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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

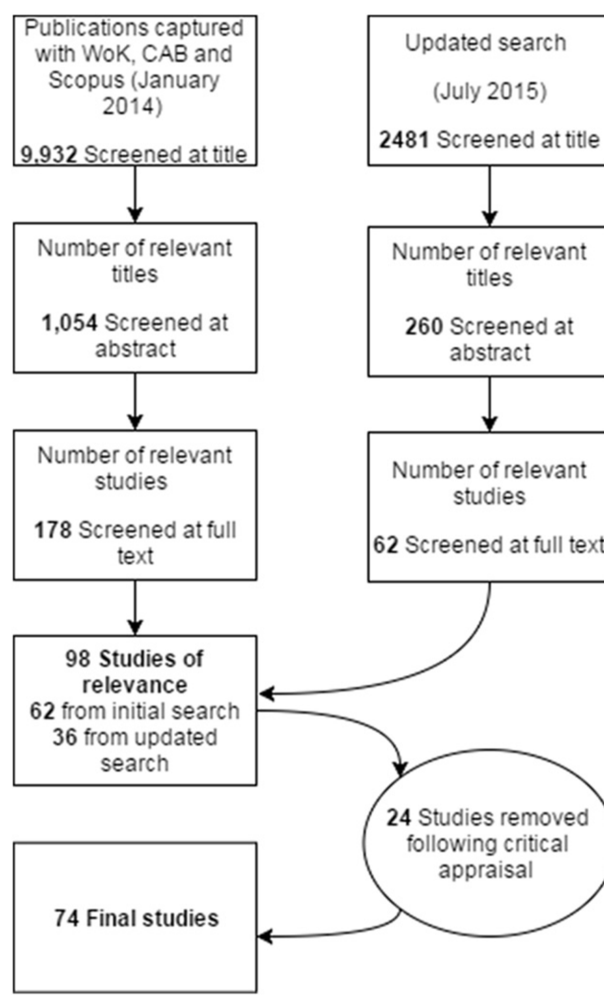

Fig. 1. Flow diagram showing the systematic screening process.

constituted the set of documents we worked with (see Fig. 1). The initial searches were conducted in January 2014. An updated search was performed in July 2015 to account for additional articles produced during the period of the initial literature screening process. All articles were screened sequentially for relevance at title, abstract, and full text stages.

2.1. Study inclusion and exclusion criteria

At the title and abstract stage, studies were screened for relevance and accepted for the next stage of assessment if they were studies within the tropics that measured forest or tree-based ecosystem services and agricultural output.

At full text screening, final study inclusion was determined if studies met the following three criteria:

Relevant study method/design: studies showed a transparent and repeatable research design.

Relevant study comparator: studies presented comparisons between agricultural systems with and without tree presence (either replicated or longitudinal comparison).

Relevant study outcomes: studies measured and reported outcomes that showed a clear positive, negative or neutral effect of tree or forest presence on ecosystem functions in agricultural systems.

Studies were excluded from the review if they met one or more of the following criteria:

- Studied ecosystem services only at global scales.
- Exploratory studies, conceptual frameworks, non-empirical, or methods papers.
- General forestry and agricultural policy briefs.
- Studies solely on the economic evaluation and accounting of ecosystem services.
- Studies outside the tropics.
- Studies solely on the contribution of wind pollination to crop production.
- Studies with relevant results but without transparent methodology or findings.

Those articles accepted at full text were then critically appraised before data extraction. A peer-reviewed protocol provides a detailed account of the research design, methods, and inclusion criteria (Foli et al., 2014).

2.2. Data extraction

Data extraction was performed by all authors. Due to differences in reporting and use of terminology across the final suite of articles, ecosystem services derived from forests or trees were grouped according to nine simplified categories for analysis (see Table 1). Similarly, an article often examined multiple ecosystem services and therefore reported multiple study outcomes. For the analysis of this review, outcomes for each ecosystem service reported in each article were grouped in 13 categories (see: Fig. 5) by the presence or absence of trees having a positive, negative, neutral or mixed effect on any reported food production or livelihood component. Unsurprisingly, given the review focus on food production, all included studies reported a direct measure of the effect of tree or forest presence on crop production or farm yields—except in three cases where sufficient proxy measures of yields were explicitly given. These include two pest control studies (Gidoin et al., 2014; Karp et al., 2013) and one pollination study (Blanche et al., 2006).

Further analysis of the system-wide effects of trees/forests was performed by aggregating all recorded outcomes for the effects of trees/forests. These system-wide effects of tree presence were classified as representative of an overall effect on livelihood outcomes. For example, trees may have had no effect on yields when compared to non-tree controls yet had a positive effect on soil fertility within the system, thus having a net positive system-wide effect. This would result in the study being documented as an overall (system-wide) positive effect of trees and thus a positive livelihood outcome. Similarly, a negative effect on yield and a positive effect on primary production would result in an overall (system-wide or livelihood) mixed effect of tree presence. Appendix 1 provides a full list of the variables assessed in this review.

3. Results

3.1. Review statistics

The initial 9932 articles were reduced to 1054 after title screening, 178 after abstract screening and finally 62 articles for critical appraisal and data extraction after full text screening. Updated searches conducted in July 2015 identified a further 2481 articles, of which 36 were retained after full text screening. Twenty four articles were eliminated during critical appraisal—screened by a second reviewer to assess conformity to the inclusion/exclusion criteria—resulting in a total of 74 articles in the final review. Fig. 1 summarizes the screening process. All articles included in this review were published in peer-reviewed journals, with the earliest retrieved published in 1991.

3.2. Geographic distribution and research focus

A broad range of tropical countries were represented in this review. However, research was predominantly located in East and West Africa, South Asia (Indian sub-continent) and South America (Fig. 2, Table 1).

The final suite of 74 studies investigated the roles of trees and forests on crop yields across a total of nine ecosystem services. However, the majority ($n = 58$) investigated bundled ecosystem service effects (see: Renard et al., 2015) of trees and forests, resulting in 138 data points (distributed across the nine ecosystem services and 74 studies) (Table 1). Cumulatively, the most commonly studied ecosystem services were primary production and nutrient cycling, accounting for 29% and 25% of the ecosystem services studied, respectively. These patterns were consistent across the regions with the exception of Australia where both studies focused on pollination. The third most commonly studied ecosystem service varied across the regions – in Africa, resource

Table 1
regional distribution of ecosystem services studied.

	Africa ($n = 39$)	Asia ($n = 12$)	Americas ($n = 21$)	Australia ($n = 2$)	Total
Primary production	19	14	7		40
Nutrient cycling	22	9	4		35
Pollination	5	4	3	2	14
Microclimate	7	6	1		14
Resource competition	8	4	1		13
Water retention	4	4			8
Soil formation	3	1	2		6
Pest control	4		1		5
Carbon storage	2	1			3
Total services studied	74	43	19	2	138

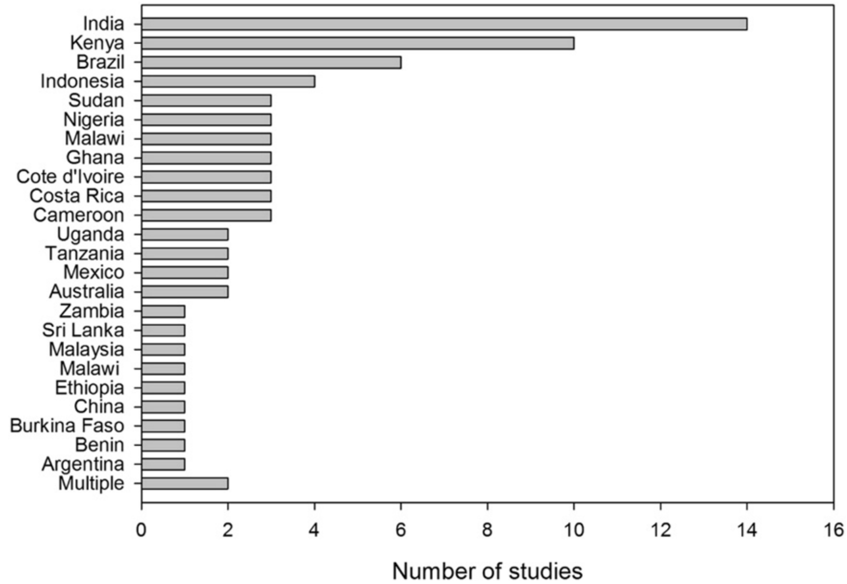

Fig. 2. Frequency plot showing study country distribution.

competition (dis-service) ($n = 8$), in Asia, microclimate ($n = 9$), and in the Americas, pollination ($n = 4$).

The study system characteristics were largely dominated by agroforestry studies (Fig. 4). Of the total 74 studies, 58 were agroforestry studies, and only 5 of these were agroforestry systems under the forest canopy – the remaining 53 were trees introduced to the farm (typically alley cropping). Only 12 studies investigated the effect of spatially distinct natural forest patches on agroecosystems, namely off-farm forests and trees – mostly consisting of studies utilizing agroforestry gradients (investigating yield outputs from a range of land use types from canopy agroforestry to monoculture full sun systems) (see Figs. 3 & 4). Furthermore, we found that most studies—particularly those with planted trees—were conducted over short timescales (<3 years, $n = 58$) (4). As such, of the 54 genera of tree species recorded, the most frequently represented were the common agroforestry taxa of *Acacia, Gliricidia, Leucaena* and *Sesbania* (represented in 12%, 11%, 6%, and 4% of studies respectively—for a full list of tree and crop species studied, see supplementary material). Of the studies that evaluated the contribution of off-farm forests and trees, eleven were researching the impact of forest distance or diversity on pollination or pest control services. While most of these were also within agroforestry systems, these were the few studies that investigated ecosystem service provision within or from natural or semi-natural forest systems—as opposed to food systems that incorporated planted trees. We found only nine long-term studies (≥7 years)

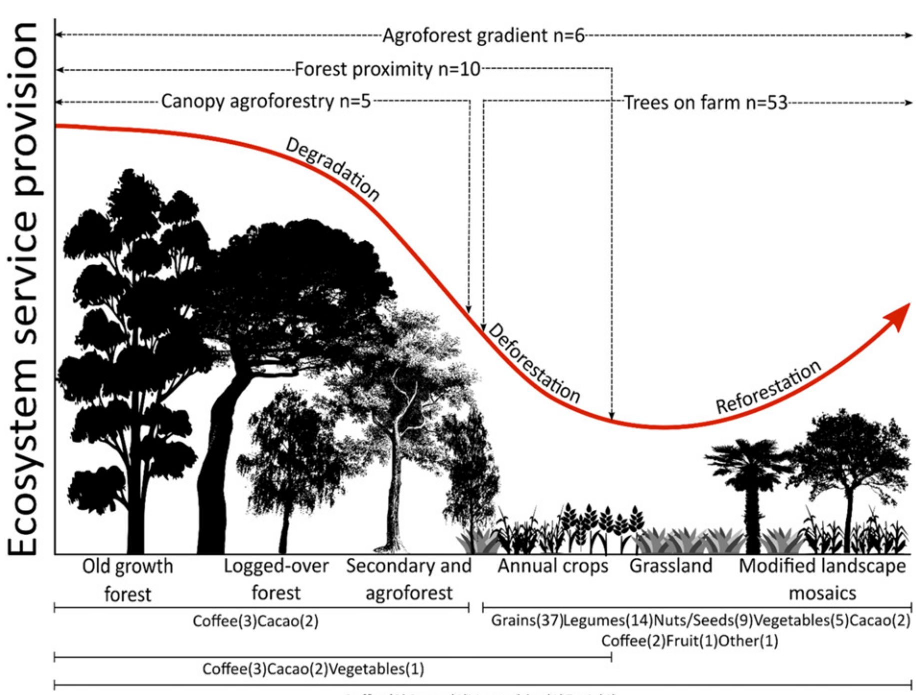

Fig. 3. Figure showing a forest transition curve and the position along which the reviewed studies are placed according to their study system characteristics (above the transition curve) and corresponding food produced (below x axis).

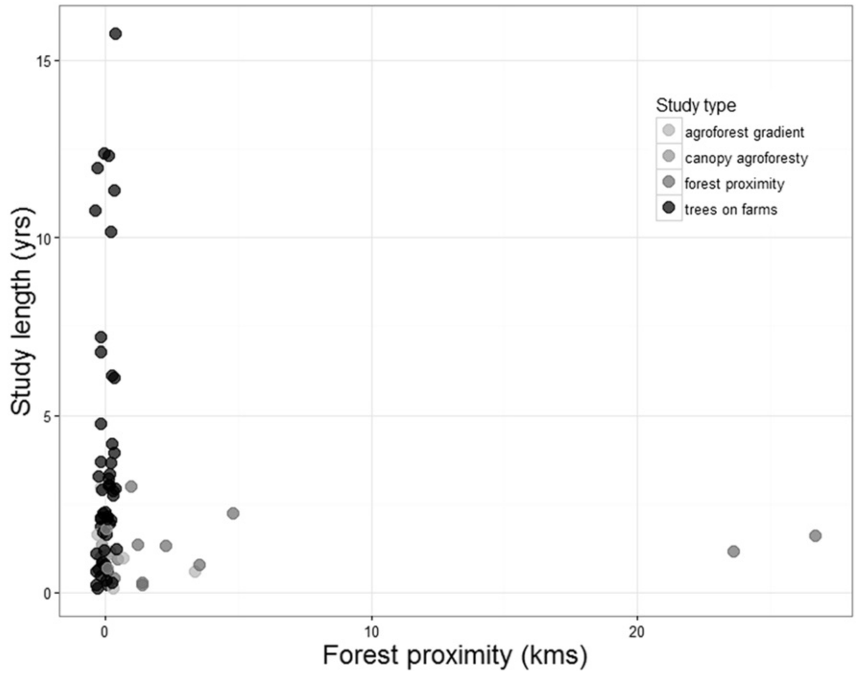

Fig. 4. Scatter plot of study durations and forest proximity for different study types.

and these were all on-farm or within research station experimental plots. Whereas studies that assessed off-farm provision of forest ecosystem services were all short term (≤3 years). Fig. 4 clearly illustrates the lack of long term, landscape-scale evaluations of forest ecosystem service provisioning.

3.3. The effect of tree presence on food production in the tropics

The overall trend across the studies shows that in the majority of cases (52%) there was a net positive (47%) or neutral (5%) effect of tree presence on food yields or food yield proxies. However, when the results are disaggregated by region, there is a degree of variability (Fig. 5). For example, in the Americas and Asia, tree presence was more likely to enhance food yields with positive effects of trees on yields reported in 58% and 54% of studies for these regions respectively; while in Asia the opposite is the case, with the majority of studies (48%) reporting decreased food yields as a result of tree presence (Fig. 5).

3.4. The "overall livelihood" effect of tree presence in the tropics

Studies often investigated multiple ecosystem services and reported on multiple outcomes – for example, one study may investigate nutrient cycling and primary production and measure effects on differences in crop yield and soil fertility. Consequently, the final set of 74 articles recorded 138 data entries for ecosystem services studied and 164 data entries for measured effects of trees. Due to inconsistencies in terminology used across the studies, we developed thirteen broad categories of effect variables. Given the review's primary focus on food production, some measurement of yield was a prerequisite for inclusion and hence had a recorded outcome for all 74 final studies. Any other effects directly linked to tree/forest presence were also recorded, with the most widely reported effects of trees other than yield being soil fertility and income (Fig. 6).

By combining the empirical data and the self-reported anecdotal evidence within the articles, the review team was able to broadly establish overall livelihood effects for each of the articles—i.e. whether there is a net positive or negative effect of tree cover on livelihoods. While it has to be noted that this was largely a subjective process and not always supported by empirical data, it was felt that this was a useful exercise as often articles that reported depressed crop yields due to resource competition effects of tree presence also reported (in discussion and conclusions) overall livelihood gains due to other economic benefits derived from trees, such as the provision or sale of fuelwood, mulch, or fodder for example. Hence, when examining the overall livelihood effects of tree presence across the 74 articles in this review, the majority report a positive effect (46%) which closely mirrors the effects on yield (47%) (Fig. 6).

The main difference when comparing the effects of trees on yields with the overall livelihood effects of trees across all studies is the reduction in the total negative effects from 36% for yield to 16% for overall livelihood effects, suggesting that a reduction in yields may be compensated by other benefits provided by trees to the farm system (Fig. 6). This cost/benefit relationship—where the cost of crop yield losses is compensated by the overall benefits of incorporating trees—is consistent across the study regions with Africa, Asia and the Americas reporting negative effects of trees on crop yields in 33%, 48%, and 33% of studies but negative effects of trees on overall livelihood outcomes in only 15%, 24%, and 8% respectively (Fig. 7).

In studies where trees were shown to have a positive effect on food yield, the overall livelihood effect was also positive (86%) and never returned a negative outcome, although 11% of studies showed a mixed effect i.e. some negative and some positive effects on overall livelihood outcomes. However, in the studies where trees decreased food yields, the overall livelihood effect were varied: in 37% of studies that showed trees having a negative effect on yield, livelihoods were also reduced; 59% of studies showed either a mixed effect or no change in livelihoods, while one study showed that negative yield outcomes were fully compensated by improved overall livelihood outcomes (Fig. 8).

4. Discussion

Despite a significant increase in ecosystem service-related research in the past two decades (Abson et al., 2014), this review illustrates that there are clear gaps in the literature with regard to the contribution of tropical forest and tree-based ecosystem services to food production. Principal amongst these is the lack of evidence for the contribution of off-farm tropical forest patches to agricultural systems. Of the few studies identified, the majority—such as those conducted by Blanche et al.,

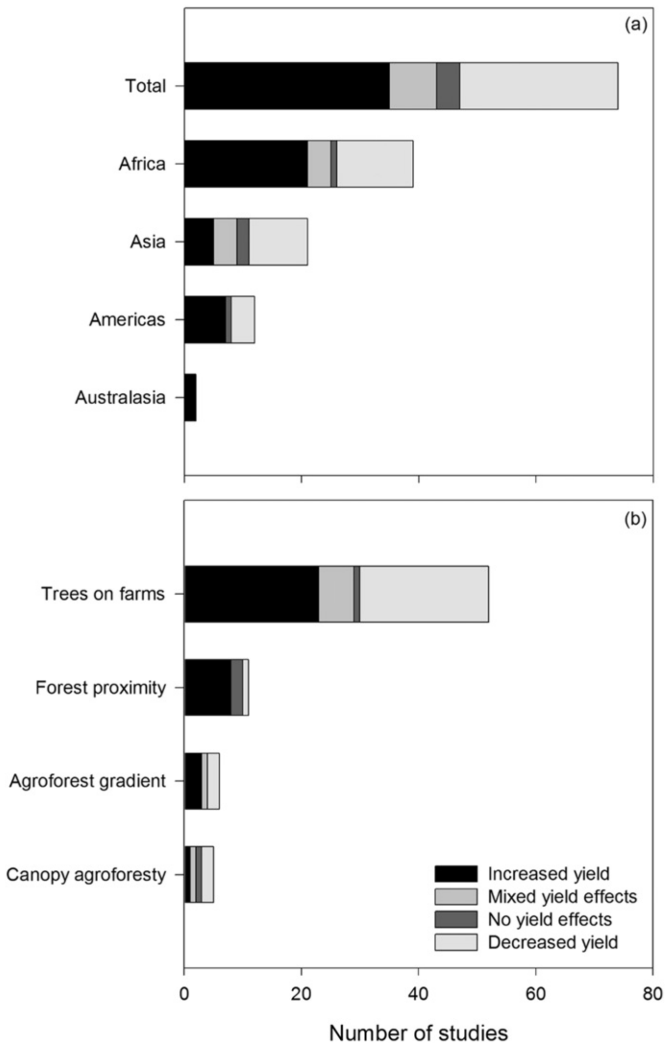

Fig. 5. Frequency plot showing tree effects on crop yields by: (a) regional distribution and (b) study system.

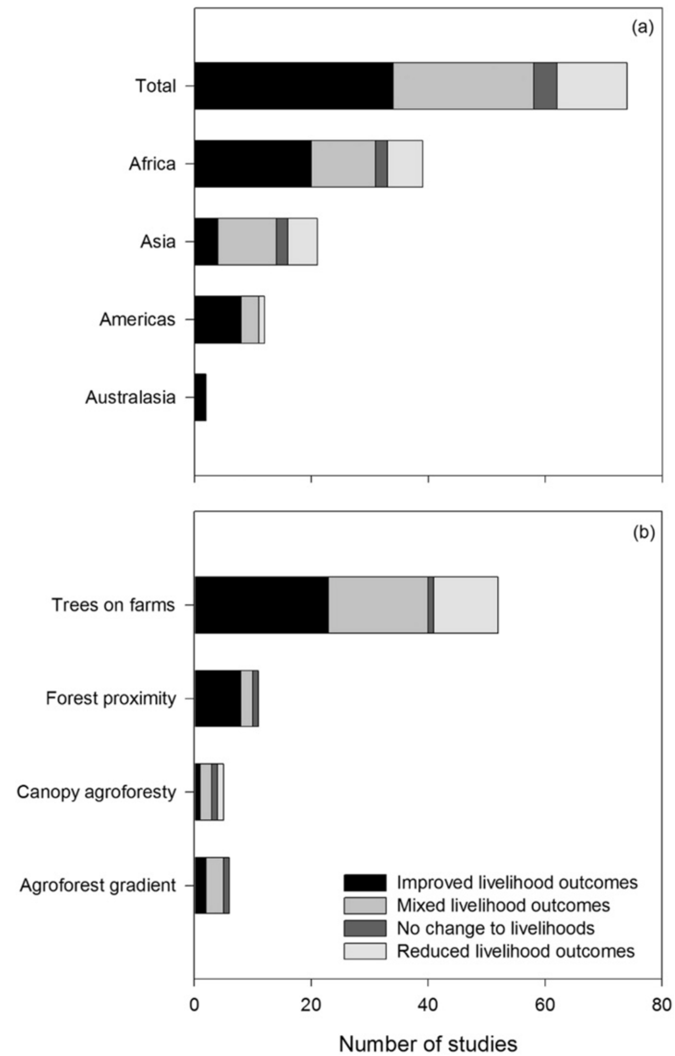

Fig. 7. The overall livelihood effects of trees (determined by the authors by summing multiple system wide effects of trees) categorised by region (a) and study system (b).

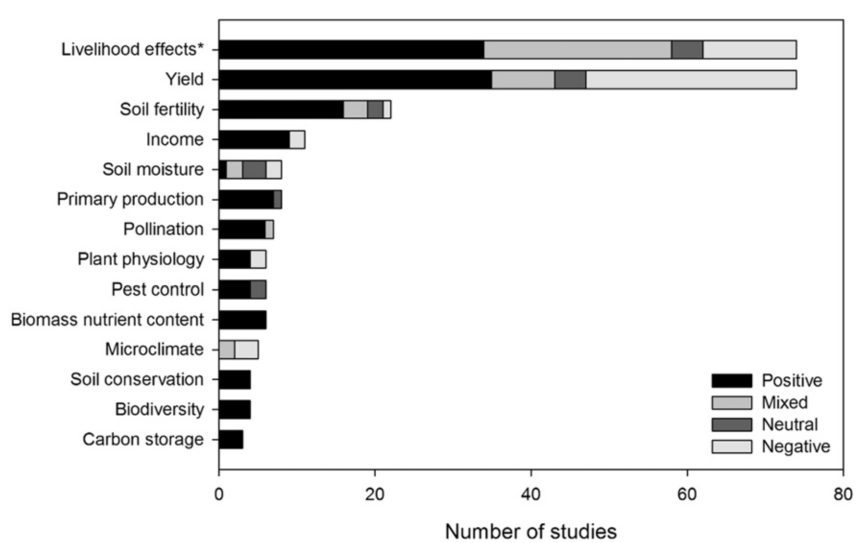

Fig. 6. Frequency plot of the effect of trees/forest on multiple system components across all studies. Non-yield effects were broadly categorised by the authors.*Livelihood effects were categorised by the authors by summing multiple system wide effects of trees.

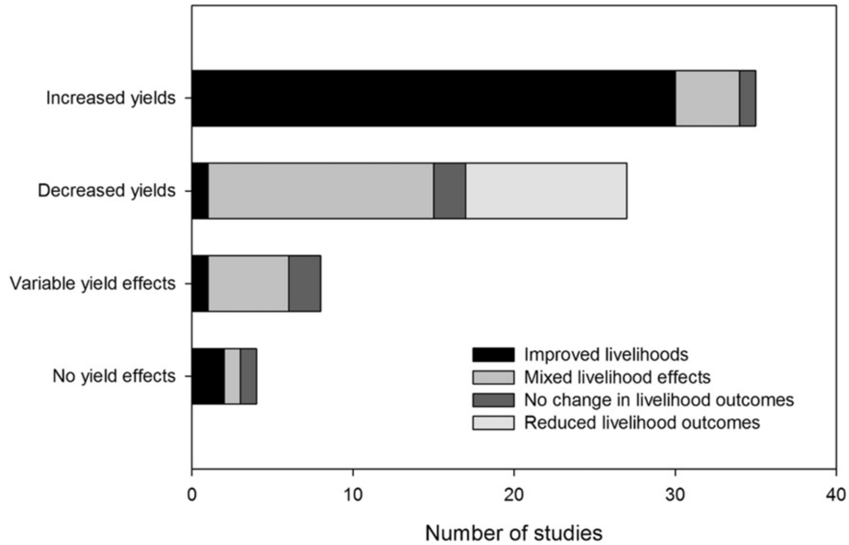

Fig. 8. Frequency plot comparing the direct effects of trees on crop yield and the overall livelihood effects reported across the study system as a result of tree/forest presence.

2006, Klein 2009, and Sande et al. 2009—used a forest distance gradient to establish the effects and thresholds for pollinator success as a sole focus.

While such studies are useful and clearly illustrate the importance of trees and forests for the delivery of a single ecosystem service, it is well acknowledged that ecosystem services do not act in isolation (Boreux et al., 2013a, 2013b; Renard et al., 2015) and therefore studies that examine the interactions of multiple ecosystem services within multiple land use configurations are much needed. As such, the key finding of this systematic review is that there is little clear evidence of the effect of multiple interacting ecosystem services flowing from forest fragments to food systems. This paucity of studies significantly limits our ability to draw conclusions as to the value of forests and trees within the landscape to proximate agricultural systems. Therefore, despite our original objective of attempting to quantify the contribution of off-farm forests and trees to food production, the results presented in this review principally reflect the contribution of trees to food production and livelihoods at the farm scale only.

The temporal and spatial scales of the studies identified in this review point to further gaps in the current understanding of the longer-term contributions of forest and trees to food production. Although spatial information was not always provided in the studies, the large majority were conducted in either smallholder agroforestry systems (typically 0.5–3.0 ha.) or research station small-scale experimental plots (for example 20 × 18 m plots), and over a study period of less than three years. Much of the evidence in this review therefore provides a snapshot in time of ecosystem processes, therefore failing to recognise the changes that can occur over space and time (Renard et al., 2015). The assessment of ecosystem services is not easy and complexity will be increased when transitioning from local to landscape scales (Swift et al., 2004), but given the extensive dialogue on ecosystem service provisioning as a contribution to long-term sustainable systems (Jordan, 2013; Scherr and McNeely, 2008; Tilman et al., 2002), it seems clear that further evidence on the spatiotemporal dynamics of ecosystem service provision to support such claims is both necessary and timely.

We strongly recommend that future research efforts attempt to bridge these gaps by moving beyond the farm gate, as it were. Research that investigates the effects that tropical forests and forest patches have on spatially distinct agroecosystems would increase our understanding of complex systems. This level of research is essential in order to further dissolve the dichotomies of biodiversity conservation and food production which often remain viewed as entities to be addressed individually (Glamann et al., 2015). A further requirement to aid our understanding is the testing of such relationships over time. We agree with Pattanayak (2009) and others (Bauch et al., 2014; Renard et al., 2015), that studies that monitor how forests function over periods beyond the traditional project cycle of 1–3 years are vital to assess the contribution of forests to food production, livelihoods, and the long-term sustainability of integrated landscape approaches (Barlow et al., 2011; Reed et al., 2016).

While many tropical countries are represented in this review, there is a clear geographical research bias towards India and East Africa. It may be the case that the climatic and natural resource conditions of these regions make them particularly pertinent for ecosystem service research; it may reflect the interests of donors funding primary research; there may be greater political will or existing national policies that support agroforestry system research; it may be the presence of research organisations in the region (i.e. ICRAF); or it may be a result of other factors of which we are not aware. An important limiting caveat of this review is that searches were conducted only in English. Consequently, it is likely that searches in other languages would reveal more studies from non-English speaking countries, providing a more even geographic distribution. One recommendation would be for future reviews to be performed in non-English languages, to complement and build upon these findings. Furthermore, a review of temperate systems would also complement the findings we have presented here.

This review indicates that the presence of forest and trees has varying effects on food production, but that the majority of studies showed a direct net positive or neutral effect of tree presence on crop yields. When other factors are considered such as environmental impacts or additional income derived from trees through sale of fuelwood for example, the overall livelihood benefit to land managers can buffer costs accrued through crop yield reductions. Even in Asia where a large proportion of studies showed the presence of trees was negatively impacting crop yields (a finding that warrants further investigation), the overall net livelihood effect suggested that farmers could reduce negative impacts and gain a long-term benefit from incorporating trees on their farms as the total negative effects were greatly reduced (48% to 24%). Given the short term nature of the studies examined here, it could be speculated that when examined over longer time scales the broader benefits of maintaining trees would become more evident.

While this is an encouraging result, the evidence presented here is not sufficient to suggest that tree presence or incorporation will always be the optimal management strategy for food and livelihood outcomes, and land managers should be encouraged to pursue a more nuanced approach to managing complex socio-ecological systems. It is important to note that many studies examined the effects of multiple ecosystem services on multiple outcomes, often with contrasting results. For example, a study may reveal environmental gains from trees planted on farms via improved soil fertility, but also report associated production losses in terms of crop yield due to resource competition (Kidanu et al., 2005; Siriri et al., 2010). Similarly, one study reported an overall negative effect but suggested this may be attributed to the fact that the surrounding forest matrix was intact and healthy and therefore the greater abundance of floral resources inhibited pollination success in the agroforestry system of interest (Boreux et al., 2013a, 2013b). A further study reported mixed success: non-intensive systems were optimal in terms of pollination, however, proximity to forest was not significant (Frimpong et al., 2011). A number of studies showed that net losses in crop yield may be compensated by the additional biomass produced from the planted trees, resulting in an overall net gain (Asase et al., 2008; Chauhan et al., 2010; Fadl, 2010). Moreover, it is clear from this review that the provisioning of individual forest ecosystem services to food production do not act in isolation. Consequently, the potential socio-environmental costs and benefits need to be contextualized and considered over time and space, with land use management strategies applied and adapted accordingly.

5. Conclusion

The study of forest and tree-based ecosystem services in the tropics suffers from both a geographic and research focus bias, and is further limited by the propensity for small-scale and short-term evaluations. The relative dearth of studies prevents us from providing a definitive answer to our original research question—to what extent do forests and trees support food production? There is insufficient evidence—most of which is not directly comparable— to assess the contribution of ecosystem services derived from forests to agricultural systems. The findings of this review very much reflect the contribution of trees to food production at the farm scale rather than the broader contribution of forests and trees within the landscape. To this end, we have generated a database of 74 articles that demonstrate both positive and negative effect of trees on food yields and broader livelihood outcomes. Our findings suggest that when incorporating forests and trees within an appropriate and contextualized natural resource management strategy, yields can be maintained or enhanced comparable to intensive monoculture systems. Furthermore, this review has illustrated the potential of achieving net positive gains through integrating trees on farms, providing practitioners with additional income sources and greater resilience strategies to adapt to market or climatic shocks.

Despite this, contemporary development pathways—particularly within the tropics—often tend towards "conventional" approaches to agriculture and food security that deplete the natural resource base (Gibbs et al., 2010; Gibson et al., 2011; Roe et al., 2014; Steffen et al., 2015). Forest conservation rhetoric largely refers to the benefits for the global community. Meanwhile, conservation of forests and trees at the local scale is often sold as generating other tangible benefits to farmers and rural people through the provisioning of ecosystem services. However, this review has highlighted that the current evidence of the latter—particularly with regard to food production outputs—remains unclear. Research efforts are urgently required to strengthen the evidence base and provide clear, robust data in order to support the transitioning to "alternative" approaches to land management. Without strong evidence linking forests derived ecosystem services to food production and livelihood benefits there remains little incentive for food producers to acknowledge the need for forest conservation at the local and landscape scale. Further evidence is required if we are to illustrate the potential local social and environmental benefits that can be achieved through both conserving trees within the landscape and incorporating them within food production systems.

This systematic review (and the accessible accompanying database) provides a valuable resource for policy makers, practitioners, and researchers in countries where efforts to integrate food production, livelihood enhancement, and tree conservation are already underway. However, it has also identified a number of key knowledge gaps, enabling us to provide the following recommendations for future research: Investigate the effect of off-farm trees and forest patches on proximate food production systems; further examine spatiotemporal forest ecosystem service dynamics; assess how these services interact with other system functions; and further develop appropriate instruments for measuring and comparing ecosystem services.

Current evidence on the association between forests, trees and food production systems in the tropics lack the necessary precision to fully inform practice and policy. A future research agenda that attempts to elucidate the above recommendations would enhance our understanding, providing further support for more integrated approaches to land management that seek to sustainably utilize rather than deplete natural resources.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.forpol.2017.01.012.

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