

- Howe GT, Aitken SN, Neale DB, Jermstad KD, Wheeler NC, Chen THH. 2003. From genotype to phenotype: unraveling the complexities of cold adaptation in forest trees. *Canadian Journal of Botany* 81: 1247–1266.
- Jorge V, Dowkiw A, Faivre-Rampant P, Bastien C. 2005. Genetic architecture of qualitative and quantitative *Melampsora larici-populina* leaf rust resistance in hybrid poplar: genetic mapping and QTL detection. *New Phytologist* 167: 113–127.
- Kawecki TJ, Ebert D. 2004. Conceptual issues in local adaptation. *Ecology Letters* 7: 1225–1241.
- Lolle SJ, Victor JL, Young JM, Pruitt RE. 2005. Genome-wide non-mendelian inheritance of extra-genomic information in *Arabidopsis*. *Nature* 434: 505–509.
- Lynch M, Conery JS. 2003. The origins of genome complexity. *Science* 302: 1401–1404.
- Lynch M, Katju V. 2004. The altered evolutionary trajectories of gene duplicates. *Trends in Genetics* 20: 544–549.
- Man H, Boriel R, El-Khatib R, Kirby EG. 2005. Characterization of transgenic poplar with ectopic expression of pine cytosolic glutamine synthetase (GS1a) under conditions of varying nitrogen availability. *New Phytologist* 167: 31–39.
- Mauricio R. 2001. Mapping quantitative trait loci in plants: uses and caveats for evolutionary biology. *Nature Reviews Genetics* 2: 370–381.
- McKay JK, Richards JH, Mitchell-Olds T. 2003. Genetics of drought adaptation in *Arabidopsis thaliana*. I. Pleiotropy contributes to genetic correlations among ecological traits. *Molecular Ecology* 12: 1137–1151.
- Monclus R, Dreyer E, Delmotte FM, Villar M, Delay D, Boudouresque E, Petit J-M, Marron N, Bréchet C, Brignolas F. 2005. Productivity, leaf traits and carbon isotope discrimination in 29 *Populus deltoides* × *P. nigra* clones. *New Phytologist* 167: 53–62.
- Morgenstern EK. 1996. Geographic variation in forest trees: genetic basis and application of knowledge in silviculture. Vancouver, BC, Canada: UBC Press, University of British Columbia.
- Neale DB, Savolainen O. 2004. Association genetics of complex traits in conifers. *Trends in Plant Science* 9: 325–330.
- Orr HA. 1998. The population genetics of adaptation: the distribution of factors fixed during adaptive evolution. *Evolution* 52: 935–949.
- Orr HA. 2003. The distribution of fitness effects among beneficial mutations. *Genetics* 163: 1519–1526.
- Paux E, Carocha V, Marques C, de Sousa AM, Borralho N, Sivadon P, Grima-Pettenati J. 2005. Transcript profiling of *Eucalyptus* xylem genes during tension wood formation. *New Phytologist* 167: 89–100.
- Pot D, McMillan L, Echt C, Le Provost G, Garnier-Géré P, Cato S, Plomion C. 2005. Nucleotide variation in genes involved in wood formation in two pine species. *New Phytologist* 167: 101–112.
- Schluter D. 2001. Ecology and the origin of species. *Trends in Ecology and Evolution*. 16: 372–380.
- Soltis PS. 2005. Ancient and recent polyploidy in angiosperms. *New Phytologist* 166: 5–8.
- Stenøien HK, Fenster CB, Kuittinen H, Savolainen O. 2002. Quantifying latitudinal clines to light responses in natural populations of *Arabidopsis thaliana* (Brassicaceae). *American Journal of Botany* 89: 1604–1608.
- Sterck L, Rombauts S, Jansson S, Sterky F, Rouzé P, Van de Peer Y. 2005. EST data suggest that poplar is an ancient polyploidy. *New Phytologist* 167: 165–170.
- Taylor G, Street NR, Tricker PJ, Sjödin A, Graham L, Skogström O, Calfapietra C, Scarascia-Mugnozza G, Jansson S. 2005. The transcriptome of *Populus* in elevated CO₂. *New Phytologist* 167: 143–154.
- Wang X, Shi X, Hao B, Ge S, Luo J. 2005. Duplication and DNA segmental loss in the rice genome: implications for diploidization. *New Phytologist* 165: 937–946.
- Wright SI, Gaut BS. 2004. Molecular population genetics and the search for adaptive evolution in plants. *Molecular Biology and Evolution* 22: 506–519.
- Zhang J, Steenackers M, Storme V, Neyrinck S, Van Montagu M, Gerats T, Boerjan W. 2001. Fine mapping and identification of nucleotide binding site/leucine-rich repeat sequences at the *MER* locus in *Populus deltoides* 'S9-2'. *Phytopathology* 91: 1069–1073.

Key words: adaptation, ecological physiology, genetic variation, genome evolution, genomics, model plant species, phenotypic plasticity, speciation.

Meetings

Challenges to plant mega-diversity: how environmental physiology can help

Environmental Physiology and Plant Diversity in Mexico: From Molecules to Ecosystems. A symposium within the XVI National Botanical Congress, Sociedad Botánica de México, Oaxaca, Mexico, October 2004

Mexico is one of the 12 megadiverse countries that together contain about half of the world's biodiversity. Specifically,

nearly 10% of known vascular plant species can be found in Mexico, owing to its intricate topography that leads to numerous microenvironments, and to the convergence of Nearctic and Neotropical biotas in this country (Neyra González & Durand Smith, 1998). A corresponding botanical knowledge has also emerged in Mexico throughout its history, contributing with the domestication of universally important plants such as bean, cacao, maize and tomato. Unfortunately, the southern Mexican states, which are the most biodiverse, are the ones facing the nation's highest rates of deforestation and the gravest hindering of socio-economic development. Thus, a pressing need for understanding the mechanisms leading to species persistence emerges simultaneously with an urgency to implement management

practices that make conservation compatible with development. In this context, the XVI National Botanical Congress considered the 'scientific and conservation challenges in a megadiverse country'. Some examples of how environmental physiology can address such challenges were discussed during the symposium.

'Because environmental productivity indices can help predict plant responses in productivity to different environmental factors, they can be utilized to evaluate different scenarios of global climate change'

From seedlings of endemic cacti to global environmental change

Cacti are emblematic of Mexico. This is reflected in many cultural aspects including the national seal, depicting an eagle perched on an opuntia, and even those stereotypical Hollywood allegories featuring a columnar cactus as a source for shade. In fact, Mexico is the center of origin and diversification for many cactus genera. Particularly, Oaxaca, the state where the meeting was held, contains the highest cactus diversity within the country. Also, perhaps most readers will not be familiar with the fact that opuntias, another contribution of the Mexican flora, are the most extensively cultivated crassulacean acid metabolism (CAM) plant worldwide, greatly exceeding the area dedicated to the better-known pineapple (Nobel, 2000).

Some cacti have C₃ metabolism after germinating and acquire CAM later during their development (Altesor *et al.*, 1992). For over a decade it has been thought that this could be the case for most cactus species, but recent studies have revealed a somewhat different story (Olivia Hernández-González & Oscar Briones, Instituto de Ecología, Xalapa, Ver., Mexico). It turns out that some columnar cacti from the tribe Pachycereeae and at least one barrel cactus from the tribe Echinocacteeae are CAM obligates; their seedlings always present a nocturnal build-up of organic acids following germination, although the amount accumulated does respond to light and water.

Approximately 700 out of *c.* 2000 known species of cacti occur in Mexico, 40% of which have government protection (NOM-ECOL-059-2001; <http://www.ine.gob.mx/ueajei/norma59a.html>). Because most of these cacti are endemic, they are especially threatened by changes in land use. This is the case for *Mammillaria gaumeri* (Britton & Rose), a small globose cactus restricted to coastal sand dunes (very valuable beach-front land) and tropical dry forests from

the northern Yucatan peninsula (Leirana-Alcocer & Parra-Tabla, 1999). Conservation efforts regarding *M. gaumeri* include the identification of favorable sites for its reintroduction following *ex situ* propagation. In particular, the responses in productivity to various microenvironmental factors, such as air temperature, photosynthetic photon flux and soil water potential, are being characterized for this species (Carlos Cervera, Centro de Investigación Científica de Yucatán, Mérida, Yuc., Mexico) to generate an environmental productivity index (EPI; Nobel, 1988). This is the first time that an EPI has been created for use in conservation.

Because EPIs can help predict plant responses in productivity to different environmental factors, they can be utilized to evaluate different scenarios of global climate change. For instance, plant responses to increasing air temperature could be estimated and areas most vulnerable to invasion by exotic species could be identified. One cause of global warming is the postindustrial increase in atmospheric CO₂ concentration. In general, higher CO₂ concentrations lead to higher plant productivities. An important caveat is that not all plants have the same response. Rapid-growth species are likely to be more sensitive than slow-growth species. This could result in shorter residence time for carbon in tropical forests because fast growing species also tend to be short-lived (Körner, 2003). For instance, lianas from the tropical forests of Yucatan show a considerably enhanced productivity under elevated CO₂ (Granados & Körner, 2002). Because lianas can affect the productivity of trees (Granados & Körner, 2002; Schnitzer & Bongers, 2002), which are the actual carbon sinks of forests (Körner, 2003), a net effect of increased atmospheric CO₂ is that tropical forests may eventually become carbon sources rather than sinks (Julián Granados, Centro de Investigación Científica de Yucatán, Mérida, Yuc., Mexico). Thus, the responses to elevated CO₂ by various functional types need to be considered when making estimates of carbon cycles at large scales. Furthermore, lianas play an integral role in several aspects of tropical forest dynamics, including a contribution to whole-plant transpiration (Schnitzer & Bongers, 2002; Andrade *et al.*, 2005). However, studies about the physiology of lianas and co-occurring trees are uncommon.

Stable 'iso-tropical' ecology

Over the last three decades, stable isotope studies have become a common part of physiological ecology in order to gain insight about various functional aspects of plant biology, including photosynthetic metabolism and water use by individual plants and by whole ecosystems (Dawson *et al.*, 2002). An area of current vigorous research using stable isotopes in plant ecophysiology is that of tracing the movement and utilization of water at various scales. For instance, variation of the natural isotopic composition of the various water compartments for an ecosystem can help

identify various ecological processes by separating the different water sources for plants in space and time. One difficulty for such studies is the procurement of water samples from the deeper layers of the soil. In most cases, such a sampling requires the efforts of a very strong graduate student using a soil borer. This task becomes even more complicated at places where, like in Yucatan, a calcareous hardpan occurs rather superficially. Nevertheless, the Yucatan peninsula also has numerous *cenotes* (singular, *cenote*), subterranean water deposits that had religious significance for the Maya. By using stable isotope tracers, *cenotes* provide a unique system for detailed accounting of potential water sources for tropical trees. In particular, preliminary work from a tropical dry forest of northern Yucatan revealed that perennial trees have access to *cenote* water, whereas deciduous trees do not (Paula C. Jackson, Kennesaw State University, Kennesaw, GA, USA). Proximity to caves has also allowed very detailed studies of water use for trees from North American temperate forests (McElrone *et al.*, 2004).

Legumes, especially shrubs and trees, tend to dominate the vegetation in tropical arid and semiarid regions of America and Africa. It is not surprising, then, that about 10% of the 20 000 known species in the Fabaceae are found in Mexico (again, Oaxaca, along with Chiapas, has the greatest legume diversity in Mexico; Sousa & Delgado, 1993; Doyle & Luckow, 2003), where just over half of the territory is arid or semiarid (Neyra González & Durand Smith, 1998). Soils from arid lands tend to be nutrient-poor, hinting that the success of legumes may be a result of the symbiotic association with nitrogen-fixing bacteria found for most species in the family (Doyle & Luckow, 2003). For tropical dry forests in the Yucatan, 21 out of 23 legume trees were nitrogen fixers, as indicated by the presence of root nodules (Louis Santiago & Todd Dawson, University of California, Berkeley, CA, USA). The contribution of biologically fixed nitrogen to the nitrogen budget of legumes can be evaluated with the nitrogen isotopic composition of leaf tissue. Indeed, biologically fixed nitrogen in trees from tropical dry forests of Yucatan tended to increase with the age of tree stands. It ranged from about 10% for 5- to 10-yr-old stands to twice as much for 20- to 30-yr-old stands. It became apparent that availability of biologically fixed nitrogen favors the higher photosynthetic rates observed for nitrogen-fixing species compared to those observed for nonfixing species.

Conclusions and Perspectives

Physiological research aims to explain the mechanisms by which plants adapt and persist in a given environment within an ecosystem. Questions of interest occur at various scales, from the spontaneous diffusion of solutes at the subcellular level (De la Barrera, 2005), to whole plant processes (Jackson *et al.*, 1999), and to ecosystem and global scales (Körner, 2003). Technological advances

leading to portable instruments have greatly contributed to the advance of ecophysiological knowledge. Nevertheless, despite the great diversity of plants and ecosystems in Mexico, studies about physiological ecology are relatively incipient in this country. Participants and attendants to the symposium committed to encourage the organization of at least three environmental physiology symposia for the next National Botanical Congress (in 2007) about CAM, stable isotopes and biological interactions. A considerably sized cohort of graduate students is nearing the completion of their PhD in several ecophysiological laboratories in Mexico. Their professional careers will surely improve our understanding of the mechanisms responsible for the impressively diverse Mexican flora.

Acknowledgements

We thank the SBM board, especially Drs Victoria Sosa and Helga Ochoterena, for facilitating the organization of the Environmental Physiology Symposium; the presenters for sharing their ongoing research; useful discussions with Drs Alfonso Delgado and Joel Flores, as well as with Rafael Bello and Enrico Yopez; and funding by a UC MEXUS postdoctoral research fellowship to E.D.I.B. and by a CONAFOR-CONACYT grant (9765) to J.L.A.

Erick De la Barrera^{1*} and José Luis Andrade²

¹Departamento de Investigaciones Científicas y Tecnológicas, Universidad de Sonora, Hermosillo, Sonora, Mexico; ²Unidad de Recursos Naturales, Centro de Investigación Científica de Yucatán, Mérida, Yucatán, Mexico

(*Author for correspondence: tel +52 6622592169; fax +52 6622592197; email erickdlb@ucr.edu)

References

- Altesor A, Ezcurra E, Silva C. 1992. Changes in the photosynthetic metabolism during the early ontogeny of four species. *Acta Oecologica* 13: 777–785.
- Andrade JL, Meinzer FC, Goldstein G, Schnitzer S. 2005. Water uptake and transport in lianas and co-occurring trees of a seasonally dry tropical forest. *Trees: Structure and Function*. doi:10.1007/s00468-004-0388-x
- Dawson TE, Mambelli S, Plamboeck AH, Templer PH, Tu KP. 2002. Stable isotopes in plant ecology. *Annual Review of Ecology and Systematics* 33: 507–559.
- De la Barrera E. 2005. On the sesquicentennial of Fick's laws of diffusion. *Nature Structural and Molecular Biology* 12: 280.
- Doyle JJ, Luckow MA. 2003. The rest of the iceberg: Legume diversity and evolution in a phylogenetic context. *Plant Physiology* 131: 900–910.
- Granados J, Körner C. 2002. In deep shade, elevated CO₂ increases the vigor of tropical climbing plants. *Global Change Biology* 8: 1109–1117.

- Jackson PC, Meinzer FC, Bustamante M, Goldstein G, Franco A, Rundel PW, Caldas L, Iglar E, Causin F. 1999. Partitioning of soil water among tree species in a Brazilian Cerrado ecosystem. *Tree Physiology* **19**: 717–724.
- Körner C. 2003. Slow in, rapid out – Carbon flux studies and Kyoto targets. *Science* **300**: 1242–1243.
- Leirana-Alcocer J, Parra-Tabla V. 1999. Factors affecting the distribution, abundance and seedling survival of *Mammillaria gaumeri*, an endemic cactus of coastal Yucatán, México. *Journal of Arid Environments* **41**: 421–428.
- McElrone AJ, Pockman WT, Martínez-Vilalta J, Jackson RB. 2004. Variation in xylem structure and function in stems and roots of trees to 20 m depth. *New Phytologist* **163**: 507–517.
- Neyra González L, Durand Smith L. 1998. Biodiversidad. In: CONABIO. *La Diversidad Biológica en México: Estudio de País, 1998*. Mexico City, Mexico: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.
- Nobel PS. 1988. *Environmental Biology of Agaves and Cacti*. New York, USA: Cambridge University Press.
- Nobel PS. 2000. Crop ecosystem responses to climatic change: Crassulacean acid metabolism crops. In: Reddy KR, Hodges HF, eds. *Climate Change and Global Crop Productivity*. New York, USA: CABI Publishing, 315–331.
- Schnitzer SA, Bongers F. 2002. The ecology of lianas and their role in forests. *Trends in Ecology and Evolution* **17**: 223–230.
- Sousa M, Delgado A. 1993. Mexican Leguminosae: Phytogeography, endemism, and origins. In: Ramamoorthy TP, Bye R, Lot A, Fa J, eds. *Biology Diversity of Mexico: Origins and Distribution*. New York, USA: Oxford University Press, 459–511.
- Key words:** conservation, crassulacean acid metabolism (CAM), ecophysiology, environmental productivity index (EPI), global change, nitrogen fixation, plant megadiversity, stable isotope.



About New Phytologist

- *New Phytologist* is owned by a non-profit-making **charitable trust** dedicated to the promotion of plant science, facilitating projects from symposia to open access for our Tansley reviews. Complete information is available at www.newphytologist.org.
- Regular papers, Letters, Research reviews, Rapid reports and both Modelling/Theory and Methods papers are encouraged. We are committed to rapid processing, from online submission through to publication 'as-ready' via *OnlineEarly* – the 2004 average submission to decision time was just 30 days. Online-only colour is **free**, and essential print colour costs will be met if necessary. We also provide 25 offprints as well as a PDF for each article.
- For online summaries and ToC alerts, go to the website and click on 'Journal online'. You can take out a **personal subscription** to the journal for a fraction of the institutional price. Rates start at £109 in Europe/\$202 in the USA & Canada for the online edition (click on 'Subscribe' at the website).
- If you have any questions, do get in touch with Central Office (newphytol@lancaster.ac.uk; tel +44 1524 592918) or, for a local contact in North America, the US Office (newphytol@ornl.gov; tel +1 865 576 5261).