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POLICY PERSPECTIVE

Land-use history determines ecosystem services and conservation value in tropical agroforestry

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Abstract

Agroforestry is widely promoted as a potential solution to address multiple UN Sustainable Development Goals, including Zero Hunger, Responsible Consumption and Production, Climate Action, and Life on Land. Nonetheless, agroforests in the tropics often result from direct forest conversions, displacing rapidly vanishing and highly biodiverse forests with large carbon stocks, causing undesirable trade-offs. Scientists thus debate whether the promotion of agroforestry in tropical landscapes is a sensible policy. So far, this debate typically fails to consider land-use history, that is, whether an agroforest is derived from forest or from open land. Indeed, 57% of papers which we systematically reviewed did not describe the land-use history of focal agroforestry systems. We further find that forest-derived agroforestry supports higher biodiversity than open-land-derived agroforestry but essentially represents a degradation of forest, whereas open-land-derived agroforestry rehabilitates formerly forested open land. Based on a conceptual framework, we recommend to (a) promote agroforestry on suitable open land, (b) maintain tree cover in existing forest-derived agroforests, and (c) conserve remaining forests. Land-use history should be incorporated into land-use policy to avoid incentivizing forest degradation and to harness the potential of agroforestry for ecosystem services and biodiversity.

KEYWORDS
biodiversity, cacao, carbon stocks, coffee, ecosystem services, forest-derived agroforestry, land-use history, open-land-derived agroforestry, rehabilitation, restoration

1 | INTRODUCTION

Agroforestry is often promoted in global initiatives as a way to simultaneously address multiple UN Sustainable Development Goals (van Noordwijk et al., 2018). Among them Zero Hunger (Goal 2), Responsible Consumption and Production (Goal 12), Climate Action (Goal 13), and Life on Land (Goal 15). Embedded it this context, the UN Decade on Ecosystem Restoration (2021–2030) emphasizes the opportunity to plant trees in agroforestry systems as a way to reverse land degradation and restore ecosystems, thereby contributing to climate change mitigation. However, the concept of agroforestry as an association of trees with crops or livestock on the same land (FAO, 2017) embraces a broad range of systems under different management schemes: Many important perennial agroforestry crops, such as cacao or coffee, can be farmed underneath shade trees. Such agroforests may be established on open land or inside forest (Moguel & Toledo, 1999), but in the latter case, they may contribute to the loss of highly diverse tropical forests (Lewis, Edwards, & Galbraith, 2015; Schroth, 2004). This drawback stimulates debate over the conservation value of tropical agroforests and whether their promotion is indeed a sensible policy (Philpott & Dietsch, 2003; Tejeda-Cruz, Silva-Rivera, Barton, & Sutherland, 2010).

Surprisingly, tropical agroforestry research has made few attempts to investigate how ecosystem functions and services as well as biodiversity differ among agroforests of contrasting land-use history, that is, between forest- and open-land-derived agroforests. Instead, researchers have commonly compared structurally simple with structurally diverse agroforests (Moguel & Toledo, 1999) and have found biodiversity and non-yield ecosystem services to generally increase with structural complexity (De Beenhouwer, Aerts, & Honnay, 2013).

Here, we collate published information on socioeconomic implications as well as ecosystem services and biodiversity in forest- and open-land-derived agroforestry and identify knowledge gaps. We find that forest-derived agroforests can be best described as a form of forest degradation whereas open-land-derived agroforests rehabilitate formerly forested open land (*sensu* Chazdon et al., 2016). We then argue that emphasizing land-use history in tropical agroforestry research and policy may foster biodiversity conservation and contribute to the safeguarding of ecosystem functions and services in tropical landscapes.

2 | SYSTEMATIC REVIEW METHOD

We relied upon a recently published evidence and gap map (Miller et al., 2020), which systematically assessed the available literature on impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being. We used their data extraction record (sup-0001) and filtered the results for the practice type "Trees integrated with plantation crops" AND "Tropical" OR "Multiple" ecoregions to match the scope of our paper. We subsequently excluded 23 studies that were either not in English (1 study), unavailable (2 studies), situated outside the tropics (5 studies), or that investigated combinations of trees with annual crops (15 studies). We then systematically reviewed the remaining 98 papers and assessed whether authors had (a) described land-use history of all agroforestry types studied, (b) directly compared between forest- and open-land-derived agroforests, (c) directly compared agroforests and their former land-use (forest/open land), and (d) discussed the topic. We provide a table with extracted data as Supporting Information.

3 | THE IMPORTANCE OF LAND-USE HISTORY IN TROPICAL AGROFORESTRY

Relatively few crops are shade-tolerant and may be planted directly inside forests (Figure 1). These crops include coffee, cacao, pepper, rubber or vanilla—all crops that can also be planted on open land, but that may partly require specific varieties or temporary artificial or natural shade. In our systematic review, 57% of studies did not describe the land-use history of focal agroforests and only 5% directly compared agroforests of contrasting land-use history. Of those studies which described land-use history, 50% investigated forest-derived agroforests, whereas 38% investigated open-land-derived agroforests and 12% compared the two, emphasizing the importance of both kinds. Forest- and open-land-derived agroforests are commonly found alongside each other in mosaic landscapes across the tropics. In Sulawesi, Indonesia, 50% of cacao plantations are forest-derived whereas the other half was established on open land (Rice & Greenberg, 2000). In north-eastern Madagascar, 70% of vanilla agroforests are open-land-derived, whereas 30% are forest-derived (Hänke et al., 2018; more on vanilla agroforests in Box). The possibility to plant the same crops inside forest and on open land highlights the relevance of land-use history when studying such agroforestry systems. Furthermore, these crops are frequently farmed within forest landscapes in tropical biodiversity hotspots, accentuating the importance of biodiversity friendly farming practices.

4 | SUITABILITY OF OPEN VERSUS FOREST LAND FOR AGROFOREST ESTABLISHMENT

Land accessibility and availability influence whether agroforests are established inside forests or on open land (Meyfroidt et al., 2014, Table 1). Establishing forest-derived agroforests is only possible where forests are available, typically at deforestation frontiers or where forest fragments are scattered in a landscape. As forests are vanishing across the tropics (Lewis et al., 2015), many farmers live far away from available forests, making open-land-derived agroforestry the only option.

Other factors are also shaping agroforestry expansion (Table 1). For example, planting crops inside forest may represent a form of land claim (Meyfroidt et al., 2014), incentivizing forest-derived agroforestry. On open-land,

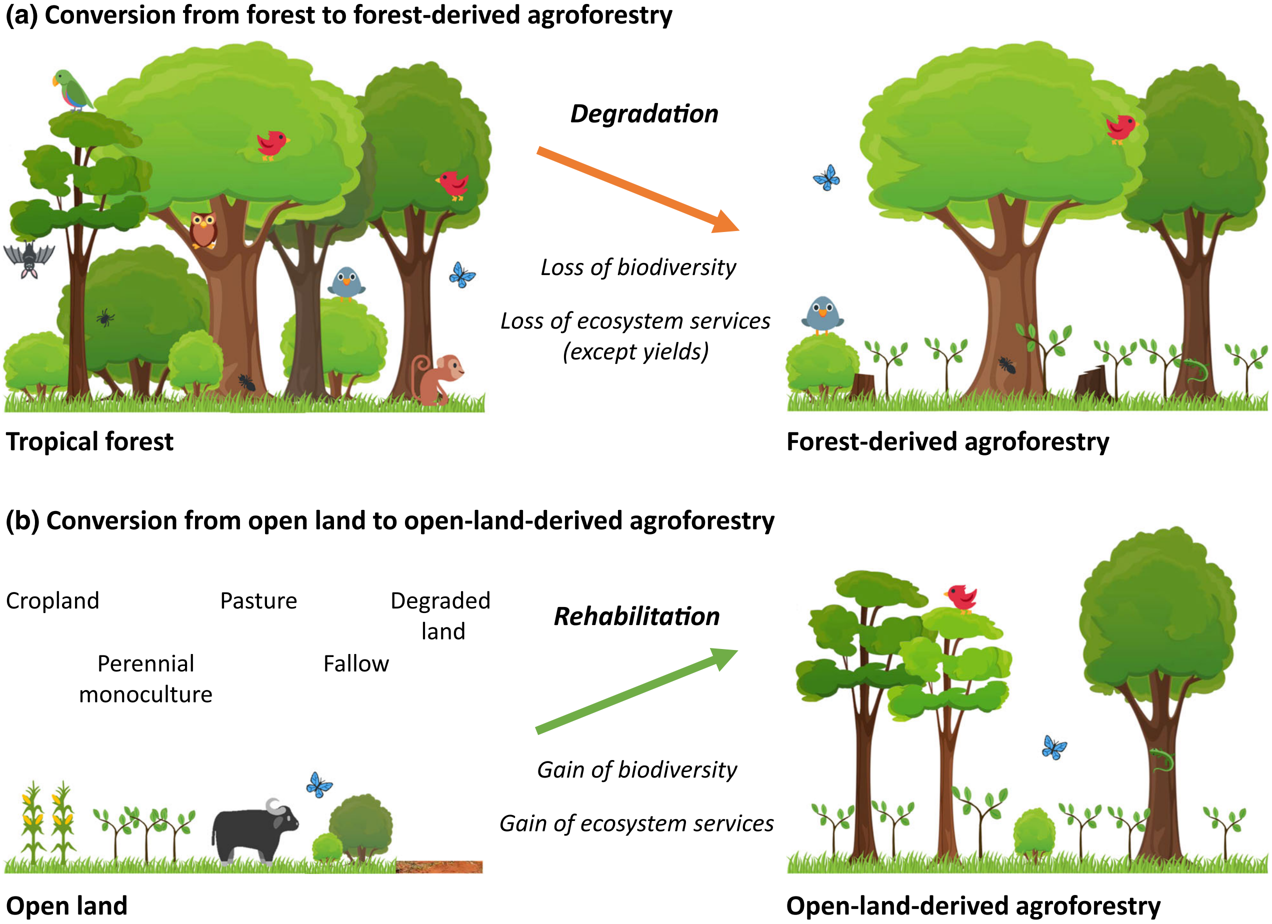

FIGURE 1 Concept of land-use history in agroforestry. (a) Forest-derived agroforests are established by thinning the forest and replacing the understory with shade-tolerant agroforestry crops such as coffee, cacao, rubber, or vanilla, thereby representing a degradation of forest with overall losses of biodiversity and ecosystem services (except for yields). (b) Open-land-derived agroforests are established by planting agroforestry crops alongside planted or naturally regenerating shade trees on suitable open land. Open-land-derived agroforestry consequently has the potential to rehabilitate cropland, perennial monocultures, pastures, fallow or degraded land, leading to gains in biodiversity and ecosystem services

land tenure must already be secured, given the significant investments needed to establish an agroforest (Ruf, 2001). Opportunity costs may apply in either case: For forests, those are likely limited to the loss of forest-specific ecosystem functions and services, whereas on open land, the costs for losing perennial monocultures, arable crop land or pastures will be considerable. Fallows may offer an opportunity for open-land-derived agroforestry, given their abundance in many tropical regions (Chazdon et al., 2009). Degraded land, typically of low value to people and nature (Lamb, Erskine, & Parrotta, 2005), could also be suitable for open-land-derived agroforestry, but only if costs, for example associated with management of invasive species or erosion control, are manageable. The price tag might also be a more general disadvantage of open-land-derived agroforestry; cacao production costs are for instance 30–50% higher in open-land-derived agroforests compared to forest-derived agroforests due to costs for fertilizers and maintenance (Ruf, 2001). Additionally, planting trees on open-land may be expensive (Ruf, 2001), while making space for forest-derived agroforestry may be attractive in itself if felled forest trees can be used or sold (Tscharntke et al., 2011).

5 | LAND-USE HISTORY AFFECTS ECOSYSTEM FUNCTIONS AND SERVICES

Establishing an agroforest on open land that was formerly forested can be regarded as a form of rehabilitation (Chazdon et al., 2016), leading to an overall increase of tree cover and associated ecosystem functions and services (Table 1). Tropical open-land-derived agroforests thus have a large carbon sequestration potential (Hombegowda, van Straaten, Köhler, & Hölscher, 2016; Nair, Kumar, & Nair, 2009; Nijmeijer et al., 2019). Forest-derived agroforests, on

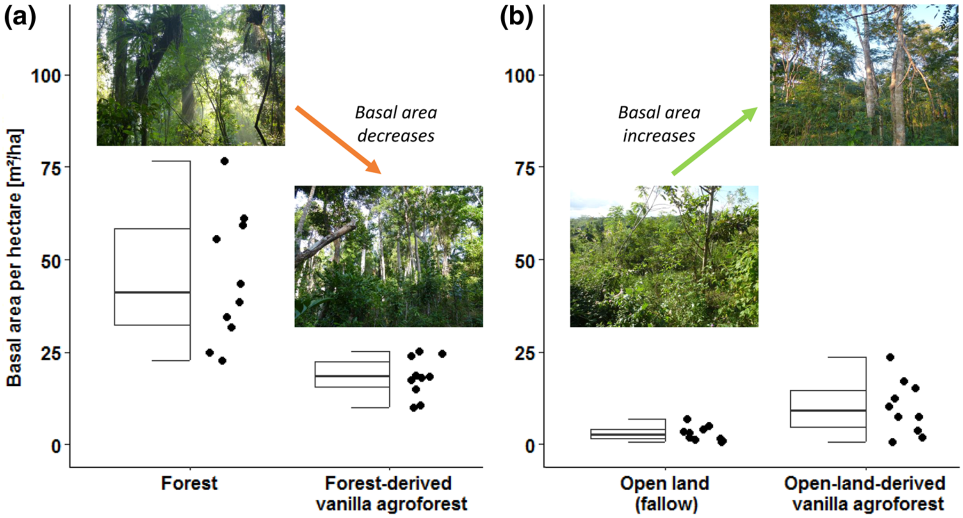

FIGURE 2 Basal area (m^2/ha) in 40 circular study plots of 1963.5 m^2. Measurements include all living trees, palms and herbs with a diameter at breast height ≥8 cm. (a) Basal area in forest-derived vanilla agroforests is 59% lower than in forests ($p < .001$). (b) Basal area in open-land-derived vanilla agroforests is three times higher than in open lands (238% increase; $p = .011$). Open-land-derived vanilla agroforests have 45% less ($p = .009$) basal area than forest-derived vanilla agroforests. Test results are based on Wilcoxon signed-rank tests

the other hand, typically store less carbon than forests (De Beenhouwer et al., 2016; Nair et al., 2009). For example, forest-derived coffee agroforests in Ethiopia lose 47% of their carbon stocks along an intensification gradient compared to forests (De Beenhouwer et al., 2016). For tree basal area, we find the same pattern in vanilla agroforests, where open-land-derived agroforests have three times more basal area than open fallow land. Forest-derived vanilla agroforests, on the other hand, have 59% less basal area than forest (Box).

Whether forest- and open-land-derived agroforestry differ in yields remains poorly understood. A single study in cacao shows no differences (Nijmeijer et al., 2019), but research has mainly focused on how tree cover is correlated with yields. In coffee, yields are typically higher under low- or medium-shade conditions (Perfecto, Rice, Greenberg, & van der Voort, 1996). In cacao, yields generally increase when shade is reduced (Blaser et al., 2018), but low-shade systems may fail to maintain yields in the long run (Clough, Faust, & Tscharntke, 2009). Yields may also be influenced by pest control services in agroforestry systems, but whether land-use history *per se* influences pest control is unknown. Similarly, it remains unclear whether land-use history affects how agroforests cope with elevated temperatures and droughts. Elucidating the interplay between land-use history, tree cover, pest control, and yields under climate change will thus help to improve agroforest management to the benefit of farmers as well as ecosystem services and biodiversity.

BOX: The case of vanilla agroforestry in Madagascar

Vanilla agroforests along with hill- and paddy rice, fallows and forest fragments form a mosaic landscape in north-eastern Madagascar which arose through rainforest conversion. High vanilla prices have led to an expansion of vanilla agroforestry at the cost of both forest and open land. Forest-derived vanilla agroforests, which make up around 30% of all vanilla agroforest (Hänke et al., 2018), are established by understory clearance and tree thinning. This conversion maintains some tree cover but basal area in forest-derived vanilla agroforests is less than half compared to forest (Figure 2). In contrast, 70% of vanilla agroforests originate from abundant open land that lays fallow as part of the slash-and-burn hill rice cultivation cycle (Hänke et al., 2018). The cessation of fire that comes with the establishment of permanent open-land-derived vanilla agroforests, enables tree recovery, resulting in a threefold higher basal area compared to open land (Figure 2). When compared directly, forest-derived vanilla agroforests have almost twice the basal area of open-land-derived vanilla agroforests. This highlights the role of agroforests of contrasting land-use history for maintaining trees and their associated functions and services.

6 | LAND-USE HISTORY SHAPES VEGETATION STRUCTURE AND BIODIVERSITY

Planting crops inside forest and the accompanying simplification of vegetation structure leads to a loss of biodiversity (De Beenhouwer et al., 2013; Tscharntke et al., 2011). Although immigrating generalist or open-land specialist species may compensate for some of the losses in species richness, forest specialists (De Beenhouwer et al., 2013; Perfecto et al., 1996) and threatened species (Schroth, 2004) are particularly affected. This species turnover exacerbates conservation concerns of forest-derived agroforestry. Nevertheless, forest-derived agroforests surpass alternative forms of forest conversion, such as slash-and-burn practices (Perfecto et al., 1996; Schroth, 2004). Planting agroforests on open land should, in contrast, enhance structural complexity and increase resource diversity, thereby bolstering biodiversity of forest-associated taxa (Figure1). However, few studies compare open-land-derived agroforests with their respective baselines (Rice & Greenberg, 2000). This is also reflected in our systematic review, where only two studies compared biodiversity of open-land-derived agroforestry with open land whereas 14 studies compared forest-derived agroforestry with forest (see also Table 1 and Supporting Information). Direct comparisons between forest-derived and open-land-derived agroforests are scarce, but published studies show a more forest-like species composition (Hoehn, Steffan-Dewenter, & Tscharntke, 2010; Valencia, Naeem, García-Barrios, West, & Sterling, 2016), fewer invasive species (Bos, Tylianakis, Steffan-Dewenter, & Tscharntke, 2008), and higher species diversity (Nijmeijer et al., 2019; Siebert, 2002) in forest-derived agroforests.

However, the differences between agroforests of contrasting land-use history might diminish over time. Oftentimes, forest-derived agroforests lose tree cover due to logging of existing trees, natural mortality and limited recruitment (De Beenhouwer et al., 2016; Shumi et al., 2018; Valencia et al., 2016), typically resulting in a reduction of biodiversity (Philpott et al., 2008; Tscharntke et al., 2011). Contrastingly, open-land-derived agroforests gain tree cover over time and could thereby enter into a positive biodiversity trajectory (Perfecto et al., 1996). In this context, contrasting trajectories in forest- and open-land-derived cacao agroforests in Cameroon have equalized tree diversity after ~25 years (Nijmeijer et al., 2019).

Furthermore, legacy effects could reduce the gap in biodiversity between forest- and open-land-derived agroforests over time. Extinction debts suggest a continuing loss of biodiversity as populations that are not viable under new conditions go extinct (Jackson & Sax, 2010). Evidence for extinction debts comes from forest-derived agroforests in Ethiopia, where epiphytes are less likely to occur in long-converted agroforests further away from the historic forest edge (Hylander & Nemomissa, 2017). Conversely, open-land-derived agroforests may enjoy an immigration credit (Jackson & Sax, 2010; Shumi et al., 2018), implying that species have not yet immigrated into newly established agroforests, despite suitable habitat. “Paying out” extinction debts and immigration credits would thus reduce differences in species richness between forest- and open-land-derived agroforests.

7 | DISCUSSION

Agroforestry is often seen as an economically viable land-use option that benefits people and nature alike (Schroth, 2004), thereby contributing to reaching the UN Sustainable Development Goals. To what extent will depend on whether an agroforest is established on open land or at the cost of biodiverse tropical forest. Nonetheless, forest-derived agroforestry represents a limited loss of ecosystem functions and biodiversity compared to more destructive conversion methods such as slash-and-burn or a combination of intensive logging and grazing (Figure 3). Conversely, agroforestry on formerly forested open land will typically have a positive effect on ecosystem services and biodiversity: The land gains vertical habitat complexity through the restoration of shade trees and crops on open land, which in turn increases biodiversity and ecosystem functions and services. In short, open-land-derived agroforestry will often perform worse than forest-derived agroforestry in absolute terms but forest-derived agroforestry degrades forest whereas open-land-derived agroforestry rehabilitates open land that was once forested (Box, Figure 3).

7.1 | Incentivizing positive land-use trajectories

Maintaining tree cover in forest-derived agroforestry (Figure 3) might be associated with lower yields (Blaser et al., 2018; Perfecto et al., 1996) and establishing open-land-derived agroforests instead of forest-derived ones might come at extra direct costs (Ruf, 2001; Tscharntke et al., 2011). Incentives such as sustainability certification schemes could, however, make both economically viable (Philpott & Dietsch, 2003; Tscharntke, Milder, Rice, & Ghazoul, 2014). Analogously, farmers could profit from

TABLE 1 Characteristics of forest-derived and open-land-derived agroforests with a comparison between the two. Characteristics are separated into suitability of land for agroforest establishment, ecosystem functions and services, and vegetation structure and biodiversity. References are reviews where available. If no studies were available, we formulated hypothesis that are formatted in italics

Characteristic		Characteristics of forest-derived agroforests	Characteristics of open-land-derived agroforests	Comparison between forest-derived and open-land-derived agroforests	References
Suitability of land for agroforest establishment					
Land availability		Forest land may be the only land available to farmers, particularly if their means to purchase land are limited.	Open land may be the only land available at places without forest or where remaining forests are protected or otherwise inaccessible.	Advantages and disadvantages of either type depend on local and individual context.	Meyfroidt et al. (2014), Ruf (2001)
Land tenure & rights		Agroforest establishment inside forest may represent a land claim. Land rights determine land availability. Forests may be protected, preventing forest-derived agroforestry.	Land must already be claimed before agroforest establishment. Land tenure insecurity discourages agroforestry establishment.	No direct comparison available, *strong land rights will facilitate open-land-derived agroforestry whereas strict forest protection may hamper forest-derived agroforestry.*	Meyfroidt et al. (2014), Ruf (2001)
Competition with previous land use		Direct land-use competition limited, but loss of forest-generated ecosystem functions and services.	Competition with services and yields derived from cropland, perennial monoculture, pasture or fallow. Less problematic on degraded land.	No direct comparison available, *trade-offs exist for both types. Advantages and disadvantages depend on local context.*	Meyfroidt et al. (2014)
Production costs		NA	NA	Production costs are higher in open-land-derived agroforestry compared to forest-derived agroforestry.	Ruf (2001)
Ecosystem functions and services					
Supporting	**Soil fertility**	Nutrient acquisition incl. N fixation through forest remnant or planted (legume) trees; litter fall maintains soil fertility.	Nutrient acquisition incl. N fixation through planted (legume) trees; particularly useful if resource needs of chosen trees and agroforestry crop are complementary. *May also depend on former use of open land.*	No direct comparison available, *possibly higher soil fertility in forest-derived agroforestry but potential for carry-over effects from previous land-use in open-land-derived agroforestry. May change over time.*	Cannell, Van Noordwijk, and Ong (1996), Tscharntke et al. (2011)
	Water regulation & supply	Integrity of water cycle with high evapotranspiration and low surface run-off may be retained.	Improved integrity of the water cycle with enhanced evapotranspiration and reduced surface run-off.	No direct comparison available, *possibly higher integrity of water cycle in forest-derived agroforestry.*	Abdulai et al. (2018), Blaser et al. (2018), Wanger, Hölscher, Veldkamp, and Tscharntke (2018)

Continues

TABLE 1 Continued

Regulating	**Climate regulation**	Above-ground carbon stocks are lower than in forests. Within forest-derived agroforests, biomass is often times reduced over time as trees are cut. Soil organic carbon can be maintained if trees are kept.	Above-ground carbon stocks are initially low, but can be elevated to medium levels with time. Soil organic carbon is initially low but may rebound over time.	No direct comparison available, *open-land-derived agroforestry typically have lower carbon stocks compared to forest-derived agroforestry.*	De Beenhouwer et al. (2016), Hombegowda et al. (2016), Nair et al. (2009)
	Climate change adaptation	Possibly dependent on tree cover; studies report mixed results about the direction of the effect for cacao.	Possibly dependent on tree cover; *given that trees are often actively planted, tree species adapted to climate change could be chosen.*	No direct comparison available, *more active choice of tree species in open-land-derived agroforests could be an opportunity for climate change adaptation.*	Abdulai et al. (2018), Blaser et al. (2018), Wanger et al. (2018)
	Erosion prevention	Little change compared to forest if trees are maintained.	Improvement over open land.	No direct comparison available, *possibly better in forest-derived agroforests which have not experienced clear cuts or fire.*	Labrière, Locatelli, Laumonier, Freycon, and Bernoux (2015)
	Biological control	Pest control services and disease prevalence (in coffee and cacao) both increase with tree cover, leading to potential trade-offs between the two.	*Pest control services and disease prevalence may increase with tree cover recovery.*	No direct comparison available, *pests and disease may differentially affect forest- and open-land-derived agroforests.*	Blaser et al. (2018), Clough et al. (2009)
Provisioning	**Primary crop yield**	Yield gains in coffee and cacao are common when shade tree cover is reduced from high to medium shade, but long-term yields may suffer under low shade conditions.	*Possible yield reduction in coffee and cacao agroforests where shade tree regeneration leads to higher canopy cover.*	No difference in cacao yield between forest- and open-land-derived agroforestry (but only one study available).	Clough et al. (2009), Nijmeijer et al. (2019)
	Secondary crop yield & raw materials	Products may be harvested if useful plants and trees are kept, promoted or planted. Trees can be cut and used.	Useful plants/trees can be planted during agroforest establishment but might take time until first harvest; dependent on product.	No direct comparison available, *the more active choice of tree species in open-land-derived agroforestry predicts higher secondary crop yields in such systems.*	Tscharntke et al. (2011)

Continues

TABLE 1 Continued

Vegetation structure and biodiversity				
Tree cover & structure	Initially high tree cover and structure may be reduced with time if trees are extracted.	Initially low tree cover and structure, may be elevated to medium levels with time through tree growth.	Typically lower tree cover and simplified structure in open-land-derived agroforestry than in forest-derived agroforestry (See also Box).	Nijmeijer et al. (2019), Ruf (2001), Tscharntke et al. (2011)
Tree diversity	Selective cutting of trees reduces diversity compared to forest. More useful trees (see above) are more likely to be kept.	Diversity is highly managed as trees are planted or selected by farmers. Species are typically chosen based on their usefulness, suitability and availability.	Normally lower in open-land-derived agroforestry than in forest-derived agroforestry.	Nijmeijer et al. (2019), Tscharntke et al. (2011), Valencia et al. (2016)
Biodiversity	Generally lower than in forest. May be taxon-specific and/or on the level of species composition rather than species richness. Effects will be strongest for forest-dependent species.	Generally higher than in open land. Effects may be taxon specific and/or on the level of species composition rather than species richness. Open-land species may decrease following agroforest establishment.	Overall lower in open-land-derived agroforestry than in forest-derived agroforests, but open-land and generalist species may be more common in open-land-derived agroforests.	De Beenhouwer et al. (2013), Hoehn et al. (2010), Perfecto et al. (1996), Philpott et al. (2008)
Legacy effects	Extinction debts are likely to exist, suggesting a loss in species over time even under stable tree cover.	Immigration credit is likely to exist, suggesting a gain in species over time under stable management regime.	No direct comparison available, *realizing legacy effects would lead to reduced differences between forest- and open-land-derived agroforests in terms of biodiversity.*	Hylander and Nemomissa (2017), Jackson and Sax (2010), Shumi et al. (2018)

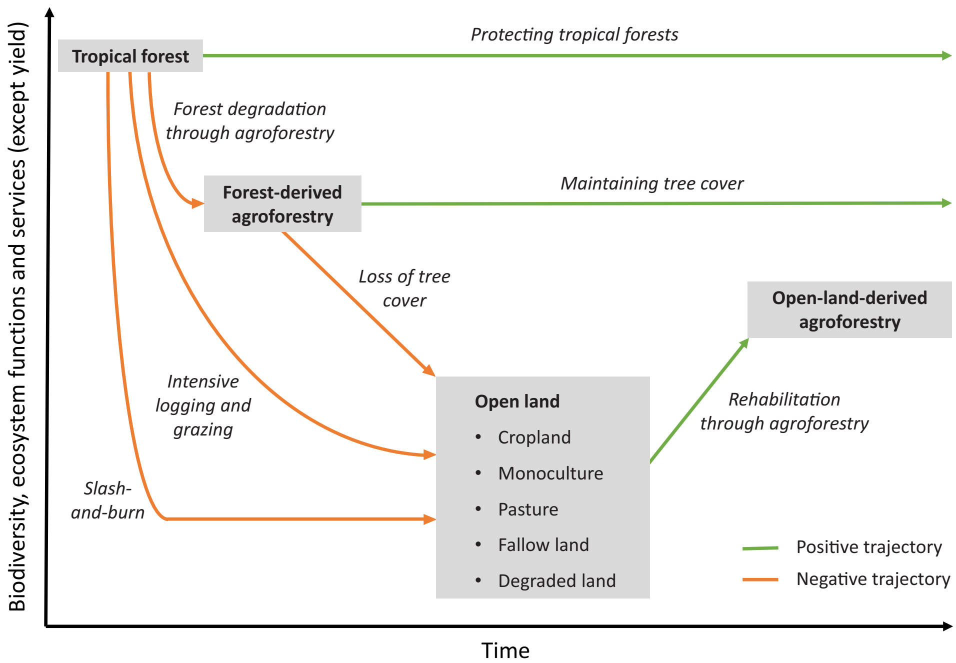

FIGURE 3 Conceptual framework of land-use history for tropical agroforests including possible transformation pathways. Forest-derived agroforestry represents a decline of biodiversity, ecosystem functions, and services compared to forest (except crop yields). Conversely, open-land-derived agroforestry represents an improvement over previous land use. In direct comparison, forest-derived agroforestry outperforms open-land-derived agroforestry if tree cover is maintained. Importantly, the framework only applies to formerly forested land in the tropics and is not applicable to naturally open land, such as savannahs. Note that both axes are not absolute, that is, processes may happen faster or slower (x-axis) and losses and gains could be stronger or weaker (y-axis), depending on environmental and socioeconomic context

payments for ecosystem services aimed at carbon sequestration in their open-land-derived agroforests (Salzman, Bennett, Carroll, Goldstein, & Jenkins, 2018). Interestingly, many sustainability standards prohibit "forest conversion into production land" (e.g., Rainforest Alliance, Organic, Fair Trade [International Trade Centre, 2019]), effectively excluding forest-derived agroforests. But in practice, many certified agroforests are forest-derived (e.g., vanilla: Hänke et al., 2018; coffee: Philpott & Dietsch, 2003). This is not *per se* problematic if sustainability certification ensures that ecosystem functions and services as well as biodiversity are maintained in long-established agroforests (Tscharntke et al., 2014). To avoid incentivizing forest degradation, the certification of recently converted forest-derived agroforests should nonetheless be avoided. On the other hand, open-land-derived agroforests might struggle to meet certification criteria, despite the improvement over previous land use. For instance, Rainforest Alliance requires "diverse native shade canopies for shade-tolerant crops" (International Trade Centre, 2019) – a criterion that will typically be harder to meet in open-land-derived agroforestry (Rice & Greenberg, 2000). In this case, rules could be adapted so that open-land-derived agroforests with a lower proportion of native trees still qualify for sustainability standards. In sum, sustainability standards and payments for ecosystem services should be sensitive to land-use history in order to avoid adverse outcomes.

7.2 | Key research questions on land-use history of tropical agroforests

First, we encourage studies that investigate the time scale of described processes. In forest-derived agroforestry, we hypothesize a rapid loss of biodiversity and ecosystem functions and services during the initial transformation from forest and a somewhat slower decline thereafter. In open-land-derived agroforestry, recovery time will again depend on the focal variable, but may be only a few years for certain ecosystem functions (Nijmeijer et al., 2019). In this context, time series will be particularly interesting. Second, research quantifying the extent of biodiversity and ecosystem functioning gain and loss during transformation is equally important. Third, elucidating how forest- and open-land-derived agroforestry could be utilized to restore land-sharing/sparing connectivity landscapes would be highly interesting (Grass et al., 2019). For example, one could imagine landscapes with forest-derived agroforests as buffers around protected areas and corridors of open-land-derived agroforestry connecting forest fragments—thereby reaping the advantages of both types.

7.3 | Policy implications

Agroforestry is widely promoted to address multiple UN Sustainable Development Goals, but policy often does not distinguish between forest- and open-land-derived agroforests. Here, we find that ecosystem functions and services as well as biodiversity are strongly influenced by land-use history in agroforests, suggesting a high relevance of land-use history for policy. Policies aiming to conserve biodiversity and ecosystem services should (a) prioritize forest protection over forest-derived agroforestry, (b) promote forest-derived agroforestry only as an alternative to deforestation, (c) incentivize tree cover maintenance in existing forest-derived agroforests, (d) encourage open-land-derived agroforestry on suitable open land, particularly on fallow and degraded land, and (e) stimulate applied research on land-use history.

Our framework is relevant to numerous policy tools. Those include payments for ecosystem services and sustainability certification, but can be extended to agricultural subsidy schemes, zero-deforestation commitments and governmental land-use policy, among others. Notably, all approaches will need to be highly adapted to local context as environmental and socioeconomic factors influence whether and where the promotion of forest- respectively open-land-derived agroforestry is a sensible policy.

AUTHORS' CONTRIBUTIONS

All authors conceived ideas and planned the paper; DAM conducted the systematic review, produced Figures 1 and 3, and led the writing of the manuscript; KO collected basal area data and created Figure 2. All authors contributed to the writing and gave final approval.

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SUPPORTING INFORMATION

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