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Graphical review

Reducing intensification by shifting cultivation through sustainable climate-smart practices in tropical forests: A review in the context of UN Decade on Ecosystem Restoration

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ABSTRACT

The tropical forests provide important ecosystem services at local and global scales (i.e. climate regulation, carbon cycling, and food resources). Shifting cultivation (SC) is the most common traditional farm system in tropical forest landscapes, which along with hunting and gathering from forests, have been the main food sources and livelihoods. This traditional SC was probably sustainable for nomadic indigenous populations for centuries. However, the non-traditional shifting cultivation is a consequence of cultural changes of indigenous communities influenced by western culture that induce land-use changes using new technologies, promoting the high local-scale expansion and intensification, and overhunting. The intensification occurs due to the short-term farm system, low crop diversity or monocultures, and larger slash and burn forest patches inducing agricultural expansion due to higher commercial crop demand. This expansion and intensification determine the loss of biodiversity and ecosystem services, forest degradation and fragmentation, higher greenhouse gas emissions, defaunation and local extinction. Thus, degraded forest rehabilitation with different sustainable food systems (i.e. Agroforestry) can reduce the expansion and intensification of SC. Restored forest, agroforestry, and second-growth forests can be restored as reservoirs for valuable biodiversity and a host of different ecosystem services. Tropical forests are central to climate change mitigation efforts and should prioritize the UN Decade on Ecosystem Restoration. In this context, we provide a review on the effects of shifting cultivation intensification on tropical forest landscapes as a base to apply sustainable climate-smart practices in the context of UN Decade on Ecosystem Restoration.

1. Introduction

The tropical forests are of Earth's most biodiverse and carbon-dense regions (Sullivan et al., 2017), which provide important ecosystem services at local and global scale (Fig. 1), i.e. climate regulation, carbon cycling, and food resources (Chazdon, 2014; Lewis et al., 2015; Hubau et al., 2020). Moreover, tropical forests have historically been vital to the livelihood of indigenous and non-indigenous communities; for example, through homegardens, shifting cultivation, non-timber forestry resources and hunting (Bush et al., 2015; Heinimann et al., 2017; Roberts et al., 2018). However, the land-use changes (i.e. logging, overhunting, agriculture) are the main drivers that threaten the tropical forests (Fig. 2), and can trigger biodiversity loss and forest degradation, and consequently release of greenhouse gas emissions and increase the effects of global climate change (Sullivan et al., 2017; Chazdon, 2014; Lewis et al., 2015; Hubau et al., 2020; Ferreira et al., 2018). Thus, many tropical countries aspire to protect forests from fulfilling biodiversity and climate mitigation policy targets based on strategies for restoration (Sullivan et al., 2017; Ferreira et al., 2018; Dubey et al., 2020).

Shifting cultivation (SC) is a traditional land-use system to ensure livelihood in the Amazon (Villa et al., 2020). The traditional SC have small areas (0.1–0.8 ha) and short cycles of agriculture (1–3 years) with

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high crop diversity followed by fallow periods of 2–7 years [Fig. 2], while long cycles comprise fallow periods of more than 15 years (Villa et al., 2020; Villa et al., 2017; Mukul and Herbohn, 2016). However, these spatial and temporal dynamics of SC have changed considerably during the last decade due to the high demand of national and international markets (Villa et al., 2020; Villa et al., 2017). This non-traditional shifting cultivation (Fig. 3) induces cultural changes using external inputs (Villa et al., 2020) such as fertilizers, mechanization, or pesticides (Fig. 3). These changes generate SC intensification and expansion, which occurs due to the reduction of fallow time between two cutting and burning events, and induces forest degradation and fragmentation, higher greenhouse gas emissions, loss of ecosystem services and biodiversity, defaunation and local extinction, as illustrated in Fig. 3 (Walandari, 2017; Villa et al., 2018; Karki, 2017; Jakovac et al., 2015; Peres et al., 2016; Curtis et al., 2018; Hattoria et al., 2019). Local defaunation can also generate a dispersal limitation of zoochoric and larger tree species, which induces a dominance of light-demanding, smaller and non-zoochoric pioneer tree species (Peres et al., 2016). Recent research demonstrated that both the SC intensification based on the increase in the area (Fig. 3) and the number of SC cycles are decisive for either recovery or loss of forest structure and diversity, as indicated in the Fig. 4 (Villa et al., 2018; Jakovac et al., 2015).

The second growth forests (SGF) that are regrow after SC (Fig. 4B) may be important to recover the biodiversity and ecosystem services (Fig. 1), such as global carbon dynamic and stock (Arroyo-Rodríguez et al., 2015; Poorter et al., 2016; Rozendaal et al., 2019). After a SC cycle the SGFs can recover up to 80% of tree species richness (Rozendaal et al., 2019) and more than 50% of aboveground biomass stock (Poorter et al., 2016) in a short time range of nearly 20–30 years (Fig. 4B). However, after a second (Fig. 4C) to a fifth SC cycle (Fig. 4D) in the same forest patch, reduces the recovery of SGF and promotes loss of biodiversity (including loss of seed banks and regrow species) and ecosystem services (forest multifunctionality), defaunation by loss of habitats, and biological invasion in degraded forest (Mukul and Herbohn, 2016; Walandari, 2017; Villa et al., 2018; Jakovac et al., 2015; Peres et al., 2016; Hattoria et al., 2019). In this sense, the restoration, sustainable management and conservation strategies to achieve the goals during UN Decade on Ecosystem Restoration depend critically on integrative and multidisciplinary approach (Dubey et al., 2020).

In this context, we provide a review on the causes and consequences of shifting cultivation intensification in tropical forest landscapes as a base to apply sustainable climate-smart practices in the context of UN Decade on Ecosystem Restoration. Thus, we explain basic criteria that could potentially justify the sustainable food system to reduce forest degradation and fragmentation, greenhouse gas emissions, loss of ecosystem services and biodiversity, due to expansion and intensification by SC.

2. Strategies for restoration

We emphasize that integrating knowledge and understanding how shifting cultivation affects tropical forest landscapes (secondary, old-growth, and primary forest) can greatly increase the effectiveness of attempts to conserve, recover and increase ecosystem services and biodiversity along with mitigate climate change (Ferreira et al., 2018; Villa et al., 2020). Furthermore, it is necessary developing effective

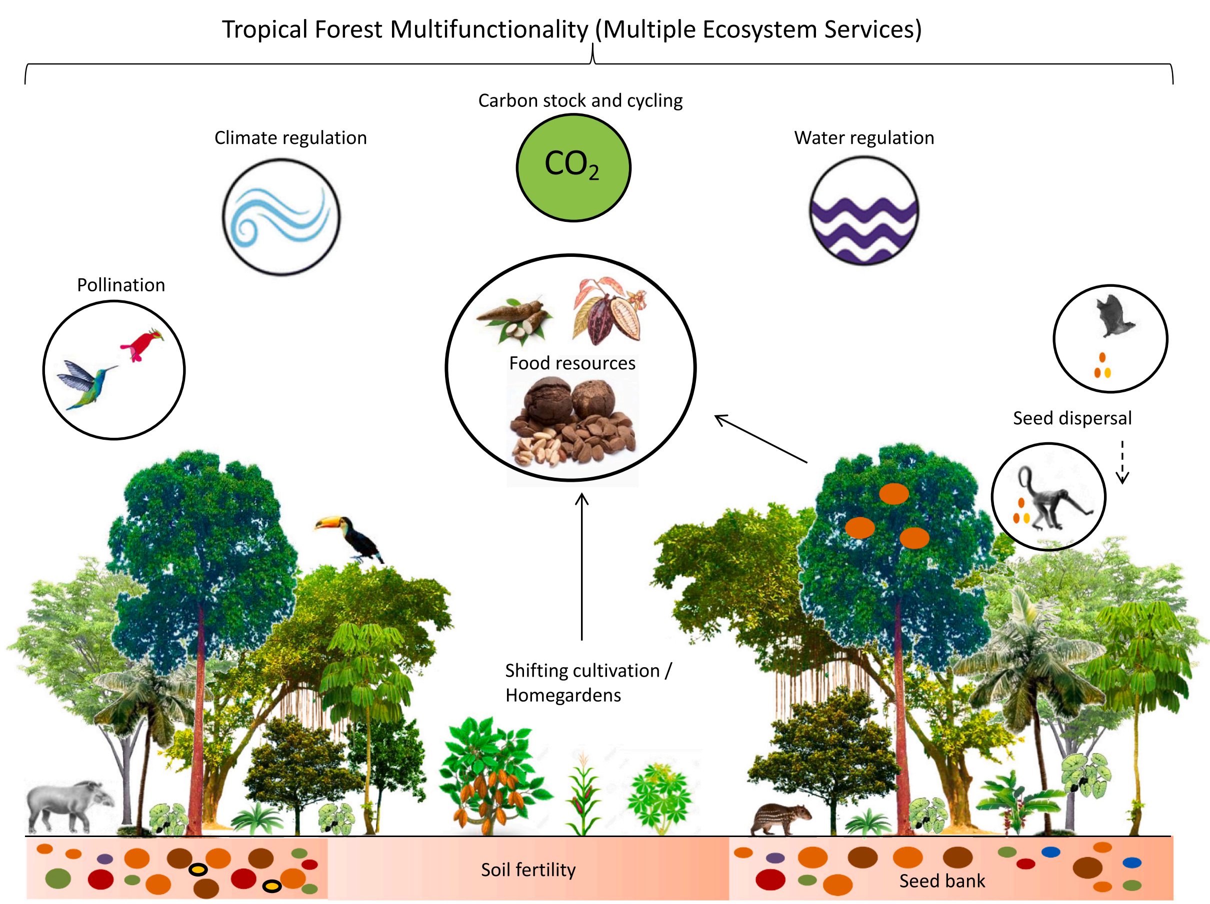

Fig. 1. Tropical forests cover only 8% of Earth's land but harbor more than half of terrestrial biodiversity and store one-third of terrestrial carbon (Sullivan et al., 2017). These forests provides important ecosystem services at local and global scale (i.e. the benefits that people obtain from ecosystems), such as soil fertility, pollination and seed dispersal, water regulation and carbon stock that have local and global impact, including effects on the Earth's climate system and carbon cycling (Chazdon, 2014; Lewis et al., 2015; Hubau et al., 2020).

sustainable climate-smart practices to forest restoration and conservation policies to safeguard co-benefits in the tropical forest (Villa et al., 2020). Information on forest responses to past and present land-use changes can help to enhance our understanding and improve predictions of future climate changes for developing effective forest restoration and conservation policies to safeguard ecosystem services and biodiversity in the tropical forest. Thus, we propose that knowing how traditional and non-traditional shifting cultivation shape the tropical forest biodiversity and ecosystem dynamic, it is possible to establish a tipping point for the application of policies and strategies to reduce carbon emissions from deforestation and degradation at local scale and, maintain sustainable food system and restored forest (Fig. 5B-C). Moreover, the restored forest (Fig. 5B), agroforestry rehabilitation (Fig. 5C), and SGF that are regrowing (Fig. 5D) may be important

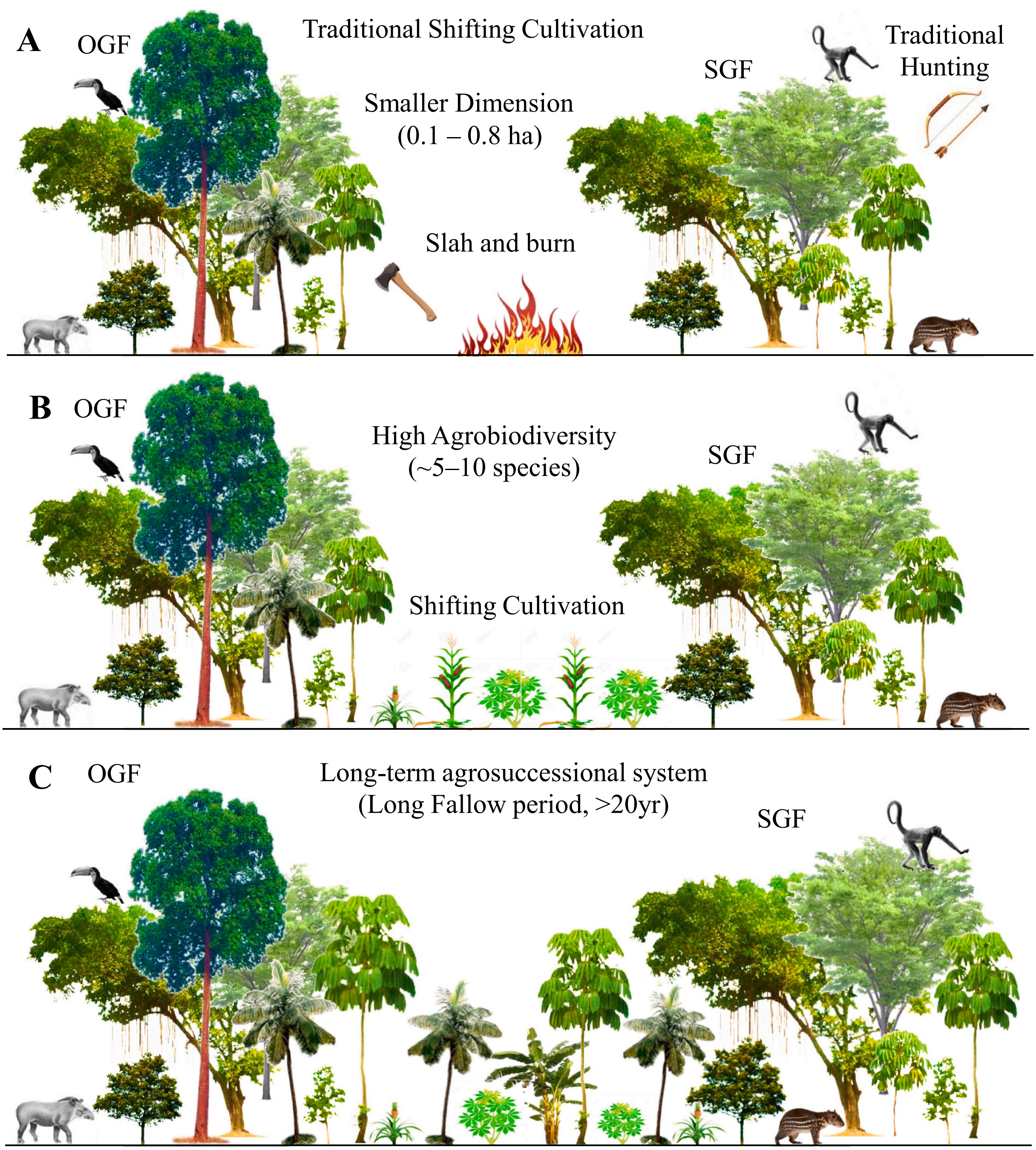

Fig. 2. Shifting cultivation (SC) is the most common traditional farm system in tropical forest landscapes, that along with hunting and gathering from forests have been the main food sources and livelihoods (Heinimann et al., 2017; Roberts et al., 2018; Villa et al., 2020; Villa et al., 2017). Traditional shifting cultivation (i.e. practiced by pristine and nomadic indigenous communities) involves clearing a small forests patches (0.1–0.8 ha) of old-growth forest (OGF) or second-growth forest (SGF) using slash-and-burn method (A), for the establishment of high crop diversity between two and four years (B) (Villa et al., 2020; Villa et al., 2017; Mukul and Herbohn, 2016; Walandari, 2017). These SGF that are re-growing after SC are traditionally know as fallows (i.e. land recovery time), which have lasted for long periods (>20 years) as a long-term agrossucessional system (C) allowing complete forest regeneration of SGF (Villa et al., 2020; Mukul and Herbohn, 2016; Villa et al., 2018). This traditional land-use pattern (subsistence farming and hunting) was probably sustainable for nomadic indigenous populations for centuries, changing territories temporarily in order to access new sources of resources and, therefore, new forests patches for SC (Bush et al., 2015; Heinimann et al., 2017; Roberts et al., 2018).

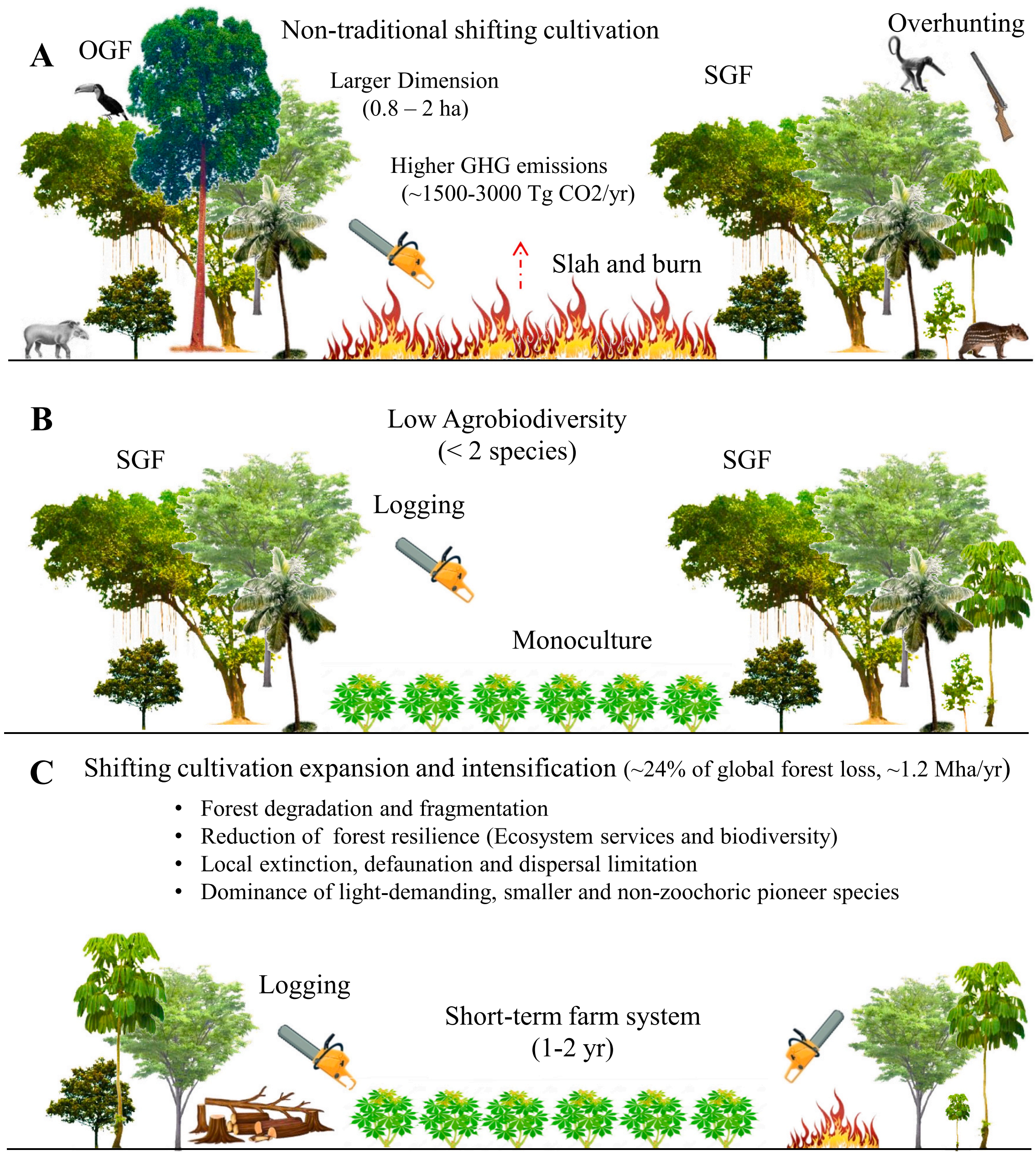

Fig. 3. Non-traditional shifting cultivation is a consequence of drastic cultural changes of indigenous communities influenced by western culture (Villa et al., 2020; Walandari, 2017; Villa et al., 2018; Karki, 2017; Jakovac et al., 2015). These cultural changes also induce land-use changes using new technologies (i.e. chainsaws, shotguns), which promote the high local-scale expansion and intensification of SC, and overhunting (Villa et al., 2020). This non-traditional shifting cultivation (i.e. practiced by indigenous and non-indigenous communities) consist in cutting larger forests patches (0.8–2 ha) of old-growth forest or second-growth forest (SGF) using slash-and-burn method (A), for the establishment of low crop diversity or monocultures (i.e. short-term farm system) between one or two years (B) without presenting an traditional fallow period. The intensification occurs due to the short-term farm system with the reduction of fallow time between two SC cycles, low crop diversity or monocultures, and larger slash and burn forest patches inducing agricultural expansion due to higher commercial crop demand, such as cassava, corn, soy (Villa et al., 2020; Walandari, 2017; Villa et al., 2018; Karki, 2017; Jakovac et al., 2015). Thus, the expansion and intensification of SC has been recognized as an anthropogenic driver that determines loss of biodiversity and ecosystem services, forest degradation and fragmentation, higher greenhouse gas (GHG) emissions, defaunation and local extinction (Chazdon, 2014; Lewis et al., 2015; Villa et al., 2020; Peres et al., 2016; Curtis et al., 2018; Hattoria et al., 2019).

biodiversity and ecosystem services reservoirs (Chazdon, 2014; Rozendaal et al., 2019).

Most studies on tropical forest recovery based on the chronosequence approach to compare different stand age of second-growth forest and old-growth reference forest have focused on changes in structure, diversity and species composition after disturbance (Villa et al., 2020; Villa et al., 2017; Mukul and Herbohn, 2016; Walandari, 2017; Villa et al., 2018; Karki, 2017; Jakovac et al., 2015; Arroyo-Rodríguez et al., 2015; Poorter et al., 2016; Rozendaal et al., 2019). Thus, studies comparing second-growth forest and old-growth reference forest have suggested that regenerated areas may harbor higher tree species diversity, due to the coexistence of light-demanding pioneer and shade-tolerant species (Fig. 5D) from advanced successional stages (Villa et al., 2020; Villa et al., 2018; Rozendaal et al., 2019). Therefore, second-growth forest that are regrow after disturbance has already been demonstrated as a viable passive forest restoration method (Fig. 4B), with higher tree diversity recovery compared with active restoration with a limited number of tree species (Martins, 2018). However, despite

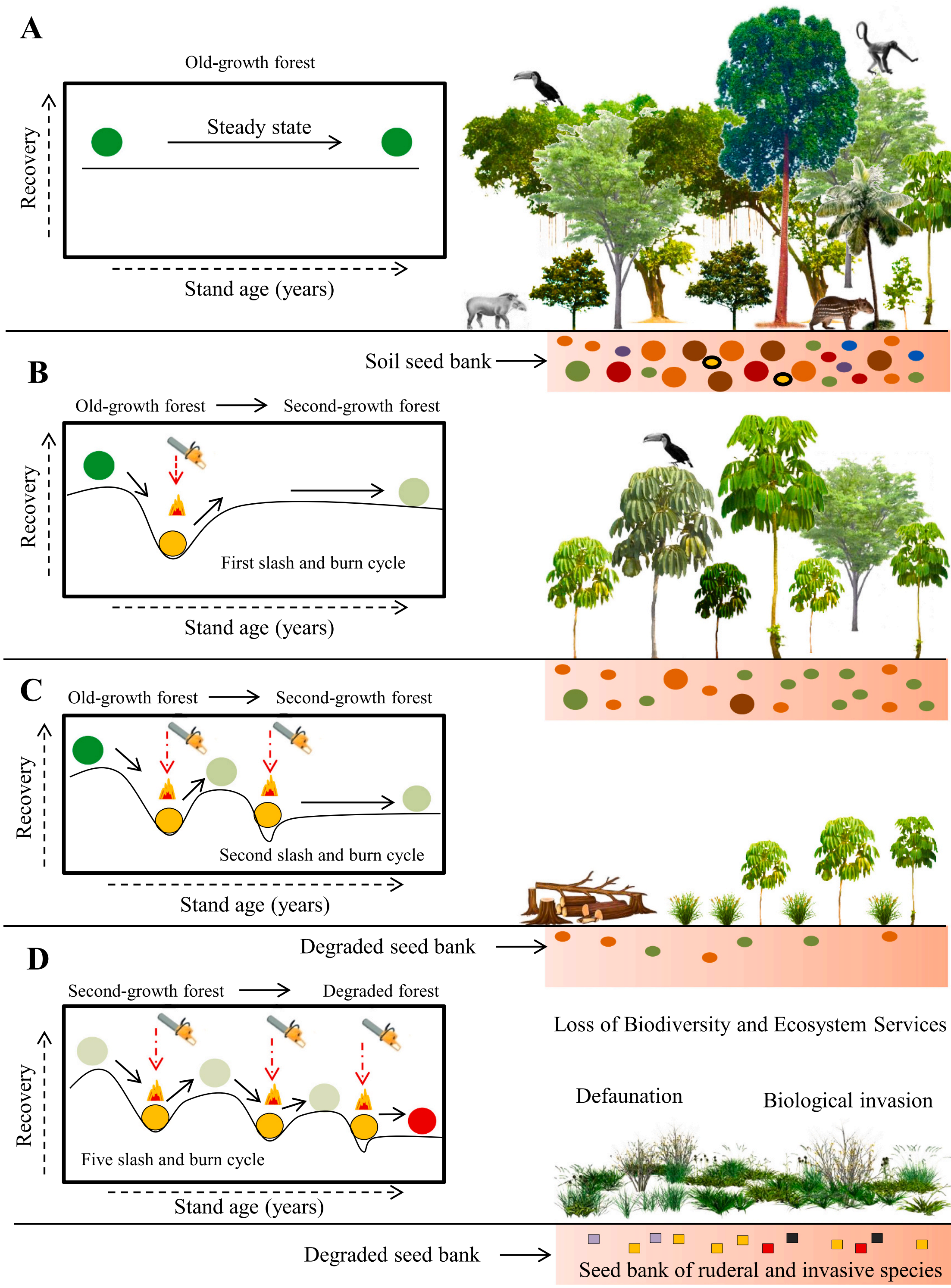

Fig. 4. Shifting cultivation (SC) intensification trajectory. According to the classical model diagram of forest recovery and loss of forest recovery (A-D), the balls represent states of a forest ecosystem, which can be defined by biodiversity and ecosystem services, i.e. tree species richness and carbon stock recovery respectively (Villa et al., 2018; Arroyo-Rodríguez et al., 2015; Poorter et al., 2016; Rozendaal et al., 2019). The dark green balls represent the old-growth forest in steady state (A), and the black arrows represent the trajectory of forest recovery and loss of forest recovery. Red arrows represent disturbances (first, second and five slash and burn cycles) by shifting cultivation (yellow balls in valleys). The light green balls in the peaks represent thresholds of second-growth forest (SGF) recovery. After a SC cycle the SGFs can recover the tree species richness and aboveground biomass stock (B). However, after a second (C) to a fifth SC cycle (D) in the same forest patch, reduces the recovery of SGF (Mukul and Herbohn, 2016; Walandari, 2017; Villa et al., 2018; Jakovac et al., 2015; Peres et al., 2016; Hattoria et al., 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

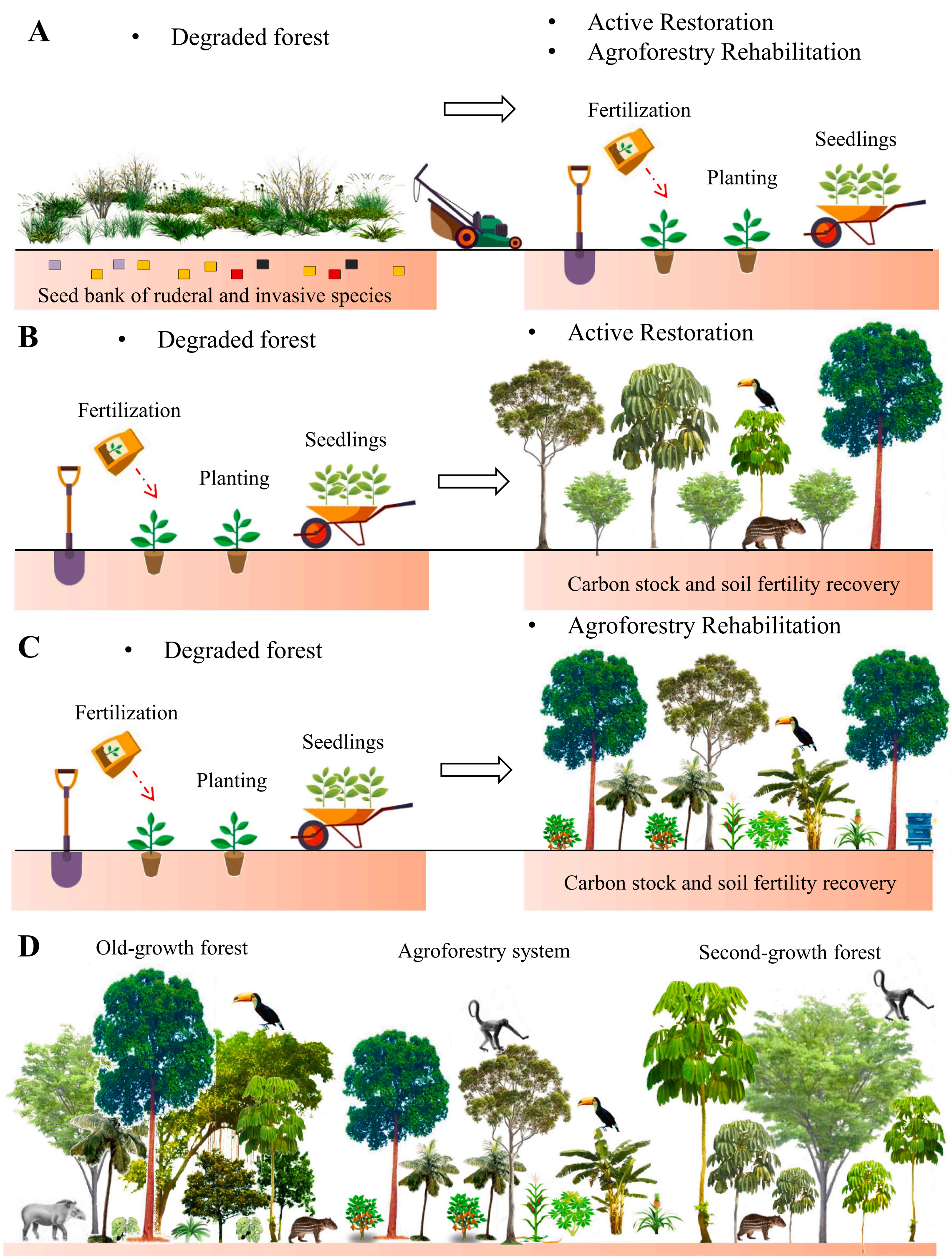

Fig. 5. Integration of different types of forest management to reduce greenhouse gas emissions from deforestation and forest degradation. Degraded forests lose resilience (natural regeneration is limited), therefore it is necessary to apply active restoration methods (A) (Martins, 2018), such as planting native seedlings (B) or rehabilitation with agroforestry (SAF) as sustainable food systems that provides livelihoods and food security (C). Degraded forest rehabilitation with different SAFs can reduce or avoid the expansion and intensification of SC in human-modified tropical forest landscapes (D), consequently reduce deforestation of new forest patches in OGF and SGF (Villa et al., 2020).

that currently, SGF become central to climate change mitigation efforts on a global scale, preserving the world's extensive old-growth and primary forests (Fig. 4A), will also conserve ecosystem services-biodiversity co-benefits (Sullivan et al., 2017; Chazdon, 2014; Lewis et al., 2015; Hubau et al., 2020). Therefore, it is important to maintain the essential protected tropical forest, because there are key tree species unique in OGF and primary forests, which have different ecosystem functions beyond carbon stock (Sullivan et al., 2017; Chazdon, 2014; Lewis et al., 2015; Hubau et al., 2020).

In human-modified and degraded tropical forest landscapes where natural regeneration is limited, active restoration has high relevance (Martins, 2018). Active restoration involves the implementation of management techniques in degraded areas (Fig. 5A,B], such as direct seeding, tree seedling planting or transposition of seed banks from old-growth forests (Martins, 2018). Finally, restoration methods (passive and active restoration) and rehabilitation based on sustainable climate-smart practices (i.e. Agroforestry systems) can be effective and complementary to integrated forest restoration management (Fig. 5). The specific sustainable climate-smart practices show that agroforestry, organic manure application and switching from degraded lands to improved lands have a vast potential of reducing GHG emissions and forest degradation (Waldén et al., 2020; Anuga et al., 2020). This approach can increase the production and income compared to a monoculture and degraded SGF at local-scale (Waldén et al., 2020). Moreover, sustainable forest management using agro successional system can reduce intensification of shifting cultivation and recovery degraded forest. This relationship of diversity and ecosystem services recovery is recognized as co-benefit when there is a positive relationship (Villa et al., 2020).

We highlight five strategies to mitigate the carbon increase in the atmosphere due to deforestation, such as i) reducing emissions from deforestation and ii) from forest degradation; iii) conservation of forest biodiversity and carbon stock; iv) sustainable management of forest; v) enhancement of forest biodiversity and carbon stock (Villa et al., 2020). Specifically, against the negative effects of SC expansion and intensification, sustainable climate-smart practices strategies are necessary to maintain conservation and sustainable management of ecosystem services in tropical forest landscapes. The Agrorestry system (AFS) potential as sustainable and permanent food systems (Fig. 5C), reduce or avoid the expansion and intensification of SC, reduce deforestation of new forest areas (Villa et al., 2020). These strategies can simultaneously reduce emissions from deforestation and degradation, further to conserve, recover and increase biodiversity and ecosystem services (Fig. 5D).

3. Conclusion

We highlight that shifting cultivation intensification reduces biodiversity and ecosystem services along tropical forests. Against this negative scenarios must be reversed through comprehensive, rapid and feasible restoration and rehabilitation actions and substantial policies cross-national planning to achieve a positive relationship between ecosystem services and biodiversity. This major challenge requires direct and urgent commitments from tropical countries to maintain their cultural and political identities but standardizing actions to conserve, recover and increase biodiversity and ecosystem services based on passive and active restoration methods and sustainable climate-smart practices. Thus, understanding the shifting cultivation intensification dynamic may provide fundamental insights in the context of UN Decade on Ecosystem Restoration. The AFS has higher potential as sustainable food systems for degraded forest rehabilitation and reduction of the expansion and intensification of SC. We expected that AFS should be implemented in local communities, in particular, those undergoing human-modified tropical landscapes where there is a high intensification of SC. We recommended measuring and quantifying how sustainable forest management allows to recover and increase co-benefits in AFS and SGF.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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