Landscape management strategies in response to climate risks in Indonesia

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LANDSCAPE MANAGEMENT STRATEGIES IN RESPONSE TO CLIMATE RISKS IN INDONESIA

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Content

Cover page: Tropical landscapes from the case studies in West Kalimantan and Central Java (Indonesia). People living there have been impacted by droughts and floods as part of the effects of climate variability and change (pictures by Giacomo Fedele).

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Abstract

Ecosystems play an important role in strategies for facing climate change because they address both its causes and effects through the delivery of ecosystem services. Ecosystems act as safety nets for rural livelihoods and as buffers against damages by supplying provisioning services (e.g., food and timber) and regulating services (e.g., water regulation and erosion control). In addition, carbon sequestration by ecosystems contributes to mitigate climate change. Land management affects ecosystem services in diverse ways and, because of trade-offs, can enhance the supply of one ecosystem service of interest at the expense of others. For example, the conversion of forests to agriculture to increase food production may degrade water regulation. Although trade-offs are recognized, knowledge on how changes in land management affect ecosystem services and their beneficiaries is still limited. This research aims to increase our understanding of how land management changes impact the resilience of local communities to climate hazards and the provision of ecosystem services at regional and global level. We combined multi-disciplinary and participatory methods to analyze changes in the management of forests and trees in the responses of local communities to climate hazards. Across four rural communities affected by floods and droughts in tropical forest landscapes in Indonesia, we inventoried forests, surveyed households, discussed with focus groups, and analysed satellite images. To analyse how ecosystem services are affected by changes in land management, we developed a conceptual framework to account for the multiple human contributions in the delivery of ecosystem services.

The findings showed how communities used ecosystems in their responses to climatic impacts and how changes in land management affected the supply of ecosystem services. In the study sites with least forests, communities had the highest needs for forest ecosystem services to help them adapt to drought. Between 5 and 45% of the households reported at least one coping strategy based on products from forests and trees, for example harvesting timber or collecting leaves, rubber, and wild vegetables. Several anticipatory strategies at the community level aimed to protect or restore forests to reduce the impacts of droughts and floods on soil and water. Communities were not passive beneficiaries of ecosystem services but actively contributed to their delivery in multiple ways. They managed land, mobilized human and human-made assets (e.g. skills, fertilizers), allocated benefits, and appreciated their contribution to well-being. Such actions determined who benefited from ecosystems and how. The human contributions in the delivery of ecosystem services depended on community rules (e.g. logging restrictions or taxes), assets (e.g. access to transportation or irrigation systems), values (e.g. perception of environmental degradation), and spatial factors (e.g., location of houses and crops in disaster prone areas). The land management strategies of local communities in response to climate hazards also affected the delivery of ecosystem services at regional and global scales, through changes in biodiversity, water regulation, and carbon sequestration. An improved understanding of human inputs and trade-offs in the delivery of ecosystem services can inform the design of sound ecosystem-based solutions for strengthening the resilience of local people to climate hazards while providing other global benefits for sustainable development.

Key words: socio-ecological systems, ecosystem services, climate change adaptation, mitigation, natural resource management, forested landscapes.

Résumé

Les écosystèmes jouent un rôle important dans les stratégies visant à faire face au changement climatique parce qu'ils s'attaquent à la fois à ses causes et à ses effets grâce à leurs services écosystémiques. Les écosystèmes agissent comme des filets de sécurité pour les communautés rurales et comme tampons contre les impacts climatique en fournissant des services d'approvisionnement (par exemple la nourriture et le bois) et des services de régulation (par exemple la régulation de l'eau et le contrôle de l'érosion). De plus, la séquestration du carbone par les écosystèmes contribue à atténuer le changement climatique. La gestion des terres affecte les services écosystémiques (SE) de diverses manières et, en raison de l'existence de compromis (« tradeoffs »), peut améliorer l'offre d'un SE au détriment des autres. Par exemple, la conversion des forêts à l'agriculture pour augmenter la production alimentaire peut dégrader la régulation de l'eau. Bien que les compromis soient reconnus, les connaissances sur la façon dont les changements dans la gestion des terres affectent les SE et leurs bénéficiaires sont encore limitées. Cette recherche vise à améliorer notre compréhension de la façon dont les changements dans la gestion des terres influent sur la résilience des communautés locales face aux aléas climatiques et sur la fourniture de SE aux niveaux régional et mondial. Nous avons combiné des méthodes multidisciplinaires et participatives pour analyser les changements dans la gestion des forêts et des arbres dans les réponses des communautés locales aux aléas climatiques. Dans quatre communautés rurales touchées par des inondations et des sécheresses dans des paysages forestiers tropicaux en Indonésie, nous avons inventorié les forêts, enquêté les ménages, discuté avec des groupes focaux et analysé des images satellite. Pour analyser comment les SE sont affectés par les changements dans la gestion des terres, nous avons développé un cadre conceptuel pour rendre compte des multiples contributions humaines dans la fourniture des SE.

Les résultats ont montré comment les communautés ont utilisé les écosystèmes dans leurs réponses aux impacts climatiques et comment les changements dans la gestion des terres ont affecté la fourniture de SE. Dans les sites d'étude les moins forestiers, les communautés avaient les plus grands besoins de SE forestiers pour les aider à s'adapter à la sécheresse. Entre 5 et 45% des ménages ont rapporté au moins une stratégie d'adaptation basée sur des produits issus des forêts et des arbres, par exemple la récolte du bois ou la collecte des feuilles, du caoutchouc et des légumes sauvages. Plusieurs stratégies d'anticipation au niveau communautaire visaient à protéger ou à restaurer les forêts afin de réduire les impacts des sécheresses et des inondations sur le sol et l'eau. Les communautés n'étaient pas des bénéficiaires passifs des SE, mais ont contribué activement à leur fourniture de multiples façons. Elles ont géré les terres, mobilisé du capital humain ou manufacturé (par exemple les savoirs, les engrais), distribué les bénéfices et apprécié leur contribution au bien-être. Ces actions ont déterminé qui bénéficie des écosystèmes et comment. Les apports humains dans la fourniture des SE dépendaient de règles communautaires (par exemple, restrictions de coupe de bois ou taxes), du capital (par exemple moyens de transport ou d'irrigation), des valeurs (par exemple les perceptions de la dégradation de l'environnement) et des facteurs spatiaux (par exemple la localisation des habitations et des champs dans les zones sujettes aux catastrophes). Une meilleure compréhension des apports humains dans la fourniture des SE et des compromis entre services peut guider la conception de solutions basées sur les écosystèmes pour renforcer la résilience des populations locales aux risques climatiques tout en fournissant d'autres bénéfices globaux pour le développement durable.

Mots clés : systèmes socio-écologiques, services écosystémiques, adaptation au changement climatique, atténuation du changement climatique, gestion des ressources naturelles, paysages forestiers.

Résumé substantiel

Les écosystèmes jouent un rôle important dans les stratégies visant à faire face au changement climatique parce qu'ils s'attaquent à la fois à ses causes et à ses effets grâce à leurs services écosystémiques. Les écosystèmes agissent comme des filets de sécurité pour les communautés rurales et comme tampons contre les impacts climatique en fournissant des services d'approvisionnement (par exemple la nourriture et le bois) et des services de régulation (par exemple la régulation de l'eau et le contrôle de l'érosion). De plus, la séquestration du carbone par les écosystèmes contribue à atténuer le changement climatique. La gestion des terres affecte les services écosystémiques (SE) de diverses manières et, en raison de l'existence de compromis (« tradeoffs »), peut améliorer l'offre d'un SE au détriment des autres. Par exemple, la conversion des forêts à l'agriculture pour augmenter la production alimentaire peut dégrader la régulation de l'eau. Bien que les compromis soient reconnus, les connaissances sur la façon dont les changements dans la gestion des terres affectent les SE et leurs bénéficiaires sont encore limitées.

Cette recherche vise à améliorer notre compréhension de la façon dont les changements dans la gestion des terres influent sur la résilience des communautés locales face aux aléas climatiques et sur la fourniture de SE aux niveaux régional et mondial. Nous avons combiné des méthodes multidisciplinaires et participatives pour analyser les changements dans la gestion des forêts et des arbres dans les réponses des communautés locales aux aléas climatiques. Dans quatre communautés rurales touchées par des inondations et des sécheresses dans des paysages forestiers tropicaux en Indonésie, nous avons inventorié les forêts, enquêté les ménages, discuté avec des groupes focaux et analysé des images satellite. Pour analyser comment les SE sont affectés par les changements dans la gestion des terres, nous avons développé un cadre conceptuel pour rendre compte des multiples contributions humaines dans la fourniture des SE.

Au cours du second chapitre, nous avons identifié les principaux aléas climatiques qui affectent les moyens de subsistance et les biens des populations dans les zones d'étude au cours de la dernière décennie il s’agit des inondations, des sécheresses et de la prolifération d’insectes nuisibles. Nous avons aussi décrit l'impact des risques liés au climat tels que la raréfaction des ressources en eau, la dégradation des maisons, la baisse des rendements agricoles et la perturbation des systèmes de transport (principalement les rivières et les routes).

Nous avons ensuite étudié le rôle des forêts et des arbres dans la réduction de la vulnérabilité humaine à ces risques à l'échelle locale. Nous avons identifié différentes stratégies de réponse des populations locales dans les quatre villages étudiés. La plupart des stratégies de réponse aux aléas climatiques incluent des solutions techniques (par exemple, l'acquisition de systèmes de pompage de l'eau, l'augmentation de la protection physique des maisons mais aussi des étangs à poissons et la modernisation des équipements dans les plantations de caoutchouc). Plusieurs autres stratégies visent également à accroître l'utilisation d'intrants agricoles (engrais et pesticides), à modifier les pratiques agricoles (nouvelles variétés de semences ou rotation des espèces cultivées) et à rechercher une aide extérieure (réseaux sociaux ou agences gouvernementales). Au niveau des ménages, quelques stratégies sont basées sur les services écosystémiques fournis par les forêts et les arbres notamment pour se remettre d'un aléa climatique, ou pour anticiper et amortir les éventuels futurs impacts. La plupart des stratégies basées sur les forêts et les arbres, comme la vente de bois ou de caoutchouc, l'utilisation de feuilles comme fourrage pour le bétail et la collecte de légumes sauvages pour la nourriture humaine, sont des stratégies réactives consécutives á un aléa climatique. Au niveau des communautés rurales, les stratégies collectives comprennent la gestion proactive des forêts et des arbres pour atténuer les risques liés au climat, principalement par les services écosystémiques de régulation. Par exemple, certaines communautés rurales coordonnent l'introduction d'arbres dans les jardins, conservent la végétation le long des rivières et des collines, et reboisent les terres arables les moins productives.

Le rôle des forêts et des arbres dans la réduction de la vulnérabilité des populations locales aux impacts du changement climatique varie selon trois facteurs différents, tels que le type de services écosystémiques (approvisionnement ou régulation), le calendrier des stratégies (réactif ou proactif) et les types de forêts (forêts naturelles ou plantations). Les services d'approvisionnement sont les plus importants dans les stratégies d'adaptation des ménages (en particulier comme stratégie d'adaptation individuelle après une catastrophe), tandis que les services de régulation sont moins signalés (mais font partie de la stratégie collective d'anticipation des catastrophes). Les forêts naturelles et les plantations ont été utilisées différemment selon la disponibilité des produits (bois, bois de chauffage, produits forestiers autres que le bois, etc.) et leur accessibilité en cas de catastrophe. Par conséquent, il est important de distinguer les services écosystémiques, le calendrier des stratégies et les types de forêts lors de l'évaluation de la vulnérabilité des populations locales, afin de saisir pleinement la contribution des forêts et des arbres à la réduction de la vulnérabilité humaine.

Dans le chapitre 3, nous avons évalué comment les changements majeurs d'usage des sols au niveau local en réponse aux risques climatiques affectent l'offre de divers services écosystémiques. Nous avons considéré plusieurs bénéfices apportés par des écosystèmes pertinents à différentes échelles (biens, eau, carbone et biodiversité). Les populations locales ont déforesté ou protégé et planté des arbres dans leurs paysages pour diversifier les moyens de subsistance locaux et maintenir la productivité des sols dans des conditions changeantes liées aux variations climatiques et à la pénurie de ressources naturelles. Les résultats soulignent comment ces changements dans l'utilisation des sols ont affecté les services d'approvisionnement des forêts et de l'agriculture et ont augmenté les bénéfices locaux. Ces changements ont affecté la biodiversité et les services de régulation de l'eau, ainsi que la séquestration du carbone, et ont donc eu un impact à d’autres échelles que l'échelle locale. Nous avons illustré comment certaines stratégies (telles que la plantation de teck dans les jardins ou les terres cultivées moins productifs) se sont répandues dans le paysage et ont entraîné une transformation importante du paysage. Nous avons analysé le rôle du renforcement des feedbacks dans les systèmes socio-écologiques gérés par les acteurs locaux qui ont perçu que certains changements dans l'utilisation des terres affectent positivement les moyens de subsistance, réduisent les risques et génèrent d'autres sortes de bénéfices.

Le chapitre met en évidence comment les nécessités locales peuvent conduire à des changements dans l’usage des sols avec des conséquences sur les divers services écosystémiques et les bénéficiaires. Comprendre les compromis possibles ou les synergies entre les services écosystémiques lors de ces changements est crucial. La gestion du paysage pour l'adaptation (ou le renforcement des services d'adaptation) contribue non seulement aux moyens d'adaptation locale, mais peut également être bénéfique pour la biodiversité, l'eau et l'atténuation du changement climatique. L'analyse a montré que les populations ont déjà développé des initiatives locales pour protéger les arbres ou augmenter la couverture des arbres et que ces initiatives peuvent être étendues. L'ajout des bénéfices de l'adaptation aux objectifs de gestion des écosystèmes signifie donc s'appuyer sur des initiatives locales qui contribuent à atteindre simultanément plusieurs objectifs de développement ou de gestion durable, y compris la réduction des vulnérabilités locales. Ce point est particulièrement pertinent en raison du nombre croissant d'initiatives internationales qui reconnaissent les liens entre différents défis mondiaux et donc le besoin de solutions intégrées, telles que le changement climatique, la biodiversité et le développement durable dans les Objectifs de développement durable des Nations Unies et les objectifs d'Aichi de la Convention sur la diversité biologique.

Dans le chapitre 4, nous avons évalué l'offre potentielle de services écosystémiques forestiers, la demande des communautés locales et les décisions de gestion pour mobiliser ces services afin de réduire les impacts de la sécheresse. Il n'est pas surprenant que les indicateurs sélectionnés pour évaluer l'offre de services écosystémiques (superficie forestière, biomasse et diversité des arbres) aient des valeurs plus faibles dans les villages moins boisés que dans ceux ayant plus de forêts. Cependant, dans les paysages à faible couvert forestier, où l'offre de services écosystémiques était plus limitée, les gens ont accordé une importance plus grande aux forêts et aux arbres pour réduire les impacts de la sécheresse.

La distinction entre l'offre potentielle de services écosystémiques et la demande des communautés locales peut aider à comprendre les moteurs des décisions de gestion des sols. La gestion active des sols peut, par exemple, refléter la nécessité d'accroître les avantages des écosystèmes pour répondre aux aléas climatiques dans un contexte de forte demande et de faible offre. Au contraire, dans les endroits où les forêts sont abondantes mais où les populations adoptent peu de stratégies de gestion basées sur elles, il peut y avoir des contraintes qui rendent certains services des écosystèmes forestiers moins adaptés aux réponses aux aléas climatiques. Ces contraintes peuvent survenir parce que les forêts et leurs produits peuvent être directement affectés par l'événement climatique, qu'elles ne sont pas physiquement accessibles pendant l'aléa climatique, que les droits d'accès sont limités, qu'elles nécessitent du temps et des ressources financières limitées, ou qu'elles n'étaient pas gérées proactivement avant l'événement climatique. Par conséquent, les approches qui tiennent compte à la fois de l'offre et de la demande de services écosystémiques peuvent améliorer l'opérationnalisation des écosystèmes et les évaluations de la vulnérabilité. De telles évaluations peuvent être utiles pour identifier les obstacles ou les conditions favorables qui pourraient être ciblés par les politiques et les plans de gestion durable des terres.

Au cours du chapitre 5, nous avons reformulé le cadre d'analyse des services écosystémiques en mettant en évidence les mécanismes de médiation qui décrivent la manière dont les humains influencent chaque étape de 'offre de services écosystémiques. Le cadre d'analyse inclut des facteurs contextuels qui influencent les choix des individus et facilitent ou entravent le flux des services écosystémiques. Nous avons appliqué ce cadre à des études de cas issues de la littérature et d'analyses empiriques *in situ* dans des paysages forestiers tropicaux en Indonésie. Les résultats ont montré comment les différents mécanismes spécifiques au contexte qui sous-tendent les actions humaines influencent et façonnent les contributions des services écosystémiques au bien-être humain. Cela se fait au travers de plusieurs mécanismes liés à la gestion des services écosystémiques (promotion des propriétés et structures foncières spécifiques), la mobilisation (ajout d'intrants anthropiques), l'allocation-affectation (affectation de finalité et distribution au bénéficiaire) et l'appréciation (attribution de valeur). Ces mécanismes sont influencés par les décisions des individus ainsi que par leur position sociale et leur pouvoir le long de la cascade ES, qui dépendent de facteurs spécifiques liés aux règles, aux biens, aux valeurs et au contexte spatial. En facilitant ou en entravant les flux de services écosystémiques, certains acteurs peuvent déterminer qui bénéficie des services écosystémiques et influencer le bien-être des autres.

Dans ce chapitre, nous avons discuté de la manière dont les processus écologiques sont activement maintenus, complétés ou partiellement modifiés par des interventions humaines pour coproduire des services écosystémiques pouvant générer des avantages pour l'homme. Ainsi, nous avons suggéré des ajustements à la chaine des services écosystémiques pour répondre à la critique selon laquelle la prestation des services écosystémiques est décrite comme un flux linéaire et direct de la nature vers les gens, avec peu d'attention aux retro-alimentations ou aux contributions humaines. Nous avons décrits des mécanismes socio-écologiques et des facteurs contextuels qui interviennent dans l'offre de services écosystémiques à différentes étapes de la cascade. Un examen plus explicite des mécanismes et des facteurs de médiation dans les évaluations des services écosystémiques permettrait aux gestionnaires de l'environnement et aux décideurs de prendre des décisions plus stratégiques. L'inclusion et l'analyse des mécanismes de médiation sous-jacents aux décisions humaines le long de la cascade ES peuvent aider à comprendre les rôles spécifiques des différentes acteurs, leurs intérêts convergents ou divergents et la nature distributive des ES (qui obtient quoi?). De plus, les cascades d'ES peuvent être utilisées comme «chaînes causales d'impact» pour évaluer l'impact des changements d'affectation des sols sur le bien-être humain. En examinant les mécanismes qui façonnent le flux des services écosystémiques à différents niveaux de la cascade des SE, nous améliorons notre compréhension des rôles des différentes parties prenantes et de leurs relations de pouvoir dans la prestation des services écosystémiques. Cette idée peut aider à concevoir des interventions de gestion des terres bien informées qui favorisent une prestation plus équitable et durable des services écosystémiques.

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List of Acronyms

ABIES	Agriculture alimentation Biologie Environnement Santé
AGB	Above Ground Biomass
CGIAR	Consultative Group for International Agricultural Research
CIFOR	Center for International Forestry Research
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
DBH	Diameter at Breast Height
EbA	Ecosystem-based Adaptation
ES	Ecosystem Services
IPBES	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
FAO	Food and Agricultural Organisation of the United Nations
LANDSAT	Land Remote Sensing Satellite Program
MEA	Millennium Ecosystem Assessment
MM	Mediating Mechanism
MF	Mediating Factor
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organisation
NTFPs	Non-Timber Forest Products
PES	Payment for Ecosystem Services
REDD+	Reducing Emissions from Deforestation and forest Degradation
SES	Social-Ecological System
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1

General Introduction

A participatory mapping exercise with the local community in the house of the village secretary of Tubang Jaya (West Kalimantan). Over several evenings, we mapped the landscape, described characteristics and uses, and discussed local management practices (picture by Febrina Desrianti).

1.1 Background

Rural communities in developing countries often depend on land-based activities, such as agriculture and forestry, for their livelihoods. Around 3.3 billion people, almost half of the world population, live in rural areas of developing countries with limited technical or financial assets and livelihoods dependent on natural resources. A global study that surveyed almost 8,000 rural households in 24 countries across Latin America, Asia, and Africa showed that forests accounted on average for more than one quarter of household income (Angelsen et al. 2014). Forests provide several direct benefits for livelihoods, such as food, medicinal plants, and timber. Forests and trees also indirectly supports human wellbeing by regulating water flows, maintaining soil fertility, and creating recreation opportunities. The benefits provided by nature to people and supporting human wellbeing are often called ecosystem services (MEA 2005a).

People's livelihoods are increasingly affected by multiple global environmental, social, and economic changes that exacerbate vulnerabilities. For example, extreme climate events have affected agricultural yields, reduced access to clean water, and destroyed infrastructure (IPCC 2014). These impacts disproportionally affect people already under pressure due to poverty, rapid urbanization, market fluctuations, or political instability. Many rural communities in developing countries are vulnerable to natural hazards, particularly those living in hazardous areas (e.g., coastal areas or flood-prone low catchment areas) and those with limited financial resources, insurance, and economic alternatives (IPCC 2014).

People modify ecosystems in order satisfy livelihoods needs and adapt to changes (Reyers et al. 2013a, Steffen et al. 2015). Ecosystems around the world have been converted into intensively managed systems, such as crop monocultures and tree plantations, to maximise food and wood provision. While managed systems tend to increase products with economic values, they often do so at the expense of other less tangible benefits, such as water regulation or cultural heritage (Foley 2005, Rodríguez et al. 2006). Ecosystem conversion and land-use intensification are among the major drivers of loss of biodiversity and ecosystem services (Pereira et al. 2005). When ecosystems are increasingly degraded or simplified, they provide fewer opportunities to support people livelihoods.

Several studies have shown that sustainable land management and the conservation of ecosystem services can contribute to reduce people vulnerabilities to climate change (Folke et al. 2010, Andersson et al. 2015) and contribute to adaptation (Pramova et al. 2012, Doswald et al. 2014, Lavorel et al. 2015). For example, forest restoration can support people adaptation to climate change by increasing livelihood diversification and providing alternative sources of food during extreme weather events (McSweeney 2005, Paavola 2008). Reforesting slopes can reduce erosion in case of extreme precipitations (Robledo et al. 2005) and protect water supply (Scott et al. 2005). The conservation and restoration of mangroves protect coastal settlements from storms and waves (Adger 1999). Appropriate land management can contribute to the adaptation of local communities, who own or manage one-quarter of the world's tropical forests (White and Martin 2002, Sunderlin et al. 2008) and cultivate the majority of the lands (FAO 2015).

Numerous initiatives for climate change adaptation and poverty alleviation consider the role of ecosystems in reducing social vulnerability (Munang et al. 2013). An approach called ecosystem-based adaptation (EbA) has emerged among practitioners as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change" (CBD 2009). This approach includes the conservation, restoration and sustainable management of ecosystems and biodiversity to address climatic risks. United Nations bodies (UN Environment, UN Framework Convention on Climate Change, UN Convention on Biological Diversity), government institutions (European Union, German cooperation agency), as well as NGOs (IUCN, CI, WWF) have promoted and applied EbA in their portfolios. Furthermore, in the recent Paris Agreement, parties have mentioned the role of sustainable land management in climate adaptation and mitigation and 23 countries have specifically indicated land management in their national contributions to climate actions (UNFCCC 2015). For example, Vietnam is planning to increase protected forests in coastal regions to safeguard communities from storms, whereas Indonesia is expecting an increase in productivity and resilience of food systems thanks to more sustainable practices in agriculture and fisheries.

Despite the potential of sustainable ecosystem management to address climate change, the implementation of ecosystem-based strategies is still rare (Laukkonen et al. 2009, Harvey et al. 2014, Doswald et al. 2014). Only 3% of the total climate finance support adaptation projects based on biodiversity and ecosystem services (Climate Policy Initiative 2015). Reasons include knowledge gaps on viable ecosystem-based adaptation options and successful stories (Carpenter et al. 2009a, Villamagna et al. 2013, Moore et al. 2014). There is a particular need to assess how local communities respond to climate-related challenges, for example how rural farmers reduce risks of harvest losses due to droughts, and how they use ecosystem services in their responses (Laukkonen et al. 2009, Vignola et al. 2012, Klein et al. 2014). Such assessments can inform the design of ecosystem-based approaches that alongside with other technical and policy measures can reduce the impacts of climate change.

1.2 Key concepts

1.2.1 Social-ecological systems

The concept of social-ecological systems (SES) highlights the reciprocal interactions between humans and nature (Berkes and Folke 1998). It builds on theories about the co-evolutionary nature of human and ecological systems (Norgaard 1994), which emphasize how they cannot be seen in isolation. As argued by Berkes and Folke (1998), this coupled system approach emerged in opposition to the conventional utilitarian views of nature and its commodification. Humans are at the same time a driver of change and a component of ecological system. The concept of SES has been shaped by theories on complex and adaptive system (Holland 1992, Luhmann 1993), which are particularly relevant for analysing interconnected challenges (Binder et al. 2013). Current global environmental issues, such as climate change and loss of biodiversity, must be analysed with SES approaches (Folke 2006, Young et al. 2006, Ostrom 2009).

Rural communities shape forest landscapes by practicing traditional farming and forestry. They are an example of social-ecological system, in which people's livelihoods depend on ecosystems that in turn are modified by human activities (e.g. Figure 1.1). Rural communities have accumulated experiences over generations, which are reflected in local norms and knowledge. Such knowledge helps manage lands so that they can continue to deliver multiple benefits despite changes and uncertainties (De Loë et al. 2001, Olsson and Folke 2001). As result, rural people have often shaped landscapes with remarkable ecological, cultural, and aesthetic values (Martín-López et al. 2012, Plieninger and Bieling 2012).

Figure 1.1. Typical rural landscapes at the study sites in West Kalimantan (top) and Central Java (bottom). The hilly landscape in West Kalimantan is characterized by dipterocarp forests that are being replaced by shifting cultivation and rubber plantations. In Central Java the landscape is dominated by small-scale agricultural fields with rice and vegetables as well as teak plantations. Pictures by Serge Rafanoramana and Giacomo Fedele.

1.2.2 Social-ecological systems and resilience

The concept of resilience has emerged to analyse the dynamics and sustainability of social-ecological systems (Folke et al. 2002, Walker et al. 2004). Resilience describes a property of social–ecological systems that sustain structures and processes by resisting, adapting and transforming in response to stress (Folke et al. 2002, Gunderson and Holling 2002). This perspective contrasts with approaches focusing on equilibria or negating system variations, for example assuming constant fish or timber production rates (Folke et 2006). In the resilience thinking, it is crucial to understand how to manage feedbacks between social and ecological systems in ways that maintain the ability to cope with future disruptions (Cowling et al. 2008, Collins et al. 2011). Management can reshape social and ecological interactions in different ways and can thus influence system resilience.

Rural areas with smallholder farmers are complex, diverse, and risk-prone systems that respond in different ways to external stresses (Morton 2007). As part of this complexity, rural people are often depicted as either resilient or vulnerable to climate change or other environmental stresses (Maru et al. 2014). On the one hand, such social-ecological systems are rich in biodiversity and cultural values that can help people to reduce risks and increase their capacities to respond. On the other hand, rural people dependency on natural resources makes them particularly sensitive to natural hazards (Wunder et al. 2014, Sudmeier-Rieux et al. 2006). This dual view is echoed in the debates on whether the dependence of rural livelihoods on forest ecosystems means a safety net or a poverty trap (Angelsen and Wunder 2003). Multiple social, economic, or environment factors can explain why rural social-ecological system have different capacity to respond to shocks (Table 1.1).

Table 1.1. Characteristics of rural social-ecological systems that makes them differently capable of respondomg to shocks (e.g. climatic, economic, social). Based on IPCC (2014).

Factors influencing capacity to respond to shocks	
hindering factors	**enabling factors**
- lack of infrastructure, technology, services	- local ecological knowledge, social cohesion
- population growth, migration	- family labour, remittances, mobility
- high dependency on natural resources	- diversified livelihoods and resources
- poverty, inequalities, low education levels	- sense of place and long-lasting experiences
- remoteness and hazards prone locations	- access to communal and collective goods
- unclear land rights (traditional or informal)	
- difficult market access and price volatility	

1.2.3 Ecosystem services

The concept of ecosystem services (ES) has been introduced in the early 1980s to highlight the benefits provided by nature to humans (Ehrlich and Mooney 1983). It helped address the failure of societies to recognize the value of nature for well-being, which has been argued to explain many unsustainable or damaging environmental practices (Costanza et al. 2017). Ecosystem services have been defined as the benefits that people obtain from ecosystems, directly or indirectly, for their well-being (MEA 2005). The Millennium Ecosystem Assessment (2005) has described the links between ecosystem services and human well-being in terms of security, basic material for a good life, health and good social relations (Figure 1.2). Since the publication of the Millennium Ecosystem Assessment, there has been a quick and strong increase in the number of papers using the ES concept in environmental or policy sciences, among others (Fisher et al. 2009, Lele et al. 2013). The research on ES has had three major contributions: it has increased the focus on ecological processes of relevance to humans, enlarged the scale of analysis from site-specific to regional-global studies, and increased interdisciplinary collaborations (Lele et al. 2013).

Ecosystem services have been classified in different ways depending on the analytical purposes and disciplinary perspectives (Fisher et al. 2009). However, as noticed by De Groot et al. (2010), similar definitions are used in widely applied classifications, such as De Groot et al. (2002), MEA (2005), and Maes et al. (2016). *Provisioning services* refer to ecosystem goods, such as crops, wood, and meat (De Groot et al. 2002). *Regulating services* refer to ecological processes and include water purification, carbon sequestration, maintenance of soil fertility, and pollination. *Cultural services* refer to recreation, spiritual values, or cultural heritage and are the services most influenced by human preferences. The Millennium Ecosystem Assessment (2005) also included *supporting services* (e.g. habitat, nutrient cycling and soil formation) that underpin other ES. However, due to the risks of double counting supporting services as part of other services, they are not always considered as ES (Fisher et al. 2009, Nahlik et al. 2012).

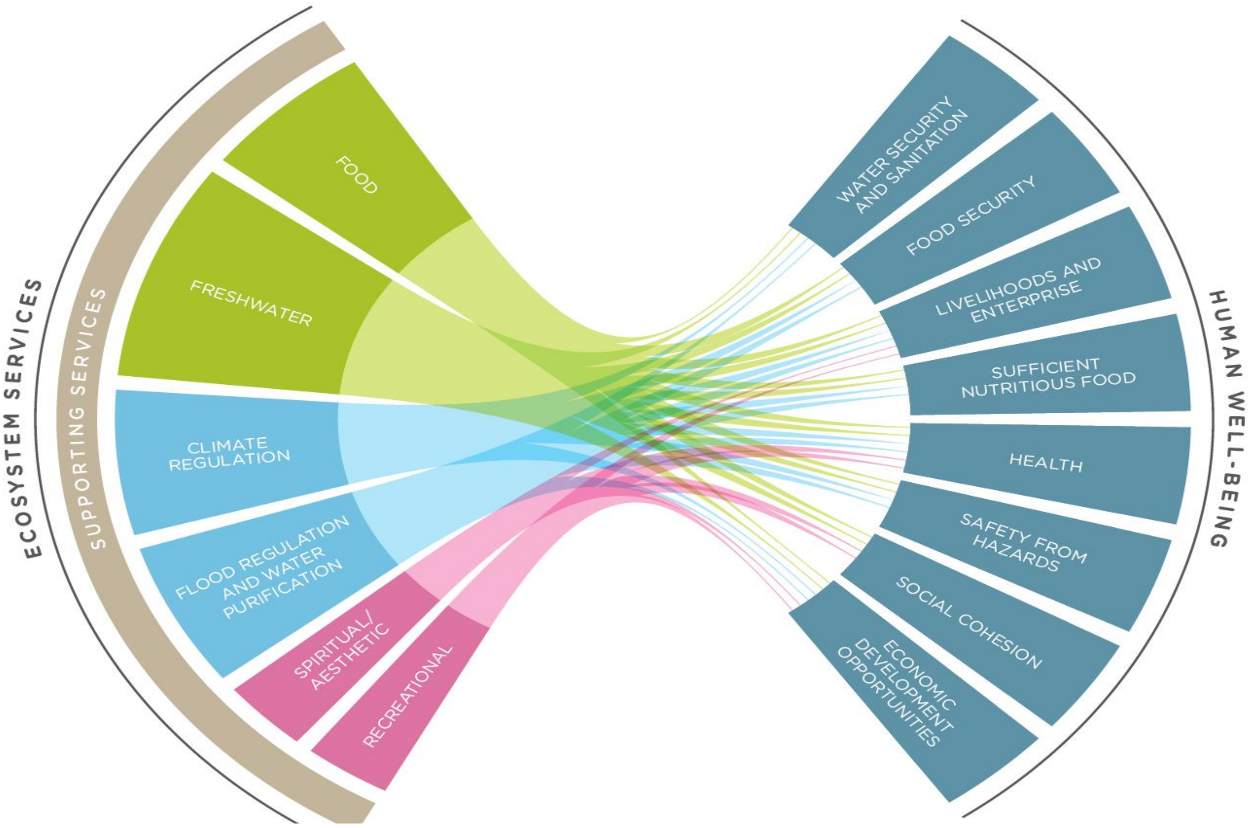

Figure 1.2. A revisited Millennium Ecosystem Assessment (2005) diagram that shows the links between human well-being and ecosystem services in terms of security, basic material for a good life, health and good social relations. (source: IUCN Water 2012).

The framework recently developed by IPBES (the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) expands previous frameworks on the relationships between people and nature (Díaz et al. 2015b and Figure 1.3). It builds on the Millennium Ecosystem Assessment framework, increases its interdisciplinarity, and provides a common ground to facilitate multiple scientific and policy initiatives. One of the innovative aspect of the framework is the explicit consideration of different knowledge systems and perspectives of different stakeholders or scientific disciplines (Díaz et al. 2015b). It represents this plurality of human–nature relationships by including scientific, indigenous, and practitioner knowledge systems, as well as cultures. The framework also highlights the role of anthropogenic assets and institutions that mediate the delivery of ecosystem services. This representation of ecosystem services as co-production of ecological and human processes is increasingly conceptualized in the literature (Burkhard et al. 2012a, Reyers et al. 2013b, Spangenberg et al. 2014c).

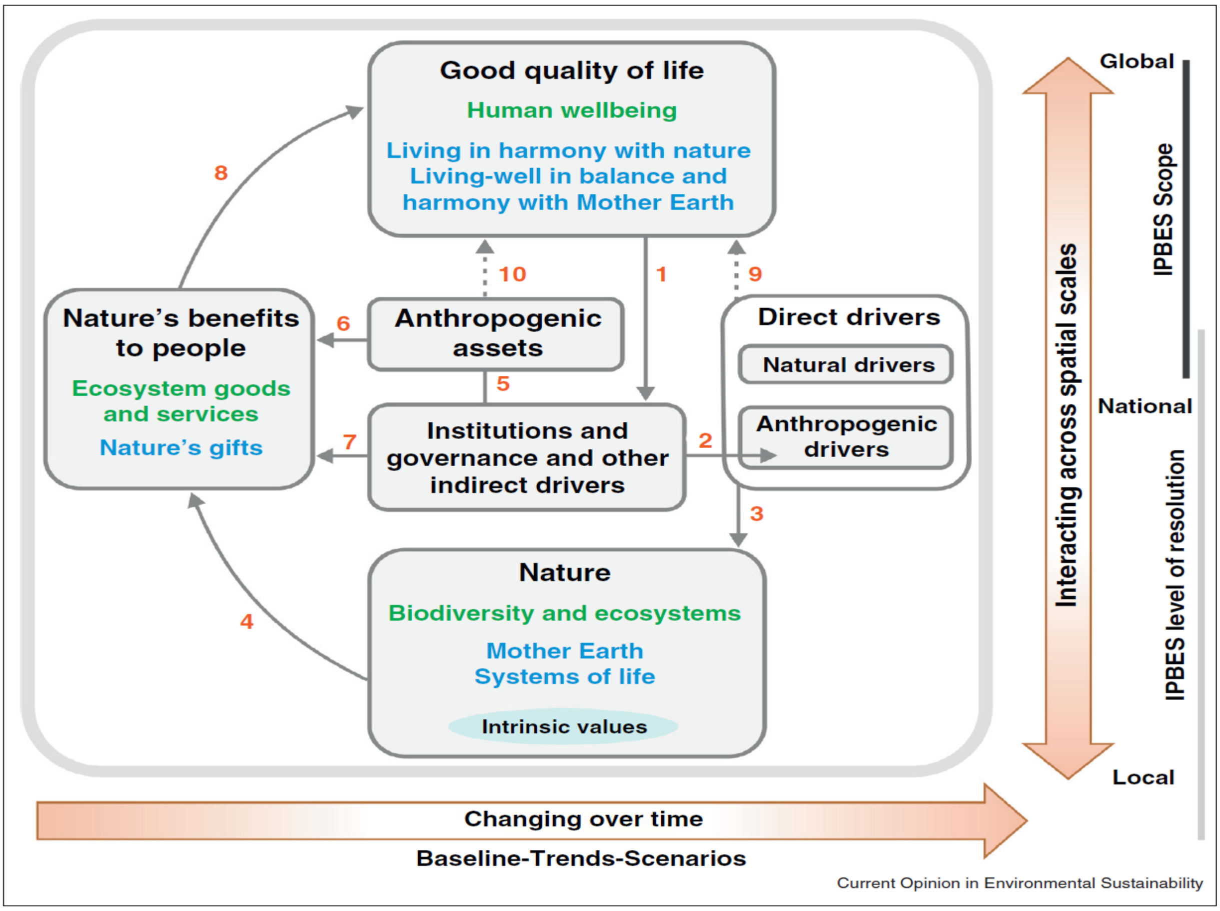

Figure 1.3. The IPBES conceptual framework (Diaz et al. 2015).

1.2.4 The ecosystem service cascade

The ecosystem services cascade framework describes several steps involved in the delivery of ES (Haines-Young and Potschin 2010, Figure 1.4). It has proved useful for analytical purposes to break down the different subsequent steps that generate ES, i.e. the ES flow from nature to people (Spangenberg et al. 2014a, Fischer and Eastwood 2016, Maes et al. 2016). The subsequent staps of the cascade describe biophysical structures and processes, which drive ecosystem functions, which produce services, which benefit humans, who value these benefits. In other words, the left side of the cascade can represent the capacity of an ecosystem to supply services, while the right side can represent people use of the services or demand for them (e.g. Burkhard et al. 2012, Wolff et al. 2015). Distinguishing the steps of the ES delivery and understanding the balance between supply and demand is at the heart of the sustainability debate (Villamagna et al. 2013, Schröter et al. 2014).

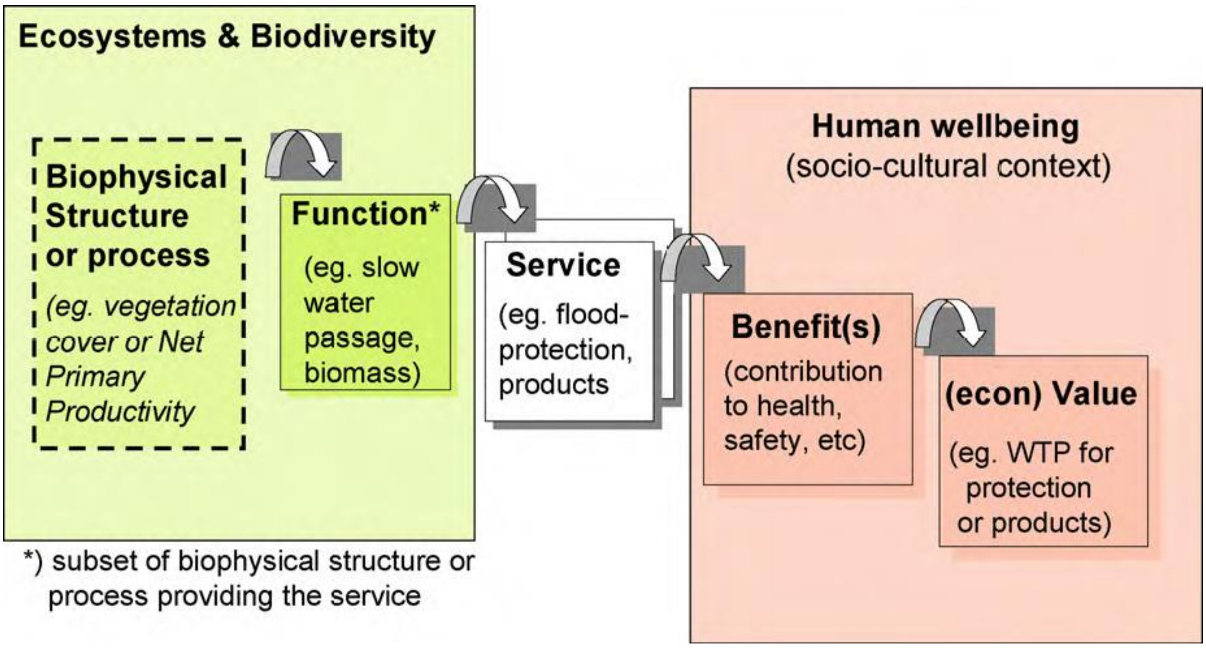

Figure 1.4. The Ecosystem Services Cascade of Haines-Young and Potschin (2010).

Although widely used, the ES cascade has been criticized for several reasons. Criticisms are mostly related to its focus on ecological processes, neglecting many social processes that can shape the ES flow. The cascade represents ES flows linearly without any feedback loop (Spangenberg et al. 2014) and does not show the variety of beneficiaries and values of ES (Hinkel et al. 2015). For example, forests do not automatically generate benefits for hunters: animals need to be captured, transported, and sold to the market (economic value) or eaten (nutritional value). Several authors have proposed to better analyse the socio-economic processes intervening in each step of the cascade such as land management (Oudenhoven et al. 2012), governance (Primmer and Furman 2012), or socio-political decisions (Hausknost et al., 2017). Despite these recommendations, the latest versions of the ES cascade by Potschin-Young et al (2017) and its critical assessment by Costanza et al. (2017) only included one arrow back from people to ecosystems to represent human feedbacks in a generic way, without further specifying in which steps of the cascade such feedbacks occur.

1.2.5 Human inputs in ecosystem services

The flow of ecosystem services can be hindered or transformed through human inputs, which are sometimes required. Human actions and decisions impact in multiple ways the delivery of services along the ES cascade, which then determine who can benefit from them and how (Spangenberg et al. 2014). The supply of ES depends on biophysical properties that can be modified through land management practices. For example, farmers change plant diversity by selecting certain species with valuable characteristics (e.g. drought resistant rice variety or more productive fruits trees). In addition, human inputs are needed to complement or receive the benefits from ecosystems. Farmers improve harvests by investing labour or mechanical power and by applying technical knowledge (Díaz et al. 2015b), whose use might be limited by legal, financial, and cultural constraints (Palomo et al. 2016). Furthermore, the distribution of benefits from ecosystems can be facilitated or hindered by infrastructure, such as roads or irrigation systems.

Ecosystem services can be delivered by systems with different intensity of human inputs, from natural to technological. An example of this gradient is the intensification of agricultural practices, from natural forests to urban settings, in which human inputs are increased to maximise the provision of food (see Figure 1.5 with the example of cherry provisioning service).

These varying intensity of human inputs in ecosystems creates different anthropogenic landscapes (Braat and de Groot 2012). Van Oudenhoven (2015) distinguishes five different types of landscapes with increasing human influence: natural ecosystems, low or high intensity land use, converted, or abandoned/urban.

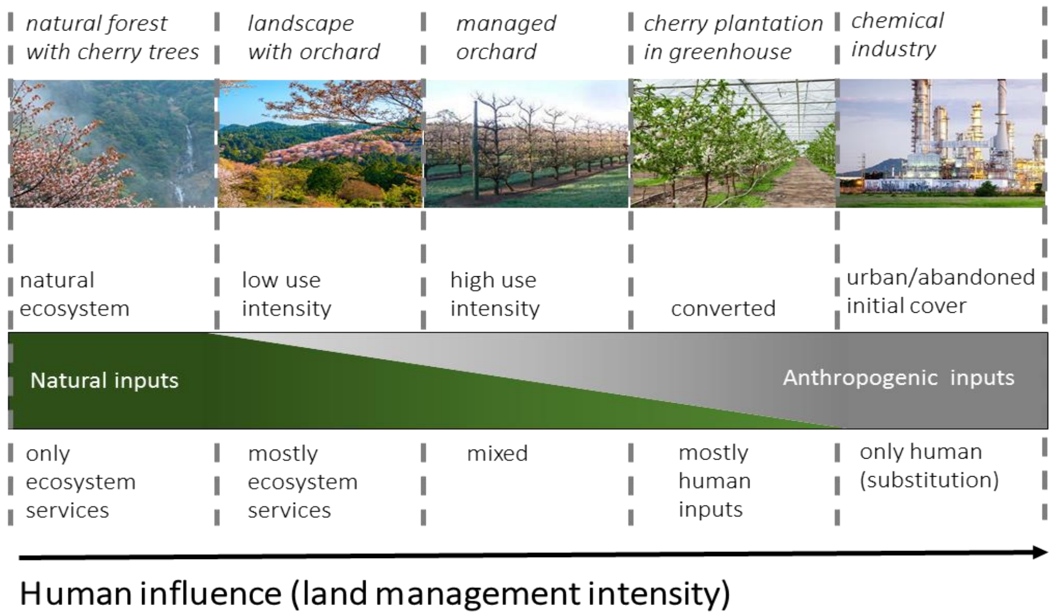

Figure 1.5. Example of gradient of increasing human influence on land and the associated categories of land use and ES co-production. The example shows the provisioning ecosystem service of cherries from natural to artificial systems (from forests to chemical products). Modified from Wu et al. (2013), Van Oudoven (2015), and Palomo et al. (2016). Pictures from gettyimage.com.

1.2.6 Trade-offs between ecosystem services

Increasing human inputs and intensifying land uses often result in trade-offs between products (e.g., timber or crops) and other ecosystem services. A low intensity land use can provide a diversity of ecosystem services, but it might not be an optimum for provisioning or regulating services as reported by a literature review in mountain ecosystems (Locatelli et al. 2017 and Figure 1.6). On the contrary, high intensity of land use to increase provisioning services generally have adverse effects on cultural and regulating services (Bennett et al. 2009a, Raudsepp-Hearne et al. 2010a). This relates to the debate on land sparing and land sharing: the former refers to land intensification in part of a landscape, whereas the latter refers to extensification (for example with agroforestry) to produce goods and other services in the same place. For example, agricultural production can be maximized in most fertile areas and biodiversity conserved in rich ecosystems elsewhere (land sparing) or both conservation and production can be integrated in the same lands (land sharing). It has been suggested that deciding which approach is most appropriate depends on the social and ecological context (Fischer et al. 2008), which imply a better understanding of trade-offs between ES.

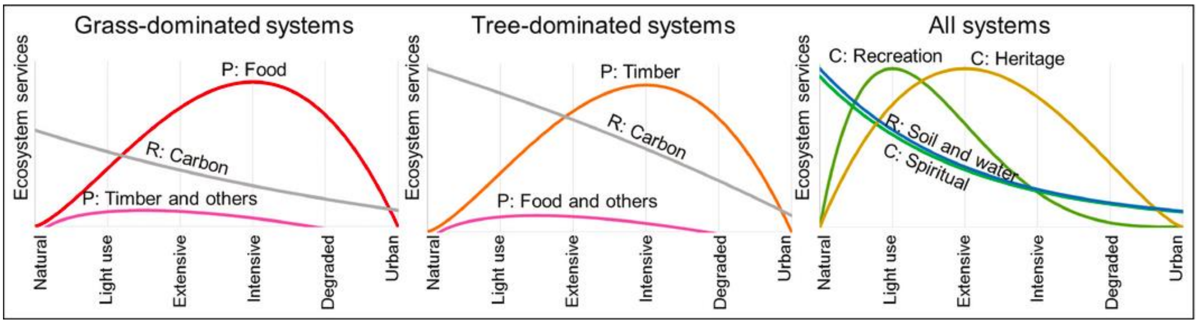

Figure 1.6 Three typical cases of changes in ecosystem services supply following land-use intensification from natural to urban in mountain regions (Locatelli et al. 2017).

Ecosystem services assessments can make trade-offs explicit and, thus, inform the design of sound land management plans. They help explain current ES flows and identify how land management alternatives impact ES under different future scenarios (Pagella and Sinclair 2014). By filling the information gap on where ecosystems have the highest potential to contribute to well-being, such assessments support spatial prioritization (Bourne et al. 2016). This information gap has been identified as one of the reason for policy makers to overlook ecosystem management in comparison to other alternative technical solutions to increase societal resilience (Scarano 2017).

1.2.7 Managing resilience and ecosystem services

Policy and management interventions can be designed to influence human actions on ecosystems and their consequences on the resilience of social-ecological systems (Gunderson, 2000). They include approaches such as ecosystem-based adaptation (EbA) or nature-based solutions (NBS) to adaptation (Keesstra et al. 2017, Faivre et al. 2017). According to Scarano (2017), EbA should be conceived as a policy mix with ES-related policy instruments (e.g, protected areas and restoration programmes), associated with socioeconomic and development-related policies (e.g., poverty reduction and infrastructure programs) and climate change mitigation instruments (e.g., clean energy plans and reductions of emissions from deforestations).

The design of EbA strategies must be based on a good understanding of vulnerability, which is defined by the IPCC as “the propensity or predisposition to be adversely affected” by a driver of change and “encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Agard and Schipper 2014). Assessing the vulnerability of a social-ecological systems must provide an holistic pictures of the sensitivity and adaptive capacities of ecosystems and societies (Heltberg et al. 2009, Moser 2010). Such assessments have evolved from earlier studies of climate change impacts to more integrated analysis of the underlying causes of social-ecological vulnerability, including for example poverty or inequity. It is increasingly recognized that vulnerability, adaptation, and resilience must be analysed by considering the multiple interacting climatic and non-climatic stressors to which social-ecological systems are exposed (Burkett et al. 2014). In addition, it is crucial is analyse the capacities and priorities of different stakeholders and their relations to ecosystems and their services (Palomo et al. 2016).

1.3 Study sites: rural tropical forested landscapes in Indonesia

The study sites for this research were in Indonesia, an archipelago country particularly prone to damages by natural hazards (EM-DAT 2017). Indonesia is among the top five countries most frequently affected by tropical storms, extreme precipitations events, and volcanic activity (EM-DAT 2013). Most people depend on natural resources for their livelihoods, based on farming, forestry, and fisheries, and are sensitive to climate variations. Although Indonesia is the second country with the largest forest area, extensive areas have been lost in recent decades (FAO 2015).

We selected two contrasting provinces, West Kalimantan and Central Java, both prone to climate-related hazards. They differ in forest areas and types (with low and high intensity of human intervention in West Kalimantan and Central Java, respectively) and face medium to high risk of droughts (BNPB - National Agency for Disaster Management 2012). In each of the two provinces, we selected two rural villages affected by recent droughts with more (V1 and V3) or less (V2 and V4) forest cover (see map in Figure 1.7).

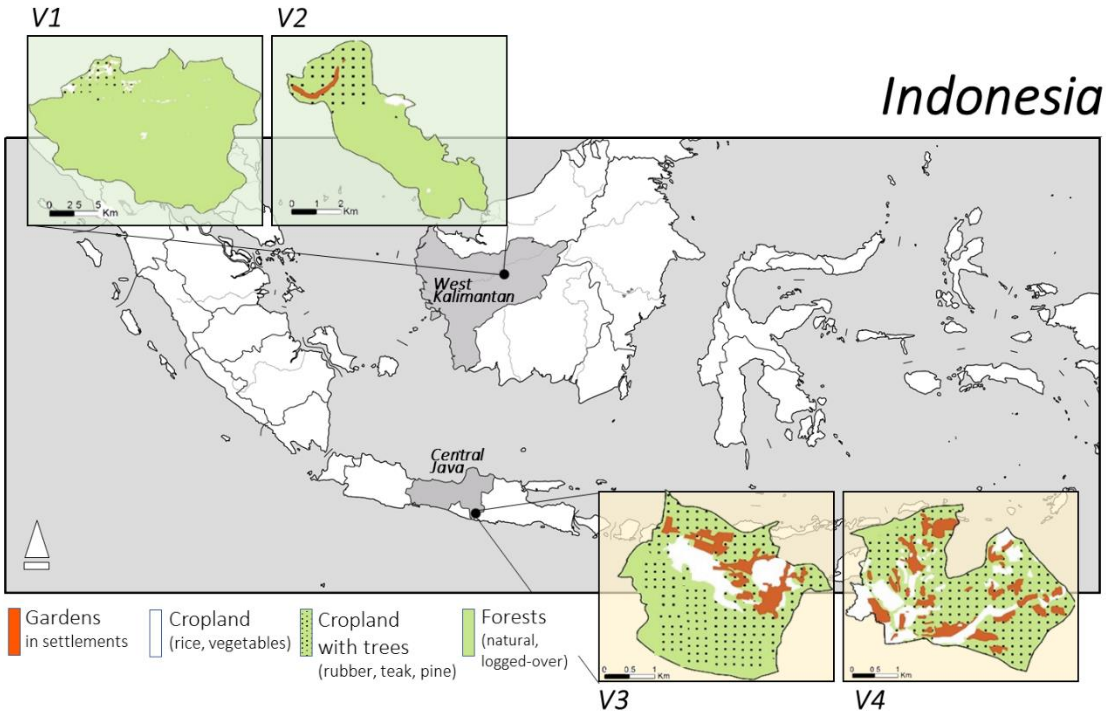

Figure 1.7. Location and land cover of the four study sites in Central Java and West Kalimantan.

The selected provinces are at different stages of the forest transition. The forest transition theory refers to similar trends in historical changes in forest cover observed in many countries, with an initial phase of decreasing forest cover followed by a second phase of increasing forest cover (Mather 1992). Forest transition phases have been used to analyse food security issues (van Noordwijk et al. 2014), ecosystem services (Foley 2005), and land management (Braat and de Groot 2012). Some authors have considered that these Indonesian provinces are at two distinct phases of the forest transition: West Kalimantan being in an early phase and Central Java in a latter one (e.g. Gupta et al. 2013, Boissière et al. 2014, van Noordwijk et al. 2014) (Figure 1.8). However, we recognize that we cannot compare the two provinces as if Central Java represented the future of the West Kalimantan, because of the multiple other differences in geography, culture, and drivers of changes.

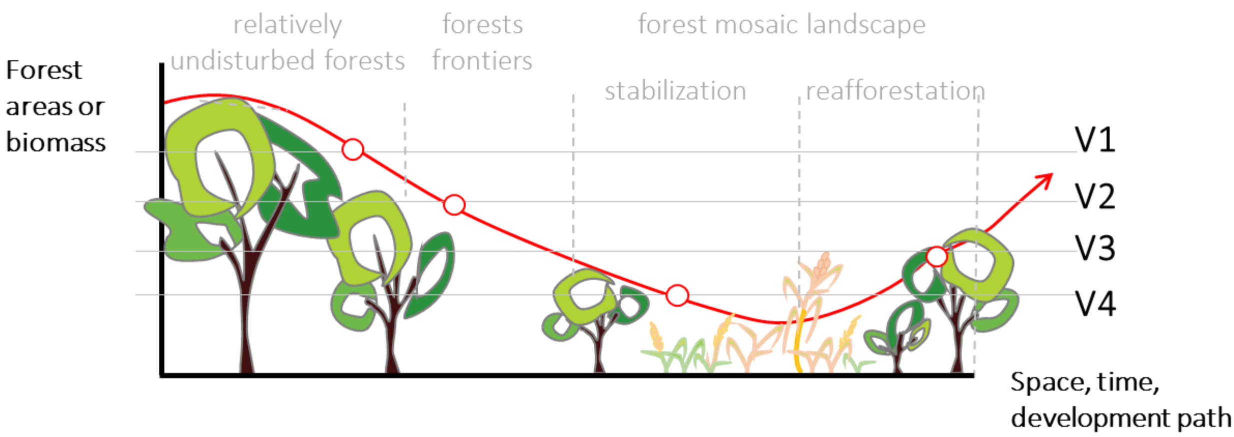

Figure 1.8. Schematic representation of a forest transition and the relative position of the four study sites (V1–V4) representing different situations of forest cover (adapted from CIFOR 2011).

West Kalimantan host one of the most diverse rainforests in the world. Forested lands are also source of income when converted to agriculture or given in concession for timber, rubber, and other industrial plantations. The two selected villages of Nanga Jemah (V1) and Tubang Jaya (V2), in Kapuas Hulu District, are located on the upstream part of the Boyan River. On the hillsides (100–500 m a.s.l.) of the Muller-Schwaner Mountain Range grow most of the remaining dipterocarp forests of Borneo (MacKinnon et al. 1997). The local annual average rainfall is around 2665 mm/year (Fick and Hijmans 2017) and the soils are Ultisols. The main local livelihoods are artisanal gold mining, agriculture (upland rice, maize, cassava and sweet potato) and forest product harvesting of, e.g. Borneo ironwood (Eusideroxylon zwageri – belian), rubber, and agarwood (dark resinous heartwood of Aquilaria spp. infected by a fungus known locally as gaharu). More information on the study sites is provided in chapters 2-3 and in Table 3 of chapter 5.

The island of Java is one the most populated area in Indonesia, but it is also where most of the reforestation efforts occur in Indonesia. The study villages in Central Java of Selopuro (V3) and Sendangsari (V4), in Wonogiri District, are located in the foothills of the southern part of the Thousand Mountains (Pegunungan Seribu), where the Bengawan Solo River originates. Local precipitations are 2290 mm/year on average (Fish and Hijmans, 2017). The area is characterized by very rocky soils (Entisols). The hilly landscape is dominated by forest plantations and agricultural land. Other tree species with commercial values, mostly teak, are planted on private land, in fields or on dry land (tegalan). The main livelihoods in both sites are agriculture, with rice, maize and soybean rotations depending on predicted precipitations.

1.4 Research questions and approach

This research is guided by the question "*how does landscape management affect the resilience of social-ecological systems to climate variability and change with consequences at different scales?*". Central in this research are the interactions in social-ecological systems and their dynamics in a context of climate variability and change. The main objective is to investigate how local landscape management can increase the resilience of social-ecological systems to climate hazards and minimize negative side-effects. Because of the importance of interactions between people and nature for human well-being, we focused on the processes that link both social and ecological systems: people decisions on land management (e.g. land-use plans and forest management) and ecosystem services (e.g. water and soil regulation, carbon sequestration, food and raw materials provision).

The main research question was split into four sub-research questions to cover different aspects in the social-ecological system (Figure 1.9):

1. *How people perceive **benefits** from ecosystem services and **use** them in their adaptation strategies to climate hazards?*
2. *How does landscape **management** strategies in response to climate hazards affect the **supply** of ecosystem services at multiple scales?*
3. *How do ecosystem services **supply** and people **needs** explain strategies to manage ecosystem services?*
4. *How do people **decisions and inputs** influence the delivery of ecosystem services?*

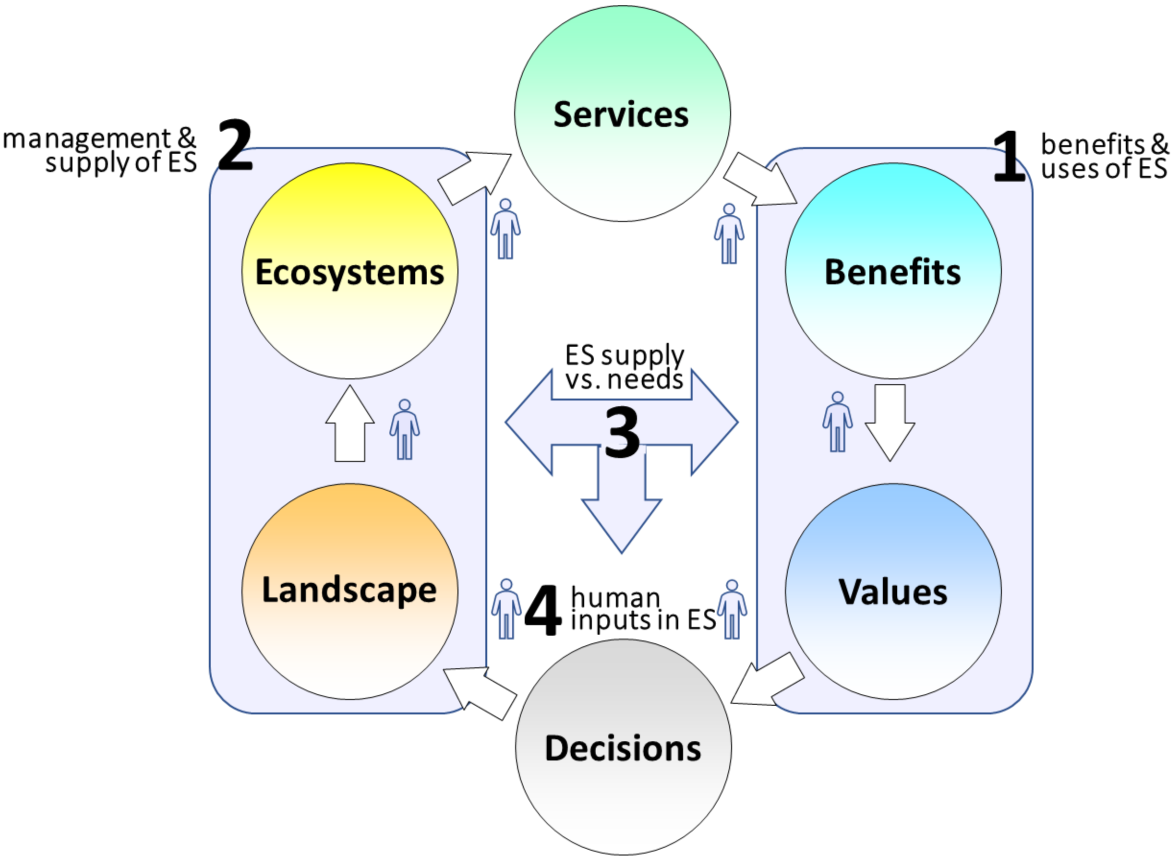

Figure 1.9. Overview of the thesis structure with the sub-research questions located according to their focus in this representation of the social-ecological systems and ecosystem services (ES) flow.

The four sub-research questions refer to different aspects of the delivery of ES as represented on a circular version of the ecosystem service cascade (Figure 1.9). The circular flow emphasizes the feedback loops in ES that connects the societal demand for ecosystem services (benefits and values) with their supply by ecosystems (landscape and ecosystems). The arrows and the human symbols represent people's decisions that contribute to shape the flow of ES in several steps. The sub-research questions 1 and 2 focus on ES flows with social and ecological perspectives respectively. The first focuses the uses of ecosystems and their benefits for human resilience (demand for ES), whereas the second focuses on the impact of such uses on the ecological properties and functions (ES supply). The sub-research question 3 refers to the interplay between ES supply and demand to understand how it influences people decisions to manage landscapes. Finally, with the sub-research question 4, we aim to identify the multiple human inputs in the ES flow and not only through decisions on landscape management.

The methods used in the research were multi-disciplinary and participatory (see overview in Table 1.2). We combined biophysical and social methods to assess ES, as well as local and scientific knowledge. Our research methods drew on transdisciplinary research and participatory rural appraisals techniques. To guide our data collection and analysis, we used the Sustainable Livelihoods Framework, which considers five capitals (natural, physical, financial, human and social) as the basis of local livelihood choices (Ashley and Carney 1999). The research protocols are in the annex (Annex). The field work was conducted between March 2014 and June 2015.

Table 1.2. Number and type of research activities conducted in the four study villages (V1-V2 in West Kalimantan and V3-4 in Central Java).

Research activity	V1	V2	V3	V4	TOT
Focus Group Discussions	7 (73 pp.)	7(104)	5 (76)	5 (76)	24 (329)
Community visioning workshops	1 (13 pp.)	1 (12)	1 (15)	1 (12)	4 (52)
Households survey	50	50	77	79	256
Forest inventories plots	30 (1.2 ha)	30 (1.2)	30 (1.2)	30 (1.2)	120 (4.8)
Landsat time series image analysis	3	3	3	3	12

To study the demand side of ecosystem services and their uses, we conducted several focus group discussions and household interviews. In the focus groups discussions, we used participatory rural appraisal techniques, such as historical timelines, participatory mapping, seasonal calendars, problem trees, and sociograms (see Annex for protocols). The exercises and the discussions with the communities were aimed to understand how people and nature interactions changed due to the impacts of natural hazards (e.g. droughts, floods, pest and diseases outbreaks). We focused on changes in ecosystem services and in land management decisions. These research methods are described in more detail in chapter 2 and 3. In the household surveys, we assessed the impacts of climatic events on people assets (e.g. houses, fields, and economic activities) and their response strategies (see questionnaire in Annex and chapter 2). In the community visioning workshops, we explored future plans and priorities for the village lands as well as how climate and other drivers of change influenced them.

For assessing the supply side of ecosystem services, we combined forest inventories and remote sensing analysis. The current land uses and ecological characteristics in the village territory were assessed through forest inventories, in which we estimated above ground carbon stocks in trees and tree species richness (see Annex for protocols). Carbon stocks were calculated using an allometric equation for tropical trees and dry wood specific densities from the ICRAF Wood Density Database. Past land uses and changes were analysed with three historical Landsat images (1994, 2004, and 2014). The results were cross-checked during the participatory mapping exercise. More details on these research methods are provided in chapter 3.

1.5 Structure of the thesis

This PhD thesis is organized in six chapters that cover the different research questions. Between the general introduction (Chapter 1) and the conclusion (Chapter 6), the Chapters 2 – 5 reproduce the scientific papers (published or submitted) that address the four sub-research questions.

In Chapter 2, we explore the role of forests and trees in influencing local people's vulnerabilities to climate variations. We describe the losses and damages caused by drought, floods, and pest outbreaks to four rural communities. In addition, we assess the strategies undertaken by the communities to respond to the impacts of climate variations and reduce vulnerabilities. Among these strategies, we focus on those based on ecosystem services provided by forests and trees (e.g. selling timber or rubber, replacing livestock fodder for leaves, planting trees in gardens). The role of forests and trees in reducing people's vulnerabilities is discussed depending on the type of ecosystem service (provisioning or regulating), in relation to the phase of the climatic hazard (pre-disaster or post-disaster phase), and the ecosystem state (higher or lower forest cover).

In Chapter 3, we assess how rural communities adapt to multiple risks by changing land uses and how these changes affect the supply of ecosystem services. We consider different benefits provided by ecosystems to different scales (products, water, carbon, and biodiversity). Because of existing trade-offs among ecosystem services, land-use changes have different consequences for ES beneficiaries across spatial scales. We illustrate how some land-use decisions expand and scale up when local actors perceive their benefits, leading to reinforcing feedback loops (i.e. more land-use change leading to more benefits, leading to more land-use change). The chapter highlights the importance of ecosystem services assessments that consider feedback loops driven by beneficiaries. In this way, ecosystem services assessments can help identify emerging local adaptation pathways with multiple benefits that can be expanded to address climate change challenges and other sources of vulnerability.

In Chapter 4, we assess different dimensions of the delivery of ecosystems services that support human resilience: ecosystem potential supply of ES, people demand or need for ES, and the strategies to mobilize ES. The chapter reports the potential of forest ecosystems to provide ES relevant for adaptation in sites with high or low forest cover. In addition, it presents how people manage ecosystems and how they perceive ecosystems as part of their responses to drought. We discuss how supply of and demand for forest ecosystem services can explain the uses of forests and trees in adaptation strategies and the implications for land management decisions.

In Chapter 5, we propose a revisited ecosystem services cascade that highlights how humans influence each step in the delivery of ecosystem services through mediating mechanisms and factors. We apply the framework to the empirical Indonesian case studies. We show how human actions determine the contribution of ecosystem services to well-being through management, mobilization, allocation-appropriation, and appreciation. These mechanisms are influenced by people decisions along the ES cascade, which depend on specific factors related to rules, assets, values, and spatial context. The discussion highlights how functional ecological processes need to be actively maintained, complemented, or partially modified by human interventions to co-produce ecosystem services. By controlling ES flows, some stakeholders can determine who benefits from ES and influence the well-being of others. The proposed changes in the ecosystem services cascade can help design sound and operational environmental assessments that can serve as basis to develop sustainable land management practices.

CHAPTER 2

Ecosystem-based strategies for community resilience to climate variability in Indonesia.

*Crossing a rubber plantation (*Hevea brasiliensis*) to reach a forest inventory plot on the hills of Tubang Jaya (West Kalimantan). Local people clear-cut semi-natural forests to plant rubber trees, which help diversify livelihoods and cope with losses of crops due to floods and drought (picture by Giacomo Fedele).*

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Ecosystem-based strategies for community resilience to climate variability in Indonesia

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Abstract

Rural communities have long been using ecosystems to sustain their livelihoods, especially in times of disasters when forests act as safety nets and natural buffers. However, it is less clear how climate variability influences changes in land uses, and their implications for human well-being. We examined how forests and trees can reduce human vulnerability by affecting the three components of vulnerability: exposure, sensitivity, and adaptive capacity. A total of 24 focus group discussions and 256 household surveys were conducted in two smallholder-dominated rural landscapes in Indonesia, which were affected by floods, drought and disease outbreaks. Our results suggest that forests and trees are important in supporting community resilience and decreasing their vulnerabilities to climate-related stresses in different ways. The role of trees varied according to the type of ecosystem service, whether provisioning or regulating, in relation to the phase of the climatic hazard, either in the pre-disaster phase or in the post-disaster recovery phase. It is therefore important to distinguish between these elements when analyzing people's responses to climatic variability in order to fully capture the contribution of forests and trees to reducing people's vulnerability. Landscape spatial characteristics, environmental degradation and community awareness of climate variability are crucial because if their linkages are recognized, local people can actively manage natural resources to increase their resilience. Interventions related to forests and trees should take into consideration these aspects to make ecosystem services a valuable option for an integrated strategy to reduce disaster risks and climate-related vulnerabilities.

Keywords: Climate variability, climate change adaptation, ecosystem services, Ecosystem-based Adaptation, natural resource management, socio-ecological systems, social vulnerability

2.1 Introduction

Societies have long been using and managing ecosystems for subsistence, livelihoods and protection against risks caused by fluctuations in rainfall and temperature (CBD 2009). In times of extreme weather events, the literature has often identified forests as important safety nets and natural buffers that help reduce people's vulnerability by providing food, drinkable water, shelter and regulation of ecological processes (e.g. Angelsen and Wunder 2003, McSweeney 2004). In many parts of the world, natural systems and resources are a critical asset for local communities because they provide the foundations to respond to extreme weather events or disasters, especially if other technological options are limited (Sudmeier-Rieux et al. 2006, Roberts et al. 2011). Such dependency on natural resources, however, can also make rural populations prone to social and economic vulnerabilities, which a changing climate can exacerbate (IPCC 2014).

The effects of climate variability are already visible in many parts of the world, where people have been experiencing a general increase in extreme high temperatures, in drying trends, and in the number of heavy precipitation events (IPCC 2014). According to the Intergovernmental Panel on Climate Change (2014), climate variability refers to fluctuations in the means of climatic parameters such as those mentioned above, and can appear as unusual events and changes that occur within relatively short timeframes (seasons or years). If changes in variability are persistent for an extended period such as decades or longer, it can suggest that a change in climate has occurred (IPCC 2014). The effects of climate variability, due to either subtle shifts or more extreme events, directly impact poor people's lives. It has been predicted that the effects of climate variability will cause a decline in agricultural yields, reduce access to water, increase the severity of damages to assets in flood-prone areas, and increase vulnerability to human and non-human diseases (e.g. vector-borne diseases or pest species) among other impacts (IPCC 2014). Rural areas are particularly at risk from the impacts of climate variability due to their underlying vulnerabilities related to geographic situations, limited financial and technological means, and the sensitivity of their livelihoods to weather conditions, which can turn a hazard event into a disaster.

Healthy, diverse and well-managed ecosystems are able to resist, absorb and recover from unwanted changes and risks (CBD 2000, Gunderson and Holling 2002). Community management decisions can change the type, magnitude, distribution and relative mix of services that ecosystems provide, which in turn can reduce or increase a community's vulnerability to adverse climate (Rodríguez et al. 2006). Adaptation strategies, based on ecosystems, can complement and sometimes substitute other approaches involving hard infrastructure, technological solutions or capacity building (CBD 2009, Raudsepp-Hearne et al. 2010). In this way, communities can respond to the challenges posed by climatic variability, while also generating additional positive environmental, social, economic and cultural benefits, making sustainable ecosystem management a cost effective and suitable option for community climate change adaptation.

Although research on adaptation to climate-related stress based on ecosystems is relatively new, there is an increasing recognition of the role of ecosystems in response strategies to climate change (Doswald et al. 2014, Pramova et al. 2012). Several guiding principles have been developed by international organizations (CBD 2000, UNEP 2012, GIZ 2013, UNFCCC 2013, EU 2009) and practitioners (e.g. BirdLife International, International Union for Conservation of Nature and Natural Resources, World Wide Fund for Nature, in Heath et al. 2009, Colls et al. 2009, Andrade Pérez et al. 2010). However, regarding scientific knowledge on climate change and variability, few studies have focused on aspects related to human adaptation at the local level (IPCC 2012), in rural areas (IPCC 2014) within forested landscapes (IUFRO 2009). In addition, the recent IPCC 5th Assessment Report (IPCC 2014) indicated that more research was needed to better understand how climate variability influences changes in land use, which in turn can affect the provision of ecosystem services relevant for people's well-being. Especially lacking is quantitative evidence of the effects of management practices and landscape configurations (including forest types) on benefits to climate change adaptation (Harvey et al. 2013).

Indonesia has one of the largest areas of tropical forest in the world, which is rapidly disappearing (FAO 2010) and is among the top five countries most frequently hit by natural disasters (EM-DAT 2013). In this study, we examined the benefits provided by ecosystems in reducing local community vulnerability to climate variability in two smallholder-dominated rural landscapes in Indonesia, where households experience floods, drought and diseases outbreaks. In particular, we assessed the roles that forests and trees play in helping communities reduce their exposure and sensitivity, and increase their adaptive capacity to climate variability and decrease disaster risks (IPCC 2014). The chapter is organized into five sections: research background, study sites and methodology, results, discussion and conclusion. The results section is divided into three parts: i) a description of the exposure to climatic variability and their impacts on local people's lives, ii) the sensitivity of the socio-ecological systems, and iii) household response strategies. At the end of each section, we focus on the results related to forests and trees. The discussion focuses on: i) the role of forests and trees in reducing the potential impact of disasters (exposure and sensitivity) and ii) their role in strengthening local people's response strategies (adaptive capacities).

2.2 Methods

2.2.1 Study sites and selection criteria

Our four study sites were located in the provinces of West Kalimantan and Central Java (see Fig. 2.1). Criteria for site selection encompassed the communities' exposure to recent severe weather events and a diversity of forest conditions (low to high levels of degradation) and population density (low to high levels). In West Kalimantan, we selected two villages (Nanga Jemah and Tubang Jaya) characterized by low population density and low forest degradation compared to the two villages (Selopuro and Sendangsari) in Central Java. We also chose the villages according to their vegetation cover to allow further comparison (Table 2.1).

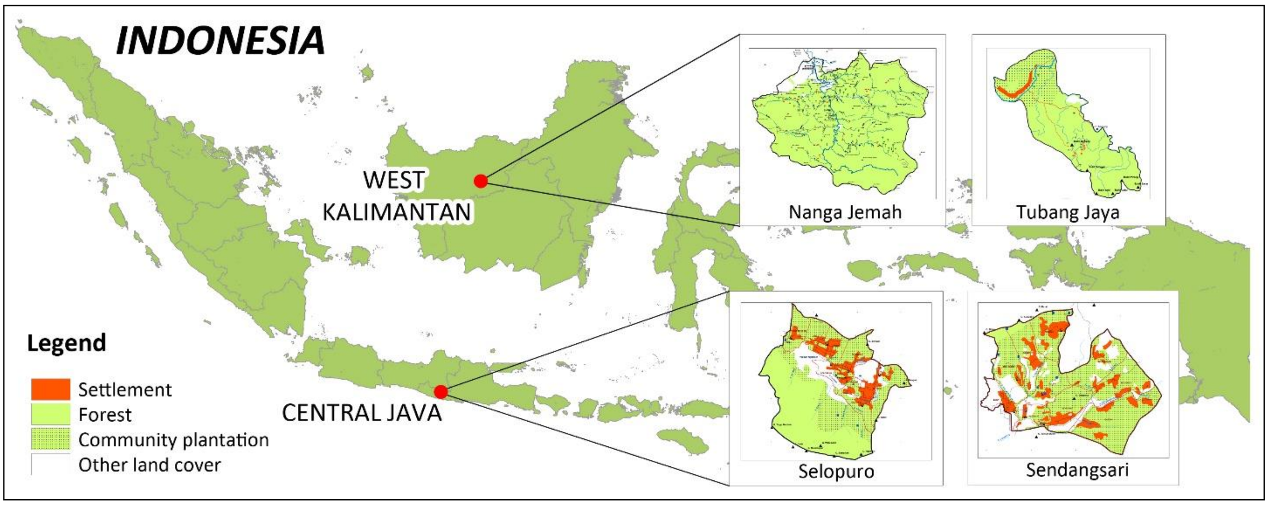

Figure 2.1. The location of the study sites: two villages in West Kalimantan Province and two in Central Java Province. In each province one village with more forest and tree cover (Nanga Jemah in West Kalimantan and Selopuro in Central Java) and one with less (Tubang Jaya in West Kalimantan and Sendangsari in Central Java) were selected (green areas in the map). (Source: participatory mapping)

In West Kalimantan, the villages of Nanga Jemah and Tubang Jaya, in Boyan Tanjung Sub-district, Kapuas Hulu District, are located on the banks of the Boyan River. The Boyan River flows through the foothills (100 – 500 m a.s.l) of the Muller-Schwaner Mountain Range (PPSP 2013), in which most of the remaining dipterocarp forests of Kalimantan are found (MacKinnon 1996). Local livelihoods are centered on artisanal gold mining, agriculture and harvesting forest products such as the Borneo ironwood (*Eusideroxylon zwageri – belian*), and *gaharu* (from the heartwood of *Aquilaria* spp. infected by a fungi). The main agricultural crops include upland rice, maize, cassava and sweet potato. The agricultural land is dotted amongst rubber plantations, secondary forests, and natural forests, which provide additional income. Other livelihood activities include animal husbandry, fishing in rivers or growing fish in ponds, and hunting.

In Central Java, the villages of Selopuro and Sendangsari, in Batuwarno Sub-district, Wonogiri District, are located in the karst and limestone foothills of the southern part of the Thousand Mountains (*Pegunungan Seribu*) where the Bengawan Solo River originates (Surono et al. 1992). Both villages border pine monoculture forests and mixed species forest that are owned and managed by Perum Perhutani, a state-owned company. Other trees in the landscape include white albizia (*Falcataria moluccana – sengon laut*), teak (*Tectona grandis – jati*), and mahogany (*Swietenia macrophylla – mahoni*) growing on private land, along fields or on dry land (*tegalan*). In 2004, Selopuro's planted 'community forests' received the Indonesia Ecolabel Institute (LEI) certification. The main livelihoods in Selopuro and Sendangsari are in agriculture, mostly rice, corn and soybean as well as income from occasional off-farm jobs. Laborers help either in the villages during field preparations for seeding, weeding or at harvesting time, or temporarily migrate to cities to work as construction workers or merchants. Most of the population raises livestock to support their income, mostly cows and goats.

Table 2.1. Socio-economic and environmental characteristics of the four study villages in the provinces of West Kalimantan and Central Java

	West Kalimantan		**Central Java**	
	Nanga Jemah	Tubang Jaya	Selopuro	Sendangsari
Tree cover [% village territory]	98.2%	97.5%	75.5%	64.2%
Village plantations [% village territory]	4.2%	25.6%	39.5%	62.0%
Population density [households/ha]	0.7	4.1	65.3	72.6
Main livelihoods (in order of importance)	Rubber farmer, gold miner, farmer	Gold miner, rubber farmer, farmer	Farmer, cattle farmer, construction labour	Farmer, cattle farmer, farm labour
Climate-related event (in order of importance)	Flood, drought, human disease	Flood, drought, human disease	Drought, plants disease	Drought, plants disease, flood
Households affected by the most important climatic event	37%	52%	100%	100%

2.2.2 Research methods

Quantitative and qualitative participatory methods were combined to gather information on interactions between the social and ecological systems that help people to adapt to the adverse effects of climate change. To guide our data collection and analysis, we used the Sustainable Livelihoods Framework, which considers five capitals (natural, physical, financial, human and social) as the basis of local livelihood choices (DFID 1999). We took a closer look at the natural capital, which include the resource stocks (e.g. land, water, or forests) as well as the ecosystem services (e.g. soil stabilization, pest control, water regulation and purification). According to the Sustainable Livelihoods Framework, the availability and control of assets under constraints of policies, regulations and vulnerabilities influence local people's ability to achieve livelihood outcomes such as food security. We broke down the concept of vulnerability in its defining three components: exposure, sensitivity, and adaptive capacity, following the most-widely used definition from the IPCC Fourth Assessment Report (IPCC 2007) in order to tackle these distinct aspects for a better overall understanding of the salient issues. A reduction of climate vulnerability can be achieved by a combination of measures that reduce the exposure and the sensitivity of social-ecological systems or enhance their adaptive capacity, which in turn improves their resilience to climate hazards. We used Folke's (2006) definition of resilience as the capacity of social-ecological systems to cope with, adapt to, and retain essential structures, processes, and feedbacks and learn to live with uncertainty and surprise (such as climate variability). We distinguished people's responses to climatic events between coping and adaptive strategies. Coping strategies refer to short-term actions aimed at meeting immediate needs and are always reactive, whereas adaptive strategies take into consideration long-term perspectives and possible future changes, which can be either reactive or anticipatory (IPCC 2012).

We conducted 24 focus group discussions (FGD) using different participatory rural appraisal techniques, and 256 household surveys selected through stratified random sampling. The participants in the focus group discussions were selected by taking into consideration different areas of expertise, sources of livelihoods, and gender, as well as geographical representation within the village. Five to seven FGDs were conducted per village (more FGDs in the larger villages in West Kalimantan), through which we explored the dependencies of community livelihoods on natural resources and climate as well as their interactions. The household surveys were conducted with a representative sample size according to the equation of Arkin and Colton (1963) at a 95 % confidence level and a ±10% relative error limit. The survey aimed at obtaining specific information on assets, damages and response strategies of local people affected by the consequences of climate variability. For quantitative and qualitative analysis, we coded and categorized local people's answers. The major themes that emerged were then analyzed in more detail, comparing trends in percentages of people and strategies between sites.

In order to better understand climate variability at the village level, we used satellite data of the Tropical Rainfall Measuring Mission (TRMM). The TRMM estimations combine microwaves and infrared technologies that are calibrated against ground based monthly rain gauge totals to produce 3-hourly precipitation information at a spatial resolution of 0.25° latitude/longitude (or approximately 25 km). We used monthly average precipitation anomalies in order to reveal unusual trends. Anomalies represent the deviation from the mean and were calculated by subtracting long-term climatological monthly trends from observed data. This dataset (Huffman et al. 2010) was chosen because of its finer estimations compared to other satellite information when we checked against ground measurements in areas nearby our study villages.

2.3 Results

2.3.1 Exposure to climate variability and their impacts

Participants in our focus group discussions identified several climatic events that severely affected their productive activities or assets in the last 10 years. They suffered from multiple climate-related events such as floods, drought, and disease outbreaks (see Table 2.1). In West Kalimantan participants highlighted, among the most severe climate-related events, the recent floods of December-January (2012/13 and 2013/14), the chikungunya disease (viral disease transmitted by infected mosquitoes) of 2010 (a year's duration) as well as the droughts of 2012 and 2014. The main climatic events identified by households in Central Java were the dry periods in 2002, 2011, 2012, the plant disease outbreaks (*Patah leher* or "rotten neck" a rice leaves blast disease most likely caused by the fungus *Pyricularia oryzae*) in 2010 and 2013, as well as the heavy rains of 2008 and 2010.

The information gathered in the focus group discussions were compared with monthly precipitation anomalies calculated from TRMM satellite data (Fig. 2.2). There is a good match between perception and extreme weather events reported by local people and satellite estimates for rainfall in all study sites. In West Kalimantan, the floods local people reported corresponded with precipitation anomalies of up to +200 mm/month. In Central Java, dry periods were identified in the same year climatic data showed a below-average rainfall (around -75 mm/month). Diseases that affected humans (caused by a vector-borne virus) and crops (due to a rice fungal pathogen) have a good overlap with particularly wet periods as estimated by satellite data. This could be explained by the fact that both these kinds of human and rice plant diseases spread easily in a wet environment (Ditsuwan et al. 2011 and Iglesias and Rosenzweig 2007 respectively).

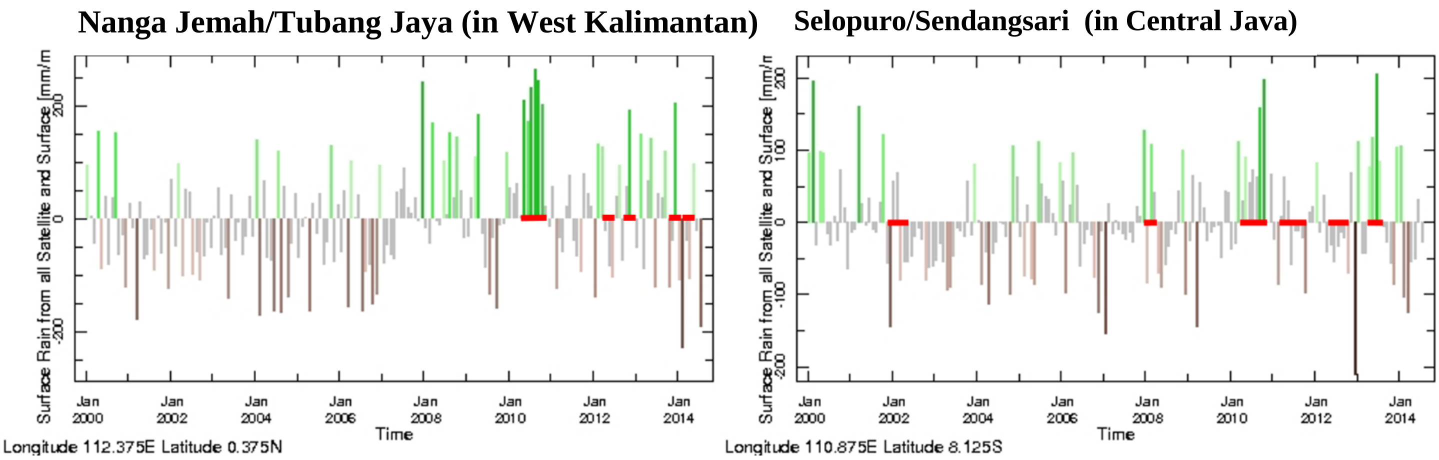

Fig. 2.2. Monthly precipitation anomalies in Nanga Jemah and Tubang Jaya, West Kalimantan and Selopuro and Sendangsari in Central Java. The darker the color the higher the precipitation anomaly in ± mm/month compared to the average. The red thick bars on the X-axis indicate the occurrence of climate-related events as identified by the communities (see text). Source: TRMM 3B-42 ver. 6 (Huffman et al. 2010)

According to the villagers, their primary difficulty in preparing for future climate-related risks was the increased unpredictability of weather in the past few years, with noticeable changes in precipitation intensity (Sendangsari), frequency (Tubang Jaya), or both (Nanga Jemah and Selopuro). No remarkable change in the seasonality of livelihood activities compared to 10 years ago was identified by farmers, who preferred to continue following traditional practices. However, time shifts and adjustments for some agricultural practices were reported by several farmers. For example, in West Kalimantan slash and burn for cultivating upland rice, spraying herbicides and picking fruit all had to be delayed due to rain. Villagers in West Kalimantan also indicated that they were still using traditional practices to predict seasonal changes based on their observations of natural phenomena such as the flowering of fruit trees, insect behaviors and cloud shapes. Approximately 38 % of people in Nanga Jemah and 15 % in Tubang Jaya were aware of imminent floods or drought using traditional knowledge. However, according to some villagers, traditional predictions have now become less reliable. Regardless of the source, external or traditional knowledge, the majority of people (around 60%) thought there was insufficient information available, especially in more remote areas such as the villages in West Kalimantan.

Table 2.2. Impacts of drought on main livelihood activities, water and food in West Kalimantan and Central Java Note: The percentages indicate the proportion of people who experienced such consequences and the average change in quantity and quality compared to normal times.

	West Kalimantan				Central Java			
	Nanga Jemah		Tubang Jaya		Selopuro		Sendangsari	
Impact on resources/ activities/people	% people n=50	quantity quality[1]	% people n=50	Quantity quality	% people n=78	quantity quality	% people n=77	quantity quality
Agriculture	66		66		91		88	
Rice	54	-52 % --	28	-55 % -	70	-58 % -	84	-56 % --
Maize	8	-75 % =	2	-50 % -	47	-77 % --	13	-61 % --
Vegetables	48	-74 % --	30	-70 % ---	1	-40 %	2	-75 % ---
Forest related								
Timber	21	-69 %	4	-63 %	0	0 %	0	0 %
NTFPs	20	-88 %	22	-69 %	0	0%	0	0%
Rubber	74	-42 %	86	-33 %	N/A	N/A	N/A	N/A
Off farm								
Gold mining	8	-50 days	34	-38 days	N/A	N/A	N/A	N/A
Labor	N/A	N/A	N/A	N/A	20	-3 months	14	-4 months
Health								
Unsafe water	28	30 days	46	34 days	16	93 days	27	93 days
Sickness	22	3 days	14	3 days	3	1 day	6	2 days
Food shortages	0	0 days	0	0 days	4	0 days	16	30 days
Food prices	8	+ 0.56 USD[2]	2	0 USD	39	+ 0.11 USD	45	+ 0.12 USD

Note: [1]Quality changes:=no decrease nor increase, (-/+) slight decrease/increase, (--/++) moderate decrease/increase, (---/+++) major decrease/increase.[2]USD rate November 2014 was USD 1 = IDR 12,197. N/A = no household undertaking these activities.

People affected by drought reported losses for on- and off-farm activities, as well as changes in food, water and health conditions (Table 2.2). Most of the impacts caused by drought were related to a decrease in quantity and quality of products harvested compared to the normal situation, either because of damage (farm activities) or impaired access (off-farm). The impacts that caused the biggest loss in well-being were, in order of importance: decreases in agricultural production in all locations (66% of people in West Kalimantan and 90% in Central Java), followed by clean water access in West Kalimantan (28-46%) and higher food prices in Central Java (39-45%). Maize and vegetables were the cultivated lands most severely impacted by drought in terms of losses in productivity, followed by rice whose yields were halved in all villages. In West Kalimantan, transportation was severely disrupted due to low water level in the river, which subsequently effected Non-Timber Forest Products (NTFPs) harvests. Several other activities that depended on water also were discontinued, causing the loss of job opportunities for workers in gold mining, farming or construction in all locations.

Harvest failures can also affect demand and supply and thus influence market prices. Fewer households reported an increase in food prices in West Kalimantan (less than 10 %) compared to Central Java (around 40%), which could imply more people in Central Java were not able to cover their needs from their own production and had to buy extra supplies. At the same time, only people in Central Java, especially the village with less forest, suffered from food shortages. This could indicate that alternative sources of food are less abundant in places with less forest.

2.3.2 Livelihoods and their sensitivity to climate variability

The communities in the four study villages were mostly rural smallholder farmers characterized by their diversity of livelihood sources and dependency on natural resources. Several household decisions on productive activities were taken according to weather conditions, relying on favorable temperature and rainfall for agriculture or forest related activities. Such dependencies demonstrate the tight relationships between the social and natural systems in these landscapes.

In West Kalimantan, most of the households in the two villages used forests and trees for their livelihoods (lumbermen, rubber farmers and NTFP collectors), while in Central Java the majority were involved in agriculture and animal husbandry. The respondents identified both agriculture and forest related activities as being sensitive to climate variability. In addition to their main source of livelihood, people in all study villages had a range of activities to supplement their income. In Central Java, they were mostly off-farm such as construction work, temporary migration, and animal husbandry. In West Kalimantan, forest related works include cutting and transporting trees and collecting NTFPs (e.g. rubber tapping, birds and mammals, *gaharu* or agarwood). Interestingly, the diversification of livelihoods decreased with decreasing forest and tree cover (see Fig. 2.3).

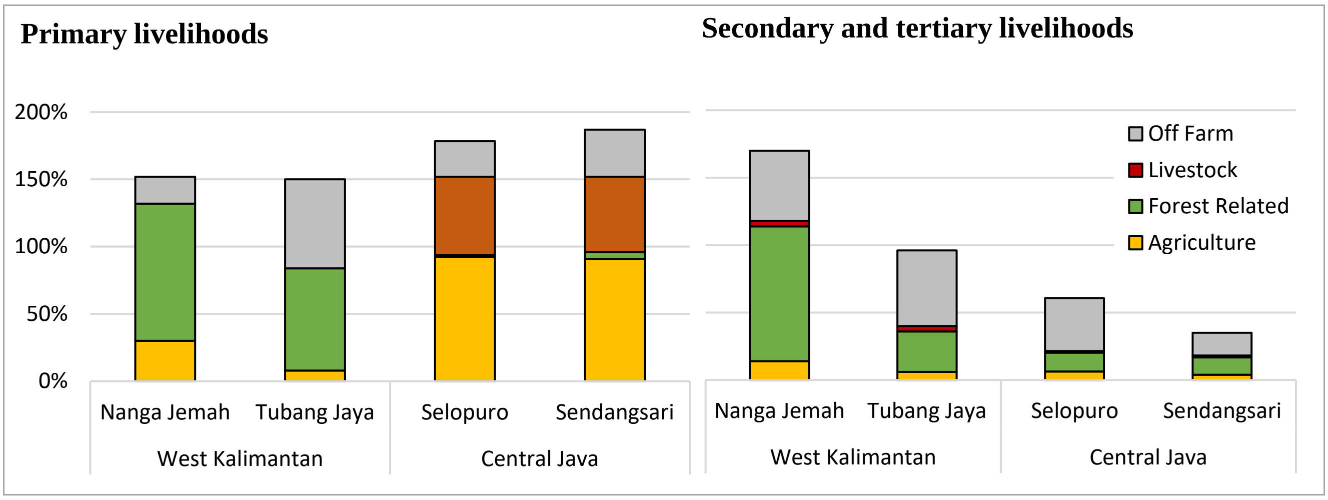

Fig. 2.3. Diversification of livelihoods in the study sites in West Kalimantan and Central Java according to the percentage of people involved (values more than 100% because of multiple activities). (Source: data from household survey (Nanga Jemah and Tubang Jaya N = 50; Selopuro N = 79; Sendangsari N= 77). Note: For more details on the activities included in each livelihood category see Table 2.2.

Although the people interviewed were generally not able to elaborate on the reasons why disasters were happening, around one quarter of the affected households (and in Tubang Jaya more than half) linked the occurrence of disasters with environmental conditions, in particular environmental degradation. In all study sites, trees and forests were highly valued for decreasing the impact of extreme weather events; they were considered 'very important' or 'important' in helping to prevent severe drought and floods. There was a gradual increase in the recognition of these benefits as vegetation cover decreased (from 41% in Nanga Jemah, 55% in Tubang Jaya, 75% in Selopuro to 82% in Sendangsari).

Villagers in all locations also associated water issues with environmental conditions. For example, in Central Java, villagers recalled that water sources started to decrease 15 years ago when semi-natural forests were replaced with a pine monoculture plantation. Villagers' satisfaction with water-related regulating services such as water quality and soil conservation, followed similar trends as forest cover (see Fig. 2.4). They perceived water quality corresponded with changes in forest cover. In one case, the village with the least forest in West Kalimantan, said the increase in their water quality was not related to a change in forest cover, but to the construction of water wells supported by the government. In Central Java water availability increased due to a similar program. This highlights the need to consider technological innovation when assessing sensitivity to climate variability.

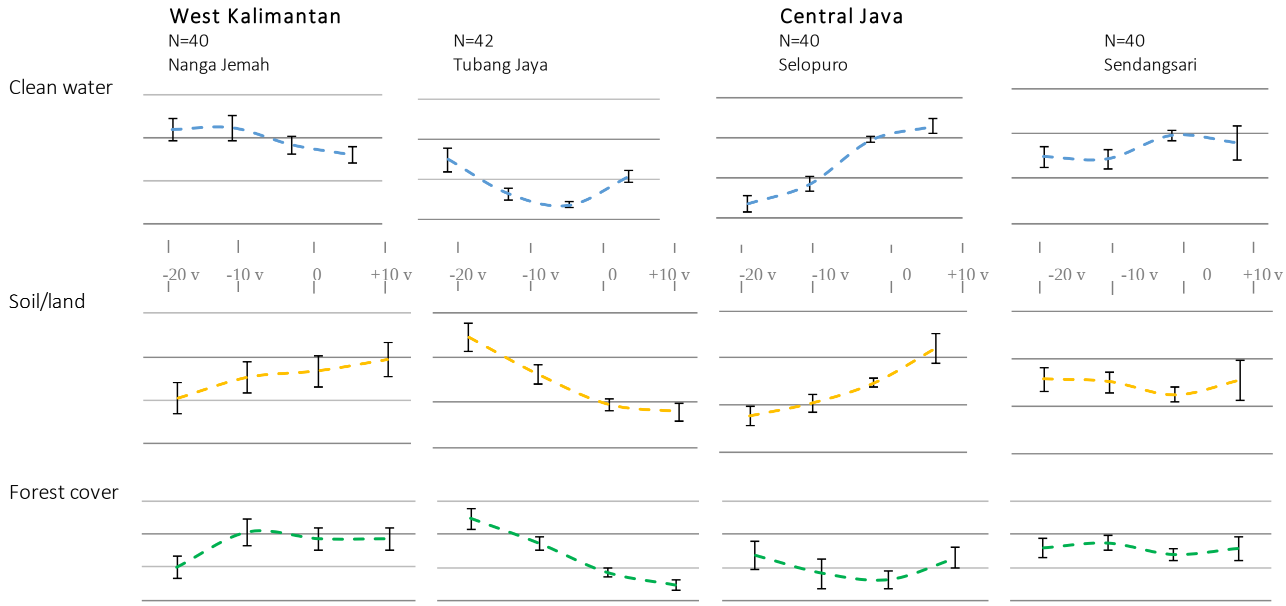

Fig. 2.4. Local perceptions of water and soil quality, and changes in forest conditions over time from 20 years ago to 10 years in the future. (Source: Focus group discussions where participants scored their satisfaction with the condition of water, soil and forests on a scale (Y axis) from "very satisfied" (5) to "very unsatisfied" (1)).

While community dependence on environmental factors can increase their sensitivity to climatic variability, forests and trees offer several opportunities to reduce the associated risks. Communities plan according to landscape characteristics to reduce the risk of being severely affected by disasters. For example, the risks of floods were considered in the selection of new locations for housing as well as for productive activities, when opening forests for rubber plantations, agriculture, or building new fish ponds. Similar concerns were taken into account when building new houses or making renovations. People decided on the locations and the height of the house poles based on their experience of the highest water level previously reached and predictions. In both sites in West Kalimantan, entire hamlets relocated to safer places further away from the river to avoid flooding. In the last 20 years Tubang Jaya moved four times and Nanga Jemah once. In Central Java some agricultural fields were abandoned or converted to other land use to avoid wildlife (monkeys and boars) damage to crops and low productivity, and also because of forest expansion and reduced human capital (aging population and migration). This was mostly dry land near forest margins that were cultivated once, or occasionally twice, a year with red rice (an early maturing species that is more drought resistant), corn, soybeans, cassava, and trees on the edges.

People in all study locations used trees in order to protect or restore watershed services and reduce potential future impacts. Slopes were stabilized against erosion by planting trees on the hills surrounding the villages and by building terraces with the help of government programs in Central Java (1973-75). In West Kalimantan, to reduce riverbank erosion, villagers planted and maintained durian and other trees, coconut and palms, along the river. Formal and informal regulations were also established at the village level to ban logging and maintain trees in strategic locations such as hilltops or along rivers.

In Central Java in the late 70s, a farmer planted teak on his land with such success that the practice spread. The farmer explained that he started because of the better opportunities for this type of land. Trees required less attention compared to crops especially in such dry areas. Trees also offered more flexibility since they can be used whenever needed, and are more profitable in the market. In Selopuro, there is now an organized group with official representatives in each sub-village, and together they have agreed on regulations governing the management of trees in their area. Currently, all hamlets have planted teak, mahogany, and white albizia in their gardens. Not only have these trees provided alternative incomes, but they have also helped bring water to the surface. Households in the surroundings now no longer experience as severe shortages of clean water during dry seasons as before. According to some farmers, they were also able to extend the planting season and share the water among multiple users.

2.3.3 Adaptive strategies in response to climate variability

Households in the study villages have been experiencing the impacts of climate variability and have been devising a variety of strategies to respond (Table 2.3). For response strategies, we do not distinguish between villages with different levels of tree and forest cover as the difference in households' numbers was only a maximum of ±7%. On average the main climatic event in each village resulted in around four strategies adopted per household (± 0.1) for responses to floods in West Kalimantan and drought in Central Java, while for secondary events (i.e. drought in West Kalimantan and plant diseases in Central Java), there were 1.8 strategies adopted per household (± 0.1 depending on the village). Nanga Jemah had a slightly lower average than the others (1.3 strategy/household). The strategies were categorized according to the livelihood capital the household used to overcome the difficulty (means), which should not be confused with sectors affected by climatic stress (target). We also considered the level at which they are implemented: actions that are taken at the individual or household level (spontaneously or autonomously) and those that were taken more collectively at the village level (often government/policy supported practices).

Table 2.3. Summary of household response strategies to drought and floods in the study sites in West Kalimantan and Central Java. The numbers indicate the percentage of the total activities adopted and are only those used by more than 5% of households.

Capital	Response strategies to climate variability				
		West Kalimantan (Flood N = 367; drought N = 160)		Central Java (Flood N = 9; drought N = 620)	
Natural	**Drought**	9% 5%	- Water seeds and crops - store clean water or find alternative sources (e.g. river) for household consumption	20% 16% 6% 15%	- Pump or drain groundwater for agriculture - diversification of crop and species - selling yields, livestock, timber - substitute livestock fodder for leaves - expand crops in areas near water - plant trees and use fuel wood
	Flood		- Relocate house/crops to higher places - plant trees to avoid landslide - store clean water - change seed variety; - harvest forest products (timber, NTFPs)		- Plant trees to avoid erosion
Physical	**Drought**	20% 7%	- Fertilize rubber trees - use pesticides and fertilizer on crops	7%	- Stem river or build water channels - dig a well or pipe water to the house - use irrigation system for crops
	Flood	12% 12% 6%	- Moving assets to higher place - install net in fish pond - change equipment in rubber collection or in wood transportation - elevate house		
Social	**Drought**				- Clean water assistance from government - consult government agricultural experts
	Flood		- Temproary shelter with family/neighbors - provide help in cleaning/recovery		
Financial	**Drought**		- Save money in preparation		- Buy drinking water and rice - buy gasoline for waterpump - borrow money from social groups or neighbors
	Flood				
Human	**Drought**	9% 4% 24%	- Stop activities (e.g. mining, logging) - change transportation arrangements - change rubber harvest timing	6%	- Stop or reduce farming - manage food supply and change diet - find new job opportunities (migration) - change timing of planting and harvesting
	Flood	8% 5%	- Preventive collection and storage - collect lost items - stop activties (gold mining, rubber, logging) - monitor river flow - maintain house and clean environment		- Change harvest timing - cleaning the field - planting management

In West Kalimantan, during or after floods, local communities focused on the recovery of their main livelihoods and immediate needs (around 60% of the strategies were for short term benefits). Most of their actions used physical capital or existing infrastructure to protect valuable goods, for example to secure the harvested rubber (19%), move household assets into roof spaces or rafters (12%), or protect fishponds with nets (12%). In addition, few households discontinued the harvesting of rubber, cutting trees and gold mining (< 5%). In case of drought, half of the people adopted strategies related to rubber harvesting (fertilizing, reducing tapping, and changing equipment).

In Central Java in times of drought, 70% of the strategies reported in the household surveys were for short-term benefits in response to the consequences of drought. Local people used natural capital to address issues related to water harvesting and management (20%), substituted livestock fodder for leaves (15%), and sold timber or fuel wood (6%). Around 6% of the participants adopted more long-term strategies of species diversification, and changed from paddy to other cash crops (locally known as *palawija*) or seed varieties of paddy and soybean. In addition, 6% of the local people avoided possible loss or damage due to a lack of water by stopping or reducing the number of species and/or the amount planted during the driest months, mostly soybeans and peanuts.

Although several response strategies to floods and drought were employed, trees and forests represented only 2-6% of the total interventions used. People in places with less forest cover used more of their natural capital and trees in response to climate-related events (see Fig. 2.5).

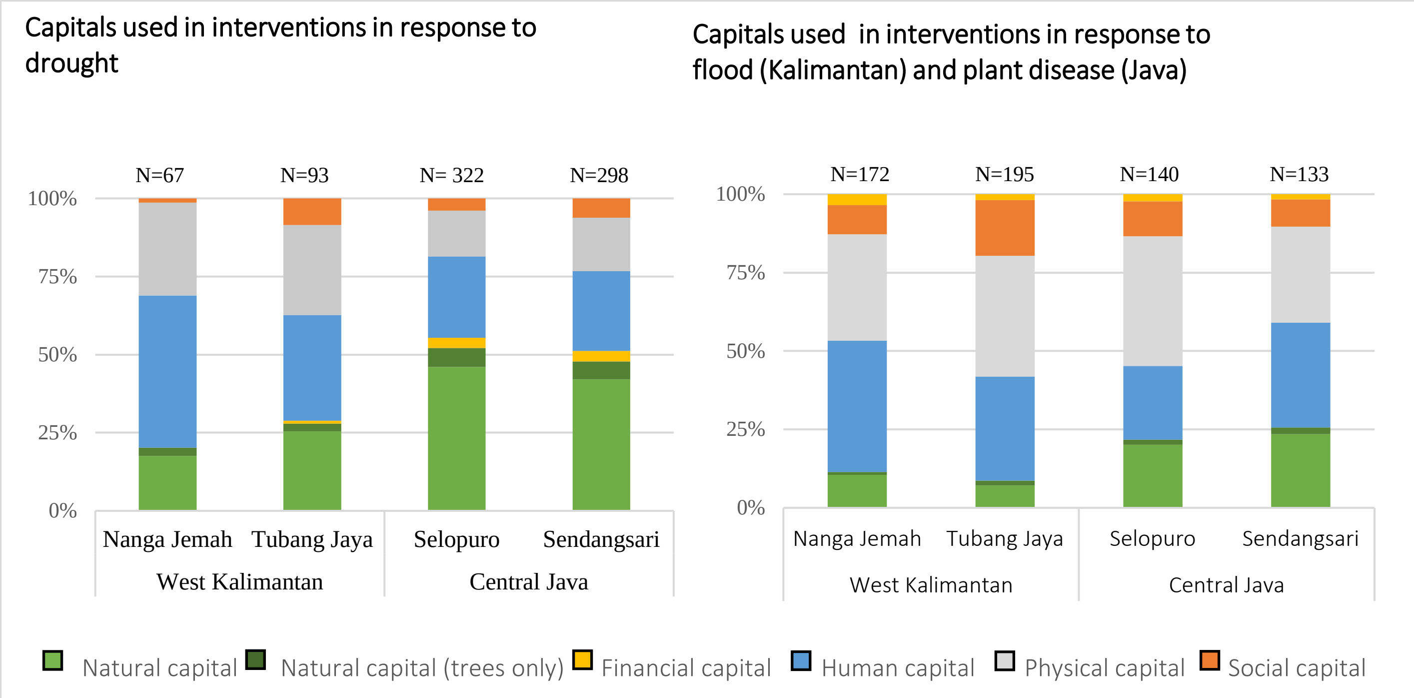

Fig. 2.5 Capital used by households to respond to drought and floods or plant diseases in the study villages in West Kalimantan and Central Java. N indicates the total number of interventions undertaken by the households interviewed. (Source: household surveys).

Several collective actions that provide benefits for adaptation were found at the village or sub-village level, which typically involved shared means (people or land). Forests are ideal for collective actions as they are often held under communal or state tenure. Their resources are available due to free access or traditional regulations. In the four sites, a common response strategy was to extend agriculture or collection of natural resources wherever possible, especially in communal or more risky areas (insecure use rights or exposed to extreme weather). For example, farmers started planting on riverbanks (Nanga Jemah, Tubang Jaya and Sendangsari), at the edge of water reservoirs as the level decreased (in Selopuro) or on hilltops (in villages in West Kalimantan). In Central Java, when certain resources become limited due to drought, people entered the perimeters of the Perum Perhutani to collect leaves, fuel wood, and grass, and to use water resources.

In the focus group discussions, the participants identified several local rules aimed at the sustainable use of forest resources and to maintain vegetation cover. For example, in the Central Java community forest, for each tree felled, 10 must be planted if space and conditions allow. In West Kalimantan, in Nanga Jemah no more than three trees may be felled at the same time, while in Tubang Jaya a village rule bans the felling of ‘primary’ forest for cultivation and prescribes the use of secondary regrowth instead. Government supported programs for raising awareness and technical advice have been implemented, such as preventive interventions (terraces, wells and water harvesting systems, and reforestation) and household assistance (seeds, rice, and water tanks).

2.4 Discussion

2.4.1 Using trees to reduce exposure and sensitivity

The four study sites in West Kalimantan and Central Java have all experienced intra-seasonal variations in precipitation. Vogel (2000) wrote that rainfall has been regarded as the most significant climate parameter affecting human activities. In Indonesia, agricultural production is strongly influenced by annual and inter-annual variations in precipitation, where the Austral-Asia monsoon and El Nino-Southern Oscillation (ENSO) dynamics play an important role (Naylor et al. 2007). Having regularly experienced drought, floods and disease outbreaks, the people interviewed were well aware of the climatic variability and associated risks. Other studies have found that farmers recognize subtle changes in climate (Maddison 2007, Bewket et al. 2013, Boissière et al. 2013, Kalinda 2014). Household experiences of recent climatic variability showed clear agreement with satellite estimations of anomalies.

Farmers decide when and what crop varieties to plant based on their prediction of precipitation trying to reduce the risk of crop failure by diversifying income opportunities. Fluctuations in precipitation and temperatures can quickly lead to shorter or more unpredictable periods during which the risks of losses increase dramatically. Because the study villages are predominantly dependent on rainfed agriculture or forest products for their livelihoods, which are highly prone to damage due to climate-related events, they can be defined to be climate-sensitive resource dependent (Adger 2006). In addition, some farmers decided to cultivate their land even in unfavorable conditions, often leading to low crop yields or harvest failure during the driest months. As a result, local communities are pursuing a range of livelihood activities to spread the risk associated with crop losses.

Livelihood diversification helps reducing vulnerability, unless several activities are affected by climate variability. Expanding livelihoods opportunities with less climate-sensitive activities mitigate climate-related risks by helping before (*ex-ante*) or to cope later (*ex-post*) (Godoy et al. 1998, Lanjouw 1999, Adger 2006). Both strategies eventually help families to smooth income fluctuations given the seasonality of agricultural production (Kant et al. 1996, Paavola 2008). Villages with more abundant vegetation had a larger range of income opportunities. However, even though forests and trees contribute to broadening adaptation options, they can be themselves affected by climatic events (i.e. prevent access to forest resources or impairing the delivery of ecosystem services), putting people who rely heavily on forest resources more at risk. For example, some of the new livelihoods, such as harvesting rubber, raising livestock or fish, gold mining or farm labor, also remain sensitive to climate variability. Therefore, promoting diversified livelihoods should focus on alternatives that are less climate dependent, especially in areas where people's activities are based on natural resources, which although diversified could still be sensitive to climate variability.

All households affected by climatic events implicitly or explicitly recognized the importance of natural capital, including forests and trees, in regulating the intensity of natural disturbances. This is central to adaptation as it enables communities to actively use their natural capital. They can then take advantage of the services delivered by ecosystems and their physical protection together with geographic features in reducing climate-related risks. Past experience and future projections were part of the rationale in the selection of locations for productive activities or housing settlements. This is particularly valid for West Kalimantan, probably due to the nature of the main disaster (flood), but also due to the fewer constraints in land availability compared to Central Java. Land availability and financial resources are, however, the main reasons for delaying or not taking action. In these cases, such activities were simply discontinued. Other studies on perceptions of climate variability point out that farmers are more likely to adapt if they can perceive the changes in the climate (Maddison 2007, Simelton et al. 2013).

High awareness on the linkages between the effects of climate variability and environment conditions helped communities not only to locate their property and economic activities in less risky places, but also allowed them to actively reduce future impacts through landscape interventions. Exploiting spatial diversity in the landscape to improve livelihood outcomes has been seen as a possible strategy that people can use to spread the risks associated with climate variability (Eakin 2000). In fact, several communities tried to maintain or enhance land characteristics of interest in strategic places, such as trees on hilltops or along rivers to prevent erosion and regulate water run-off, when considering climate-related risks. These interventions were mostly collective and often involved formal or informal regulations. Interestingly, in places with less forested areas, people's strategies to respond to climate-related risks were more based on planting trees or harvesting tree parts. This makes ecosystem restoration and reforestation plans that are already recognized and accepted locally viable options. In these cases, supporting existing collective efforts and organizations would help communities reach a scale that provides visible benefits and ensures continuity.

People took action to protect, increase or manage trees with particular attention to the positive benefits of maintaining and regulating water availability, as shown by the household survey. This is the case for new teak plantation in Central Java where most environments are already degraded, as well as in more pristine forests of West Kalimantan, where existing tree cover is kept in specific areas. Villagers' considerations are in line with studies that recognize the important role of forested landscapes in regulating watershed processes (Pattanayak et al. 1999). On the other hand, findings from Bosch and Hewlett (1982) highlighted that the afforestation of former grassland with pine not only reduces annual stream flow but also reduces the dry season flow, which can decrease water availability for agricultural purposes. Vincent et al. (1995) estimated that an increase in coniferous species could proportionally reduce annual water yields. Furthermore, deciduous tree species (e.g. teak in our study site) were found to typically generate less evapotranspiration than evergreen and thus help diminishing negative effects on the water balance (Wattenbach et al. 2007, Ellison et al. 2012). The findings highlight the importance of selecting appropriate species and locations when planning changes in tree cover over large areas, as well as the role that local experiences related to land management can play in informing such initiatives. In this way, it is possible to provide additional adaptation benefits while minimizing unwanted side-effects in surrounding areas.

2.4.2 Using trees to strengthen response strategies and adaptive capacities

Few families adopted strategies based on the use of forests and trees to respond to climatic shocks, as shown by the household surveys. However, several response strategies targeting forest related activities are used where livelihoods depend on them as shown in West Kalimantan. These strategies mostly involve changes in land management practices. In Central Java, local people use tree leaves as fodder and sell timber, but more as a last resort after having sold other assets such as livestock. The limited use of forest products is in partial contrast with the forest safety nets or their natural insurance role that has been observed elsewhere (floods in East Kalimantan, Indonesia: Liswanti et al. 2011; floods and diseases in Peru: Takasaki et al. 2004; floods and drought in Malawi: Fisher et al. 2010; storms, flooding and plant and animal diseases in Vietnam: Völker and Waibel 2010). At the same time, however, in other places an increase in the use of forest products, because of climatic events, was not observed (floods and drought in Papua, Indonesia: Boissière et al. 2013; environmental shocks around the world: Wunder et al. 2014; hurricane in Honduras: McSweeney 2004).

Provisioning services of forests are often used in reactive (*ex-post*) strategies, whereas anticipatory (*ex-ante*) strategies rely more on regulating services. We argue that the importance of trees and forests for reducing human vulnerability can be described more clearly by specifying the type of ecosystem service provided in relation to the particular phase of the climatic hazard, whether before or after the impacts of the climatic events materialize (i.e. phases of disaster risk management). People in the study villages valued regulating services from forested ecosystems for their function in preventing or reducing possible impact caused by climatic hazards, especially for their role in regulating water and soil processes. The provisioning services of forests were mostly used in reactive strategies after the occurrence of a climatic hazard. People harvested trees' parts to substitute sources of income or food (e.g. they sold timber or firewood, or used leaves as fodder for animals). In addition, distinguishing the type of ecosystem services and people's response strategies would help ensure that the full potential of forested ecosystems is accounted for when comparing and selecting the most cost-effective options to reduce climate-related vulnerabilities.

There could be some methodological caveats that underestimate the role of forests. People who live near forests, and utilize them regularly, might not consider unusual to undertake additional forest activities in relation to a climatic event and thus such activities may go unreported. Another explanation could be that regulating services of ecosystems were not specifically taken into account in previous research or the focus was on reactive strategies. Furthermore, several forest products require time to harvest and process before being used. Their harvest access can also be interrupted due to the climatic event, and therefore less suited in case of urgent need. Their benefits might also be evident later on. Moreover, it remains challenging for researchers and communities alike to clearly identify and quantify these benefits. This is probably related to the intrinsic differences in the services; regulating services are more abstract and easier to demonstrate qualitatively, do not immediately display changes in use, and provide collective benefits, but do not require direct access in order for people to benefit. On the contrary, provisioning services are more tangible, easier to measure quantitatively, stocks are depleted by use, and usually specific individuals who control the resources gain the benefits.

2.5 Conclusion

This chapter revealed that smallholders in the four communities in Indonesia living in areas with different vegetation covers and changes are actively engaging in several strategies related to the use of forests and trees to respond to the adverse impacts of climate variability such as drought, floods and disease outbreaks. However, these strategies constitute a limited contribution to overall vulnerability reduction when considered alongside the variety of measures taken by the study communities. Most of the people responded to the climatic hazards adopting technological solutions (e.g. pumping water, developing irrigation systems and protective systems, and changing to more modern equipment), increasing the use of agricultural inputs (fertilizers, pesticides, and seeds varieties), adjusting agricultural management practices and crop species rotation, and seeking external help through social networks or government agencies. The role of forests and trees is particularly important as part of community *ex-ante* strategies to better prepare for and reduce potential damages (i.e. decrease exposure and sensitivity). However, the role as a coping and recovery mechanism is more limited and few people rely on forests and trees during or immediately after hardship situations by using forest products (e.g. selling timber or NTFPs).

Local communities living in areas with fewer trees, which tend to have a more degraded environment and be closer to the ecosystem thresholds for sustaining ecological functions, have experienced more changes and seem to value more and be more involved in managing the remaining vegetation. In these areas, in order to still be able to benefit from ecosystem services, especially those related to water regulation and provision and soil stabilization, people have to actively influence their natural capital. On the other hand, in areas with more preserved forests people can benefit more passively without having to develop particular actions that affect them. In addition, in villages with more forests, livelihoods are more diversified, suggesting that they have more available alternatives to replace a temporary loss of income due to climatic events. Nevertheless, several natural resource dependent activities are also highly sensitive to climatic variability making them a double-edged sword. Therefore, in areas where people’s activities depend on natural resources, efforts to promote livelihood diversification should focus on alternatives that are less climate-sensitive in order to mitigate climate-related risks.

In future research or development interventions, it is crucial to understand the complex linkages between forest cover and human vulnerability by considering the whole local context and temporal dimension. There is a need to explicitly distinguish the support of forests according to the timing, *ex-post* vs. *ex-ante* adaptation respectively, and the nature of the service, regulating vs. provisioning services. This would help take into account the full benefits provided by forested ecosystems, in particular for reducing and mitigating climate-related risks through water regulation and provision, and soil stabilization. The role of ecosystems regulating services is not always fully taken into account or could be easily underestimated when comparing possible adaptation interventions. Nonetheless, it is an essential part of the safety net function of forests. In addition, other factors greatly influence community vulnerability, such as alternatives related to other capitals including technological development, the awareness and experience with the event, the ecosystems' conditions, in particular threshold effects of tree cover degradation on ecosystem services. Furthermore, people's lives are impacted by multiple and interconnected disturbances that can be slow or sudden in nature, such as subtle shifts in climate or extreme weather events. However, focusing on the effects of and common solutions to climate variability (such as ecosystems management) rather than the differences in time-frame of their occurrence (long/short or sudden/gradual impacts) would help the development of comprehensive strategies to reduce people's vulnerability and increase their resilience that span across sectors and disciplines (e.g. disaster risk reduction and climate change adaptation).

Community awareness regarding climate variability and environmental degradation is crucial. If these linkages are recognized, it encourages people to actively manage their environment and natural resources, which could be an entry point for ecosystem-based interventions. Furthermore, for adaptation it would help to identify priority spots where there is a strong demand from local users for ecosystem services that can support the reduction of climate-related risks. Favorable spatial land characteristics that influence ecosystem services relevant for strengthening people's adaptation, especially regarding the regulation of water and soil processes, should be identified and carefully evaluated, and future changes planned together with local communities. These are prerequisites that make ecosystem services a valuable option for an integrated strategy to reduce disaster risk and climate-related vulnerabilities that suit existing community contexts and needs and thus are more likely to be successful.

2.5.1 Acknowledgement

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Chapter 3

Reducing risks by transforming landscapes: cross-scale effects of land-use changes on ecosystem services

Local farmers in West Kalimantan practice shifting cultivations. Deforestation on hilltops and along rivers is not permitted by recent village rules (picture by Serge Rafanoramana).

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Reducing risks by transforming landscapes: cross-scale effects of land-use changes on ecosystem services

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Abstract

Globally, anthropogenic environmental change is exacerbating the already vulnerable conditions of many people and ecosystems. In order to obtain food, water, raw materials and shelter, rural people modify forests and other ecosystems, affecting the supply of ecosystem services that contribute to livelihoods and well-being. Despite widespread awareness of the nature and extent of multiple impacts of land-use changes, there remains limited understanding of how these impacts affect trade-offs among ecosystem services and their beneficiaries across spatial scales. We assessed how rural communities in two forested landscapes in Indonesia have changed land uses over the last 20 years to adapt their livelihoods that were at risk from multiple hazards. We estimated the impact of these adaptation strategies on the supply of ecosystem services by comparing different benefits provided to people from these land uses (products, water, carbon, and biodiversity), using forest inventories, remote sensing, and interviews. Local people converted forests to rubber plantations, reforested less productive croplands, protected forests on hillsides, and planted trees in gardens. Our results show that land-use decisions were propagated at the landscape scale due to reinforcing loops, whereby local actors perceived that such decisions contributed positively to livelihoods by reducing risks and generating co-benefits. When land-use changes become sufficiently widespread, they affect the supply of multiple ecosystem services, with impacts beyond the local scale. Thus, adaptation implemented at the local-scale may not address development and climate adaptation challenges at regional or national scale (e.g. as part of UN Sustainable Development Goals or actions taken under the UNFCCC Paris Agreement). A better understanding of the context and impacts of local ecosystem-based adaptation is fundamental to the scaling up of land management policies and practices designed to reduce risks and improve well-being for people at different scales.

Key words: climate change, adaptation, ecosystem services, forest management, landscape, land-use changes, social-ecological systems, transformation, cross-scale interactions

3.1 Introduction

Many societies around the world are facing major environmental challenges that are increasingly complex, uncertain, and interconnected (Steffen et al. 2015). Global drivers of change such as climate change, human population growth, resource use and environmental degradation, urbanization, and economic globalization are exacerbating the vulnerability of people in already fragile contexts. In order to respond to these challenges, people have developed adaptation strategies to reduce risks to livelihoods and maintain well-being. These adaptation strategies can be anticipatory or reactive and include building infrastructure (e.g. for water storage and flood protection), changing social-economic behaviors (e.g. reducing consumption, selling assets and borrowing money), or using natural resources (e.g. improving crop varieties, harvesting forest products and protecting coastal mangroves).

Nature provide benefits to people from ecosystem services, including the mitigation of impacts of natural hazards and strengthening social capacity to respond to environmental change (Millenium Ecosystem Assessement 2005, Lavorel et al. 2015). Provisioning services from forests and agroecosystems provide food, energy, water and construction material that help many rural communities around the world to diversify livelihoods and distribute risks (Angelsen et al. 2014). In addition, regulating services, including soil fertility and micro-climate regulation, support agriculture and buffer natural hazards (Sudmeier-Rieux et al. 2006). Forested ecosystems also regulate ecological processes such as water flows and carbon sequestration, with well-being benefits to people who live beyond the location of the forests (Pramova et al. 2012). Some studies, building on land multifunctionality and sustainable management, suggest integrated approaches to adaptation, for example, climate-smart agriculture for food systems (Harvey et al. 2014b), sustainable forest management (FAO 2015), landscape approaches to land-use planning (Scherr et al. 2012, Sayer et al. 2013), and nature-based solutions in environmental policies (European Union 2015).

Ecosystems can help people achieve multiple development objectives simultaneously, including adaptation to climate change and other hazards, but the contribution ecosystems can make depends on how lands are managed and benefits are shared (Bennett et al. 2009b). Land uses are defined as the sum of management arrangements, activities, and inputs that people undertake in a certain land cover type (FAO and UNEP 1999). Land uses shape ecosystem characteristics and the bundles of ecosystem services as well as any trade-offs between services over space and time (Rodríguez et al. 2006, Daw et al. 2011a). Land-use changes often enhance the supply of one or more ecosystem services of interest at the expense of others, for example, the increase of food production may degrade regulating services (Foley 2005, Rodríguez et al. 2006). In addition, a land-use change that is adaptive for some individuals or groups may have unintended off-site effects for others at different scales (Adger et al. 2005). Therefore, as trade-offs create winners and losers in how people benefit from ecosystems, so land-use changes may reduce livelihood risks for some stakeholders (especially those deciding on land-use changes) but increase risks for others, locally or further afield (Reyers et al. 2013a, Harvey et al. 2014b, Locatelli et al. 2015).

Despite the importance of trade-offs and off-site effects in relation to making ecosystem service assessments useful and operational (Tallis and Polasky 2009, de Groot et al. 2010), there has been limited research on how land-use changes lead to trade-offs between ecosystem services (reviewed in (Seppelt et al. 2011)), particularly across spatial scales and beneficiaries (Myers and Patz 2009, Robards et al. 2011). Another challenge is to better understand the processes that change dominant social-ecological structures, e.g. societal learning feedback loops that can transform institutions or practices related to the management of agricultural and forest ecosystems (Rickards and Howden 2012, Chung Tiam Fook 2017). In this study, we analyze how rural communities in two tropical forested landscapes in Indonesia have changed land uses to maintain their livelihoods and adapt to several environmental, economic, and social risks. We describe the impacts of major land-use changes on the supply of ecosystem services, with consequences for well-being at local (provision of products), regional (water regulation), and global scales (carbon sequestration), as well as across multiple scales (biodiversity, which supports all ecosystem services). We discuss how local land-use changes are reinforced and spread at the landscape scale and how local land-use changes can trigger larger-scale transformations to more resilient development pathways.

3.2 Methods

3.2.1 Analytical framework

In order to understand how land-use changes affect interactions within social-ecological systems, we used a modification of the ecosystem services cascade of Haines-Young and Potschin (Haines-Young and Potschin 2010). This framework details steps in the flow of services from ecosystems to societies: each is step mediated by decisions that determine the flow of services and benefits (Spangenberg et al. 2014c). In our analytical framework, drivers of change affect the state of ecosystems and social systems, which in turn alter land management and the supply of ecosystem services (Fig 3.1). For example, frequent wildfire (as a driver of change) might convert savannah woodland to grassland (as an impact on the state of the ecosystem) and local people might decide to leave (as an impact on the social system). To reduce impacts, people can adapt by adjusting land uses (e.g. abandon agricultural fields, plant fire-tolerant trees, introduce grazing and prescribed burning), building infrastructure (e.g. create firebreaks, establish early warning systems, install new water pumps), or changing social-economic behaviors (e.g. increase awareness, organize fire-fighting groups, subscribe to insurance).

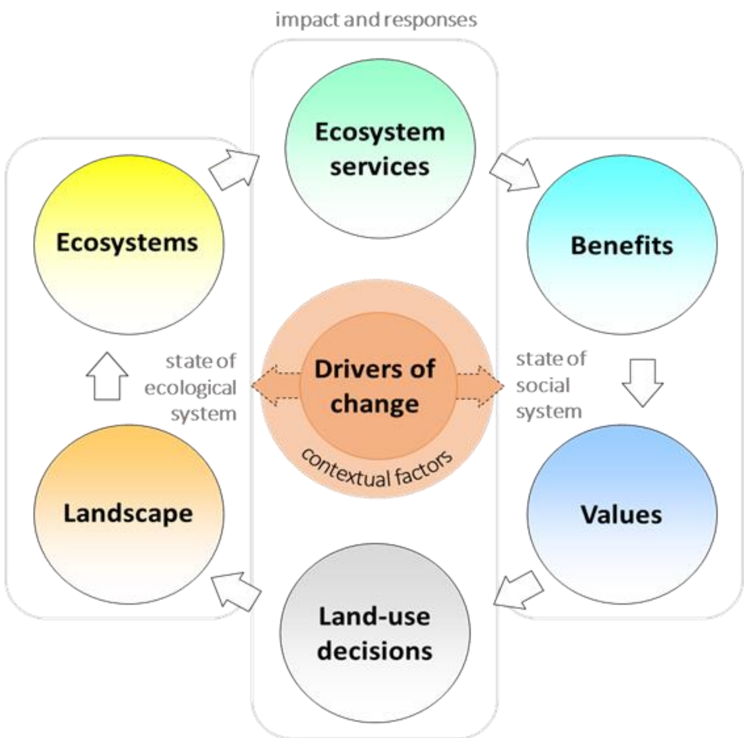

Fig 3.1. The modified ecosystem services cascade framework. Drivers of change affect the state of social and ecological systems. Changes in landscape properties or societal values influence land-use decisions and the supply of ecosystem services. A change at one point in the system triggers further changes because of the reinforcing loop of ecosystem services flows, whereby benefits derived from particular land uses lead to more changes by local people to those land-uses to ensure supply of more services.

The framework highlights how land-use decisions by local actors can spread through reinforcing loops via the ecosystem service flow (circular arrows in Fig 3.1), which connects societal demand for ecosystem services with their supply by ecosystems. When people value socio-cultural, ecological, or economic benefits from certain land uses, they are more likely to make decisions that favor such land uses. Once implemented, these land-use decisions increase the supply of ecosystem services, which in turn increase benefits and the appreciation of the value of ecosystem services by beneficiaries who push for replication and spread of the land-use decisions that result in the supply of those services. Therefore, a reinforcing loop is created that sustains the direction of change and contributes to spreading the land use to new places and people by scaling out and up. In this way, a local change can become widespread in a landscape or region and have impacts for people far beyond the local scale. Reinforcing loops are not the only influences on the spread of land-use decisions; contextual factors include rights of access and use, livelihood priorities, and peoples' capacities that control the human inputs necessary to co-produce ecosystem services (Horcea-Milcu et al. 2015).

3.2.2 Study sites

Indonesia is particularly affected by natural hazards (EM-DAT 2017): it is in a region of archipelagos characterized by tropical storms and volcanic activity and a large number of its people depend on natural resources-based livelihoods, such as farming, forestry, and fisheries, that are sensitive to natural hazards. Although Indonesia is rich in tropical forests, extensive areas have been lost in recent decades (FAO 2015).

We selected the provinces of West Kalimantan and Central Java because of the diversity of forest cover and of drivers of change and development. Most areas of these provinces face medium to high risk of natural hazards, according to the Indonesian National Board for Disaster Management (BNPB - National Agency for Disaster Management 2012). In each province, we selected two study sites in landscapes with varying forest cover (Fig 3.2). The sites in West Kalimantan were dominated by relatively abundant "natural" dipterocarp forests with some rubber plantations, whereas in Central Java the sites were strongly influenced by human activities, consisting of mixed cropping (rice, soya, maize) and secondary forests (mostly plantation teak and pine).

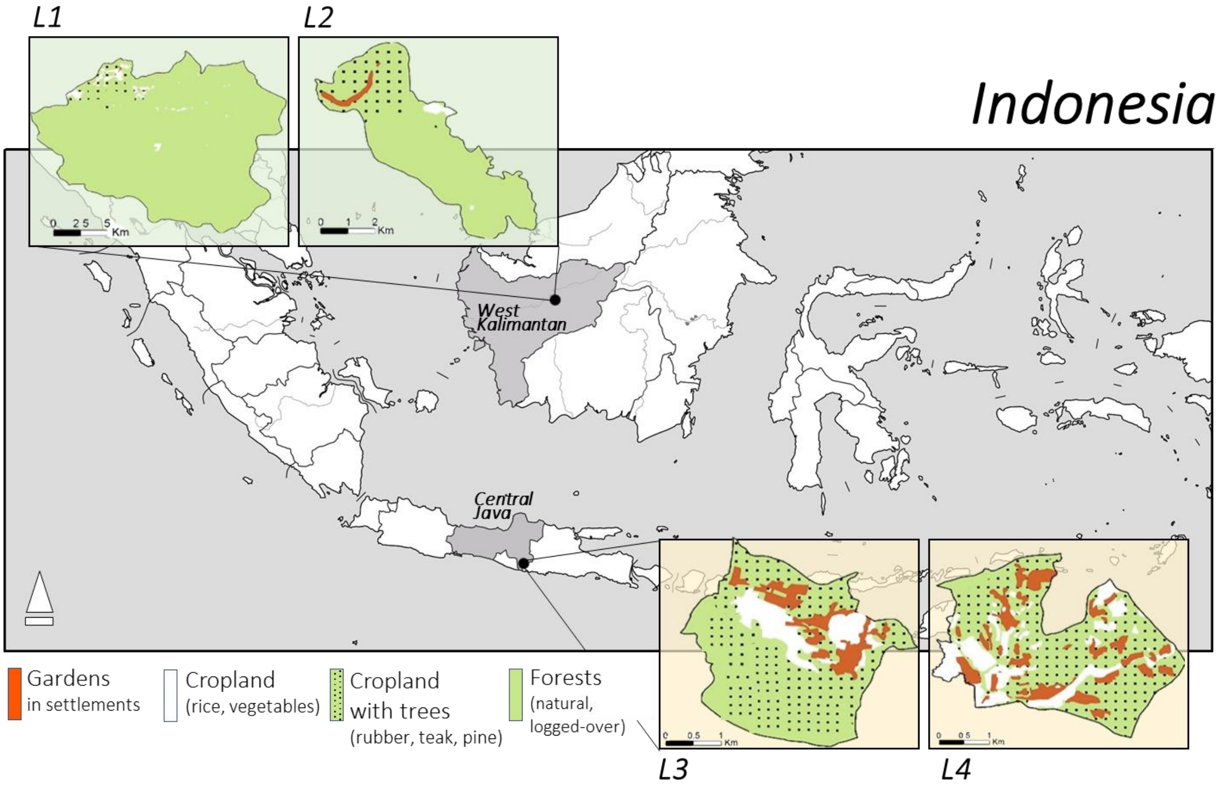

Fig 3.2. Map of the study sites. Land cover in the studied landscapes (L) in the Indonesian provinces of West Kalimantan (L1, L2) and Central Java (L3, L4) in 2014.

3.2.3 Methodological approach

We used a transdisciplinary approach to identify how local people changed land uses to adapt their livelihoods to multiple risks, and to assess the impact of these changes on ecosystem services. In focus group discussions (20 in total), we identified the drivers of change that impacted peoples' lives and the responses to these changes since 1994. Among the adaptation strategies reported by communities, we selected those that led to changes in land uses applied by most people over a large part of the landscape.

We assessed the impact of land-use changes on multiple benefits provided by ecosystems in order to understand the effects on adaptation and well-being of people at different scales. Ecosystem services can support peoples' adaptations by reducing impacts of climate hazards or other risks and strengthening capacities to respond (Sudmeier-Rieux et al. 2006, Lavorel et al. 2015). In particular, provisioning services of forests and agroecosystems can help diversify local livelihoods and income sources (Wunder et al. 2014). Regulating services of water flow and purification buffer water quality and quantities with local and regional benefits (Pramova et al. 2012). In addition, global climate regulation through carbon sequestration, help avoid further climate change and represents a long-term strategy, lessening the need for adaptation (Maes et al. 2016). Finally, biodiversity underpins many ecosystem services with benefits from local to global scales (Pereira et al. 2005); thus increasing species diversity has positive effects for timber and water supply, pest control, and regulation of soil, water and climate (Balvanera et al. 2006, Harrison et al. 2014).

We used four indicators to assess selected ecosystem services and their evolution with land-use changes (Table 3.1): values of harvested products, peoples' satisfaction with clean water availability, amount of carbon stocked in aboveground biomass, and tree species richness. Data on these indicators were collected in structured interviews (160 people and key informants) and forest inventories (120 plots). We compared the indicators for current land uses (2014) with estimations of land uses before change (1994 or 2004), assessed using Landsat 7 ETM+ images for 1994, 2004, and 2014. The interpretation of satellite images was complemented by participatory mapping and ground-truthing. For estimating the amounts of biodiversity, carbon, and harvested products of past land uses, we used space-for-time substitution with analogue land uses currently found in the landscapes (Raudsepp-Hearne et al. 2010b). For clean water availability, we asked people directly about their perceptions.

Table 3.1. Overview of the indicators and methods used to assess land-use changes and their impact on ecosystem services.

Indicator	Unit	Description	Data source(s)
Land-use type	Qualitative and ha	Type and area of each land use in the village territory in 1994, 2004, and 2014.	Remote sensing (Landsat 7 ETM) Participatory mapping
Carbon	t C/ha	Mean aboveground carbon stocks per land-use type.	Tree inventories
Biodiversity	Number of species	Mean tree species richness per land-use type.	Tree inventories
Water	1 (low) - 5 (high)	Stated satisfaction (low–high) of local people with clean water availability (quantity and quality) for 1994, 2004, and 2014.	Key informant structured interviews
Products	USD/ha/y	Estimated economic value of harvested forest and agricultural products per land-use type (i.e. actual land use for cash or subsistence per year).	Key informant structured interviews Secondary literature

3.2.4 Focus group discussion: major land use changes

In focus group discussions, we identified why and how local people have adjusted land uses to respond to drivers of change since 1994. To guide discussions, we used rural appraisal techniques of participatory mapping, historical timelines, seasonal calendars, and problem-trees exercises (Dazé et al. 2009, Narayanasamy 2009). For each discussion (5 per village, 20 in total), we invited 12–15 participants representing different livelihoods (farmers, forest users, off-farm workers, and local authorities), genders, and locations within the study sites.

3.2.5 Interviews and secondary literature: clean water & products from the land

To assess clean water, due to lack of historical hydrological data, we asked 40 local adults per village to score their satisfaction with current and past availability of clean water, i.e. quality and quantity for domestic and agricultural purposes. They scored water conditions on a 5-point scale (from very unsatisfied to very satisfied), for the current situation, 10 years ago, and 20 years ago (i.e. 2014, 2004, 1994). Scores were drawn on a graph and the trends discussed with the interviewees. Their explanations helped us check the reasons for changes in water conditions (e.g. land-use changes, technological improvements, climate variations). People assessed the water benefits at landscape scale rather than between land uses. However, land-use changes were widespread, so we assumed they influenced perceived trends in clean water availability.

To estimate the value of harvested products from each land use, we asked key informants about harvesting frequencies, quantities, and local market prices. Crop yields per hectare per year were taken from official provincial statistics (BPS 2017). For forest products, we used harvestable tree stocks per hectare from our forest inventories, checked against tree stocks and yearly livelihood incomes from forestry from other studies in the same villages, sub-district or district (Table S3). We then calculated average gross local monetary value of harvested products from each land-use type per hectare per year, including cash and cash-equivalents in the case of subsistence farming, i.e. actual use values without labor costs.

3.2.6 Forest inventories: aboveground carbon stocks and diversity of tree species

Carbon stocks in aboveground biomass and tree species richness were assessed using field inventories and their mean values were used for each land-use type. We inventoried 81 plots selected using stratified random sampling based on the land-use types previously identified by remote sensing and participatory mapping (Table S5). Sample size was defined depending on expected carbon stocks in each land-use type according to the formula suggested by Winrock International (Pearson et al. 2005), and was adjusted to have at least four plots per land-use type. In circular nested plots with an area of 400 m^2, we measured tree diameters (>2 cm) at breast height (DBH), estimated their height, and identified species with the help of parataxonomists and databases of previous studies in the region (Pearson et al. 2007).

Carbon stocks were calculated using the improved allometric equation for tropical trees (Chave et al. 2014). Dry wood specific density data were obtained from the ICRAF Wood Density Database (ICRAF 2016) according to the lowest level of botanical identification possible; otherwise, mean values were used. For crop land, we assumed an aboveground carbon stock of 2 t C/ha, with little likelihood of temporal change because of annual cropping and replanting (Hairiah et al. 2010).

3.3 Results

3.3.1 Drivers of change and response strategies

At all four study sites, livelihoods were mostly based on land-use activities. In West Kalimantan, most people harvested rubber, practiced traditional gold mining, and cultivated rice for subsistence. People cited extreme fluctuations in rainfall, leading to floods or drought as the most severe impact in the last 20 years (Table S1). These hazards disrupted river and road transport, preventing logging and mining, with floods damaging houses, and crops, and fish ponds. People in Central Java were mostly smallholders who cultivated rice and vegetables, and raised goats and cows. People identified wildlife grazing, drought, and pest outbreaks as major hazards, impacting livelihoods by reducing agricultural production (by up to half), clean water availability, and indirectly decreased farm labor and increased food prices.

People responded with a range of adaptations to maintain livelihoods. In West Kalimantan, they repaired flood-damaged houses, fields and fishponds or relocated them, harvested forest products such as fruit, birds, and deer, or borrowed money. In Central Java, people bought water and food, worked off-farm, temporarily migrated to cities for jobs, sold livestock or plantation timber, and changed diets (eating less rice, feeding animals with leaves). In both provinces, farmers changed crop varieties, reduced harvest times, and used fertilizers and pesticides. Other technical adaptations included building irrigation channels and wells, pumping or transporting water, stabilizing slopes with terracing (Central Java) or protecting vegetation (West Kalimantan).

3.3.2 Major land use changes

Local people reduced livelihood risks through land-use changes (Table 2, L1-4). In West Kalimantan, people converted forests to rubber plantations to diversify livelihoods and maintain their income in case of floods and droughts (Table 3.3, L1). The area of rubber plantations, and the number of people working them, have increased by around 40% in the last 20 years. Since the 1990s, farmers have expanded the traditional practice of shifting cultivation, whereby forests are cut and burned to grow upland rice. After a few years of rice cultivation, the lands is planted with rubber trees. Rubber plantations offer a flexible alternative to cultivation and a supplementary income source: productivity is less affected by drought than is cropping, trees can be tapped at any time and the harvested latex stored, allowing farmers to wait for good times to sell (prompted by urgent need or high prices).

Another change was the introduction of a new village rule to preserve forests in 2011 (Table 3.2, L2), which banned shifting cultivation in less degraded forests, mostly on hills (around 45% of the village territory). In these forests, people could harvest non-timber forest products (NTFPs) such as firewood, rattan, agarwood, and birds, or selectively log a few trees for local use, but not along rivers. The village chief explained that the rule was established to "*avoid that our next generations experience difficulties in finding natural and forest resources and face intense floods and hot weather*".

Table 3.2. Description of the major land-use changes (L1–4) that the local people undertook to adapt and maintain well-being under the impacts of drivers of change.

Study site	Landscape intervention	Land-use Changes and actors	Description of specific land management measures
L1	Forest conversion	Farmers convert logged-over forests to rubber plantations	clear-cut forests through slash and burn maintain or plant fruit trees (e.g. durian, rambutan) cultivate rain-fed rice (2–3 y) and plant rubber trees (~30 y) fertilize, remove competing vegetation, tap rubber
L2	Forest protection	Village leader introduces deforestation ban to protect forests	introduce rule to ban deforestation in less degraded forests harvest NTFPs and trees for local uses (selective logging) do not cut down big trees and fruit trees along rivers
L3	Agroforestry	Villagers plant trees in gardens (forest gardens)	plant teak in gardens coordinated by farmer association assist natural regeneration, thin and prune trees, fertilize follow rules for harvest (DBH>20 cm, age>20 y), replant (1:10)
L4	Reforestation	Farmers reforest less productive croplands	abandon less productive croplands on slopes plant or assist regeneration of teak and mahogany follow social norms to replant trees after cutting

In Central Java, a new land use involved planting trees on private lands near settlements which helped diversify farmers' livelihoods and income opportunities (Table 3.3, L3). In the late 1980s, a farmer started this agroforestry practice in his garden and some years later it was replicated by neighbors who created forest gardens (around 60% of gardens). The farmers formed an association to coordinate management practices and was later supported by an NGO. In 2004, the forest gardens of three hamlets became a certified community forest (they were given a sustainable natural resource management label). According to the head of the certified forests group: "*at the beginning we planted trees to complement income from crops, but later on we also realized the positive impact on water springs*".

Another widespread land-use change in Central Java was the abandonment of less productive croplands of rice, soya, and peanut (around 15% of all rain-fed cropland). Although some rice fields are close to the river and cultivated up to three times per year, most are on rain-fed terraced slopes. These less productive croplands were cultivated with rice only if enough rain was expected and were otherwise planted with other crops or left fallow. However, due to rainfall variability, harvest failures were frequent. Farmers reforested some less productive fields by allowing natural regeneration occur or planting teak and mahogany (Table 3.2, L4). This land-use change spread during the early 2000s, when farmers reported more frequent harvest losses because of foraging by monkeys and wild boars at the village margins.

Table 3.3. Objectives that triggered land-use changes, enabling factors and perceived effects.

Study site	Objective of land-use changes	Contextual factors enabling land-use changes	Perceived effects of land-use changes
L1	Increase income opportunities despite extreme weather	- good rubber prices - new settlement, bridge, road - government inputs for rubber (seedlings, techniques, fertilizers)	- more flexible and diversified livelihoods - less clean water in rivers (for fishing, drinking, washing) - more severe floods when heavy rain
L2	Maintain (scarce) natural resources for future local needs	- political change (new village and leader) - experiences with forest changes (logging, mining, shifting cultivation) - perceived increasing impact of climate variability (drought, floods, heat)	- more efficient use of degraded land - little improvement in clean water (but more expected)
L3	Diversify income opportunities	- coordination by farmer association - support from NGOs - experiences with water shortages - good teak demand and prices	- more flexible and diversified livelihoods - more water in dry season for cultivation
L4	Maintain (low) land productivity (droughts, wildlife, pests)	- low soil fertility (far from river, rocky, slopes) - lack of labor (migration and aging)	- fewer harvest losses from drought, pests, and wildlife than for crops - lower workload than for crops

3.3.3 Biodiversity

Logged-over or protected forests in West Kalimantan hosted similar tree species richness (mostly *Shorea* spp., *Syzygium* spp., and *Turpinia* spp.) (Fig 3.3, Table S2). A few rubber plantations (*Havea braziliensis*) were mixed with fruit trees, such as mango or durian, which led to an average of around 3 species in this land use. In Central Java, croplands and gardens had low tree species richness (0–3). Gardens, mostly planted with cassava, maize, and medicinal herbs, were sometimes mixed with coconut, banana, and bamboo trees. The tree species richness was higher (up to 5) in forest gardens and mostly included teak (*Tectona grandis*) or mahogany (*Swietenia macrophylla*). The same species were used to reforest less productive croplands in addition to some natural regeneration with shrubs and other trees such as *Acacia* spp. and *Pterocarpus* spp.

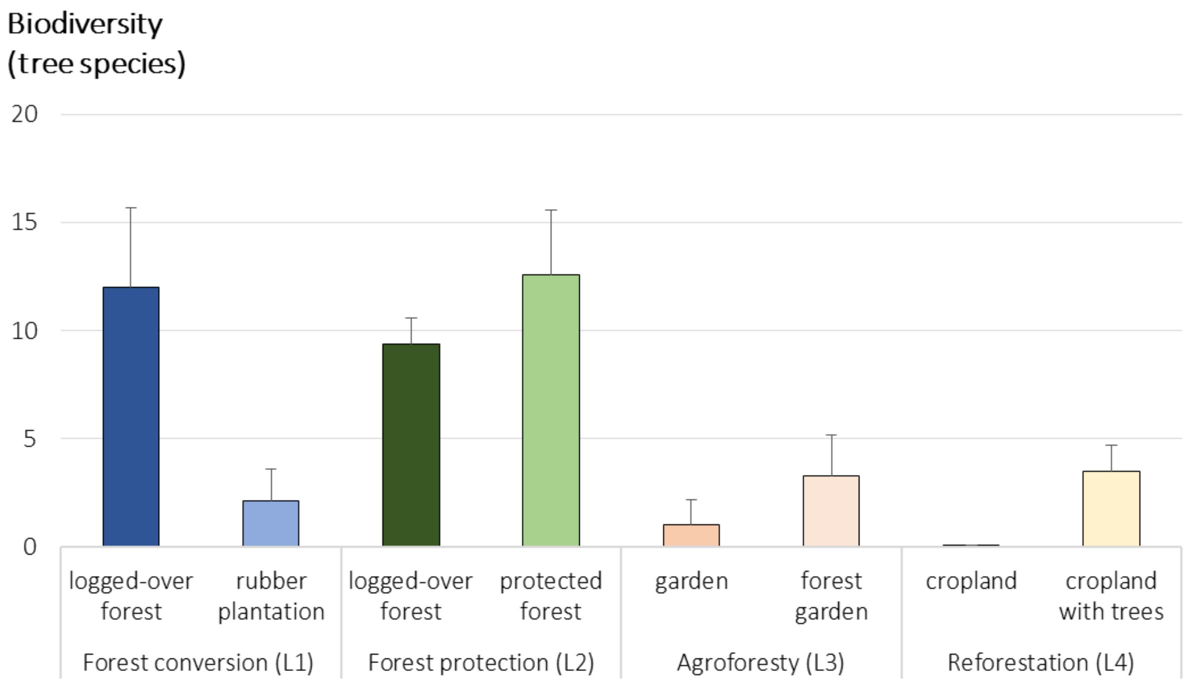

Fig 3.3. Mean number of tree species per land use (± SD) that were changed by local people as part of their adaptation strategies to hazards (L1–4).

3.3.4 Products from the land

In West Kalimantan, local livelihoods depended on several forest and tree products such as timber, rubber, and other NTFPs (e.g. agarwood, fruits, deer, birds). The main timber species harvested for building or trade was the Bornean ironwood (*Eusideroxylon zwageri*); however, it was becoming increasingly rare. People extracted timber for an estimated value of 180 USD/ha/y and collected NTFPs worth 30 USD/ha/y (Fig 3.4). Rubber plantations were the most profitable land use, whose latex collection was worth 375 USD/ha/y.

In Central Java, the highest income source was croplands planted with rice in irrigated fields near the river and harvested up to three times per year, or in rain-fed fields and harvested once a year (785 USD/ha/y). During the first planting season, farmers cultivated red rice (an early-maturing drought-resistant variety). When the least productive croplands were abandoned and trees planted, the harvested product value fell to 40 USD/ha/y. Food (vegetables and cassava) and medicinal plants in gardens were worth 80 USD/ha/y, and when mixed in with agroforestry in forest gardens, reached 110 USD/ha/y.

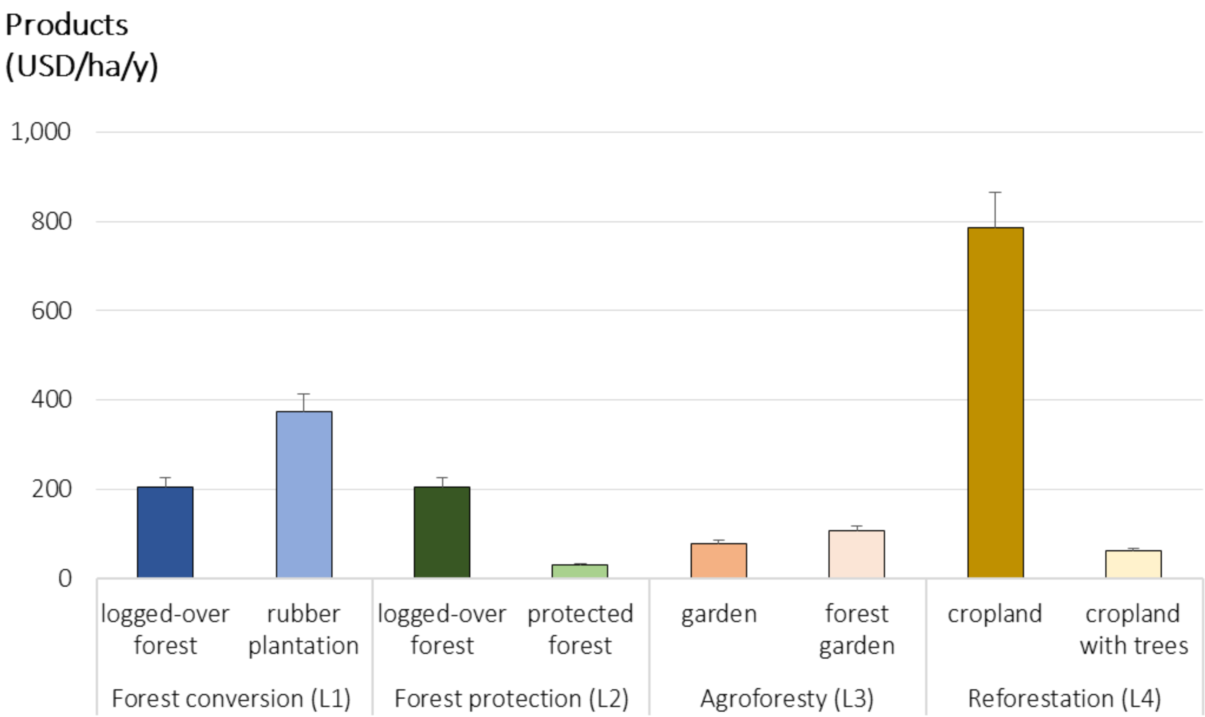

Fig 3.4. Mean values of harvested products from the land (USD/ha/y ± 10% uncertainties). Land uses that were changed by local people as part of their adaptation strategies to hazards (L1–4).

3.3.5 Clean water

The perception by local people of clean water availability evolved differently in the two regions over the last 20 years (Fig 3.5). In West Kalimantan, clean water availability decreased slightly at places where forests were converted into rubber plantations (L1) or protected (L2). However, the time elapsed since forest protection started at L2 may be too short to have noticeable effects on water. In Central Java, clean water perceptions have improved, during the last 20 years, when the number of trees increased in the landscape (L3–4). Several respondents connected these trends with recent changes in forests, such as the building of new wells or water channels (Table S4). For example, villagers in West Kalimantan reported that "*shifting cultivations and gold mining activities are decreasing the soil fertility and water quality*" (L1) or "*in the future the water might get better because of the new regulations that prevent the mining*" (L2). In Central Java, interviewees mentioned that *"water conditions are improving because the community forest grows very well"* (L3) and that "*there are many reforestation activities that if they continue will help us to have more secure sources of fresh water"* (L4).

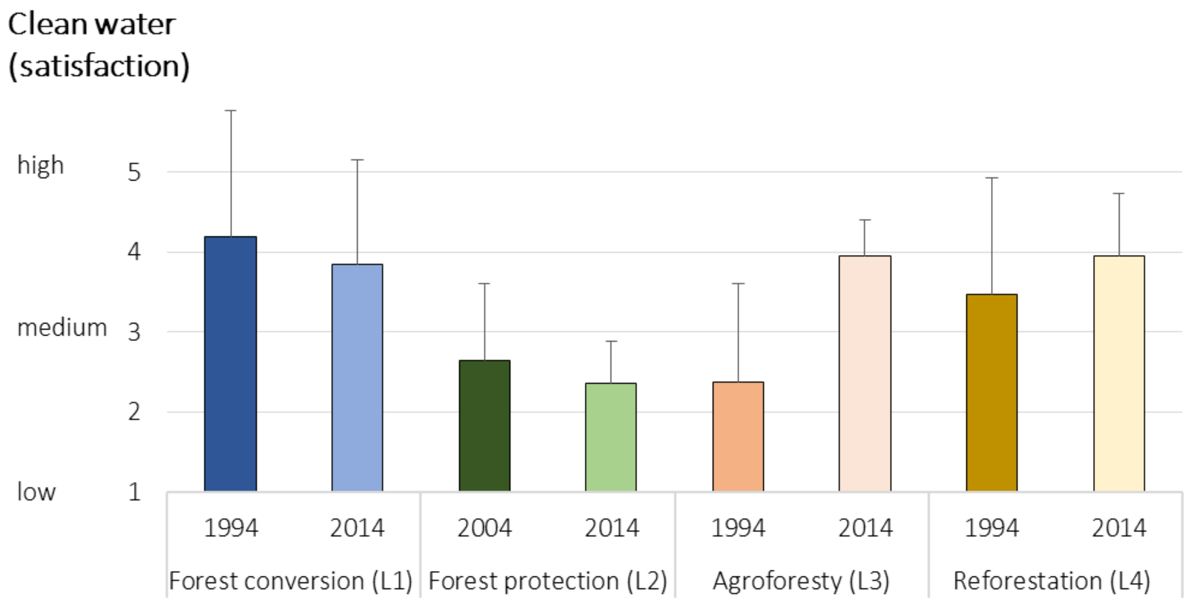

Fig 3.5. Local peoples' scores of clean water availability during the last 10–20 years (from high to low satisfaction ± SD). Changes in satisfaction with clean water availability during the periods when the selected major land-use changes occurred as part of the adaptation strategies to hazards (L1–4).

3.3.6 Carbon

Carbon stocks in aboveground biomass were highest in the semi-natural protected forests (198 t C/ha) and in old logged-over forests (130 t C/ha) in West Kalimantan (Fig 3.6 and Table S5). In rubber plantations, carbon stocks were 80% less than in logged-over forests (L1). In Central Java, gardens and croplands had the lowest aboveground carbon stocks (15 t C/ha and 2 t C/ha, respectively). Trees planted in these lands stored up to 49 t C/ha (L3–4).

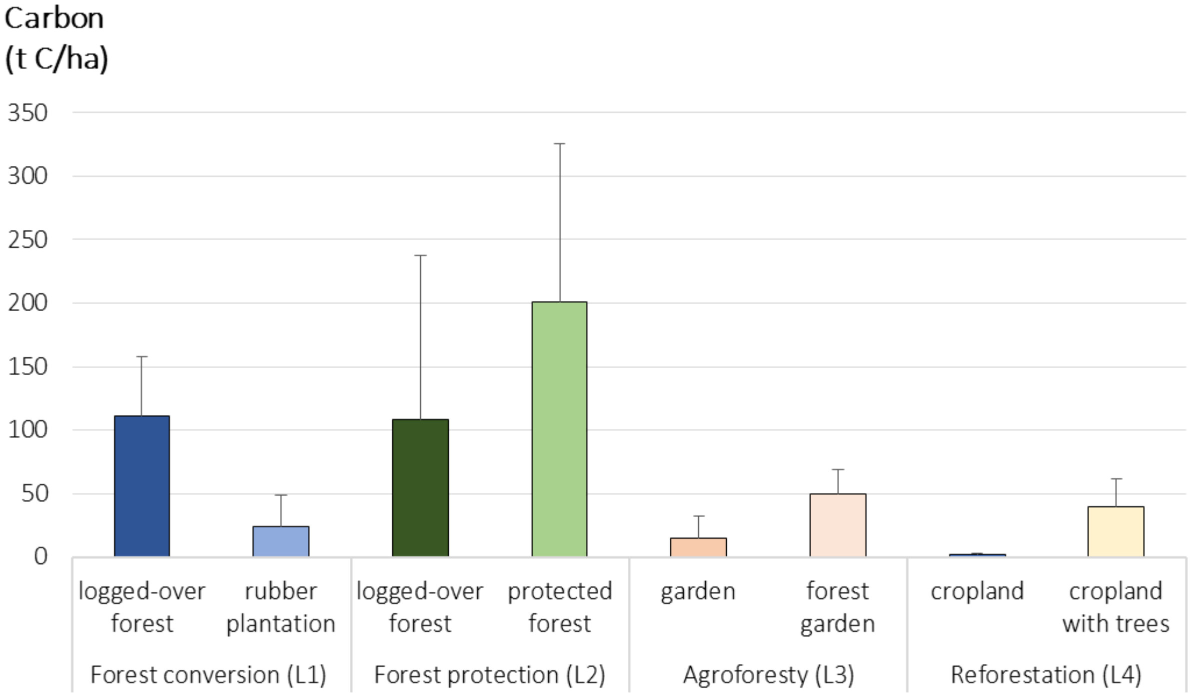

Fig 3.6. Mean carbon stock (t C/ha ± SD) in aboveground biomass. Measurements were taken for the land uses that were changed by local people as part of their adaptation strategies to hazards (L1–4).

3.3.7 Trade-offs

Selected land-use changes increased most ecosystem services but some trade-offs occurred (Fig 3.7). In West Kalimantan (L1), the conversion of logged-over forests into rubber plantations favored products at the expense of biodiversity, carbon, and water benefits. Conversely, in Central Java (L4), the reforestation of less productive cropland resulted in a decrease of products and an increase of biodiversity, carbon, and clean water. Forest protection in West Kalimantan (L2), increased biodiversity and carbon stocks but limited the income from forest products. The agroforestry practices in forest gardens in Central Java (L3) increased all ecosystem services without any particular trade-offs between biodiversity, carbon, products, and clean water.

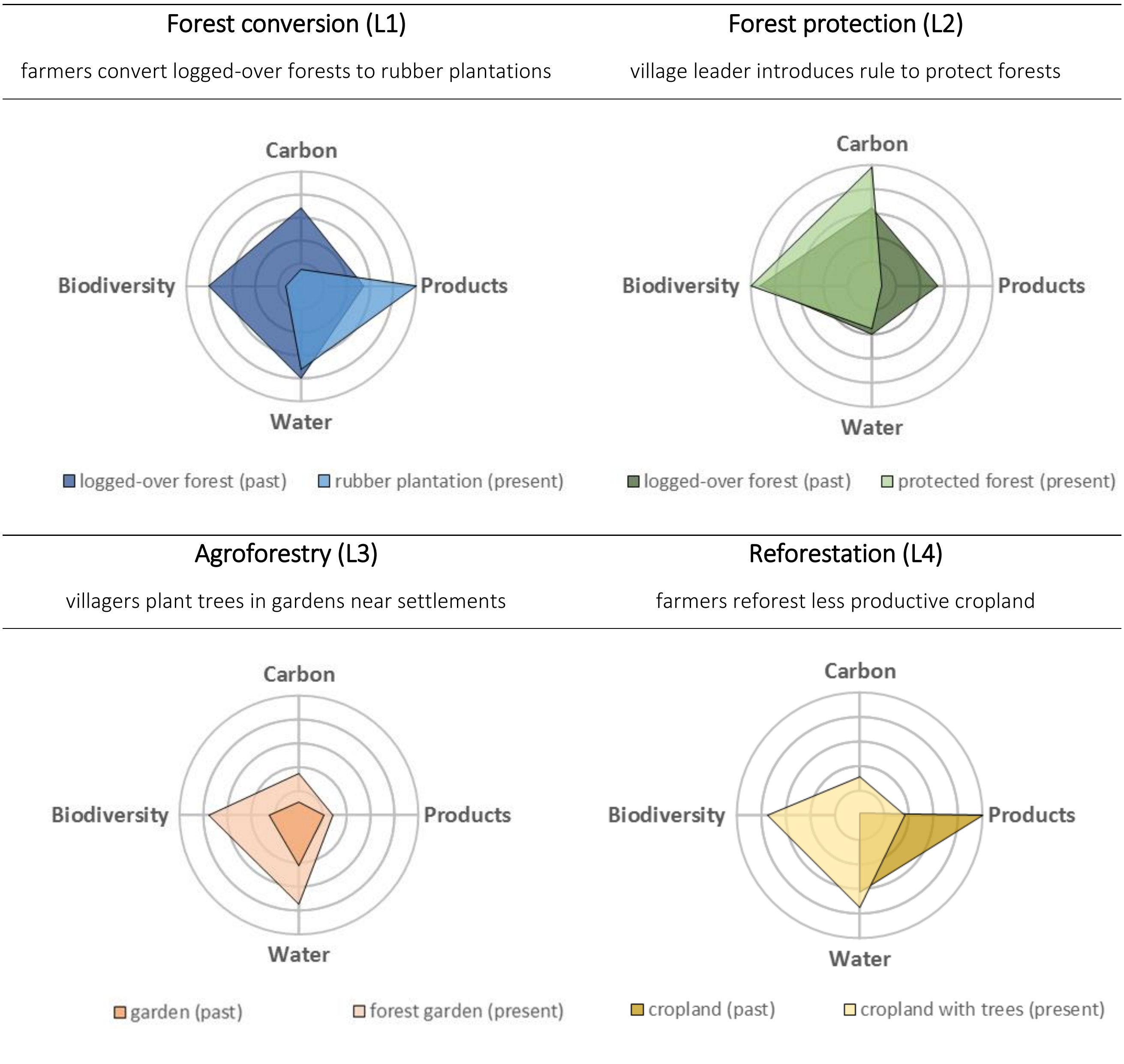

Fig 3.7. Changes in ecosystem services (land products, carbon sequestration, water purification and regulation) and biodiversity. Changes in ecosystem services and biodiversity before and after selected land-use changes as per people's adaptation strategies. The value of each indicator is normalized from 0 (minimum possible value at the center of the spider plot) to 5 (maximum observed value on the outermost circle).

3.4 Discussion

3.4.1 Drivers and impacts of land use change

Over the last 20 years, local people have changed land uses by adjusting their management of trees to reduce risks to livelihood linked to natural resource scarcity, low agricultural productivity, and climate hazards. Similarly, other rural communities in tropical landscapes have started local initiatives to manage forested areas to improve ecosystem services and adaptation benefits. For example, farmers in Southeast Asia adapted land uses by mixing plantations of rubber, coffee, or cacao with crops in agroforestry systems (Michon et al. 2007, van Noordwijk et al. 2014). Farmers in the Sahel reforested dry lands to make livelihoods resilient to drought following changes in governance and farming practices (Sendzimir et al. 2011). Smallholders in the Ecuadorian Andes planted trees on agricultural lands or protected forests to prevent burning and cattle grazing and to increase economic diversification (Farley 2010), motivated by the community perception that forest conversion to other uses would negatively affect water quality and availability.

Changes in land uses to increase local benefits from ecosystems have consequences for other services that span spatial scales. Local people modify forest and agroecosystems to change supply of products, diversify livelihoods and reduce risks, but these changes affect regulating services that benefit people in other areas. Land-use decisions that increase provisioning services for local benefits lead to trade-offs with regulating services that are then reduced, providing fewer benefits at larger scales (e.g. conversion of forest to rubber plantations). Conversely, restoration of regulating services for water leads to a decrease in local benefits from provisioning services (e.g. reforestation of cropland or forest protection). Similar trade-offs or synergies between provisioning and regulating services have been reported (Rodríguez et al. 2006, Bennett et al. 2009b).

Local strategies for adaptation based on land-use changes result in co-benefits and trade-offs at the global scale. Three of four land-use strategies (L2–4) increased local and regional benefits (more products and cleaner water), but also global benefits for climate mitigation (more carbon stocks). Such strategies met the converging interests of local and global stakeholders for solutions to climate change. However, local strategies can also result in trade-offs for carbon sequestration, as for conversion of forests to rubber plantations (L1), where interests of local people to strengthen livelihoods diverged from the global priority to reduce carbon emissions. Understanding the impact of local adaptation strategies on ecosystem services that can have benefits at the global scale, can help implement successful actions for climate change that account for different stakeholders' interests. Climate change mitigation initiatives (e.g. REDD+, climate-smart agriculture) that consider local ecosystem benefits are more likely to be legitimate and long-lasting.(Ravindranath 2007, Locatelli et al. 2011, Klein et al. 2014).

3.4.2 Mechanisms reinforcing decisions to change land use

When local actors perceive that strategies based on small-scale land use changes are successful, they can expand strategies and spread change at landscape scale. As we showed, a single-farmer initiative or a rule made by a village chief will be followed by others. Attempting large-scale change without preliminary small-scale change is difficult and risky (Moore et al. 2014). However, even if changes spread within a community, disparities may exist between groups due to varying power relations, capacities, dependencies, or access rights that should be considered (Armitage 2005, Thoms 2008). Positive effects on ecosystem services that are socially accepted and inclusive create feedback loops that shape trajectories of social–ecological systems (Carpenter and Folke 2006, Enfors 2013).

Perception by local actors that land-use changes improve livelihoods and reduce risks creates a reinforcing loop that increases the spread of such changes: supply of more ecosystem services leads to broader adoption of change in land-use (Fig 1). Several people at the study sites appreciated new land uses that offered more flexible, diverse, and resilient income opportunities (e.g. rubber in L1 or teak in L3–4). People also valued improved clean water conditions as co-benefits of the land-use changes (due to tree cover in L2–4). Ecosystem service flows connect supply with demand; when more people appreciate certain ecosystems or landscape states, so more decisions are implemented that shape landscape characteristics according to peoples' interests. Since changes in societal values due to observed outcomes of land-use decisions can trigger reinforcing loops, it is important that people have opportunities to explore different strategies and learn from experience (Folke et al. 2005, Pelling 2007). This outcome may be achieved by empowering local groups to develop and implement new land-uses and practices.

3.4.3 Factors facilitating decisions to change land uses

The introduction of new land uses by local actors to improve livelihoods and reduce risks is facilitated by the states of or changes in social or ecological systems, which create “windows of opportunity” (Olsson et al. 2004, Biggs et al. 2009). As we found in West Kalimantan, floods, drought, or natural resource scarcity can trigger changes in forest use. Extreme weather variability and restricted forest access due to logging concessions have triggered adjustments in land management in the region (Bakkegaard et al. 2016, Bong et al. 2016). Other opportunities for new land uses can be triggered by changes in the social–institutional context at different scales; for example, when a new local leader introduces rules for use and management of community forests. In addition, external factors that trigger changes in land-use decisions include new forest and climate policies, demographic change, or economic development. Changes in government forest policies and in levels of control were common in the colonial and reformation period in Java and determined the land-use decisions made by local people e.g. to plant or cut trees (Peluso 1995, Potter 2001). Lack of labor due to migration and aging populations can lead to reforestation of abandoned agricultural land. Increased commodity prices or construction of new roads or water systems can also influence peoples’ uses of ecosystems.

Land-use changes that lead to improved livelihoods may not spread automatically because reinforcing loops depend on human actions and contextual factors. Dominant rules and power relations, values, and knowledge can hinder or facilitate people’s adaptation decisions and actions (Pelling and Manuel-Navarrete 2011, O’Brien 2012, Gorddard et al. 2016). As shown in the case studies, the experiences of farmers affected by logging or water shortages, as well as knowledge of market prices and the values and rules developed through community organizations, facilitated changes in land uses. Other factors might hinder change, such as lack of land tenure rights and infrastructure (including market access). Overall, contextual factors influence land-use decisions and other inputs to co-production and delivery of ecosystem services to final beneficiaries (Spangenberg et al. 2014a) and can change the trajectory of social–ecological systems (Dobusch and Schüßler 2013, Wise et al. 2014).

3.4.4 Implications of local land-use decisions at larger scales

Local adaptation strategies can introduce novel ways of managing ecosystems that then spread at the landscape scale through reinforcing loops and have impact beyond the local scale. Such responses have been described as transformative adaptations (Matyas and Pelling 2015, Lavorel et al. 2015, Colloff et al. 2016), although a consensus on their definition is lacking (Moore et al. 2014) (but see (Feola 2015)). In contrast, coping responses are usually reactive, tactical, and short-term (Davies 1993) and incremental adaptations tend to be anticipatory responses that extend current practices, but without changing prevailing systems of social organization, economic structures, and modes of production (Davies 1993, Kates et al. 2012b). Transformative adaptations are generally collective strategies, undertaken at large scale or intensity, novel to the prevailing social-ecological system, and that cause major system changes (Kates et al. 2012a). In addition, they impact at several scales and challenge dominant feedback loops in the system (Moore et al. 2014). Transformational responses might be required to address long-term, large-scale, nonlinear, and uncertain changes such as those triggered by climate change (Olsson et al. 2014, Wise et al. 2014). Strategies that seek to cope with, or incrementally adapt to, changed circumstances, may be insufficient when changes are particularly extreme or rapid, and where people are especially vulnerable (Thornton and Comberti 2017).

Successful bottom-up land-based strategies offer the prospect of promising pathways for development that can be replicated and scaled up. Landscapes can provide multiple ecosystem services that support the livelihood needs of those managing them and provide co-benefits for people located more distantly. Whoever controls access to the land usually derives benefits from provisioning services, but people further away also benefit from regulating services via off-sites effects. Certain land-use practices are already suited to, and embedded in, local contexts, thereby increasing the chances of sustainability and success. As shown in the case studies, people may have local initiatives in place to protect or increase tree cover in the landscape. Therefore, land-based approaches that build on local initiative with inclusive benefits can contribute to achieving several development objectives simultaneously. This point is particularly relevant with the increase in international initiatives on climate change, biodiversity and sustainable development such as the UN Sustainable Development Goals, the UNFCCC Paris Agreement and the Convention of Biological Diversity Aichi Targets.

3.5 Conclusion

In this paper, we illustrated four cases of major land-use changes adopted by local people in response to multiple risks in two rural regions of Indonesia. Local people converted, protected, or planted trees in their landscapes to diversify local livelihoods and maintain land productivity under changing conditions such as climate variation and natural resource scarcity. Changes in land use mostly affected provisioning services of forests and agricultural ecosystems and produced local benefits, but also affected biodiversity and the regulating services of water quality and quantity and carbon sequestration, which have impacts beyond the local scale.

Our assessment of the impact of local land-use changes on products, water, climate, and biodiversity revealed some multiple benefits, but also trade-offs and off-site effects not initially considered by the people who initiated the changes; an important consideration in operationalizing ecosystem assessments. Not all land-use changes simultaneously meet multiple development and climate objectives, because actors at different scales may have diverging interests. Widespread changes in land uses entail shifts in peoples' priorities, practices, and rules related to ecosystems and their benefits. New perceptions and strategies developed by local communities can arise from learning and experiential knowledge of the effects of change. Positive feedback loops from land-use changes with local benefits, combined with enabling contextual factors, can spread new land uses to different people and places (i.e. can scale land-use changes up and out). In this way, some land-use changes can radically modify large areas and alter dominant feedback loops at different scales. Changes in social–ecological systems with such characteristics have been associated with transformative adaptations.

Ecosystem services assessments that consider feedback loops and multiple impacts on different ecosystem services and beneficiaries can help environmental managers and policy makers design and implement more locally appropriate and sustainable land-use decisions. The complexities and uncertainties of the impact of drivers of global change might require radical changes. However, such changes imply shifts in current values related to social-ecological systems can be challenging because of dominant views, traditions, and the interests of powerful stakeholders. Therefore, building on currently emerging local adaptation pathways that demonstrate multiple benefits across scales can help strengthen and scale up responses to climate change and other sources of vulnerability.

3.5.1 Acknowledgements

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3.6 Supplementary materials

Table S1. Drivers of change and ranking (top 1-3) as identified by local communities in the four study landscapes (L1-L4)

Drivers of changes	L1	L2	L3	L4
Top1	floods (2012)	floods (2012)	wildlife damages (2014)	wildlife damages (2014)
Top2	drought (2014)	drought (2014)	drought (2011/12)	drought (2011/12)
Top3	cattle disease (2013)	chikungunya disease (2010)	rice disease (2013)	rice disease (2013)
-	chikungunya disease (2010)	traditional gold mining (>1995)	community foret certification (2004)	landslides (2012)
-	Improve in infastructure (2005-10) e.g. bridge, road, water sytem	improve infrastructure (1995-2010) bridge, road, water system	floods (2008)	floods (2008)
-	scarcity of Borneo Ironwood (>2013)	end of logging company operations (1985)	infastruture water system (2006)	Illigal logging (2000s)
-	new village by splitting (2011)	new village and leader (2010)	NGO techncal support for natural resources (2000s)	conversion of forest to pine by state (1990-200)
-	landslides	village rule to ban deforestation (2011)	increase migration (>1980)	increase migration (>1980)
-	machines for gold mining and river sedimentatin (>2013)	illigal logging and natural resource scaricty (2011)		
-	village hamlet relocation	village reolocation (1994)		
-	rubber prices increase/decrease	rubber prices increase/decrease		

Table S2. Statistics about tree species diversity in the four study landscapes (L1-L4). Data from forest inventories.

Biodiversity (# of tree species)	Forest conversion - L1		Forest protection - L2		Agroforestry - L3		Reforestation - L4	
	logged-over forest	rubber plantation	logged-over forest	protected forest	garden	forest garden	cropland	cropland with trees
Plots	16	7	10	13	4	7	0	24
Mean	12.00	2.14	9.40	12.62	1.00	3.29	0.00	3.50
SD	3.69	1.46	1.19	2.99	1.15	1.89	0.00	1.18
Min	6	1	4	9	0	1	0	2
Median	12	2	10.5	12	0	3	0	3
Max	18	5	15	19	0	7	0	6

Table S2.1. Tree diversity (family, genus, and species) in the four study landscapes (L1-L4) according to land use type. Data from forest inventories.

L1 – Logged-over forest		
Family	**Genus**	**Species**
Anacardiaceae	Mangifera	sp. 1
Annonaceae	Maasia	glauca
Annonaceae	Xylopia	sp. 1
Apocynaceae	Alstonia	angustifolia
Apocynaceae	Alstonia	sp. 1
Celastraceae	Lophopetalum	javanicum
Clusiaceae	Garcinia	sp. 1
Compositae	Vernonia	arborea
Datiscaceae	Octomeles	sumatrana
Dileniaceae	Dilenia	excelsa
Dileniaceae	Dilenia	ovata
Dileriaceae	Dilenia	borneensis
Dilleniaceae	Dillenia	sp. 1
Dipterocarpaceae	Dryobalanops	beccarii
Dipterocarpaceae	Hopea	dasyrrhachis
Dipterocarpaceae	Hopea	mengarawan
Dipterocarpaceae	Shorea	bracteolata
Dipterocarpaceae	Shorea	kunstleri
Dipterocarpaceae	Shorea	sp. 1
Dipterocarpaceae	Shorea	sp. 2
Dipterocarpaceae	Shorea	beccariana
Durio	kutejensis	sp. 1
Euphorbiaceae	Coccoceras	sp. 1
Euphorbiaceae	Endospermum	diadenum
Euphorbiaceae	Macaranga	costulata

Euphorbiaceae	Macaranga	hypoleuca
Euphorbiaceae	Mallotus	mollissimus
Euphorbiaceae	Mallotus	sp. 1
Euphoribiaceae	Elateriospermum	tapos
Fabaceae	Dialium	indum
Fabaceae	Mucuna	sp. 1
Fabaceae	Tamarindus	indica
Fagaceae	Castanopsis	inermis
Fagaceae	Lithocarpus	blumeanus
Hypericaceae	Cratoxylum	arborescens
Lamiaceae	Vitex	pinnata
Lauraceae	Eusideroxylon	borneense
Lauraceae	Nothaphoebe	umbelliflora
Leguminosae	Intsia	sp. 1
Leguminosae	Koompassia	excelsa
Leguminosae	Saraca	sp. 1
Leguminosaea	Paraserianthes	sp. 1
Leguminosaea	Paraserianthes	sp. 2
Lythraceae	Duabanga	moluccana
Magnoliaceae	Talauma	sp. 1
Melastomataceae	Bellucia	pentamera
Meliaceae	Aglaia	pachyphylla
Meliaceae	Aglaia	sp. 1
Meliaceae	Aglaia	tomentosa
Meliaceae	Aglaia	pachyphylla
Meliaceae	Toona	sureni
Moraceae	Artocarpus	odoratissimus
Moraceae	Artocarpus	sp. 1
Moraceae	Artocarpus	elasticus
Moraceae	Ficus	fistulosa
Moraceae	Ficus	septica
Moraceae	Ficus	variegata
Moraceae	Ficus	racemosa
Moraceae	Ficus	septica
Moraceae	Ficus	variegata
Myristicaceae	Horsfieldia	cinerea
Myrtaceae	Syzygium	fastigiatum
Myrtaceae	Syzygium	leptostemon
Myrtaceae	Syzygium	pseudoformosum
Myrtaceae	Syzygium	sp. 1
Phyllanthaceae	Glochidion	rubrum
Rubiaceae	Nauclea	sp. 1
Rubiaceae	Neonauclea	excelsa
Rubiaceae	Timonius	borneensis
Sapindaceae	Nephelium	ramboutan-ake
Sapotaceae	Burckella	Cocco
Sapotaceae	Palaquium	semaram
Staphyleaceae	Turpinia	sp. 1
Sterculiaceae	Scaphium	macropodum

Theaceae	Eurya	Japonica
Unknown 1		
Unknown 2		
Unknown 3		
Unknown 4		
Unknown 5		
Unknown 6		
Unknown 7		
Unknown 8		
Verbenaceae	Vitex	sp.

L2 – Logged-over forest

Family	Genus	Species
Anacardiaceae	Mangifera	sp. 1
Annonaceae	Meiogyne	sp. 2
Apocynaceae	Alstonia	angustifolia
Celastraceae	Lophopetalum	javanicum
Cypteroniaceae	Dactylocladus	stenostachys
Dipterocarpaceae	Hopea	sp. 1
Dipterocarpaceae	Shorea	bracteolata
Dipterocarpaceae	Dryobalanops	abnormis
Ebenaceae	Diospyros	maingayl
Euphorbiaceae	Coccoceras	sp.
Euphorbiaceae	Endospermum	diadenum
Euphoribiaceae	Elateriospermum	tapos
Fabaceae	Tamarindus	indica
Guttiferae	Mesua	ferrea
Hypericaceae	Cratoxylum	arborescens
Lamiaceae	Vitex	pinnata
Lauraceae	Nothaphoebe	umbelliflora
Leguminosae	Intsia	sp.
Lythraceae	Lagerstroemia	sp.
Magnoliaceae	Talauma	sp. 1
Malvaceae	Grewia	sp. 1
Melastomataceae	Bellucia	pentamera
Meliaceae	Toona	sureni
Moraceae	Artocarpus	maingayi
Moraceae	Ficus	racemosa
Moraceae	Ficus	sp. 1
Moraceae	Artocarpus	kemando/integer
Moraceae	Artocarpus	Odoratissimus
Moraceae	Ficus	septica
Moraceae/Euphorbiaceae	Artocarpus	odorantissimus/populneus
Myristicaceae	Horsfieldia	cinerea
Myrtaceae	Syzygium	fastigiatum
Myrtaceae	Syzygium	leptostemon
Myrtaceae	Syzygium	sp. 1
Myrtaceae	Syzygium	glomeratum
Myrtaceae	Syzygium	pycnanthum

Myrtaceae	Syzygium	sp. 2
Phyllanthaceae	Glochidion	rubrum
Rubiaceae	Psydrax	dicoccos
Rubiaceae	Neonauclea	excelsa
Sapindaceae	Nephelium	cuspidatum
Sapindaceae	Pometia	tomentosa
Sterculiaceae	Scaphium	macropodum
Theaceae	Eurya	Japonica
Ulmaceae	Gironniera	nervosa
Unknown 1		
Unknown 2		
Unknown 3		
Unknown 4		
Unknown 5		
Unknown 6		
Unknown 7		

L1 - Rubber plantation

Family	Genus	Species
Anacardiaceae	Mangifera	indica
Arecaceae	Eugeissona	utilis
Bombacaceae	Durio	zibethinus
Dipterocarpaceae	Shorea	macrophylla
Euphorbiaceae	Hevea	brasiliensis
Fabaceae	Tamarindus	indica
Moraceae	Artocarpus	maingayi
Sapindaceae	Nephelium	lappaceum

L2 – Protected forests

Family	Genus	Species
Anacardiaceae	Mangifera	sp. 1
Anacardiaceae	Mangifera	sp. 2
Annonaceae	Cyathocalyx	sp. 1
Annonaceae	Meiogyne	sp. 1
Annonaceae	Xylopia	sp. 1
Apocynaceae	Alstonia	angustiloba
Burseraceae	Dacryodes	rostrata
Calophyllaceae (Guttiferae)	Calophyllum	sp. 1
Celastraceae	Lophopetalum	javanicum
Combretaceae	Terminalia	chebula
Dileniaceae	Dilenia	excelsa
Dilleniaceae	Dillenia	sp. 1
Dipterocarpaceae	Dipterocarpus	mundus
Dipterocarpaceae	Hopea	sp. 1
Dipterocarpaceae	Hopea	sp. 2
Dipterocarpaceae	Shorea	beccariana
Dipterocarpaceae	Shorea	bracteolata
Dipterocarpaceae	Shorea	lepidota
Dipterocarpaceae	Shorea	macrophylla
Dipterocarpaceae	Shorea	quadrinervis

Dipterocarpaceae	Shorea	sp. 1
Durio	kutejensis	sp. 1
Ebenaceae	Diospyros	caudisepala
Ebenaceae	Diospyros	confertiflora
Ebenaceae	Diospyros	maingayl
Elaeocarpaceae	Elaeocarpus	floribundus/floribunda
Elaeocarpaceae	Elaeocarpus	macrocerus
Euphorbiaceae	Endospermum	diadenum
Euphorbiaceae	Macaranga	costulata
Euphorbiaceae	Macaranga	hypoleuca
Euphorbiaceae	Mallotus	paniculatus
Euphorbiaceae	Neoscortechinia	kingii
Fabaceae	Koompassia	malaccensis
Fabaceae	Tamarindus	indica
Fagaceae	Lithocarpus	blumeanus
Guttiferae	Calophyllum	soulattri
Guttiferae	Garcinia	parvifolia
Hypericaceae	Cratoxylum	arborescens
Hypericaceae	Cratoxylum	cochinchinensis
Lauraceae	Nothaphoebe	umbelliflora
Leguminosae	Intsia	sp. 1
Leguminosae	Koompassia	excelsa
Leguminosae	Saraca	sp. 1
Leguminosaea	Paraserianthes	sp. 1
Loganiaceae	Fagraea	sp. 1
Magnoliaceae	Talauma	sp. 1
Melastomataceae	Bellucia	pentamera
Moraceae	Artocarpus	anisophyllus
Moraceae	Artocarpus	kemando/integer
Moraceae	Artocarpus	odoratissimus
Moraceae	Artocarpus	sp. 1
Myristicaceae	Horsfieldia	cinerea
Myrtaceae	Syzygium	cinereum
Myrtaceae	Syzygium	fastigiatum
Myrtaceae	Syzygium	leptostemon
Myrtaceae	Syzygium	sp. 1
Myrtaceae	Syzygium	sp. 2
Myrtaceae	Syzygium	sp. 3
Oxalidaceae	Sarcotheca	diversifolia
Rubiaceae	Nauclea	sp. 1
Rubiaceae	Timonius	borneensis
Sapindaceae	Dimocarpus	sp. 1
Sapindaceae	Nephelium	lappaceum
Sterculiaceae	Scaphium	macropodum
Theaceae	Eurya	Japonica
Unknown 1		
Unknown 2		
Unknown 3		
Unknown 4		

Unknown 5
Unknown 6
Unknown 7
Unknown 8
Unknown 9

L3 – Forest garden

Family	Genus	Species
Fabaceae	Acacia	sp.
Fabaceae	Cassia	siamea
Meliaceae	Swietenia	macrophylla
Verbenaceae	Tectona	grandis

L4 - Cropland with trees

Family	Genus	Species
Anacardiaceae	Anacardium	occidentale
Anacardiaceae	Campnosperma	brevipetiolata
Anacardiaceae	Mangifera	indica
Annonaceae	Annona	muricata
Arecaceae	Cocos	nucifera
Bombacaceae	Durio	zibethinus
Boraginaceae	Ehretia	javanica
Fabaceae	Albizia	chinensis
Fabaceae	Paraserianthes/Albizzia	falcataria
Gnetaceae	Gnetum	gnemon
Lecythidaceae	Barringtonia	racemosa
Leguminosae	Acacia	mangium
Leguminosae	Acacia	sp. 1
Leguminosae	Dalbergia	latifolia
Leguminosae	Pterocarpus	indicus
Meliaceae	Swietenia	macrophylla
Moraceae	Artocarpus	heterophyllus
Myrtaceae	Syzygium	cumini
Myrtaceae	Syzygium	nervosum
Pinaceae	Pinus	merkusii
Salicaceae	Flacourtia	ap.
Verbenaceae	Tectona	grandis

Table S3. Information on land products in the four study landscapes (L1-L4) according to land use type. Data from different sources (i. from key informants, ii. from secondary literature in the region: crop yealds (BPS-statistics Indonesia 2017), ironwood densities (Prajadinata et al. 2011, Wahyuni 2011), rubber yealds (Shantiko et al. 2012, Suyanto et al. 2009), iii. from forest inventories: teak wood). 1 USD = 13,360 IDR in November 2016.

Land Use (Product)	Price per unit[i]	harvestable quantities (yealds)[ii iii]	Harvest intensity per year[i]	Family income per year [ii]	Average area per family [i]	Total	Literature
Forests (Ironwood)	200,000,000 *IDR/tree*	0.047 *trees/ha*	<1 *tree/year*	15,000,000 *IDR/ year*		176 *USD/ha/y*	110- *USD/ha/y*
Forests (NTFPs)	10,000 *IDR/kg*			4,000,000 *IDR/ year*	10 *ha/family*	30 *USD/ha/y*	30-50 *USD/ha/y*
Rubber plantation (latex)	8000 *IDR/kg*	2 *kg/ha/day*	310 *days/years*	15,000,000 *IDR/ year*	3 *ha/family*	371 *USD/ha/y*	350-450 *USD/ha/y*
Cropland (rice/soya)	7,000 *IDR/kg*	1,500 *kg/ha/season*	1 *season/year*		2 *ha/family*	786 *USD/ha/y*	
Forest garden (Teak)	200,000 *IDR/tree*	150 *trees/ha*	0.05 *trees/year*	700,000 *IDR/year*	0.25 *ha/family*	112 *USD/ha/y*	
Cropland with trees (Teak)	200,000 *IDR/kg*	70 *trees/ha*	0.05 *trees/year*			52 *USD/ha/y*	
Garden (vegetables)	7,000 *IDR/kg*	150 *kg/ha/season*				79 *USD/ha/y*	

Table S4. Water conditions (low-high satisfaction with quality and quantity) as perceived by local people in the four study landscapes (L1-L4) according to land use type. Data from focus group discussion (FGD).

Water conditions	Forest conversion - L1		Forest protection - L2		Agroforesty - L3		Reforestation - L4	
[1 (low)-5 (high)]	*1994*	*2014*	*2004*	*2014*	*1994*	*2014*	*1994*	*2014*
People	36	40	42	42	38	40	40	40
Mean	4.2	3.9	2.6	2.4	2.4	4.0	3.5	4.0
SD	1.6	1.3	1.0	0.5	1.2	0.5	1.4	0.8
Min	1	1	1	1	1	2	1	2
Median	4	3	3	2	2	4	4	4
Max	5	5	4	3	5	5	5	5
Trends explanations :	- decreases due to gold mining activity in forests		- many people do activity in the river and the forest		- improvements thanks to trees in croplands		- changes in forest densities and species influence water springs	
	- stable because the water sources are in the hills		- improvements because some mining will be closed due to regulation		- improvements thanks to technologies		- improvements thanks to reforestation activities	
	- floods make water dirty and muddy		- better because communities build some borewell		- teak trees improve water conditions		- improvements with government help with watersytem	

Table S5. Above ground carbon estimations in the four study landscapes (L1-L4) according to land use type. Data from forest inventories. (* = data from the literature)

Biomass	**Forest conversion - L1**		**Forest protection - L2**		**Agroforesty - L3**		**Reforestation - L4**	
(t C/ha)	logged-over forest	rubber plantation	logged-over forest	protected forest	garden	forest garden	cropland	cropland with trees
Plots	16	7	10	13	4	7	0 *	24
Mean	111	24	108	201	15	49	2	39
SD	47	25	129	125	17	20	1	22
Min	25	8	0	79	0	27	NA	13
Median	118	12	0	183	0	63	NA	32
Max	190	75	0	470	0	69	NA	109

CHAPTER 4

Forest ecosystem services in the responses of rural communities to climate hazards in Indonesia.

*Villagers measuring the diameter of a meranti tree (*Shorea spp.*) in the forest of Tubang Jaya (West Kalimantan). Forests and trees provide construction wood, fruits, and regulate water and soil processes (picture by Giacomo Fedele).*

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Forest ecosystem services in the responses of rural communities to climate hazards in Indonesia

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Abstract

Forests and trees contribute to diversifying livelihoods, maintaining agricultural production, and protecting land and infrastructure. Forests can act as safety nets for rural livelihoods and as buffers against potential damage by supplying provisioning services (e.g., food and timber) and regulating services (e.g., water and soil protection). However, there is a lack of understanding of how land management practices influence people's vulnerability in rural areas, especially in response to climate hazards. In this study, we assessed at the same time different aspects of ecosystem services delivery: the potential supply of ecosystem services, the perceived demand for them by local communities, and the strategies to mobilize such services in a context of climate hazards. In four villages in Indonesia with different forest cover, we analyzed ecosystem services through focus group discussions, household surveys, forest inventories, and satellite images. In landscapes with low forest cover where the supply of ecosystem services is limited, people rated forests and trees as having high importance in reducing the impacts of droughts and undertook more actions to enhance the provision of ecosystem services. In such landscapes, the scarcity of services and the high demand for them can explain why local people actively manage forests to satisfy their adaptation needs. In sites with low forest cover, forest regrowth might be partially driven by people's recognition of and demand for forest ecosystem services that help people to respond to hazards (i.e., adaptation services). A better distinction between supply, demand, and mobilization of ecosystem services can make ecosystem services assessments more operational for designing sustainable and locally appropriate land management practices.

Keywords: ecosystem-based adaptation; climate change; drought; forest ecosystem services; natural hazard; social vulnerability

4.1 Introduction

Landscapes support the well-being of societies by providing them with opportunities to live, work, and recreate. They supply several direct benefits to people such as food, water, and timber for home consumption or selling (provisioning services). Landscapes also regulate water flows and soil processes (regulating services) that support livelihood activities. Rural communities particularly depend on land-based activities for their livelihoods (e.g., agriculture, forestry, fisheries). Landscapes with forests and trees represent important sources of livelihoods in tropical regions and account for more than one quarter of rural household income (Angelsen et al. 2014). Many smallholder farmers also benefit from forest ecosystem services (ES) that support agriculture by regulating soil fertility, pollination, and shade (Minang et al. 2014). However, the livelihoods of rural communities in tropical landscapes are especially vulnerable to multiple and inter-connected shocks resulting from economic, political, or environmental changes (Wunder et al. 2014).

In the case of stresses and shocks, forests and trees provide multiple ES that contribute to maintaining people's well-being by increasing resilience. Their diverse provisioning services (e.g., food, timber, fuelwood) represent safety nets for livelihoods affected by shocks, and their regulating services (e.g., water regulation and soil protection) buffer against natural disasters (Sudmeier-Rieux et al. 2006, Pramova et al. 2012). These multiple roles of forests become even more important for people in already vulnerable contexts due to poverty, the effects of climate variability, and lack of technical adaptation options (IPCC 2014).

Initiatives to alleviate poverty and limit the adverse effects of climate change have increasingly considered the role of ecosystems in reducing vulnerability. In the development sector, ecosystem-based approaches such as ecosystem-based adaptation (EbA) or ecosystem-based disaster risk reduction (Eco-DRR) recognize that ES can contribute to reduced human vulnerability to climate variability and to increased resilience (Renaud et al. 2010). Scientific studies have shown the importance of land management practices and ES for societal resilience (Folke et al. 2010, Andersson et al. 2015) and climate change adaptation (Pramova et al. 2012, Doswald et al. 2014). However, knowledge is missing on how the supply of and demand for ES drive decisions on land management in the context of climate hazards, which exacerbate the consequences of ecosystem degradation on people and create new demands for ES as buffers and safety nets.

The aim of this study is to analyze the potential supply of ES, the demand for them by local communities, and the management strategies communities use to mobilize such services in a context of climate variations. We analyzed ES and peoples' perceptions in four Indonesian sites with forested landscapes, where ecosystems ranged from well-preserved seminatural forest to more degraded forest and where people had experienced climate events and ecosystem changes. People had been affected by multiple shocks such as floods, droughts, and pest outbreaks, but we focused on drought, which had been experienced in all sites under similar conditions. After presenting the conceptual framework, the sites, and the methods, the paper reports how people managed ecosystems and how they perceived ecosystems and ES as a response to drought. It also assesses forest ecosystems and their potential to provide services in sites with high or low forest cover. It then discusses how supply of and demand for forest ES can explain the uses of forests and trees as part of local adaptation strategies.

4.2 Materials and Methods

4.2.1 Analytical Framework

Many frameworks of coupled social–ecological systems recognize the interactions between nature and humans and integrate knowledge and methods from multiple disciplines (Binder et al. 2013). The concept of ES is one way to represent the connections between ecosystems and human well-being (Haines-Young and Potschin 2010, Bennett et al. 2015, Díaz et al. 2015a). Similarly, the concept of resilience has emerged to describe properties of social–ecological systems that sustain structures and processes by resisting, adapting, and transforming the system in response to stress (Gunderson and Holling 2002, Walker et al. 2006).

Our framework is based on the “ecosystem services cascade” framework, which links the ecological characteristics of ecosystems to services for the benefit of humans (Haines-Young and Potschin 2010). However, it has been criticized for its linearity and lack of feedback loops (Bastian et al. 2012, Müller and Burkhard 2012, Spangenberg et al. 2014c). In our modified ES cascade (Fig. 1), we distinguish between: i) the supply of ES, ii) the social demand for ES, and iii) the management decisions that shape their actual use and benefits. First, ecosystems have the capacity to provide services, which can possibly be used by humans (Burkhard et al. 2014, Serna-Chavez et al. 2014). Second, ES might be recognized as useful by people according to their direct uses and desires (including risk reduction) (Wolff et al. 2015),which create a specific demand for ES (Burkhard et al. 2012b, Villamagna et al. 2013). The demand for ES depends on beneficiaries and thus might exceed the actual benefit received (Schröter et al. 2014, Wolff et al. 2015). And third, in order to mobilize these services, people might need to add inputs (e.g., labor, time, resources, knowledge) and comply with certain constraints (e.g., legal, financial, cultural), which highlight the co-production of ES (Spangenberg et al. 2014b, Díaz et al. 2015b, Palomo et al. 2016b).

These three aspects determine how people benefit from ES, and people’s management decisions are key in order to benefit from the ES (Díaz et al. 2015a, Palomo et al. 2016b). Management decisions connect ES supply and demand and can lead to changes in either ecosystems or in socioeconomic adjustments (Oudenhoven et al. 2012, Daw et al. 2016). For example, farmers dissatisfied with the current crop yields (i.e., different supply and demand of

ES) can make decisions to extend their fields by cutting forests (the "ecosystem management" arrow in Fig. 4.1) or to diversify livelihoods (the "socioeconomic adjustments" arrow in Fig. 4.1).

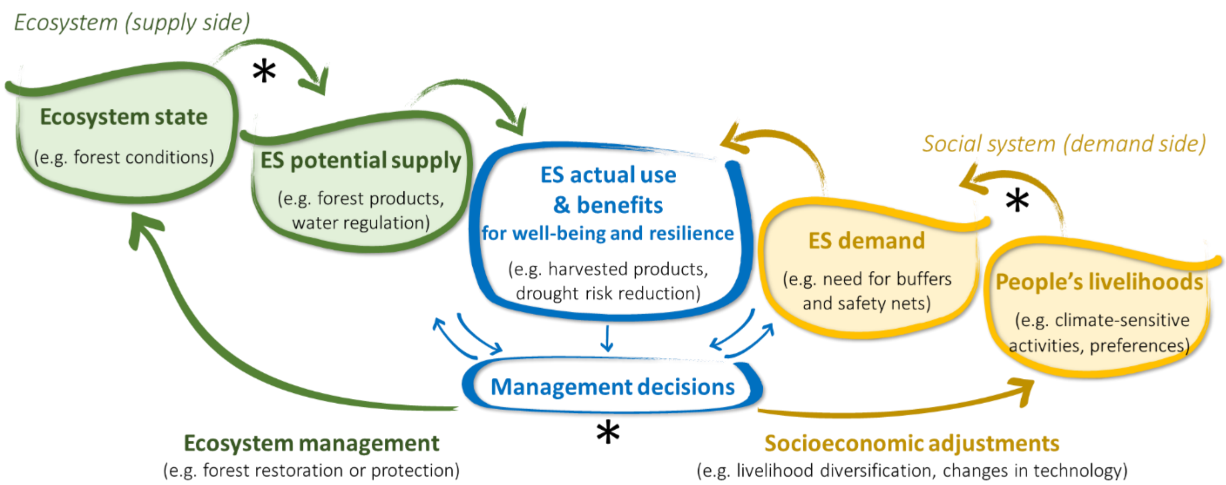

Figure 4.1. Conceptual framework for assessing how ecosystem services (ES) contribute to people's well-being and resilience (adapted from (Haines-Young and Potschin 2010, Burkhard et al. 2014, Spangenberg et al. 2014c)). Ecosystem service supply depends on the ecosystem state and reaches beneficiaries who have a demand for ES (depending on their assets and strategies). The potential supply and demand of ES determine their actual use and benefits. People's dissatisfaction with the actual use of ES drives management decisions that modify ecosystems or socioeconomic conditions. The three asterisks indicate the foci of this study.

4.2.2 Study Site

Indonesia has one of the largest areas of tropical forest in the world, which is rapidly disappearing (FAO 2010, Hansen et al. 2013). It is also among the top five countries most frequently affected by natural disasters (EM-DAT 2013). For this study, we selected the provinces of West Kalimantan and Central Java because of their differences in forest covers (with low and high intensity of human influence) and because they face medium to high risk of droughts according to the national disaster management authority (BNPB - National Agency for Disaster Management 2012). In each of the two provinces, we selected two rural villages affected by recent drought with more (V1 and V3) or less (V2 and V4) forest cover (Fig. 4.2).

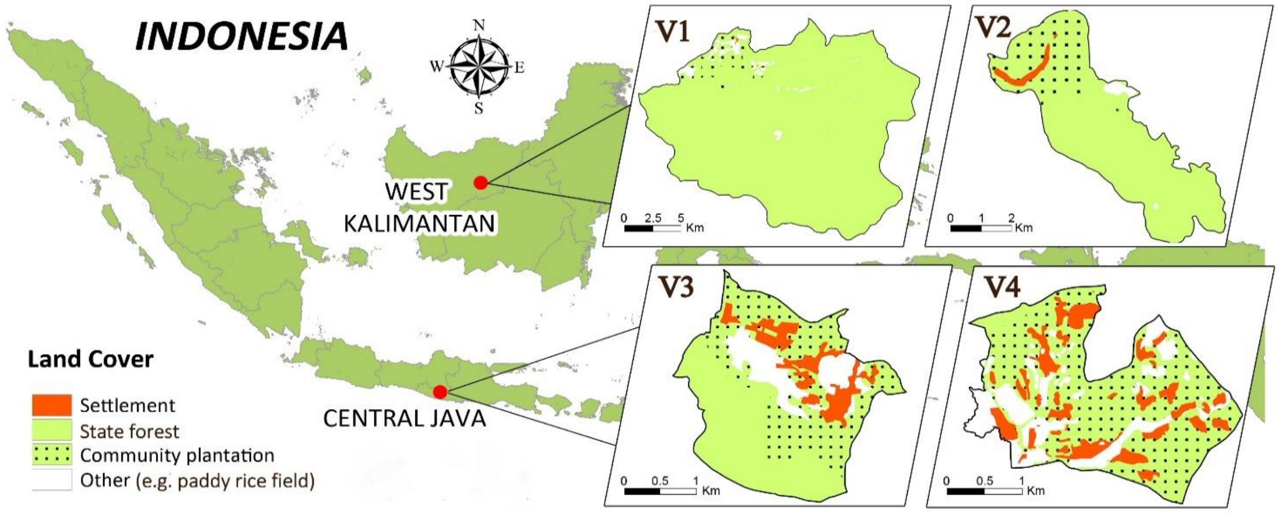

Figure 4.2. The location of the four study sites: preserved natural forests (V1 and V2 in West Kalimantan Province) and a mosaic landscape of degraded forests, plantations, and agricultural land (V3 and V4 in Central Java Province). Source: Landsat images analysis (land cover areas) and participatory mapping (land cover/uses).

In West Kalimantan, the villages of Nanga Jemah (V1) and Tubang Jaya (V2), in the Kapuas Hulu District, lie upstream of the Boyan River. Most of the remaining dipterocarp forests of Borneo grow on the hillsides (100–500 m a.s.l.) of the Muller-Schwaner Mountain Range (MacKinnon et al. 1997). Logging activities by companies with land concessions stopped in the mid-1980s (Shantiko 2013). Local livelihoods focus on artisanal gold mining, agriculture (upland rice, maize, cassava and sweet potato), and forest harvesting of products including Borneo ironwood (*Eusideroxylon zwageri* – *belian*), rubber, and agarwood (dark resinous heartwood of *Aquilaria* spp. infected by a fungus known locally as *gaharu*). Some farmers practice shifting cultivation and clear forest or fallow land to crop upland rice for three years before either being left fallow or planted with rubber trees (Shantiko et al. 2013). Other activities include animal husbandry, hunting birds and small mammals, fishing in rivers, and growing fish in ponds (Table 4.1).

In Central Java, the villages of Selopuro (V3) and Sendangsari (V4), in the Wonogiri District, are located in the foothills of the southern part of the Thousand Mountains (Pegunungan Seribu) where the Bengawan Solo River originates. On the slopes of the hills at the borders of both villages, pine monoculture and mixed species forests are owned and managed by Perum Perhutani, a state-owned company. Other tree species with commercial value, mostly teak, are planted on private land, in fields or on dry land (*tegalan*). The main livelihoods in both sites are agriculture, with rice, maize, and soybean rotations depending on predicted precipitation. In gardens or less productive lands, farmers plant vegetables, cassava, medicinal plants, and red rice (an early maturing species that is more drought-resistant) in agroforestry systems or with trees on the fields' edges. In addition, farmers raise livestock, mostly cows and goats, to support their income or work as laborers helping in the villages during field preparations for seeding or weeding, or at harvest time (Table 4.1).

Local communities in the study sites have suffered from a lack or an excess of water due to climate hazards, which affected their productive activities, assets, and physical health. Floods, droughts, or disease outbreaks caused direct economic losses due to damages to crops, fish ponds, or infrastructure, or indirectly due to impaired access to roads or rivers that are used for transporting products or people. For the purpose of this paper, we focused on the drought because this type of climate hazard had been experienced by each of the study communities (in 2014 for V1–2 and in 2011/2 for V3–4) and it was ranked by people in each site among the top-3 events (climate and non-climate related) that most severely impacted the communities. Villagers referred to drought as extended dry periods with low or no rainfall that had consequences for domestic or agricultural water availability. Although average annual precipitation might be relatively high, there are important temporal and spatial variations (Table 4.1, bottom).

Table 4.1. Socioeconomic and environmental characteristics of the four study villages and the impact of climate events on people's livelihoods.

		West Kalimantan		Central Java	
		V1	V2	V3	V4
Social–ecological context	Main livelihoods (by decreasing importance)	Rubber farming, gold mining, crop farming	Gold mining, rubber farming, crop farming	Crop farming, cattle, construction	Farming, cattle, farm labor
	Population density	0.01 households/ha	0.1 households/ha	0.5 households/ha	0.7 households/ha
	Nearest market distance (by motorbike)	90 min	30 min	5 min	15 min
	Land tenure	state production & protection forest, *de facto* private land	state production forest, *de facto* private land	state protection forest, *de jure* private land	
	Tree plantations	Rubber (*de facto* private land)		Pine (state land), Teak (private land)	
	USDA Soil type	Ultisols	Ultisols and Inceptisols	Entisols	
	Main tree species in forests (plant family)	Dipterocarpaceae Rubiaceae	Dipterocarpaceae Myrtaceae	Meliaceae and Verbanaceae	
Hazards	Shocks and stresses identified by local people (ranked by decreasing impact)	1. Floods (2012), 2. Drought (2014), 3. Chikungunya disease (2010)		1. Wild animals (2014), 2. Drought (2011/2012), 3. Rice diseases (2013)	
	Duration of reported droughts[†]	4 months		7 months	
	Precipitation anomaly during reported droughts[†]	–35%		–43%	
	Average rainfall[†] (± SD)	315 ± 65 mm/month		154 ± 112 mm/month	

([†]) data from Tropical Rainfall Measuring Mission (TRMM) for 1960–2015 at the study locations 110.875E / 8.125S (V1–2) and 112.375E / 0.375N (V3–4). Duration of reported droughts is the number of months with below-average rainfall during the drought years reported by respondents. Precipitation anomaly is the average reduction of rainfall during droughts (i.e., months with below-average rainfall during reported drought years) compared with the average rainfall during the same months in the 1960–2015 period.

4.2.3 Data Collection

Quantitative and qualitative methods from social and biophysical sciences were combined to gather information on different aspects of the delivery of ES from forests in the studied social–ecological systems. We followed the proposed framework to analyze supply and demand of ES for adaptation to drought and to explore the management decisions made by people in response to droughts by changing ecosystem or socioeconomic practices (Table 4.2).

Table 4.2. Description of the indicators used to assess the potential supply, the demand, and the actual use of ES from forests and trees in response to droughts.

Framework element	Indicators	Links between indicators and the framework element	Data source(s)
Potential supply	Forested areas, Biodiversity, Biomass	More forested areas, biodiversity, and biomass in the landscape increase the potential supply of ES	Remote sensing; Forest inventories; Focus group discussions (participatory mapping)
Demand	Perceptions of the impacts of droughts on livelihoods; Perceptions of how forests reduce drought impacts or how deforestation increases them	More people affected by drought, and more value and knowledge on the importance of forests to reduce vulnerabilities to climate hazards, increase the demand for ES	Household survey (impacts and perceptions of hazards); Focus group discussions (causes/effects of hazards)
Management decisions	Individual and collective strategies used to respond to drought based on forests and trees	More strategies used to respond to drought based on forests and trees indicate that decisions include the management of ES	Household survey (responses to hazards); Focus group discussions (natural resources management)

Field work was conducted in three rounds of approximately one month each per province between March 2014 and June 2015. For assessing the supply of ES (i.e., the biophysical characteristics of the forested land that can reduce drought impacts and help people to cope with their effects), we inventoried forests in 120 plots. For assessing the demand for ES (i.e., the perception of local people on the importance of forests for reducing drought impacts and for coping with their effects), we surveyed 256 households. Household surveys were conducted with open-ended questions and scoring exercises that lasted around one and a half hours each. We selected a representative sample of households, proportional to the number of people affected and stratified by geographic location in the villages based on the equation of Arkin and Colton (1963) at a 95% confidence level and a ±10% relative error limit (i.e., V1,2=50; V3=77; and V4=79 households). Adult volunteers available at the time of the survey were interviewed as representatives of the households (i.e., they talked on behalf of all people living in the same house). To identify how people responded to droughts (i.e., decisions on ecosystem management and socioeconomic adjustments for reducing drought impacts and for coping with their effects), we used the information from the household surveys for individual strategies and focus group discussions (12) for more collective strategies.

4.2.4 Potential Supply of Ecosystem Services

In order to assess the landscape potential to supply ES that can reduce the impacts of droughts on people, we used three indicators: land cover, biomass, and species richness (Table 4.2). As shown during the surveys and in the focus groups, people benefit from regulating services that preserve water flows (buffers) and provisioning services that are used as food and energy or for trade when other products are scarce due to drought (safety nets). The potential supply of these ES depends on ecosystem properties (e.g., tree diversity, area, canopy, and root morphology), which influence rainfall interception, water infiltration into the soil, soil stability, and the availability of useful products (Pramova et al. 2012). Our three indicators can help compare the supply of ES between two villages in the same area. Landscapes with large forest areas and high biomass are good providers of water regulation services (Sprenger et al. 2013), and forest cover, biomass, and species richness are positively correlated to the potential supply of forest products (Maes et al. 2016).

Biomass and species richness were assessed through field inventories and their means calculated for each land-use type. We inventoried 120 plots (30 in each village) with an area of 400 m^2 each, located using a stratified random sampling based on land use. The land-use types (e.g., forested areas, rubber or teak plantations, agricultural land, and settlements) were estimated through an unsupervised classification method based on remote-sensing Landsat images. A participatory mapping exercise helped identify the land-use type and confirm their locations. The sample size for the inventories was defined depending on expected biomass amounts per land-use type according to the formula suggested by Winrock International (Pearson et al. 2006), adjusted to have at least four plots per land-use type. The sampling intensity was of 0.004% (V1) and 0.06% (V2) for the large but relatively homogeneous forests in the West Kalimantan villages, whereas it was of 0.2% (V3) and 0.3% (V4) in the smaller and mostly planted forests in the Central Java villages. In circular nested plots, we measured tree diameters (>2 cm) at breast height (DBH), estimated their height, and identified their species with the help of parataxonomists (see (Brown et al. 2005, Pearson et al. 2007)). Above-ground biomass was calculated through the improved allometric equation for tropical trees of Chaves et al. (Chave et al. 2014). The parameters for dry wood specific density were obtained from the ICRAF Wood Density Database (ICRAF 2016) according to the lowest level of botanical identification possible; otherwise, mean values were used.

4.2.5 Demand for Ecosystem Services

Participatory approaches are commonly used with beneficiaries of ES to assess their perceptions and demands for benefits from nature (e.g., (Palomo et al. 2013, Vollmer and Grêt-Regamey 2013)). Previous studies on the demand for ES have indicated that it is influenced by the needs of potential beneficiaries, their awareness, and the opportunity costs for various uses (Schröter et al. 2014, Wolff et al. 2015). To assess the demand for ES by people facing droughts, we used information from household surveys. We asked respondents about their perceptions of periods in which they experienced difficulties in their livelihoods caused by drought (for example, average duration of clean water scarcity), the causes and effects of droughts, as well as the positive or negative influence of forests and trees. With an open-ended question about the factors contributing to drought ("*What are the reasons or the causes contributing to the drought of [year and months]?*"), we observed whether respondents acknowledged the role of forests in buffering drought impacts. Responses from the survey were compared with the drought factors mentioned during the focus group discussions. In addition, to understand the households' needs, we asked the interviewees to score the role of forests and trees in their strategies for coping with droughts on a 5-point Likert scale from "not important" to "very important".

4.2.6 Management Decisions

To assess ecosystem management decisions and their rationale, we used the household surveys, during which respondents were asked to report their strategies for anticipation of or response to droughts ("*What did you or your household do to respond to the impacts of the drought of [year and months]?"*). With the term "response strategies", we mean all interventions undertaken by the household members aimed at meeting needs in times of hardship or reducing future impacts. For each household, we classified the reported response strategies into those that are: ecosystem based from forest and trees, ecosystem based from other resources, and not ecosystem based.

In addition, we conducted three focus group discussions with 12–15 participants per village following rural appraisal techniques, such as examining the seasonal calendar with discussions on natural resources management, constructing a cause–effect diagram with "problem trees" for climate hazards, and using participatory mapping for land use/cover and change (Narayanasamy 2009). During these focus group discussions, we collected information about collective strategies at the sub-village or village level and discussed the most common household response strategies to drought in order to triangulate the validity of information from the survey.

4.3 Results

4.3.1 Supply of Ecosystem Services Contributing to Adaptation

The potential supply of ES from forests and trees was higher in villages with more forest compared to the villages in the same area with less forest (V1>V2 in West Kalimantan and V3>V4 in Central Java). The three selected indicators, namely forest area, biomass, and biodiversity of ES, were lower in the villages with less forest as compared to those with more forest (Table 4.3).

Table 4.3. Indicators related to the potential supply of ES for reducing the impacts of droughts. Source: remote sensing and forest inventories.

	West Kalimantan		Central Java	
	V1	V2	V3	V4
Area [% of village territory with tree cover]	98%	95%	79%	70%
Biodiversity [mean number of tree species in the village territory ± SD]	10 ± 6	9 ± 5	3 ± 1	3 ± 1
Biomass [mean t C/ha in village territory]	141	109	37	33

Most of the landscape in V1 and V2 (>95% of area) was still covered by relatively species-rich seminatural forests (10 tree species on average, Fig. 4.3) with some rubber plantations occasionally mixed with fruit trees (full list of species in Supplementary Materials). The land in V3 and V4 presented a mosaic of patches of agricultural fields and tree plantations of just a few species, such as pine and teak (3 tree species on average, Fig. 4.3). The remaining trees were mostly found on hill slopes, in private gardens as agroforestry systems, and on less productive agricultural land as secondary successions (>70% of land).

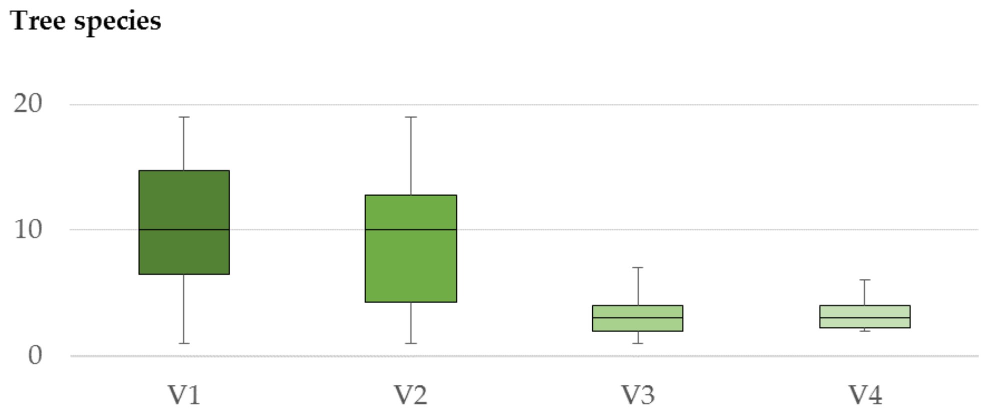

Figure 4.3. Mean number of tree species in the four village territories. Source: forest inventories.

4.3.2 Demand for Ecosystem Services Contributing to Adaptation

In the villages with less forest (V2 and V4) compared to those with more forest in the same area (V1 and V3, respectively), more people recognized the importance of forests and trees in reducing the impacts of drought (Table 4.4). This role of forests was rated significantly higher by people in V3-4 than in V1-2 ($p<0.001$ pairwise comparisons of the means with Tukey-Kramer method). People that recognized this role of forests and trees mentioned that they helped in regulating water flows with positive effects on water scarcity ("thanks to farmers planting teak in their fields, there are more water springs", "community forests are growing very well and clean water is improving") or that they were expected to do so ("new rules to prevent mining and community efforts to plant trees on the river banks will help to improve water conditions").

In the village with less forest in West Kalimantan (V2), more people perceived that deforestation increased the impacts of drought compared to the people in the village with more forest (V1), whereas in Central Java it was the opposite. This could be related to the recent experiences with changes in forests, a reduction (in V2) or an increase (in V3). Several interviewees recognized that deforestation or forest degradation was one of the causes of climate-related disasters because of the negative effects on soil stability and moisture (e.g., "the water was not caught or absorbed", "the soil became more fragile" and "because more sediments are washed away, the river becomes shallower").

In villages in the same area (i.e., V1-2 and V3-4), people reported similar duration of hardship due to drought. During focus group discussions, local communities reported that the latest droughts disturbed the clean water availability for 1 month (in V1 and V2) or 3 months (in V3 and V4) on average. They described that the lack of water caused damages to crops, fruits, and vegetables (V1-4) and impaired river transportation (V1-2), leading to lower income or fewer labor opportunities (e.g., logging, farming, and gold mining), food shortages and higher prices, and more time needed to fetch clean water for washing and cooking.

Table 4.4. Indicators related to the demand for ecosystem services for reducing the impacts of droughts. Source: household surveys.

	West Kalimantan		Central Java	
	V1	V2	V3	V4
Perceived importance of forests and trees for reducing impacts of droughts [% of people who rated it as being of high importance]	40%	55%	75%	85%
Perceived role of deforestation in increasing impacts of droughts [% of people who mentioned deforestation as a factor]	22%	56%	24%	19%
Perceived impacts of droughts [reported duration of clean water scarcity during drought]	1 month	1 month	3 months	3 months

4.3.3 Management Decisions for Adaptation Purposes

Surprisingly, more people in villages with less seminatural forest responded to droughts with strategies based on forests and trees or on other natural resources than did those with larger areas of such forests (Fig. 4.4). In the Kalimantan villages, from 5 to 7% of the households reported strategies based on forests and trees (V1 and V2, respectively), whereas in the Central Java villages, 44 and 37% of the households reported such strategies (V3 and V4, respectively).

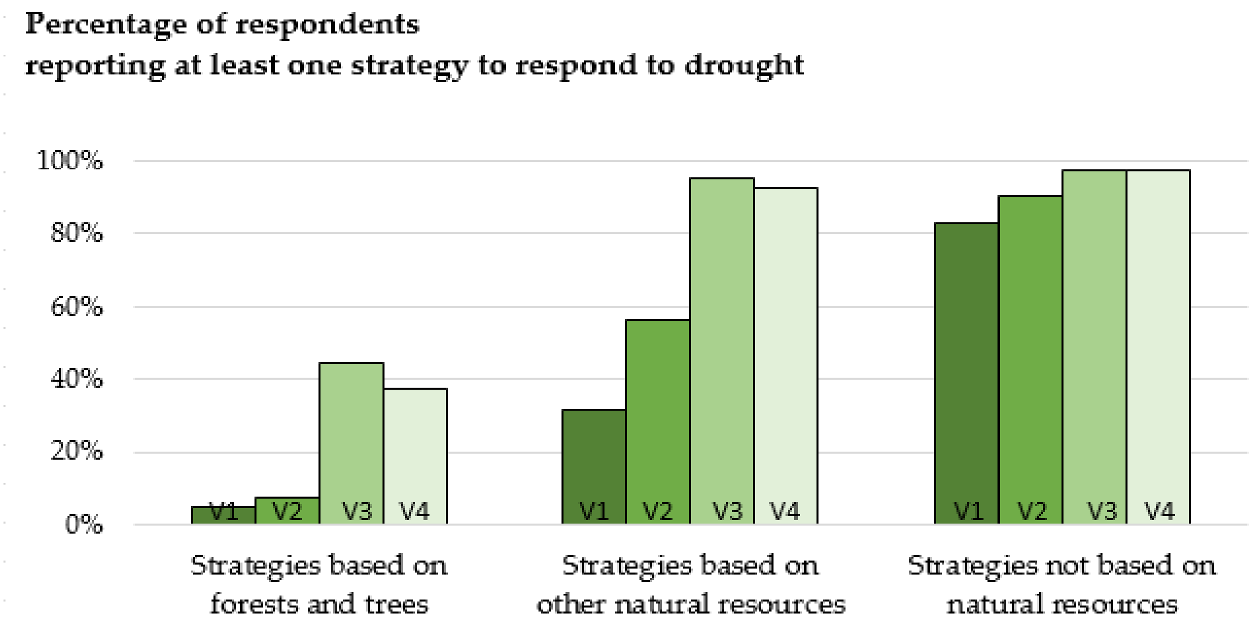

Figure 4.4. Frequency of households reporting response strategies to drought based on forests and trees (e.g., harvesting timber or fuelwood), based on other natural resources (e.g., changing crops or improving water management), or not based on natural resources (e.g., borrowing money or finding off-farm jobs). Source: household surveys.

Most of the strategies based on forests and trees used forest provisioning services to replace sources of food or incomes ("*when harvest is low or fails, we can look for other jobs in the forests*" and "*we can benefit from selling or using several forest products*"). In V1 and V2, people reported that in response to the drought, they harvested and sold fuelwood or timber from natural forests, collected wild fruits or vegetables for food consumption, and collected rubber and hunted as alternative activities for income. In V3 and V4, people harvested wood from plantations to sell for energy or construction, and collected non-timber forest products (NTFPs) such as tree leaves for animal fodder in order to maintain income sources during drought. In all villages, some people planted trees to replace crops on land that was less productive or at risk of harvest failure due to drought.

Some respondents also reported that, as part of their response strategies to droughts, they were harnessing the regulating services of forests and trees by preserving them in specific areas ("*big trees can be kept along the river or hill tops to protect the soil and water sources*", "*trees can be planted or let regrow in critically dry lands*"*).* Trees were part of such strategies especially for their role in water and soil processes (e.g., water runoff, soil erosion, soil fertility), microclimate regulation (e.g., heat, humidity), and physical protection (e.g., from landslides). For example, in order to anticipate and minimize possible impacts of climate hazards, people maintained or planted new trees along rivers (in all villages) and in agricultural fields (V3 and

V4). These regulating services maintained land productivity and protected farmer livelihoods in general, but were of particular relevance in times of scarce rainfall.

Similar to tree-based strategies, more households reported strategies to cope with the impacts of drought that were based on other natural resources in V2 than V1, whereas in V3 and V4 the percentages of households were similar (Fig. 4.3). These strategies were specifically targeting agricultural systems that were affected by drought. They included improving water management (e.g., with irrigation in agriculture), managing soil fertility (e.g., with manure), using alternative fodder sources for livestock (e.g., rice straw), or changing crop varieties (e.g., using more drought-resistant "red rice" seeds or replacing rice with other crops such as maize, cassava, and beans).

Other strategies based on socioeconomic adjustments or anthropogenic assets were prevalently adopted in the villages with less forest in Kalimantan (V2) and Central Java (V3-4). These strategies included applying chemical fertilizers to crops or rubber trees, changing harvest times, borrowing money, buying water bottles and food, changing the diet, selling livestock, or finding off-farm sources of income in the villages or by temporarily migrating to other cities.

In addition to individual households' strategies, communities developed a number of collective initiatives to manage tree and forest cover with the explicit objective of improving water and soil regulation, as well as timber and food provision (Table 4.4). Local authorities or associations had initiatives aimed at protecting or restoring specific forested areas. Climate considerations were part of the reasons for starting these initiatives, together with ensuring livelihoods in a context of market fluctuations, urgent cash needs, limited land availability, low soil fertility, and limited accessibility. For example, the village leader of V2 introduced a formal regulation in 2011, to protect natural forests on hills or along rivers *"for maintaining forest products for our children and protecting us from too hot and wet weather that causes erosion and floods"*. In 2004, the farmer association in V3 promoted tree planting in gardens and on agricultural land which made *"abandoned and less productive land become more (economically) profitable and with the time we also saw benefits for water sources"*. In V1 and V4, similar rules and practices were observed, such as social norms for enforcing forest preservation on some hills and informal logging rules for replanting trees cut in community forests.

Table 4.5. Collective strategies (planned, implemented, and/or controlled by communities in coordination with local authorities or associations) to manage ecosystem services from forests and trees. Source: household surveys and focus group discussions.

Site	Extent[1]	Collective strategies
V1	*	- Apply informal rule to protect trees along rivers and hill tops to control erosion and landslides. - Establish "village forest" (in process) and introduce ban for outsiders and informal harvest rules to limit logging activities. - Collect a logging tax (10% of revenue) to be used for public interests (e.g. repair damage to roads, common buildings).
V2	**	- Introduce formal village rule that protects big trees along rivers for NTFP provision and soil stabilization. - Introduce formal ban of "primary" forest clearing for future uses, maintaining water sources and protecting against heat.
V3	***	- Plant trees in private gardens and agricultural field and build terraces to protect soil and water (initiative coordinated by farmer association). - Avoid the use of water-demanding tree species and replace crops with trees in less productive areas (strategy supported by government and farmer associations).
V3& 4	***	- Adopt formal (V3) and informal (V4) rules for sustainable forest management (minimal harvesting tree diameter and age, mandatory replanting) to maintain tree cover and protect water sources.
V4	**	- Replace crops and houses by tree plantations in areas identified as being at risk of erosion and landslides.

([1]) Extent was evaluated as being on one of three levels: * small extent, ** medium extent, *** large extent, assessed qualitatively based on the proportion of land targeted by the actions.

Local people reported that forested landscapes helped to respond not only to drought, but also to other environmental, social, or economic shocks and stresses. In V3-4, several crop fields were afforested with teak plantations because trees were not damaged by wild monkeys and boars looking for food. In addition, teak plantations compared to agricultural cultivation required less labor that was particularly insufficient due to the high migration of young men. Furthermore, trees could be harvested whenever needed, for example serving as natural insurance to pay for hospitalization fees in case of serious illness (in V3-4). The preserved forests represented alternative sources of food or income when crop yields or rubber prices were too low (e.g., deer, birds, wild vegetables, and fruits).

4.4 Discussion

4.4.1 Potential Supply, Demand, and Management Strategies for Ecosystem Services

Landscapes with less seminatural forests provided less forest ES for reducing the impacts of drought. Several other studies reported similar changes in the supply of ES (Steffan-Dewenter et al. 2007, Gamfeldt et al. 2013, Ferraz et al. 2014). However, high potential supply does not necessarily mean high benefits for well-being or resilience, as some services require active management or other additional anthropogenic inputs before becoming actual benefits to humans (Reyers et al. 2013a, Burkhard et al. 2014). In addition, some provisioning services might not be available or related activities may be discontinued (e.g., farming or harvesting forest products) because they are affected themselves by the climate hazard.

In contrast to the potential supply, the demand for forest ES that helped people adapt to drought appeared to increase when the forests became scarce. Similar increases of demand for regulating and provisioning services from forests in places with less forest have been observed in other empirical studies (Pfund et al. 2011, Urech et al. 2012, Hartter et al. 2014) or explained in theoretical studies (Rudel et al. 2005), although not directly related to climate adaptation. A possible reason is the higher awareness of the benefits of ES of people that had more direct experience with environmental degradation and natural resource scarcity (Sodhi et al. 2010, Meijaard et al. 2013, Villamagna et al. 2013). Similarly, our respondents highlighted experiences with the negative consequences of deforestation caused by logging, agriculture, and mining activities in West Kalimantan (V1-2), or conversion to pine plantations in Central Java (V3-4). On the contrary, people also reported that when forests were re-established or protected along rivers, on hill slopes, or in agricultural fields they noticed positive effects for water and soil.

Local peoples' strategies for responding to drought relied more often on ES in those villages with more degraded forests than in the others. This might be explained by the higher demand for ES recorded in these places, which drives peoples' decisions on possible responses. The low supply can also be a motivation for strategies to actively manage land in order to improve the delivery of ES. For example, in places with high forest cover in West Kalimantan, people might benefit more passively from the still abundant forests and their products and regulating services. On the contrary, in places were forests are scarcer, like in Central Java, people might need to actively manage their land (e.g., by planting or maintaining trees in strategic areas where trees can reduce natural hazards impacts or provide other key services). Similar local efforts to actively manage landscapes with few forests for reducing climate vulnerabilities have been reported in the cases of: the regreening of the Sahel (Sendzimir et al. 2011), the establishment of domestic forests in Southeast Asia (Michon et al. 2007, van Noordwijk et al. 2014), or the planting of trees in agricultural lands in the Ecuadorian Andes (Kathleen A. Farley 2010).

A possible caveat in assessing strategies to respond to climate hazards based on ES is the difficulty in identifying them due to different types and contexts. Benefits provided by forests and trees can be underreported by people living in forested landscapes (such as in V1 and V2) because people use and interact with forests on a daily basis and see these activities as business as usual. In addition, discussing the benefits from forest regulating services is sometimes challenging because they are less tangible. Furthermore, there might be a scale effect because individual actions (deforestation or reforestation) on a small area will not change water regulation at the watershed scale. Managing such services usually requires coordinated action at a large scale, sometimes larger than the scale of community action. Moreover, the local impacts of climate hazards and the response strategies depend on a combination of factors related to both the characteristics of the hazard (e.g., type, intensity) and the affected communities (e.g., experiences, land tenure, land use rights, capacities). This calls for particular attention to be paid to designing appropriate research methods that can capture the diversity of the benefits from forests and of the contextual factors influencing the impact of the hazards.

4.4.2 Ecosystem Services that Help People to Adapt to Drought

Distinguishing between supply, demand, and management to mobilize benefits of ecosystems improves understanding of how ES contribute to increasing people's well-being and adaptation. This is particularly relevant for the emerging concept of adaptation services. Lavorel et al. (Lavorel et al. 2015) define adaptation services as ES that specifically contribute to moderating the impact of climate hazards on people and strengthening their capacities to anticipate and respond to such events. As observed in our case studies, ES can be the basis of several rural livelihoods, some of which can also reduce peoples' vulnerabilities to multiple shocks, and another subset of these services can specifically reduce the impact of climate hazards on people's well-being. Understanding when ES also represent adaptation services do not seem straightforward. Our results suggest that the use of ES to respond to climate hazards, in particular several provisioning (food, timber, NTFPs) and regulating services (water and soil conservation) from forests, vary according to context and thus cannot be defined as adaptation services *a priori*.

Several characteristics of the social-ecological systems affected by multiple hazards influence the delivery of adaptation services. Such characteristics can be related to the ecosystem supply side (e.g., forest cover and conditions, spatial distribution), to the beneficiaries or demand side (e.g., location, knowledge, values, infrastructure), and to their interactions through management and use (e.g., land rights and rules, livelihood dependencies, natural resource availability and accessibility during hazards). Even in places with relatively high potential supply of ES, people might not automatically benefit from certain products that they cannot access or mobilize due to barriers (i.e., such services are not adaptation services), as showed by the fewer management strategies adopted and the lower demand in West Kalimantan. In these places, the use of forest products such as fruits, rubber, and wood was limited during drought by the lack of water, which impaired river transportation and reduced productivity. In addition, low market prices for forests products (e.g., rubber, rattan) or insecure land tenure hindered their use as part of adaptation strategies. Furthermore, forest products required time to be harvested and processed, especially from natural forests because of low accessibility, and therefore were less suited in the case of urgent need. Such constraints of accessibility, legal rights, power relations, or price volatility have been reported in the uses of forest products (e.g., (Eriksen et al. 2005, Robards et al. 2011, Felipe-Lucia et al. 2015a)).

On the contrary, in places where forests are more degraded and have less potential supply of ES, people might still benefit from adaptation services by managing the remaining tree cover more actively. This is the case in Central Java, where forests were more degraded, and farmers had high demand for ES and applied several management strategies that mobilized adaptation services. They established (mixed) tree plantations and agroforestry systems in gardens, let secondary successions grow on less productive agricultural lands, or preserved forests along riverbanks or in watershed areas. Such rural smallholder attempts to maintain multifunctional forest landscapes have also been reported in other studies (Michon et al. 2007, Farley 2010, Lambin and Meyfroidt 2010).

Even if the focus of this study was on climate hazards, land management choices depend on several other factors. People also base land management decisions on a diverse array of environmental, economic, and social drivers (e.g., changes in market prices, labor availability, land area and fertility, household needs). Because such changes are often interconnected and concurrent, it is difficult to distinguish between the contributions of ES to reducing people's vulnerability to climate hazards from other social-economic shocks.

4.4.3 Importance to Identify Potential Supply, Demand, Management Strategies

As the supply, demand, and management strategies that determine adaptation services varied in the study sites with different forest cover, our analysis showed the importance of differentiating these three factors when assessing ES and vulnerabilities. A high supply of ES does not necessarily contribute to adaptation services. Similarly, a high demand for ES might not be satisfied by the actual use and benefit of adaptation services.

High supply of ES, their regular use in daily activities, and management constraints might limit the use of ES as a mean to adapt in places where they are in relatively good conditions (like West Kalimantan). This could help explain why other studies in rural areas with relatively well-preserved forests did not observe any remarkable increase in the use of forest products as a response to hazards. This was the case for peoples' responses to floods, drought, storms, or diseases outbreaks in the national biosphere reserve of Honduras (McSweeney 2004), in the relatively undisturbed natural forests of Indonesian Papua (Boissière et al. 2013), and in multiple countries in close proximity to rich forests (Wunder et al. 2014).

On the contrary, high demand for ES and opportunities to manage landscapes with less forest cover might incentivize the management of adaptation services (similar to the village in Central Java). This is the case in other studies that also found an increase in the use of forest services in times of climate hardship, for example, in forests with rubber and acacia plantations in Viet Nam (Völker and Waibel 2010), in shifting cultivation areas in Peru (Takasaki et al. 2004), in degraded forests and pine plantations in Malawi (Fisher et al. 2010), in savannah landscapes in Burkina Faso (Koffi et al. 2016), and near a degraded forest concession with logging and shifting cultivation in Indonesian East Kalimantan (Liswanti et al. 2011).

4.5 Conclusion

We analyzed how the drought response strategies of rural communities relied on the benefits provided by forests and trees in four tropical forest landscapes with different forest cover. People perceived that forests provided important ES for reducing the impact of droughts and were actively using or managing these adaptation services in their response strategies. Local people harvested more forest products, increased tree cover in agricultural lands, developed sustainable management practices for existing forests or plantations, and protected vegetation cover on hilltops or slopes and along rivers. In this way, some provisioning and regulating services supported the diversification and resilience of rural livelihoods (i.e., represented adaptation services).

In a context of climate variability and change, people had a higher demand for adaptation services in landscapes with more degraded forests, where the potential supply for such services was lower. The high demand encouraged management decisions to restore adaptation services and to use strategies based on forests and trees. At the same time, fewer management strategies based on trees might indicate the presence of constraints that make some services from forest ecosystems less suitable as a response to climate hazards. These constraints can occur when the forests and their products are directly affected by the climate hazard, are not physically accessible, or extraction of products is limited in times of crisis due to time and financial capacity. Therefore, people are not only final beneficiaries of ES, but their livelihoods, preferences, assets, and land-use decisions determine the benefits of ecosystems for adaptation to climate hazards (i.e., whether they represent adaptation services).

Distinguishing between the potential supply of ES, the demand for them, and their actual benefits for local stakeholders can help us understand the drivers of land management decisions. Actively managing and prioritizing certain land characteristics may, for example, reflect the need to increase the benefits from ecosystems to respond to climate hazards in a context of high demand and low supply. Land management strategies reveal peoples' motivations for increasing ES supply when there is a demand for them. Therefore, approaches that consider these different sides of the delivery of ES can improve the relevance of ecosystems and vulnerability assessments by identifying possible barriers or enabling conditions that could be targeted by sustainable land management policies and plans.

4.5.1 Acknowledgments

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CHAPTER 5

Mechanisms mediating the contribution of ecosystem services to human well-being and resilience

Farmers going back home after a day of work in their rice fields.
Local people have modified their landscape by cultivating rice fields and planting teak to get multiple benefits (picture by Giacomo Fedele).

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Mechanisms mediating the contribution of ecosystem services to human well-being and resilience

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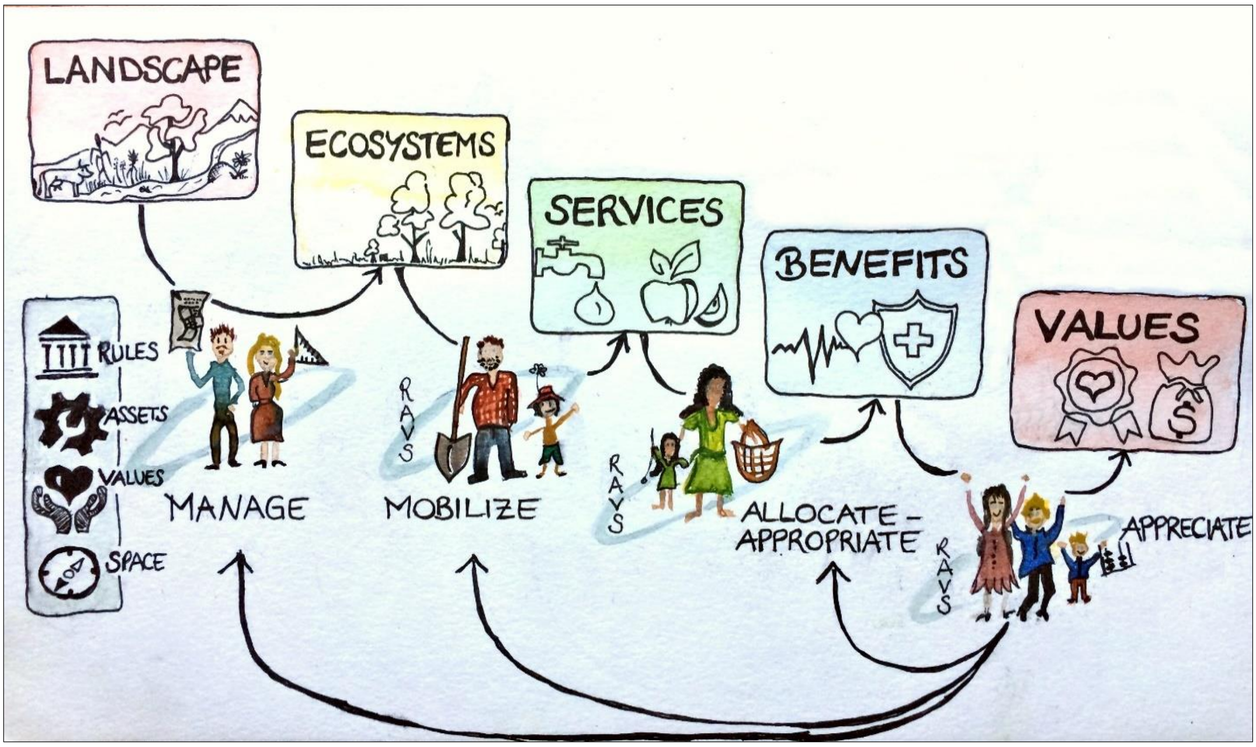
Abstract

Human benefits from ecosystems result from complex interactions between ecological and social processes. People affect ecosystems' capacity to deliver services that contribute to the well-being of humans and their resilience. The delivery of ecosystem services (ES) has often been considered as a linear and direct flow from nature to people without feedbacks or human inputs. We adjusted the widely used ES cascade to highlight how humans mediate each step in the ES delivery. We then applied the proposed framework to empirical field studies in Indonesia. We focused on the role of forested landscapes to increase rural people's resilience to climate hazards such as drought and floods. We found that human actions determine benefits from ES through several mechanisms (ES management, mobilization, allocation-appropriation, and appreciation). These mechanisms are influenced by peoples' decisions along the ES cascade, which depend on specific factors related to rules, assets, values, and spatial context. By facilitating or hindering ES flows, some stakeholders can determine who benefits from ES and influence the well-being of others. A better understanding of the mediating mechanisms, factors, and feedbacks in ES delivery can support the design of sound environmental assessments and sustainable land management practices.

Keywords: social-ecological systems, human well-being, human agency, landscape management, Indonesia, forests.

Graphical Abstract



5.1 Introduction

People continuously modify ecosystems, either to satisfy livelihoods needs, to gain economic benefits, or to adapt to social and environmental changes (Reyers et al. 2013a, Steffen et al. 2015). The tight interactions of people with the environment are the essence of complex social-ecological systems (Gunderson and Holling 2002, Cumming et al. 2006). An example of interactions in social-ecological systems are ecosystem services (ES) that represent nature's benefits to people (MEA, 2005a). Benefits from ecosystems include provisioning services (e.g. clean water, food, timber), regulating services (e.g. climate and water regulation), and cultural services (e.g. spiritual experience, recreation). Because ES are jointly produced in social-ecological systems, both ecosystem processes and human actions contribute to deliver ES (Reyers et al. 2013a, Comberti et al. 2015). Several interdisciplinary research initiatives have explored the ways humans transform and interact within social-ecological systems to increase their well-being. These studies include the Millennium Ecosystem Assessment (MEA, 2005b, Carpenter et al., 2009) and the Resilience Alliance (Olsson et al. 2004, Folke et al. 2004, Kantsler and Steinberg 2005).

Studies on ES have differentiated the supply by ecosystems, the demand of society, and their actual or realized benefits. In this way, they highlight the role of humans in ES delivery

(Villamagna et al. 2013, Spangenberg et al. 2014c). In fact, whether humans can benefit from ES does not only depend on ES supply. It also hinges on the management strategies of stakeholders, their capacities, their access to ES, and their needs in accordance with different social, economic, and institutional contexts (Daw et al. 2016, Wieland et al. 2016). For example, Hicks and Cinner (2014) used an entitlements approach in coral reef fishing communities. They showed that ES benefits are mediated by key access mechanisms related to rights, economics, knowledge, social relationships, and institutions. In addition, a study in a farming landscape in central Romania (Horcea-Milcu et al. 2015) showed that six groups of factors mediate the relationships between ES and human well-being: (i) ES characteristics, (ii) policies, formal institutions, and markets, (iii) social and power relations, (iv) household decisions, (v) perceptions of equity, and (vi) individual values.

The contribution of ES to human well-being happens through different steps as illustrated by the ES cascade framework (Haines-Young and Potschin 2010). The cascade represents subsequent steps in the generation of ES – from biophysical structures and processes to ecosystem functions and ES to benefits and values. This framework has been widely applied (Fischer and Eastwood 2016, Maes et al. 2016). It was further developed to better include the socioeconomic processes intervening in each cascade step (Spangenberg et al., 2014a) (Fig. 5.1) and the role of management (Oudenhoven et al. 2012), governance (Primmer et al. 2015), or socio-political context (Hausknost et al. 2017).

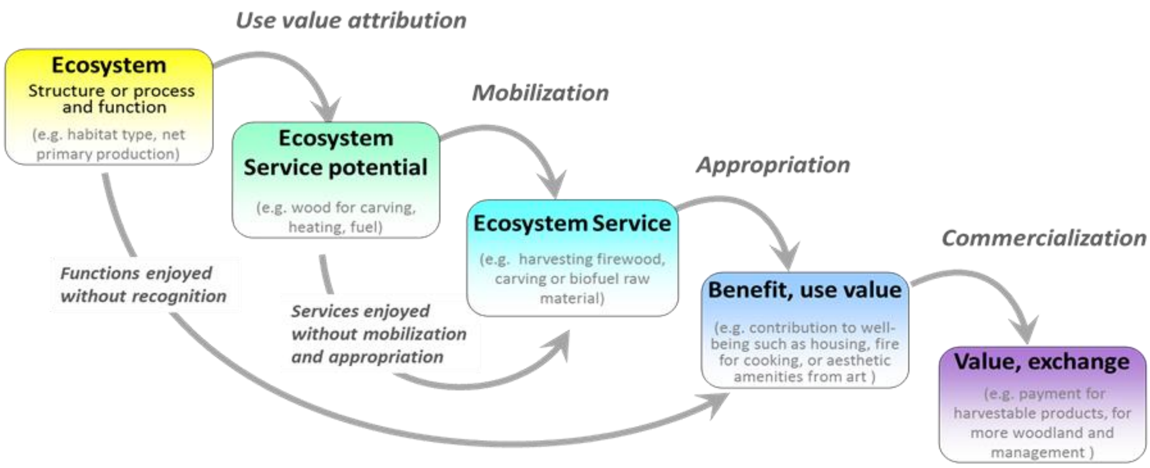


Fig. 5.1. The ecosystem services cascade with the socioeconomic processes leading from one step of the cascade to the next (modified from Spangenberg et al., 2014a). The ES cascade framework represents subsequent steps (colored boxes) in the generation of ES from biophysical structure and process to human benefits and value. The original framework is from Haines-Young and Potschin (2010) and the processes proposed are by Spangenberg et al. (2014a).

This paper analyses the social-ecological mechanisms and the contextual factors that mediate how a landscape and its ES contribute to human well-being. It proposes a framework that expands the ES cascade to focus more on the socioeconomic interactions between subsequent steps of the cascade (i.e. social-ecological system integrated approach). First, the paper introduces the framework of mediating mechanisms and factors based on existing concepts in the literature. The framework includes the influence of humans along the ES cascade to highlight in which steps and how people interact with ecological processes to produce and deliver ES. It emphasizes social-ecological interactions, in which human actions mediate ES flows through mechanisms, factors, and feedback loops. Taking into account these complexities and anthropogenic feedbacks, the framework helps to understand the role and responsibilities of humans in shaping ecosystems and their services. Then, the framework is tested with case studies from empirical in-situ analysis in Indonesia. We considered ES from forested landscapes that contribute to human well-being in the form of increased resilience to climate variability and hazards (as part of resilience to shock and stress in the security constituent of well-being [MEA, 2005b]). Finally, the paper discusses the importance of mediating mechanisms and factors in shaping the generation of ES benefits and the possible implications for land management and policies. We suggest that including such aspects in ES assessments can help design policies and projects based on ecosystems that are more appropriate and feasible in local contexts.

5.2 Conceptual framework of mediating mechanisms and factors

5.2.1 Multiple human contributions along the ES cascade

Human actions play a key role in mediating the delivery of ES – from landscapes to final beneficiaries – and depend on social-ecological contexts. People regulate the combination of ecological and social processes that creates ES through co-construction (making of meaning) and co-production (making of things) (Díaz et al. 2015a, Fischer and Eastwood 2016). Human actions are determined by the capacity of individuals to act independently and make choices, i.e. human agency (Barker 2000). In turn, people's capacity to act depends on structural forces such as institutions and norms that constrain or enable certain choices (Giddens 1984). What individuals can do and be in relation to ES have also been referred to as environmental endowments and entitlements (Leach et al. 1999).

To improve understanding of multiple human contributions, several authors have suggested disaggregating the analysis of ES by specifying the actors involved along the ES cascade and their influences. Analyzing actors, either individuals or groups, is important because their different characteristics (e.g. dependencies, power, interests) give them varying legitimacy and capacities to influence a system (Mitchell et al. 1997). In this direction, several studies have assessed the different social actors' capacities to act on and access ES (Spangenberg et al. 2014c, Hicks and Cinner 2014), their different power relations (Felipe-Lucia et al. 2015b), their aspirations and needs (Horcea-Milcu et al. 2015, Daw et al. 2016), their identities and values (Díaz et al. 2015a, Fischer and Eastwood 2016), and their roles in distributing benefits (Fisher et al. 2009, Serna-Chavez et al. 2014).

We base our ES mediating mechanism and factor framework (Fig. 5.2) on the ES cascade of Haines-Young and Potschin (2010). It is complemented by Spangenberg et al. (2014a) with the human interactions leading from one step of the cascade to the next. We further modified the framework to better acknowledge mediating mechanisms (processes that lead from one step to the other), mediating factors (contextual factors influencing the mechanisms), feedback loops, and the diversity of stakeholders involved. The mediating mechanisms can represent different steps in the process of ES creation and delivery, which is generically referred to as co-production (e.g. Palomo et al., 2016; Reyers et al., 2013). It has also been proposed to reverse the ES cascade into a stairway to highlight the societal efforts involved in creating ES flows, which depend on socio-cultural preferences and political decisions (Hausknost et al. 2017). The mediating factors can represent the social-ecological contexts in which actors take decisions and that has been referred to as social structure (Giddens 1984), contextual factors (Horcea-Milcu et al. 2015), and driving forces (Geist and Lambin, 2002). The feedback loops result from the perceptions and actions of ES beneficiaries or stakeholders that influence ES flows.

In contrast to previous frameworks, ours does not focus on specific ES (e.g. provisioning and cultural services in Spangenberg et al., 2014a) and perspectives (e.g. political in Primmer et al., 2015). In another difference to Spangenberg et al. (2014a), we do not distinguish between potential and actual ES in the cascade (as the difference is unclear for most regulating services). Nor do we distinguish between use value and exchange value in the two final steps of the ES cascade (as such valuations may be viewed as alternatives rather than consecutive steps).

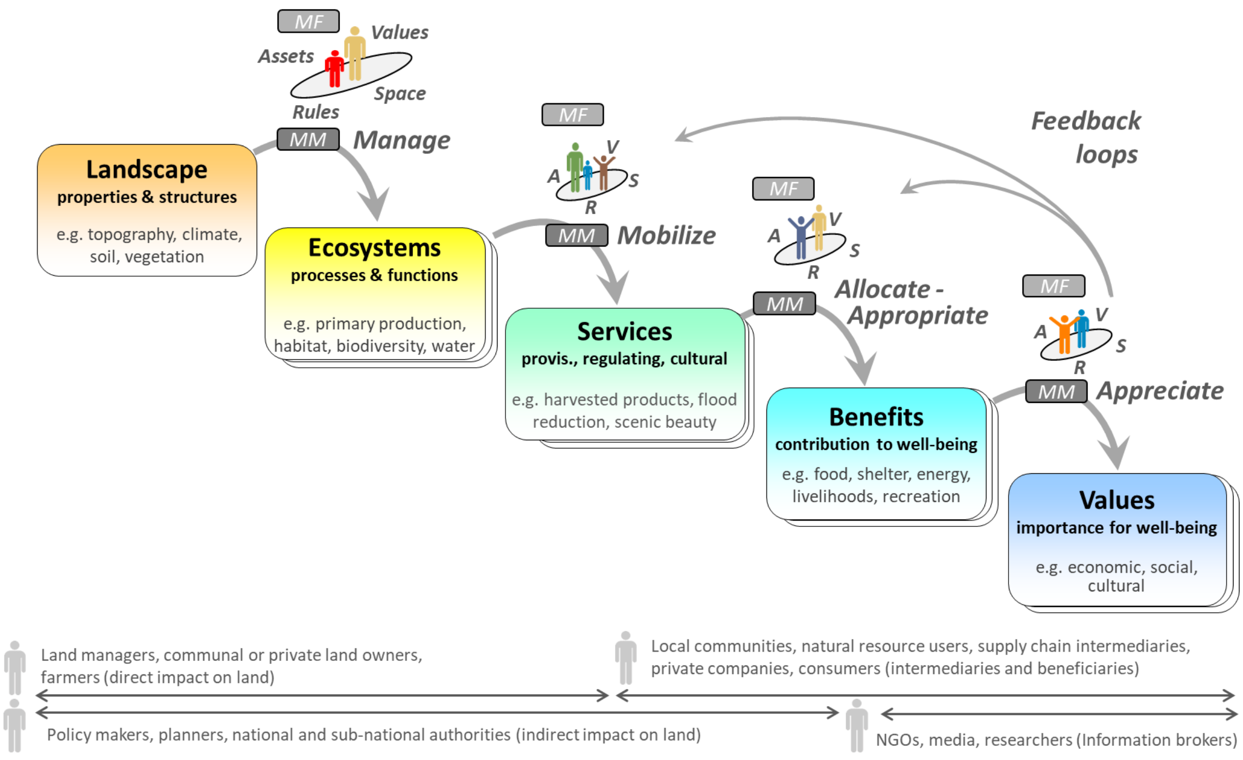


Fig. 5.2. The framework on mediating mechanisms and factors in ecosystem service delivery. It builds on the cascade framework (Haines-Young and Potschin, 2010; Spangenberg et al., 2014a). Mediating mechanisms (MM) control ES flows along the cascade (rightward arrows). Mediating factors (MF) influence mediating mechanisms depending on the diversity of stakeholders involved (examples at the bottom). Feedbacks (leftward arrows) are created by the influence of ES appreciation on mediating mechanisms.

5.2.2 Mechanisms mediating ES flows

We identified four mediating mechanisms (MM) that represent the ways humans intervene in each step of the ES cascade and determine how ES flows are delivered. These mechanisms are management, mobilization, allocation-appropriation, and appreciation (Table 5.1).

Management: people modify biophysical properties and ecosystem structures through management interventions with the aim of protecting, altering, enhancing, or restoring certain ecosystem characteristics of interest (MEA, 2005). For example, indigenous people in the Amazon domesticated several plants with large fruits to enhance their benefits for food production and thus modified the diversity of the forest ecosystem (Levis et al. 2017). In another example, Vietnamese farmers supported the reforestation of a watershed area to enhance regulating services related to soil fertility with benefits for cultivating paddy rice (Meyfroidt 2013).

Mobilization: people add anthropogenic inputs and assets such as work, knowledge, and money to ecosystem functions in order to generate ES (Díaz et al. 2015a). For example, food or timber production requires the use of technical knowledge and harvesting tools. In order to collect the leaves of Marantaceae plants, some women in Ghana have to negotiate with their husbands and co-wives to set aside labor time from other farm or domestic activities (Leach et al. 1999).

Allocation-appropriation: people allocate ES or let them flow to different purposes and beneficiaries. This determines actively or passively who will receive the final benefits depending on power relationships, interests, availability of alternatives, and cost-benefit opportunities (Daw et al. 2011b). For example, cattle farmers in Romania decided to sell or keep cows depending on social assistance policies (Horcea-Milcu et al. 2015). Similarly, water authorities in collaboration with local communities in the Pangani River Basin in Tanzania regulate the water flows through a dyke. In so doing, they decide how much water is allocated for electricity production, irrigation of agricultural land, and wetland habitat downstream (Colls et al. 2009).

Appreciation: people appreciate the contribution of ES to well-being and attribute particular values (e.g. economic, social, or cultural) to them that shapes the demand for ES. For example, an aboriginal Australian community recognize the spiritual values of landscape features, such as natural waterfalls or lakes (Hill et al. 2012).

Not all ES need to go through each step of the ES cascade to provide benefits to people. For example, carbon sequestration or air purification can directly benefit people without any human action or mediation, including knowledge of the ecosystem functions in climate and micro-climate regulation. Similarly, several regulating services and cultural services do not require further human actions through mobilization and allocation-appropriation to be enjoyed. Rather, they depend on the location of people where ES is delivered. For example, wetlands regulate water flows and vegetation on slopes stabilizes the soil. These services reduce the risks of floods or landslides for settlements nearby. In so doing, they provide benefits to downstream or downslope people who are not required to act to mobilize such benefits.

Table 5.1. Mediating mechanisms (MM) determine the contribution of ecosystem services to human well-being by controlling ES flows along the ecosystem services cascade (i.e. management, mobilization, allocation-appropriation, and appreciation). (P = provisioning, R = regulating, C = cultural services).

Mediating mechanism	Description	Example	Reference
MM-Management	People change or preserve land proprieties and structures (soil, water, biodiversity) to enhance specific characteristics of ecosystems of human interest in ways that alter the supply of services.	Plant fruit trees (P), reforest hills (P, R, C), terrace land (R), protect wetland (R, C).	van Oudenhoven et al., 2012 Primmer et al., 2015 Spangenberg et al., 2014a/b Comberti et al. 2015
MM-Mobilization	Anthropogenic inputs and assets (including knowledge) might be added to ecosystem functions in order to produce services that can benefit people.	Travel to nature (C), cultivate land (P), harvest wood (P), build water channel (R).	Spangenberg et al., 2014a Burkhard et al., 2014
MM-Allocation-Appropriation	Ecosystem services are assigned actively or received passively (as a result of previous actions) to a final purpose and beneficiary, i.e. who enjoys the service and how much of it.	Eat a fruit (P), enjoy an iconic bird (C), let cattle graze in field (P).	Spangenberg et al., 2014a Bennett et al., 2015 Daw et al., 2011 Robards et al., 2011
MM-Appreciation	People attribute to the benefit from ecosystem services a particular meaning or value (economic, social, cultural) for well-being, which will determine their demand.	Feel good in nature (C), recognize protection from floods (R), need food (P), energy (P), and clean water (P/R).	Daw et al., 2016 Fisher and Eastwood, 2016 Nassl and Löffler, 2015

5.2.3 Factors influencing mediating mechanisms

Mediating mechanisms transform ES along the cascade. They are determined by contextual mediating factors, which can be required for, hinder, or facilitate the delivery of ES. The literature proposes several examples of mediating factors. These include values-rules-knowledge systems (Gorddard et al., 2016) for decision-making processes in general and, more specifically, driving forces (Geist and Lambin, 2002) or conditioning factors (Börner and Vosti 2013) for management. Other examples are capabilities (Fischer and Eastwood, 2016) and political decisions (Hausknost et al., 2017) for mobilization, distribution factors (Horcea-Milcu et al., 2015) or access barriers (Wieland et al., 2016) for appropriation-allocation, and socio-cultural factors for appreciation (Martín-López et al. 2012).

We classify mediating factors in four groups, namely rules, assets, values, and space. These can be associated with specific stakeholders and contexts (examples of possible combinations of MF and MM in Table 5.2).

Rules can be the formal or informal principles that govern people's behavior, belief systems, and organizational structure (Ostrom 2011). They control the rights of people related to access, distribution, and participation in decision making. For example, a nationally-permitted timber concession grants the timber company authority to change tree composition and structure as well as restricts access to forests (MF-Rules for MM-Management).

Assets include tangible and intangible goods and capabilities that people use for means of living. They influence the ability of people to act and achieve livelihood outcomes and can include the five "capitals" assets (human, natural, physical, social, economic) of the Sustainable Livelihoods Framework (Scoones 1998). For example, the lack of farm labor due to migration or the presence of other job opportunities can lead to agricultural abandonment (MF-Assets for MM-Mobilization).

Values are a set of ethical precepts that determine the way people select actions (priorities) and evaluate events (Schwartz 2012). They are the basis of a society's culture and thus determine principles in life and what is perceived as important, beneficial, or useful (Díaz et al.

2015a, Hirons et al. 2016). For example, trust in traditional medicine increases the importance of medicinal plants and their habitat (MF-Values for MM-Appreciation).

Space refers to the location where benefits are supplied, beneficiaries are found, or risks are present (Fisher et al. 2014). For example, the presence of a population located downstream from a forest determines to what extent hydrological ES can benefit society. Such ES are spatially constrained to the water basin unless distant populations receive water through transfers by irrigation canals or pipes (MF-Space for MM-Allocation-Appropriation).

Table 5.2. Examples of mediating factors (MF Rules, Assets, Values, Space) required for, hindering, or facilitating the mediating mechanisms (MM Management, Mobilization, Allocation-Appropriation, Appreciation) along the ES cascade. These may influence the possibility of different stakeholders to get benefits from forested landscapes.

Mediating mechanisms (MM) / factors (MF)	MF-Rules (institutions, access, rights, markets)	MF-Assets (knowledge, skills, technology, money, infrastructure, social network)	MF-Values (identities, beliefs, aspirations and preferences)	MF-Space (locations, accessibility or transportability)
MM-Management	A private forest company manages a logging concession (MM) attributed by national authorities (MF).	Coastal villagers restore mangroves (MM) after receiving seedlings from NGOs (MF).	Hunters preserve a forest (MM) because they believe in forest spirits (MF).	Communities cut trees in a forest (MM) because they live close by and can physically access it (MF).
MM-Mobilization	Women carve wood handcrafts (MM) thanks to the tools and training given by a women's association (MF).	Farmers improve crop production (MM) by investing their time, money, and skilled labor (MF).	Local people collect mushrooms (MM) because of culinary traditions (MF).	Tourists observe wildlife (MM) after travelling to a lookout site (MF).
MM-Allocation - Appropriation	Coffee farmers get a better income (MM) thanks to a fair-trade system (MF).	The district water authorities distribute water to several users (MM) thanks to pipe systems (MF).	Farmers sell more rice instead of eating it (MM) by changing diets and eating more vegetables (MF).	A water company gets clean water (MM) because it is located downstream of a forest (MF).
MM-Appreciation	A national institution (MF) monitors the effects of ecosystem changes on health and communicates its results (MM).	Thanks to social media (MF), people understand better the benefits of environmental protection (MM).	Local traditional practices and folklore (MF) increase the appreciation of villagers for medicinal plants and their habitat (MM).	People living near a traffic-congested highway (MF) appreciate trees (MM) for their role in reducing air pollution.

5.2.4 Feedback loops between mediating mechanisms

Not only mediating factors can influence mediating mechanisms, but also several feedback loops resulting from the appreciation of ES (from MM-Appreciation back to other MM). These feedbacks represent the demand for ES by beneficiaries that perceive how ES influence well-being thanks to experience or knowledge. In addition, these feedbacks are mediated by the mental processes of perception, interpretation, and evaluation of environmental changes (Meyfroidt, 2013). The way people recognize and appreciate the benefit from ES also has an impact on their behaviors and interactions with the environment. When people recognize that changes in the state of ecosystems or benefits are part of the consequences of anthropogenic actions, they might be motivated to mitigate or reverse such changes by adjusting practices (Schad et al. 2012, Meyfroidt 2013). As a result, these feedbacks might not only reinforce or hinder people's decisions related to ecosystems and their services (i.e. other mediating mechanisms), but they can also modify people's perceptions of ecosystem states and associated beliefs, values, and rules (i.e. mediating factors).

First, the feedback loop resulting from the appreciation of ES can lead to adjustments in land management policies and practices (MM-Appreciation=>MM-Management). For example, there may be increased societal recognition or scientific understanding of the capacity of forests ecosystems to store carbon or regulate water flows in a context of climate change. This can increase the political motivation to reduce deforestation, e.g. through REDD+ or ecosystem-based adaptation policies (Pramova et al. 2012).

Second, different appreciations of ES can affect decisions to mobilize them (MM-Appreciation=>MM-Mobilization). For example, rural communities in Madagascar use Pandanus leaves to produce mats and baskets. This leads women to ask their husbands to guide them to remote forests and carry back harvested leaves (Fedele et al. 2011).

Finally, another feedback can influence the allocation-appropriation of benefits from ecosystems (MM-Appreciation=>MM-Allocation-Appropriation). For example, the popularity of quinoa among Western consumers increases prices for the seeds. This leads farmers in the Andes to export more seeds instead of eating them (Brett 2010).

5.3 Applying the framework to forest ecosystem services & resilience

5.3.1 Approach to the empirical field studies

We applied the proposed framework to empirical field studies in Indonesia. We focused on rural forested landscapes that contribute to people's well-being by decreasing their vulnerability to climate hazards (e.g. drought and floods). We analyzed ES contributions to the security constituent of well-being (MEA, 2003). However, we recognize this is related to other constituents (e.g. health, basic material, and good social relations).

Several ES from forested landscapes can decrease the vulnerability of rural people to climate hazards (Pramova et al. 2012). Forests help diversify incomes or provide alternative food in times of hardship. They also stabilize the soil, control local microclimate, and regulate water. Several studies reported the use of forest ES by local communities for coping or adapting to drought. For example, local communities consumed or sold forest products (e.g. fruits, leaves, or charcoal) in Vietnam (Hoang et al., 2014) and Mali (Djoudi et al., 2013), exploited forest cultural values by guiding tourists in Ghana (Agyeman, 2014), and continued cultivating maize thanks to micro-climate regulating services from forests in Uganda (Hartter et al., 2014). The application of the framework to these four cases from the literature is described in the Supplementary materials.

We selected two provinces of Indonesia, the country with the second largest net forest loss (FAO 2015) and the fifth most frequently affected by natural hazards (EM-DAT 2017) in the last five years. West Kalimantan province is characterized by relatively abundant "natural" dipterocarp forests with some rubber plantations. Conversely, Central Java province has mixed patches of agriculture fields and secondary forests mostly of planted teak and pine (Fig. 5.3). In the two provinces, we selected a rural area in the upper part of watersheds. These areas have been particularly affected by recent climate hazards, such as floods and droughts (based on a preliminary survey).

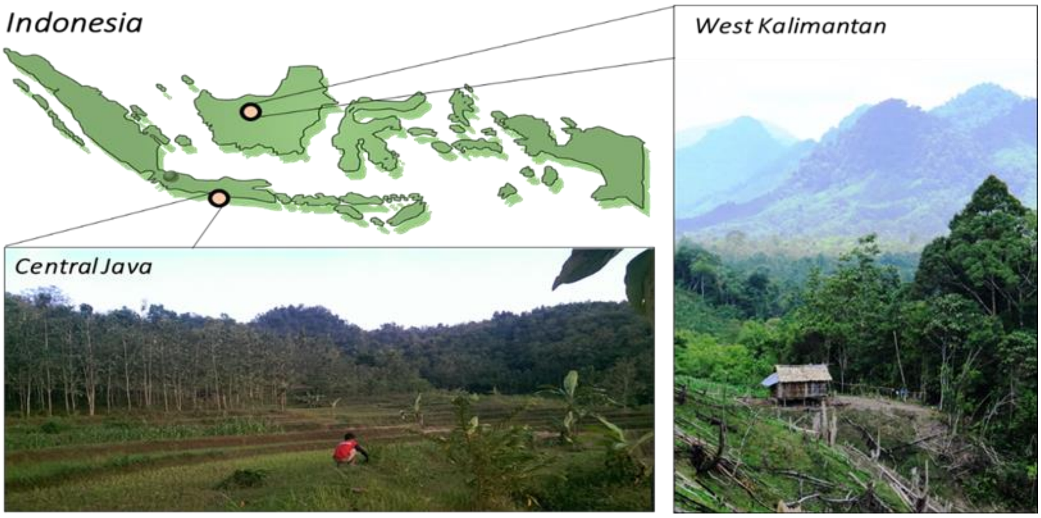


Fig. 5.3. Rural forested landscapes in the Central Java and West Kalimantan study sites. The photos depict teak plantations and rice fields in Central Java and dipterocarp forests and shifting cultivations in West Kalimantan.

The climate hazards affected the livelihoods, assets, and health of the local communities in the study sites. In West Kalimantan, the main livelihoods were rubber farming, artisanal gold mining, and subsistence farming. Because they lived close to a river, local people were often affected by floods. These damaged houses, destroyed crops, and washed away fish from ponds and rubber latex from plantations. In addition, the disruption of the river and the road transport stopped logging and mining activities. In Central Java, communities cultivated rice, maize, soya, peanuts, and vegetables, or raised goats and cows. The droughts reduced agricultural production (up to half of the usual harvest), farm labor, and clean water, and increased food prices.

Data were gathered with interdisciplinary and participative methods. We combined qualitative and quantitative information collected during fieldwork between March 2014 and June 2015. We conducted 180 semi-structured household interviews with adult volunteers available at the time of the visit. In addition, we held 22 focus group discussions with 12-15 participants (farmers, forest users, and off-farm workers, local authorities, and women). During these discussions, we asked about their satisfaction level with the conditions of water, soil, and forest resources over time and discussed possible reasons for changes. In each focus group discussion, we applied several rural appraisal techniques such as participatory mapping, historical timelines, and seasonal calendars (Dazé et al. 2009, Narayanasamy 2009). These were intended to elicit information on the impacts of climate hazards on people's lives and response strategies including those based on forests and trees.

5.4 Results from two empirical case studies in Indonesia

The two case studies in Indonesia highlighted how local communities in different social-ecological contexts responded to the impacts of climate-related hazards on assets, livelihoods, and clean water (Table 5.3). The affected communities had to repair flood damages and coped with drought effects by finding alternative sources of income, food, or clean water (including from market). In addition, they adjusted agricultural practices (e.g. species, fertilizers, irrigation, location) to reduce risk of harvest losses. Some local response strategies were based on forests and trees (Table A1 in Supplementary Materials). People diversified income opportunities or replaced other activities by collecting forest products, such as timber, rubber, agarwood, birds, and deer (Kalimantan), and firewood, pine resin, and leaves for fodder (Java). Forest ecosystems were considered important for both current and future needs: "*maintaining forests is important to ensure that our children will have natural products for their needs,*" said a workshop participant. In addition, people perceived that forests helped preserve land fertility (Java) and stability (Kalimantan), supported farming, and protected people and assets in case of climate hazards (e.g. *"forests and trees help protect us from too hot and wet weather that causes erosion and floods")*.

Table 5.3. Characteristics of the social-ecological systems assessed in the provinces of West Kalimantan and Central Java, Indonesia (data from field survey).

Context	Indicator	**West Kalimantan**	**Central Java**
Ecological	Landscape type	Forest dominated landscape with some shifting cultivations	Mosaic landscape of forest and agriculture
	Forested area (% land cover)	97%	75%
	Main trees (plant family) (densities)	Dipterocarpaceae (40 trees/ha), Rubiaceae (20 trees/ha)	Meliaceae (95 trees/ha) Verbanaceae (90 trees/ha)
	Tree plantations (% land cover)	Rubber (8%)	Pine (5%), Teak (70%)
Social-economic	Main livelihoods (% people)	Rubber (95%), gold mining (50%), farming (30%)	Farming (100%), cattle (60%), construction (15%)
	Services (irrigation, roads, electricity)	Poor	Good
	Nearest market (by local transport)	60 min	15 min
	Population density	0.05 households/ha	0.6 households/ha
Governance	Land tenure	State production & protection forest, private land *de facto*	State protection forest, private land *de jure*
	Participation in decision making	Disputes on forest uses and influential local elite	Strong local organizations, but often no voice

Hazards	Shocks and stress (identified and ranked by decreasing impact by communities)	1. Floods (2012), 2. Drought (2014), 3. Human disease (2010)	1. Wildlife damages (2014), 2. Drought (2011/12), 3. Rice disease (2013)
	Exposure to extreme precipitations	Floods from the river (lasting up to 1 week)	Extended dry period with low or little rain (up to 7 months)
	Water shortages (% people affected)	For agriculture, domestic or transportation uses (40%)	For agriculture and domestic uses (20%)
	Impact on livelihoods (% people affected)	Damages to assets (30%), Loss of crops or rubber harvests (65%).	Loss of crop harvest (90%) Lack of labor opportunities (20%), higher food prices (45%).

5.4.1 Protecting forests in watershed to buffer flood associated risks (West Kalimantan)

In West Kalimantan, local people appreciated forests for buffering the water flows during extreme rainfall and reducing flood damages (MM-Appreciation) (Fig 5.4.). People living near the river experienced floods almost yearly, but they affected larger areas for longer periods recently. Local people associated the increasing intensity of floods with the degradation of forests in the last 20 years: "*agriculture practices (over short periods) and gold mining activities affected the qualities of soil and water,*" "*because companies (previously) and locals (currently) cut several large trees the water flows directly into the river.*"

Local communities managed and protected forests in the watershed (MM-Appreciation=>MM-Management). For example, a village introduced a rule in 2011 to ban deforestation on hills and tree cutting along rivers, where people kept durian and planted other fruit trees, coconut trees, and rubber trees (MM-Management). These trees also replaced more flood-sensitive land uses such as settlements, fishponds, and gardens, which were relocated (entire village hamlets moved twice in the 1990s). By planting or preserving trees and forests, people reduced damages to houses or fields due to floods and erosion that helped them to continue living on those lands (MM-Allocation-Appropriation). However, several households were still affected because either they lacked land or money to move their houses or to build higher poles or an extra floor. In addition, the government did not improve infrastructure in their areas (lack of MF-Assets). This encouraged people to rely more on other readily available means (e.g. by managing forested land) in order to reduce the disaster risks from floods (MM-Appreciation=>MM-Allocation-Appropriation).

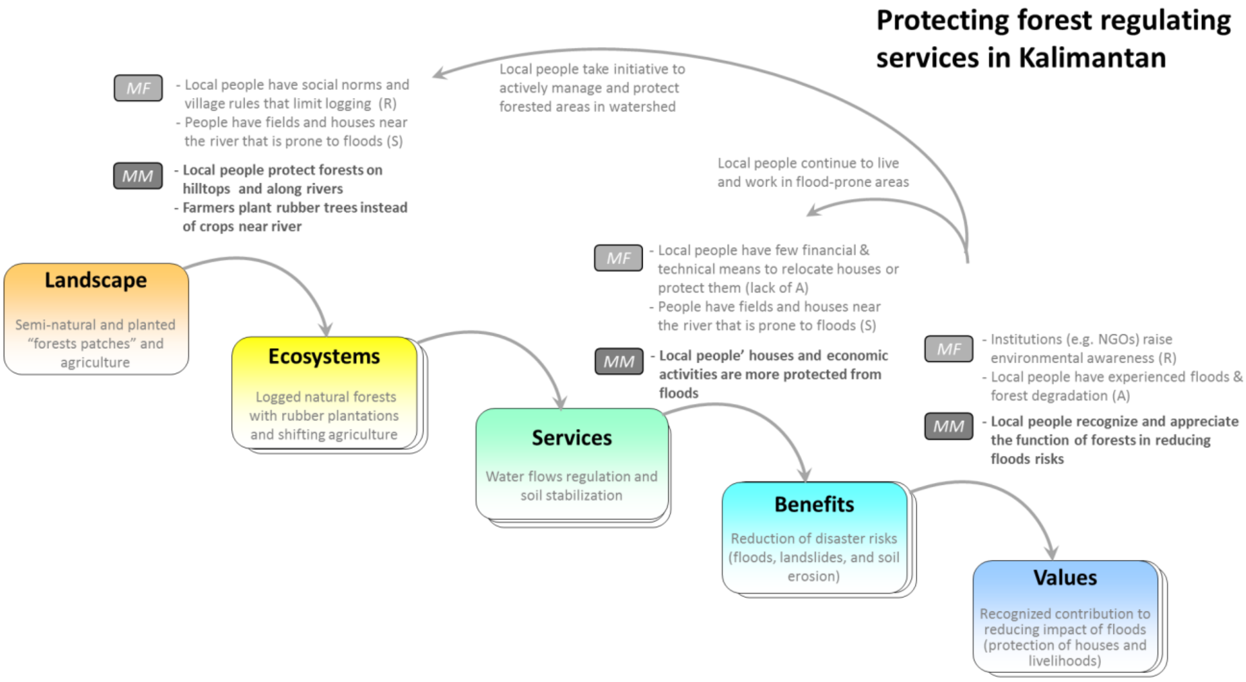


Fig. 5.4. Cascade of ecosystem services to buffer flood associated risks by protecting forests in watershed in Kalimantan.

5.4.2 Re-greening agricultural land to maintain water for agriculture (Java)

Smallholder farmers in Central Java reported water shortages for cooking, washing, and cultivating due to several extended dry periods. As part of the responses to water shortages people adjusted farming practices (Fig. 5.5). Farmers noted that changes in forest cover and species composition exacerbated the effects of drought (MM-Appreciation). In the mid-1970s, the state-owned forestry company converted semi-natural forests into pine monoculture plantations. People recalled that "*when the forest still had different trees, the soil was more fertile and water more abundant.*"

In the early-2000s, the tree cover increased again. This was due to the planting of teak and mahogany in private gardens (agroforestry) and on the least productive dry rice fields (MM-Management) promoted by the farmer association (MF-Rules). Over time, people perceived multiple benefits: "*land became more (economically) profitable and we also saw benefits for water sources.*" The success of the initiative led more farmers to plant trees on their land so that the gardens of three village hamlets are currently covered by trees (MM-Appreciation=>MM-Management). To respond to drought, farmers also changed crops to more drought-resistant varieties (e.g. red rice, maize, soya, and peanut). In addition, they modified crop rotations and quantities according to expected rainfalls (e.g. rice only in the first planting season followed by other crops or fallow).

Some farmers appropriated benefits from state-owned properties and collective goods such as water and land for farming in accordance with local authorities and communities (MM-Allocation-Appreciation). For example, families previously relocated due to the construction of a provincial water basin were still able to cultivate the surrounding areas once the water regressed in dry periods. In addition, landless people could rent some communal lands for agriculture thanks to a village land-sharing scheme. To share water benefits, people also established local management groups (MF-Rules), built irrigation channels, and pumped water from the river or wells (MF-Assets). This management was informed by experiences with water scarcity due to drought and overuse, and the related social tensions and higher prices (MM-Appreciation=>MM-Allocation-Appropriation).

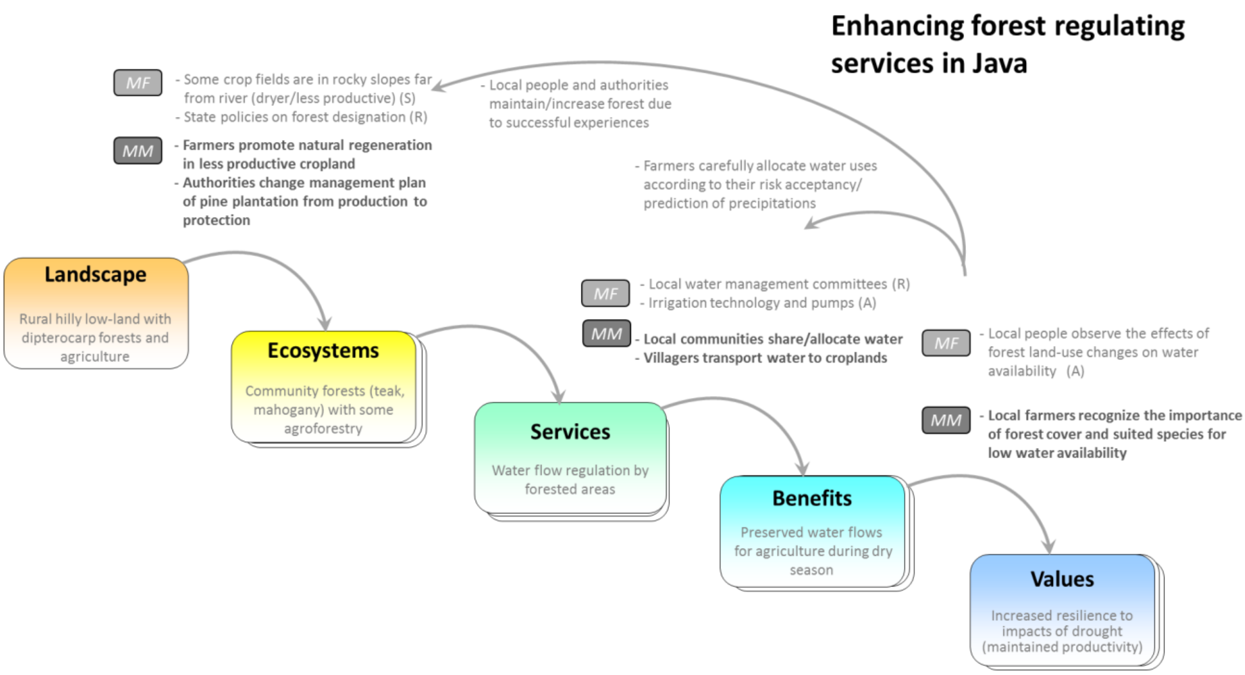


Fig. 5.5. Cascade of ecosystem services to maintain water for crops during droughts by reforesting less productive lands in Java.

5.4.3 Managing forests sustainably for alternative livelihoods (Kalimantan/Java)

Local people in both study sites used forests for timber and other products that helped overcome food and income shortages during drought and floods (Fig. 5.6). They sold valuable forest products to intermediaries, such as ironwood, meranti, and rubber (Kalimantan), or teak, mahogany, and firewood (Java). In addition, they used wild vegetables and deer for food, or leaves for fodder. Forests products helped local communities to diversify their livelihoods and to have alternative income opportunities (MM-Appreciation). In Java, the trade of timber was facilitated by a sustainable certification and the community forests association that helped negotiate higher prices (MF-Rules). Conversely, in Kalimantan, timber trade was more limited. This was due to the remote location of the remaining harvestable trees (species and sizes) and the volatility of rubber prices (lack of MF-Rules).

Communities converted secondary forests into rubber plantations or rice fields in Kalimantan. In Java, they converted some private gardens or least productive fields into agroforestry systems and teak plantations (MM-Management). They also followed social norms or rules to manage forests more sustainably (MF-Rules). For example, in Java they replanted 10 times the number of trees cut in community forests (as per rule book established in 2004). In Kalimantan, they did not cut "primary" forests for mining or agriculture (village rule of 2011), and they established management plans for the "village forest" (committee rules). Local people wanted to maintain forests to satisfy present and future needs (MM-Appreciation=>MM-Management), e.g. *"the rules help us to manage the use of natural resources more sustainably,"* and *"gardens are becoming more green and teak plantations are an investment for the future."*

People fertilized teak or rubber plantations, harvested wood, or tapped the trees for latex, and transported forest products by road or river (MM-Mobilization). These activities were facilitated by the inactivity of the logging company, as well as the presence of forest roads, chainsaws, and speedboats (MF-Assets) in Kalimantan; and by the farmer association coordination (MF-Rules) in Java. However, the use of rivers and bare-soil roads for transportation depended on rainfall (lack of MF-Assets). Both communities established harvest rules (MF-Rules) to increase their own economic benefits (MM-Appreciation=>MM-Mobilization). In Kalimantan, they set a limit on harvest quantities, and established a ban for outsiders, off-limits areas, and harvest taxes. In Java, they prescribed thinning, tree spacing, or minimal diameter harvesting. The tree products were sold to intermediaries depending on market prices and needs (MM-Allocation-Appropriation). People stored rubber latex in the houses, or kept teak on plantations. However, for urgently needed cash, they cut or sold tree products in a practice called “*tebang butuh*” (i.e. “fell as needed” to pay for rice, hospital visits, and school fees).

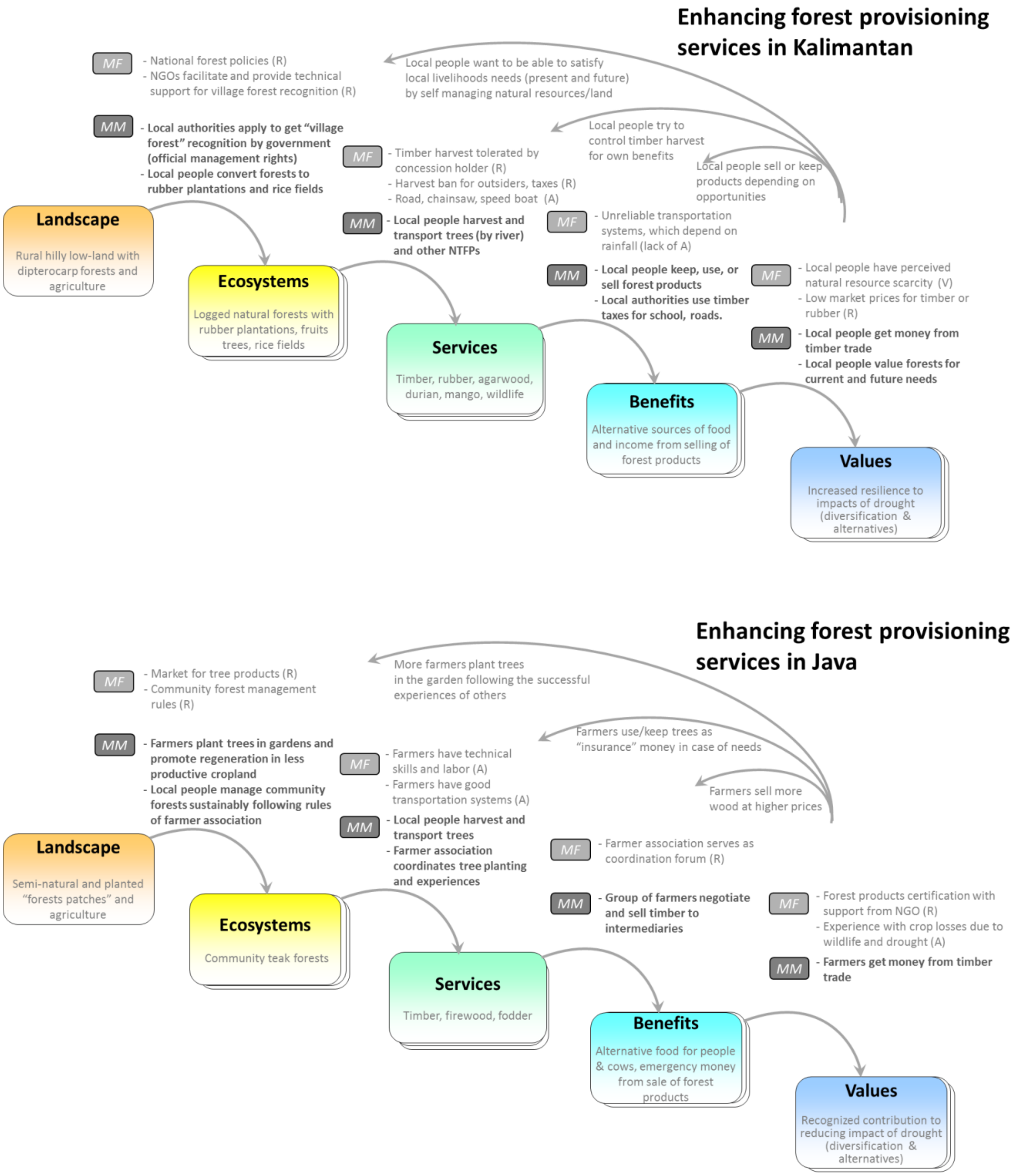


Fig. 5.6. Cascades of ecosystem services from forests and trees to support alternative livelihoods and increase community resilience to climate hazards (floods and drought) in Kalimantan (top) and Java (bottom)

5.5 Discussion

The application of the framework revealed complex interactions between ES flows and different actors that jointly determined how ES were delivered and who benefited. Consideration of mediating mechanisms along the ES cascades helped identify multiple contributions of actors in shaping the ES flows. In addition, the contextual mediating factors helped explain important structural and agency differences in ES flows as well (e.g. values and rules). The crucial role of human interactions in all steps of ES delivery highlighted the importance of an interdisciplinary social–ecological system perspective when assessing ES (Palomo et al., 2016, Díaz et al., 2015; Reyers et al., 2013, Hicks and Cinner, 2014).

Mediating mechanisms (MM) are influenced by multiple mediating factors (MF) that interact among themselves. For example, the remoteness of villages (MF-Space) can explain the lack of infrastructure (MF-Assets) or law enforcement (MF-Rules). This is the case in the rural communities living close to forests in Kalimantan, which had less access to technical solutions or services (e.g. basic water systems or rain-fed agriculture). Similarly, other studies reported that farmers in remote areas lacked irrigation systems in Uganda (Hartter et al., 2014) or alternative animals' fodder in Vietnam (Hoang et al., 2014). In these cases, the lack of substitutes for ES made people benefit more from ES (e.g. water regulation, erosion control, and product consumption). On the other hand, alternative solutions (e.g. technology for water pumping and filtration, jobs, and product markets) might reduce the need to rely on benefits from ES. However, more research on this issue is required (Palomo et al. 2016a).

The diversity of actors that intervene in the mediating mechanisms of the ES delivery determine the final ES contributions to human well-being (Spangenberg et al. 2014b, Fischer and Eastwood 2016). Along the same ES cascade, actors might have diverging interests or needs (i.e. different values, rules, or assets). These differences can lead to conflicts or co-benefits (Locatelli et al. 2013, Lazos-Chavero et al. 2016). As the case of Indonesia showed, there were intermediaries for forest products and national authorities managed some forests. Despite different actors and priorities (e.g. subsistence, conservation, and development), the actions of those in control of management and mobilization resulted in benefits for the local people. However, when the actors involved in ES delivery have divergent views, their relative influences may determine the distribution of benefits (Horcea-Milcu et al. 2015). This is particularly clear for the multiple coexisting forms of land tenure and rights (MF-Rules). Rural communities with formally defined land tenure managed them autonomously (e.g. “village forest” in Kalimantan, private lands in Java). In others, use rights depended on negotiated temporary agreements with authorities (e.g. cut leaves and grass from state forests in Java). In still others, use rights might depend on customary practices that may not be aligned with national laws such as illegal crop cultivation or firewood collection in state forests in Vietnam or Mali (Hoang et al., 2014 and Djoudi et al., 2013).

The framework allows for consideration of who controls the flows of ES along the cascade and who gets the benefits. Distinguishing between different groups of actors and understanding their power asymmetries is key when applying the framework because they affect the ES flows. The analysis of mediating mechanisms and factors helps identify actors’ actions and responsibilities in piloting certain ES flows. It also helps understand their consequences on social conflicts, ecosystem degradation, equity, and sustainability (Martín-López et al. 2012, Djoudi et al. 2013).

The dominant views of certain actors influence the mechanisms of ES delivery and as a result they can either facilitate or hinder the ability of other groups to obtain benefits. Contrary to common beliefs, some apparently more vulnerable groups actually showed higher capacities to respond to climate hazards. For example, the tolerance and solidarity of authorities in Java in granting access to land for displaced farmers (MF-Rules) decreased inequalities. In another example in Mali, thanks to their skills and fewer social constraints(MF-Assets and MF-Rules), women of lower social class had more income opportunities to cope with drought than women of higher social class (Djoudi et al., 2013). Through environmental awareness (MF-Assets), some migrants in Uganda adopted more sustainable forest practices compared to local inhabitants (Hartter et al., 2014).

People’s evaluation of changes in ecosystems and their benefits can trigger feedbacks on land-use decisions by local actors (Marshall et al. 2005). Actors that appreciate benefits from ecosystems and notice changes, such as scarcity of timber or water, soil erosion and low productivity, can adjust their practices to reach certain desired social-ecological conditions (e.g. enhancing forest and tree management in Java and Kalimantan). In addition, people’s experience and learning can modify beliefs and attitudes related to ecosystem and their services (as part of mediating factors). The motivation of local actors together with other mediating factors (e.g. forest policies, natural resources prices) ultimately influence the implementation of people's land-use decisions.

Feedback loops originating from the appreciation of ES benefits (MM-Appreciation) may either reinforce or challenge the current ES flows. Impact on ES flows depends on actors' satisfaction and control over the mediating mechanisms. Positive feedbacks, in which beneficiaries appreciate the current ES flows, can strengthen the management, mobilization, and appropriation-allocation mechanisms (MM) that contribute to the well-being of those beneficiaries. For example, in Java, people valued forest ES contributions to their livelihoods. They thus followed national initiatives to conserve or restore forests. However, when actors are excluded or only marginally benefited from the current ES flows, they may create negative feedback loops. This, in turn, can lead to changes in the mediating mechanisms. In several cases, local people can react to ES benefit exclusion by pressuring the current forest management policies and practices. In Kalimantan, people began a process of recognition for local forest management rights. In Mali, local communities proposed new or stronger local institutions for fairer natural resources management (Djoudi et al., 2013). In Vietnam, rural farmers tried to open up negotiations for less restricting national policies on forest uses to be able to practice agroforestry in these lands (Hoang et al., 2014).

The application of the framework also considers the influence of actors at different scales, which are included as part of the mediating factors. Although the case studies focused on local scales, several behaviors or decisions of communities were influenced by policies or dynamics at higher scales that were outside of their control. Regional factors included migration patterns in Java, and shifting cultivations practices in Kalimantan. National factors included land concessions policies and infrastructure development in Kalimantan. At the international scale, factors can include global markets, for example for wood or rubber in Indonesia or for ecotourism in Ghana (Agyeman, 2014).

The proposed framework helps disentangle how ES flows can take different forms depending on multiple actors involved in mediating mechanisms. Still, it remains challenging to identify the steps of the ES cascade and describe their flows. A methodological challenge, for example, is related to analyzing people's decisions and their drivers in order to identify mediating factors. Similarly, due to the heterogeneity of actors and power dynamics, it remains challenging to assess all different perspectives. In addition, actors' interests, perceptions, and roles change over time (Lazos-Chavero et al. 2016). Therefore, actors might adjust their behavior to follow new social, political, or ecological circumstances. Although we recognize the importance of including these dynamics in ecosystem services assessments, in this study we only provided a snapshot of current social-ecological situations. However, it could be possible to build multiple ES cascades at different times following the proposed framework and the changes in mediating factors associated with the actors involved.

In addition, landscapes often provide multiple ecosystems services simultaneously that interact and overlap, which increases the complexity of applying the framework. Here we built separate ES cascades for the field case studies in Indonesia. Analyzing more ES at a time would help identify trade-offs between different ES, actors, and management strategies (Bennett et al. 2009b, Locatelli et al. 2013).

5.6 Conclusion

In this paper, we modified the widely-used ES cascade framework to describe more accurately the social-ecological interactions that influence ES flows. The framework reflects the importance of human decisions that mediate the social-ecological processes that co-produce ES in each step of the cascade. The framework can guide and structure ES assessments and highlight several social-ecological interactions that shape ES delivery for a specific ES at a given time.

Consideration of mediating mechanisms and factors in ES assessments would enable environmental managers and policy makers to make more informed decisions. Such information can identify who is able to get what benefits. In so doing, it can highlight potential barriers or conflicts to be tackled, or enabling conditions to be strengthened. In addition, ES cascades can represent “impact chains” that can be used to develop different indicators to evaluate the impact of land-use changes on human well-being. A better understanding of the mechanisms and factors shaping the flows of ES can help design land management interventions that promote the equitable and sustainable delivery of ecosystem services towards increased human well-being.

5.6.1 Acknowledgements

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5.7 Supplementary materials

5.7.1 Additional information about the Indonesian case studies

Table A1. Three empirical cases from Indonesia on ecosystem services from forests and trees that increased community resilience to climate hazards (floods and drought). The ecosystem services cascades were mapped out using the framework on mediating mechanisms (MM management, mobilization, allocation-appropriation, and appreciation) and factors (Rules-Assets-Values-Space).

Framework elements	**Protecting forests in watershed to buffer flood associated risks (Kalimantan)**	**Re-greening agricultural land to maintain water for agriculture (Java)**	**Managing community forests sustainably for alternative livelihoods (Kalimantan and Java)**
Landscape	Low land hilly landscape with dipterocarp forests and some agricultural fields.	Landscape with a mix of agricultural fields and forest patches (mostly few species plantations on hilltops and gardens).	Same as 1+2
MM **Management**	Local people protect forests on hilltops and along rivers (MM) through official village rules and social norms (MF-Rules). Farmers plant rubber trees instead of crops in areas near river (MM) because trees resist floods, which are frequent in this location (MF-Space).	Farmers promote natural regeneration (MM) in less productive cropland far away from water sources (MF-Space). Authorities change management plan of pine plantation (MM) from production to protection (MF-Rules).	Local people manage community forests sustainably (MM), following formal rules (MF-Rules) from farmer association (Java) or management committee (Kalimantan). Farmers plant trees in gardens (Java) or convert forests to rubber plantations (Kalimantan) (MM) because of markets for tree products (MF-Rules).
Ecosystem structure and processes+	Logged tropical natural forests with rubber plantations (H. Braziliensis), fruit trees, shifting cultivation of rice, and small settlements along rivers.	Planted tropical dry forests (teak, mahogany, pine), agricultural land with crop rotations (rice, soya, corn) and agroforestry.	Same as 1+2
MM **Mobilization**	None	None	Local people harvest and transport forest products to intermediaries (MM) using vehicles (Java) or river boats (Kalimantan) (MF-Assets). Harvest of timber by local people (MM) is tolerated by land concession holders (Kalimantan) or coordinated by famer association (Java) (MF-Rules).
Actual Service	Forest regulating services for controlling water flows and stabilizing soil.	Forest regulating services for controlling water flows and soil fertility.	Forest and trees provisioning services for wood (both sites), rubber, agarwood (gaharu), durian, mango, wildlife (Kalimantan) and fodder (Java).
MM **Allocation-appropriation**	Local people's houses and economic activities are protected from floods (MM) despite living near the river (MF-Space) and lacking financial and technical means (lack of MF-Assets).	Local communities share/allocate water (MM) through local associations (MF-Rules). Villagers transport water to croplands (MM) through irrigation systems and pumps (MF-Assets).	Famers in Java negotiate and sell timber to intermediaries (MM) through the farmer association (MF-Rules). Local people in Kalimantan keep, use, or sell forest products (rubber, timber) (MM) depending on favorable market prices (lack of MF-Rules) and transportation conditions (lack of MF-Assets).

Benefit for well-being	Reduced disaster risks from climate hazard (protection from floods, landslides, soil erosion).	Preserved water moisture and soil fertility for maintaining agriculture production during droughts.	Alternative sources of food (people and animals) and income from selling forest products during droughts or floods.
MM **Appreciation**	Local people recognize and appreciate the function of forests in reducing floods risks (MM) thanks to experiences (MF-Assets) and institutions (e.g. NGOs) that raise awareness (MF-Rules).	Local farmers recognize the importance of forest cover and suitable species for water availability (MM) thanks to observation of the effects of land-use changes (MF-Assets).	Local people appreciate forest benefits for cash or subsistence (MM), which were increased by forest certification (MF-Rules) in Java.
Value	Recognized contribution of forest ES to increasing resilience and reducing flood impacts (by protecting houses and livelihoods).	Recognized contribution of forest ES to increasing resilience and reducing the impacts of drought (by maintaining agriculture productivity).	Recognized contribution of forest ES to increasing resilience and reducing the impacts of drought and floods (by providing diversified and alternative livelihoods).

5.7.2 Findings from four selected case studies in the literature

We applied the proposed framework to case studies in the literature. We searched published case studies through Google Scholar (key words: hazard AND climate AND rural AND ("resilience" OR "adaptive capacity") AND ("forest ecosystem services" OR "ecosystem services from forests"). Among the numerous results (>400), we selected the four case studies with the best information about ES cascade steps (e.g., stakeholders, management, benefit sharing) and that represented different ES types.

The four case studies highlighted how forested ecosystems in tropical or sub-tropical areas in Mali, Vietnam, Uganda, and Ghana provided different types of ES (provisioning, regulating, and cultural) that helped rural communities reduce the impact of droughts on livelihoods (Table A1 or Fig. A1-4). Extended low rainfall periods decreased the productivity of crucial land-based activities (agriculture, livestock, forestry, and fisheries). In response, local people developed strategies to cope or adapt, including some based on forests and trees. They diversified livelihoods, for example, but they also replaced lost income opportunities in several ways. They used or sold forest products (fruits and leaves from agroforestry systems in Vietnam or charcoal in Mali) or exploited forest cultural values (income from accompanying tourists to watch wildlife in Ghana). In addition, the micro-climate regulating services from forests helped maintain farms during drought (e.g. continued production of maize and potatoes in Uganda).

Table A2. Four case studies from the literature on ecosystem services from forests and trees contributing to rural people's resilience to drought in Mali, Vietnam, Uganda, and Ghana. For each case study, we mapped out the ES cascade using the framework on mediating mechanisms (MM management, mobilization, allocation-appropriation, and appreciation) and factors (MF Rules, Assets, Values, and Space).

	Forest ecosystems services contributing to people's resilience to drought			
Case study	Firewood collection in a former lake in Mali	Food production through agroforestry in Vietnam	Local climate regulation for agriculture by protected areas in Uganda	Ecotourism to diversify livelihoods in Ghana
ES	Provisioning	Provisioning	Regulating	Cultural
Reference	*Djoudi et al., 2013* *Brockhaus et al., 2013*	*Hoang et al., 2014* *Nguyen et al., 2013*	*Hartter et al., 2014* *Hartter et al., 2012*	*Agyeman, 2014*
MM-Management	Natural reforestation in former lake (MM) because of less grazing due to war (lack of MF-Rules). No long-term forest management (MM) by communities or state (lack of MF-Rules).	Farmers plant trees in cropland (MM) using their agroforestry knowledge (MF-Assets). Farmers replace some trees with crops or other trees in state forest (MM) because of weak law enforcement (lack of MF-Rules).	Farmers maintain forests (MM) partly because of protected areas rules (MF-Rules).	Villagers reduce wood harvest for charcoal production and protect indigenous trees (MM) for cultural value (MF-Values). Villagers manage vegetation along river and forest (MM) because tourists enjoy nature (MF-Values).
MM-Mobilization	Only women of lower social class harvest firewood and produce charcoal (MM) because of social norms (MF-Values).	Farmers cultivate land and harvest agroforestry products (MM) investing money and labor (MF-Assets).	Farmers cultivate land (MM), whose productivity is higher near the national park (MF-Space), and lack irrigation (lack of MF-Assets).	Local people organize tourist activities in nature (MM) by using canoes and knowledge of the area (MF-Assets).
MM-Appropriation-Allocation	Women negotiate prices and sell charcoal to intermediaries (MM) because they lack means of transport (lack of MF-Assets).	Farmers eat/sell part of the harvest (MM), but suffer from low market prices (lack of MF-Rules). Farmers feed animal with leaves (MM) because of no alternative (lack of MF-Assets).		Local people work in ecotourism-related activities (MM) thanks to its proximity to a national park (MF-Space). Community shares revenue from tourism (MM) through public projects (e.g. school) coordinated by village committee (MF-Rules).
MM-Appreciation	Women value forest as income source during drought (MM) because it is the only resource they have access to (lack of MF-Assets). Women in town buy and appreciate charcoal (MM) as local energy source (MF-Values).	Farmers recognize that tree-based systems are more resilient to drought than farming (MM) because of experiences with crop failure and forest degradation (MF-Assets).	Farmers appreciate forests' role in maintaining rainfall and temperature for agriculture productivity (MM) thanks to awareness of the consequences of forest losses (MF-Assets).	Local people recognize forest benefits (MM) because tourists like nature activities (MF-Values). Tourists enjoy experiences with iconic species and indigenous culture (MM).

The rural communities in the four case studies managed forested landscapes to maintain livelihoods and protect them from several economic or environmental shocks, including climate hazards (MM-Management). Although climate considerations were not the only reason, people increased or maintained tree cover in several areas. For example, near a lake that dried out in Mali, natural reforestation of Prosopis and Acacia trees supported women with firewood to substitute lost agricultural activities. In Vietnam, fruit trees and Acacia were intercropped in fields of rice, soya, and potatoes to reduce droughts' impact and diversify products (food, wood, and fodder). In Ghana, people protected Baobab and Shea trees and managed swamp vegetation for tourists, who wanted to observe wildlife and iconic trees. In Uganda, people near a national park complied with conservation rules because they recognized the importance of trees to maintain soil fertility for agriculture. In the four case studies, the forested areas belonged to the state. Thus, national policies and rules influenced local management practices (MF-Rules). Local people had official management rights in Uganda and Ghana, but not in Mali and Vietnam, where they followed customary rights.

In all case studies, people invested time, labor, and skills to mobilize the forest ES to help increase resilience to drought (MM-Mobilization). They collected wood and produced charcoal (Mali), practised agroforestry, harvested crops, fruits, and fodder (Vietnam), and facilitated tourists' visits to wildlife (Ghana). In Uganda, the micro-climate regulating services from forests did not require any further human input to maintain soil fertility for agricultural production during droughts. However, several case studies reported that the lack of technical capacities, financial resources, land availability, political influence, or infrastructure hindered ES mobilization (lack of MF-Assets).

People in the four case studies enjoyed the benefits from forest ES directly or shared them (MM-Allocation-Appropriation). For example, women in Mali sold charcoal to intermediaries; farmers in Uganda and Vietnam used crops for subsistence; and communities in Ghana shared common revenues from tourism by investing in village schools.

The long distance to the market (MF-Space) hindered the trade of products in Mali, Uganda, and Vietnam. On the other hand, the proximity of the villages to forests helped communities get benefits from the provision of timber in Mali, from the water and micro-climate regulating services in Vietnam and Uganda, or from the cultural services in Ghana. In addition, local associations coordinated benefit sharing. They were supported by formal and informal rules at sub-national/national levels (MF-Rules) to share benefits equally (Ghana). When it was not the case, as in Mali or Vietnam, people complained about the lack of such benefit-sharing systems (lack of MF-Rules).

In the four case studies, communities valued forested landscapes for their contributions to maintain sources of food or income when other opportunities were limited due to droughts (MM-Appreciation). Local people sold forest products (Mali), crops (Uganda and Vietnam), or forest-related cultural services (Ghana). In addition, women in cities in Mali appreciated the charcoal coming from the Prosopis forests for its better quality, and the tourists in Ghana enjoyed observing wildlife in their natural habitat.

Experiences with land degradation, resource scarcity, and harvest losses due to climate hazards all reinforced community perceptions of the importance of forests and trees. Information campaigns from NGOs or government agencies (MF-Assets) also helped spread this message. In fact, the communities in all four case studies recognized linkages between forest conditions and the impact of drought. The specific linkages were related to rainfall in Uganda; soil fertility in Vietnam; and livelihood opportunities in Ghana and Mali.

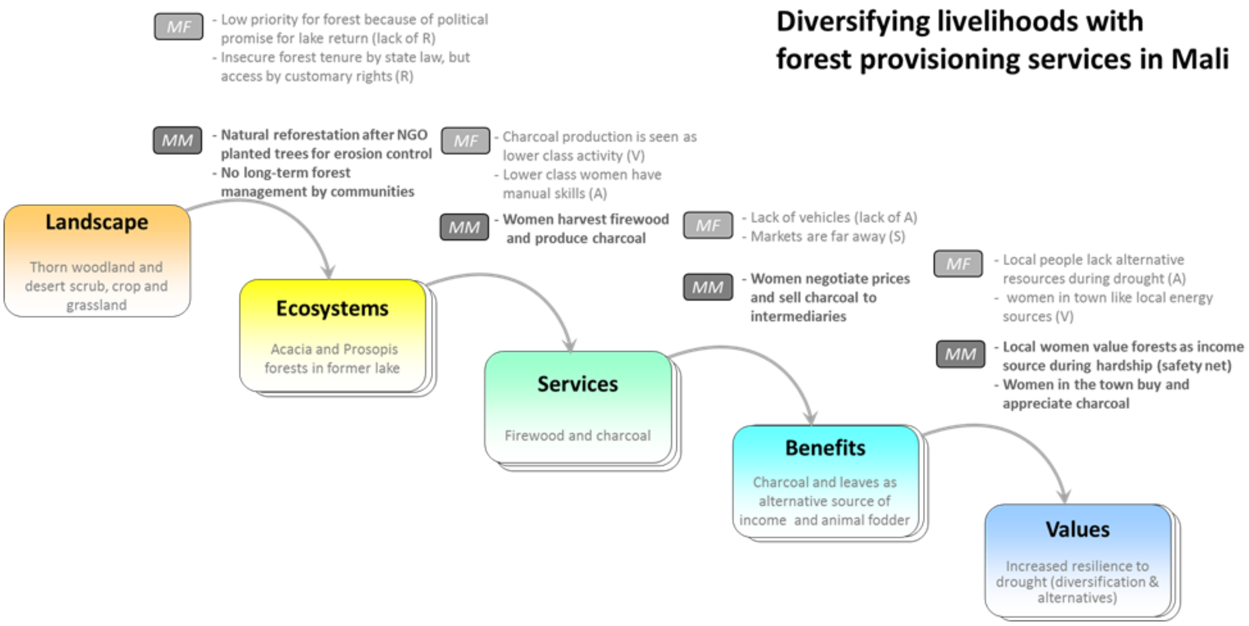

Fig. A1. Cascade of ecosystem services from forests and trees to support firewood collection in a former lake in Mali.

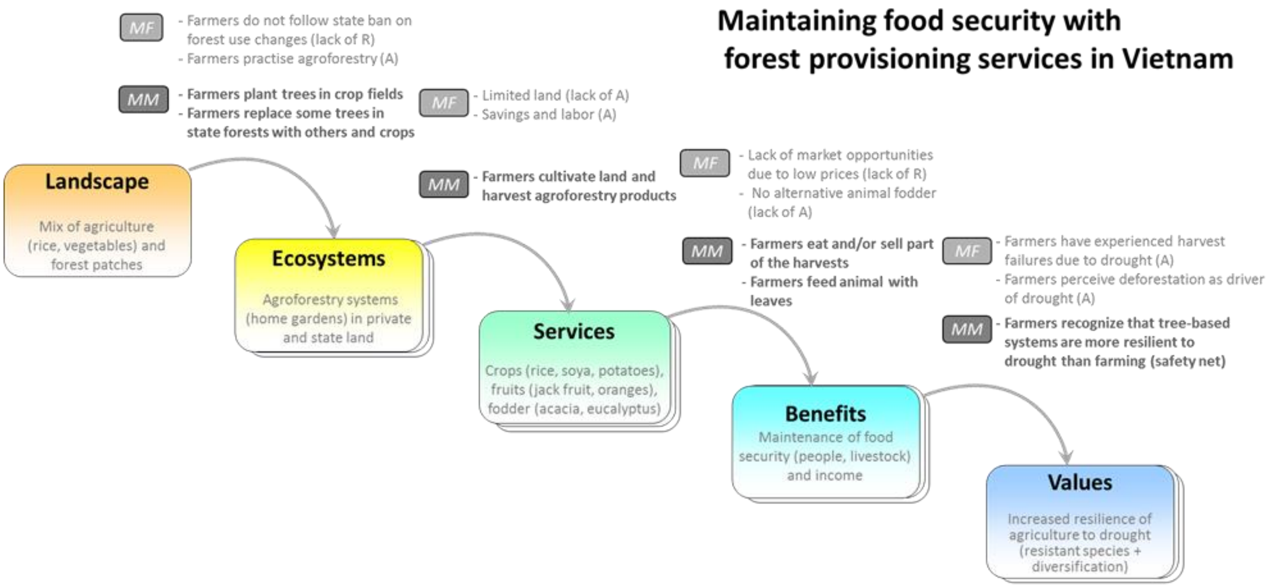

Fig. A2. Cascade of ecosystem services from agroforestry systems to support food production in Vietnam.

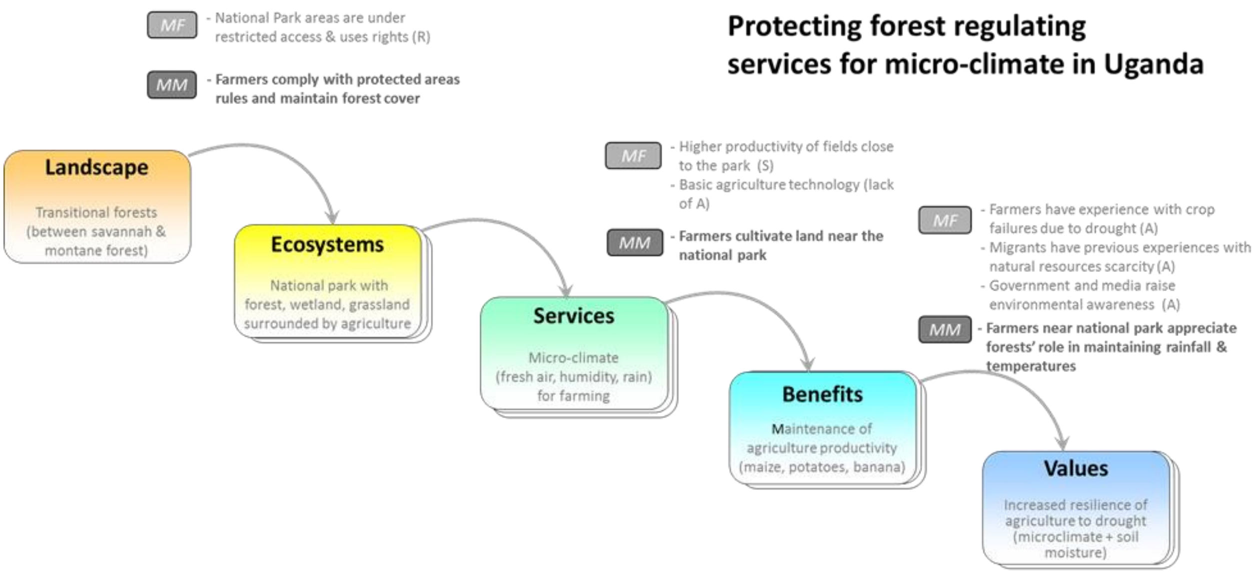

Fig. A3. Cascade of ecosystem services by protected areas to support local climate regulation for agriculture in Uganda.

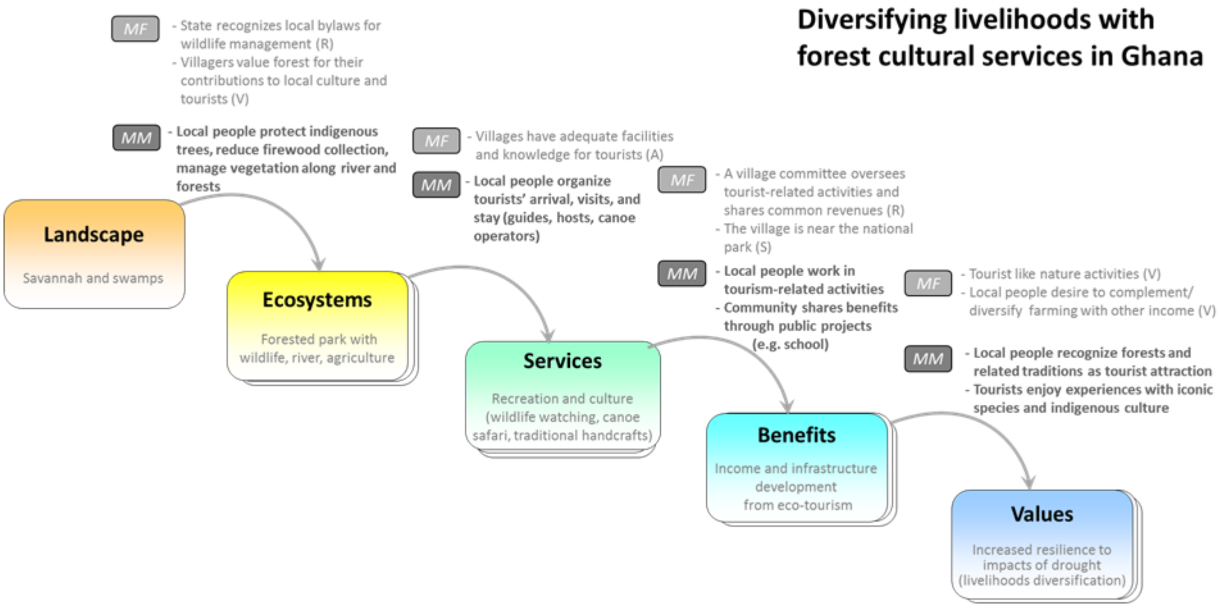

Fig. A4. Cascade of ecosystem services by ecotourism site to diversify livelihoods in Ghana.

CHAPTER 6

Synthesis, discussion, and conclusions

Travelers in the shade of an old tree overlooking a landscape in the uplands of Flores. This research in Indonesia helped shed some light on the multiple human contributions and impacts on ecosystem services (picture by Samson Foli).

6.1 Summary of the findings

This thesis investigated four research questions related to local land management practices and the provision of ecosystem services in a context of climate variability and change. The four research questions are recalled here below and the main findings are summarized with recommendations for improving ecosystem assessments and policies or practices related to climate change adaptation.

Sub-Research Question 1: How people perceive benefits from ecosystem services and use them in their adaptation strategies to climate hazards?

In chapter 2, we identified the major climate hazards that affected livelihoods and assets in the study sites in the last decade, namely floods, droughts, and pest outbreaks. We described the impact of those climate-related hazards such as reduced clean water, damaged houses, declined agricultural yields, and disrupted transportation systems (river and road). We then investigated the role of forests and trees in reducing local human vulnerabilities to those hazards. We identified different response strategies implemented by local people in the four studied villages. Most of the strategies to respond to climatic hazards were technical solutions (e.g. pumping water, increasing physical protection to houses and fish ponds, modernizing equipment in rubber plantations). Several other strategies also aimed to increase the use of agricultural inputs (applied fertilizers and pesticides), change agricultural practices (new seeds varieties or crop species rotation), and seek external help (e.g. through social networks or government agencies). Few household strategies were based on ecosystem services provided by forests and trees. Tree and forest based strategies were used either for recovering after the climate hazards and for anticipating and buffering possible future impacts. Most strategies based on tree and forest products, such as selling timber or rubber, substituting leaves for livestock fodder, and collecting wild vegetables for food, were reactive strategies for recovery from climate-related hazard. Community collective strategies included the anticipatory management of forest and trees for buffering climate impacts, mostly though regulating services. For example, local communities coordinated trees planting in gardens, protected vegetation along rivers and hill slopes, and reforested less productive croplands.

The role of forest and trees in reducing local people vulnerability to the impacts of climate change varied according to three different factors, such as the type of ecosystem services (provisioning vs regulating), timing of strategies (reactive vs anticipatory), and forest types. Provisioning services were most prominent in household adaptation strategies (especially as individual coping strategy after the disaster), while regulating services were less reported (but were part of collective anticipatory strategy before the disaster). Natural and planted forests were used differently depending on the availability of products (e.g. timber, firewood, NTFPs) and their accessibility during disasters. Therefore, it is important to distinguish ecosystem services, strategy timing and ecosystem types when assessing vulnerability and ecosystem services, in order to fully capture the contribution of forests and trees to reducing human vulnerability.

Sub-Research Question 2: How does landscape management strategies in response to climate hazards affect the supply of ecosystem services at multiple scales?

In chapter 3, we assessed how major land-use changes at the local level to respond to climate risks impact the supply of multiple ecosystem services. We considered several benefits provided by ecosystems that are relevant at different scales (products, water, carbon, and biodiversity). Local people converted forests, protected them, or planted trees in their landscapes to diversify local livelihoods and maintain land productivity under changing conditions such as climate variation and natural resource scarcity. The results highlight how these changes in land uses affected provisioning services from forests and agriculture and increased local benefits. These changes affected biodiversity and water regulating services, as well as carbon sequestration, and had therefore an impact at scales beyond the local scale. We illustrated how some strategies (such as planting teak trees in garden or less productive crop fields) spread in the landscape and resulted in an extensive transformation of the landscape. We analysed the role of reinforcing feedback loops in the socio-ecological system driven by local actors who perceived that some land-use changes positively affected livelihoods, reducing risks and generating other co-benefits.

The chapter highlights how local needs may lead to land-use changes with consequences on multiple ecosystem services and beneficiaries. Understanding possible trade-offs or synergies between ES during those changes is crucial. Landscape management for adaptation (or the enhancement of adaptation services) does not only contribute to local adaptation pathways but can also potentially benefit biodiversity, water, and climate change mitigation. The analysis showed that people have already developed local initiatives to protect trees or increase tree cover and that these initiatives can be expanded. Adding the adaptation benefits to ecosystem management objectives means therefore, to build on local initiatives that contribute to achieve several development or environment objectives simultaneously, including the reduction of local vulnerabilities. This point is particularly relevant due to the increasing number of international initiatives that recognize the linkages between different global challenges and thus the need for integrated solutions, such as climate change, biodiversity, and sustainable development in the UN Sustainable Development Goals, the UNFCCC Paris Agreement and the Convention of Biological Diversity Aichi Targets.

Sub-Research Question 3: How do ecosystem services supply and people needs explain strategies to manage ecosystem services?

In chapter 4, we assessed the potential supply of forest ecosystem services, the demand for them by local communities, and the management decisions to mobilize such services to decrease drought impacts. Not surprisingly, the selected indicators to assess the supply of ecosystem services (forest area, biomass, and tree biodiversity) had lower values in the villages with less forest compared to those with more forest. Yet, in landscapes with low forest cover, where the supply of ecosystem services was more limited, people rated forests and trees with higher importance to reduce impacts of droughts and undertook more actions to enhance ecosystem services provision for this purpose.

Distinguishing between the potential supply of ecosystem services and the demand for them by local communities can help understand the drivers of land management decisions. Actively managing land may, for example, reflect the need to increase the benefits from ecosystems to respond to climate hazards in a context of high demand and low supply. On the contrary, in places where forests are abundant but people adopt few management strategies based on them, there might be constraints that make some services from forest ecosystems less suitable in responses to climate hazards. These constrains can occur because forests and their products can be directly affected by the climate event, they are not physically accessible during the climate event, or people have limited access rights, or they require time and financial resources that are limited, particularly when ecosystem services were not managed pro-actively, before the climate event. Therefore, approaches that consider both the supply and the demand sides of the delivery of ecosystem services can improve the operationalization of ecosystems and vulnerability assessments. Such assessments can be useful to identify barriers or enabling conditions that could be targeted by sustainable land management policies and plans.

Sub-Research Question 4: How do people decisions and inputs influence the delivery of ecosystem services?

In Chapter 5, we proposed a revisited ecosystem services cascade that highlights how humans influence each step in the delivery of ecosystem services (mediating mechanisms). The revisited cascade includes contextual mediating factors that influence people's choices and thus facilitate or hinder the flow of ecosystem services. We applied the framework to case studies from the literature and from empirical in-situ analysis in tropical forested landscapes in Indonesia. The results showed how different context specific mechanisms underlying the human actions influence and shape ES contributions to human well-being. This occurs through several mechanisms related to ES management (promotion of specific land proprieties and structure), mobilization (addition of anthropogenic inputs), allocation-appropriation (assignment of final purpose and distribution to beneficiary), and appreciation (value attribution). These mechanisms are influenced by people decisions as well as their position and power along the ES cascade, which depend on specific factors related to rules, assets, values, and spatial context. By facilitating or hindering ES flows, some stakeholders can determine who benefits from ES and influence the well-being of others.

In this chapter we discussed how ecological processes are actively maintained, complemented, or partially modified by human interventions to co-produce ecosystem services that can result in human benefits. Thus, we suggested adjustments to the ecosystem services cascade to address the criticism that ES delivery is depicted as a linear and direct flow from nature to people, with little attention to feedbacks or human inputs. We introduced social-ecological mechanisms and contextual factors that mediate the delivery of ES in different steps of the cascade. A more explicit consideration of mediating mechanisms and factors in ES assessments would enable environmental managers and policy makers to make more informed decisions. Including and analysing the mediating mechanisms underlying human decisions along the ES cascade can help to understand the specific roles of different stakeholders, their converging or diverging interests, and the distributional nature of ES (who gets what?). In addition, ES cascades can be used as “impact chains” to assess the impact of land-use changes on human well-being. By considering the mechanisms shaping the flow of ES at different levels of the ES cascade, we enhance our understanding of the roles of different stakeholders and their power relations in the delivery of ES. This insight can help design well informed land management interventions that promote a more equitable and sustainable delivery of ecosystem services.

6.2 Methodological considerations and challenges

Integrated assessments of ecosystem services and climate change impacts in rural forest tropical landscapes are challenging because of the needs for multidisciplinary approach and data. By combining social and ecological methods, our approach tried to get a holistic understanding of socio-ecological systems, but also faced methodological challenges. For example, it was difficult to obtain the same level of information detail for social and ecological data. Challenges also related to the cross-scale nature of this research, as socio economic data is mostly related at the household and village scales while ecological and climatic data was relevant at the plot, landscape or regional scales.

The assessments of the ecosystem services at the local scale was constrained by the lack of proxy indicators and their reliance on data on soil, vegetation, precipitations, and water fluxes that were rarely available for the study areas. For instance, the lack of ecological spatial data at fine scale at village scales hindered the use of modelling for estimating the supply of ecosystem services. The use of species richness in ES assessment is debatable because services might depend more on specific functional properties of species rather than their diversity.

The interpretation of perceptions of the importance and the use of ecosystem services can be also biased. The use of forest products can be underreported by people living in forested landscapes (e.g. West Kalimantan) according to cultural and social norms. For instance, people might underestimate their use of provisioning ecosystem services because they interact with forests on a daily basis and perceive these activities as ordinary and natural. In addition, benefits from forest regulating services are less tangible and thus more difficult to identify with communities. Another challenge is related to the heterogeneity of communities in regards to social positions, wealth, and personal histories. This creates methodological challenges when analysing sensitive issues like access to and use of natural resources. The proper use of participatory methods can address some of those challenges. A relationship of trust between the researcher and the communities is also a way to improve data collection.

One methodological challenge is related to understanding the rationale of local people for deciding upon land management strategies. The strategies of farmers or local people are explained by land availability, market prices, family needs, financial resources, and climate vulnerabilities. The global and regional and political economy of natural resource might play an important role in shaping farmer decision and land use changes for some globally traded forest and tree products. In addition, decisions are highly context-dependent, which makes difficult comparisons between sites with different characteristics.

6.3 Future perspectives

This research was designed to strengthen our understanding on land management practices that shape the delivery of ecosystem services in a context of climate variability and change in rural communities. The findings can inform the development of balanced and context specific ecosystem-based responses. In Indonesia, climate change policies and plans consider the important role of sustainable management of forests and agriculture to achieve climate change adaptation and mitigation objectives. For example, the Indonesia's National Determined Contribution (NDC) aim to reducing carbon emission by 26% by 2020 and increase resilience and plans include improvements in forest and agricultural management practices (e.g. "conservation agricultural approach", "Community Based Forest Management" with forest protection and restoration e.g. Fig 6.1) (Governement of Indonesia 2015). In addition, the National Action Plan on Climate Change Adaptation (BAPPENAS 2013) aims to reduce vulnerabilities in the agriculture and forestry sectors by 2030. These existing policy entry points represent opportunities to help address one of the major obstacle for Indonesian climate policies, namely the "insufficient […] knowledge on vulnerability and adaptation options in forestry and agriculture" (Gregorio et al. 2015). Therefore, we reflect in the next section on the relevance of our research findings, linking them to emerging scientific debates and their contribution to relevant ongoing policy processes to help tackle climate change issues in their complexity.

Fig. 6. 1. Tourists observing nature and wildlife in a national park in Kalimantan. Picture by Giacomo Fedele.

6.3.1 Building on local efforts to scale-up ecosystem-based adaptation

Ecosystem-based adaptation (EbA) is one of several strategies to address the effects of climate change. While local communities already adapt by using ecosystems and their services, the mainstreaming of EbA in climate policies and initiatives is still limited partially due to a lack of knowledge on successful stories. There are few examples of ecosystem-based adaptation from rural tropical regions, especially compared to developed countries as well as other hard infrastructure or policy solutions. The findings of this research provide evidence on how rural communities affected by climate hazards are taking actions to cope with, and anticipate, such impacts. In addition, we reported several autonomous adaptation strategies of rural communities based on trees and forests. Furthermore, we described the contextual factors that facilitated or hindered the adoption of such strategies (e.g. values, rules, assets, knowledge, space).

Widespread and integrated solutions are needed to limit global temperature increase below 2 °C and increase resilience as committed in the Paris Agreement and the actions planned in the national determined contributions (NDCs). Such solutions include EbA measures, as they contribute to both climate change adaptation and mitigation objectives. The design of ecosystem-based adaptation can benefit from existing examples of good practices, innovations, and experiments if they are documented, such as the "seeds of good Anthropocene" initiative (Bennett et al. 2016). In our four Indonesian case studies, rural communities have developed initiatives to reforest, develop agroforestry, and protect forests and can be part of these examples (Chapter 2-3). Bottom-up EbA strategies with multiple benefits (e.g. resilience, biodiversity conservation, food security, and low carbon development) could be expanded with support from policies. Such up-scaling could support the goals of protecting 17% of terrestrial land (Aichi Target 11 of the convention on biodiversity) and restoring 150 million hectares or 15% of degraded land by 2020 (Bonn Challenge and Aichi target 15 respectively).

6.3.2 Emphasizing human roles in ecosystem services delivery

Our analysis supports the view that ecosystem services are not a free gift from nature to humans, but rather that multiple inputs from people are crucial for their co-production and delivery. Humans drive changes in ecosystems and regulate their service supply, distribution, and benefits to final users. Acknowledging these roles, we proposed a multidisciplinary and integrated framework on mediating mechanisms and factors (Chapter 5) to assess ecosystem services and land management options. Through the case studies in Indonesia, we demonstrated how analysis guided by this framework can reveal the variety of human actors and contributions in delivery of ecosystem services. The benefits people can derive from ecosystems are embedded in a specific social context and articulates within social practices, power relations, values and norms. Stakeholders involved in the ecosystem services cascade have different power, capacities, and worldviews, which can facilitate or hinder the flow of ecosystem services (highlighted in the "mediating factors" discussions in Chapter 5). Some groups can act as barriers, whereas other groups might enable or catalyse ES delivery. In addition, actors influencing the ES flows might act at different scales or be influenced by factors at different scales, for example the management and appreciation of ecosystems and their benefits can be influenced by international climate policies and demands for natural resources. Therefore, ecosystem assessments that include the diversity of human roles from ES supply to final benefits can identify leverage points to be addressed by policies or projects. The IPBES Framework is a promising recent effort in this direction because it embraces the diversity of values that people attribute to nature and go beyond currently dominant economic valuations (Díaz et al. 2015).

The plurality and heterogeneity of stakeholders should be better considered when assessing ecosystem services because it can help design more locally appropriate and sustainable conservation or development projects. Human benefits from ecosystems are rooted in existing institutions and cultural norms that might maintain relations of inequality or on the contrary contribute to shifting power relations. Therefore, there is a need to assess changes in the flow of ecosystem services, not primarily as a reaction to external stressors and changes, but also as a result of internal power dynamics, structures and institutions, taking into account collective and individual strategies.

6.3.3 Reconciling diverging interests at landscape scale

Competing interests can arise everywhere in ecosystem services, from who should manage the land to who should get access to benefits, resulting in trade-offs among different services and people. Along the same ES cascade, actors might have diverging interests or needs (i.e. values, knowledge, or assets), which can lead to different management choices. Climate change can drive land-use changes that alter ecosystem services, which in turn can lead to trade-offs at different scales. There are well-known trade-offs between the provisioning services and other services that can be relevant for climate change adaptation. As shown in Chapter 3, maintaining food security despite decreasing precipitation might be achieved through agriculture intensification (e.g. more rubber plantation in West Kalimantan), but it is likely that such practice will further reduce water regulations and carbon sequestration. It is challenging to try to balance different land-use interests, such as increasing food production, conserving biodiversity, and reducing carbon emissions, especially in a context of increasing population growth and land scarcity. A continued delivery of ecosystem services with inclusive benefits at different scales will require a mix of landscape planning and policy solutions tailored to local contexts.

To identify locally appropriate EbA measures that also provide benefits at higher scales, it is key to understand, analyse, and involve multiple stakeholders at different scales. The involvement of multiple stakeholders and interests is one of the main principles of the landscape approach (Sayer et al. 2013). Thus, there is a need to better link the flow of ecosystem services to the social dimensions (e.g. heterogeneities, existing power relations, and institutions) to avoid solutions which might exacerbate exiting power misbalances and create new vulnerabilities. Participatory methods for gathering local knowledge can complement scientific analysis. Including the analysis of varying interests and views on ecosystem services in early stages of the research design can highlight trade-offs and synergies and enhance the relevance of findings for practitioners and policy makers. Identifying local EbA measures that minimize trade-offs between ecosystem services can help implement successful actions for climate change that consider different stakeholder interests at different levels (Chapter 5). This could be particularly important for climate change mitigation initiatives (e.g. REDD+, climate-smart agriculture, sustainable forest management) that could consider local benefits (e.g. for adaptation) to improve their legitimacy and sustainability.

6.3.4 Guiding landscapes transformations for sustainable futures

Different framings of climate change adaptation, including Ecosystem-Based Adaptation, have been debated by climate scientists and practitioners. However, the debate is still dominated by views on incremental adaptation rather than on more radical adaptation that transform human interactions with nature (Bassett and Fogelman 2013). Most of the current strategies to respond to climate change issues seek to accommodate changes, rather than addressing the root causes of vulnerability, creating more sustainable alternatives, or anticipating changes. However, the IPCC recognizes that without considering transformational changes in our interactions with nature we might invest in unviable adaptations and miss opportunities for longer-term solutions. Transformative adaptations in ecosystem management can avoid critical changes in ecosystems, deliberately guide already ongoing shifts, or restore ecosystem functions to previous states. Successful bottom-up ecosystem-based strategies, such as increasing tree cover in gardens and crop fields (in Central Java) or restricting forest uses along rivers or on slopes (in West Kalimantan) can be replicated and scaled up becoming transformational. Therefore, ecosystems management to be part of the options not only for adaptation solutions, but also for transitions that lead to more sustainable and inclusive development trajectories.

Because climate change is causing unprecedented impacts on ecosystems and the people who depend on them, management responses aimed at coping or incrementally adapting might no longer be enough. To match the scale and intensity of the challenges caused by climate change, transformative responses are unavoidable or even desired. In some cases, the possibility of losses need to be considered. A common thread running through the Sendai Framework (UNISDR 2015) and the Paris Agreement (UNFCCC 2015) is the recognition of ecosystems in disaster risk reduction and adaptation strategies because they can be part of solutions but also critically affected. Scientific progress should underpin such ambitious policy objectives. Colloff et al. (2017) argue that it is time to redirect 'normal' science towards new models because the world has changed so much, also due to climate change. In this regard, the transformative adaptation of social-ecological systems relates to a social process in which we critically re-evaluate the relation of humans with nature, the political-economic and governance arrangements, and the value systems for nature, in light of the risks that climate change poses or will pose in the future.

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ANNEXES

Annex 1: household survey

A. General Information - ASSETS

[Ask the participant for their consent to participate (and record) the interview. Explain to the respondents that we will start asking general questions regarding the whole household (= answer will refer to all members[1]), the information will be kept completely confidential and anonymous (published in aggregated form)]

1.	Country /Province :	[__/ __]	code: 1=Indonesia (1= Kal, 2= Java)
2.	Village :	[___] Name [____]	code: 1= with more forest, 2= with less forest
3.	Date :	[__ __ ______] dd/mm/yyyy	code:
4.	Household:	[__ __]	unique progressive number
5.	Sex:	□ (1) Woman □ (0) Man	
6.	Marital status :	□ (1) Single □ (2) Married or living together □ (3) Widowed □ (4) Divorced	
7.	Total number of household members:	[___] number	
8.	The highest education level <u>completed</u> by the HH (wife or husband only):	□ (1) Not graduated from Elementary School □ (2) Elementary school □ (3) Lower/Junior High School □ (4) Higher/Senior High School □ (5)University (Undergraduate/ Graduate)	

9. House conditions *[**Observation** only – no questions should be asked regarding this topic]*

	Code	*Low (=1)*	*Medium (=2)*	*High (=3)*
1. Roof material (mostly, quality)		*Local biotic materials No/little value added: e.g. thatch*	*Local materials Medium value added: e.g. local wood boards or tiles*	*Nonlocal material High value added: e.g. metal, ceramic tiles*
2. Wall material (mostly, quality)		*Local biotic materials No/little value added: e.g. leaves, poles, bamboo*	*Local materials Medium value added: e.g. local wood boards*	*Non-local material High value added: e.g. masonry*
3. Floor (mostly, quality, elevated or not)		*No/little value added: e.g. soil*	*Local materials Medium value added: e.g. local wood boards*	*Non-local material High value added: e.g. metal, ceramic tiles*
4. Rooms		*Room number approximate (observations)*		

[1] **<u>Definition of Household:</u>** include all people that are living (spending most of the time, including night) in the same house and that are eating from the same kitchen

5. Electricity		*1 = no electricity used; 2 = yes, through unpaid connection to grid or through village system (mini-generator, mini-hydro, solar-battery system); 3 = yes, through paid connection to electrical grid; 4 = use of own generator; 5 = other (specify) (observations)*
6. Water		*1 = stream, river, pond; 2 = common faucet or well, or neighbour's faucet or well, or common rain-fed reservoir; 3 = own well or own rain-fed reservoir; 4 = piped water from groundwater beneath house; 5 = piped water from municipal system or water company; 6 = other (specify) (observations)*
7. Toilet		*1 = stream, river, pond, field, forest or neighbour's faucet or well, or common rain-fed reservoir 2 = shared latrine with pit or floating over water (not flushed with water) 3 = own latrine with pit or floating over water (not flushed with water 4 = own latrine, with water (flushed by pouring water)5 = own flush toilet , with piped water but not septic system) 6 = own flush toilet, with piped water and with septic system 7 = other (observations)*
8. Cooking		*Codes: 1 = fuelwood; 2 = charcoal; 3 = other vegetative biomass (shrubs, leaves, agricultural residues); 4 = dung; 5 = biogas; 6 = coal; 7 = oil; 8 = kerosene; 9 = liquefied petroleum gas (LPG); 10 = electricity; 11 = solar; 12 = other (specify (observation)*

10. What are the main source of livelihood/ income of your HOUSEHOLD (including all members as identified in Question 8))?
[=the socio-economic activity that the household members spend most of the <u>*time*</u> *working on]*

	1. Primary (the majority of the household time, >50% of time)	2. Secondary (25-50% of time)	3. Tertiary (<25% of time)
1. What activity?			

11. How much land do you own, or do you rent (in ha if possible)?

[Interviewers will make sub categories and sum up all answers for the categories and/or areas to get the total amount]

[2]Different lands	1. Total Area (ha)	2. Ownership Code format XY X=de facto (informal) Y= de jure (law) Code X/Y [1= state, 2= community, 3= own HH 4= other HH
Forest		
1. Natural forest		
2. Managed forests		
3. Plantation		
4. Fragment forests		
Agriculture		
5. Cropland		
6. Pasture (for grazing)		
7. Agroforestry		
8. Fallow or degraded or not used or unproductive		
9. Aquaculture/Ponds		
10. Other (specify: bush, grassland, wetland)		
11. Total land owned		
12. Total rented out		
13. Total rented in		

[2] Natural forest consists of indigenous (native) tree species. It is managed only to a very limited degree, i.e. one may practice 'tolerant forest management in which the native vegetation is largely conserved or reconstructed through successional processes'(Weirsum, K. 1997). In natural forests, most beneficial trees occur spontaneously, although there may be some degree of management to stimulate the frequency and growth of these trees, e.g. by clearing competing vegetation.

2. Managed forest consists predominantly of indigenous vegetation with active management to increase the frequency and productivity of beneficial species. The management will include felling (trimming, thinning in addition to regular harvesting) and planting of indigenous or exotic species

3. Plantation consists of forest stands established by planting and/or seeding in the process of afforestation or reforestation. They are composed either of a) introduced species (all planted stands), or b) intensively managed stands of indigenous species, which meet all the following criteria: one or two tree species planted, even age class, regular spacing. (FAO definition)

Closed forests have a canopy cover above 40 %. Examples include tropical rainforest and mangrove forest. • Open forests have a canopy cover between 10 and 40 %. Open forests generally have a continuous grass layer. Examples include the wooded savannahs and woodlands in Africa and part of the cerrado and chaco in Latin America

4. Forest fragment small isolated tracts or patches of remaining forest surrounded by human modified environments (depending on local context: <100ha)

12. Do you own the following assets? If yes, how many/much?
[Assets: List of assets that could be used to respond to climatic events]

Assets	1. Does your Household own this following objects? *Code: [0=no,; 1=yes]*
1. Water pump	[___]
2. Car or Truck	[___]
3. Boat	[___]
4. Bicycle	[___]
5. Motorbike	[___]
6. phone	[___]
7. TV	[___]
8. Radio	[___]
9. Fishing nets	[___]
10. Water filters	[___]
11. Water storage thank	[___]
12. Running/tap water	[___]
13. Well/borehole (for HH water)	[___]
14. Protection dams/walls	[___]
15. Water ponds	[___]
16. Computer/Laptop	[___]
17. Internet access	[___]
18. Seed stocks	[___]
19. Irrigations systems	[___]
20. Chemicals (Pesticide, herbicides, fungicides)	[___]
21. Fertilizers	[___]
22. Solar panel	[___]
23. Tractor	[___]
24. Generator	[___]
25. Refrigerator	[___]
26. Air Conditioning	[___]
27. Electric Fan	[___]
28. Bank account	[___]
29. Separate house for farm animals	[___]
30. Room in/out of house for business (shop/atelier)	[___]
31. Others (please specify)	[___]

13. Is your household (you or one of the members) involved in any community activities/groups on a voluntary basis (no pay received)?

1. Name of group	2. Group type *Code: [e.g. 0=none, 1=health group; 2=Religious group; 3= professional group (farmers, hunters, …); 4=management group (official committee in regulations), 5= politic, 6=Saving group; 7=Seed bank group, 8= security group (patrols); 9=education groups; 10= social support group 11= other please specify…]*	3. How involved are you in this group? Code= 1= member; 2= leading role, 3= other function (secretary, cashier, …)	4. If member (Q3=1), do you have a say in decision making? Code: 0=no, 1= partially/ irregularly, 2= yes
1. ___________________________	[___]	[___]	[___]
2. ____________________________	[___]	[___]	[___]
3. ___________________________	[___]	[___]	[___]
4. ____________________________	[___]	[___]	[___]

B. Climate Sensitivities/Impacts

18. How [Event 1] and [Event 2] affected your household?
Can you tell us about the things that were affected and the damages and losses due the climatic events?

Code2: [1=First major damage/loss according to the importance on how this affected their life; 2=Second major damage/loss; 3=Third major damage/loss] !! no possibility of having the same score !!]

Affected/Damages/Losses	1. Quantity Affected/ Experienced? *[Numeral code: see unit in next column]*		Unit [eg. House, dollars, …]	2. Which effect caused the most loss in your well-being? Top 3 ranking Event 1 *[code2=1,2,3]*	3. Which effect caused the most loss in your well-being? Top 3 ranking Event 2 *[code2=1,2,3]*
	Event1	Event2			
1. Damage of household parts			Yes (=1)/ no (=0)		
2. Damages or losses of assets/belongings			Yes (=1)/ no (=0)		
3. Lost employment/income sources			# days		
4. High fuel/transport costs			Yes (=1)/ no (=0)		
5. Debt to reimburse/ took loans			local currency		
6. Sickness/health costs			# people		
7. High food prices			+/- local currency		
8. Starving or reducing food intake			# days with less food		
9. Unsafe/irregular drinking water			# days		
10. Insecurity/theft			Yes (=1)/ no (=0)		
11 Death of household member			# people		
12 Loss of productive equipment			# items		
13 Decline of harvest yields from land (agriculture, forestry)			Yes (=1)/ no (=0)		
14 Loss of animals (including fisheries)			Yes (=1)/ no (=0)		
15 psychological stress (change in routine)			# people		
16 Loss of school time			# days		
17 Other (specify)					
18 Other (specify)					
19 Other (specify)					

19. *We are now interested in knowing more about your activities related to land and natural resources (agriculture, forestry, fishery) and the effects of [Event 1] and [Event 2] .*

- Can you tell us the most important crops that you cultivate ?
- Can you tell us the most important forest products that you collect? this include NTFP, fruits from forests, and trees for wood and energy
- Can you tell us the most important animals that you have (including fish)?
- Can you tell us other source of income of your household from non-farm activities?

- Which one of the activities that you have listed were affected by the climatic event [Event 1] and [Event 2]?

- Are there other products from the nature that are not this list but that were particularly affected by the climatic event [Event 1] and [Event 2]?
- Are there other products that were collected in the past but now not anymore?
- Are there other products that become particularly important where there is a [type of Event 1] and [type of Event 2]?
- Think about alternative products too.

[1] 1. Logs; 2. Sawn timber; 3. Poles; 4. Bamboo; 5. Rattan; 6. Firewood; 7. Charcoal; 8. Latex (e.g. rubber); 9. Resin; 10. Forage; 11. Thatch; 12. Lianas and vines; 13. Medicinal plants; 14. Medicinal animals; 15. Food: mammals; 16. Food: birds; 7. Food: fish; 18. Food: reptile/amph.; 19. Food: insects; 20. Food: fruit; 21. Food: vegetable; 22. Food: mushroom; 23. Food: nut; 24. Food: honey; 25. Wildlife: mammals; 26. Wildlife: birds; 27. Wildlife: fish; 28. Wildlife: reptile/amp.;29. Mineral, ore, rock; 30. Other

Natural resource/ products[3]	1. affected by the climatic events [1 +2]	2. What is the effect? *Code: Postcode*	3. Quantity affected? yeald/ harvest % or quantity		4. Quality of the products harvested/ collected *Code: [1= very good; 2= good 3= average; 4= poor, 5= very bad]*		5. What is the breakdown consumptio n/sale? [in % of own consumption]		6. What is the price per Unit to buy OR sell? [Money, (local currency)	
	E1 *[0=no, 1]* E2 *[0=no, 1]*	Description	Quantity usually	Quantity due to	before	*Due to..*	befor e	*Due to*	befor e	Due to
1.										
2.										
3.										
	`									
4.										
5.										

21. Has your household performed any changes in the tree/forest area?:

	1. [Code: 0=no; 1=yes]	2. How many *[Q1:# of trees Q2 # of species taken care of]*	3.names	4. When? [how many times in the last 5 *years*]	5. What was the purpose? [Codes: 1=cropping; 2=pasture; 3=tree plantation; 4=non-agricultural uses, 5= timber, 6=others…)	6. Any correlation with climatic event? *[specify]* *Code: (0=no, 1=yes event 1, 2= yes, event 2, 3= yes both events)*
1. Have you planted trees in the last 5 years? (use time line FGD)	[____]					
2. Have you managed/take care of any species in the last 5 years?	[____]					

22. How trees and forests helped your household to be less impacted by [event 1] and [event 2] ? :

Event 1 : [____]   Code: [1=very important; 2=important; 3= so so , 4=low important, 5= not important]
Event 2 : [____]   Code: [1=very important; 2=important; 3= so so , 4=low important, 5= not important]

Qualitative explanations:

____

____

D. Response Strategies

We are now going to talk about the actions that your household took for [Event 1] and [Event 2].

23. Can you tell us about the actions that your household undertook when the [Event 1] happened?

- … Can you tell us more about the actions your Household took, before, during, after the event?
- .. can you tell us more about the strategies that were successful and also about those that were NOT successful
- … more about strategies that were short-term (quick benefit, to cope with) and long – term (benefit are seen later, anticipatory, adaptive)

a. Event 1

0. Short Description of the action (title/key word)	1. Long description of the action	2.[do not ask but fill – it help to have overview] Associated to which capital? code: **N= Natural,** S= Social, P= Phisical, F= Financial, H= Human	3. Did you undertake this action? *[Code: 0= none implemented , 1= implemented first time, 2= implemented several time, 3=start but not finished/test, 4=future plan,]*	4. Who did you receive help from? *Code: [0=no one, 1= Individually; 2= relatives; 3= Community (friend, neighbors); 4= Government agencies; 5=Politicians; 6=NGOs; 7=others, specify]*	5. When did you undertake this action? *Code: [0=during event 1= before 2= after*	6. Was this action successful in decreasing the impact of the event? *Code: [1=very ineffective, 2= Ineffective, 3= Average, 4= Effective, 5= Very effective*

1. Action 1[4]						
2. Action 2						
3. Action 3						
4. Action						
6. Action						

[4] (Human:)

Using your capacities and skills?

- Health
- Nutrition
- Education
- Knowledge and skills
- Capacity to work

(Natural:)

Using natural resources?

- Land
- Water
- Tree and forest products
- Wildlife
- Services

(Social)

Using your relationship with friends and family?

- Networks and connections
- Relations (trust support)
- Formal and informal groups
- Common rules and sanctions
- Collective representation
- Mechanisms for participation in decision-making
- Leadership

(Physical):

Using infrastructure, technology or tools?

- transport - roads, vehicles, etc.
- secure shelter & buildings
- water supply & sanitation
- energy
- livestock/animals
- communications
- Equipments
- Seed, fertiliser, pesticides

(Financial)

Using your savings (money)?

- Savings
- Credit/debt - formal, informal, NGOs
- Remittances
- Pensions
- Wages

b. Event 2

1. Short Description of the action (title/key word)	1. Long description of the action	2.[do not ask but fill – it help to have overview] Associated to which capital? code: N= Natural, S= Social, P= Phisical, F= Financial, H= Human	3. How often or plan? *[Code: 0= none implemented , 1= implemented first time, 2= implemented several time, 3=start but not finished/test, 4= not yet, future plan, 5= other]*	4. Who did you receive help from? *Code: [0=no one, 1= Individually; 2= relatives; 3= Community (friend, neighbors); 4= Government agencies; 5=Politicians; 6=NGOs; 7=others, specify]*	5. When did you undertake this action? *[number of week when the event happened - #=before, 0= during the event, + #= after the event 1= 1 week 0.15= 1 day 0.006= 1h*	4. Was this action successful in decreasing the impact of the event? *Code: [1=very ineffective, 2= Ineffective, 3= Average, 4= Effective, 5= Very effective*
1. Action 1[5]						
2. Action 2						
3. Action 3						

…………………………

E. knowledge & Innovation

[This final section is about the knowledge and long-term adaptation options]

24. *Now we would like to find out more about any kind of information that you received regarding the climatic events before it happened?*

	1. Did you know that the event was going to happen? If yes, how? *Code: [0= did not know, 1= own knowledge 2= head of village, 3=from relatives; 4= community; 5= NGO; 6= government; 7= other]*	2. What type of information did you received? *Code: [1=Forecast (trend), 2= Forecast (trend) + instruction, 3= extreme event alert, 4=extreme event + emergency instructions]*	3. How did your household receive the information related to climatic events? *Code: [0= no, 1=radio, 2=phone 3=hearsay, 4=TV, 5=internet]*	4. How did you use this information to be better prepared? *Code*	5. Do you think your houshelod had enough information regarding the event? *Code: [0= no; 1= yes; -9= I don't know]*
1. Event 1					
2. Event 2					

25. How is your household prepared to respond to climatic events compared to 10 years ago? Why?

a. Event 1

Code: [1=a lot more, 2=slightly more, 3= about the same, 4= slightly less, 5=a lot less] [] [______]

b. Event 2

Code: [1=a lot more, 2=slightly more, 3= about the same, 4= slightly less, 5=a lot less] [______]

26. According to you what are the reasons of the causes contributing to these events to occur [event1/2] ?

Event1

Event2

G. Closing of the household survey

[*Thank you for taking the time to answer our questions. You have given us very important information that will allow us to better understand challenges and solutions related to climate variations in your area. The analysis that we will do, will be useful for different people that are interested in how natural resources can help to decrease people's vulnerability.*

Annex 2: focus group discussions

Research protocols for the focus group discussions are online in this repository (short URL: goo.gl/DLX7qt). They include the following participatory rural appraisal activities: community meeting (scoping), historical timeline, participatory mapping, seasonal calendar with sensitivity matrix, natural resources uses and rights, and stakeholders Venn diagram.

Title : Landscape management strategies in response to climate risks in Indonesia

Keywords : Socio-ecological systems, ecosystem services, climate change adaptation, mitigation, natural resource management, forested landscapes.

Abstract :

Ecosystems play an important role in strategies for facing climate change because they address both its causes and effects through the delivery of ecosystem services. Ecosystems act as safety nets for rural livelihoods and as buffers against damages by supplying provisioning services (e.g., food and timber) and regulating services (e.g., water regulation and erosion control). In addition, carbon sequestration by ecosystems contributes to mitigate climate change. Land management affects ecosystem services in diverse ways and, because of trade-offs, can enhance the supply of one ecosystem service of interest at the expense of others. For example, the conversion of forests to agriculture to increase food production may degrade water regulation. Although trade-offs are recognized, knowledge on how changes in land management affect ecosystem services and their beneficiaries is still limited. This research aims to increase our understanding of how land management changes impact the resilience of local communities to climate hazards and the provision of ecosystem services at regional and global level. We combined multi-disciplinary and participatory methods to analyze changes in the management of forests and trees in the responses of local communities to climate hazards. Across four rural communities affected by floods and droughts in tropical forest landscapes in Indonesia, we inventoried forests, surveyed households, discussed with focus groups, and analysed satellite images. To analyse how ecosystem services are affected by changes in land management, we developed a conceptual framework to account for the multiple human contributions in the delivery of ecosystem services.

The findings showed how communities used ecosystems in their responses to climatic impacts and how changes in land management affected the supply of ecosystem services. In the study sites with least forests, communities had the highest needs for forest ecosystem services to help them adapt to drought. Between 5 and 45% of the households reported at least one coping strategy based on products from forests and trees, for example harvesting timber or collecting leaves, rubber, and wild vegetables. Several anticipatory strategies at the community level aimed to protect or restore forests to reduce the impacts of droughts and floods on soil and water. Communities were not passive beneficiaries of ecosystem services but actively contributed to their delivery in multiple ways. They managed land, mobilized human and human-made assets (e.g. skills, fertilizers), allocated benefits, and appreciated their contribution to well-being. Such actions determined who benefited from ecosystems and how. The human contributions in the delivery of ecosystem services depended on community rules (e.g. logging restrictions or taxes), assets (e.g. access to transportation or irrigation systems), values (e.g. perception of environmental degradation), and spatial factors (e.g., location of houses and crops in disaster prone areas). The land management strategies of local communities in response to climate hazards also affected the delivery of ecosystem services at regional and global scales, through changes in biodiversity, water regulation, and carbon sequestration. An improved understanding of human inputs and trade-offs in the delivery of ecosystem services can inform the design of sound ecosystem-based solutions for strengthening the resilience of local people to climate hazards while providing other global benefits for sustainable development.

Titre : Stratégies de gestion des terres dans les réponses aux aléas climatiques en Indonésie

Mots-clés : systèmes socio-écologiques, services écosystémiques, adaptation au changement climatique, gestion des ressources naturelles, paysages forestiers.

Résumé :

Les écosystèmes jouent un rôle important dans les stratégies visant à faire face au changement climatique parce qu'ils s'attaquent à la fois à ses causes et à ses effets grâce à leurs services écosystémiques. Les écosystèmes agissent comme des filets de sécurité pour les communautés rurales et comme tampons contre les impacts climatique en fournissant des services d'approvisionnement (par exemple la nourriture et le bois) et des services de régulation (par exemple la régulation de l'eau et le contrôle de l'érosion). De plus, la séquestration du carbone par les écosystèmes contribue à atténuer le changement climatique. La gestion des terres affecte les services écosystémiques (SE) de diverses manières et, en raison de l'existence de compromis (« tradeoffs »), peut améliorer l'offre d'un SE au détriment des autres. Par exemple, la conversion des forêts à l'agriculture pour augmenter la production alimentaire peut dégrader la régulation de l'eau. Bien que les compromis soient reconnus, les connaissances sur la façon dont les changements dans la gestion des terres affectent les SE et leurs bénéficiaires sont encore limitées. Cette recherche vise à améliorer notre compréhension de la façon dont les changements dans la gestion des terres influent sur la résilience des communautés locales face aux aléas climatiques et sur la fourniture de SE aux niveaux régional et mondial. Nous avons combiné des méthodes multidisciplinaires et participatives pour analyser les changements dans la gestion des forêts et des arbres dans les réponses des communautés locales aux aléas climatiques. Dans quatre communautés rurales touchées par des inondations et des sécheresses dans des paysages forestiers tropicaux en Indonésie, nous avons inventorié les forêts, enquêté les ménages, discuté avec des groupes focaux et analysé des images satellite. Pour analyser comment les SE sont affectés par les changements dans la gestion des terres, nous avons développé un cadre conceptuel pour rendre compte des multiples contributions humaines dans la fourniture des SE.

Les résultats ont montré comment les communautés ont utilisé les écosystèmes dans leurs réponses aux impacts climatiques et comment les changements dans la gestion des terres ont affecté la fourniture de SE. Dans les sites d'étude les moins forestiers, les communautés avaient les plus grands besoins de SE forestiers pour les aider à s'adapter à la sécheresse. Entre 5 et 45% des ménages ont rapporté au moins une stratégie d'adaptation basée sur des produits issus des forêts et des arbres, par exemple la récolte du bois ou la collecte des feuilles, du caoutchouc et des légumes sauvages. Plusieurs stratégies d'anticipation au niveau communautaire visaient à protéger ou à restaurer les forêts afin de réduire les impacts des sécheresses et des inondations sur le sol et l'eau. Les communautés n'étaient pas des bénéficiaires passifs des SE, mais ont contribué activement à leur fourniture de multiples façons. Elles ont géré les terres, mobilisé du capital humain ou manufacturé (par exemple les savoirs, les engrais), distribué les bénéfices et apprécié leur contribution au bien-être. Ces actions ont déterminé qui bénéficie des écosystèmes et comment. Les apports humains dans la fourniture des SE dépendaient de règles communautaires (par exemple, restrictions de coupe de bois ou taxes), du capital (par exemple moyens de transport ou d'irrigation), des valeurs (par exemple les perceptions de la dégradation de l'environnement) et des facteurs spatiaux (par exemple la localisation des habitations et des champs dans les zones sujettes aux catastrophes). Une meilleure compréhension des apports humains dans la fourniture des SE et des compromis entre services peut guider la conception de solutions basées sur les écosystèmes pour renforcer la résilience des populations locales aux risques climatiques tout en fournissant d'autres bénéfices globaux pour le développement durable.