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Tropical Ecosystems in the 21st Century

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Preface

1. Introduction

Tropical ecosystems are home to a disproportionate number of the world's species (Gaston, 2000), but are under increasing pressure from anthropogenic impacts (Pimm et al., 2014). These include overhunting in both terrestrial and marine ecosystems (McCauley et al., 2015; Ripple et al., 2019), habitat degradation, fragmentation and conversion to agriculture (Gibbs et al., 2010; Phalan et al., 2013), transmission of invasive species worldwide (Seebens et al., 2018), and ongoing climate change (Deutsch et al., 2008). These species losses have negative impacts on ecosystem functioning and provision of ecosystem services. Most importantly, many of these factors are taking place concurrently and interact, resulting in synergistic impacts on biodiversity and ecosystem processes (Brook et al., 2008). In this context, it is not surprising that levels of biodiversity loss, although uncertain, are far higher than background rates and are accelerating (Ceballos et al., 2015; Pimm et al., 2014). With an increasing global population and rising per-capita caloric and protein demands (Tilman et al., 2011a), there has never been more pressure on tropical ecosystems. At the same time, there is an increasing body of information demonstrating the important role that biodiversity can play in supporting ecosystem services, including food production (e.g. Garibaldi et al., 2011; Tscharntke et al., 2005). Reconciling these pressures with biodiversity conservation and the maintenance of functioning productive tropical landscapes, represents perhaps the biggest challenge facing the world today.

The last year has seen worrying reports of continued losses and change, with deforestation and associated fire increasing in the Brazilian Amazon (Escobar, 2019), and long-term changes being reported in even small taxa, such as insects (Wagner, 2020), which because of their short generation times and generally large population sizes, might be expected to be more resilient than other groups. On the other-hand, there has been a recent increase in public interest in human impacts on the natural world, particularly among younger age groups (Gardner and Wordley, 2019). From a scientific perspective, recent advances in technology, particularly remote sensing (Turner et al., 2003) and molecular techniques (Anderson and Cairney, 2004), are enabling human impacts on the natural world to be studied over larger areas and at finer scales than ever before, bringing a heightened level of understanding that has not been possible in the past.

It is clear that the natural world and tropical ecosystems in particular, have never been more at risk. However, the opportunities for understanding changes and hence informing conservation and more-sustainable management of tropical landscapes are equally unprecedented. Now is an opportune time to explore the current state of knowledge in tropical ecosystems at a global scale and to predict future change. With this aim, this special edition brings together 11 publications that investigate drivers behind changes in the tropics, both from a whole-ecosystem perspective (e.g. Lugo et al., 2020; Pellegrini and Jackson, 2020) and with regard to particular focal taxa (e.g. Lamarre et al., 2020; Pinho et al., 2020). These publications explore how different drivers can interact, the differences between one-off and longer-term perturbations, and the impacts of interactions between components of tropical systems that influence long-term effects. We include several papers discussing large-scale experiments, where biodiversity (Wu et al., 2020), litter dynamics (Sayer et al., 2020) and climate (Reed et al., 2020) have been manipulated, to understand the impacts of changes on whole ecosystems and to forecast future change. We also include papers that highlight the importance of long-term and large-scale comparative studies (Lamarre et al., 2020; Pellegrini and Jackson, 2020) for understanding species decline and the role of modern molecular methods (Bani et al., 2020; Zinger et al., 2020) and statistical techniques (Ghosh et al., 2020) in cataloguing change and informing conservation action.

2. Papers in this edition

Commonly the first stage in habitat alteration of tropical forests involves selective logging and timber removal, with logged and disturbed forests now representing the commonest forest type in parts of the tropics (e.g. Edwards et al., 2011). Increasingly, it is also this habitat that is converted to agriculture (Gibbs et al., 2010), making an assessment of the biodiversity and ecosystem service value of logged forests particularly timely. In Chapter 1, Bousfield et al. (2020) review the known environmental and socioeconomic value of logged forests. The authors describe how logging alters forest structure, and hence community composition for a wide range of animals and plants. However, they find that logging has more limited effects on species richness, especially compared with conversion to agriculture.

This value of logged forests is also reflected in the maintenance of important ecosystem functions, such as carbon storage, climate regulation and, to some extent, watershed maintenance. Logging can reduce the socioeconomic value of forests for local communities, but, if conducted in a socially responsible manner, can also result in benefits. In particular, strategies such as reduced impact logging and better spatial management of harvesting and road networks can reduce negative impacts on biodiversity and ecosystems services for local communities, while tailored management can also improve recovery of forests.

In some cases, disturbed forests can also develop novel communities of plants, with their own characteristics and functions. Such novel ecosystems are a key feature of the Anthropocene and can represent valuable habitats in their own right (Lindenmayer et al., 2008). In Chapter 2, Lugo et al. (2020) take a long-term perspective and review information on novel tropical forest ecosystems. They introduce case studies from an island (Puerto Rico), a montane continental region (the Andes), and the lowland continental tropics (Venezuela). The forests in all three areas show novel species composition, with a high dominance of certain species and differences in functional traits from the forests historically found in the area. These novel ecosystems also differ in functioning, with generally higher growth rates, and more-rapid turnover of wood and leaf litter nutrients.

Ultimately the functioning of communities can be heavily influenced by interactions between species, as well as the diversity of the system itself (e.g. Tilman et al., 2011b). In order to understand such effects in tropical forests, large-scale experiments can be particularly important, as they enable driving factors to be identified at a scale that is appropriate for high-complexity systems (Fayle et al., 2015). In Chapter 3, Wu et al. (2020) present findings from the large-scale Sabah Biodiversity Experiment and investigate the effects of species diversity on forest structure. This experiment was established in 2001, and comprises 124 four-hectare plots, each containing different tree diversity treatments (unplanted, monocultures, 4 and 16 species mixtures). Using high spatial resolution satellite imagery and advanced remote sensing, Wu et al. (2020) find higher vegetation cover in mixed-species treatments than monocultures and greater vegetation cover in enrichment planted plots compared to nonenrichment plots. This is one of the first experimental demonstrations of biodiversity effects (i.e. overyielding) in a tropical forest system and backs up classic and contemporary studies from grassland ecosystems (Eisenhauer et al., 2019; Tilman et al., 2011b). Such a result is particularly critical, given current levels of biodiversity loss.

Fire is still a common method used to clear forest vegetation for agriculture in large parts of the tropics, despite the negative impacts that such practices can have on biodiversity, soil condition and carbon storage (Cochrane, 2001). Negative impacts can also be exacerbated when fire is employed in low-rainfall conditions, which may become more frequent in some parts of the tropics as a result of climate change (Timmermann et al., 2002). The majority of studies on fire have considered single-burn events, while human action and positive feedback effects through increased tree mortality and standing deadwood, can mean that these single-burns are followed by long-term differences in the fire regime (Cochrane et al., 1999). In Chapter 4, Pellegrini and Jackson (2020) combine a literature review and metaanalysis to investigate the impact of single-fire events (pulse) vs sustained changes (press) in a fire regime. They find that levels and availability of different nutrients respond differently to single or repeated burns, depending on how their availability is regulated in the system. Similarly, they show that microbial biomass and decomposition rates are likely to shift with the fire regime, particularly as a result of heat-induced mortality and declines in organic material. Taken together, these findings have important implications within the tropics, where shifts in fire regimes, often associated with weather patterns and land-use change, are accelerating (Cochrane et al., 1999). The study also highlights how sustained change can have differing impacts on an ecosystem than a single perturbation event.

Within tropical ecosystems, there can also be complex interactions between biotic and abiotic components of the system and between aboveground and belowground parts of the system (Richardson et al., 2010), making it difficult to determine which factors are responsible for supporting functions such as primary productivity. Large-scale experiments can again be important in teasing apart these effects. In Chapter 5, Sayer et al. (2020) present findings from a large-scale, long-term litter manipulation project—the Gigante Litter Manipulation Project. Based in Panama, this project has manipulated leaf litter levels (in 15 large litter removal, addition and control plots) over the last 15 years, to experimentally test the long-held assumption that nutrient recycling from high litterfall in tropical forests is essential for maintaining primary productivity. The study demonstrates clear effects of changing litter levels on some soil nutrients (particularly nitrogen, calcium and magnesium) but more variable effects on others. The study also demonstrates a variety of knock-on effects to the rest of the ecosystem. For example, decreased availability of nitrogen in litter removal soils is likely to have stimulated microbial degradation of soil organic matter, resulting in reduced soil organic carbon concentrations and microbial biomass. This work again demonstrates the value of experiments to tease apart complex links within structurally and biologically complex tropical systems (Fayle et al., 2015).

Processes operating in tropical regions can be heavily influenced by changing weather patterns and climate change (e.g. Eycott et al., 2019). Once again, manipulative experiments can be key to understanding the complex nature of these effects. In Chapter 6, Reed et al. (2020) present findings from a recently established experiment based in Puerto Rico, the Tropical Responses to Altered Climate Experiment, that is experimentally warming a tropical forest for the first time. The experiment consists of six 4-m diameter plots, half of which are heated with infrared heaters. The study also takes advantage of two hurricanes that occurred during the experimental warming to investigate the synergistic effects of large-scale disturbance and warming. The study finds that experimental warming affected carbon, nitrogen, and phosphorus cycling, and increased microbial biomass, that hurricane damage affected a wide range of soil biogeochemical measurements, and that there was an interaction between the effects of warming and hurricane damage. These results indicate that biogeochemical cycling and, by association, many other processes within tropical systems will likely change in the future with global warming and changes in the frequency of extreme weather events.

It is, therefore, clear that the biodiversity of tropical systems and complex interactions between components of these ecosystems can have marked effects on ecosystem functioning. In Chapter 7, Pinho et al. (2020) review the importance of a specific aspect of tropical systems—very large tropical forest trees (mega-trees), to assess their value for supporting biodiversity and ecosystem services. In particular, they find that tropical mega-trees represent a key habitat for a diverse suite of organisms from all trophic levels. They provide nonredundant niche-space, buffer microclimate, have a disproportionate role in carbon sequestration and aboveground biomass, and provide important ecosystem services for people. However, because of their size and relative rarity, such trees are disproportionately affected by habitat change and conversion, threatening biodiversity and associated ecosystem services. Indeed, it is the large and relatively long-lived trees that Lugo et al. (2020) highlight as being missing from novel forest ecosystems. Such an apparently important role of a small subset of the total community that is particularly vulnerable to anthropogenic impacts is reminiscent of the loss of ecologically important megafauna globally (Malhi et al., 2016), and highlights the importance of targeted conservation action.

While the vulnerability of large, relatively scarce and long-lived organisms is fairly well established (e.g. Ripple et al., 2019), in Chapter 8 Lamarre et al. (2020) investigate the current state of knowledge of declines in a numerous and small-bodied group: the insects. The paper highlights the recent increase in studies demonstrating declines in insects worldwide, with links to multiple interrelated drivers, including habitat and climate change. They also highlight the current lack of knowledge of the state of insect communities in the tropics, despite the fact that these areas contain a far higher diversity of species than better-studied temperate regions (Gaston, 2000). Intriguingly, the long-term tropical studies that exist seem to indicate that patterns of insect change in the tropics are less-clear than in temperate regions. Generally, studies show large fluctuations in insect abundance over short time-scales linked to stochastic events, but no consistent long-term declines. The large fluctuations in numbers shown by the insects, demonstrates the clear need for more long-term monitoring in the tropics. The authors go on to introduce the ForestGEO arthropods initiative, which is based within seven of the Forest Global Earth Observatory (ForestGEO) plots across the tropics, and is already gathering data on long-term tropical insect change. A key issue with studying tropical insects is their extreme diversity and lack of information on their ecology, making it hard to draw general conclusions about the ecosystem impacts of any change. To address this, the paper highlights the importance of focussing on aspects of the community such as functional and physiological traits, to allow inferences to be drawn about the effects of change on the wider ecosystem. The study also highlights the importance of molecular approaches, such as DNA metabarcoding, and machine learning to increase the speed of data-gathering and processing, and the scope of data available.

Indeed, it is clear that modern molecular and computational techniques are leading to a phase-shift in understanding of tropical ecosystems, providing information that is likely to be key to contemporary conservation efforts. In Chapters 9 and 10, Zinger et al. (2020) and Bani et al. (2020) discuss the application of environmental DNA (eDNA) based approaches in different tropical ecosystems and how these may be used to inform conservation research. Zinger et al. (2020) focus their study on tropical rainforests (particularly neotropical forests) to explore the current application of different eDNA methods in addressing ecologically relevant research questions, as well as challenges associated with both using and improving these methods. They also discuss potential applications of eDNA-based approaches to future tropical forest research. Bani et al. (2020) provide a complementary examination of eDNA-based methods, but targeted on specific conservation actions associated with spatial planning decisions within marine ecosystems. They highlight the important role that eDNA-based approaches are likely to have in the future in informing spatial planning for conservation and global biomonitoring initiatives.

Given the wealth of large datasets, increased monitoring efforts in the tropics, and modern techniques generating unprecedented amounts of data, statistical techniques to study tropical ecosystems also need to become more sophisticated to take full advantage of this level of information and reliably quantify linkages between different components of an ecosystem. In Chapter 11, Ghosh et al. (2020) provide a new statistical toolbox for 21st century ecology. The authors propose ecologists move beyond standard correlation and regression-based approaches when analysing links between biological and environmental variables, to the application of 'copula'. Like regressions, this approach describes the association between two or more variables, but separates information on marginal distributions and remaining information related to the association. Copulas are regularly applied within other quantitative disciplines (e.g. finance), but have yet to be applied in ecology, although they represent a promising avenue for developing a more-sophisticated understanding of associations between ecological variables.

3. Conclusion

The chapters included in this volume of *Advances in Ecological Research* provide an overview of the state of knowledge of tropical ecosystems, current threats, and likely future change. It is clear that tropical ecosystems are experiencing a range of interacting threats, but that current understanding of these systems is still lacking, especially when compared to temperate regions. Several papers in this edition emphasize that current knowledge of human impacts on the environment is disproportionately informed by temperate studies (e.g. Lamarre et al., 2020; Pellegrini and Jackson, 2020), where ecosystem processes may differ from the tropics, making it difficult to draw reliable inferences on the long-term impacts of environmental change in the tropics. However, comparative studies drawing information from across regions, and long-term whole-ecosystem manipulative studies are yielding important novel information to fill this gap. Added to this, modern molecular approaches are increasing the scope of options for monitoring high-diversity tropical ecosystems on a scale that has not been possible before.

The next big challenge in tropical ecology is to bring this information together to inform and test conservation action, reverse tropical biodiversity loss, and support healthy tropical ecosystems into the future.

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