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Editorial

Applying ecological insights to increase productivity in tropical plantations

In the 19th and 20th Centuries, forest productivity was examined largely as a retrospective exercise: growth of forests was tracked over time, and these historical trends were projected empirically into the future (Puettmann et al., 2008). Silviculturists explained growth of trees and stands in terms of unquantifiable "growing space," explaining changes in productivity of trees and stands in response to increases and decreases in non-finite growing spaces (Oliver and Larson, 1990). Mechanistic understanding of the ecophysiology of tree growth developed in the late 20th Century to the point where growth could be examined in relation to acquisition and use of resources, and models could use a mechanistic foundation for estimating growth over time and across landscapes (Landsberg, 2003).

These mechanistic insights to forest production are particularly important for tropical plantations, which now cover more than 60 million ha around the globe (UNFAO, 2000). Many tropical plantations are established on former agricultural fields and pastures, with no prior yield data for projecting growth. Intensive management is fundamental to the successful establishment of new monoculture plantations, as well as native forest restoration. Strong responses to silvicultural operations (such as weed management, fertilization, and site preparation) provide a range of opportunities for profitable investments; complex interactions among treatments can be clarified with a mechanistic understanding of the "why?" behind growth responses. Improved genetics and silviculture typically increase yields by 10–20% each rotation, and intensive research (both basic and applied) provides the foundation for sustaining this high rate of increase. Short rotations also increase the importance of year-to-year variations in weather, with major implications for wood supply and harvest scheduling.

These issues were examined at an IUFRO-sponsored workshop on *Processes Controlling Productivity in Tropical Plantations* in November 2008 in Porto Seguro, Bahia, Brazil (Fig. 1). Fifty oral and poster presentations highlighted research from around the tropical regions of the world, and 17 of these presentations were compiled into this special issue of *Forest Ecology and Management*.

A focus on the ecology of forest production included papers presenting original research as well as synthesis of knowledge, examining the "why?" behind observed empirical responses of trees and stands to silvicultural treatments and site factors. Models based on ecophysiology at the level of trees and stands provided new insights into factors influencing growth, and papers illustrated the state of the art in combining models with data from remote sensing and field inventories to map productivity across managed landscapes. Each paper in this special issue provides insights on more than one of these topics.

Silvicultural experiences with resource supplies, growth and ecophysiology were reviewed for South Africa (Du toit and coauthors) and for Australia (Forrester and coauthors). The role of stand structure and dominance in determining the growth of *Eucalyptus* trees and stands was examined in Hawaii and Brazil by Doi and coauthors; even after 50 years and more than 500 Mg/ha of stand mass, dominant trees accounted for more than a proportional share of stand growth.

The factors influencing productivity of *Eucalyptus* plantations at landscape scales were examined by Almeida and coauthors; field data combined with the 3-PG model showed that two features of water (vapor pressure deficit and soil water availability) accounted for most of the variation in growth across 180,000 ha in eastern Brazil. Marsden and coauthors used satellite data to estimate structure, light use, and growth of *Eucalyptus* plantations at landscape scales; stand growth was higher when canopies developed high light absorption early in a rotation, and where the efficiency of using light was high. Waring and coauthors combined remote sensing and 3-PG modeling to provide high-precision representation of forest growth across explicit landscapes. Current estimates of landscape-scale production will be improved with better estimates of seasonal changes in the efficiency of canopies in converting light to photosynthate, as well as changes in canopy conductance.

Several papers examined some of the many facets of tree physiology and ecosystem biogeochemistry in *Eucalyptus* plantations. Nouvellon and coauthors charted within-season changes in specific leaf area in the Congo, and Forrester and coauthors examined changes in water use with stand age in Australia. Laclau and coauthors summarized a decade of research on biogeochemistry in the Congo and Brazil, documenting very conservation nutrient cycling patterns. In another paper, Laclau and colleagues found that applications of sodium chloride could at least partially alleviate potassium deficiencies in *Eucalyptus*—a remarkable and not well-understood finding.

Although most work in tropical forest plantations deals with monocultures, multi-species silviculture is gaining in importance. Forrester and coauthors examined how combining *Eucalyptus* with nitrogen-fixing *Acacia* increased total stand growth, water use, and (most strikingly) the efficiency of water use (1.7 kg wood/m^3 transpiration for the mixture versus 0.94 kg wood/m^3 transpiration for monocultures). Dordel and coauthors tested the influence of nurse-tree species (and silvicultural operations) on the establishment and growth of *Toona ciliata* plantations; *Grevillea*

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Fig. 1. Group photograph of participants in the IUFRO-sponsored workshop on *Processes Controlling Productivity in Tropical Plantations* in Porto Seguro, Bahia, Brazil, November 2008.

Table 1
Summary of Company opinions on value derived from the Brazil *Eucalyptus* Potential Productivity (BEPP) Project.

Survey question	Average rating (standard deviation)
1. How important was the participation of the Company in the Project from the perspective of: (1 = not important, 10 = extremely important)	
A. Increasing scientific understanding and training in measurement techniques?	7.8 (2.2)
B. Improving operational activities?	6.1 (1.7)
C. Improving long-term strategies?	8.4 (1.6)
2. The BEPP focused his research on measuring the overall productivity of forest systems including the allocation to roots. How novel was this approach for your company? (1 = nothing new, 10 = extremely new)	7.0 (2.6)
3. How much has the production ecology approach helped with how your Company "thinks" forest productivity in an operational context? (1= not helpful, 10 = extremely helpful)	7.3 (2.4)
4. The production factors examined in BEPP were water, nutrition, uniformity and clonal material. How valuable was this knowledge for: (1 = not valuable, 10 = extremely valuable)	
A. The effect of water	7.5 (2.5)
B. The effect of improved nutrition	6.1 (2.0)
C. The effect of uniformity of tree sizes within stands	8.8 (1.8)
D. The effect of clonal material	6.3 (2.3)
5. During the development of BEPP and related projects, we developed two approaches for extending insights from intensive experiments at individual locations to other areas managed by the companies. How valuable were these two approaches (1 = not valuable, 10 = extremely valuable)	
A. The twin-plot approach to extrapolating across Company lands	9.0 (1.8)
B. The use of ecophysiological models (such as 3-PG) to extrapolate across Company lands.	7.4 (2.4)
6. Overall, how valuable were the Company's participation and investment in BEPP? (1 = not valuable, 10 = extremely valuable)	8.3 (1.8)

robusta proved to be a better nurse species than pines. Campoe and coauthors took a novel approach of applying intensive silvicultural methods (commonly used in *Eucalyptus* plantations) to enhance native forest restoration. Intensive silviculture (including weed control and fertilization) allowed the native forests to achieve canopy closure in just 4 years.

The Porto Seguro workshop showcased the Brazil *Eucalyptus* Potential Productivity (BEPP) Project, where the rotation-long carbon budgets were compiled for sites across Brazil in response to irrigation, fertilization, genetics, and stand structure. Four papers in this issue (by Stape, Ryan, Binkley, Hubbard, and coauthors) examined whole-rotation patterns in forest growth, carbon budgets, resource use efficiency, stand structure and dominance. Current operational practices largely eliminate nutrient deficiencies, but irrigation treatments showed that limited water supplies restrict growth by an average of 30%. The allocation of carbon belowground was remarkably small in these rapidly growing plantations, and irrigation and fertilization had no effect on this portion of the carbon budget. Dominant trees not only intercepted more light, but also used light more efficiently to grow wood; a large part of the age-related decline late in the rotation results from a loss of light use efficiency by non-dominant trees.

The BEPP project exemplified coordinated, collaborative research among forest companies, universities, and government agencies, with investments in research that advanced both science and management. Near the end of the BEPP Project, the companies were surveyed about the value of investing in process-focused research. The lowest rankings were for the contribution of the BEPP Project to improving company practices of fertilization and genetic selection (Table 1), because the companies already benefitted from major investments in research and operations on these topics. The highest ratings of were given for the new insights on the importance of stand structure uniformity, and the twin-plot approach (Stape et al., 2006; Ferreira and Stape, 2009) for extrapolating research results across company lands.

In another decade, the productivity of tropical forest plantations will have increased by another 10–20%. These increases will eventually approach the capacity of biological systems to process environmental resources into wood fiber. The insights provided by the papers in this special issue contribute to the gains in productivity, and the conceptual approaches in these papers provide the maps for narrowing the gap between operational yields and the potential productivity of forested landscapes in the Tropics.

References

Ferreira, J.M., Stape, J.L., 2009. Productivity gains by fertilization in *Eucalyptus urophylla* clonal plantations across gradients in site and stand conditions. Southern Forests 389, 253–258.

Landsberg, J.J., 2003. Physiology in forest models: history and the future. Forest Biometry, Modelling and Information Sciences 1, 49–63.

Oliver, C.D., Larson, B.C., 1990. Forest Stand Dynamics. Wiley, New York.

Puettmann, K.J., Messier, C., Coates, K.D., 2008. A critique of Sliviculture: Managing for Complexity. Island Press, Washington, DC.

Stape, J.L., Binkley, D., Jacob, W.S., Takahashi, E.N., 2006. A twin-plot approach to determine nutrient limitation and potential productivity in *Eucalyptus* plantations at landscape scales in Brazil. Forest Ecology and Management 223, 358–362.

UNFAO, 2000. Outlook Studies—The Global Outlook for Future Wood Supply from Forest Plantations. GFPOS Working Paper #3, Rome, Italy.

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