

The Long Lens of History

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Environmental Change and the Future Health of the Harvard Forest

Ecosystem studies at the Harvard Forest proceed from a unique view of the landscape through the long lens of history. This longer-term and historical view of ecosystem response to human use at the Harvard Forest did not begin with the formation of the LTER program or the work described in this book. In his classic essay on forests and social change titled "The View from John Sanderson's Farm," Hugh Raup, former director of the Harvard Forest, compares the rapid pace of economic development and the maturation of the New England economy with the relatively slow development to maturity of a forest. As Raup put it, "Foresters have always had trouble with time because the human mind produces changes in the uses of wood several times faster than trees can grow." He concluded by describing the Harvard Forest as a failure in its initial purpose, "a firm commitment to the ideal that good forest management could and should be economically self-supporting." The root cause of this failure was the inability of foresters and conservationists to envision rapid changes in technology and human values of the land and woods and to focus instead on the inherent functions of the land itself—a belief that "the stage was more important than the actors."

Raup's essay was published in 1966, at the beginning of an energetic era of environmental concern and just as the first classic papers in modern ecosystem studies were appearing in scientific journals. In a sense, Raup's descriptions of failure of purpose at the Harvard Forest were prey to the same rapidly moving social forces he described. He apparently could not envision the continued development and persistence of the Harvard Forest as a center for long-term environmental research: the setting for a series of interrelated experiments exemplifying modern (from the perspective of the early twenty-first century) interdisciplinary environmental science. In a sense, this failure of vision proves the very idea at the core of the essay: we cannot predict what holders of the land will

do next and how that will be conditioned by forces in the larger world.

The past, however, does not change. At the Harvard Forest we are blessed with a historical record that allows some precision in the description of how the lands have been used, and also how natural disturbances such as hurricanes weave into this history. Surprisingly, the study of human impacts on ecosystems has only recently become an important part of what American ecologists do. Although classic papers on the development of communities and ecosystems over successional and even geological time frames have formed the basis of the science, the vast majority of studies occur in areas deemed to be “free” of human impact. This assumption has allowed the dismissal of land-use history as an important component of the responses measured in the present.

Over the past decade this perspective has changed. There may be several reasons for this. One must be the accumulation of images of the Earth from space, which constantly reinforce the reality that very few if any large regions of the Earth are predominantly “natural.” Environmental awareness reinforces the idea that the study of “pristine” ecosystems, however that might be defined, may have declining relevance in a world driven by human activity. A second could be an increasing emphasis on interdisciplinary work, especially between the natural and social sciences. Even a brief introduction to anthropology or some aspects of history points to the recurring waves of human cultural concentration and dissipation that have swept over the inhabitable parts of the globe. A third is clearly the result of investigations like those described here that underscore the enduring legacy of past human activities on modern conditions.

The longer the legacy of past land use, the more critical it is to understand that history and the imprint it leaves in the soils and forest conditions that we sample today. Here, the Harvard Forest results have particular relevance. The detailed history of change over several centuries presented in this book (Chapter 4) is linked directly to the responses we measure in the long-term experiments. The tower-based measurements of carbon accumulation (Chapters 10 and 19) may vary from year to year in response to short-term changes in climate, but the long-term average is well above zero because of previous removals of carbon in wood and soils going back to the time of John Sanderson. Similarly, the hardwood stand in the chronic nitrogen experiment accumulates and retains huge amounts of added nitrogen because of soil and plant conditions resulting from the centuries-long history of the site. We are just beginning to understand the effects and longevity of ecological legacies from history. There is still much to be learned.

In his introduction to a volume titled *Humans as Components of Ecosystems*, published in 1993, the historian William Cronon captures the recent movement of ecology away from the enumeration of ecologi-

cal museums (the remaining pristine sites) to the understanding of disturbed systems. He notes that understanding responses to disturbance is critical and that such responses often offer greater insights into the function of ecological systems (after all, every experiment is a disturbance designed to gain just such insight). He concludes that recent interactions of ecologists with environmental concerns have “encouraged ecologists to recognize that their field, like geology and evolutionary biology, is a genuinely *historical* science, with analytical problems and approaches that are unavoidably different from those of less time-bound fields like physics or chemistry.”

How important is this temporal perspective? One could liken ecological research without the historical dimension to the plight of the residents of Flatland in the whimsical Victorian volume of the same name by Edwin Abbott. Limited to a life in two dimensions, the residents of Flatland can see only the perimeter of things, and the true shape of objects and beings must be intuited. A brief journey into three dimensions is a revelation to one Square as he perceives the outline of previously unknown dimensions.

So with a historical perspective, we may begin to understand what appears unexplainable in the present. Two ecological examples can be used. In Chapter 5 we described homogenization of tree species distribution across central Massachusetts due to human use of the landscape. What was ordered along climatic gradients and explainable in terms of environmental controls before the European presence has become disordered. Currently, there is no apparent relationship between forest composition and environmental variables at this spatial scale. We cannot reorder the distribution perfectly because we do not understand the history of every site, but if we could, with the perspective of time and history, a logical ordering would likely reappear. We wonder if the same is true for the distribution of soil nutrient content and cycling rates. These rates vary widely over distances of tens of meters and those differences are hard to explain. If the history of each site (each field in Sanderson’s farm) were known, would we be able to predict the distribution of nutrients and their rates of cycling?

If our long lens into the past remains imperfect, the lens into the future is even murkier. Hugh Raup concludes that we cannot foresee human valuations or activities in the forests, and the rapid change in social forces relative to the rates of natural change in ecosystems is inescapable. Raup highlights this statement with a glance toward the immense colonial houses, built between 1820 and 1850, that line the main street in the town of Petersham. The owners were prosperous farmers and tradesmen living well in nineteenth-century New England and with every intention of staying for generations to come. They could not foresee the continental-scale revolutions in industry and transportation that

would ultimately drive their open countryside back to forest. With the current population less than half of its nineteenth-century maximum, Petersham and its large houses testify to the immensity of social and landscape changes and our limited ability to anticipate them. Certainly, the farther into the future we try to project, the less likely we are to be right. But even over the short term, Raup gives us the example of the Erie Canal as a watershed event that changed land-use patterns in New England in a matter of decades, suggesting that change may come precipitously and in ways that cannot be anticipated.

With this caveat, we can look to the future of the New England forests and attempt to discern at least which forces and stresses might result in the most rapid shifts in distribution and function.

Critical Changes in Physical and Chemical Climate

Regionally and globally, human activity is altering the chemistry of the atmosphere. At the global level, the burning of fossil fuels and a net conversion of forests to agriculture cause a continuing increase in CO₂ concentrations. This is predicted to drive changes in physical climate, generally increasing temperature and altering precipitation. The changes in CO₂ are clear and measurable. Increases in temperature are becoming detectable. Changes in the more chaotic climate variables such as total precipitation, frequency and intensity of storms, and recurrence of global climatic shifts such as the El Niño Southern Oscillation continue to elude direct measurement, and predicted changes vary widely depending on the model used. Predictions for changes in both temperature and precipitation at the regional scale are especially variable between models.

Coincident with the release of carbon to the atmosphere is the release of nitrogen, as well as the conversion of atmospheric nitrogen to reactive oxides, especially in high-compression automobile engines. Both the reactive nitrogen oxides and partially burned hydrocarbons contribute to the formation of ground-level ozone ("smog").

Together, these changes in atmospheric chemistry and the resulting changes in climate represent the strongest potential threat to the health of New England's existing forests. However, the interactions of all of these major "stressors" may be surprising, and not all predicted responses are negative.

Carbon dioxide is the basic substrate for photosynthesis, and the very low concentration of this trace gas in the atmosphere severely limits carbon fixation in most plants. Increases in CO₂ are predicted to increase rates of photosynthesis and also to increase water-use efficiency (the ratio of carbon gained through photosynthesis to water lost through transpiration), thus reducing drought stress. The relative degree of

change in photosynthesis and water-use efficiency depends in part on whether plants respond to higher CO₂ concentrations by reducing the rate of gas exchange with the atmosphere.

Nitrogen is the primary limiting nutrient in New England forests, as we have discussed in previous chapters. While nitrogen deposition may act as a fertilizer in this respect, Chapter 12 presents the concept of nitrogen saturation, by which excess nitrogen may lead to nutrient imbalances in plants and acidification of soils and streams. However, the chronic nitrogen experiment suggests that the amount of nitrogen required to reach saturation may be very large, and any increases in plant growth due to CO₂ enrichment would increase this capacity.

In contrast, there is no positive side to ozone. As an oxidant gas, ozone penetrates into foliage and damages cell membranes, which then require investments of energy to repair. This reduces net photosynthesis in a linear and predictable way and also reduces forest growth (Chapter 17). As entrance into leaves is required for damage, any reduction in this exchange rate due to increases in CO₂ could mitigate ozone damage. On the other hand, any reduction in forest growth due to ozone will reduce the forest's capacity to take up nitrogen and could speed the process of nitrogen saturation.

Most predictions for changes in precipitation call for increases globally, while the regional distribution of this increase varies widely between models. In some scenarios, critical areas of the Earth are predicted to see reduced rainfall. Although New England is a humid and generally well-watered region, drought can limit forest growth in certain places and times. Thus, we would expect increases or decreases in precipitation to increase or decrease forest growth.

Response to temperature remains a major unknown. Although photosynthesis and respiration are both highly sensitive to temperature and the optimal temperature for a plant at a given time can be described, we know relatively little about a plant's ability to acclimate—to create a different optimal temperature for net photosynthesis. This remains one of the major unknowns in predicting the response of forests to climate change.

The daily range in temperature (from daily maximum to minimum) also affects plants to the extent that it represents the dryness of the air. In less humid air, the difference between maximum and minimum temperature is larger. More humid air also means less transpiration and a higher water-use efficiency, and so less chance of drought stress. In general, minimum temperatures are predicted to increase more than maximum temperatures in a higher CO₂ atmosphere.

We are currently extending the PnET model discussed in Chapter 17 to include the simultaneous effects of all of these factors. Completion of this effort will provide at least one quantitative prediction of the interactive effects of all of these changes on New England forests.

Population and Land-Use Change: A Comparison with Environmental Change

As with Hugh Raup's predictions and observations, however, such modeling efforts cannot anticipate the radical or precipitate change that might make many of these predictions irrelevant. As an example, the previous paragraphs describe the response of intact forests that are not disturbed by human use over the period of prediction. For a fifty-year prediction window, the fraction of New England forests to which this applies may be small. Many forests will be harvested for commercial use and others by private landowners for wood or fuel. A major disruption in the global distribution of petroleum (another "oil crisis," as in the 1970s) could result in greater demand for wood-fired power plants and domestic wood burning for heat. It would not take very long, nor a very large increase in the fraction of energy consumed as wood in the region, to completely change the age structure, biomass, species composition, and appearance of the New England forest. In this way, the congruence of a high population density, high energy usage, and large tracts of mature forests could prove a volatile mixture.

Although harvested forests may recover, the ultimate sink for forestlands is conversion to residential, commercial, or industrial use. Unlike the farmlands and pastures of the 1800s, developed lands are unlikely to be abandoned under anything short of a cataclysmic change in the social structure and are unlikely to revert to forests within any kind of reasonable planning horizon. The U.S. Census Bureau predicts that population in the six New England states will increase from 13.6 million in 2000 to 15.3 million in 2025, an increase of nearly 13 percent. It is certainly risky to convert that to expansion in urban and suburban land use and equate such an expansion into conversion from forests (Dr. Raup's caveat rings in our ears here). Still, assuming that New Englanders maintain their current habits with regard to living in cities or suburbs, it seems that a conservative estimate of a 13 percent increase in urban and suburban land use is reasonable. As most of the agricultural land has already disappeared, through conversion to urban/suburban areas or reversion to forests, much of future conversion must come from currently forested landscapes.

How does this compare with estimated rates of change in environmental parameters over the same period (to 2025)? Carbon dioxide concentrations in the atmosphere are expected to increase by 8 to 22 percent, depending on the degree of control over emissions exerted by the global community, and total nitrogen emissions to the atmosphere in the region might increase by 10 to 15 percent over the same period. The production of ozone is linked to emissions of nitrogen and might be expected to increase by the same percentage, but changes in combustion

technologies (and additional Clean Air Amendments) could reduce both of these significantly. The climatic indicators receiving the bulk of popular attention at the turn of the millennium, temperature and precipitation, are expected to change very little according to the latest predictions from the major climate models. From 2000 to 2025, global temperatures should increase by about 1°C, and precipitation should increase by about 1 percent. Regional predictions are more variable among models, but in general temperature increases will be greater at higher latitudes, and the estimate for New England is about 2°C for the period 2021–50, with about a 5 percent increase in precipitation.

Given the mixed and counterbalancing effects of climate, CO₂, nitrogen, and ozone on forests, it seems that a 15 percent expansion of non-forest land over the region, tied directly to human population levels, may represent one of the most important forces for change in the region. Add to this the potential demand for wood as fuel, and the role of human use of the land looms even larger. To researchers at the Harvard Forest, this would signify a continuation of, rather than a break from, the past. History, and the direct human use of the landscape, has dominated the environment in and around the Harvard Forest area for nearly 300 years (and perhaps longer). The indirect effects of human activity through alterations in climate and atmospheric chemistry will continue to alter the biogeochemistry of the forests here in measurable and important ways, ways that in turn contribute to the global response of forests to a changing environment. But, as Hugh Raup's "actors" in the New England landscape, we will determine directly whether forests remain an important part of the "stage."