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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.

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., 2013; Steffen et al., 2015). The tight interactions of people with the environment are the essence of complex social-ecological systems (Cumming et al., 2006; Gunderson and Holling, 2002). 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 (Comberti et al., 2015; Reyers et al., 2013). 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 (Folke et al., 2004; Kantsler and Steinberg, 2005; Olsson et al., 2004).

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 (Spangenberg et al., 2014b; Villamagna et al., 2013). 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

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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. 1) and the role of management (Oudenhoven et al., 2012), governance (Primmer et al., 2015), or socio-political context (Hausknost et al., 2017).

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.

2. Conceptual framework of mediating mechanisms and factors

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., 2015; 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 (Hicks and Cinner, 2014; Spangenberg et al., 2014b), their different power relations (Felipe-Lucia et al., 2015), their aspirations and needs (Daw et al., 2016; Horcea-Milcu et al., 2015), their identities and values (Díaz et al., 2015; 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. 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

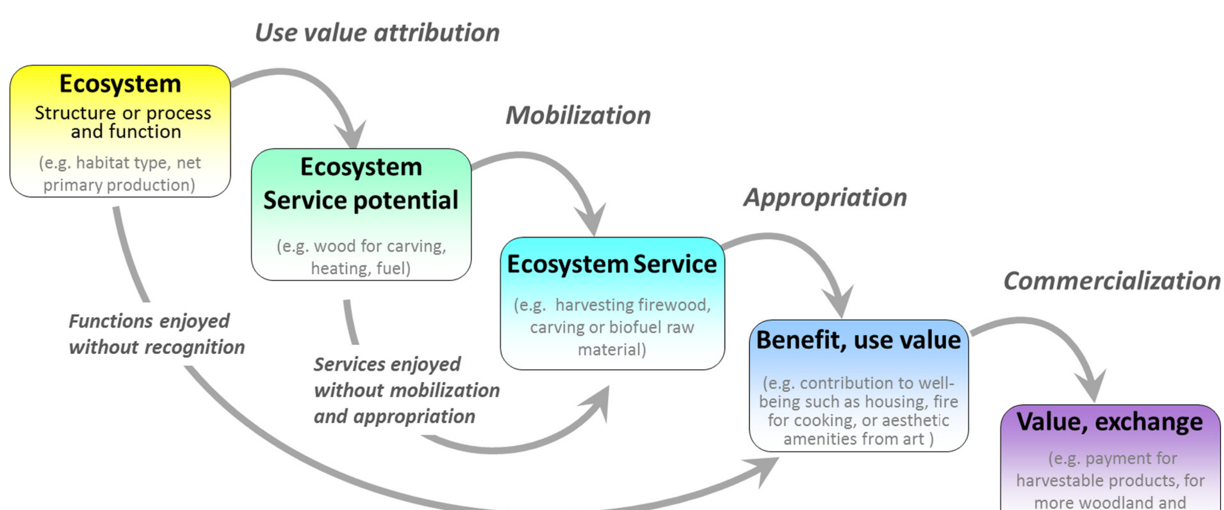

Fig. 1. The ecosystem services cascade with the socioeconomic processes leading from one step of the cascade to the next (modified from Spangenberg et al., 2014a). The ES cascade framework represents subsequent steps (colored boxes) in the generation of ES from biophysical structure and process to human benefits and value. The original framework is from Haines-Young and Potschin (2010) and the processes proposed are by Spangenberg et al. (2014a).

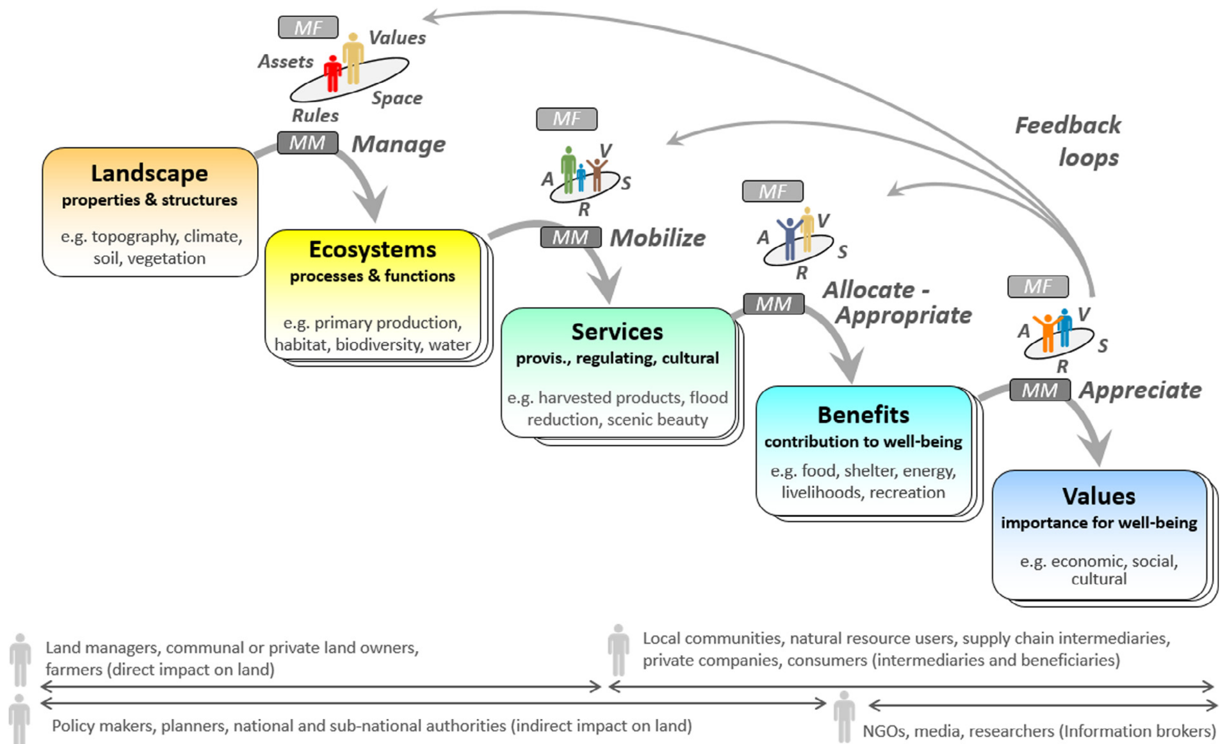

Fig. 2. The framework on mediating mechanisms and factors in ecosystem service delivery. It builds on the cascade framework (Haines-Young and Potschin, 2010; Spangenberg et al., 2014a). Mediating mechanisms (MM) control ES flows along the cascade (rightward arrows). Mediating factors (MF) influence mediating 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.

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).

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 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, 2005a,b). 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., 2015). 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., 2011). 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

Table 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).	Oudenhoven et al. (2012), Primmer et al. (2015), Spangenberg et al. (2014a, b), and 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) and 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), and 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), Fischer and Eastwood (2016) and Nassl and Löffler (2015)

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.

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

Table 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.

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).

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 (Meyfroidt, 2013; Schad et al., 2012). 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).

3. Applying the framework to forest ecosystem services and resilience

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, 2005b). 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; Nguyen et al., 2013) and Mali (Djoudi et al., 2013; Brockhaus 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., 2012, 2014). The application of the framework to these four cases from the literature is described in the Supplementary Materials (Appendix A).

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. 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).

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.

3.2. 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 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

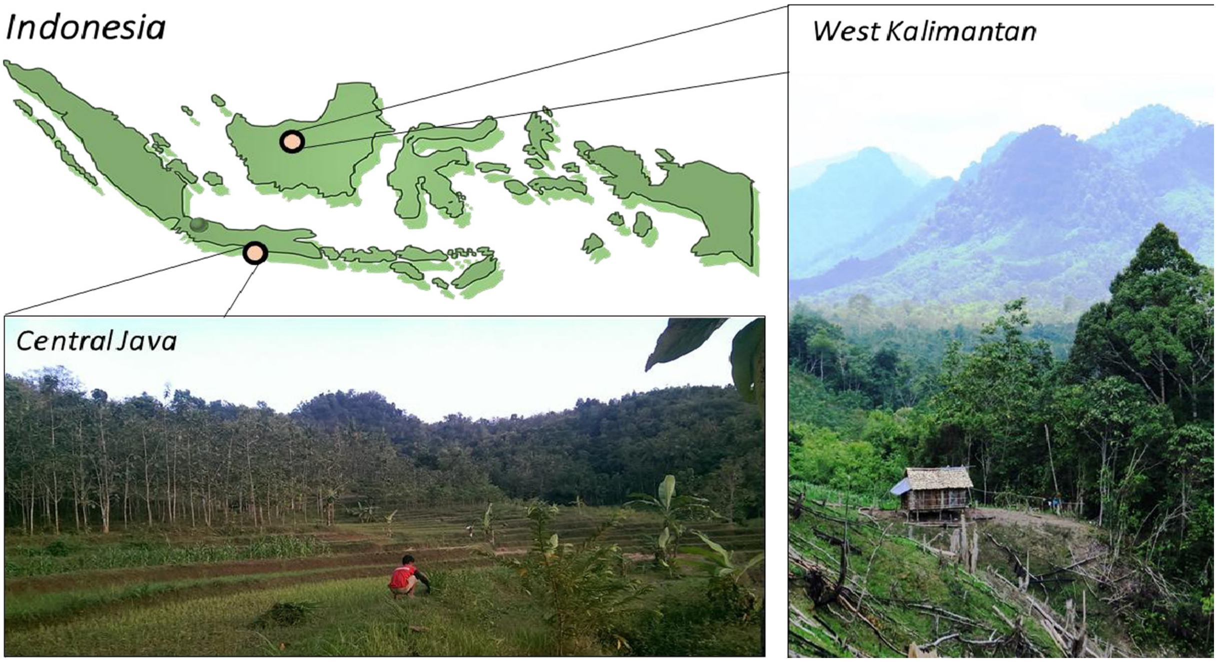

Fig. 3. Rural forested landscapes in the Central Java and West Kalimantan study sites. The photos depict teak plantations and rice fields in Central Java and dipterocarp forests and shifting cultivations in West Kalimantan.

Table 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%).

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*”).

3.2.1. 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. 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

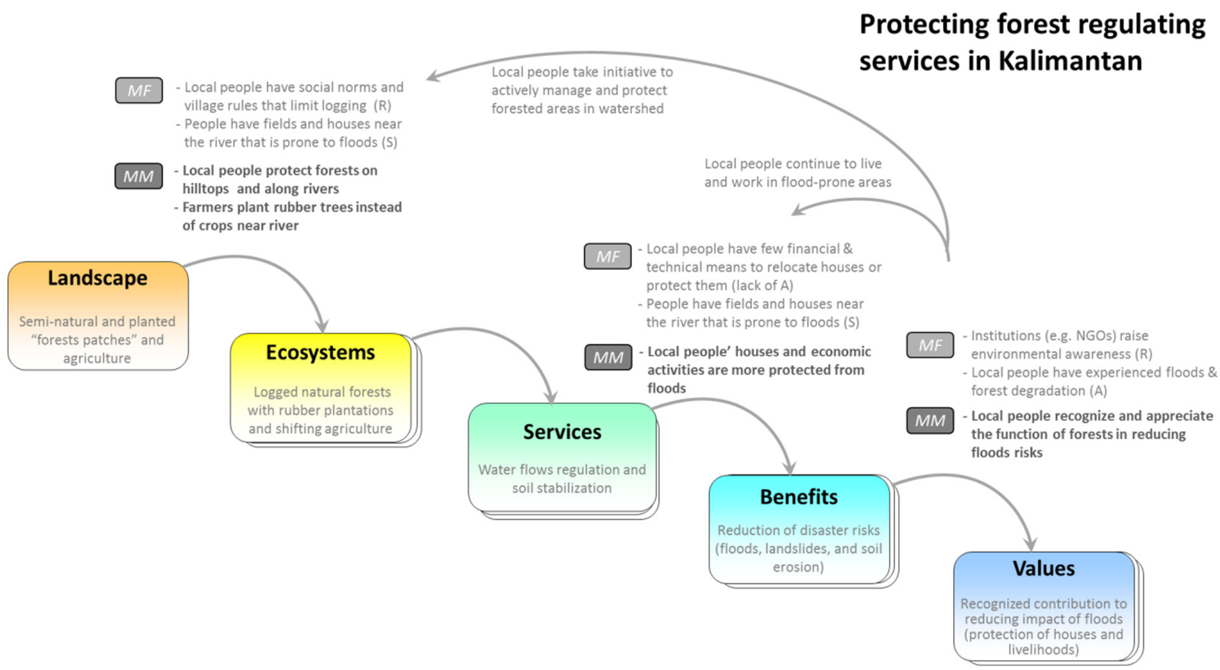

Fig. 4. Cascade of ecosystem services to buffer flood associated risks by protecting forests in watershed in Kalimantan.

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).

3.2.2. Re-greening agricultural land to maintain water for agriculture (Central 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). 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).

3.2.3. Managing community forests sustainably for alternative livelihoods (Kalimantan and 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. 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

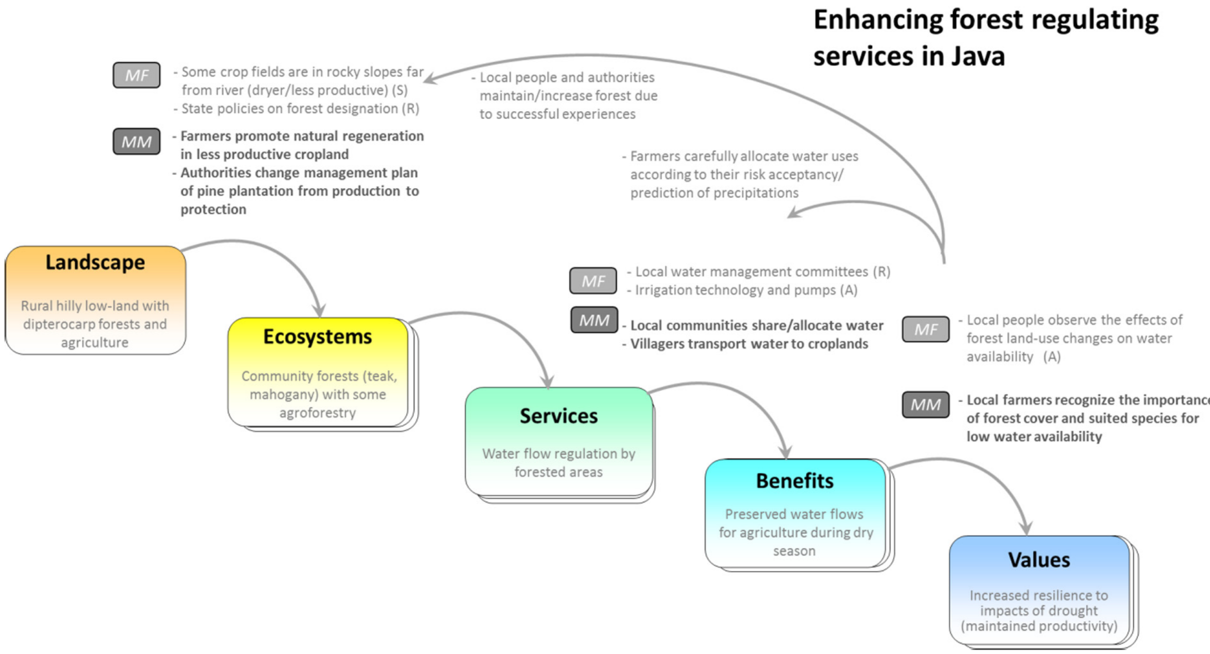

Fig. 5. Cascade of ecosystem services to maintain water for crops during droughts by reforesting less productive lands in Java.

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).

4. 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., 2016).

The diversity of actors that intervene in the mediating mechanisms of the ES delivery determine the final ES contributions to human well-being (Fischer and Eastwood, 2016; Spangenberg et al., 2014a). 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 (Lazos-Chavero et al., 2016; Locatelli et al., 2013). As the case of Indonesia showed, there were intermediaries for forest products and national authorities managed some forests. Despite different actors and priorities

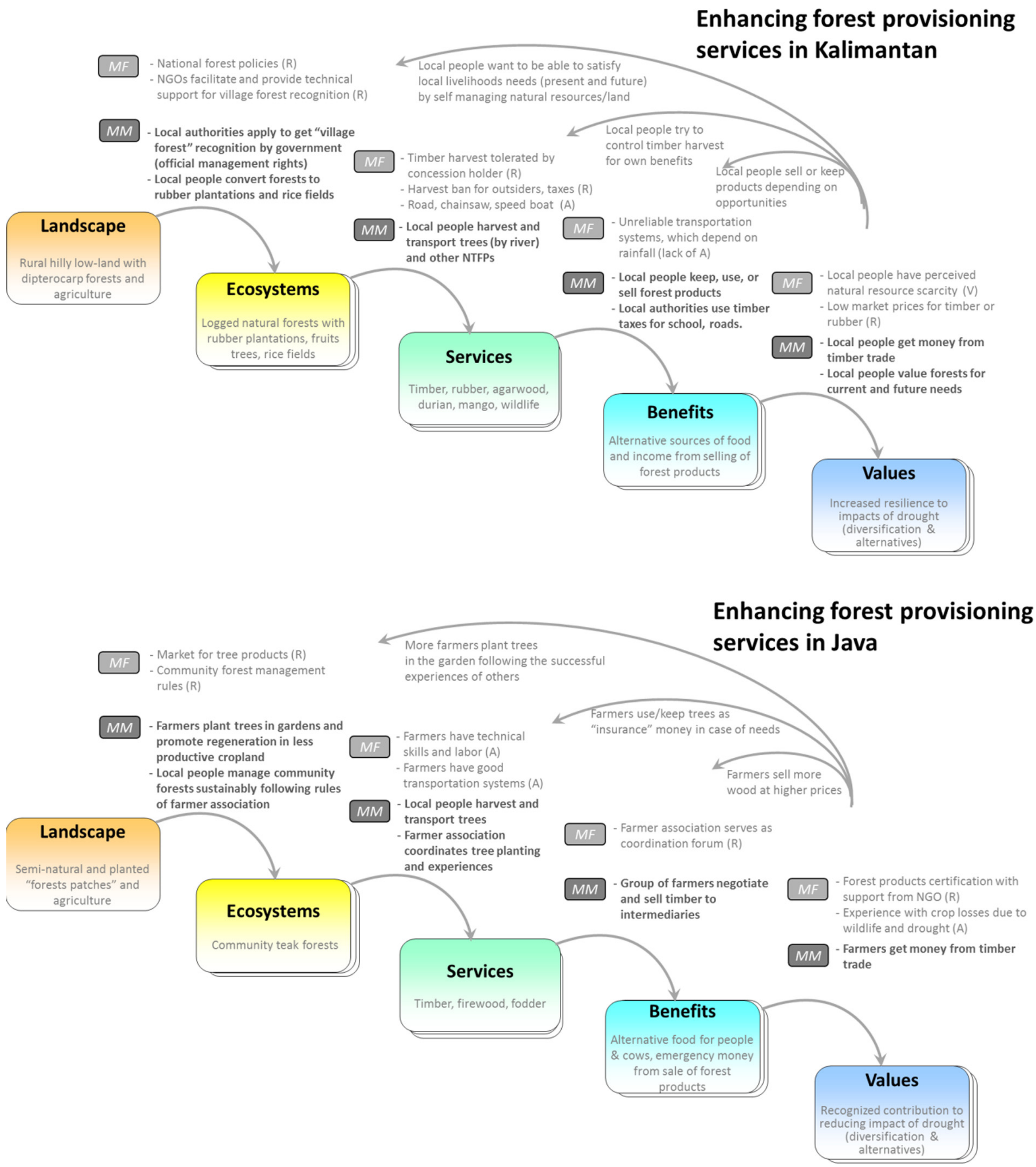

Fig. 6. Cascades of ecosystem services from forests and trees to support alternative livelihoods and increase community resilience to climate hazards (floods and drought) in Kalimantan (top) and Java (bottom).

(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 (Djoudi et al., 2013; Martín-López et al., 2012).

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., 2009; Locatelli et al., 2013).

5. 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.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecoser.2017.09.011.

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