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REVIEW

Political Ecology of Commodity Agroforests and Tropical Biodiversity

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Abstract

Though human-modified tropical landscapes are increasingly well studied, the processes that influence and govern biodiversity outcomes, especially in commodity production landscapes (e.g., coffee, rubber, arecanut), remain poorly understood. A review of the existing literature reveals that research in general focuses on individual components of a cascading set of relationships from political and economic forces, to producer decisions, to agroforestry structure, to habitat and diversity. The linkages between these components remains underdeveloped; efforts to unite the full "chain of explanation" remains elusive, making it difficult to form firm claims or testable hypotheses about how the ecology and biodiversity of such commodity systems are determined. To form more robust hypotheses about such relationships would require more integrative team efforts than heretofore have been common. Our review suggests that though some important relationships are well-understood, and some emerging policy emphases can be identified, policy-relevant science is still on the horizon in this frontier area.

Introduction

Among human-influenced landscapes, agroforestry has special promise as a site for biodiversity conservation in the tropics (Chazdon *et al*. 2008). Agroforestry commodity production systems in particular, those tree covered but intensively used landscapes of coffee, rubber, arecanut, and cacao, can create and maintain habitat and support native species (Bhagwat *et al*. 2008). However, the variation in the ecological value of these habitats, the factors that govern habitat quality, and the forces that maintain or erode biodiversity, are far less well-explained. This paucity of explanation reflects an overall lack of research focus on anthropogenic environments (Ricketts & Lonsdorf 2013), the novelty of these ecosystems (Hobbs *et al*. 2006), as well as the fine scale at which these environments occur, causing them to be missed in large-scale surveys and remote sensing (Mendenhall *et al*. 2011).

Perhaps the most important barrier to explaining conservation outcomes on these commodity production lands, however, is the fact that the numerous key influences operate beyond the bounds of local ecological systems (Robbins 2012); human decision-making in commodity agroforests follow economic incentives, policies, and labor costs, among other political and economic factors. There is a complex *political ecology* in short, that influences biodiversity habitat in tropical commodity production, making explanation a wide-ranging challenge.

As such, though numerous policy instruments have been advocated for conservation in agroforestry contexts (Schroth & McNeely 2011), most such efforts might be viewed as premature, or at least difficult to evaluate; there remains little theoretical or empirical evidence of strong causal linkages and outcomes, traced from commodity economies through agroforestry practices, to diversity outcomes. Reviewing research in *tropical commodity agroforests*—distinct from nonforest areas, subsistence agroforestry, relict forest fragments, and abandoned forest land—this review assesses what is known, emphasizes what is not, stresses the policy implications of our limited understanding, while presenting modest methodological recommendations to advance our knowledge.

Biodiversity potential of tropical commodity agroforestry

Conservation scholarship has demonstrated the association between agricultural change, forest cover decline, and ongoing loss of biodiversity (Lewis O.T. 2009; Vitousek *et al.* 1997). Specifically, in the subtropics and tropics, forest cover loss has been identified as a key driver in predicting biodiversity decline (Hansen & DeFries 2010). Plantation agriculture and its expansion specifically have been associated with biodiversity loss (Hartemink 2005) and, in commodity production landscapes, new forms of cultivation have made agriculture less hospitable to biodiversity (Ambinakudige & Choi 2009). In India, human-impacted forests do not appear as effective as they could be for conservation, relative to fully enclosed conservation reserves (Shahabuddin & Rao 2010). So too, human agricultural livelihoods often interfere with the operation of formal state reserves and parks (Karanth & DeFries 2010). At the same time, it is clear that anthropogenic environments have long accommodated wildlife. One key to reconciling human activity and biodiversity conservation, therefore, lies in the heterogeneity of habitats present in human-dominated landscapes (Benton *et al.* 2003).

Several compelling frameworks and significant debates have emerged from this long-standing revelation. Reconciliation Ecology argues that human-influenced landscapes might expand the quantity of habitat (Rosenzweig 2003). This has led to robust debate on whether or not agricultural intensification (especially in food production) might allow more land to be taken out of production for conservation (Phalan *et al.* 2011).Forest transition through the abandonment of areas of commodity production and the succession of these lands into secondary forest has also been a matter of intense scrutiny (Chetana *et al.* 2012; Hecht *et al.* 2014).

Even so, demands for plantation products like cacao, coffee, and rubber are likely to persist or increase in upcoming decades. Given that agroforest crops like these cover a far larger area in most tropical countries than do conservation areas, their capacity to erode or maintain biodiversity has become a critical conservation question. Findings that associate such commodity agroecologies and biodiversity conservation have been reported from India (Daniels 2003; Bali *et al.* 2007; Ranganathan *et al.* 2008; Anand *et al.* 2010), Latin America (Naughton-Treves *et al.* 2003; Perfecto & Vandermeer 2010), West Africa (Obiri *et al.* 2007), and Southeast Asia (Clough *et al.* 2011; Kathirithamby-Wells 2011).

The central emerging general lesson for conservation is that tropical commodity agroforestry agriculture has a potential for habitat creation. This conclusion suggests a need for increasingly rigorous assessment to pick apart the specific influences that might account for relatively higher or lower diversity in such systems. The question becomes: what ecological structure of commodity agroforestry systems encourages biodiversity and what political and economic contexts create conditions to foster such structure?

The chain of explanation from biodiversity in agroforestry to policy and economy

To understand ecological outcomes in such landscapes requires an acknowledgment of a chain of influences that contribute to explaining biodiversity and habitat, or its absence, in agroforestry. These begin within the structure of species populations in and around plantation landscapes and the degree of influence that plantation agroecological conditions, including canopy density, intercropping, inputs, and crop mixes, have on those populations. These specific agroecologies are, in turn, influenced by producer choices and strategies, including the specific availability of labor or technological inputs, the scale of the farm operation, and the diversity of household economies. Those producer decisions and their associated strategies are themselves further influenced by political and economic forces at the regional and international scale, including commodity prices, transportation networks, institutions or laws like price supports or producer cooperatives, as well the broader changing context of regional demography that influences labor availability and price. An increase in the volatility of coffee prices owing to new actors in global production (e.g., Vietnam in the early 2000s), for example, coupled with a removal of subsidies in some markets (as in some African states in the 1990s), may lead to producers intensifying production by opening tree canopy and increasing chemical inputs. This might further result in declining habitat for tree-dwelling species and harm to input-sensitive species (e.g., amphibians).

Recognizing this political ecology (Figure 1) governing commodity biodiversity–a cascading set of relationships from political/economic forces, to producer decisions, to agroforestry structure, to habitat/diversity–underlines the difficulty of making firm claims or forming testable hypotheses in such commodity systems. Our ability to trace and predict the influence of global or regional political and economic changes (e.g., commodity price changes, subsidies, or market institutional innovations)

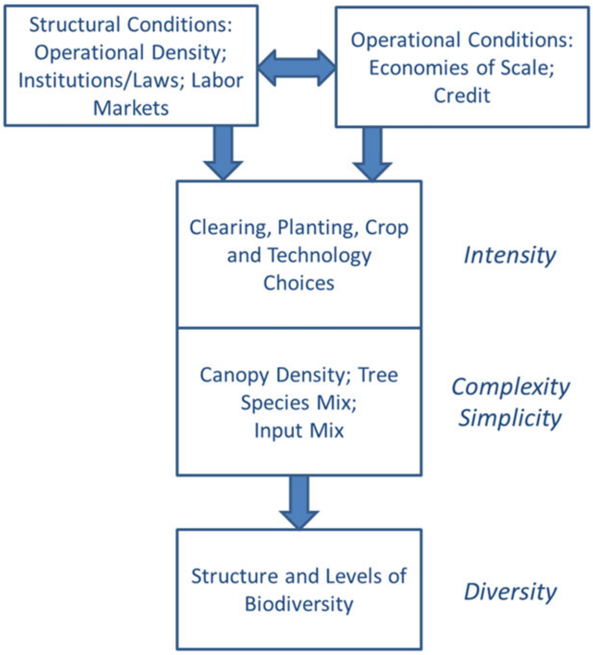

Figure 1 Biodiversity and production decisions in agroforestry, relative to structural and operational conditions.

on biodiversity in associated plantation landscapes, therefore, is limited, even while isolated components of this chain of explanation are increasingly well understood. We briefly consider each component in turn.

From commodity agroecology to biodiversity

The linkage between the specific structure of agroforestry plantations and biodiversity outcomes is an area of growing knowledge. While some agroforests closely resemble their wild counterparts in terms of species diversity (Correia *et al*. 2010), many do not precisely mimic their function as habitat (Harvey & Villalobos 2007). These landscapes, depending on their relationship to ambient ecosystems, may also favor some species at the expense of others (Philpott *et al*. 2008; Sodhi *et al*. 2010), making them potentially valuable parts of a complex conservation mosaic, if not a replacement for native forest cover. This finding, that specific agroecological conditions in plantations favor or disfavor specific species, is consistent with other studies showing that the specific cultural and agroecological practices have significant influence on diversity outcomes. Human-dominated landscapes in Costa Rica, characterized by coffee plantations, pasture, and remnant forest, were shown to harbor a significant diversity of reptiles and amphibians, for example. In this case, however, key differences are notable. For example, large and pond-reproducing amphibians fared better on anthropogenic landscapes while smaller, stream-reproducing species required remnant forests (Mendenhall *et al*. 2014).

In coffee agroforestry in South India, farms with greater herbaceous ground cover, larger, mature shade trees, and greater tree species richness have been shown to harbor greater small mammal abundances and diversity (Caudill *et al*. 2014). Similarly, in Mexican cacao production, more simplified planted agroforestry systems were shown to harbor some important habitat for migratory birds but perform more poorly as harbors for biodiversity relative to more “rustic” plantations, characterized by cultivation beneath native forest trees (Greenberg *et al*. 2000). This reinforces a more specific conclusion: more complex agroforests may perform more consistently as habitat than more simplified ones do. Indeed, at the landscape level, proximity to fragments of natural forests has been shown to increase the productivity of commodity plantations through pollination, pest control, and other ecosystem services (Karp & Daily 2013; Ricketts & Lonsdorf 2013). This is not to downplay the negative impacts of native forest for producers (e.g., nuisance species), but to stress the role of complexity in providing critical habitat.

In general therefore, tree diversity, canopy density, and understory layering, among other variables, all significantly influence biodiversity outcomes, even within the same crops types and regions. Comparative and broad-scale evaluation of this relationship remains somewhat underdeveloped, however, and studies of agroecology and biodiversity are rarely structured to account for, or explore, decision-drivers at the farm scale.

From agroecology to producer practices

The forces that encourage or discourage producers to maintain or erode the conditions described above (e.g., tree diversity) are linked to producer decisions, on-farm. The broadly inclusive fields of land change science and political ecology have especially stressed the competing forces at work on these practices and decisions in agroforestry areas. Ordonez *et al*. (2014) demonstrate that on-farm tree diversity can vary greatly between farms, owing to producer decisions, with influences stemming from farmer preferences, seed dispersal mechanisms, tree domestication and delivery via nurseries. Agroforestry research has convincingly demonstrated that agroforestry systems vary significantly in terms of factors like farm size, tree species diversity and density, cropping intensity, use of inputs, and agricultural labor force (Dhakal *et al*. 2012).

Given this sort of variability in producer strategies, the remarkable persistence of complex agroforestry systems—characterized by biodiversity-relevant agroecological conditions described above—is notable. This is in part a result of the ecosystem services that trees provide for producers (Johns 1999; Tscharntke *et al.* 2011). In southern India, for example, shade-grown coffee produces sustained yields owing to the protection provided by intercropped tree species against fierce monsoon rainfall (Ambinakudige & Sathish 2009). In coffee agroforests in particular, the maintenance of system complexity is associated with pest control (Vandermeer *et al.* 2010). Producers may choose to maintain high native tree diversity owing to the benefits of such practices for production yields, as where native shade tree species discourage pests in cacao production in West Africa (Bisseleua *et al.* 2013) and Costa Rican coffee (Karp *et al.* 2013), or where tree-dwelling birds and bats suppress arthropods and increase crop productivity in Southeast Asia (Maas *et al.* 2013). Other research has shown more complex or inconsistent effects, as where bats in Costa Rican coffee plantations do not provide benefits to production by mediating pest outbreaks, while birds do (Karp *et al.* 2013). These benefits may be accrued without the awareness of producers, of course, as where coffee growers maintain native trees for shade, mulch, soil nutrition, timber, or recreation rather than in support of pollination services or pest control (Abraham *et al.* 2013).

Security of tenure, diversity of producer livelihoods, institutional arrangements for local resource management, and national agricultural policy may also impinge on decisions to maintain varying canopy densities and layers, as well as tree and understory species diversities, but these influences are less well documented. Smallholders, notably, operate under differing opportunities and limits than larger holdings, especially relative to intensity of cultivation and modes of technology adoption (Perfecto & Vandermeer 2010). These hold clear implications for wildlife persistence in small farmsteads vis-à-vis larger ones.

Globally, intensified systems have been observed to expand at the expense of more extensive, habitat-protecting production regimes (Geist & Lambin 2001). Clearly, however, the shift toward a more intensive regime of agroforestry production, typified by more open canopy, decreased tree and crop species diversity, and increased use of chemical inputs relative to labor inputs, may be hypothesized to create biodiversity-relevant habitat transformations. This has been observed in cacao agroforests in Brazil (Cassano *et al.* 2014), as well as those in Sulawesi, Indonesia (Bos *et al.* 2007).

The drivers of these farmer decisions toward intensity are numerous, but include insecurity over tree tenure incentivizing deforestation (Kazianga & Masters 2006), the availability of improved but shade-intolerant hybrid crop types that encourage intensification and open canopy (Obiri *et al.* 2007), increased costs of production associated with maintaining canopy cover (Schroth *et al.* 2000), and migration leading to demographics of producers with few stakes in forest maintenance (Ruf 1995). These are coupled with the influence of fluctuating commodity market pressures that direct producers toward intensification, either to capture high-return opportunities or to make up for periodic market "busts" in key crops (Ruf 2011).

These have together been observed to work against the maintenance of complex agroforests (DeForesta & Michon 1996), with a pronounced tendency toward simplification of production systems, including the reduction of tree and shrub diversity, the opening of canopy, and the dominance of single crop species (Kusters *et al.* 2008). Generally, this transition is described to move steadily from mature forest mixed with crops to mixed agroforestry, and onwards to monoculture, with local conservation attitudes and traditions impinging little on the overall trend (Feintrenie *et al.* 2010). Subtle producer decisions, including the selective cutting of key tree species, can also slowly transform the ecology of agroforestry landscapes in ways that reduce wildlife habitat (Rolim & Chiarello 2004).

In the case of some smallholder agroforestry production, however, intensity and high yields can co-occur with diversity, assuming adequate complexity of the system is maintained, including adequate shade, sufficient hand labor, and specific inputs. Compellingly here, biodiversity of trees, fungi, invertebrates, and vertebrates have been shown to not decrease with yield (Clough *et al.* 2011).

In sum, several things are increasingly well understood in commodity agroforestry production including: (1) the high variability of biodiversity-relevant structural decisions by producers; (2) the tendency for local livelihood conditions to favor intensification decisions; and (3) the resultant (but not inevitable) simplification of traditionally complex agroforestry systems. Less well explored are the ways key variables (e.g., tenure, crop types, migration) impinge on specific agroecological decisions within the intensification process, whether these are canopy, tree diversity, or chemical inputs, that maintain or erode system complexity. So too, few if any studies of producer decision variability and change have been conducted to include assessment of actual biodiversity outcomes resulting from specific decisions or suites of decisions. As a result, it is still impossible to determine the degree to which farm-scale diversity is influenced by factors like market regulation, price supports, subsidized inputs, scale of production, or specific configurations of property rights.

From producer practices to political and institutional economics

The linkage of these processes, especially intensification, to contextual and wider scale pressures and incentives is made all the more complex by the unstable and turbulent flows of crops and capital in global commodity circulations. Indeed, nonstate experiments that seek to influence diversity outcomes amidst commodity production often fail for precisely overlooking these bottom-line questions. A case from coffee production in Western Ghats India shows, notably, that even the most well-meaning experiments tend to stress conservation outcomes at the expense of the political-economic conditions and constraints faced by local producers (Garcia *et al.* 2010).

As such, a dominant driver of producer decisions is farm gate prices of key commodities, mediated by the scale and type of production. These together have significant influence on the intensity of production and the simplification of the agroecology. A decline in coffee prices between 2000 and 2004 resulted in a loss of agroforests in southern Guatemala, with medium scale farms apparently the most sensitive to this impact (Haggar *et al.* 2013). Farm scale, therefore, may mediate/exacerbate shifts in commodity prices.

State institutions also have a significant influence on agroforestry intensification decisions. A fall in coffee prices, coupled with hurricane activity led to a decline in coffee production overall in the latter part of the 20th century in Puerto Rico, for example. More significantly, however, surviving coffee production in the region is owed heavily to state-sponsored crop and farm insurance and cash subsidies, which were available only to high-intensity, sun-grown coffee producers (Borkhataria *et al.* 2012). Price supports may encourage intensification and simplification in agroforestry systems, though research in this area remains highly limited.

The role of available labor, its regional and seasonal availability, and its overall and periodic price, have enormous implications for agroforestry. Where labor is scarce or expansive, most obviously, there are increased incentives to substitute chemical inputs for hand-weeding or cultural practices that address pests. Such forms of intensification might be predicted to heavily influence biodiversity at the farm scale. Conversely, labor scarcity might be predicted to lead to land abandonment (Aguilar-Stoen *et al.* 2011). Research on labor and agroforestry, relative to biodiversity, is enormously scarce, making analysis of the role of labor highly speculative.

In the area of political-economy, research and analysis have focused on alternative trade systems and third-party certification, where premiums are assured to producers to maintain less-intensive production regimes in commodities like coffee. This work stresses the need for certification to ensure a sufficient price premium for producers to encourage nonintensive (and by implication: biodiversity-friendly) production (Perfecto *et al.* 2005). Research in this area has highlighted the potential for these approaches to maintain extensive and complex production systems as well as human livelihoods (Gobbi 2000). The work has documented consistently and repeatedly, however, where and how such schemes fail to maintain traditional producer livelihoods (Mutersbaugh 2002). Nevertheless, alternative trade systems research has been focused far less on the ongoing influence of these incentives to encourage specific producer decisions on farm-scale ecosystem structure, or on the impact of such schemes on biodiversity-relevant outcomes.

In short, though a host of political and economic drivers are associated with agroforestry intensification and associated simplification, consistent and strong relationships remain elusive. While impact of crop prices is increasingly well understood, as is the potential role of certification schemes, the specific and consistent agroecological implications of changes in farm gate prices, development of state subsidies, declining availability of cheap labor, and alternative trade systems, remain largely unknown.

Commodity agroforestry and biodiversity needs: integrated policy and analysis

The key conclusions from a review of the literature, therefore, stress the sensitivity of biodiversity outcomes in commodity landscapes to larger scale economic and political processes, as well as contextual factors governing producer agroforestry decisions, all with indirect implications for diversity. As summarized in Table 1, current research has established several critical links, including demonstrating strong relationships between key elements of agroecology and biodiversity outcomes, between socioeconomic stressors and intensification of production, and the importance of price volatility on crop transitions.

We might preliminarily conclude that:

(1) the complexity/simplicity of agroforestry systems impinges on biodiversity; movement toward ecological simplicity likely leads to decreased diversity;
(2) decisions toward simplicity are conditioned by farm-level contextual factors, especially commodity price

Table 1 Status of research along the chain of explanation in agroforestry production landscapes

Component in the chain of explanation	Status of research	Areas of weakness
Political Economy ↓ Producer Decisions	• Establishing impact of price volatility on cropping choices • Extensive research on alternative trade networks • Evaluating certification instruments	• Underexamination of labor markets and dynamics • Underexamination of nonstate institutional impacts • Poorly linked to direct analysis of agroecology and diversity
Producer Decisions ↓ Agroecology	• Demonstrating high variability in ecological structure of agroforest production systems • Establishing recurrent pattern of intensification at the regional scale • Enumerating range of stressors impinging on farm intensity decisions	• Lack of specificity in impacts on differing agroecological decisions • Unlinked to assessments of biodiversity outcomes
Agroecology ↓ Biodiversity	• Establishing strong relationship between key variables (canopy, tree diversity, understory) and biodiversity outcomes • Demonstrating role of agroforestry in a broad conservation matrix	• Crop and species-specific studies only • Unlinked to studies on producer decisions/behavior

variability; more consistent prices likely lead to toward maintenance of complexity;

(3) these decisions in turn respond to the presence of institutions that encourage or offset production intensity; crops with high price volatility likely encourage intensification and simplification with concomitantly lower levels of diversity, though price supports to offset variability may do the same.

Taken together, these general observations should encourage policymakers concerned with biodiversity to consider the impact of price supports and seek to influence trends like the shift from high-volatility commodity crops to low-volatility ones. This focus would necessarily be in contradistinction to a focus solely on protected area development, commodity certification, and payment for ecosystem services. Instead it would stress the raw and sometimes overwhelming influence of production conditions and commodity production itself.

Some further hypotheses might be forwarded, though these demand far more rigorous assessment, including: the smallest and largest holders may be able to maintain complexity/diversity in the face of labor/price pressures, owing to self-exploitation on the one hand and diversified resources on the other; decreased labor availability (increasingly common in tropical rural areas) may encourage simplification. Again, biodiversity policy might include further serious examination of political economic conditions and shifts, including rural labor conditions and the migration of workers out of the countryside. Policy might further identify differential targets for support, especially by farm scale and crop.

To this end, Table 2 represents a first-cut approximation of likely consequences of several available policies, to help structure decision-making based on current knowledge. Notably, policies that subsidize production of high-shade crops can be predicted to benefit some species, but at the expense of yields. Directly payment for ecosystem services likely performs similarly. Subsidies for inputs (a common regime in many tropical contexts), though useful for insulation from price volatility, likely negatively impact some key species. Less frequently observed policy options, including subsidies or investment in labor or infrastructure for rural workers (e.g., electrification or health services), however, though serving the same economic purpose, would likely have a reverse (or positive) impact on input-sensitive species.

As this review has suggested, however, further and more specific conclusions remain elusive because not all components of this chain of explanation are equally well explored. It is unclear whether and to what degree, for example, canopy-sensitive species would respond to input subsidies or subsidies for labor. Similarly, more input-sensitive species may or may not be impacted by subsidies for specific crops. Finally, the impact of income diversification, through things like remittances, homestay tourism, or processing, is entirely unknown.

The central source of these uncertainties is the fact that biodiversity studies remain largely rooted in small-scale or regional case analysis. Studies of agroforestry producers typically lack specificity regarding differing key

Table 2 Consequence table for structured decision-making in agroforestry production and biodiversity

	Producer conditions		Likely diversity outcomes	
	Yields	Insulation from price volatility	Canopy-sensitive biodiversity (e.g., avians)	Input-sensitive biodiversity (e.g., amphibians)
Subsidies for higher shade crops (e.g., Arabica coffee)	−	+	+	?
Input subsidies (e.g., fertilizer/pesticides)	+	+	?	−
Payments for ecosystem services	−	?	+	+
Investment/subsidies in services or pay for labor	?	+	?	+
Income diversification (e.g., homestays)	?	+	?	?

decisions within the farming system. Finally, political-economic explorations have underexamined labor markets and nonstate institutional impacts on decision-making, among other factors.

More profoundly, the links of each element of this chain to another remain only loosely documented. This is in part because each component remains relegated to disciplinary specialization that deters more comprehensive analysis. While work on biodiversity is conducted in fields allied with Conservation Biology, research on farm-scale decisions and intensification are rooted in work linked Agricultural and Applied Economics, while studies of the impact of markets and institutions are largely found in research traditions like Geography and Development Studies, focusing on management, development, or political economy.

To form more robust hypotheses about cascading relationships between biodiversity, farm-scale operations, regional policy, and global economy, and so to understand how policy might actually impinge on biodiversity outcomes in valuable agroforestry landscapes, would require more integrative team efforts than heretofore have been common. Testing such hypotheses in a meaningful way, moreover, would require the development of broader, more interdisciplinary, and extensive research efforts, not reflected in the current literature. What is needed, in other words, is a rigorous assessment, within several commodities of regional importance, of producer decisions that result in biodiversity-relevant cropping decisions, and technology and cultivar choices. These decisions must further be linked, in a clear and credible way, to specific biodiversity outcomes. Finally, a survey of the institutional, political, and economic conditions must be conducted to ascertain which factors, if any, consistently direct these specific production decisions. In sum, despite decades of promising work, an integrated analysis of commodity biodiversity remains on the horizon.

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