Preface
Ants and Plants: A Prominent Interaction in a Changing World

The chief enemy of an ant is another ant.
This is the measure of the ants' success.
It is true of only one other living creature – man.
Derek W. Morley 1953

In the end, I suspect it will all come down to a decision of ethics – how we value the natural worlds in which we evolved and now, increasingly, how we regard our status as individuals.
Edward O. Wilson 1988

Ants and flowering plants are dominant in most terrestrial ecosystems, and their evolutionary histories have been crossing paths for at least 100 million years (Wilson & Hölldobler 2005). The study of ant-plant interactions has increased markedly over the past century with the monographs by Bequart (1922) and Wheeler (1942), but most especially in the past 50 years since Daniel Janzen's pioneering experimental work on the Central American ant-inhabited acacias (Janzen 1966). During this time, different aspects of the natural history and evolutionary ecology of ant-plant systems have been highlighted in a number of books (Buckley 1982; Beattie 1985; Huxley & Cutler 1991; Gorb & Gorb 2003; Rico-Gray & Oliveira 2007; Hölldobler & Wilson 2010).

Research on ant-plant interactions comprises a wide range of topics, including plant defense, pollination, seed dispersal, damage by leaf-cutting ants, seed predation, ant-fed plants, the association of ants with trophobionts (exudate-producing insect herbivores), applied ant ecology (as related to agriculture and restoration), and all forms of combinations among these subjects. Ant-plant interactions are geographically widespread and have already been studied in many types of terrestrial communities. Indeed, they offer an excellent opportunity to investigate the effects of both historical and ecological factors (including global change) on the evolution of mutualistic as well as antagonistic ant-plant systems (Heil & McKey 2003). Most interspecific interactions, however, are highly facultative, and the diversity of species involved in ant-plant associations can vary considerably even over short geographic ranges, suggesting that a landscape approach should be employed when investigating such interaction systems (Bronstein 2015). Our understanding of the ecology and evolution of ant-plant interactions and their effects on community organization requires an assessment of how the diversity of ants and their use

of plants varies across regions, landscapes, habitat gradients, and, most importantly, under the effect of different patterns of global change (Kiers et al. 2010).

The Problem

In the past few decades human activities have altered and degraded natural environments at an unparalleled speed and scale. With the continual loss of global biodiversity, current ecological research has focused on assessing the factors that cause species loss as well as on the ways through which ecosystem functioning can be assured (Ellis 2015). Given that current biodiversity is the product of diversification of both species and the interactions among them, conservation programs need to put increased emphasis on the preservation not only of species but also of their interactions (Price 2002). Thus the knowledge that a species is present or absent is not sufficient to predict its impact on communities and ecosystems. Not only are species unevenly distributed, but their interactions also vary along environmental gradients and under different disturbance regimes. In the past few decades it has become increasingly apparent that the outcome of interspecific interactions may vary not only under different ecological conditions and across habitats, but also according to human impact and global change (Tylianakis et al. 2008).

Habitat disturbance and change are significant threats to the functioning of communities and ecosystems since they may not only alter the outcome of interspecific interactions, including ant-plant mutualisms, but also may make them vulnerable to colonization by opportunistic invasive species (Ness & Bronstein 2004). Accumulated evidence from recent decades has demonstrated that human activities can affect the habitats where ants (and plants) live in diverse ways, including deforestation and/or fragmentation, urbanization, agriculture, pasture, soil, fire, land management, and climate change (Andersen & Majer 2004). The effects of anthropogenic disturbance on ant communities may include loss of diversity, change in species composition, change in interspecific interactions, change in trophic interactions with plants and insect herbivores, as well as alterations in ant-derived ecosystem services such as seed dispersal, plant protection, and soil productivity (Lach et al. 2010). Although ant-plant mutualisms have evolved in spatially and temporally variable environments, little is known about the degree of resilience of these associations in the face of the current global changes and man-induced disturbances.

Scope of This Book

This volume is about man-induced effects on the interactions between two major components of terrestrial ecosystems: ants and plants. The book is broad in scope and is aimed at raising relevant ecological questions from an array of topics within ant-plant interactions in altered habitats around the world. Chapters provide an

in-depth summary of current understanding for researchers already acquainted with general insect-plant interactions, and a window into the ecology of ant-plant interactions for the mostly uninitiated international community. We hope that this volume will serve as an important resource for undergraduate and graduate students in conservation biology and its applications, as well as working conservationists and natural resource managers around the globe. The research-level text is suitable to readers from a wide range of backgrounds, including basic and applied entomologists, botanists, behavioral, evolutionary, and applied ecologists, agronomists, conservationists, and landscape managers. This book brings together research from a variety of regions and environments worldwide, including South, Central, and North America, Africa, Japan, Polynesia, Indonesia, and Australia. Agricultural systems from regions apart are also treated in the volume since they have extensively reshaped natural landscapes, modifying the number and types of interspecific interactions compared to those present in natural ecosystems. A number of chapters included in this book were presented in the Symposium on "Ant-Plant Interactions in a Changing World" that took place at the XXV International Congress of Entomology, held in Orlando (Florida, USA) in September 2016.

We aimed for a worldwide assessment of man-induced effects on ant-plant interactions, incorporating a diversity of approaches that range from landscape levels to finer scales of interactions and processes. Although we have organized the book into six parts in accordance with the scale and/or type of interactions, the reader will often make connections between and among parts given the complexity and interdependence of ecological processes at various levels. Part I deals with the major effects of habitat heterogeneity (vegetation mosaics), fragmentation, and plantations on arboreal and ground ant communities, ant functional groups, and on the multiple impacts of leaf-cutting ants on vegetation. Part II examines man-induced effects (e.g., climate change, grazing, fire, fragmentation, human settlements) on primary and secondary seed dispersal by ants in temperate forests and neotropical ecosystems. Part III addresses how facultative and obligate ant-plant protective mutualisms are affected by habitat heterogeneity and human disturbance in temperate and tropical habitats. Topics include species producing ant-attractants (and their variable quality), plasticity in defense strategies against herbivory (mediated or not by visiting ants), complex obligate ant-plant systems affected by vertebrate defaunation, and evolutionary responses of ant-plant systems to global change. Part IV examines the effect of invasive ant species on interaction systems involving native ants, insect trophobionts, associated herbivores, flower visitors, and plants. The topic is addressed in relation to ant-plant systems in continental and insular habitats. Part V applies the accumulated knowledge on ant-plant-herbivore interactions from natural ecosystems in insect pest management programs of agricultural systems. Potential ecosystem services (and disservices) provided by ants in the recovery of human-modified landscapes are also treated. Part VI provides an overview of the major challenges created by global changes on interspecific interactions, particularly ant-plant mutualisms (obligate and facultative), pointing out evolutionary consequences, promising avenues of investigation embracing both

fundamental and applied aspects of ant-plant interactions, and possible strategies and approaches to maintain viable conserved communities.

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References

Andersen, A. N. & Majer, J. D. (2004). Ants show the way down under: invertebrates as bioindicators in land management. *Frontiers in Ecology and the Environment*, 2, 291–8.

Beattie, A. J. (1985). *The Evolutionary Ecology of Ant-Plant Mutualisms*. Cambridge University Press, Cambridge.

Bequaert, J. (1922). Ants in their diverse relations to the plant world. *Bulletin of the American Museum of Natural History*, 45, 333–621.

Bronstein, J. L. (editor). (2015). *Mutualism*. Oxford University Press, Oxford.

Buckley, R. C. (1982). *Ant-Plant Interactions in Australia*. Dr. W. Junk, The Hague.

Ellis, E. C. (2015). Ecology in an anthropogenic biosphere. *Ecological Monographs*, 85, 287–331.

Gorb, E. V. & Gorb, S. N. (2003). *Seed Dispersal by Ants in a Deciduous Forest Ecosystem: Mechanisms, Strategies, Adaptations*. Kluwer, The Hague.

Heil, M. & McKey, D. (2003). Protective ant-plant interactions as model systems in ecological and evolutionary research. *Annual Review of Ecology, Evolution, and Systematics*, 34, 425–53.

Hölldobler, B. & Wilson, E. O. (2010). *The Leafcutter Ants: Civilization by Instinct*. W. W. Norton & Company, New York.

Huxley, C. R. & Cutler, D. F. (editors). (1991). *Ant-Plant Interactions*. Oxford University Press, Oxford.

Janzen, D. H. (1966). Coevolution of mutualism between ants and acacias in Central America. *Evolution*, 20, 249–75.

Kiers, E. T., Palmer, T. M., Ives, A. R., Bruno, J. F., & Bronstein, J. L. (2010). Mutualisms in a changing world: an evolutionary perspective. *Ecology Letters*, 13, 1459–74.

Lach, L., Parr, C. L., & Abbott, K. L. (editors). (2010). *Ant Ecology*. Oxford University Press, Oxford.

Morley, D. W. (1953). *The Ant World: Their Evolutionary History, Their Behavior, Their Many Varieties and the Organization of Their Society*. Penguin Books Ltd., Harmondsworth, Middlesex, UK.

Ness, J. H. & Bronstein, J. L. (2004). The effects of invasive ants on prospective ant mutualists. *Biological Invasions*, 6, 445–61.

Price, P. W. (2002). Species interactions and the evolution of biodiversity. In: C. M. Herrera & O. Pellmyr (editors). *Plant-Animal Interactions: An Evolutionary Approach*. Blackwell Science, Oxford. pp. 3–25.

Rico-Gray, V. & Oliveira, P. S. (2007). *The Ecology and Evolution of Ant-Plant Interactions*. University of Chicago Press, Chicago.

Tylianakis, J. M., Didham, R. K., Bascompte, J., & Wardle, D. A. (2008). Global change and species interactions in terrestrial ecosystems. *Ecology Letters*, 11, 1351–63.

Wheeler, W. M. (1942). Studies of neotropical ant-plants and their ants. *Bulletin of the Museum of Comparative Zoology*, 90, 3–262.

Wilson, E. O. (1988). The current state of biological diversity. In: E. O. Wilson (editor). *Biodiversity*. National Academy Press, Washington, DC. pp. 3–18.

Wilson, E. O. & Hölldobler, B. (2005). The rise of the ants: a phylogenetical and ecological explanation. *Proceedings of the National Academy of Sciences of the United States of America*, 102, 7411–14.