34–43.

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