Given the high diversity found in most ectomycorrhizal fungal communities, examining functional differences among species is important to integrate the parts of the aforementioned ecological hierarchy (Koide *et al.*, 2007). Jean Garbaye (INRA, Nancy, France) presented recent work linking taxonomic diversity with the diversity of enzymatic activity associated with individual ectomycorrhizal root tips. The method assays individual excised root tips for multiple enzymatic activities with a microtiter dish format (Courty *et al.*, 2005). At the community level, Garbaye demonstrated that rare ectomycorrhizal species often contributed disproportionately to total enzymatic activity, indicating their potential importance for ecosystem functioning. He also showed that enzyme activity varied considerably within species depending on environmental conditions, soil depth and time of year. A major attraction of this assay is that it has a very high throughput; however, the removal of extraradical hyphae during tip preparation creates an artifact that complicates comparisons among species. An alternative way to assay enzymatic activity under field conditions was presented by Brooks *et al.* (University of British Columbia, Canada) in a poster. This technique involved taking an imprint of the enzymes from a soil profile onto a membrane, assaying the activity of selected enzymes (in this case phosphatase) and correlating it with the ectomycorrhizal fungi or other organisms present at that particular point in the soil. While this method allows one to assay the contributions of extramatrical hyphae along with other soil organisms, it is not well suited to the same high-throughput analyses that the excised tip method offers. Thus, like other methods in this field, these approaches provide useful, but limited, views into this complex symbiosis.

The small meeting format and the limited number of talks provided many opportunities for lively discussions. These were enhanced by the frequent comments from Sir David Read (University of Sheffield, UK), whose voluminous work on mycorrhiza laid the foundation for much of the current research (Alexander, 2007). Overall, the continuity between past and present, methods and theory, and opinions and data made this meeting a productive step towards the future in this vibrant field. The program and the abstracts are available on the web for those who were unable to attend (http://www.newphytologist.org/mycorrhizal/default.htm).

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Key words: community, ecology, ectomycorrhiza, fungi, genetics, population.

Mycorrhizas in tropical forests: a neglected research imperative

Mycorrhizas in Tropical Forests, a workshop held at Universidad Técnica Particular de Loja (UTPL), Loja, Ecuador September, 2008

Mycorrhizal research in tropical forest has a long history. Janse's (1896) paper of 'Les endophytes radicaux de quelques

plantes javanaises' was published a mere 11 years after Frank (1885) first coined the term 'mycorhiza'. It contains not only some of the first accurate depictions of arbuscular, orchid and ericoid mycorrhizas, but also detailed descriptions of the mycorrhizas of both orchidaceous and nonorchidaceous myco-heterotrophic plants. Even in Janse's time, the presence of many different mycorrhizal interactions on co-existing, but phylogenetically distant, tropical forest plants was apparent. Inexplicably, given the ecological and economic importance of tropical forest, and the probable role of mycorrhizas in maintaining their biodiversity and productivity (Alexander & Lee, 2005), the mycorrhizas of tropical forest plants did not attract much attention in the next 100 years. Indeed, even in this century, only 170 of the 5600 papers published on mycorrhizas since 2000 refer explicitly to tropical forest (Fig. 1). However, things may be about to change, as the attention of mycorrhizal researchers turns belatedly to the threats to biodiversity in tropical forests, their importance in understanding the evolution and biogeography of mycorrhizal fungi and their pivotal role in the earth's carbon cycle and climate system (Gilbert & Strong, 2007). The workshop on 'Mycorrhizas in Tropical Forests' held in Loja, Ecuador, September 2008, was therefore particularly timely. Twenty-six participants from 12 countries attended the workshop, which included presentations, poster sessions, field excursions and many free-ranging discussions. Abstracts of all the talks and posters, and details of the participants, can be found on the website (http://www.mycorrhiza-research.de/Workshop/01Welcome.html).

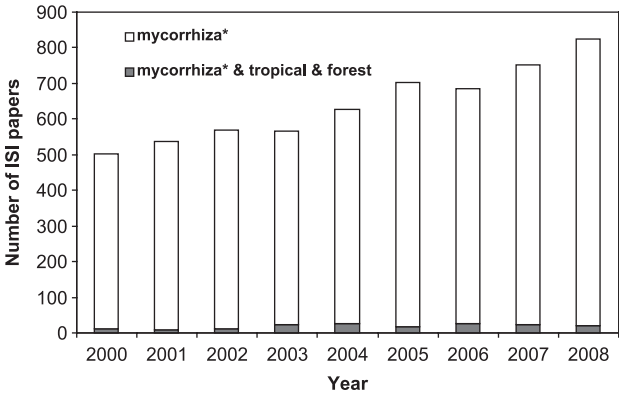

Fig. 1 The number of ISI journal papers from 2000 to 2008 dealing with mycorrhizas in tropical forest (search string: mycorrhiza* & tropical & forest), compared with the total mycorrhizal literature (search string: mycorrhiza*).

'... we know that mycorrhizal fungal communities in undisturbed tropical forest can be complex and species rich, we do not understand how important that complexity is to forest diversity, productivity and resilience.'

In his opening lecture, Ian Alexander (University of Aberdeen, UK) introduced four broad themes: the link between mycorrhizal fungal community composition and ecosystem processes; the biogeography of tropical mycorrhizas; the importance of fungal taxonomy; and the challenge of demonstrating the relevance of mycorrhizal fungal diversity to forest resilience and restoration. There followed much debate about the relative importance of biotic and edaphic factors in determining the composition of mycorrhizal fungal communities of tropical trees, and the significance of fungal community composition to the composition of tree regeneration. Scott Mangan (Smithsonian Tropical Research Institute, Panama) showed that spatial differences in arbuscular mycorrhizal fungal (AMF) communities affected the composition of tree seedling communities in Panama and that there were strong feedbacks between hosts and AMF fungi. Jean Weber (Institute of Tropical Forestry and Forest Products, University Putra Malaysia) used spatial statistics to show an inverse relationship between the density of ectomycorrhizal (ECM) *Shorea* seedlings and the density of parents in Malaysian dipterocarp forest. Amadou Bâ (Université des Antilles et de la Guyane, Guadeloupe) demonstrated how AMF increase the flooding tolerance of the wetland tree *Pterocarpus officinalis* Jacp. in Guadeloupe.

A number of participants highlighted how tropical forest studies can shed new light on the biogeography and evolution of mycorrhizal fungi (Thelephorales, Leho Tedersoo (University of Tartu, Estonia)); Sebacinales, Sabrina Setaro (Wake Forest University, NC, USA); Tulasnellales, Juan Pablo Suarez (Universidad Técnica Particular des Loja, Ecuador) and their hosts (Dipterocarpaceae, Bernard Moyersoen (Université de Liège, Belgium); Orchidaceae, Tupac Otero (Universidad Nacional de Colombia, Colombia)). There was wide-ranging discussion of the need for, value of and optimization of automated taxonomic methods to deal with the plethora of new, insufficiently identified, fungal sequences that are likely to result from increased environmental sampling in tropical forest (Markus Göker, Eberhard-Karls-University Tübingen, Germany), and the particular problems of, and ways to resolve, species recognition in AMF were highlighted (Arthur Schüssler, Ludwig-Maximilians-University Munich, Germany).

The enduring fascination of myco-heterotrophic plants was much in evidence. Stephan Imhof (University Marburg, Germany) showed how painstaking three-dimensional reconstruction reveals the complex ways in which nonphotosynthetic hosts manipulate development of AMF. Marc-André Selosse

(CEFE-CNRS, Université Montpellier II, France) hypothesized that higher availability of photosynthates for tropical ECM fungi leads to the reduced specificity he found in tropical mycoheterotrophic orchids; in the absence of suitable ECM fungi, saprobic fungi may even be sufficiently active under hot and wet conditions to act as carbon sources. Ingrid Kottke (Eberhard-Karls-University Tübingen, Germany) and her team demonstrated elegantly how careful morphological/anatomical studies on tropical plants coupled with molecular information can challenge our concepts of what constitutes an arbuscular, ecto- or ericoid mycorrhiza.

While tropical forests can still yield new and unexpected aspects of mycorrhizal biology, many questions fundamental to the very existence of the forest remain unanswered. For example, although we know that mycorrhizal fungal communities in undisturbed tropical forest can be complex and species rich, we do not understand how important that complexity is to forest diversity, productivity and resilience. Similarly, although we know that logging and forest conversion reduce fungal diversity, we have no hard evidence that reconstructing that diversity is important for restoration, or indeed how long it might take for the original community to reform. It was encouraging therefore that several participants addressed the potential for the practical application of mycorrhizal research in a range of locations (María Díez (Universidad Nacional de Colombia, Colombia) in Colombia; Tesfaye Wubet (Helmholtz Centre for Environmental Research, Halle, Germany) in Ethiopia; Ingeborg Haug (University Tübingen, Germany) in Ecuador; and Laura Aldrich-Wolfe (North Dakota State University, USA) in Costa Rica).

Loja proved to be an ideal location for the workshop, both for its ready access to the mega-diverse montane tropical rain forest and páramo of Southern Ecuador, and the example it provided of the benefits of international collaboration, as shown by the wealth of information emerging from this ecosystem as a result of the research programme on mycorrhizas in tropical forest established by Ingrid Kottke (Eberhard-Karls-University Tübingen, Germany) and Juan Pablo Suarez (Universidad Técnica Particular des Loja, Loja, Ecuador).

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Key words: biodiversity, fungal biogeography, fungal communities, mycorrhiza, tropical forest.