1 The Forest–Climate Question

November 10, 1888, was a fine autumn day before the dreary span of winter in Washington, DC. The afternoon was warm, one of several days with pleasant temperatures, and there was only a trace amount of rain.[1] The agreeable weather likely lifted the spirits of Washingtonians, and as night fell and the sky darkened and the temperature dropped, there was an air of excitement and anticipation among leading intellectuals in the nation's capital. Nearly 300 years of European settlement had greatly altered the landscape of the United States.[2] The Virginia and New England countryside found by the first English colonists contained extensive old-growth forest. Thereafter, the landscape was cleared of forests, felled for their wood products and replaced by homesteads, towns, and farmland. The vast virgin forests of New England – towering white pines, giants of the forest, famed for the masts they had provided the navy; mixtures of beech, maple, and birch along with hemlock and spruce in northern states; oaks and hickories in southern New England – had long since been felled.[3] Similar widespread clearing had altered the forests of Virginia and other states along the eastern seaboard, and the same pattern of forest clearing was repeated in the Midwest and Great Lakes regions with the westward expansion of the population.[4] A popular belief at the time was that deforestation was decreasing rainfall. Conservationists advocated this viewpoint in their desire to protect forests from further destruction. Land developers picked up the theme and promoted planting trees in the arid western portions of the country to increase rainfall, and the US Congress enacted just such legislation. The emerging science of meteorology provided a counternarrative. As weather observations became more widespread throughout the country and extended over longer periods of time, meteorologists could find no evidence for a changing climate. In this backdrop, fifty scholars, politicians, and concerned citizens – members of the Philosophical Society of Washington and their guests, the largest assembly in recent weeks – gathered at the Cosmos Club in northwest Washington to hear a lively debate on the subject.[5]

The Society was founded in 1871 as a forum to discuss relevant scientific topics of the day. At the previous meeting two weeks earlier, Bernhard Fernow, society member and chief of forestry for the federal Department of Agriculture, had lectured on forest–rainfall influences, arguing that forests do indeed increase rainfall.[6] Fernow was an ardent forest conservationist. He believed that "no other people of the earth have consumed virgin forests as lavishly as have the people of the United States."[7] The challenge of the forester was to balance conflicting uses of forests, both private and communal interests, to provide forest products while preserving "the forest conditions which are favorable to climate and waterflow." Fernow's presentation had struck a nerve among society members, but there was little time for in-depth discussion. The Society organized a special symposium for its 324th meeting on November 10 to consider the question, "Do forests influence rainfall?"

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Fernow returned and faced a withering rebuttal from fellow society member Henry Gannett, chief geographer for the US Geological Survey. That same year, Gannett had published a study that refuted the premise that forests affect rainfall.[8] Now, before society members and Fernow, he denounced Fernow's reasoning as "a case of theory run riot."[6] Although Gannett's previous article was "sufficiently clear for the average reader," Fernow had "misunderstood" the analysis. Gannett was obliged to "state it once more" and "to state this plainly" to ensure no further confusion: "Forests exercise no influence whatever upon rainfall." Gannett closed his lecture by asking, "Is it worthwhile to go on planting trees for their climatic effects?" His own reply affirmed the "uselessness of it," and he concluded with an admonishment not to cultivate trees in the western lands in an effort to increase rainfall. Rather, because forests evaporate considerable quantities of rainwater that otherwise might be harnessed for irrigation, Gannett advised that the trees be cleared "in order that as much of the precipitation as possible may be collected in the streams."

The proceedings of the meeting were duly reported in the scholarly journal *Science*, where the editors commented on the unseemliness of the forest–rainfall topic with the view that "much of the discussion of it, unfortunately, has not been of a purely scientific character."[9] The premise that forests increase rainfall, as expressed in the editorial, was not being studied for the betterment of society but rather was being advocated for financial or personal gain at the expense of truth and public good. None of this satisfied the appetite of society members for a learned resolution, and the arguing carried over for a third meeting. Fernow and Gannett were joined by society members and meteorologists Cleveland Abbe and Henry Hazen from the federal Weather Bureau.[10] Abbe was the first chief meteorologist for the government and laid the foundations for modern weather prediction, for which he is recognized today by the American Meteorological Society in its distinguished service award.[11] In his lecture, Abbe cautioned the audience on ascribing undue influences to forests given the difficulty of accurately measuring rainfall.[12] He subsequently published a sharp critique of the forest–rainfall theory, which was not supported by "rational climatology."[13]

The notion that forests influence the climate of a region had captured the imagination of scholars and the public alike since Christopher Columbus encountered the new lands. It swelled as the first European settlers reached the shores of America and found a landscape of boundless forests with a climate markedly different from that of their homelands. The debate coursed throughout the first 300 years of the nation, first with a confident belief that clearing forests was improving climate, only to be followed with concern for a reduction in rainfall upon loss of forests, and then an optimistic understanding that planting trees would increase rainfall. With time, the rhetoric became even more personal and still more vitriolic than expressed in the autumn of 1888. European states, too, looked inward at the loss of forests across their own lands brought on by centuries of inhabitation and likewise asked if the climate was changing. Similar concern reached across the world to India, Australia, New Zealand, and Africa with the spread of European empires. But on those November evenings in Washington, DC, the die was cast: the study of climate was the domain of physical meteorologists. There was no room for foresters, and there was without doubt no influence of forests on climate.

Except this was wrong. The science was not settled. It was only in hiatus, suppressed during the birth of meteorology as a scientific endeavor by rigid opposition from those adamantly seeking a geophysical explanation for climate. Modern climate science developed over the last few decades shows that the views expressed by Gannett, Abbe, and others were mistaken. Climate is not solely the study of atmospheric physics and fluid dynamics. It requires knowledge of the ecology, physiology, and biogeochemistry of terrestrial ecosystems and the many physical, chemical, and biological processes by which not just forests but also grasslands, croplands, and other ecosystems affect climate. In an era in which humans are now the dominant climate-altering factor on the planet, the way in which we treat forests – felling or planting trees, managing their growth – is one way in which we change climate. This time, however, it was atmospheric scientists voicing the alarm at the end of the twentieth century.

The rising concentration of carbon dioxide (CO_2) in the atmosphere had sparked concern about climate change. Climate science emerged as a facet of atmospheric science, and new theories and mathematical models of atmospheric circulation and global climate were needed to understand how human activities alter climate. Some visionary scientists, in building their models, rediscovered that forests influence climate. These scientists found that they had to include mathematical equations for plants and their roots, leaves, and stomata in their models. They discovered that the characteristics of forest canopies – the amount of solar radiation absorbed and reflected by leaves; the height of the canopy; the openness of stomata; the depth of roots – affect the accuracy of the models. Atmospheric scientists, in developing their theories and applying their models, rediscovered that forests mattered, and a few prescient ones, seeing the destruction of the Amazonian rain forest, asked once more if deforestation could be changing climate.

And so, the debate about forests and climate continues today, but now in the context of human-caused climate change. Trees remove CO_2 from the atmosphere during their growth and store the carbon molecules in biomass. As leaves, branches, and other organic debris fall to the ground and decay, carbon accumulates in the soil. For this reason, ecologists advocate forest protection and tree planting as a nature-based solution to mitigate planetary warming by removing CO_2 from the atmosphere. Indeed, the socioeconomic pathways devised by economists and policymakers to limit planetary warming below critical thresholds require sizable storage of carbon in forests to counter anthropogenic emissions. Because of their large carbon storage potential, stopping the clearing and degradation of tropical rain forests, preserving and restoring forests in other regions, and planting new forests rank high in public imagination as solutions to fight climate change.[14]

Yet carbon storage is but one way in which forests influence climate. As the developers of climate models discovered, forests affect temperature, precipitation, and atmospheric circulation through a variety of meteorological processes, sometimes in ways that counter the carbon benefits of forests. Climate scientists speak of the absorption, reflection, and emission of solar radiation; evaporation of water from soil and transpiration by plants; the turbulent exchange of heat with the atmosphere; momentum absorption by plant canopies; and the production of biogenic aerosols – climate processes that differ among forests, grasslands, and other types of vegetation. Climate scientists use their mathematical models of Earth's climate to study these processes, the climate consequences of deforestation, and the potential for forests to lessen planetary warming. Some scientists use satellites orbiting the planet to ascertain the temperature difference between forest and non-forest land, and still others contrast meteorological measurements made at forests with those at open fields to discern climate differences. Hydrologists, too, study deforestation and forest management, but in the context of water supply to towns and cities. That forests determine climate at regional, continental, and global scales is a profound change in our understanding of climate.

Two images taken from space illustrate starkly different perspectives of the science of our planet (Figure 1.1).[15] The blue marble view of Earth – the famed full-color photograph taken on December 7, 1972, by Apollo 17 astronauts looking homeward while speeding to the moon and the first to show Earth as an entire disk – emphasizes white clouds swirling over blue oceans. The image shows the African continent with the Atlantic Ocean to the west and the Indian Ocean to the east. Antarctica is a white mass at the bottom of the photograph. North Africa and the Arabian Peninsula are visible at the top of the image as

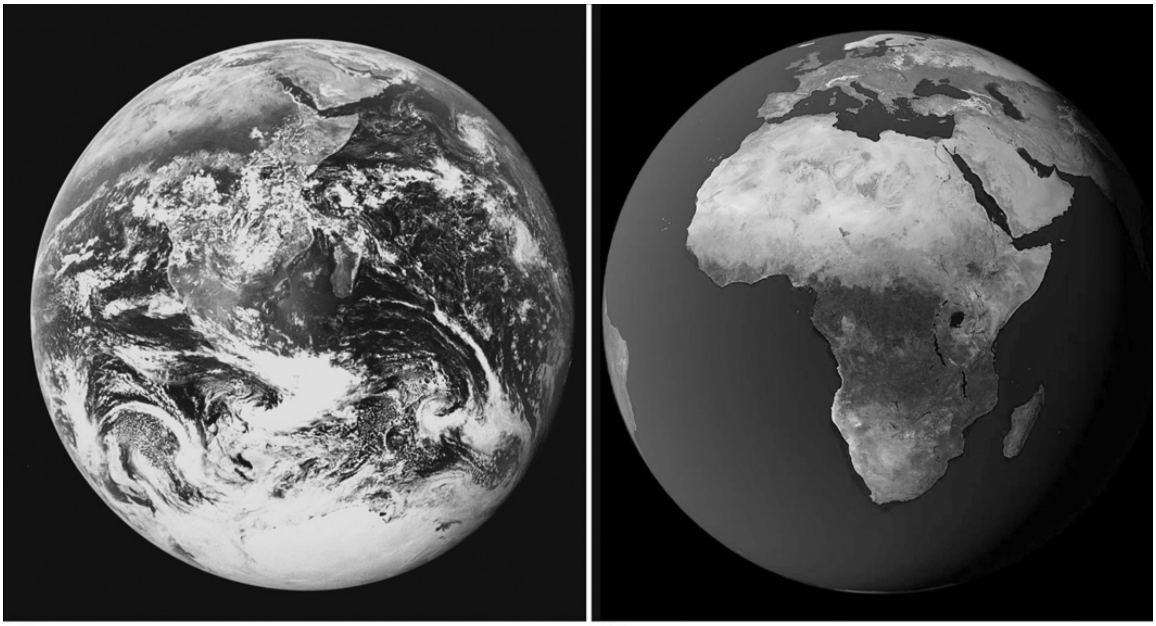

Figure 1.1 Two spaceborne images of Earth as a "blue marble" (a) and as an "emerald planet" (b). Panel a is the iconic "blue marble" photo taken from Apollo 17 and represents the geophysical view of the atmosphere in motion. The original is a full-color image of blue oceans, white clouds, and tannish-brown land. Panel b is a "Blue Marble: Next Generation" image showing Africa and portions of Europe. This "emerald planet" view of Earth emphasizes the biosphere. The original NASA image, courtesy of Reto Stöckli and Robert Simmon, is colorized to show blue oceans, green forest vegetation, and tannish-brown grasslands and open lands.

tannish-brown land devoid of vegetation. Clouds obscure much of the lush, green tropical forests of central Africa. The blue marble embodies the geophysical perspective in which climate is understood as fluid air and water in motion. Newer satellite technologies recreate the imagery, but peer beneath the clouds to see the forests. These satellite images depict extensive green continents plush with vegetation. In the right panel of Figure 1.1, the tropical forests of central Africa emerge as a wide swath of dark gray extending across the continent. The full-color image presents Earth not as a blue marble but as an emerald planet. It is a biological view of Earth – of life, and the trees and plants that inhabit the world.

Both perspectives are correct in their own context, but a complete understanding of our planet requires merging the geophysical understanding of climate with the biological understanding of ecosystems. This blended viewpoint recognizes the deep interconnections between atmospheric science and ecology. It is a perspective that has gained prominence in the last few decades as scientists seeking to understand how the world is changing have adopted a holistic view of Earth as a system and the interconnectedness of the physical and living realms. It is a view that some earlier scholars, before the specialization that characterizes science today, embraced in their studies of forests and climate, and it is this interdisciplinary view of climate that meteorologists so resoundingly rejected at the end of the nineteenth century. How has the notion that forests influence climate and that management of forests can improve climate, which was so readily advocated and then so vehemently dismissed as fanciful, reemerged in the twenty-first century?

And what does the narrative of the forest–climate controversy tell us as we embark on the new paradigm of Earth system science and planetary stewardship? Like forests themselves, there are many ways to see the story line.

The first central element is the telling of the narrative itself. Historians of science have rebuked the men who argued for an influence of forests on climate, both in the belief that climate was changing and for linking the supposed change to the destruction of forests.[16] The intellectual debate about forests and climate played out on a broader stage of European colonialism and the accompanying settling of newfound islands and continental lands. In the narrative of historians, deforestation was first seen as a means to improve the different, and therefore unhealthy, climates of faraway lands compared with the more favorable climate of Europe. When deforestation was recognized for its harmful effects, reforestation and forest conservation became the new cry. In this sense, the intellectual, governmental, and popular interest in forests and climate was an effort to promote colonization and settlement by improving the climate while also endorsing the superiority of Europeans, not the indigenous populace, in their knowledge of how to best manage the lands.[17] Concern over forests and climate change must also be understood in terms of conflict over forest regulation and state versus individual rights to manage forests. Individuals advocating a national policy to manage forests for climate benefits clashed with equally spirited individuals asserting private ownership of forests and denying any influence of forests on climate.[18] The emerging science of meteorology, too, looms over the historical narrative.[19] The early arguments for a changing climate were largely anecdotal, lacking in observation. Meteorologists, as they measured temperature and precipitation and advanced their understanding of climate, provided the missing quantitative and predictive rigor. In this story line, it was the critical skepticism of meteorologists that righted the duplicity of forest advocates.

The story of forests and climate, thus, is mostly told in a historical narrative as being scientifically wrong; advanced for political, economic, or cultural reasons; or perhaps a necessary instruction as we once more confront the intertwined science and politics of human-caused climate change. One writer called the reasoning "occasionally ingenious and often devious."[20] The heated debate during the years 1877–1912 over forest influences on rainfall has been described as a "period of propaganda," a view that seeped into subsequent historiographies.[21] The origins of modern-day environmentalism can be found in the forest–climate debate, but the actors in that history have been described as "propagandists" or as "propagandizing."[22] A review of the controversy in America noted "its false assumptions," in which warnings of a changing climate "formed effective propaganda" and were "secure from speedy refutation."[23] To a forest historian, foresters chased "this will-o'-the-wisp" to boost their standing as a profession.[24] A writer of historical ecology described the subject as "the realm of armchair speculation" in which proponents "managed to construct grandiose theories on the basis of a few known facts."[25] These criticisms predate our current understanding of forest influences on climate, but recent scholars still cite the period as "a checkered history that should elicit caution."[26] It was "a few bold scientists" who countered widespread claims about the effects of deforestation in the Hapsburg Empire during the late nineteenth century.[27] A review of the forest–rainfall controversy in nineteenth-century France, told through the perspective of a hydrologist, characterized the debate in terms of romantic and emotional foresters on one side and scientifically rigorous engineers on the other.[28]

What has been called the forest–climate question or debate or controversy has been told as a cautionary tale, without doubt a politicization of science that used exaggerated threats to influence governmental policy and even a xenophobic expression of European supremacy, but it has not been told from a modern scientific perspective. When interpreted in that light, the proponents of forest influences on climate, while

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not always correct, were also not necessarily wrong. Many of the scientific questions posed in today's research on forests and climate change have their origins in the forest–climate question. In focusing on the rhetorical excesses of the controversy, historians have been blinded to the emerging new science of what was then being called forest meteorology.

The second element of the story line, therefore, is to see the narrative not as an unscientific misstep, but rather as the foundation for the interdisciplinary study of Earth as a system. The modern paradigm of Earth system science presents the world as an interconnected system, not only the atmosphere and land with its ecosystems, watersheds, and soils, but also the oceans, sea ice, glaciers, and the people that inhabit the planet. Earth system science has been portrayed as new, emerging only in the last few decades, and as providing the scientific basis to responsibly manage the planet in the era of the Anthropocene.[29] The multi-century controversy over deforestation and climate change confounds that view. It presents an alternative narrative in which inadvertent, or even purposeful, modification of climate is longstanding, but by felling or planting trees.[30] Further to this, the central tenet of Earth system science – the interconnection between the biosphere and atmosphere – is, in fact, a centuries-old idea, first conceived in the long-held belief that forests influence climate and doomed to fail by the disciplinary specialization of the sciences. Narrow-mindedness prevented a vision of the world as an interconnected system.

The legacy of that failing lives on today, seen in the different scientific tools and research methods by which not only ecologists and climate scientists, but also hydrologists study forests and climate change. Atmospheric scientists, at the close of the nineteenth century, narrowly defined climate science to the exclusion of ecology, and now, in partnership with oceanographers and other physical geoscientists building the new generation of Earth system models of climate, are once again defining the relevance of ecology for the Earth system. If the rebirth of Earth system science is to be successful and not collapse under the burden of interdisciplinarity, we must understand the forest–climate controversy. *Seeing the Forest for the Trees* is the necessary story of the history and science of forest–climate influences and how the disciplinary geophysical perspective of climate became the interdisciplinary study of Earth as a system.

Thirdly, as the forest–climate controversy so distinctly evinces, the narrative of forests and climate must be presented through the lens of a robust interdisciplinary viewpoint, one deeper than can be attained through the standpoint of a single field of study. Many academic fields are engaged in the science, but the methods used, the questions asked, and even the language of science vary across disciplines. The various scientific communities too often talk across academic disciplines rather than exchange knowledge among disciplines. When faced with a complex, all-consuming problem, it is too easy to fall back on the narrowness of academic specialization and the comfort found in knowledge and scholarship in a limited, disciplinary context. Yet narrowness often brings hubris. The science of forests and climate change requires broad interdisciplinarity; not the self-assurance of narrow expertise, but rather the humility fostered by multiple, and often contrasting, viewpoints. If not, if proffered through traditional disciplinary study, we are doomed to repeat the hubris and disciplinary chauvinism voiced by Gannett, Abbe, and others. *Seeing the Forest for the Trees* takes a broad approach to forests and climate by integrating perspectives across the physical and biological sciences and between the humanities and sciences. We have still not broken through the disciplinary barriers that doomed the first birth of the science or that have shaped its historical telling. We need improved communication across disciplines if we are to better advocate for forests in a changing climate.

The fourth element of the narrative is hubris. Just as in the past, today's advocacy of forests as a nature-based solution to the perils of climate change – forests for climate protection – can be overheated. The science, as before, is uncertain and the evidence conflicting. There is no one common voice with which to speak of forests and climate. One climate scientist in the historical debate, presenting a review of the differing accounts on forest–climate influences at the end of the nineteenth century, drew on the tale of Ariadne from Greek mythology, in which Ariadne gave her lover Theseus a clew (a ball of thread) to guide him out of the Minotaur's labyrinth.[31] Today's scientists are still seeking the clew to solve the forest–climate puzzle. The influence of forests on climate has been argued for more than five centuries without resolution. Some readers may be disappointed to find that this book, too, provides no unqualified verdict. Others, however, may celebrate the mysteries and complexities of nature and reflect upon humankind's connection to forests, marveling in the question posed by Alexandre Moreau de Jonnès in 1825: does nature, with its intricate interdependencies, tie the fate of humanity to that of forests?[32]

The fifth element to the forest–climate controversy, then, is the story of our relationship with nature, our stewardship of the planet, and our hubris in engineering nature for a better climate. It is a belief in human superiority over nature and that we control climate, first by deforesting the land and then by replanting it. In rejecting the science at the end of the nineteenth century, humankind's ability to change climate was also rejected and a decades-long dissonance between human actions and climate ensued throughout the twentieth century.[33] Now, we once again talk of purposely geoengineering climate. Yet deep in the background, hidden behind the anthropocentric view that forests are a means to control climate, is the majesty, mystery, and wonder of the natural world. Nature continues to amaze us, and there are many things about the functioning of planet Earth that we still do not understand, either scientifically or morally. Yet for all the secrets still to be discovered and the morality to be reasoned, one truth is evident: Peoples across the ages and in all regions of the world have voiced a close connection between forests and climate and a knowledge that trees influence the climate around homes, in towns, and wherever there are forests. This is a recurring theme throughout history and speaks to our sense of place in the world. The narrative of deforestation traces across the history of humankind, and the controversy about forests and climate is one chapter in that narrative. It is an expression of the indelible way in which forests have shaped humanity. The forest–climate controversy is the history of an idea: that our past has been intertwined with forests, and our future is too.

The sixth element to the narrative is that if we see forests only in the context of climate services, we miss the larger meaning of trees in our lives. Humankind has had a long and complex relationship with forests. Forests have inspired artists and writers who have captured their wonder in paintings and in prose. Their preservation has been advocated by conservationists who have touted the environmental, recreational, and aesthetic benefits of forests; by medical experts for physical and mental health; and forests have garnered the attention of scientists seeking to understand their inner workings. Forest timber has fueled the economic growth of countries throughout the world, and their mysteries and wilderness have fed the dark imaginations of people. Societal views of forests have evolved from foul and sinister – to be conquered – and a source of timber – to be exploited for wealth – to advocacy of the many societal benefits, including climate stabilization; but forests must be seen as more than a public utility. The climate benefit of forests is an anthropocentric reading of nature – that nature exists to serve us. It is utilitarian in its rationale, in which society values the goods and services provided by forests. But what if the climate benefit is not so great after all? What if some forests provide benefits while others do not? And what if the science is not exact enough to provide an answer with a high level of confidence? These very questions span the 400-year history of the forest–climate question from 1500 to 1900, and they are still relevant today. There is no one simple story to tell. The science and advocacy of forests for their climate services, like before, is contentious. The science is complex and messy, and our relationship with forests is confounded. We need to effectively cut the Gordian knot presented by that messiness to voice a coherent meaning; we have to see the forest for the trees.

Seeing the Forest for the Trees presents a broad interdisciplinary perspective of forests, climate change, and our future. Chapters 2–6 examine the forest–climate question throughout history and the conflict between meteorologists and forest conservationists in the worldwide debate over forest influences on temperature, rainfall, and streamflow. Chapter 2 focuses on temperature and the belief that deforestation was improving the cold winters found in America. Chapter 3 shifts the focus to water – the rain that falls from the sky and the water conveyed in streams – and the advocacy for planting trees to increase the supply of water. Chapter 4 traces the spread of planting trees for rain throughout the world. Chapters 5 and 6 examine the convergence of science and public policy as the science of forest meteorology was formalized (Chapter 5) and as meteorologists forcibly pushed back (Chapter 6). As the debate reached its zenith, the naysayers prevailed and forest influences on climate faded from consideration. Chapter 7 looks at the history of forests in environmental thought and how trees and forests are portrayed in the humanities. Forests, after all, are much more than climate regulators. Can romanticism blend with science to answer the forest–climate question?

The remaining chapters present the science: How do we know in what way forests affect climate, and what is the scientific basis for forest–climate influences? Chapter 8 offers a primer on global physical climatology. This is the traditional geophysical view of climate. In addition, there is the biological understanding of climate in which forests and other ecosystems influence climate at local, regional, and global scales. Chapter 9 on forest biometeorology presents the processes by which forests interact with the atmosphere. Chapter 10 considers the scientific tools used to study forest biometeorology. Then, Chapters 11–15 show the influences of forests on climate through various physical, chemical, and biological processes. Chapter 11 examines forest influences at the local (micro-)scale of forest microclimates. Subsequent chapters look at the larger (macro-)scale. Chapter 12 elaborates on the hydrologic cycle to understand how forests affect water availability. Chapter 13 delves into the carbon cycle and the role of forests to remove CO_2 from the atmosphere. Chapter 14 examines forest influences at the macroscale in various regions throughout the world, and Chapter 15 provides specific case studies. The final chapters consider climate-smart forests and how forests of the future can be managed for their climate benefits. Chapter 16 defines what is meant by a climate-smart forest. Chapter 17 examines the processes controlling forest biogeography and the stresses forests face in the coming years. Chapter 18 is a concluding essay that ties together the various themes and provides perspective.

The language of today's science was not available to scholars of the nineteenth century and before, and so the forest–climate history can be foreign to modern sensibilities. Before the advent of academic specialization, indeed before the designation "scientist" was crafted in the early nineteenth century, scholars of nature studied natural history, which was defined as "a description of any of the natural products of the earth, water or air."[34] From this general usage emerged the broad classification of science into the modern branches of physics, chemistry, and biology. Meteorology was developing as a science in the nineteenth century, and climatology was used specifically to mean the study of climate. Actors in the debate can be identified as meteorologists or climatologists. With the close connection between physics and meteorology, many were physicists. Today's academia embraces the broader terminology of atmospheric science, and climate science is preferred to climatology.

Botany was established as a field of study, and forestry was establishing its scientific basis. “Ecology” was not coined as a word until 1866, when Ernst Haeckel defined it as the science of the relations of organisms to the surrounding environment, both physical and biological.[35] Instead of ecologists as they exist today, there were botanists, foresters, and horticulturalists. “Ecosystem” became a concept only in 1935, and it took many years to define what an ecosystem is and how to study it.[36] The general usage today embodies the interrelationship between the physical and biological environments. A terrestrial ecosystem combines living organisms and their physical environment into a functional system linked through biological, chemical, and physical processes. Closely associated with ecosystem is the term biosphere, which in fact precedes ecosystem in the lexicon of ecology. Eduard Suess introduced the term in 1875 to designate the living component of Earth, one of the enveloping spheres, along with the atmosphere, hydrosphere, and lithosphere, and Vladimir Vernadsky, in 1926, provided the modern conceptualization of the biosphere in terms of energetics and biogeochemical cycles.[37] Today, biosphere is used interchangeably with ecosystem, or to also mean specifically the sum of all ecosystems on the planet. None of this semantics, however, detracts from a general understanding of the forest–climate controversy as a deep splintering in the science of the environment that can be seen in today’s disciplinary study of atmospheric science and ecology.