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The impacts of shifting cultivation on secondary forests dynamics in tropics: A synthesis of the key findings and spatio temporal distribution of research

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ABSTRACT

Shifting cultivation has been attributed to causing large-scale deforestation and forest degradation in tropical forest-agriculture frontiers. This view has been embedded in many policy documents in the tropics, although, there are conflicting views within the literature as to the impacts of shifting cultivation. In part, this may be due to the complex nature of this land use making generalizations challenging. Here we provided a systematic map of research conducted on shifting cultivation in tropics. We first developed a literature search protocol using ISI Web of Science that identified 401 documents which met the search criteria. The spatial and temporal distribution of research related to shifting cultivation was mapped according to research focus. We then conducted a meta-analysis of studies ($n = 73$) that focused on forest dynamics following shifting cultivation. A bias in research on anthropology/human ecology was evident, with most research reported from the tropical Asia Pacific region (215 studies). Other key research foci were – soil nutrients and chemistry (72 studies), plant ecology (62 studies), agricultural production/management (57 studies), agroforestry (35 studies), geography/land-use transitions (26 studies). Our meta-analysis revealed a great variability in findings on selected forest and environmental parameters from the studies examined. Studies on ecology were mainly concentrated on plant diversity and successional development, while conservation biology related studies were focused on birds. Limited impacts of shifting cultivation on some soil essential nutrients were also apparent. Apart from the intensity of past usage site spatial attributes seems critical for the successful development of fallow landscapes to secondary forests. Further research is needed to help ascertain the environmental consequences of this traditional land-use on tropical forests. Scientists and policy makers also need to be cautious when making generalizations about the impacts of shifting cultivation and to the both the social and environmental context in which shifting cultivation is being undertaken.

1. Introduction

Shifting cultivation, swidden or slash-and-burn is a widespread land-use common in the tropical forest agriculture frontier, and has formed the basis of land uses, livelihoods and customs in upland areas for centuries (Dressler et al., 2015; van Vliet et al., 2012; Mertz et al., 2009a; Metzger, 2003). While reliable information on the number of people who engaged in shifting cultivation is unavailable, Mertz et al. (2009b) has estimated about 14–34 million people alone from tropical Asia depend on shifting cultivation. In tropical regions, it has also been estimated that shifting cultivation is responsible for as much as 60 percent of the total deforestation and is considered as a prominent source of greenhouse gas emissions (Davidson et al., 2008; Geist and Lambin, 2002). At the same time, however, this traditional land-use practice remains central to the livelihoods, culture and food security of millions of people in tropical region (Dalle et al., 2011). In tropical developing countries, the practice of shifting cultivation is sometimes synonymous with poverty and low productivity of

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land (Schroth et al., 2004). In recent years, the extent of land under shifting cultivation and the people who depend on it for livelihoods and food security has been declining due to rapid urbanization and economic development in some countries (van Vliet et al., 2012; Mertz et al., 2009a). In many parts of South and South East Asia, local and regional land-use and development policies have been developed to reduce shifting cultivation due to a perceived negative impact on environment (van Vliet et al., 2012; Fox et al., 2009). There is, however, growing recognition from scientists of the importance of this traditional land-use to small holder's livelihoods and food security (Fox et al., 2009; Mertz et al., 2009a,b; Ziegler et al., 2011). At the same time, controversies still persist among policy makers and the scientific community on the suitability of this traditional land-use from environmental and conservation perspectives (Bruun et al., 2009; Lawrence et al., 2010a).

Shifting cultivation is still a dominant land-use/practice in countries rich in biodiversity and forest cover, and many of these countries also has some of the highest rates of deforestation (Baccini et al., 2012). Understanding shifting cultivation is therefore critical for sustainable forest management, biodiversity conservation, and proper land-use and development planning in tropical regions (DeFries and Rosenzweig, 2010). The issues associated with shifting cultivation however, are complex, and involve the intersection of socio-economic, environmental and policy issues. In recent years evidence-based science has been embraced by scientific communities as a desirable approach to design appropriate environmental policies (Lele and Kurien, 2011). In this paper, we review and analyze empirical research on shifting cultivation following a protocol. Our focus was on the spatio-temporal patterns of research on shifting cultivation across the tropics in order to identify research trends and gaps in research. We then performed a meta-analysis of literature that focused on forest dynamics following shifting cultivation with emphasis on the effect of shifting cultivation on key forest and environmental parameters including - plant ecology, conservation biology, soil nutrients and chemistry, and soil physics and hydrology. We finally presented a meta analysis where selected environmental attributes were compared with primary forests and/or other tree based land-use/cover. The drivers of change of shifting cultivation in tropics, with related livelihoods and environmental consequences have been reviewed by van Vliet et al. (2012) based on an analysis of the literature between 2000 and 2010. We extend that analysis to include papers published from 1950 to 2014. Importantly, our study builds on van Vliet et al. (2012) by providing more detailed analysis of the dynamics of tropical secondary forests after shifting cultivation, and factors that may influence the recovery of such landscapes. Our paper provides a general overview of the research on shifting cultivation, gaps in research and secondary forest dynamics after shifting cultivation. Uncovering such issues with greater certainty is useful for both conservation and management of declining tropical forests.

2. Methodology

2.1. Document search for systematic map

We searched the relevant literature using the ISI Web of Science (WoS, Thomson Reuters) database (Web of Science, 2014). WoS was selected as it is one of the most powerful, comprehensive, and widely used search engine for the analysis of interdisciplinary and peer-reviewed literature (Jasco, 2005). There are many terms that have been used locally to explain shifting cultivation (e.g. *jhum* in Bangladesh and parts of India, *kaingin* in the Philippines, *bhasme* in Nepal, *ladang* in Indonesia, *conuco* in Venezuela, *tavy* in Madagascar etc.). However, shifting cultivation, swidden and slash-and-burn are the most commonly used and generally accepted terms that have been used to delineate this land-use (Mertz et al., 2009a. In our literature search we used a combination of those keywords using the search term – (shifting cultivation or swidden or ('slash and burn') in the title. Our review was limited to peer-reviewed articles published between January 1950 and January 2014.

Our search initially yielded 551 documents of which 460 were relevant to our study (Supplementary material 1). All 460 retrieved documents were then reviewed based on their title and abstract to evaluate their suitability for inclusion in the final review. We considered only the articles that reported empirical studies from tropical countries. We then excluded any review, meta-analysis, methodological paper, and paper from outside the tropics (Fig. 1). This resulted in a list of 401 articles that met our final selection criteria.

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2015.10.005.

2.2. Document characterization

We classified the documents according to their main research subject focus (Table 1) as interpreted through their title, abstract and corresponding journal title and classification. Documents were classified into the following subject categories: (i) agricultural production/management; (ii) agroforestry; (iii) anthropology/human ecology; (iv) conservation biology; (v) geography/land-use transitions; (vi) plant ecology; (vii) soil nutrients and chemistry; (viii) soil physics and hydrology; and (ix) others. The year of the publication and geographic location of the research (i.e. country/region) were noted for each document.

2.3. Document selection for meta-analysis

The main emphasis of our meta-analysis was on the secondary forest dynamics following shifting cultivation and the impacts of shifting cultivation on forest characteristics considering primary or undisturbed forest as control. Therefore, articles from subject foci – plant ecology, conservation biology, soil nutrients and chemistry, and soil physics and hydrology have been included. Since we focused on forest dynamics following shifting cultivation we restricted our analysis only to articles that presented a comparison of the related parameters with undisturbed forests (i.e. primary or secondary forest without prior history of shifting cultivation). Seventy three articles met our final selection criteria for that meta-analysis, comprising 34 studies on plant ecology, 14 studies on conservation biology, 17 studies on soil nutrients and chemistry, and 8 studies on soil physics and hydrology.

2.4. Data interpretation and analysis

For our systematic map we compared the number of research studies on different subjects, conducted in different time span as well as in different geographic regions. We performed Student's *t*-tests with *p*-value (one-tailed) to see any significant difference in number of research studies on shifting cultivation during different time period as well as in different tropical regions. All statistical analyses were implemented using MS Excel and R statistical package (version 3.1.0; R Development Core Team, 2012). For mapping spatial distribution of research on shifting cultivation, we used the package 'rworldmap' (South, 2011; Supplmenetary material 2).

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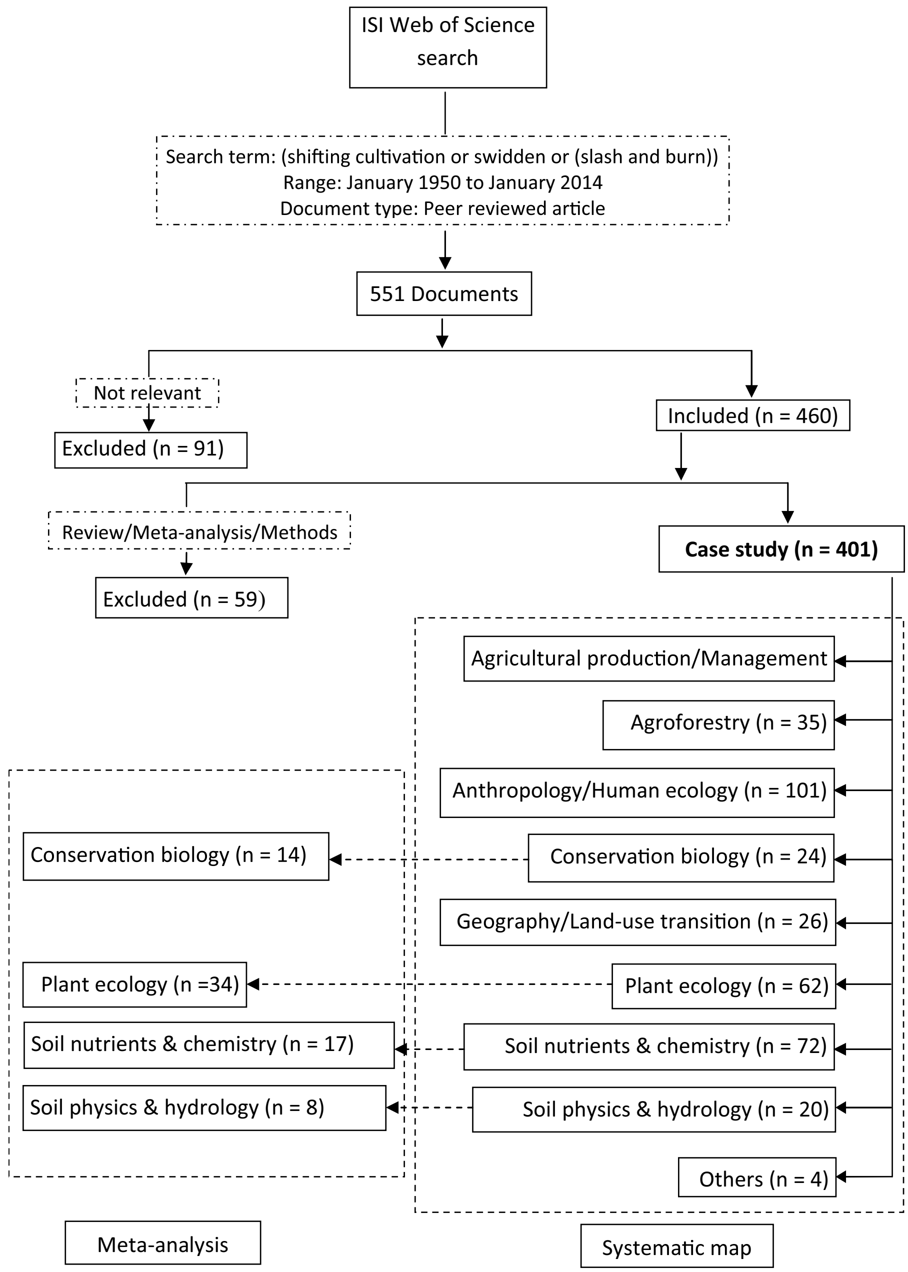

Fig. 1. Summary of literature used for systematic map and meta-analysis.

Table 1
Example of documents under different subject focus.

Subject/Topic	Example
Agricultural production/Management	Agricultural crop yield, weed management etc.
Agroforestry	Agro-biodiversity, cultural management, non-timber forest products (NTFPs), and NTFPs domestication
Anthropology/Human ecology	Socio-political issues related to shifting cultivation, indigenous knowledge, history, perceptions and attitudes on shifting cultivation etc.
Conservation biology	Wildlife diversity and assemblage in shifting cultivation landscapes.
Geography/Land-use transitions	Spatial land-use/cover change analysis, land-use change dynamics etc.
Plant ecology	Plant biodiversity, plant succession, biomass and species recovery, soil seed bank etc.
Soil nutrients and chemistry	Soil nutrients, soil organic carbon, and other chemical properties of soil.
Soil physics and hydrology	Soil erosion, soil infiltration capacity, soil particle stability etc.
Others	Documents other than the above research focus, e.g. Trace gas emissions from shifting cultivation.

3. Results and discussion

3.1. Spatio-temporal dynamics of research on shifting cultivation

3.1.1. Spatial distribution of research on shifting cultivation

Our study revealed spatial heterogeneity and biases in research focus, as well as a high degree of variability in the number of research studies across tropical countries and regions. Altogether 412 studies from 45 countries representing three tropical regions (i.e. tropical Asia and the Pacific; Africa and tropical America) were covered by the retrieved documents ($n = 401$). The geographic distributions of the studies are shown in Fig. 2. Of these studies, 215 (52.2%) were from tropical Asia and the Pacific, 131 (31.8%) from tropical America and the Caribbean, and 66 (16%) were from Africa. A small number of articles ($n = 9$) reported empirical studies from more than one country. The largest number of studies was reported from India ($n = 58$, 14%), followed by Brazil ($n = 43$, 10.4%), Mexico ($n = 38$, 9.2%), Indonesia, and Lao PDR ($n = 32$, 7.8%) (Supplmenetary material 3) and coincide within tropical countries where deforestation rates are relatively high (see Baccini et al., 2012).

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2015.10.005.

When considering the geographic focus, most research took place in tropical Asia and the Pacific region ($t = 3.18$; $p < 0.05$). Significantly more research was conducted on anthropology and human ecology issues ($t = 4.35$; $p \leq 0.01$) with the majority of these studies being conducted in the Asia and the Pacific region (56 studies, 26%) region and in tropical America (32 studies, 24.4%). Plant ecology related studies were the most common in Africa ($n = 16$, 24.2%) and in tropical America ($n = 25$, 19%). Research on soil nutrients and chemistry was prominent ($n = 46$, 21.4%) in the Asia-Pacific region (Fig. 2).

3.1.2. Temporal pattern of research on shifting cultivation

The majority of research related to shifting cultivation has been published since 2001 ($t = 2.1$; $p = 0.52$), with the major foci being on anthropology/human ecology (22%), plant ecology (20.7%), and soil nutrients and chemistry (14.2%). The majority of the research was on soil physics and hydrology (80%), geography/land-use transitions (73%) and plant ecology (72.6%) has occurred since 2001. Fig. 3 illustrates the changes in research focus in the retrieved documents between 1950 and 2014.

Research on anthropology and human ecology was prominent ($n = 101$) throughout almost the entire period except during 1981–1990. Research on agricultural production/management ($n = 17$) and soil nutrients and chemistry ($n = 16$) was also prominent after anthropology/human ecology during 1981–1990. During 1991–2000 soil nutrients and chemistry was a major focus of the researchers ($n = 23$). In recent years, research on the environmental impacts of shifting cultivation (e.g. soil physics and hydrology, plant ecology etc.) have received more attention.

A similar pattern is also common in case of geography and land-use transition research which may be attributed to the rapid advancement and access to spatial information technologies (for example: satellite imagery and advanced methods to monitor changes in shifting cultivation landscapes).

3.2. Impact of shifting cultivation on tropical forest dynamics

In tropical forested landscapes shifting cultivation has long been considered environmentally harmful and unsustainable (see – van Vliet et al., 2012; Ziegler et al., 2011, 2009; Bruun et al., 2009). However, what is often overlooked is that in many cases alternative land-uses to shifting cultivation fallow forests may have potentially greater negative impacts (Dressler et al., 2015; Vongvisouk et al., 2014). However, there are only a few studies that have investigated the change in environmental values of these

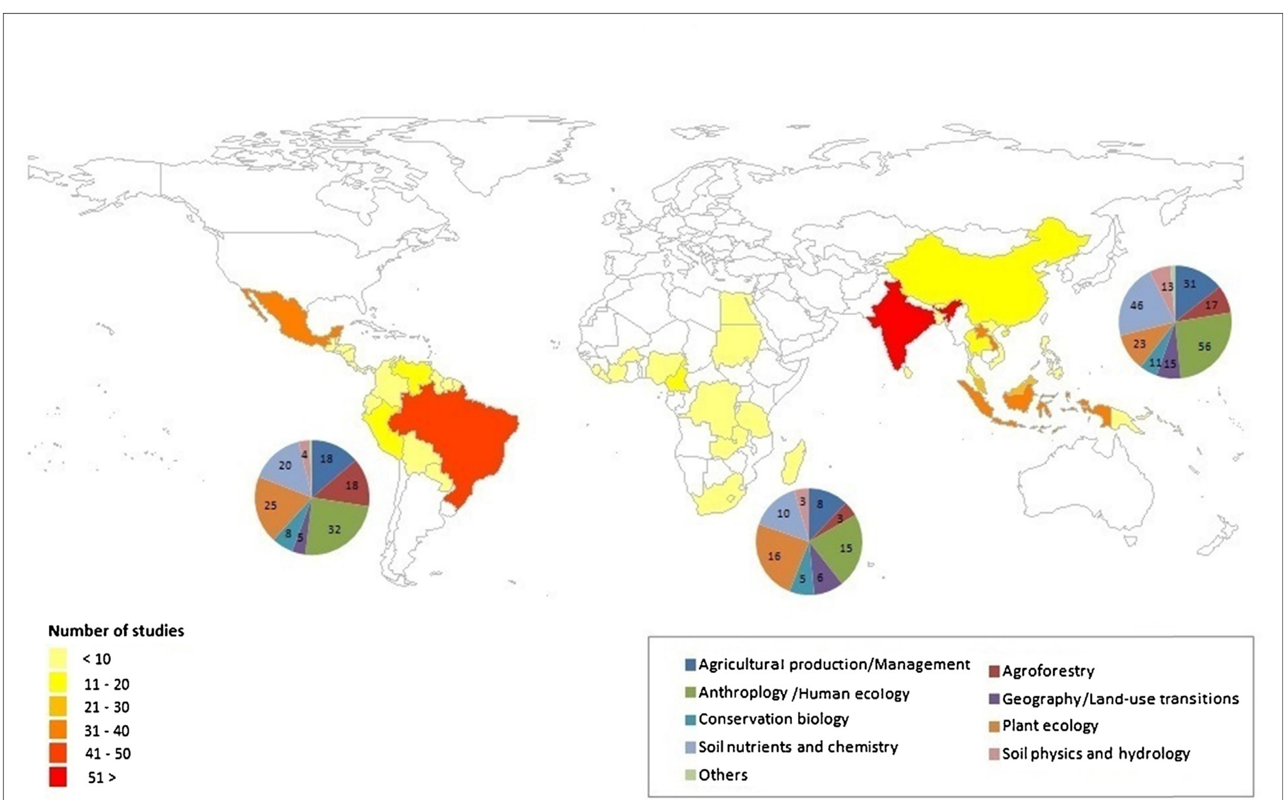

Fig. 2. Geogrpahical distribution of the studies on shifting cultivation by country.

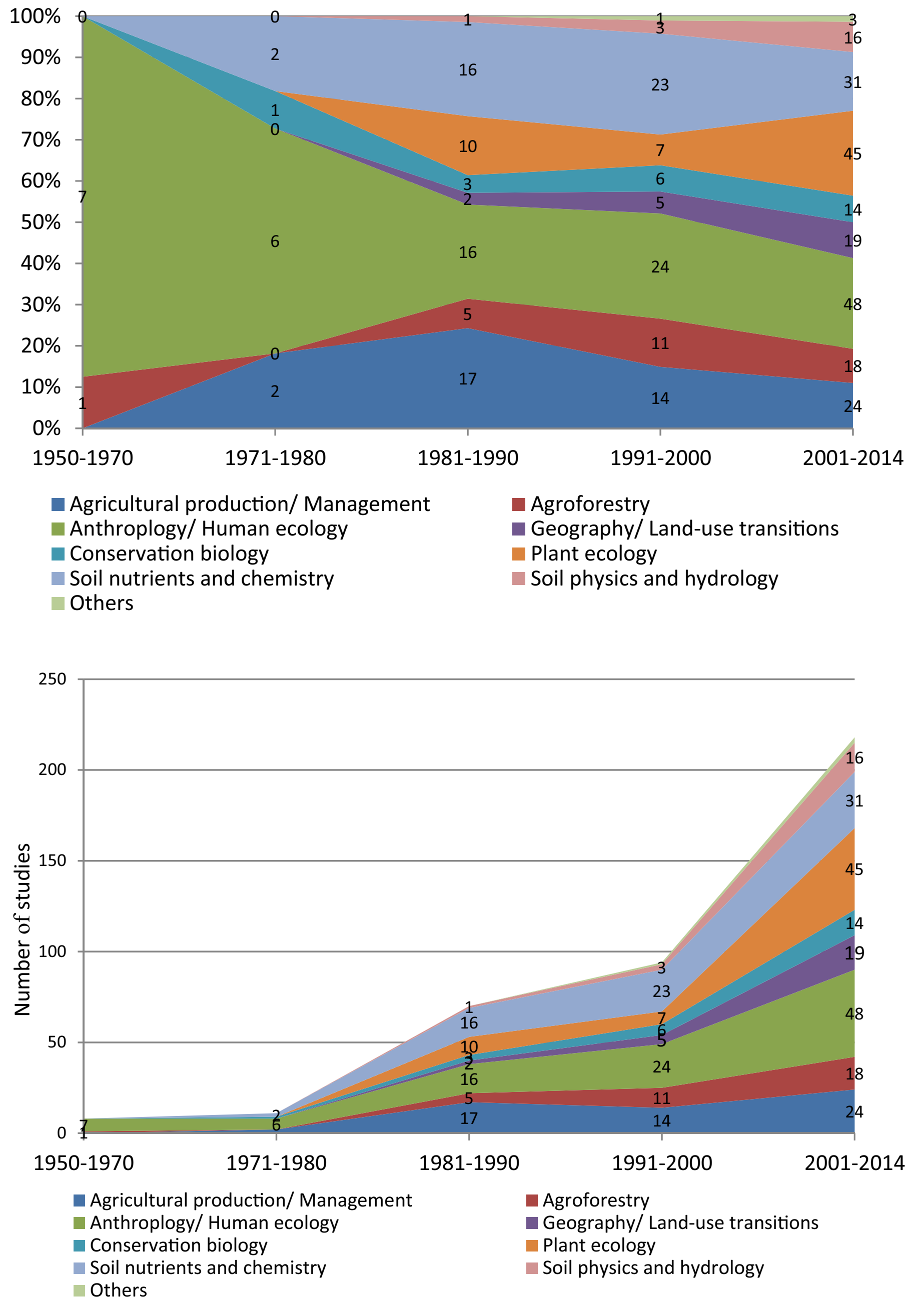

Fig. 3. Temporal changes in research focus between 1950 and 2014 (top: percentage; below: number).

alternative land-uses that may replace fallow secondary forests. From these studies, there is a growing evidence that the expansion of monoculture tree crops like rubber and oil palm in many parts of tropical Asia, which has replaced traditional shifting cultivations systems, has resulted in increased deforestation, biodiversity loss and deterioration of other related environmental parameters (Ahrends et al., 2015; Bruun et al., 2013; van Vliet et al., 2012).

Our meta-analysis revealed that there is a high degree of variability with respect to the impacts that shifting cultivation has on forest characteristics, wildlife, soil nutrients, and soil physical and hydraulic properties (Annex 1). Interestingly, most of the studies used a chrnosequence approach for monitoring change in different forest attributes in secondary fallow forest following the shifting cultivation (Annex 1). Fig. 4 presents the key insights of the retrieved documents with quantitative data ($n = 73$). Albeit a diverse research focus, a contrasting effect of shifting cultivation in forest characteristics is evident from the literature. It is important to notice here that our comparison was limited to only fallow forests and primary or old growth secondary forests without any history of shifting cultivation. Due to limited data we were unable to include other possible landuse/cover changes that may also replace fallow shifting cultivation landscape in tropics with potentially greater harmful effects. Details of the changes in forest characteristics, and their recovery pattern and determinants are discussed hereafter as per subject foci.

3.2.1. *Plant ecology*

Our meta-analysis of studies on plant ecology revealed a general negative impact of shifting cultivation on plant diversity and species composition (see Ding et al., 2012; Do et al., 2011; Castro-Luna et al., 2011; Fig. 4a). Interestingly, studies that focused on early successional stage following shifting cultivation found

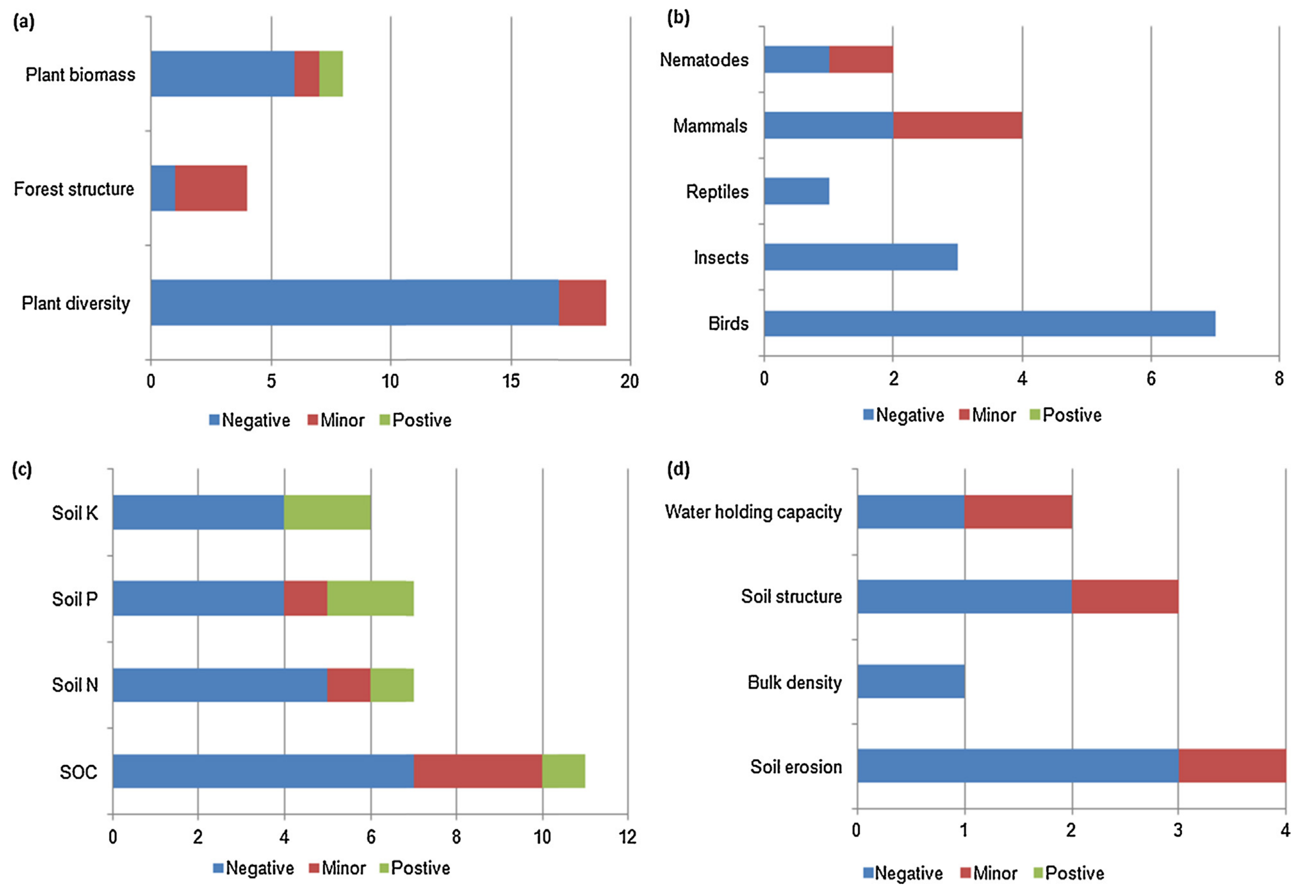

Fig. 4. Reported effect of shifting cultivation on (a) major forest characteristics; (b) selected wildlife selected taxa, (c) major soil nutrients and (d) soil physical and hydraulic properties. (Note: this is based on comparison with primary or old growth secondary forests without any history of shifting cultivation, and does not include other possible potentially more harmful land-use/cover changes that may also replace fallow shifting cultivation landscapes).

minor effect of shifting cultivation on plant diversity indices (e.g. Phongoudome et al., 2013; d'Oliveira et al., 2011; Raharimalala et al., 2010). A conspicuous negative impact of shifting cultivation on plant diversity compared to undisturbed forest was reported by Ding et al. (2012), Wilde et al. (2012), Do et al. (2011) and Castro-Luna et al. (2011) respectively from tropical China, Madagascar, Vietnam and Mexico. Species richness, however, did not differ significantly between undisturbed forests and secondary forests that have been subjected to shifting cultivation (Klanderud et al., 2010). Some studies found traditional forest management practices like logging less harmful than shifting cultivation when considering species diversity and composition (e.g. Ding et al., 2012).

Both fallow age and intensity of previous use influence the recovery of species composition and diversity after shifting cultivation (Ding et al., 2012; Schmook, 2010; N'Dja and Decocq, 2008). Young fallow areas have less diversity of species, but that diversity recovers quickly (Schmook, 2010). Similarly, it was found that, plant diversity recovered rapidly following shifting cultivation in Mexico, with continuous accumulation with age (Read and Lawrence, 2003). In Madagascar woody species become prominent in fallow secondary forests after about ten years (Raharimalala et al., 2010; Klanderud et al., 2010). In such circumstances, an active management strategy may be necessary to restore mature-forest species in fallow secondary forest (Bonilla-Moheno and Hol, 2010). It may however take around 60 years to achieve biodiversity of an old growth forest in such landscape (Do et al., 2010). Interestingly, when considering the factors that influences species diversity and composition, it was found that, soil type did not influence species diversity in the fallow secondary forests (N'Dja and Decocq, 2008).

Compared to species diversity, forest structure is slow to recover following shifting cultivation. For example, Piotto et al. (2009), found that it may take as long as 40 years to recover the structure of an old-growth forest after they have been used for shifting cultivation in Brazil. It has also been found in Cameroon that forest structure is much slower to recover in fallow secondary forests following shifting cultivation compared with logged forests i.e. 30–60 years compared to five to 14 years respectively (Gemerden et al., 2003) However, recovery of some specific stand structure parameters, such as stand density, can be rapid in young fallow areas (Phongoudome et al., 2013).

Biomass recovery follows a similar trend to the recovery of species diversity, with a rapid initial recovery phase which subsequently slows. Biomass accumulation increases with abandonment age (Raharimalala et al., 2012). Both above and below ground biomass recovers rapidly at early successional stage with an estimated accumulation rate between 7.5 and 15.0 Mg ha^{-1} $year^{-1}$ (Kenzo et al., 2010). Similarly, Gehring et al. (2005) found that biomass recovery is rapid in the early successional stages, with about 50 percent of the biomass recovering within 25 years after last use. Read and Lawrence (2003) from Mexico reported that recovery of biomass may take as long as 55–95 years after shifting cultivation. Similarly, Do et al. (2010) found in Vietnam that it may take about 60 years to achieve 80 percent biomass of an undisturbed forest. Substantial recovery of biomass has been found in Brazil following repeated fire events, with recovery to pre-fire AGB level within 30 years (d'Oliveira et al., 2011).

Burning following initial clearing has been found to have a positive influence on biomass accumulation in fallow secondary forests in the early successional stage (d'Oliveira et al., 2011; Kenzo et al., 2010; Tschakert et al., 2007). The rate of recovery of biomass is also affected by intensity and number of prior shifting cultivation cycles. For example, Lawrence (2005) found that the rate of biomass accumulation declines by about 10 percent with each subsequent shifting cultivation cycle.

In fallow secondary forests seed is crucial for species recovery and regeneration (Vieira and Proctor, 2007), and distance from intact forests or from forests that provide regular seed sources can also influence the recovery of species diversity (Sovu et al., 2009; Wangpakapattanawonga et al., 2010). Lawrence et al. (2005), for instance, reported that seed rain declined with increasing distance from the undisturbed forest. Interestingly, the largest seed banks were found in young fallow areas in the Brazilian Amazon (Vieira and Proctor, 2007).

3.2.2. Conservation biology

Most studies on conservation biology reported a negative impact of shifting cultivation on selected animal taxa (Fig. 4b). Our analysis however does not include exotic or monoculture planatations established in fallow secondary forests that have sometimes been found more harmful for local fauna (Ahrends et al., 2015). The majority of the studies ($n = 7$) were, limited to bird diversity and abundance in fallow secondary forests. In India, it has been found that bird diversity and abundance increase with an increase in the fallow age (Raman et al., 1998), although undisturbed forests remain as the main habitat of specialized forest birds (Raman, 2001; Bowman et al., 1990). Intensity of past shifting cultivation use greatly influences the diversity of birds in fallow secondary forest in tropical China (Zhijuna and Young, 2003). The diversity and abundance of large frugivores (i.e. birds that feed on large fruits) also increases with the increase in fallow age (Schulze et al., 2000).

Shifting cultivation also been found to have a negative (but minor) impact on small mammal diversity and abundance in Peru (Naughton-Treves et al., 2003), and Zaire (Wilkie and Finn, 1990), with hunting intensity having a much greater influence (Naughton-Treves et al., 2003). Other lower taxa animal appear to recover quickly after shifting cultivation, with their composition and richness being greatly influenced by the alteration of forest structure (Yoshima et al., 2013).

3.2.3. Soil nutrients and chemistry

Studies on soil nutrients and chemistry have reported a mixed effect of shifting cultivation on associated soil parameters (Fig. 4c). Generally, shifting cultivation involves burning of forest vegetation, and it is quite likely that it increases the amount of organic matter in soil via ash (Tanaka et al., 2001; Giardina et al., 2000; Adedeji, 1984). Soil nutrient losses can be potentially higher following shifting cultivation due increased soil run-off associated with forest clearing and site spatial characteristics like slope (Rodenburg et al., 2003; Brand and Pfund, 1998).

In Mexico, Giardina et al. (2000) found that, apart from ash, heating of soil during the burning of forests also acts as an important mechanism of nutrient release in the soil. Interestingly, Osman et al. (2013) found that, soil organic carbon (SOC) was greater in fallow secondary forests than in adjacent natural forests in Bangladesh. In Thailand, Tanaka et al. (2001) found that, while burning increases SOC, it also results in a decrease in microbial biomass C in soil. In contrast, a 32% decrease in SOC due to combustion has been reported in Mexico (García-Oliva et al., 1999). Some other land-uses like oil palm plantations may have however even more detrimental effect than shifting cultivation when considering soil C (Bruun et al., 2013).

Other nutrients, including soil available nitrogen (N), phosphorus (P) and potassium (K) also exhibit mixed effects following shifting cultivation. For instance, in China, Yang et al. (2003) found that fire reduced the total N and P in soil by about 20% and 10% respectively, while K was increased. Similarly, Brand and Pfund (1998) have reported a positive effect of shifting cultivation on soil available P and K in a 5 year old fallow secondary forest, but negative impact on Ca and Mg available in soil. In contrast, in Nigeria, Adedeji (1984) found that, soil K and N decreased rapidly after clearing for shifting cultivation, and in a 6 year old fallow forest the soil nutrient levels were still far below those found in a nearby undisturbed forest.

A long fallow period appears to be important to restore the essential soil nutrients (Funakawa et al., 2009). For instance, in Madagascar, Raharimalala et al. (2010) found that it may take about 20 years to restore soil nutrients after shifting cultivation. Intensity of past use (i.e. number of fallow cycles) does not appear to influence soil P, at least in Indonesia (Lawrence and Schlesinger, 2001).

3.2.4. Soil physics and hydrology

Studies on soil physics and hydrology reported mostly negative impacts of shifting cultivation on associated soil attributes in fallow secondary forests (Fig. 4d). In most cases, subsequent fire resulted in disruption to soil physical and hydraulic properties (Hattori et al., 2005; García-Oliva et al., 1999). Clearing and burning of forest at the initial stage of shifting cultivation cause increased soil run-off (Rodenburg et al., 2003). Dung et al. (2008) found significant increases in soil erosion and runoff compared to undisturbed forest in Vietnam. Gafur et al. (2003, 2004) also found a considerable amount of soil loss (3 Mg ha^{-1} year^{-1}) through runoff due to shifting cultivation in forests of Bangladesh. In contrast, Osman et al. (2013) however, did not found any considerable effect of shifting cultivation on soil physical properties including – water holding capacity, bulk density, moisture content and particle density.

In Malaysia (Hattori et al., 2005) and Thailand (Grange and Kansuntisukmongkol, 2003) it has been found that shifting cultivation accelerates soil erosion and deteriorates soil hydrological properties in fallow secondary forests. Soil loss decreased exponentially from burned to early stage of secondary forest development following the shifting cultivation (Thomaz, 2013). However, Grange and Kansuntisukmongkol (2003) did not find any detrimental effect of fallow length on soil physical attributes after shifting cultivation.

4. Conclusions

In tropical forested landscapes shifting cultivation is still a dominant land-use, although in recent years, both the intensity and extent of shifting cultivation have changed in many countries (van Vliet et al., 2012, 2013). Our systematic map revealed a large spatio-temporal variability and gaps in research on shifting cultivation across the tropics. There is great variability in the numbers and focus of research studies dealing with various aspects of shifting cultivation. Most research has been on anthropology and human ecology issues. In contrast, research on environmental consequences is still limited, and only gaining wider attention from researchers in the recent years.

Due to its complex nature, diverse focus, and differences in the context, it is difficult to generalize the findings of research on shifting cultivation systems. Our meta-analysis on the impacts of shifting cultivation on forest dynamics and related bio-physical and environmental parameters revealed great variability in research findings. There were a relatively large number of studies on plant ecology and fewer studies on soil physics and hydrology. A limited number of studies on environmental consequences of other land use/covers that are common after shifting cultivation in tropics was also evident. Plant diversity and composition was the most common aspects of plant ecology research while conservation biology related research were mainly focused on bird diversity. A limited impact of shifting cultivation on some soil essential nutrients were also evident from our meta-analysis. Apart from fallow length and intensity of previous use, site spatial attributes like slope, nearness to natural forests and permanent seed/dispersal source also seems critical for successful development of fallow secondary forests.

The sustainability of shifting cultivation systems continues to be debated in many tropical countries, and it is clear that this traditional practice will remain an important land-use and subsistence strategy in those countries many years ahead (Lawrence et al., 2010b; Neergaard et al., 2008). In developing tropical countries, shifting cultivation is still seen as a threat to the natural forest (Hett et al., 2012), and has been widely promoted as a practice having a detrimental impact to the environment (Neergaard et al., 2008; Fox et al., 2000). However, when discussing shifting cultivation, scientists and policy makers should also consider alternative land-uses with potentially greater negative impacts, like sedentary agriculture, commercially driven large scale plantations or monocultures (Dressler et al., 2015). Policy makers also need be cautious while designing policies, with careful consideration to the small-holder farmers to whom shifting cultivation is still the mainstay of livelihoods and food security.

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Annex 1 Summary of studies used in meta-analysis on impacts of shifting cultivation on forest dynamics

Primary area	Source	Country	Forest type	Study approach[a]	Specific focus	Environmental consequence[b]	Reference land-use[c]
Conservation biology/zoology (*n* = 14)	Yoshima et al. (2013)	Malaysia	Humid forest	Comparison	Invertebrate diversity	Minor	Undisturbed forest[d]
	Matsumoto et al. (2009)	Malaysia	Humid forest	Chronosequence, 2–20 yr	Ant diversity	Negative	Undisturbed forest
	Borges (2007)	Brazil	Humid forest	Chronosequence, 4–35 yr	Bird diversity	Negative	Undisturbed forest
	Gathorne-Hardy et al. (2006)	Indonesia	Humid forest	Chronosequence, 2–60 yr	Termites activity	Negative	Undisturbed forest
	Naughton-Treves et al. (2003)	Peru	Humid forest	Comparison	Mammalian diversity	Minor	Undisturbed forest
	Zhijuna and Young (2003)	China		Comparison	Bird diversity	Negative	Undisturbed forest
	Anderson (2001)	Honduras	Humid forest	Comparison	Bird diversity	Negative	Undisturbed forest
	Raman (2001)	India	Dry forest	Chronosequence, 1–100 yr	Bird diversity	Negative	Undisturbed forest
	Schulze et al. (2000)	Guatemala	Humid forest	Comparison	Bat diversity	Negative	Undisturbed forest
	Raman et al. (1998)	India	Dry forest	Chronosequence, 1–100 yr	Bird diversity	Negative	Undisturbed forest
	Raman (1996)	India	Dry forest	Comparison	Primate/squirrel abundance	Negative	Undisturbed forest
	Bowman et al. (1990)	Papua New Guinea	Humid forest	Chronosequence	Bird/butterflies/ reptile diversity	Negative	Undisturbed forest
	Wilkie and Finn (1990)	Zaire	Humid forest	Comparison	Mammalian diversity	Minor	Undisturbed forest
	Mishra and Ramakrishnan (1988)	India	Dry forest	Chronosequence, 1–15 yr	Nematode abundance	Negative	Undisturbed forest
Plant ecology (*n* = 34)	Phongoudome et al. (2013)	Lao PDR	Humid forest	Chronosequence	Plant diversity, forest structure	Minor	Undisturbed forest, Logged forest
	Raharimalala et al. (2012)	Madagascar	Humid forest	Chronosequence	Forest biomass	Negative	Undisturbed forest
	Wilde et al. (2012)	Madagascar	Humid forest	Chronosequence	Plant diversity	Negative	Undisturbed forest
	Ding et al. (2012)	China	Humid forest	Chronosequence	Plant diversity	Negative	Undisturbed forest, Logged forest
	d'Oliveira et al. (2011a,b)	Brazil	Humid forest	Long term monitoring	Forest biomass	Minor	Undisturbed forest
	Do et al. (2011)	Vietnam	Humid forest	Chronosequence	Plant diversity	Negative	Undisturbed forest
	Castro-Luna et al. (2011)	Mexico	Dry forest	Chronosequence	Plant diversity	Negative	Undisturbed forest, Logged forest
	Bonilla-Moheno and Hol (2010)	Mexico	Dry forest	Chronosequence 5–15 yr	Seedling survival	Negative	Undisturbed forest
	Rahamiralala et al. (2010)	Madagascar	Humid forest	Chronosequence, up to 40 years	Plant diversity	Minor	Undisturbed forest
	Wangpakapattanawonga et al. (2010)	Thailand	Humid forest	Chronosequence, 1–6 yr	Plant diversity/ succession	Minor	Undisturbed forest
	Schmook (2010)	Mexico	Dry forest	Chronosequence	Plant diversity/ succession	Negative	Undisturbed forest
	Kenzo et al. (2010)	Malaysia	Humid forest	Long term monitoring	Forest biomass	Positive	Undisturbed forest
	Do et al. (2010)	Vietnam	Humid forest	Chronosequence, 1–26 yr	Plant diversity, Forest biomass	Negative	Undisturbed forest
	Klanderud et al. (2010)	Madagascar	Humid forest	Chronosequence	Plant diversity	Negative	Undisturbed forest

Annex 1 Summary of studies used in meta-analysis on impacts of shifting cultivation on forest dynamics (*Continued*)

Primary area	Source	Country	Forest type	Study approach[a]	Specific focus	Environmental consequence[b]	Reference land-use[c]
	Lawrence et al. (2010a,b)	Mexico/ Indonesia	Dry/Humid forest	Long term monitoring	Forest biomass	Negative	Undisturbed forest
	Piotto et al. (2009)	Brazil	Humid forest	Chronosequence, 10–40 yr	Plant diversity, Forest structure	Minor	Undisturbed forest
	Sovu et al. (2009)	Lao PDR	Humid forest	Chronosequence, 1–20 yr	Species diversity, Forest structure	Negative	Undisturbed forest
	Eaton and Lawrence (2009)	Mexico	Dry forest	Chronosequence, 2–25 yr	Forest biomass	Negative	Undisturbed forest
	N'Dja and Decocq (2008)	Ivory Coast	Humid forest	Chronosequence, 1–30 yr	Plant diversity	Minor	Undisturbed forest, Logged forest
	Gehring et al. (2008)	Brazil	Humid forest	Chronosequence, 2–25 yr	Plant diversity	Negative	Undisturbed forest
	Ochoa-Gaona et al. (2007)	Mexico	Dry forest	Chronosequence	Plant diversity	Negative	Undisturbed forest
	Vieira and Proctor (2007)	Brazil	Humid forest	Chronosequence, 5–20 yr	Soil seed bank/ succession	Positive	Undisturbed forest
	Lawrence et al. (2005)	Indonesia	Humid forest	Chronosequence, 9–12 yr	Plant diversity	Negative	Undisturbed forest
	Gehring et al. (2005)	Brazil	Humid forest	Chronosequence, 2–25 yr	Plant diversity, Forest biomass	Negative	Undisturbed forest
	Lawrence (2005)	Indonesia	Humid forest	10–200 yrs	Forest biomass	Negative	Undisturbed forest
	Lawrence (2004)	Indonesia	Humid forest	9–12	Plant diversity	Negative	Undisturbed forest
	Kupfer et al. (2004)	Belize	Dry forest	Chronosequence, 1–10 yr	Plant diversity/ Succession	Negative	Undisturbed forest
	Metzger (2003)	Brazil	Humid forest	Chronosequence, 4–10 yr	Plant diversity/ Succession	Negative	Undisturbed forest
	Gemerden et al. (2003)	Cameroon	Humid forest	Chronosequence, 10–60 yr	Plant diversity	Negative	Undisturbed forest, Logged forest
	Read and Lawrence (2003)	Mexico	Dry forest	Chronosequence, 2–25	Forest biomass	Negative	Undisturbed forest
	Lawrence and Foster (2002)	Mexico	Dry forest	Chronosequence, 2–25	Forest biomass	Negative	Undisturbed forest
	Miller and Kauffman (1998a)	Mexico	Dry forest	Chronosequence; 2–19 yr	Plant diversity/ Succession	Negative	Undisturbed forest
	Miller and Kauffman (1998b)	Mexico	Dry forest	Comparison	Plant diversity	Negative	Undisturbed forest
	Kotto-Same et al. (1998)	Cameroon		Chronosequence, 4–70 yr	Forest biomass/ carbon	Negative	Undisturbed forest, Cacao plantation
Soil nutrient and chemistry (*n* = 17)	Bruun et al. (2013)	Malaysia	Humid forest	Comparison	SOC	Negative	Undisturbed forest, Oil palm plantation
	Osman et al. (2013)	Bangladesh	Humid forest	Chronosequence, 1–3 yr	SOC, N, P, K	SOC (+) Negative	Undisturbed forest
	Lima et al. (2011)	Brazil	Humid forest	Chronosequence	SOC, N	Negative	Undisturbed forest, Agroforests
	Rahamiralala et al. (2010)	Madagascar	Humid forest	Chronosequence	SOC, N	Minor	Undisturbed forest
	Eaton and Lawrence (2009)	Mexico	Dry forest	Chronosequence, 2–25 yr	SOC	Negative	Undisturbed forest
	Funakawa et al. (2009)	Indonesia	Humid forest	Comparison	SOC	Negative	Undisturbed forest
	Neergaard et al. (2008)	Malaysia	Humid forest	Comparison	SOC	Minor	Undisturbed forest, Pepper plantation
	Rodenburg et al. (2003)	Indonesia	Humid forest	Comparison	P	Negative	Rubber agroforest
	Gafur et al. (2003)	Bangladesh	Humid forest	Comparison	SOM	Negative	Agroforests
	Borggaard et al. (2003)	Bangladesh	Humid forest	Comparison	SOC, N, K	Negative	Agroforests
	Yang et al. (2003)	China		Comparison	N, P, K	Negative	Undisturbed forest
	Lawrence and Schlesinger (2001)	Indonesia	Humid forest	Chronosequence, 200 yr	P	Minor	Undisturbed forest
	Giardina et al. (2000)	Mexico	Dry forest	Comparison	N, P, K	Positive	Undisturbed forest
	García-Oliva et al. (1999)	Mexico	Dry forest	Chronosequence, 1–10 yr	SOC	Negative	Undisturbed forest
	Brand and Pfund (1998)	Madagascar	Humid forest	Comparison	P, K, Ca, Mg	Mixed (P,K+)	Undisturbed forest
	Salcedo et al. (1997)	Brazil	Humid forest	Comparison	SOC	Minor	Undisturbed forest
	Adedeji (1984)	Nigeria		Chronosequence, 16 yr	N, P, K	Negative	Undisturbed forest
Soil physics and hydrology (*n* = 8)	Thomaz (2013)	Brazil	Humid forest	na	Soil erosion	Negative	Undisturbed forest
	Osman et al. (2013)	Bangladesh	Humid forest	Comparison	Bulk density, water holding capacity	Negative	Undisturbed forest
	Lestrelin et al. (2012)	Lao PDR	Humid forest	na	Soil erosion	Negative	Undisturbed forest
	Dung et al. (2008)	Vietnam	Humid forest	na	Soil erosion	Negative	Undisturbed forest
	Neergaard et al. (2008)	Malaysia	Humid forest	Comparison	Soil erosion	Minor	Undisturbed forest, Pepper plantation
	Hattori et al. (2005)	Malaysia	Humid forest	Comparison	Soil structure	Negative	Undisturbed forest
	Gafur et al. (2004)	Bangladesh	Humid forest	Comparison	Soil structure	Negative	Undisturbed forest

Annex 1 Summary of studies used in meta-analysis on impacts of shifting cultivation on forest dynamics (*Continued*)

Primary area	Source	Country	Forest type	Study approach[a]	Specific focus	Environmental consequence[b]	Reference land-use[c]
	Grange and Kansuntisumkmongkol (2003)	Thailand	Humid forest	Chronosequence, 10 yr	Soil structure, water holding capacity	Minor	Undisturbed forest

[a] Where, chronosequence studies used secondary forests of different ages that have been previously used for shifting cultivation (and abandoned); comparison studies used only one age (specified or unspecified) of secondary forests (abandoned after shifting cultivation), and long term monitoring studies used the same fallow secondary forest sites for subsequent investigation over a long period of time.

[b] When referring e to a environmental consequence we consider the specific focus of that study and used undisturbed forests for any comparison.

[c] Our reference land-use for the comparisons were primarily based on forests, either logged or unlogged, and/or other tree based land-uses when available, e.g. cacao/rubber agroforests; we did not include any agricultural land-use in the analysis.

[d] Undisturbed forests includes primary or secondary forests that has never been used for shifting cutivation.

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