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Environmental Consequences of the Demise in Swidden Cultivation in Montane Mainland Southeast Asia: Hydrology and Geomorphology

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Abstract The hydrological and geomorphological impacts of traditional swidden cultivation in Montane Mainland Southeast Asia are virtually inconsequential, whereas the impacts associated with intensified replacement agricultural systems are often much more substantial. Negative perceptions toward swiddening in general by governments in the region beginning half a decade ago have largely been based on cases of forest conversion and land degradation associated with (a) intensified swidden systems, characterized by shortened fallow and extended cropping periods and/or (b) the widespread cultivation of opium for cash after the Second World War. Neither of these practices should be viewed as traditional, subsistence-based swiddening. Other types of intensive agriculture systems are now replacing swiddening throughout the region, including semi-permanent and permanent cash cropping, monoculture plantations, and greenhouse complexes. The negative impacts associated with these systems include changes in streamflow response, increased surface erosion, a higher probability of landslides, and the declination in stream water quality. Unlike the case for traditional swiddening, these impacts result because of several factors: (1) large portions of upland catchments are cultivated simultaneously; (2) accelerated hydraulic and tillage erosion occurs on plots that are cultivated repetitively with limited or no fallowing to allow recovery of key soil properties, including infiltration; (3) concentrated overland flow and erosion sources are often directly connected with the stream network; (4) root strength is reduced on permanently converted hillslopes; (5) surface and ground water extraction is frequently used for irrigation; and (6) and pesticides and herbicides are used. Furthermore, the commercial success of these systems relies on the existence of dense networks of roads, which are linear landscape features renowned for disrupting hydrological and geomorphological systems. A new conservation focus is needed to reduce the impacts of these intensified upland agricultural practices.

Keywords Slash-and-burn agriculture · Shifting cultivation · Opium · Degradation · Erosion · Landslides · Streamflow · Flood · Drought · Rainfall · Roads · Pesticides · Fertilizer

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Introduction

The World Bank (2007) estimates that there may still be more than 200 million swiddeners in Montane Mainland Southeast Asia (MMSEA); however, Mertz *et al.* (2009b), claim the real number is probably much less than 50 million (Mertz *et al.* 2009b). Other authors have estimated that as many as 400 million swiddeners or forest-dependent people were spread across tropical Asia at one time (Spencer 1966; Ma 1999; Kerkhoff and Sharma 2006). In some areas of Asia swiddening has been practiced for centuries—perhaps since the domestication of rice a few thousands years ago (cf. Hanks 1972). A simplified view of traditional swidden cultivation, which also refers to slash-and-burn and shifting cultivation, involves clearing and burning of forest plots for cultivation of subsistence crops, such as upland rice (Spencer 1966; Schmidt-Vogt 1999; Mertz *et al.* 2009a, b). The plots are cultivated for one to three seasons before being fallowed for a period typically exceeding six to 15 times the cropping period (Delang 2002; Mertz *et al.* 2009a). Abandoned fields are replaced with newly cleared land, including areas of regenerated forest on former swidden plots. Historically, frequent field relocation, sparse mountain populations, and lengthy fallows limited the extent of active cultivation within swidden landscapes during any given year. Both on-site degradation and off-site environmental impacts were therefore limited in space and time, as was found by Zinke *et al.* (1978) for an intact Lua swidden system in northern Thailand several decades ago.

Over the last several decades the nature of swidden cultivation throughout Southeast Asia has been changing rapidly in response to myriad social, economic, and political factors (Hill 1998; Rasul and Thapa 2003; Padoch *et al.* 2007; Fox *et al.* 2009). Within MMSEA (Fig. 1), initial transformations manifested as shortened fallows and lengthened cropping periods as mountain populations increased and available land diminished (e.g., Turkelboom 1999; Schmidt-Vogt 2001). A shift toward the cultivation of marketable crops followed the evolution of road and irrigation infrastructures, the development of urban market demands for agriculture products, and the initiation of crop substitution programs. Large-scale, permanent cultivation of annual crops, monoculture plantations, and greenhouse agriculture systems are currently becoming the dominant

Fig. 1 Montane Mainland SE Asia (MMSEA), defined by the *green shaded areas*, is defined herein as the lands between 300–3,000 m asl. MMSEA includes the upland regions of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China. Courtesy of John Vogler, East–West Center Program on Environment (Honolulu HI)

types of agriculture throughout much of the region (Rerkasem and Rerkasem 1994; Fox and Vogler 2005; Xu *et al.* 2005; Thongmanivong *et al.* 2005; Schmidt-Vogt *et al.* 2009). All of these transformed agriculture systems are generally more intensive than traditional swiddening—both spatially and temporally (Fig. 2). In contrast with traditional swiddening, many negative hydrological and geomorphological impacts result from the conversion to more intensive agricultural systems. This paper summarizes the consequences of the demise in swiddening in MMSEA on streamflow, water quality, surface erosion, and landslide susceptibility. The impacts on biodiversity, soil quality, and carbon storage are addressed elsewhere (Bruun *et al.* 2009; Rerkasem *et al.* 2009).

Streamflow

The net impact on the amount and timing of stream discharge of forest conversion for agriculture is determined by the combined effects on evapotranspiration and soil infiltration (Bruijnzeel 2004). The key mechanism of change is a decrease in evapotranspiration on croplands for which rainfall interception is less (van Dijk and Bruijnzeel 2001; Giambelluca *et al.* 1996, 2003). Furthermore, field crops have comparatively shallow rooting depths that limit the amount of water available for evapotranspiration during extended dry periods (Calder 1999). This fundamental difference in evapotranspiration should result in both higher annual and seasonal water

Fig. 2 Examples of changing agrarian practices in MMSEA: **a** upland rice field that is part of a traditional Lisu swidden landscape in northern Thailand; tree stumps and some mature trees (relict emergents) are left to facilitate forest regeneration; **b** intensified Khamu swidden system in northern Laos with shortened fallows and whole-sale cultivation of adjacent hillslopes; **c** former Hmong opium fields converted to permanent cultivation of vegetables including cabbage and lettuce (northern Thailand); **d** hillslopes in this former Bulan/Hani swidden landscape have been converted to a terraced rubber plantation; paddy rice is still planted in the valley bottom (Xishuangbanna, Yunnan Province China); **e** greenhouse-based flower farm covering an area of nearly 2 km^2 in northern Thailand (Karen workers)

yields, with the bulk of the increase coming during baseflow conditions (Bruijnzeel 1990, 2004) However, this response has typically only been observed in controlled experiments in small catchments where at least one-third of the forest has been converted (Bruijnzeel 2004). A fundamental difference between traditional swiddening and many of the intensified systems replacing it is the total amount of catchment area converted to cropland at any given time. In the case of traditional swiddening, rarely would the total extent of cultivation exceed this one third threshold—except, perhaps, in small sub-catchments.

Water yield changes have not generally been verified in large catchments in MMSEA despite high contemporary forest conversion rates (e.g., Thailand: Dyhr-Nielsen 1986; Alford 1992; Wilk *et al.* 2001). Nevertheless, a general public perception exists that decreased dry season flows occur commonly in catchments where substantial forest area has been disturbed or converted to agriculture, including swidden cultivation. In theory, significant and wide-spread reductions in the infiltration of rain water could result in increases in wet-season storm flow at the expense of recharging the deep soil or groundwater reserves feeding springs that typically sustain dry-season base flows (cf. Bruijnzeel 2004; Calder 2007). While increases in surface runoff are often reported for several types of land-cover conversion (e.g., mechanized logging, road building), rarely has a reduction in baseflow been shown except through diagnostic or conceptual modeling (cf. Smakhtin 2001; Bruijnzeel 1990, 2004).

In swidden systems, both fire-induced hydrophobicity and raindrop impact on exposed soils before adequate vegetative cover develops may reduce infiltrability, at least temporarily (Turkelboom 1999; Robichaud 2000; Janeau *et al.* 2003; Podwojewski *et al.* 2008). For example, the high surface runoff rates observed for initial stages of fallow vegetation in plot studies in northern Thailand probably reflect the presence of seals that formed during the cropping period when soils were exposed to rainfall (Ziegler *et al.* 2000). However, infiltration rates tend to recover quickly with the regeneration of secondary vegetation in the fallow period (Ziegler *et al.* 2000, 2004b). Furthermore, the spatial extent of cultivated area in traditional swidden landscapes should be too small for any effect of reduced infiltrability to alter catchment stream flow variables greatly. In addition, the spatial separation between fields sparsely distributed on forested hillslopes in traditional swidden systems facilitates the filtering of surface runoff before it reaches the stream system.

One example where swiddening caused significant increases in stream flow variables was associated with the *Jhum* system in Bangladesh. Clearing and cultivation of a 1-ha sub-catchment resulted in increases in peak discharge by 600% and annual runoff by 16% (Gafur *et al.* 2003). While some change in streamflow in a small sub-catchment are expected following the conversion of such a high percentage of forest (i.e., >33% threshold; see above), the observed changes in Bangladesh may reflect the effects of an intensified swidden system, for which fallow length had been decreased to only 3–5 years. Nevertheless, stream flow variables returned to near normal in the first year of fallow after one year of cultivation, demonstrating the resilience of the swidden landscape against long-lasting hydrological changes. This resilience is facilitated by the rapid regrowth of tropical vegetation, and importantly, the limited decrease in infiltrability, both in degree and in space, caused by swiddening activities.

In contrast, the transition from swiddening to more intensive forms of agriculture creates a situation where substantial reductions in infiltration may produce sufficient surface runoff to increase stormflow peaks and diminish dry season flows. Although this has rarely been confirmed in catchment studies (Valentin *et al.* 2008), several aspects of agricultural intensification make this scenario plausible: (1) a large percentage of the catchment is converted to cultivated plots that are subject to soil sealing processes (e.g., raindrop impact) for extended periods of time during the year (Janeau *et al.* 2003; Turkelboom *et al.* 2008); (2) deep excavation into subsurface soils of low permeability during the creation of planting terraces, such as those used to grow rubber in China (Fig. 2d) and vegetables in the Cameron Highlands of Peninsular Malaysia (Midmore *et al.* 1996); (3) accelerated tillage erosion that creates low-permeability tillage steps or results in subsurface soils of naturally lower infiltrability being displaced closer to the surface (Turkelboom 1999; Ziegler *et al.* 2004b); (4) a fallow period following cultivation that is too short to allow soil porosity and aggregate stability to recover sufficiently to restore infiltrability (cf. Nye and Greenland 1965; Bronick and Lal 2005); (5) creation of extensive compacted path networks that generate overland flow frequently (Fig. 2b; Ziegler *et al.* 2000, 2001a; Rijsdijk *et al.* 2007b; Turkelboom *et al.* 2008); (6) expansion of processing areas, greenhouse complexes, and other types of compacted surfaces of low infiltrability; (7) excessive surface disturbance across the landscape, such as over-grazing and yearly fires (Nikolic *et al.* 2008); and (8) destruction of natural vegetative buffers capable of infiltrating overland flow (e.g., Rijsdijk *et al.* 2007a; Ziegler *et al.* 2007c; Vigiak *et al.* 2008).

The development of reliable year-round road systems that facilitate commercial agriculture has increased the total area occupied by impermeable surfaces throughout MMSEA (Ziegler and Giambelluca 1997). Roads affect the routing of stormflow to the stream by generating runoff during most rainfall events, intercepting subsurface stormflow at the cutbank, and linking dispersed overland flow sources

(Megahan 1972; Wemple *et al.* 2001; Ziegler *et al.* 2001b, 2007b). Whereas the disruption of streamflow peaks related to intensified agriculture may result because a large percentage of the catchment area is "cultivated" simultaneously, the impact of roads may be on the same order of importance despite roads occupying a very small proportion of the catchment area (cf. Bowling *et al.* 2000; Ziegler *et al.* 2004a; Cuo *et al.* 2006, 2008). Collectively, all of the landscape disturbances mentioned above increase the propensity of the generation and concentration of overland flow; increase the connectivity of overland flow moving from the hillslope to the stream system, and, to some extent, reduce the local recharge that sustains higher and prolonged base flows.

Extreme floods in general are often assumed to be caused by forest removal and/or conversion to agriculture, but this notion is unsupported by data (van Dijk *et al.* 2009). Floods in any basin are caused when more water enters a channel than can be stored or passed downstream (cf. Rodriguez-Iturbe and Rinaold 1997; van Dijk *et al.* 2009). Large floods in MMSEA frequently occur as the result of intense rainfall from tropical storms (Thi Phuong Quynh Le *et al.* 2007; Wood and Ziegler 2008). While flooding is largely a function of storm and channel characteristics, landscape changes can increase flood probability. For example, many of the processes related to agriculture intensification described above that reduce infiltrability and concentrate overland could increase the volume and speed surface water enters a stream channel thereby increasing flow peaks (e.g., Gafur *et al.* 2003; Cuo *et al.* 2008).

Large-scale forest destruction and conversion to agriculture have been linked to reductions in rainfall (about 25% for a future deforested Amazonia; cf. Nobre *et al.* 1991; Bruijnzeel 2004; van Dijk and Keenan 2007; Malhi *et al.* 2008). Bruijnzeel (2004) estimated the total effect of historical land-cover changes on rainfall in SE Asia would be smaller than 8%. Consistent with this prediction are Kwanyuen's (2000) estimated 2–6 mm year^{-1} (~5–15%) reductions in rainfall in three northern Thailand catchments during the period 1951–1997 (however see Wilk *et al.* 2001). Thus, rainfall reductions could contribute to purported reduced dry-season flows in some streams draining headwater catchments. Again, such changes have not been detected at larger scales where river discharges have been monitored routinely for long periods of time.

The most likely cause of dry-season stream desiccation in areas where swiddening has intensified or has evolved into permanent agriculture systems is increased dry-season water use for irrigation (Fig. 2c; Alford 1992; Forsyth and Walker 2008). Unlike seasonal, rain-fed swidden cultivation, year-round planting of commercial crops requires substantial irrigation (Rerkasem 2005). Water diversion from headwater streams is a common irrigation water source throughout the region, northern Thailand in particular (Thanapakpawin *et al.* 2006; Forsyth and Walker 2008). In other areas, such as the Central Highlands of Vietnam, groundwater reserves are used heavily to irrigate commercial crops, including coffee (D'haeze *et al.* 2005). Elsewhere, potentially high dry-season water use by alien species, as suggested for rubber in Yunnan province of China, could potentially contribute to stream desiccation (Fig. 2d; Guardiola-Claramonte *et al.* 2008; Ziegler *et al.* 2009). Another contributing factor to contemporary lowland water shortages in northern Thailand is the difficulty of managing reservoir storage to both maximize water availability for dry-season irrigation of commercial crops and minimize flooding caused by late-season tropical storms (Wood and Ziegler 2008).

Water Quality

A fundamental difference between traditional swiddening and the commercial farming of fruit, vegetables, and flowers is the use of pesticides and chemical fertilizers (Midmore *et al.* 1996; Rerkasem 2005; Sidle *et al.* 2007). Agrochemicals are increasingly contributing to water quality degradation in upland agriculture areas where swiddening was once prevalent, for example in the Mae Sa catchment in northern Thailand (Ciglasch *et al.* 2005, 2006; Kahl *et al.* 2008), Inle lake in Myanmar (Sidle *et al.* 2007), and potentially, the Cameron Highlands of Malaysia (cf. Ismail *et al.* 2004; Mazlan and Mumford 2005). In general, excessive doses of chemicals are often used to ensure product marketability or because of insufficient practical experience by farmers (Rerkasem 2005). In large greenhouses and other systems used to cultivate high-value crops, operators often use fertilizers and pesticides. The increasing use of waste water for fertilization in peri-urban systems may also have deleterious environmental consequences when the effluent contains toxic contaminants (Duong *et al.* 2006; Nguyen *et al.* 2007).

Surface Erosion

Substantial soil loss has been reported for some swidden crops, including upland rice, for which annual estimates range from 2 to 350 Mg ha^{-1} year^{-1} (Table 1). This wide variation reflects, in part, differences in farming practices, as well as a host of physical variables related to climate, topography, and soil. The highest rates are typically determined for intensified systems with shortened fallow periods; and most rates only represent soil loss during the cropping phase. If the lower rates associated with lengthy fallow phases are considered, the mean long-term erosion

Table 1 Synthesis of soil loss rates for swidden agriculture in SE Asia

Location	Crop/Sys[a]	Soil loss rates during phases[b] Crop Mg ha^{-1} $year^{-1}$	Fallow Mg ha^{-1} $year^{-1}$	YSV Mg ha^{-1} $year^{-1}$	Method/note	Crop:Fal[c]
Traditional swiddening						
Thailand[d]	UR	Negligible	Negligible	Negligible	Field reconnaissance	1:10
Vietnam[e]	UR, M, JT	6	<1	–	Small catchment studies	1:8 (1980s)
Sarawak[f]	Hill *padi*	0.16–0.2	0.06–0.46	0.11–0.36	Plot studies	nr
Intensified swiddening						
Thailand[g]	UR	90–150	–	–	24–40-m plots; 50–54% slopes	1:5–20
Thailand[g]	OP, M	120–200	–	–		10–20:80+
Thailand[h]	UR	2–350 (60)	Negligible	Negligible	Obs: 10–70 m fields; 31–71% slopes	1–15:1–8
Thailand[h]	M	2–230 (18)	Negligible	Negligible	Obs: 10–70 m fields; 31–71% slopes	1–15:1–8
IBSRAM[i]	UR	5–143	na	na	Variably-sized plots at 7 of 8 sites	na
Vietnam[j]	UR	21–55	0–23	–	22.5-m plots; 22–24° slopes	1:2–5
Bangladesh[k]	*Jhum*	41	12	–	Monitored 1-ha catchments	1:5–7
Vietnam[l]	UR	13–21	1–11	<1–4	5×20 m plots	1–4:2–4
Vietnam[m]	CAS	6–16	1–10	1–2	1 m^2 microplots	na
Vietnam[e]	UR, M, JT	11	<1	–	Small catchment studies	1–2:1–4
Vietnam[m]	CAS	9	–	–	Small catchment study	na
General shifting cultivation/slash-and-burn cultivation						
Thailand[n]	Upland SC	0.1–100	–	–	Regional assessment	nr
Thailand[n]	Steepland SC	>100	–	–	Regional assessment	nr
Tropics[o]	SC	0.4–70 (2.8)	0.05–7.4 (0.2)		Review for SE Asia	nr
Thailand[p]	Yao farmers	28–64	–	–	Cs-137 retrospective study	
Xishuangbanna[q]	SC	49	–	–	Review for China	nr
Bangladesh[r]	SC	42	–	–	Plot studies on 30–46% slopes	
Hainan[q]	SC & S/B	5–32	–	–	Review for China	nr

[a] Crops are upland rice (*UR*), opium poppy (*OP*), maize (*M*), Job's tear (*JT*), cassava (*CAS*); Systems (*Sys*) refer to general slash and burn (*S/B*), shifting cultivation (*SC*)

[b] *YSV* is young secondary vegetation; *na* not applicable

[c] *Crop:Fal* refers to the ratio of years of cropping to fallow; *nr* not reported; *na* not applicable

[d] Pa Pae, Chiang Mai province (Zinke *et al.* 1978; Sabhasri 1978)

[e] Luang Prabong province: crop:fallow for tradition system was typical of the 1980s; 1990s for intensified (Valentin *et al.* 2008)

[f] East Malaysia: for *padi* (Douglas 1999); also see de Neergaard *et al.* (2008)

[g] Huai Thung Choa, Chiang Mai Province (Hurni 1982, 1983)

[h] Pahka village, Chiang Rai, Thailand: the intensified swidden values are ranges in individual fields; the value in parenthesis is the mean (Turkelboom 1999)

[i] Vlassak *et al.* (1993) summarizing several experimental sites in Thailand

[j] Rong Can village in Hoa Binh province (Fagerstrom *et al.* 2002)

[k] Chittagong Hills Tracts for *Jhum*, including cultivation of mixture of upland rice, maize, beans, chilly, turmeric, ginger, cassava, lentils, cucumber, gourd, cotton, jower, water melon, flowers and different vegetables. Fallows reduced from 15–20 to 3–5 years (Gafur *et al.* 2003; Borggaard *et al.* 2003)

[l] Hoa Bihn province (Nguyen *et al.* 2008)

[m] Hoa Bihn province (Podwojewski *et al.* 2008; Valentin *et al.* 2008)

[n] Regional assessment for Thailand (Tangtham 1997); also see Henderson and Poonsak (1984)

[o] Bruijnzeel (2004) after Wiersum (1984); median is in parenthesis

[p] Forsyth (1996)

[q] China and surrounding region (Hill and Peart 1998)

[r] Chittagong Hills Tracts, Bangladesh (Rahman *et al.* 2001)

rates are greatly reduced, as the soil is only exposed to erosive rainfall for a few weeks during a multi-year cycle (Table 1; cf. de Neergaard *et al.* 2008). Furthermore, if storage at the base of fields in vegetated hillslope buffers occurs, total export of soil from the hillslope within traditional swidden cultivation may be very low (cf. Zinke *et al.* 1978; Douglas 1999; Valentin *et al.* 2008). Many authors acknowledge the generally benign impact of swiddening, in terms of surface erosion (Nye and Greenland 1965; Douglas 1999; Bruijnzeel 2004; Sidle *et al.* 2006; Forsyth and Walker 2008; Valentin *et al.* 2008). In some instances, sensitive watershed areas such as ridge tops, hollows, seeps and other riparian areas are purposely avoided by swiddeners (e.g., Sabhasri 1978; Jones 1997; Lim and Douglas 2000). Historically, some swidden farmers may also have intentionally practiced erosion control by preferentially cultivating flatter slopes or deliberately placing charred logs horizontally across the hillslope to form revetments to curb soil loss (cf. Conklin 1957; Sabhasri 1978; Forsyth 1996).

Recent studies in MMSEA suggest that many of the highest reported erosion rates in upland areas are indicative of intensified agriculture systems having some or all of the following characteristics: (1) inadequate erosion-mitigating vegetative cover for several consecutive years or extended periods of time during the rainy season of any one year if more than one crop is planted; (2) the need for repeated weeding; (3) multi-year cropping without a sufficient fallow period during which soil porosity and aggregate stability recover and erodibility decreases; and (4) greater propensity to generate concentrated surface runoff, which contributes to rill erosion and gully formation (e.g., Turkelboom 1999; Ziegler *et al.* 2004a, b; Chaplot *et al.* 2005; Sidle *et al.* 2006; Nguyen *et al.* 2008; Podwojewski *et al.* 2008; Turkelboom *et al.* 2008; Valentin *et al.* 2008). Reduced-fallow systems in Laos, Thailand, and Vietnam experience substantial soil loss from tillage erosion during plot preparation and weeding (Turkelboom *et al.* 1997; Ziegler *et al.* 2007a; Dupin *et al.* 2009). Throughout SE Asia, high erosion rates are typically reported for various up-and-down-the-slope cultivation practices (Hill and Peart 1998; Sidle *et al.* 2006). Linear erosion features, including rills and gullies, may also be common in these intensely used landscapes (Fig. 3a; Chaplot *et al.* 2005; Turkelboom *et al.* 2008). Downslope furrowing, which is used to promote drainage of surface water from fields, often leads to linear erosion on downslope fields (Fig. 3b; Renard *et al.* 1998; Ziegler *et al.* 2001a; Turkelboom *et al.* 2008). When concentrated flow forms on long hillslopes, no achievable buffer width may be possible to reduce sediment entering the stream (Fig. 3c; Ziegler *et al.* 2006a, b).

Worldwide, footpaths and terraces are common source areas of erosion within permanent fields constructed on hillslopes because of the frequent generation of concentrated surface runoff on exposed or compacted surfaces (Collins and Neal 1998; Purwanto and Bruijnzeel 1998; van Dijk and Bruijnzeel 2004; Rijsdijk *et al.* 2007b). In comparison, many footpaths within traditional swidden landscapes are ephemeral features that affect hydro-geomorphological processes for only a brief period (Ziegler *et al.* 2001a). Severe surface erosion often results from extensive mechanical disturbance to the soil when creating broad platform terraces, such as those used in the Cameron Highlands of Peninsular Malaysia to grow temperate vegetables for urban markets in the lowlands (Midmore *et al.* 1996). Similar intensive agriculture areas can also be found in other highland cropping areas of China, Thailand, Vietnam, and the East Malaysian states, but less has been reported about the surface erosion occurring in these areas (Hill 1998; Douglas 2006; Rerkasem 2005). Unless conservation methods are employed, many of these intensified agriculture systems experience substantial soil erosion every year.

Native roads, which are now prevalent in MMSEA, are often the most important contributors to surface erosion on a per unit area basis in remote areas (Sidle *et al.* 2004, 2006). Because of substantial overland flow generated on and transported by roads, erosion has been shown to be on the same order of importance as that from agriculture lands, despite comprising much smaller areas (Turkelboom 1999, Ziegler *et al.* 2004a; Rijsdijk *et al.* 2007a). The growing use of greenhouses creates a degradation situation that is analogous to that of the expansion of settlement areas (Fig. 2e). Although surface erosion on planting beds inside an individual greenhouse is typically reduced, the runoff created on the impervious surfaces within the complex as a whole, including extensive networks of footpaths connecting individual houses, can cause linear erosion if the flow is not managed properly. In general, improper management of the flow of irrigation water across the surface of any hillslope can cause severe linear erosion (Fig. 3e; Midmore *et al.* 1996; Turkelboom 1999).

Landslides

The principal effect of forest conversion to permanent agriculture on the initiation of landslides is loss of hillslope root strength (Sidle *et al.* 1985). A converted hillslope typically has the lowest root strength 3–15 years following clearance (Sidle *et al.* 2006). This window of high landslide susceptibility marks the period when a lower triggering threshold (e.g., pore water pressure produced during a rain storm) will induce slope failure. In terms of increased risk of mass failure, both the magnitude of the reduction in root strength below some critical threshold and the period of time root strength remains below the threshold are

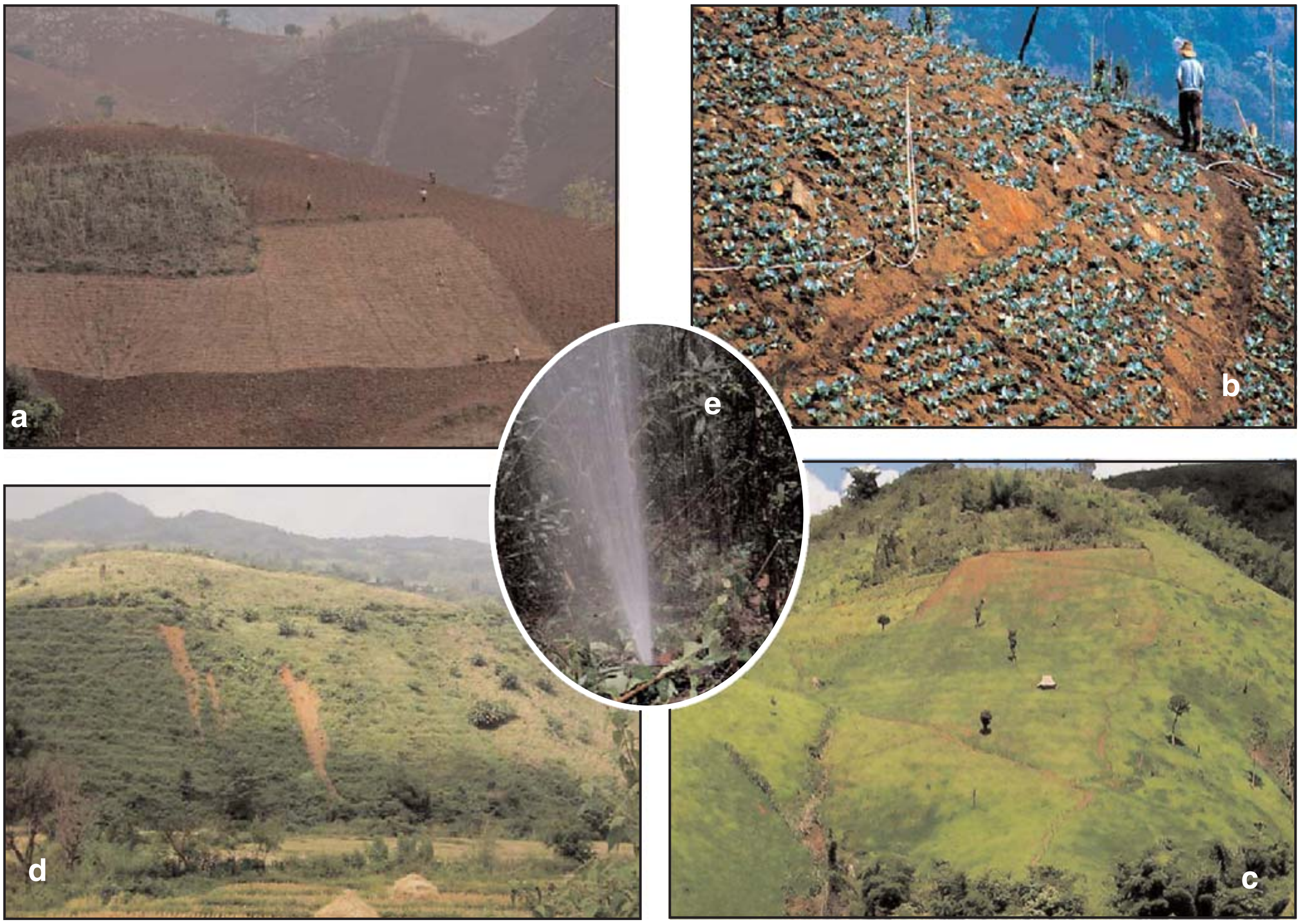

Fig. 3 **a** Rill erosion forming on long (>15 m) bare fields in northern Vietnam (*photo*: P. Schmitter). **b** Semi-permanent cultivation of cabbage in northern Thailand; down-slope furrows used to drain surface runoff from the fields often contribute to surface erosion when concentrated flow erodes the planting beds; **c** intensified rice swidden in Xishuangbanna (Yunnan province, China) where fields extend down into the extended stream network; thus limited opportunities exist for buffering of surface overland flow. Also seen is erosion (bare soil) associated with walking paths, as well as wash erosion that formed on the upper part of the slope where crop development and surface cover was retarded. **d** Shallow soil slips on young fallow slopes formerly planted with maize; these slopes have subsequently been replaced by rubber; **e** broken irrigation pipes are often the source of linear erosion and, potentially, shallow landslides

important (Sidle and Ochiai 2006). Thus, critical factors affecting increased risk are the time between forest clearance and initial regrowth and the rate of regrowth.

In the case of traditional swiddening, recovery should begin immediately and take place rapidly (Fig. 4). The traditional practice of leaving living stumps and tall trees (relict emergents) in swiddens foster fast regeneration of deep-root vegetation (Fig. 2a). When forest recovery is delayed, as is the case of lengthened cropping periods, not only is the magnitude of the decrease in root strength greater, but the period of time before hillslope root strength regenerates sufficiently to reduce the risk of failure is longer. Conversion from swidden to permanent agriculture should result in higher probability of slope failure for indefinite periods of time, especially if shallow-rooted crops are grown (Fig. 3d). Furthermore, dense and interconnected networks of roads and paths that are associated with agricultural intensification are important contributors to increased probability of landsliding (Turkelboom 1999; Sidle *et al.* 2006; Rijsdijk *et al.* 2007a).

Discussion

The distinction between traditional and intensified swidden cultivation systems is not clearly made in most assessments of the environmental consequences of swiddening. For many years the popular perception was that swiddening is a destructive system that leads only to forest destruction and land degradation (cf. Fox *et al.* 2000). Extreme examples of exhaustive cultivation on steep slopes by a few groups of swiddeners growing opium poppy in the Golden Triangle undoubtedly helped foster this negative association (Hurni 1982, 1983; Schmidt-Vogt 2001; Delang 2002). Opium

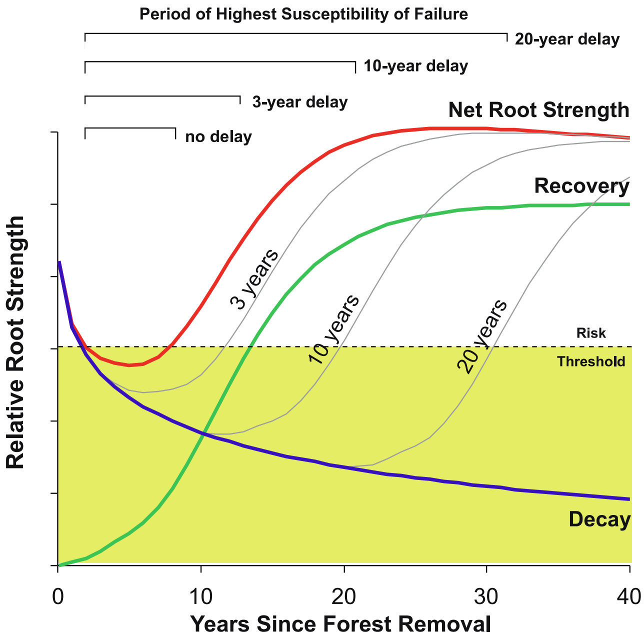

Fig. 4 Conceptual model of root strength decay following forest clearance and root strength recovery following tree regrowth/replanting. Net root strength is the sum of that associated with decay and regeneration. The period of highest risk is where the net root strength curve falls below some site-specific critical threshold. Also shown are net root strengths for the situation of a delay in replanting/regrowth of 3, 10, and 20 years. For traditional swidden agriculture, recovery would begin immediately if tree stumps are not destroyed and some tall trees (relict emergents) are present (Fig. 1a). Swiddens of shortened fallows and long cropping periods would have increased risk of mass failure. Root strength associated with permanent agriculture would remain low indefinitely (based on Sidle *et al.* 2006)

poppy cultivation exhausted soil fertility and accelerated erosion in cases where individual fields were cultivated 5 to 20 years in succession before abandonment (Hurni 1982). It is incorrect, however, to view this particular practice as traditional swiddening; these systems transformed within the last couple of centuries from subsistence-based practices to systems with a hegemony of opium poppies cultivated for cash—i.e., commercial agriculture (cf. Hill 1998). While there is evidence of commercial opium production in southern China in the late 18th century by ethnic minorities, large-scale production probably started after the Opium Wars (cf. Geddes 1976; Cooper 1984; McCoy 1991; Trocki 1999). The major influx of opium poppy cultivators (e.g., Hmong, Yao, Akha) into the Golden Triangle began about the 1870s (P. Cohen, personal communication). Opium production was not substantial prior to World War II (<100 Mg year^{-1}); and the boom began in the early 1950s as the western markets opened (McCoy 1991). Production reached 1,000 Mg year^{-1} by the 1970s, with a peak of about 3,000 Mg year^{-1} occurring in the mid 1990s (McCoy 1991; Cohen, personal communication). During the opium boom—which would have required the transformation of vast landscapes into poppy fields—much of the blame for any type of forest conversion and land degradation was often directed toward ethnic swiddeners, even those who did not cultivate poppies (Poffenberger and McGean 1993; Schmidt-Vogt 2001; Delang 2002; Forsyth and Walker 2008).

Driven by negative views of swiddening, all countries in MMSEA have attempted to control or terminate swiddening at one time or another (Fox and Vogler 2005). Governments in Vietnam and Laos, for example, began implementing programs to end or restrict swidden cultivation in 1968 and 1976, respectively (Fox *et al.* 2000; Schmidt-Vogt 2001; Thongmanivong *et al.* 2005; Lestrelin and Giordano 2007; Nikolic *et al.* 2008). As early as the 1960s, farmers in Yunnan Province China were forced to convert sloped farming land to permanent forest or grassland (Weyeraeuser *et al.* 2005). Within the last few decades swidden cultivation in Thailand has been controlled through restrictions imposed by conservation measures including the establishment of national parks and wildlife reserves, implementation of a watershed classification system, and delineation of water reserve land (Rarkesem and Rerkasem 1994; Schmidt-Vogt 2001; Delang 2002; Forsyth and Walker 2008).

Because of the emphasis on eliminating swiddening and eradicating opium, the management strategies designed to reduce land degradation in many areas of MMSEA have generally failed to prevent the occurrence of the hydrological and geomorphological impacts that are typical of the intensive agriculture practices found today. Currently, high market demand in urban centers for fruits, vegetables, flowers and other upland products is driving farmers to exert even greater pressure on soil and water resources throughout MMSEA. Reversion to traditional swidden cultivation is not likely feasible at an appreciable scale. Therefore, new conservation policies are needed to reduce the environmental impacts of the practices now being employed. Furthermore, a better understanding of how land-cover/land-use change affects hydrological and geomorphological processes is needed at all levels.

Conclusion

The long-term environmental impacts associated with traditional swiddening are virtually inconsequential because of the frequent relocation of fields, limited catchment area cultivated at any one time, and rapid regeneration of tropical vegetation following a short cultivation period. Most commonly cited examples of severe land degradation resulting from swiddening are associated with intensified systems, including opium cultivation, having insufficient fallow periods and uncharacteristically long growing periods. Once intensified or converted to more-permanent cash-crop systems, negative impacts become significant because the landscape no longer functions like a forested landscape. Landscapes where traditional swidden cultivation is practiced differ from those where swiddening has been replaced by more intensive agriculture practices because of the following: (1) differences in evapotranspiration between short-rooted cash crops and forests; (2) impairment of rainwater infiltration through repetitive surface disturbance and creation of impermeable surfaces with a high propensity to generate surface runoff; (3) an increase in the total catchment area cultivated at any one time, which increases both the spatial extent and temporal period of exposure to surface erosion processes; (4) creation of a landscape with high connectivity between hillslope overland flow and erosion sources and the stream; (5) surface and groundwater extraction for irrigation; (6) repetitive cultivation and the elimination/reduction of a fallow period, during which soil aggregate stability and porosity would otherwise be restored, some degree of soil formation takes place, and root-strength recovers; and (7) the use of fertilizers and pesticides. These differences lead to the disruption of natural stream flow response at some scales, accelerated surface erosion, elevated stream sediment loads, and greater risk of rainfall-induced landslides. Furthermore, road networks that facilitate highland commercial agriculture are probably responsible for much of the observed turbidity increases and stormflow irregularities in streams draining headwater catchments. Finally, the extent that the environmental consequences of the transition from traditional swiddening to other forms of agriculture will be realized in any one location depends on the interplay between the natural biophysical conditions and the intensity/type of the agriculture practices themselves, which is largely controlled by market demands and land-use policies.

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