One year after Tsunami Aceh

The coastal areas of Aceh, the northern tip of Sumatra, were directly hit by a Tsunami in December 2014. Conversion of coastal vegetation to urban settlements had made many people vulnerable and mangroves or other tree cover were seen as important to prevent future disasters. One year after the event, trees were back, but natural resource extraction also recovered and became more extensive, with new mining, land conversion, and logging underway.

Photo: World Agroforestry

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CHAPTER FOURTEEN

How can agroforestry be part of disaster risk management?

Meine van Noordwijk, Kurniatun Hairiah, Hesti L Tata, Rodel Lasco

Highlights

- **A**groforestry and wise use of trees in rural and urban landscapes can reduce human vulnerability to disasters
- Separate hypotheses relate to reduced exposure to and increasing resilience in the face of natural and partially anthropogenic disasters
- Examples from Asian landscapes in the past two decades provide nuance to the hypotheses

14.1 Introduction

A common definition of a disaster is: "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources. Though often caused by nature, disasters can have human origins."[1] Disasters can be of many types, based on the elements (Earth, Water, Wind, Fire and Biota) involved, the spatial and temporal scale affected and the degree to which they are natural or (partially) manmade.

The human response can be understood on a before/during/after timescale. Awareness, prevention and avoidance of risky times and places is a strategic, long-term response. The tactics of fleeing, hiding and surviving form the immediate responses, while the resilience or bouncing back afterwards has both material and immaterial (motivational) dimensions. With current understanding of the human causation of as part of global climate change[2], the categorization into 'natural' and 'manmade' disasters is further blurred, but such distinctions still play a role in policy responses and insurance coverage. The recent Lombok earthquakes show that the negative repercussions for international tourism of declaring the damage to be a 'national disaster' are an argument against such designation and in fact delay the recovery process.

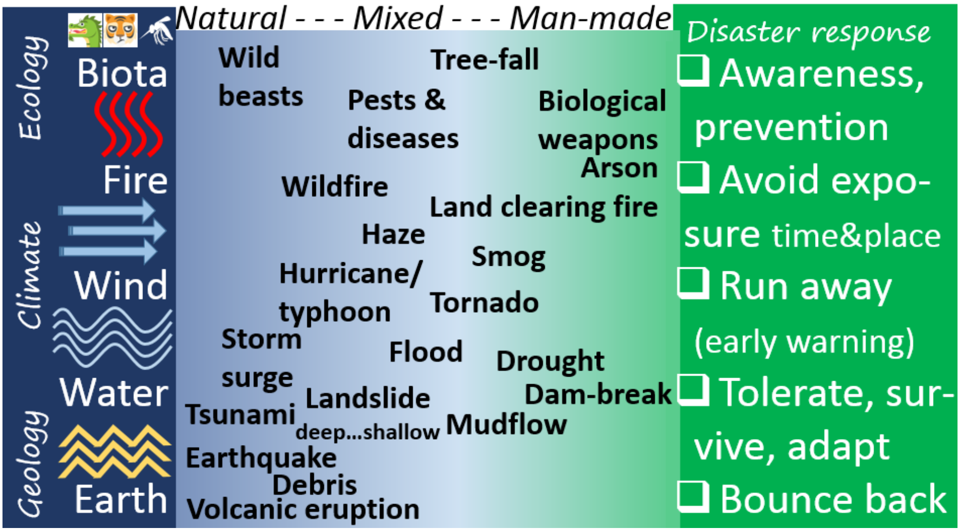

Figure 14.1 Examples of disasters classified by 'element' causing it and degree of human causation

Agroforestry as a concept has evolved from a focus on specific ***technologies*** for using trees on farm, towards an understanding of multifunctional ***landscapes*** with trees in multiple roles, and more recently efforts to harmonise agricultural and forestry ***policies*** in a holistic approach to land use for achieving sustainable development goals (SDGs)[3,4,5].

Our key hypotheses here are that:

1. Agroforestry, or the wise use of trees, can play a role in reducing exposure in risk-aware land use planning.
2. It can also help to retain or restore buffer and filter functions in the landscape that reduce and localize disturbances, such as surface flows of soil particles derived from erosion or volcanic debris.
3. Through its mitigating effects on global climate change, agroforestry also contributes to countering the current increasing trend in disaster prevalence due to climate change.

A number of studies will be briefly reviewed here that have quantified the positive and negative aspects of trees in landscapes affected by natural disasters and/or considered to be at risk:

- Tsunami (W. Aceh)
- Volcanic ash (Kelud)
- Shallow landslides (W. Java)
- Kebun lindung, protective agroforests on sloping land
- Flood risks in headwater catchments
- Haze prevention through peatland paludiculture

14.2 Tsunami (W. Aceh)

With more than 200,000 human victims, the Tsunami that hit Aceh in December 2004 was high on the global list of deadliest disasters since 1900[6]. Directly after the scale of the devastation became clear, public discussion focused on the role of mangrove conversion in the degree of avoidable damage done[7]. Two aspects were key here: building houses in locations that used to be mangrove proved to be a high-risk land use choice, while remaining mangrove between people in the hinterland and the coast provided protection from the wave impact by absorbing part of the momentum. A further analysis of the damage and victims in W Aceh, however, showed[8] that positive protection effects of trees between people's locations and the coast were largely offset by negative impacts of trees beyond where they lived. Such trees blocked escape routes and contributed to the back-and-forth debris flows that characterize a tsunami and make it hard to survive, unless one escaped to higher grounds (or climbed a strong tree) on the first warning signs (having felt the earthquake that caused the tsunami). This analysis combined data for mangrove with other coastal tree vegetation, based on a 'roughness' parameter that represented the wave impact of various types of vegetation. In hindsight, much of the mangrove planting that was part of the early disaster response might have fulfilled a ritualistic function, but did not contribute much to future risk avoidance, as the survival rate of the trees was low (for various reasons) and people still preferred to rebuild houses close to the coast[9] (Fig. 14.2).

Figure 14.2 Murals in Meulaboh (W. Aceh, Indonesia) developed as part of the recovery process for survivors, showing the destruction by the waves, the efforts to escape, the international support that we triggered and the vision for the future (fishing plus houses between the coast and trees…)

Rather than planting 'any tree', specific attention to species choice and quality of planting material through local 'nurseries of excellence'[10] helped in the economic recovery process in coastal areas[11]. In assistance of local governments, reinventing spatial planning through use of models that build in explicit risk factors[12] made a contribution to a more rational weighing of the risks (small probabilities but huge impacts) of a next Tsunami and more immediate livelihood opportunities. Across coastal areas of Indonesia the technical options for early warning, effective communication and clarity on escape routes have been replicated. There has been some progress on mangrove rehabilitation along part of the coast, especially where local communities were involved from the earliest stages[13] but the lack of a strong land use planning discipline means that the risks of a next Tsunami disaster still exists in Indonesia, and elsewhere in SE Asia.

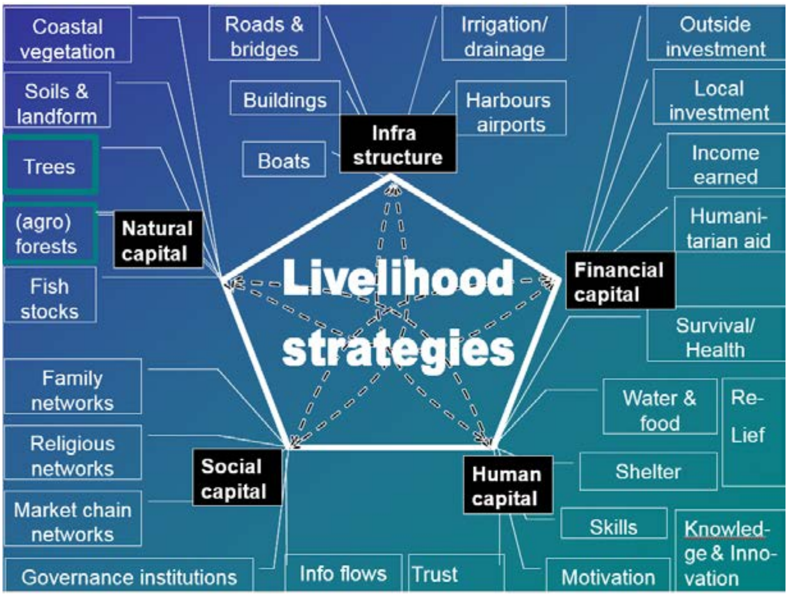

Figure 14.3 Result of a focus group discussion with local government staff of the livelihood context of Tsunami recovery in West Aceh (Indonesia), leading to stronger sectorial integration and coordination

Although its primary cause differs, storm surges after typhoon landfalls in the Philippines have similar effects on coastal populations. The degree of damage brought in 2013 to Leyte by typhoon Hainan[14] sparked interest in mangrove rehabilitation as well, with similar findings as earlier documented in Indonesia[15]. Because typhoon frequencies and pathways are influenced by ocean temperatures, there is a clear anthropogenic risk induction dimension to the storm surge debate. Strengthening tree-based coastal defence is now seen as a valid component of climate change adaptation[16].

14.3 Volcanic ash (Kelud)

In the 'ring of fire'[17] plate tectonics are the underlying cause of the vast majority of the world's earthquakes and active volcanoes. Southeast Asia has about 750 active and potentially active volcanoes, with different frequencies of eruption[18]. Eruptions, especially before the current era of monitoring of volcanic activity, caused disasters for people living on the slopes and direct surrounding, while the ash and debris deposits affect land use over much larger distances, and climatic effects of stratospheric ash have affected global climates several times per century[19], with disastrous impacts in historical records at least once per millennium. Yet, volcanic ash is also the basis of some of the most fertile soils (Andosols). Such andosols, however, develop after weathering of the ash and involve the incorporation of large amounts of carbon, challenging farming in the years directly after landscapes are blanketed by ash[20].

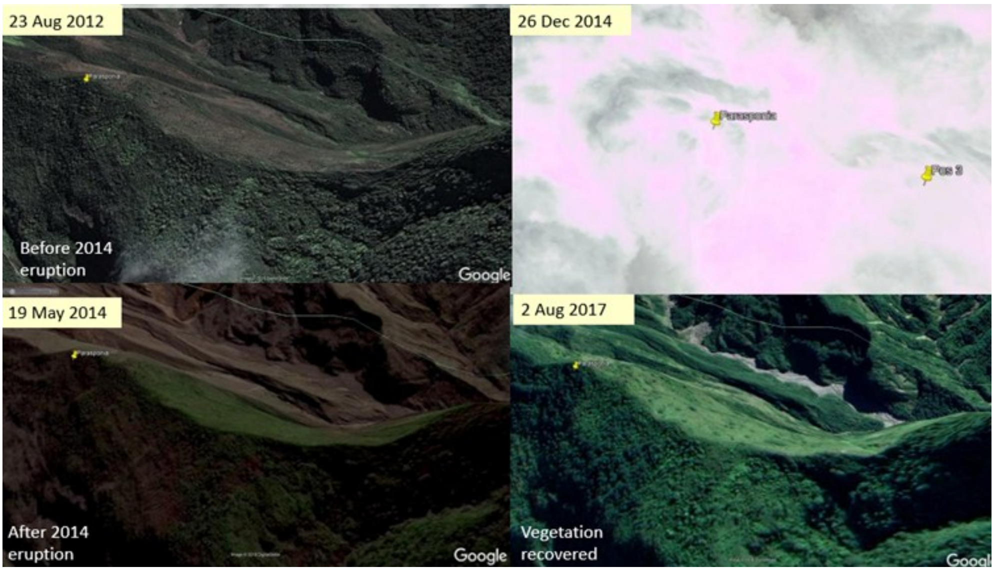

Figure 14.4 Google Earth imagery of the E slope of Mount Kelud before, during and after the most recent eruption and ash deposit that was a major disruption for many villages in the Kali Konto landscape

Only a limited number of trees can withstand the high sulphur emissions and other conditions on volcanoes, and play, through tolerance and rapid recovery after ash deposits, a role in the stabilization of fresh ash deposits, preventing mudflows and further disasters downstream in the following rainy seasons. On volcanoes with a high frequency of ash deposits a biologically remarkable genus of trees, *Parasponia*, is among the few that can tolerate and even thrive in these conditions. It is remarkable, because it is in early stages of evolution of a symbiosis with *Rhizobium* bacteria that allows it to fix atmospheric nitrogen in an otherwise N-limited environment[21]. Ongoing research on Mount Kelud in East Java explores how *P. andersonii* can be used in coffee agroforestry systems on the volcanoes slopes and direct surrounding, providing a positive twist to the regularly occurring disturbance of lives and landscapes by the ash[22].

Figure 14.5 *Parasponia andersonii* and the nodules it formed three years after this landscape position was blanketed by ash on Mount Kelud

14.4 Shallow landslides (W. Java)

Recent earthquakes in Lombok have again confirmed that man-made buildings from brick and concrete are far more vulnerable than trees when the earth shakes. Traditional wooden houses are reportedly much better adapted, absorbing the wave energy and shaking, but not collapsing. Trees also add coherence and anchoring to soil layers on slopes, shifting the threshold at which landslides occur when soil gradually accumulates over time. Because of this function, landslide risk increases after deforestation, peaking after a few years when the main woody roots have decayed. If landslide have not happened by that time, the soil compaction and reduction of infiltration rates is likely to protect the soil from landslides after that point in time. Deep landslides, beyond the reach of tree roots will still occur if soil accumulation has proceeded for a long time.

Not all trees are equally effective in preventing shallow landslides, as it depends on the architecture of the root system. Relatively simple methods have been developed to characterize tree roots in their relative share of vertical ('anchoring') and horizontal ('soil binding') roots[23]. There is a tendency for smaller trees to have rela-tively larger root systems (based on cross-sectional area of proximal roots relative to that of the stem, Fig. 14.6B)

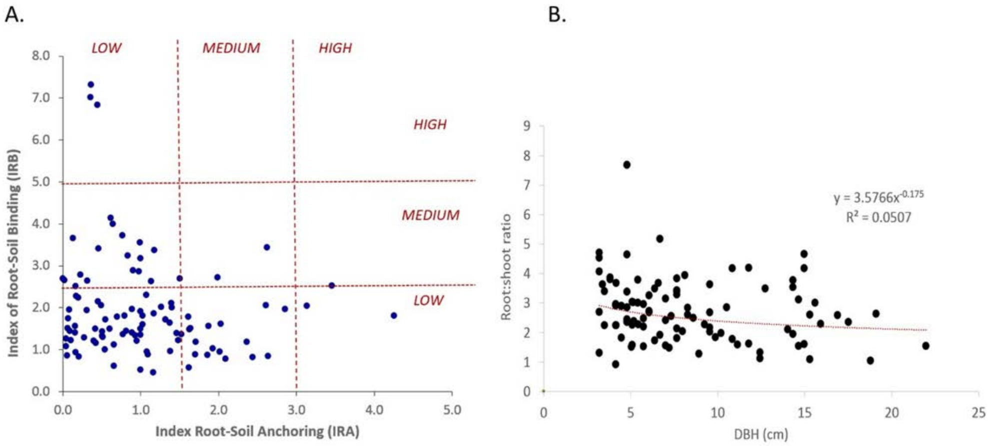

Figure 14.6 A. Tradeoff between deep anchoring and horizontal soil binding roots, and B. Reduced investment in roots with increasing stem diameter, in recent fieldwork in E Java[24]

14.5 Kebun lindung, protective agroforests on sloping land

In Indonesia land is classified first of all as forest versus non-forest, where the first is under state control (even when the legal requirements of gazettement have only been completed for a fraction of the total area claimed[25, 26,27]), and the second without substantial legal restrictions to 'environmental externalities' of private land use decisions. Both of these issues limit the options to reconcile 'development' and 'sustainability' in land use patterns. Based largely on criteria of slope, part of the forest domain is classified as 'protective forest' (*hutan lindung*; the common English translation as 'protection forest' is less accurate; the term used in a colonial past referred to 'shielding' forest), implying that it is out of bounds for logging. It also means, however, that forest management authorities have few means to implement the mandated control of external pressures. A small fraction of the national 'protective forest' now has community management agreements, with limited use rights linked to effective protection, mostly for securing local 'environmental services' as incentive. Negotiations between local communities and forest authorities have been complex and slow, because existing regulations prescribe 'solutions', rather than clarify objectively verifiable functions[28,29,30,31].

Part of the community- or privately owned non-forest land still has substantial tree cover, and on slopes acts as 'protective garden' (*kebun lindung*). Interests of downstream stakeholders in maintaining (or enhancing) the existing 'protective' functions may deserve voluntary Payments for Environmental Services, but despite promising pilot schemes, there still are substantial bottlenecks in mainstreaming such[32,33,34,35].

Effectiveness of the two types of 'kebun lindung' (the community-managed parts of 'forest' plus the privately controlled non-forest, tree-based systems) has been shown in studies of landscape-scale sediment transport[36]. A diverse tree cover contributes to landslide prevention, while a continuous litter layer protects soil from erosion and feeds the soil biota (incl. earthworms) that help to main high infiltration rates[37], thus reducing flooding risks.

14.7 Flood risks in headwater catchments

Floods are high on the list of economic damage and public health risks, even if the number of human victims is modest (different from the mudflows that were considered under 'landslides'). In fact, temporarily high water levels are a regular feature of downstream river systems, geomorphologically classified as 'floodplains'. As long as these are maintained as wetlands, they protect areas further downstream from flooding. If they are converted to urban areas, protected by dykes, this implies flooding risks both for the areas themselves (unless the dykes are high and strong), and their downstream neighbours. The greatest economic damage by flooding tends to occur in such converted floodplains – and in the public discussion of the causation of such floods 'deforestation' has been a popular 'scapegoat'.

Evidence in small-scale paired catchments has generally pointed at an increase of both total annual and peak flows when forests were logged or converted to other land uses. This is due to both a lower water use by evapotranspiration (leading to less replenishment potential of soils before they are saturated), a sealing of the soil surface and a decline in soil macroporosity, jointly determining the actual infiltration rate, depending on rainfall intensity. As there has been less convincing evidence of effects of land cover change on flood frequency[38], there has been a considerable gap between public perceptions (readily attributing disastrous floods to 'deforestation') and hydrological evidence. With a more sophisticated metric, however. The change in 'flashiness' of river flow records (Fig. 6) can now be characterized and linked directly to the part of peak rainfall events that is transferred immediately to rivers[39]. With the 'flow persistence' metric changes in land cover in the mosaic of catchments can be quantified, in interaction with climate variability and possibly climate change, showing that the buffering and temporary water storage capacity of wetlands is key to flood prevention. Beyond integrity of headwater catchments, wetlands (with or without trees) are key.

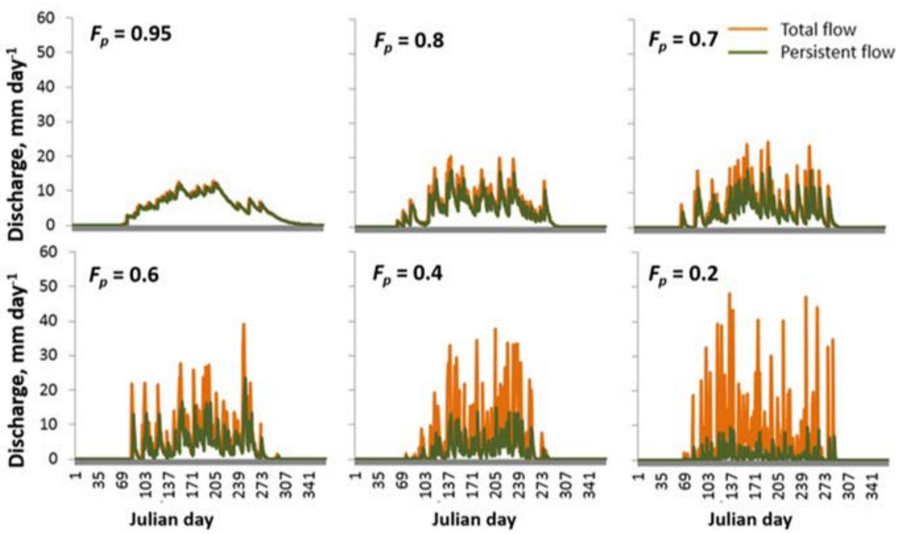

Figure 14.6 Changes in daily river-flow records when the 'flow persistence' metric (F_p) decreases from the value above 0.8 typically found in forested catchments, to values around 0.6 found in open agricultural landscapes and the lower values of urbanized, sealed subcatchments[26]

14.8 Haze prevention through peatland paludiculture

Estimates of the total economic damage by the 2016 haze episode vary[40], but the major disturbance to public health and disruption of economic activities and transport within Indonesia, plus the damage to neighbourly relations with countries affected by the haze, has been sufficient to set up a national coordinating 'peat restoration' body to make sure that such disasters won't happen again. The political momentum this achieved was hard to imagine before the 2016 event[41,42], and showed that disasters have to get over a threshold before they spark corrective action.

As landscape-level drainage for agricultural development plus canals to facilit6ate log transport were a major contributor to the peat fires, much of the attention since has been given to forms of 'canal blocking'. To be acceptable to local communities, however, the shortage of 'kebun lindung' options for wet environments has been a bottleneck. Only a few trees with internationally traded products are known to thrive in undrained peat, and their markets are relatively shallow[43].

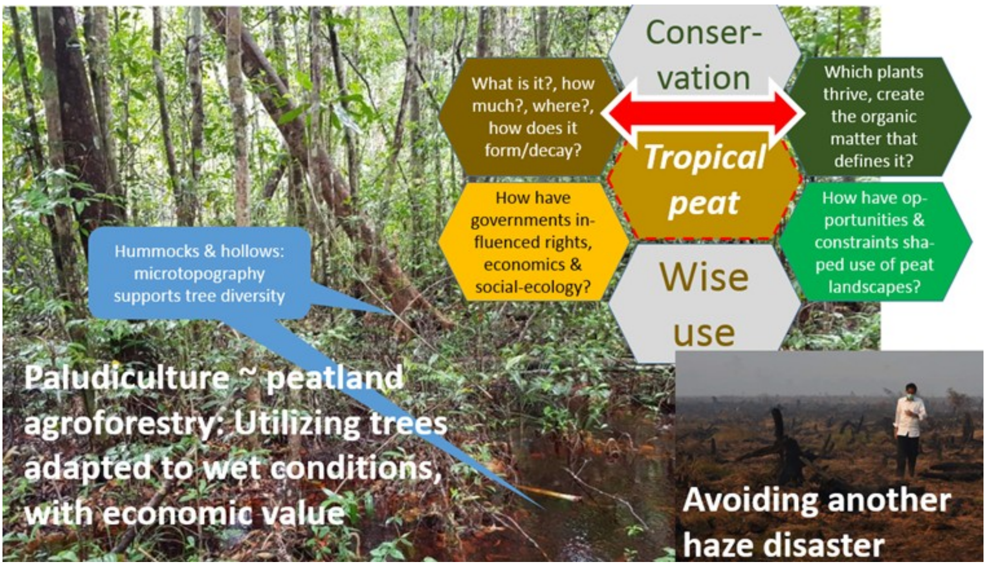

Figure 14.7 Aspects of the ongoing search for paludiculture forms of 'kebun lindung' on undrained peat

Cultivation on peatlands is constrained by saturated low pH of soils, while many tree species with high economic value needs suitable condition for living. Therefore, water on peat swamp ecosystem is drained through a canal, which reduce water table on peatland. Drained peatland causes many consequences, such as fosters decomposition rate, subsidizes the peatland[44] increases emission of greenhouse gasses[45] fire susceptibility in drought season[46,47] and floods in the rainy season[48]. Owing to human intervention and mismanagement, peatlands condition in Indonesia has degraded fast.

In the national peatland restoration programme, three approaches were employed, namely rewetting, revegetation and revitalization of local livelihoods[49]. A zonation, which is based on the depth of peatlands, is established in a peatland hydrological unit (PHU). A PHU is divided into two zones of function, those are protection and cultivation functions[108]. The regulation on peatland restoration targeted the maximum ground water level in the cultivation function of peat hydrological unit (PHU) is 40 cm below the surface. While in the protection function of PHU, the water table is suggested to be near the surface.

Paludiculture or cultivation on rewetted peatland with native tree species offers a solution to reduce emission, improving land cover and offering livelihood options. Cultivation on peatlands with a minimum or none drainage may tackle two disasters, namely fire risk in drought season and flood in rainy season. On a drained peatland in the protection function, canal has to be permanently blocked by canal backfilling. While in the production function, canal can be blocked with spillway. With the increased of water level in the rewetted peatland, only selected species can be planted. Several plant species have been recommended to be planted as paludiculture practice in Indonesia[50,51]. Recommendation of tree species selection is based on two potential risks (e.g. fire and flood risks), their economic values, and availability of potential market[110].

14.8 Mitigating global climate change as source of risks

The third hypothesis ("Through its mitigating effects on global climate change, agroforestry also contributes to countering the current increasing trend in disaster prevalence due to climate change.") has been reviewed both for its soil[52,53] and aboveground components[54,55]. Recent analysis of the way forests and treebased systems interact with global climate has pointed at effects linked to the hydrological cycle that may be (even) more important for actual climate change, and that may provide a much more direct relation between local and global benefits of enhancing functional tree cover[56].

In the last few decades, economic losses from weather- and climate-related disasters have increased[57]. While these losses cannot be definitively attributed to climate change, the possibility that they are related cannot be ruled out. In the 21st century, it is expected that climate change-related risks from some extreme events, such as heat waves, will increase with higher temperatures[2]. It is likely that average tropical cyclone maximum wind speed will increase, although the global frequency of tropical cyclones will either decrease or remain essentially unchanged[49]. Agroforestry systems offer compelling synergies between adaptation and mitigation[58]. Multiple evidence from a number of countries show that agroforestry systems improve resilience of smallholder farmers through more efficient water utilization; improved microclimate; enhanced soil productivity and nutrient cycling; control of pests and diseases; improved farm productivity; and diversified and increased farm income while at the same time sequestering carbon[59].

14.9 Discussion

Based on the six examples we can now review the three hypotheses. In all six cases we found specific evidence for hypothesis 1 ("Agroforestry, or the wise use of trees, can play a role in reducing exposure in risk-aware land use planning"), with variations in the degree of prominence of avoidance of human settlement in high-risk locations (e.g. the likely pathway of mudflows, floodplains or low-lying coastal areas) can be supported by the allocation of such lands to economically interesting tree-based land uses.

For a number of the potential 'disasters', we also found evidence for hypothesis 2 ("It can also help to retain or restore buffer and filter functions in the landscape that reduce and localize disturbances, such as surface flows of soil particles derived from erosion or volcanic debris."). Beyond that, there are circumstances in which trees help in rescue and recovery stages by providing escape options (trees to climb into), trees that provide emergency food[60] when areas are cut off from the outside world by disasters, or lianas that are sources of safe drinking water in similar settings. There are, however, various tradeoffs between the functional traits if trees that are involved in the various functions (Fig. 8). These tradeoffs may be the strongest argument so far, to maintain tree diversity as a higher-order buffering mechanism, as we often deal with multiple potential disaster categories.

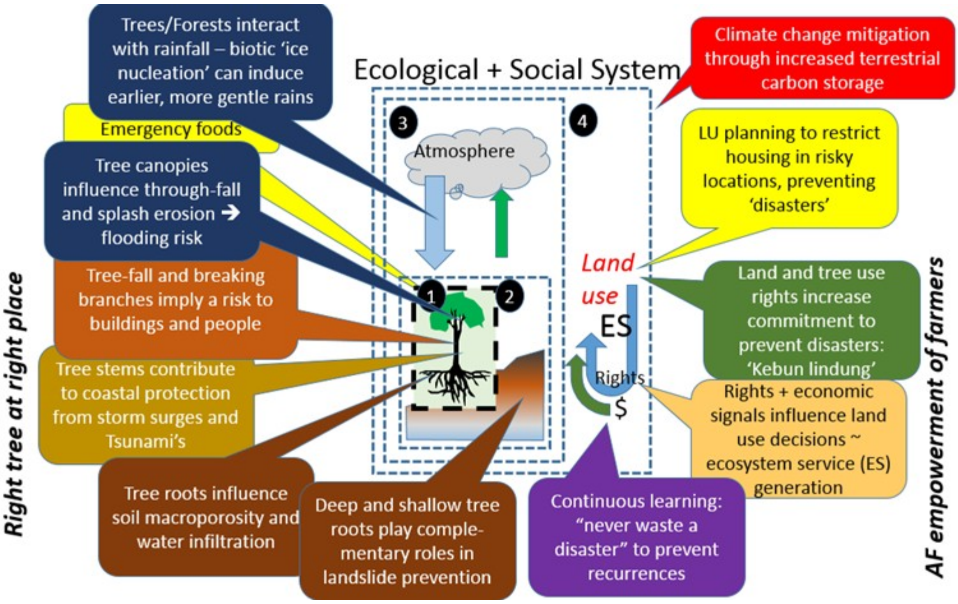

Figure 14.8 Summary of some of the disaster-relevant functional traits of trees involved, at the nested system scales of trees (1), trees + soil (2), trees + soil + climate (3), that interact with the social-ecological landscape scale (4) in shaping disaster avoidance and management

Maintaining tree diversity throughout agricultural and urban landscapes generally has positive effects on disaster risk reduction[61], but trees or their branches falling on people or buildings are a risk that requires specific attention through choice of species, regular inspection and targeted management actions. Major improvements towards 'sustainable development', whether at local, national or global scales, have been triggered by disasters. Without a direct demonstration of the damage and human suffering, it is difficult for public policy making to take warning signs seriously. A variant to Winston Churchill's "Never let a good crisis go to waste" can thus be "Never waste a disaster". In the aftermath of a disaster questions of causality and avoidability come up, and (over)simplified perceptions can shape responses beyond the immediate rescue and recovery phases. Research results need to be ready for such 'windows of opportunity', as there is no time to fully explore evidence in the short timespan before a next issue or crisis takes priority in public discourse. Maintaining diverse tree cover in agricultural and urban landscapes is usually a 'no regrets' solution, with details on the most desirables set of tree traits depending on context.

References

[1] http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/

[2] IPCC, 2014. Summary for policymakers. In: Field CB, Barros VR, Dokken DJ et al, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32

[3] van Noordwijk M. 2017. Integrated Natural Resource Management as pathway to poverty reduction: innovating practices, institutions and policies. *Agricultural Systems* http://dx.doi.org/10.1016/j.agsy.2017.10.008.

[4] van Noordwijk M, Duguma LA, Dewi S, Leimona B, Catacutan D, Lusiana B, Öborn I, Hairiah K, Minang PA. 2018. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? *Curr Opin Environ Sustain* 34:33–42.

[5] van Noordwijk M, Coe R, Sinclair F. 2016. *Central hypotheses for the third agroforestry paradigm within a common definition*. ICRAF Working Paper 233. World Agroforestry Centre (ICAR), Bogor, Indonesia.

[6] https://en.wikipedia.org/wiki/List_of_natural_disasters_by_death_toll

[7] Cochard R, Ranamukhaarachchi SL, Shivakoti GP, Shipin OV, Edwards PJ and Seeland KT. 2008. The 2004 tsunami in Aceh and Southern Thailand: a review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology, Evolution and Systematics 10*(1). pp.3–40.

[8] Bayas JL, Marohn C, Dercon G, Dewi S, Piepho H, Joshi L, van Noordwijk M, Cadisch G. 2011. Influence of coastal vegetation on the 2004 tsunami wave impact in West Aceh. *Proc. Nat, Acad. of Science* 108:18612–18617.

[9] Oktari RS, Munadi K, Arief S, Fajri IZ. 2017. Changes in coastal land use and the reasons for selecting places to live in Banda Aceh 10 years after the 2004 Indian Ocean tsunami. *Natural Hazards 88*(3). pp.1503–1521.

[10] Roshetko JM, Idris N, Purnomosidhi P, Zulfadhli T, Tarigan J. 2008, Farmer extension approach to rehabilitate smallholder fruit agroforestry systems: the" Nurseries of excellence (NOEL)" program in Aceh, Indonesia. In *IV International Symposium on Tropical and Subtropical Fruits* 975:649–656.

[11] Budidarsono S, Wulan YC, Budi LJ, Hendratno S. 2007. Livelihoods and forest resources in Aceh and Nias for a sustainable forest resource management and economic progress. ICRAF Working Paper No. 55. Bogor, Indonesia: World Agroforestry Centre (ICRAF).

[12] Lusiana B, van Noordwijk M, Suyamto D, Mulia R, Joshi L, Cadisch G. 2011. Users' perspectives on validity of a simulation model for natural resource management. *International Journal of Agricultural Sustainability* 9(2). pp.364–378.

[13] Damastuti E, de Groot R. 2018. Participatory ecosystem service mapping to enhance community-based mangrove rehabilitation and management in Demak, Indonesia. *Regional Environmental Change*, pp.1–14.

[14] Delfino RJP, Carlos CM, David LT, Lasco RD, Juanico DEO. 2015. Perceptions of Typhoon Haiyan-affected communities about the resilience and storm protection function of mangrove ecosystems in Leyte and Eastern Samar, Philippines. *Climate, Disaster and Development Journal*, 1(1).

[15] Pulhin JM, Gevaña DT, Pulhin FB. 2017. Community-Based Mangrove Management in the Philippines: Experience and Challenges in the Context of Changing Climate. In: *Participatory Mangrove Management in a Changing Climate*. Springer, Tokyo. pp. 247–262.

[16] Locatelli B, Catterall CP, Imbach P, Kumar C, Lasco R, Marín-Spiotta E, Mercer B, Powers JS, Schwartz N, Uriarte M. 2015. Tropical reforestation and climate change: beyond carbon. *Restoration Ecology 23*(4). pp.337–343.

[17] https://en.wikipedia.org/wiki/Ring_of_Fire

[18] Whelley PL, Newhall CG, Bradley KE, 2015. The frequency of explosive volcanic eruptions in Southeast Asia. *Bull Volcanol* 77(1):1. DOI: 10.1007/s00445-014-0893-8

[19] Bourassa AE, Robock A, Randel WJ, Deshler T, Rieger LA, Lloyd ND, Llewellyn ET, Degenstein DA. 2012. Large volcanic aerosol load in the stratosphere linked to Asian monsoon transport. *Science 337*(6090). pp.78–81.

[20] Ugolini FC, Dahlgren RA. 2002. Soil development in volcanic ash. *Global Environmental Research 6*(2):69–82.

[21] Geurts R, Lillo A, Bisseling T. 2012. Exploiting an ancient signalling machinery to enjoy a nitrogen fixing symbiosis. *Current opinion in plant* biology 15(4):438–443.

[22] Hairiah K, Widianto, Suprayogo D and Saputra D D. 2017. *Reklamasi lahan pertanian pasca erupsi gunung Kelud: Efisiensi serapan N dalam system Agroforestry kopi-kakao*. Final Research Report. Brawijaya University, Malang (Indonesia), 53 pp.

[23] van Noordwijk M, Hairiah K, Harja D. 2013. Rapid landslide mitigation appraisal (RaLMA): managing trees for improved slope stability. pp 126-130. In: van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D, eds. *Negotiation-support toolkit for learning landscapes*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[24] Hairiah K. 2018. *Climate change adaptation and mitigation in the Bangsri micro watershed-East Java*. Final report CCCD project. Brawijaya University, Malang (Indonesia)

[25] Fay C, Michon G. 2005. Redressing forestry hegemony when a forestry regulatory framework is best replaced by an agrarian one. *Forests, trees and Livelihoods* 15(2):193–209.

[26] van Noordwijk M, Suyamto D, Lusiana B, Ekadinata A, Hairiah K. 2008. Facilitating agroforestation of landscapes for sustainable benefits: tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model. *Agriculture Ecosystems and Environment* 126:98–112.

[27] Van Noordwijk M, Roshetko JM, Murniati, Angeles MD, Suyanto, Fay C, Tomich TP. 2008. Farmer Tree Planting Barriers to Sustainable Forest Management. In: Snelder DJ, Lasco RD, eds. 2008. *Smallholder Tree Growing for Rural Development and Environmental Services: Lessons from Asia*. Advances in Agroforestry Volume 5. Berlin: Springer. p 427-449

[28] van Noordwijk M, Tomich TP, Verbist B. 2001. Negotiation support models for integrated natural resource management in tropical forest margins. *Conservation Ecology* 5(2):21. [online] URL: http://www.consecol.org/vol5/iss2/art21, 18 pp.

[29] Pasya G, Fay CC, van Noordwijk M. 2004. Sistem pendukung negosiasi multi tataran dalam pengelolaan sumberdaya alam secara terpadu: dari konsep hingga praktek. [Negotiation support systems for sustainable natural resource management: from concept to application]. *Agrivita* 26:8–19.

[30] Colchester M, Ekadinata A, Fay CC, Pasya G, Situmorang L, Sirait MT, van Noordwijk M, Cahyaningsih N, Budidarsono S, Suyanto S, Kusters K, Manalu P, Gaveau D 2005. Facilitating agroforestry development through land and tree tenure reforms in Indonesia. ICRAF Working Paper 2005-2. Bogor, Indonesia: International Centre for Research in Agroforestry (ICRAF).

[31] Akiefnawati R, Villamor GB, Zulfikar F, Budisetiawan I, Mulyoutami E, Ayat A, van Noordwijk M. 2010. Stewardship agreement to reduce emissions from deforestation and degradation (REDD): case study from Lubuk Beringin's Hutan Desa, Jambi Province, Sumatra, Indonesia. *International Forestry Review* 12:349–360.

[32] van Noordwijk M, Leimona B, Jindal R, Villamor GB, Vardhan M, Namirembe S, Catacutan D, Kerr J, Minang PA, Tomich TP. 2012. Payments for Environmental Services: evolution towards efficient and fair incentives for multifunctional landscapes. Annu. Rev. Environ. *Resour* 37:389–420.

[33] Leimona B, van Noordwijk M, de Groot JJR, Leemans R. 2015. Fairly efficient, efficiently fair: Lessons from designing and testing payment schemes for ecosystem services in Asia. *Ecosystem Services* 12:16–28.

[34] Leimona B, Lusiana B, van Noordwijk M, Mulyoutami E, Ekadinata A, Amaruzaman S. 2015. Boundary work: knowledge co-production for negotiating payment for watershed services in Indonesia. *Ecosystems Services* 15:45–62.

[35] Namirembe S, Leimona B, van Noordwijk M, Minang PA, eds. 2018. Co -investment in ecosystem services: global lessons from payment and incentive schemes. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

[36] Verbist B, Poesen J, van Noordwijk M, Widianto W, Suprayogo D, Agus F, Deckers S. 2010. Factors affecting soil loss at plot scale and sediment yield at catchment scale in a tropical volcanic agroforestry landscape. *Catena* 80:34–46.

[37] Hairiah K, Sulistyani H, Suprayogo D, Widianto W, Purnomosidhi P, Widodo RH, van Noordwijk M. 2006. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung. *Forest Ecology and Management* 224:45–57.

[38] van Dijk AIJM, van Noordwijk M, Calder IR, Bruijnzeel LA, Schellekens J, Chappell JNA. 2009. Forest-flood relation still tenuous – comment on 'Global evidence that deforestation amplifies flood risk and severity in the developing world' by C.J.A. Bradshaw, N.S. Sodi, K. S-H. Peh and B.W. Brook. *Global Change Biology* 15:110–115.

[39] van Noordwijk M, Tanika L, Lusiana B. 2017. Flood risk reduction and flow buffering as ecosystem services: II. Land use and rainfall intensity effects in Southeast Asia. *Hydrol. Earth Syst. Sci*. 21:2341–2360.

[40] Quah E, Tan TS. 2018. Pollution Across Borders: Transboundary Fire, Smoke and Haze in Southeast Asia. World Scientific Publishing Co., Singapore.

[41] van Noordwijk M, Matthews RB, Agus F, Farmer J, Verchot L, Hergoualc'h K, Persch S, Tata HL, Lusiana B, Widayati A, Dewi S, Dewi S. 2014. Mud, muddle and models in the knowledge value- chain to action on tropical peatland issues. *Mitigation and Adaptation Strategies for Global Change* 19:863–885.

[42] Dewi S, van Noordwijk M, Dwiputra A, Tata HL, Ekadinata A, Galudra G, Sakuntaladewi N. 2015. Peat and land clearing fires in Indonesia in 2015: Lessons for polycentric governance. ASB PolicyBrief 51. ASB Partnership for the Tropical Forest Margins. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

[43] Tata HL, van Noordwijk M, Jasnari J, Widayati A. 2016. Domestication of *Dyera polyphylla* (Miq.) Steenis in peatland agroforestry systems in Jambi, Indonesia. *Agroforestry Systems* 90:617–630.

[44] Hooijer A, Page S, Jauhiainen J, Lee WA, Lu XX, Idris A, Anshari G. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9:1053–1071.

[45] Hooijer A, Page S, Canadell JG, Silvius M, Kwadijk, J, Wösten H, Jauhiainen J. 2010. Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences* 7:1505–1514.

[46] Tata HL, Narendra BH, Mawazin. 2018. Forest and land fires in Pelalawan district, Riau, Indonesia: Drivers, pressures, impacts and response. *Biodiversitas*. 19(2):494–501. DOI: 10.13057/biodiv/d190224

[47] Page S, Hooijer A. 2016. In line of fire: The peatland of Southeast Asia. *Phil. Trans. R. Soc*. B. 371: 20150176.

[48] Deltares. 2014. *Generation of an elevation model, subsidence model and flooding projection for the Rajang Delta peatlands, Sarawak*. Interim working paper for discussion.

[49] Badan Restorasi Gambut. 2017. *Rencana Kontijensi Restorasi Gambut 2017 Perubahan*. Badan Restorasi Gambut. Jakarta, Indonesia.

[50] Giesen W. 2015. Utilizing NTFPs to conserve Indonesia's peat swamp forest and reduce carbon emissions. *Journal of Indonesia Natural History* 3(2):10–19.

[51] Tata HL, Susmianto A. 2016. *Prospek Paludikutur Ekosistem Gambut Indonesia*. Forda Press. Bogor.

[52] De Stefano A, Jacobson MG. 2018. Soil carbon sequestration in agroforestry systems: a meta-analysis. *Agroforestry Systems* pp.1–15.

[53] Corbeels M, Cardinael R, Naudin K, Guibert H, Torquebiau E. 2018. The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. *Soil and Tillage Research*.

[54] Hairiah K, Dewi S, Agus F, Velarde S, Ekadinata A, Rahayu S and van Noordwijk M. 2011. *Measuring carbon stocks: across land use systems: a manual*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

[55] Zomer RJ, Neufeldt H, Xu J, Ahrends A, Bossio D, Trabucco A, Van Noordwijk M, Wang M. 2016. Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports 6.* p.29987

[56] Creed IF, van Noordwijk M, Archer E, Claassen M, Ellison D, Jones JA, McNulty SG, Vira B, Wei X. 2018. Forest, Trees and Water on a Changing Planet: How Contemporary Science Can Inform Policy and Practice. In: Creed IF, van Noordwijk M, eds. *Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities.* A Global Assessment Report. IUFRO World Series Volume 38. Vienna: International Union of Forest Research Organizations (IUFRO).

[57] IPCC. 2012: Summary for Policymakers. In: Field CB, Barros VR, Stocker TF et al, eds. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press and New York, NY: USA, pp. 1–19.

[58] Mbow CK, Smith P, Skole D, Duguma L, Bustamante M. 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Curr Opin Environ Sustain* 6:8–14.

[59] Lasco RD, Delfino RJP, Espaldon MLO. 2014. Agroforestry systems: helping smallholders adapt to climate risks while mitigating climate change. *WIREs Climate Change*. DOI: 10.1002/wcc.301

[60] van Noordwijk M, Bizard V, Wangkapattanawong P, Tata HL, Villamor GB, Leimona B. 2014. Tree cover transitions and food security in Southeast Asia. *Global Food Security* 3:200–208.

[61] van Noordwijk M, Hoang MH, Neufeldt H, Öborn I, Yatich T. 2011. *How trees and people can co-adapt to climate change: reducing vulnerability through multifunctional agroforestry landscapes*. Nairobi, Kenya: World Agroforestry Centre (ICRAF). 134p.