Tree physiology research in a changing world

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Summary Changes in issues and advances in methodology have contributed to substantial progress in tree physiology research during the last several decades. Current research focuses on process interactions in complex systems and the integration of processes across multiple spatial and temporal scales. An increasingly important challenge for future research is assuring sustainability of production systems and forested ecosystems in the face of increased demands for natural resources and human disturbance of forests. Meeting this challenge requires significant shifts in research approach, including the study of limitations of productivity that may accompany achievement of system sustainability, and a focus on the biological capabilities of complex land bases altered by human activity.

Keywords: canopy process, ecosystems, natural resources, population increase, research trends, sustainability.

Introduction

This special journal issue reports on research addressing environmental effects on forest stands. A focus of a number of the papers gathered here is the effect of global increase in atmospheric CO2 and related climate changes on growth of individual trees and stands. Other areas of focus include the measurement and scaling of fluxes between forests and the atmosphere, the measurement and modeling of forest responses to interacting environmental factors, environmental constraints on productivity, canopy structure and architecture, allocation of carbon in forest ecosystems, and the hydrology of forest catchments.

In this paper, we first review some of the trends in tree physiology research of the last several decades and examine the trends and issues in current research. We then focus on sustainability of natural resource systems as perhaps the most serious issue facing us in light of the effects of world population growth. And finally we discuss the possible roles of tree physiology research and the scientists engaged in it during the forthcoming decades.

Research trends and emerging issues

Much has changed since meetings on canopy process and canopy flux research began more than two decades ago. The major driving issue of early research was forest productivity, and the approach was to determine how stands of trees capture energy, grow and respond to stress. Thus many early studies focused on gas exchange phenomena in forest stands. At the canopy level, aerodynamic studies of latent heat flux centered on the Bowen ratio, and for branches, studies examined stomatal regulation of transpiration and photosynthesis. Radiant energy, humidity, temperature, wind and water stress were considered to be the important factors regulating gas exchange, and studies of canopy architecture and the soil–plant-atmosphere continuum provided frameworks for interpreting data. Infrared gas analyzers and porometers were in the early stages of miniaturization for convenient field use, and the use of radioactive isotopes was not uncommon, but eddy correlation techniques, the Omega factor, ceptometers, time domain reflectometry, Δ13C ratios and multiscale analyses had yet to play an important role in research.

These earlier studies set the stage for new research directions as additional issues emerged. Air pollution and acid rain were recognized as major problems, particularly in the northern hemisphere. As greenhouse gases in the atmosphere continued to increase, interest emerged both about the fertilizing effects of higher atmospheric CO2 concentrations and the potential effects of global warming. Studies of trees and canopies were supplemented by studies at larger scales, providing a hierarchical treatment of additional processes and feedback mechanisms that included, but were no longer limited to, forest trees and stands.

System complexity, scaling across time and space, and the impacts of factors such as greenhouse gases and air pollution favored rapid advances in forest process model development. Process-based simulation models provided not only systematic ways to handle a number of complex processes simultaneously, they also provided a focus on poorly understood factors such as belowground processes and respiration, and nitrogen nutrition. Additionally, models provided a means to hypothesize the effects of new combinations of factors likely to affect tree and stand behavior. Many of these efforts are currently underway, aided by new technologies by which detailed studies at multiple spatial and temporal scales can be conducted and integrated.

It seems appropriate, as we near the beginning of the 21st century, to ask how we are handling important issues in tree and forest ecophysiological research. Appropriately, global
carbon balance is clearly a concern, though there is little consensus regarding the consequences of higher atmospheric CO₂ concentrations on forest systems. A number of intensive impact studies on CO₂ and temperature effects are underway around the world (Landsberg et al. 1995). These studies should help us model CO₂ and temperature effects on the behavior of trees, including to some extent belowground processes, although they will not resolve questions about CO₂ effects on ecosystems. Studies on the carbon cycle of forests are advancing rapidly both by model development and by improving our empirical knowledge of processes such as maintenance and growth respiration, belowground carbon turnover, and nutrient interactions.

Important questions about forest behavior, and especially the carbon cycle, are not yet answered satisfactorily. Major questions exist about carbon sequestering by forests, not only for future climates but even for the present, and for both native forests and plantations. Processes regulating soil carbon are very poorly understood, even though soil carbon is one of the largest components of the global carbon balance. Mineral nutrient interactions are believed to be extremely important in regulating the carbon cycle and cycle carbon balance, but studies of mineral nutrition in forest ecosystems in many ways are still in their infancy. A growing body of evidence suggests that processes such as photosynthesis and water transport change substantially with tree and stand development, especially as trees reach the old-growth stage, but these changes are not well understood. Impacts of atmospheric contaminants on forest trees, stands and ecosystems need to be determined in the context of current and changing climate conditions, addressing both short-term acute effects and long-term chronic effects. Of these emerging issues, the concept of sustainability is perhaps the most critical and deserving of additional attention.

Sustainability and world population growth

Modern technologies of the industrial world have led to the most sophisticated systems for supporting civilizations ever developed. We place tremendous faith on the supposition that the same science and technology that brought us the industrial revolution, modern agriculture and medicine will enable us to avoid a global crisis. Yet these same technologies often have been used with a massive disregard for the natural landscape or for conservation of natural resources. We have created high-yield crop systems, including some in forestry, that are biologically sustainable only by large investment of various resources that themselves are limited in supply.

As systems are pushed further from the natural state, the resource investment needed to maintain them increases, and the true net return is lower (Kaufmann and Boyce 1995). We conveniently disregard hidden costs, failing to account fully for consumed nonrenewable resources such as fossil fuels and minerals, and especially the loss of soil productivity, habitat and fragmentation of the landscape. We often worry too late about exotic species introduced intentionally or accidentally that, for one reason or another, have serious negative consequences. Exacerbating these effects are land use changes that steadily remove land from production. Now in parts of the world, natural resources are in such short supply that humans are destroying their resource base in the short-term struggle for the basic necessities of life.

Recently, the Worldwatch Institute examined the consequences of population growth and land use practices on changes in per capita availability of various resources expected over a 20-year period from 1990 to 2010 (Table 1; Postel 1994). Sustainability can be viewed as something broader than retaining biological productivity on a given area of land. It also has social and economic components, and involves relating social and economic needs to ecological capabilities of the land (Figure 1). Where social and economic needs can be met within ecological capabilities, ecological sustainability and probably also social and economic sustainability are possible. Thus, achieving greater congruency among social and economic needs and ecological capabilities will likely improve sustainability in all areas. A major difficulty facing the world, however, is that human needs are increasing at alarming rates, yet ecosystems are often not very flexible.

While engineered ecosystems such as farms and plantations might be highly productive in the short run, they frequently require large inputs of other resources to maintain them (often imported from other ecosystems), and there may be substantial losses of biodiversity (Kaufmann and Boyce 1995). Considering such long-term processes as pest control and maintenance

Table 1. Projected changes in per capita renewable resource availability over two decades (from Postel 1994).

<table>
<thead>
<tr>
<th>Renewable resource</th>
<th>Per capita change from 1990 to 2010</th>
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<tbody>
<tr>
<td>Fish catch</td>
<td>Down 10%</td>
</tr>
<tr>
<td>Irrigated land</td>
<td>Down 12%</td>
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<tr>
<td>Cropland</td>
<td>Down 21%</td>
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<tr>
<td>Rangeland and pasture</td>
<td>Down 22%</td>
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<tr>
<td>Forests</td>
<td>Down 30%</td>
</tr>
</tbody>
</table>

Figure 1. Relationship of social and economic needs with ecological capabilities. Where overlap occurs, ecosystem sustainability is likely. Because ecological capabilities are not very flexible, creating greater overlap may require bringing social and economic needs into better alignment with ecological capabilities (from Kaufmann et al. 1994).
of healthy soil and groundwater resources, it is questionable if even the present world population can be supported indefinitely, regardless of technological innovations. Equally critical is the rate at which productive forest, range and agricultural lands are being lost due to poor management and land use changes. Nearly a decade ago, Vitousek et al. (1986) reported that humans had already reduced net terrestrial primary productivity by about 12% through land use impacts and directly used or co-opted another 27%. Since then, continued impacts on terrestrial systems and larger impacts on marine systems have occurred (World Resources Institute 1994, Brown 1995). With a fivefold increase in world population in the last century and another doubling anticipated by the middle of the next century, the potential impacts of appropriating net primary productivity on such conditions as soil carbon and ecosystem sustainability are hard to ignore. It can be argued rather convincingly that all the potential biological impacts associated with climate change in the next century pale by comparison with the likely impacts of ecosystem abuse associated with increased demands for natural resources and with losses of productivity through land use changes as world population increases.

The problem facing the world is that we do not seem to have the modern technologies, nor probably the political will, to protect the natural resource base that must be preserved for long-term global sustainability. Given the current trends in population, the economic operating paradigms of the developed world, and the likelihood that advances in renewable resource production will be smaller than during the last half century, the sustainability of social, economic and ecological systems is in doubt. The question for researchers of physiological processes in forests and of natural resources is what might be done to mitigate or forestall these consequences.

A land ethic

We have often failed to be cautious in our treatment of natural resources, adopting instead a frontier mentality. The precautionary principle (Bella and Overton 1972, Perrings 1991) involves giving the benefit of doubt to the resource rather than to its extraction or development. It is applied when there is uncertainty about possible cumulative or long-term effects, irreversible changes, or adverse interactions. In an economically driven system, these uncertainties are usually discounted or ignored, with wide-ranging consequences: loss of biodiversity, loss of a seral stage such as old-growth, change of vegetation cover type, nutrient depletion, salinization, habitat fragmentation, introduction of exotic species, encroachment by urbanization, etc.

Aldo Leopold, in his highly regarded book “A Sand County Almanac” (1949), developed what he termed a land ethic: “Quit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.” While adopting this ethic might be viewed as an activity affordable only by the wealthy, the failure of civilizations that have not lived by this ethic suggests otherwise. Leopold continues: “The fallacy the economic determinists have tied around our collective neck, and which we now need to cast off, is the belief that economics determines all land-use. This is simply not true.”

Following a land ethic, we should strive to sustain ecosystems and their biodiversity in such a way that their structure, composition and function are conserved (Grumbine 1994, Kaufmann et al. 1994). Taken as a whole, we should resist the transformation of pristine systems to impacted ones, managed natural systems to farms, and biologically functional land to polluted or damaged land, concrete, asphalt and roofs. Guidelines for a land ethic come from ecosystem analyses. Assessing ecosystem needs is one way this is done (cf. Kaufmann et al. 1994). In part, this process identifies ecosystem conditions both before significant human disturbance and under existing conditions to determine how far systems are removed from their undisturbed state. Obviously this approach is most straightforward when existing ecosystem conditions are not greatly different from earlier natural conditions, but even in those extensive areas of the world where human impacts have been large, the approach provides a basis for limiting ecosystem damage and improving ecosystem conditions. The ability to assess ecological needs allows ecological concerns about natural resources to be elevated in decision processes to the same level as economic and social concerns. By having ecological issues clearly identified on a scientific basis, the consequences of alternative economic and social courses of action can be determined.

Our scientific options and responsibilities

So what do scientists, as a group, do concerning forests and other natural resources? We must recognize that the problem is more severe than generally perceived, and that there is no magic solution to be obtained from increased science and technology. We have only two real choices: (i) mitigating impacts on natural resources by improving short-term delivery of forest products using more extensive and efficient production systems, and reducing further deterioration of the sustainability of natural resources; and (ii) through effective communications, help governments, societies and religions of the world recognize the limitations of natural resource systems to meet increasing human demands of rapidly expanding populations. This is well within the scope of responsible scientific behavior (Lee 1993).

In our scientific disciplines, we can supplement our research to increase productivity of forest systems with descriptions of the limitations of productivity. We can direct flux research and modeling efforts to include the consequences of land use choices on overall productivity, not limiting ourselves to ideal research sites that make up a relatively small proportion of global resources. We can direct nutrition, carbon flux and irrigation research to assess the long-term sustainability of soil and groundwater quality. We can direct physiological research to clarify the limits of plants to cope with multiple anthropic
stresses such as atmospheric and water pollutants, and especially their interactions. And we can work toward full accountability of all natural resources in production systems.

Doing this requires examining the fabric of our science. Embracing a responsible land ethic as an underpinning for our research involves a paradigm change requiring a new level of honesty with ourselves, our peers and superiors, and the public. It requires research concerned with not only production of forest products, but also the long-term integrity of our natural resource systems. It requires a complete accounting of natural resource costs. It requires studying all aspects of the landscape mosaic, not just the easy ones.

Our responsibilities as scientists are affected by the global carrying capacity experiment of which we are all a part. We must work to keep land productive and to retain natural resource capital. We should work to get ecological science more deeply entrenched in our thinking and in the land use decision process. And we should retain a clear focus on the kind of world we hope to hand over to future generations.

References


