Meetings

Tropical forests in a warming world

From leaf to biosphere: the effects of a warming climate on tropical forests, an organized oral session at the 96th Annual Meeting, Ecological Society of America in Austin, Texas, USA, August 2011

Global models suggest tropical forests could face significant and unprecedented warming within the next two decades (Diffenbaugh & Scherer, 2011). These findings, combined with evidence that tropical forests may be near a high temperature threshold, suggest that these systems may be more vulnerable to climate change than previously believed (Clark *et al.*, 2003; Doughty & Goulden, 2008). Currently, our ability to predict tropical forest responses to rising temperatures is limited, due in large part to a lack of data on tropical forest and tree processes (Saxe *et al.*, 2001). Given the immense amount of carbon (C) cycled through these forests, even a slight change to tropical net C fluxes could have significant consequences for global C cycling and future climate. The organized oral session *From Leaf to Biosphere: The Effects of a Warming Climate on Tropical Forests* at the 2011 Ecological Society of America meeting in Austin, Texas brought together 10 scientists from a range of fields to synthesize existing data on tropical forest responses to increasing temperature and to facilitate cross-disciplinary dialogue. These scientists presented research and offered perspectives spanning molecular to global scales (Fig. 1). Here, we synthesize the key conclusions.

'While all talks suggested the likelihood that tropical forests will respond to rising temperatures, the emerging theme was a disconcerting lack of data for tropical forests and that we still have much to learn'.

Aboveground tropical forest response to rising temperature

There is much debate about how tropical trees will respond to rising temperatures. Long-term monitoring studies at specific sites in Central American and Asian tropical forests suggest that subtle increases in average temperatures negatively affect tree growth rates (Clark *et al.*, 2003; Feeley *et al.*, 2007), whereas plot network studies in the tropical Amazonia and in Africa show increasing growth rates over the last several decades (Phillips *et al.*, 2004; Lewis *et al.*, 2009). While these long-term and large-scale observational studies are incredibly valuable and offer insight into the functioning of tropical plant communities adapted to a range of temperatures, they often confound multiple climatic, edaphic, and biotic factors, making it difficult to tease apart single drivers of change (Ryan, 2010).

Several speakers (Shaun Cunningham, Monash University, Australia; Michael Ryan, USDA Forest Service, USA; Molly Cavaleri, Michigan Technological University, USA) discussed complementary mechanistic approaches to elucidating plant–temperature relationships in the tropics, and these data suggest that tropical plants are less flexible in their responses to rising temperature than their temperate counterparts. For example, Australian tropical trees demonstrate higher physiological temperature optima but narrower photosynthetic temperature tolerances than temperate tree species (Cunningham & Read, 2002). Molly Cavaleri highlighted how data synthesized from a literature review indicate tropical plant photosynthesis is not likely to acclimate to higher temperatures because of narrow temperature tolerances and increased stomatal closure, but data from the same review suggest plant respiration *will* likely acclimate to elevated temperatures due to substrate limitation.

An emerging theme of the session, highlighted by Molly Cavaleri, Shaun Cunningham, and Michael Ryan, was the importance of measurement scale. For example, different temperature responses are found in leaf-level vs forest canopy-level studies, and patterns in growth are not necessarily predictable from patterns in photosynthetic rate. Michael Ryan also emphasized how we currently lack a basic understanding of how both stored carbohydrates and cell division respond to warmer temperatures, both of which have important roles in regulating future tropical forest C balance. He went on to make the thought-provoking suggestion that we should explore this using a model tree species that is fast growing and small in stature at maturity to help address these unknowns. Model organisms provide powerful approaches to assessing responses for a variety of scientific fields, yet how a model species would be selected and utilized remain open questions.

Shifts in community composition could also affect forest structure and function. Stefan Schnitzer (University of Wisconsin-Milwaukee, USA) presented data showing a dramatic increase in liana abundance in many tropical forests around the world. While the mechanisms behind this phenomenon remain unresolved, lianas can strongly affect the growth and survival of canopy trees, and they store and cycle C differently than the trees they replace. Therefore, understanding such community shifts is critical for predicting future tropical forest diversity and C cycling (Schnitzer & Bongers, 2011).

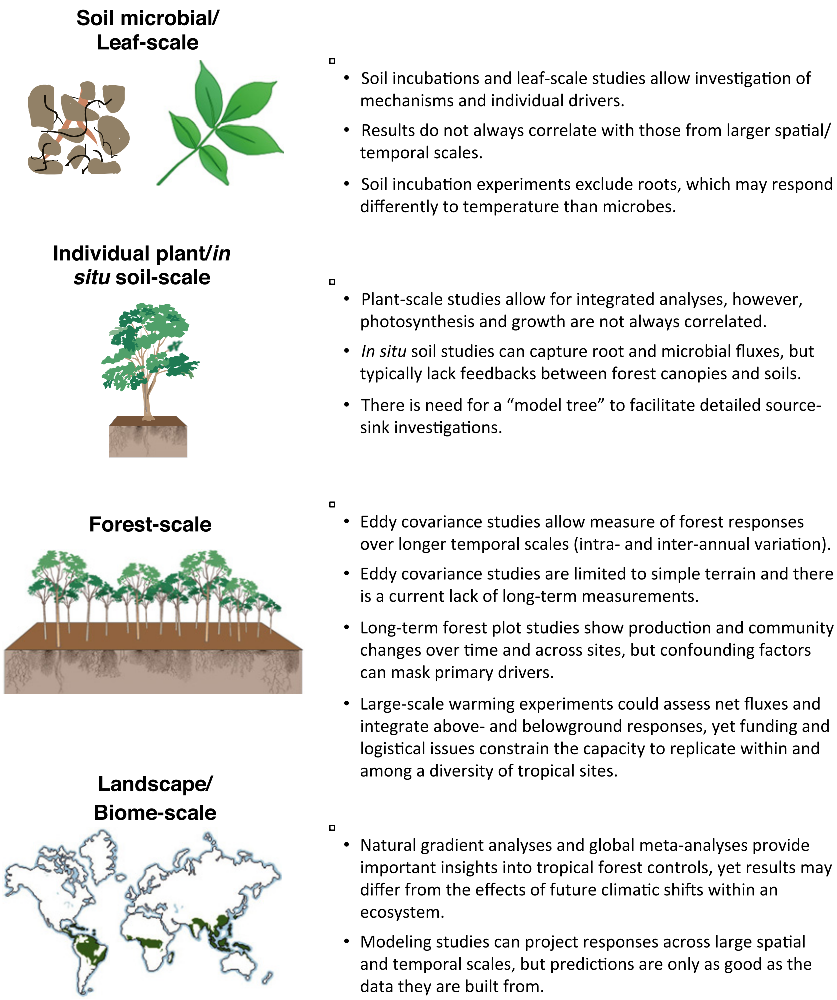

Fig. 1 There are many approaches for investigating tropical forest responses to rising global temperatures, and each approach has important advantages and constraints. Here we outline some central strengths and weaknesses for a variety of approaches that span a wide range of spatial scales. This figure does not offer a comprehensive assessment of approaches, but highlights the idea that engaging in research at all scales – through collaboration, tropical forest networks, etc. – offers a robust way forward for predicting the future of tropical forests in a warming world.

Belowground tropical response to rising temperature

Soils store twice the C found in aboveground biomass, and soil CO_2 fluxes to the atmosphere are around an order of magnitude larger than industrial fluxes (Raich & Potter, 1995; Balser & Wixon, 2009). Thus, understanding soil responses to rising temperatures is critical. In contrast to research suggesting tropical plants are relatively inflexible to changes in temperature, multiple datasets suggest tropical soil organisms are relatively dynamic and resilient (Molly Cavaleri, Michigan Technological University, USA; Joseph Craine, Kansas State University, USA; Devin Wixon presented by A. Peyton Smith, University of Wisconsin-Madison, USA). Work by Wixon and others suggests that microbes in tropical forest soils are more resilient to temperature changes, maintain a larger microbial biomass at higher temperatures, and exhibit elevated respiratory temperature optima compared with temperate soil microbes.

Another emerging theme was the large variability in soil respiration responses to changing temperature. Joseph Craine (Kansas State University, USA) presented a 1-yr incubation of soils from 28 locations and showed a wide range of respiration responses to varying temperatures, both within and among sites. These data suggest that C quality is a primary driver of variability in the temperature sensitivity of microbial respiration (Craine *et al.*, 2010). This large variability in soil respiration responses to temperature has significant implications for predicting tropical soil C loss in a warmer world.

The big picture: net changes to tropical forest C balance

Disconnects between aboveground and belowground responses to rising temperature (e.g. a dynamic soil heterotrophic community and an inflexible plant community) have important implications for net C balance. Collectively, talks highlighted the range of answers that currently exist when addressing the question 'How will tropical forest C balances respond to rising temperatures?' Modeling efforts show decreased net primary productivity (NPP) and a loss of soil C with rising night-time temperatures in a Costa Rican rain forest (Ann Russell, Iowa State University, USA). Similarly, an Amazonian eddy covariance study found a decline in net CO_2 uptake during a warm, dry year but an increase in a cool, dry year and suggests a temperature-regulated decline in respiration during the cooler year (George Vourlitis, California State University, USA). By contrast, a tropical forest meta-analysis (Cory Cleveland, University of Montana, USA) found aboveground NPP to increase with mean annual temperature and decreasing elevation (Cleveland *et al.*, 2011). Yadvinder Malhi and others (presented by Chris Doughty, University of Oxford, UK) also found that aboveground gross primary production (GPP) and NPP increased with increasing temperature along an elevation gradient in Perú and, surprisingly, there was little change in C allocation or C use efficiency.

The modeling, meta-analysis, and elevational transect studies (described earlier) all explored soil nutrient cycling and suggest that interactions between temperature and nutrient availability could play a vital role in regulating tropical forest response to warming. However, both Michael Ryan (USDA Forest Service, USA) and Molly Cavaleri (Michigan Technological University, USA) commented that while site-comparison studies are indeed valuable, comparing across sites is not the same as perturbing a system away from a 'native' temperature. Ryan, Cavaleri and Cory Cleveland (University of Montana, USA) all put forth the idea that experimentally warming a tropical site would greatly help address these issues.

Key conclusions and future challenges

While all talks suggested the likelihood that tropical forests will respond to rising temperatures, the emerging theme was a disconcerting lack of data for tropical forests and that we still have much to learn. Each of the research approaches (e.g. natural gradients, small-scale mechanistic approaches, modeling) lends important depth to our understanding, but also has its own limitations and constraints (Fig. 1). As such, our ability to determine tropical forest responses to increased temperature will require a variety of research approaches used in concert. Large-scale warming experiments are clearly essential to directly addressing this important question and would act as a complement (not as a substitute) to diverse experiments at a variety of sites. Overall, determining the temperature responses of tropical forests at a range of scales and from a variety of perspectives is critical to our evaluation of future climate.

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