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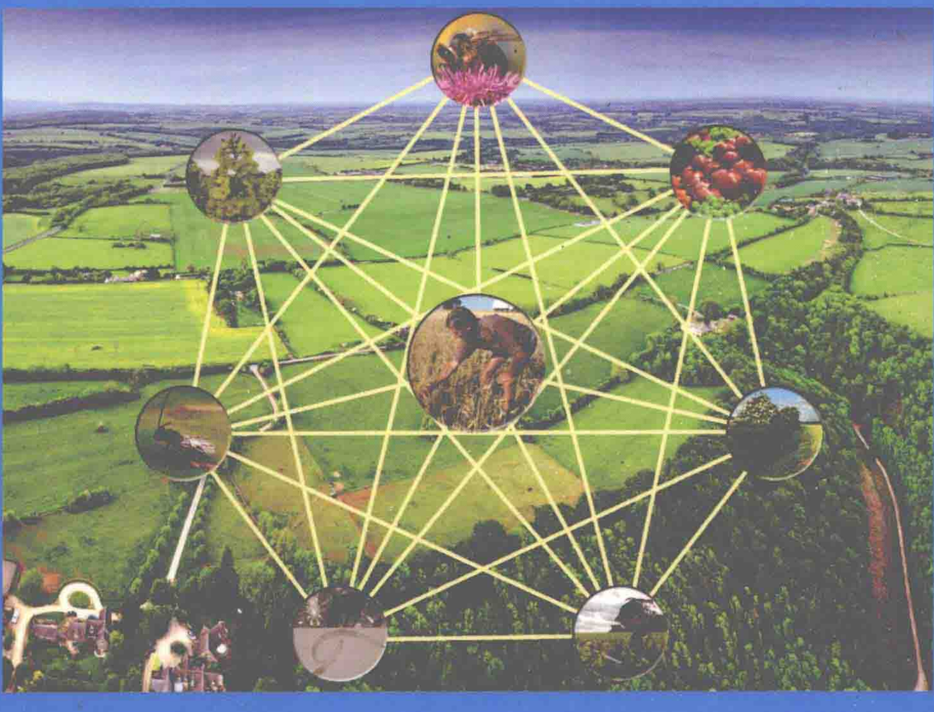
ECOLOGICAL NETWORKS IN AN AGRICULTURAL WORLD



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Series Editor

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PREFACE

Editorial Commentary: The Potential for Network Approaches to Improve Knowledge, Understanding, and Prediction of the Structure and Functioning of Agricultural Systems

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Network science has made increasingly important contributions to the understanding of ecological interactions in complex, multispecies natural systems, such as food webs and plant–pollinator networks (Ings et al., 2009; Lafferty et al., 2008; Montoya et al., 2006; Olesen et al., 2010). Our understanding of the ecological properties that confer stability and resilience to disturbance upon these systems has accelerated by viewing them as networks of interacting elements. Considerable advances have been made since the first food web studies were conducted by the pioneers of modern ecology (e.g. Elton, 1927; May, 1973), with especially marked improvements in both data and models over the last two decades (e.g. Allesina and Tang, 2012; Cohen et al., 2009; Dunne et al., 2002; McCann et al., 1998). Previously, the poor quality of data threatened to undermine the credibility of the approach (Polis, 1991). This more holistic, system-based approach has had many significant impacts on fundamental ecology, from its contribution to the complexity–stability debate to providing a means of linking across different organisational levels and spatial and temporal scales (Hagen et al., 2012; Kondoh, 2003). It is only far more recently that it has been adopted by the more applied, ecological sciences (Ings et al., 2009). The growing prominence of food web approaches is particularly evident in its influence on the management of human-exploited fish stocks (e.g. Barnes et al., 2008, 2010; Jennings and Brander, 2010; Jennings et al., 2002), where it is increasingly being used to underpin the 'ecosystem approach to fisheries' that is now being adopted on a global scale. Network approaches have not yet had the same level of impact in the sister discipline of agriculture, however, and addressing this gap is the principal motivation behind the production of this thematic volume.

Networks in agricultural ecosystems have been rather neglected, reflecting the long-held view that these artificial systems are somehow special cases that stand apart from mainstream ecology. Indeed, there has been relatively little exchange of ideas, with agroecology developing to a large extent as an isolated discipline in its own right, mirroring the situation that persisted in the relationship between fisheries science and general ecology throughout much of the twentieth century. Recently, however, there has been a noticeable change as the field has opened up: studies of networks of interacting species in agriculture, such as Pocock et al. (2012), are now not only shining new light on the structure and functioning of agroecosystems, but also contributing to, and extending, wider ecological understanding and theory.

The longstanding separation of agroecology of mainstream ecology is surprising, given that early trophic and community ecology (*sensu* Elton, 1927; MacArthur, 1955) and more recent metapopulation theory (Levins, 1969) were originally inspired by agricultural questions, such as how crop monocultures seemed especially prone to pest outbreaks, just as size-structured food webs were recognised in early fisheries science (e.g. Hardy, 1924) but then network approaches largely ignored for most of the last century. The work in this thematic volume demonstrates that agriculture is once again set to drive forward ecological research in multispecies, interactive systems, and the growing resurgence of the field is reflected in the current worldwide concern with maintaining the ecosystem goods and services on which all human societies depend (Raffaelli and White, 2013), and which are at the heart of agroecology. Globally, we will need to produce more sustainable agroecosystems that are both biodiverse and able to feed the ever-growing human population—which is projected to exceed 9 billion people by 2050. Agroecosystems already account for much of the Earth's surface, with croplands and pasturelands covering over 40% of the land area, and this is set to grow rapidly in the coming decades. It is inevitable that this expansion and encroachment on wilderness areas will lead to increased interdisciplinarity in the future, as pressures mount on both natural and artificial systems and the goods and services they supply to humanity. This combination of socioeconomic and ecological imperatives sets the scene for the role agriculture will play in the developing theory and practice of network ecology.

The apparent dichotomy between the study of agroecosystems and natural ecosystems is a false premise, as every system on the planet can be placed on a gradient of artificiality to naturalness, from urban systems at one end to the remote wilderness of Antarctica at the other, but with few, if any, being truly pristine given the global reach of human impacts (Bohan et al., 2013). Typically, agroecosystems are viewed as lying towards the more artificial end of this gradient, but in reality many exist in, and interdigitate with, natural and 'semi-natural' habitats (Massol and Petit, 2013). For instance, heathland and moorland are agroecosystems in many parts of the world, as are many grasslands, although they are often managed with a lighter touch than industrial-scale, intensively farmed arable monocultures. All support many more species than the target crop alone, which has been the primary focus of agricultural research to date, and these ancillary systems are required for the healthy functioning and service provision of the ecosystem as a whole (including supporting agricultural yields). Together, these natural, semi-natural, and cropping systems form a patchwork of interaction networks, which are themselves connected to one another and to other elements in the surrounding landscape in a spatial network. It is these attributes that form much of the focus of this volume.

Network approaches developed in mainstream ecology and other disciplines can be readily adapted and applied to agroecosystems, despite some of their apparently fundamental differences to natural systems, to help understand how local ecological networks (e.g. food webs, plant–pollinator webs, host–parasitoid webs) are themselves nested as nodes (metawebs) within a larger spatial network. The chapters in this volume also explore how network approaches can be applied to other aspects of agroecology, including the decision-making processes in land management, and how eco-evolutionary dynamics can be used to understand system-level responses (e.g. the emergence of pesticide resistance) to those choices (Loeuille et al., 2013).

This volume thus covers a broad canvas, and it embraces methodological issues as well as introduce new empirical data and models to provide a new synthesis of the current state-of-play. In fact, the considerable depth and breadth covered by seven chapters presented here highlight just how rapidly this nascent field is developing. Across this volume, there are several recurrent themes that have emerged from these chapters, which we have summarised in 10 key points:

1. Agroecosystems have important similarities to, and also differences from, natural systems, which need to be borne in mind when modelling their dynamics.
2. Temporal and spatial dynamics and heterogeneity need to be considered together, over multiple scales (Loeuille et al., 2013; Massol and Petit, 2013; Tixier et al., 2013).

3. Belowground and aboveground networks need to be united, and not studied in isolation, as has been typical to date; one cannot be fully understood without knowledge of the other (Mulder et al., 2013).
4. Different types of antagonistic and mutualistic interactions can occur within the same community—and even within the same species pairs—and advances in understanding of this diversity of interaction in agroecology are now driving those in more general ecology, which has traditionally focused on just one type of interaction network within a given community (Bohan et al., 2013; Loeuille et al., 2013; Mulder et al., 2013).
5. Diets are much harder to characterise in agroecosystems than they are in the highly resolved aquatic food webs that are dominated by gape-limited, engulfing consumers. Here, new technologies and techniques such as SIP, metasystematics, machine-learning, and text-mining are revolutionising how food webs and other networks can be constructed rapidly and realistically, and these promising novel approaches seem certain to be adopted in the near future by mainstream network ecology (Tamaddoni et al., 2013; Traugott et al., 2013).
6. There is a wide diversity of consumer behaviour and traits in agroecosystems, from suctorial fluid feeders through to spiders that use webs as tools to catch larger prey, such that the strength of body mass allometric constraints may need to be reassessed relative to the many other systems in which they are particularly powerful structuring forces (Mulder et al., 2013; Tamaddoni et al., 2013).
7. Taxonomic and functional traits are both important determinants of network structure (Bohan et al., 2013; Mulder et al., 2013; Tamaddoni et al., 2013).
8. Eco-evolutionary responses can be extremely rapid and profound, due to the prevalence of powerful artificial selection (e.g. for pesticide resistance) that accelerates their manifestation (Loeuille et al., 2013).
9. Crop type is a more powerful determinant of network structure than biogeographical setting, largely because of the biotic homogenisation that arises from filtering through the same set of constraints and management practices, which are often applied on a continental to global scale (Bohan et al., 2013).
10. Land-sharing and land-sparing approaches to management have very different outcomes for ecological networks across different landscapes, with compelling evidence that the former is likely to be far more sustainable than the latter in the future (Loeuille et al., 2013).

Although these points are addressed to varying degrees in the seven chapters presented here, there is a clear consensus that applying network approaches to agriculture offer an exciting new way to view and manage these critically important ecosystems. As we move ever deeper into the Anthropocene, it is crucial that we understand how agricultural systems determine humanity's well-being and 'safe operating space' (Millennium Ecosystem Assessment, 2005; Rockström et al., 2009). By reconnecting agroecosystems with their natural counterparts, through improved ecological understanding, we will gain a better ability to predict how they will respond to future changes, including global climate change and population growth, but also how to design novel, sustainable, and intensive agricultural systems that are better able to meet humanity's future needs.

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