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Trees for life: The ecosystem service contribution of trees to food production and livelihoods in the tropics☆

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ABSTRACT

Despite expanding interest in ecosystem service research over the past three decades, in-depth understanding of the contribution of forests and trees to food production and livelihoods remains limited. This review synthesizes the current evidence base examining the contribution of forest and trees to agricultural production and livelihoods in the tropics, where production often occurs within complex land use mosaics that are increasingly subjected to concomitant climatic and anthropogenic pressures. Using systematic review methodology we found 74 studies investigating the effect of forest or tree-based ecosystem service provision on a range of outcomes such as crop yield, biomass, soil fertility, and income. Our findings suggest that when incorporating forests and trees within an appropriate and contextualized natural resource management strategy, there is potential to maintain, and in some cases, enhance yields comparable to solely monoculture systems. Furthermore, this review has illustrated the potential of achieving net livelihood gains through integrating trees on farms, providing rural farmers with additional income sources, and greater resilience strategies to adapt to market or climatic shocks. However, we also identify significant gaps in the current knowledge that demonstrate a need for larger-scale, longer term research to better understand the contribution of forest and trees within the broader landscape and their associated impacts on livelihoods and food production systems.

1. Introduction

Forests provide a range of ecosystem functions that are fundamental to sustaining terrestrial systems (Abson et al., 2014; Chazdon et al., 2009; MEA, 2005). These functions are thought to contribute vital support to the provisioning of ecosystem goods and services needed to maintain human populations (Foley et al., 2005; Matson, 1997; Mery et al., 2005). The contribution of forests to nutrient cycling (Power, 2010), soil formation (Pimentel and Kounang, 1998), climate (Daily and Matson, 2008), and water regulation (De Groot et al., 2002) is now well established. Forests are also well recognised as important habitats for faunal and floral resources that directly provide vital provisioning services through the production of fuel and fibre (Rojstaczer et al., 2001; Vitousek et al., 1986). Furthermore, they can aid in regulating pest control (Bale et al., 2008; Karp et al., 2013; Klein et al., 2006) and supporting pollinating services (Kremen et al., 2002; Klein et al., 2007). Finally, in Africa at least, the links between tree cover, access to food and improved dietary diversity are also becoming increasingly evident (Ickowitz et al., 2014; Johnson et al., 2013).

The literature on ecosystem services has increased considerably in the last three decades and yet the concept remains contentious (Barnaud and Antona, 2014). Early proponents of the ecosystem service concept (Ehrlich and Mooney, 1983; Westman, 1977) used the term to illustrate the depletion of natural resources through anthropogenic activities that would impede the capacity of ecosystems to provide vital services. These authors and others (Daily, 1997, Chapin et al., 2000) assert that such services are provided by nature and significantly contribute to human well-being in numerous ways.

Others contest that it is the environmentally sensitive actions of humans that facilitate the provision of ecosystem services (Gordon et al., 2011; Sunderlin et al., 2005; Wunder, 2005) - discourse that is congruent with the motivation for researchers to develop and apply an

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economic valuation of ecosystems and the services they provide (Costanza et al., 1998; Woodward and Wui, 2001). Subsequent policy instruments, such as payments for ecosystem services (Wunder, 2008, 2005) have been developed to financially compensate land managers for preserving ecosystem services and refraining from destructive land-use practices. More recently, researchers have posited that ecosystem services are co-produced by socio-ecological processes—that is a mixture of natural, financial, technological, and social capital—typically requiring some degree of human intervention to support appropriation (Biggs et al., 2015; Palomo et al., 2016).

While there remains some disagreement as to how ecosystem functioning translates into the delivery of tangible benefits in the form of ecosystem services (Cardinale et al., 2012), it is now well acknowledged that the preservation of biological diversity and associated habitats can maintain or enhance ecosystem service provision (Hooper et al., 2005; Isbell et al., 2011; Lefcheck et al., 2015). As such, landscape management is increasingly considered to be best conceived through a holistic lens that encourages multi-functionality (O'Farrell et al., 2010; Reed et al., 2016; Scherr and McNeely, 2008; Vandermeer et al., 1998). In this regard, multi-functionality typically refers to either spatial or temporal segregation, or functional integration (Brandt, 2003).

This review is concerned with the latter—the integration of multiple functions within the same landscape—in this case, the contribution of forests and trees, and their associated ecosystem functions, to food production in the tropics. Food production systems globally have been greatly intensified throughout the past century. As a consequence, primary forests, trees, and the associated provision of ecosystem services have suffered sustained and ongoing decline (Foley et al., 2005; Power, 2010). Furthermore, as the social and environmental costs of industrial food production have become better understood, it is increasingly recognised that this model cannot continue to be pursued sustainably (Foley et al., 2011; Godfray et al., 2010). Therefore, alternative strategies that reconcile biodiversity conservation and food production warrant further consideration (Minang et al., 2014; Sayer et al., 2013; Sunderland et al., 2008). This is particularly pertinent in the tropics, where the majority of global biodiversity hotspots occur (Myers et al., 2000). Yet these hotspots are highly susceptible to the drivers and impacts of global environmental change such as forest conversion, high levels of poverty, and food insecurity (Gardner et al., 2009; Laurance, 1999).

Agriculture and forestry have traditionally been managed as sectorial, and sometimes antagonistic, entities, often contributing to social and environmental conflicts. However, the two are inextricably interlinked. While the drivers of deforestation and forest degradation are complex and vary by region (Lambin et al., 2001), on a global scale agriculture is estimated to be the primary driver of deforestation (Foley et al., 2005, Scherr and McNeely, 2008, Gibbs et al., 2010), responsible for approximately 80% of forest loss (Kissinger and Herold, 2012). These losses account for emissions of 4.3–5.5 Pg CO_2 eq. yr^{-1} (Smith et al., 2014), which represents approximately 11% of total global carbon emissions (Goodman and Herold, 2014), accelerating climate change, and in turn inhibiting forests capacity to provide essential ecosystem services (Laurance et al., 2014). As such, a better understanding of the interactions between forest ecosystem services and agricultural production is fundamental to the sustainable management of terrestrial resources.

This review was conceived around the notion that, despite a rapidly growing body of literature on the role and value of ecosystem services, the contribution of forests and trees—via ecosystem service provision—to adjacent or embedded food production systems in the tropics remains poorly understood. Furthermore, we speculate that the contribution of forests, in terms of ecosystem services provision, to food production systems may often be based on anecdotal evidence or may not be well supported with robust evidence of the "true" functional value. As such, this review assesses the contribution of trees and forests to food production in the tropics, where production often occurs within complex land use mosaics that are increasingly subjected to concomitant climatic and anthropogenic pressures (Gibbs et al., 2010; Steffen et al., 2015). While we acknowledge the value of tropical forests for the direct provisioning of food (i.e. fruits, nuts, leafy vegetables etc.) that contributes to local dietary and nutritional quality (Powell et al., 2015), this review is concerned with the indirect non-provisioning ecosystem service (i.e. regulating and supporting services) contribution of forests and trees, and the effect these have on food production.

This systematic review synthesizes the current evidence base by assessing the contribution of trees and forests to food production through ecosystem services derived from both within agroecosystems and extant natural forests. We anticipate this synthesis will contribute towards efforts that address the current controversies of independently addressing food production and forest/biodiversity conservation and highlight the potential of integrating land uses within multifunctional landscapes to deliver a diverse suite of ecosystem services (Foli et al., 2014; Glamann et al., 2015).

2. Methods

We followed standard systematic review methodology, detailed in Foli et al. (2014), to identify and screen literature from a number of specialist databases, grey literature sources, and key institutional websites (Foli et al., 2014). All searches were conducted in English and covered publication years from 1950 to July 2015. Preliminary searches were conducted to test the search terms and strategy in Web of Knowledge only. This initially yielded 321 hits. After expanding the number of search terms, the number of hits increased to 63,253. A final search strategy (see: Foli et al., 2014 for protocol including detail on search strings employed) was determined which yielded 9932, which

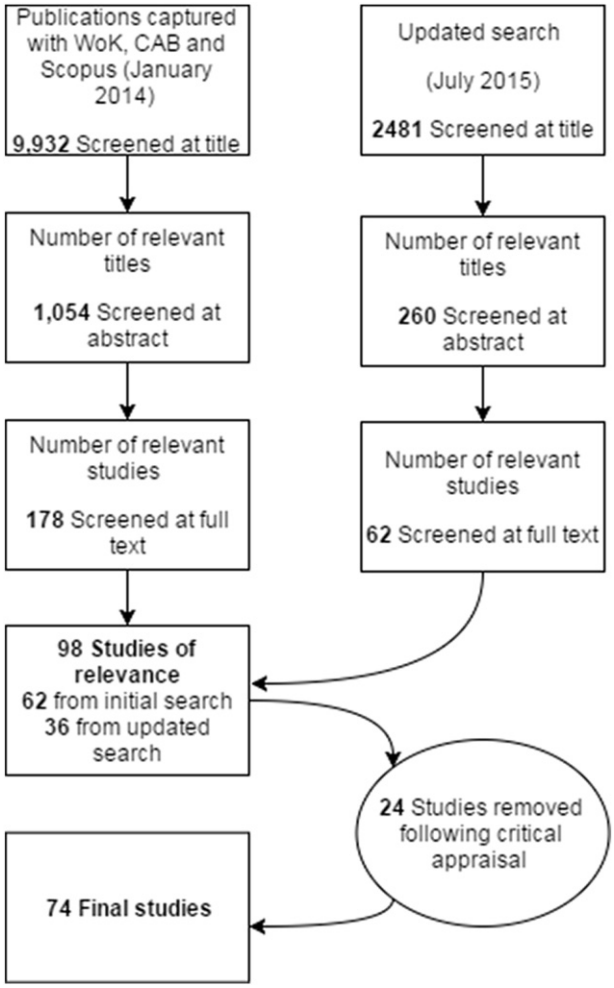

Fig. 1. Flow diagram showing the systematic screening process.