The montane multifunctional landscape: How stakeholders in a biosphere reserve derive benefits and address trade-offs in ecosystem service supply

Alan Heinze⁎, Frans Bongersa, Neptalí Ramírez Marcialb, Luis García Barriosc, Thomas W. Kuyperd

a Forest Ecology and Forest Management Group, Wageningen University and Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
b Departamento de Conservación de la Biodiversidad, El Colegio de la Frontera Sur, Carretera Panamericana y Periférico Sur s/n, Barrio María Auxiliadora, San Cristóbal de Las Casas, Chiapas C.P. 29290, Mexico
c Departamento de Agricultura, Sociedad y Ambiente, El Colegio de la Frontera Sur, Carretera Panamericana y Periférico Sur s/n, Barrio María Auxiliadora, San Cristóbal de Las Casas, Chiapas C.P. 29290, Mexico
d Soil Biology Group, Wageningen University and Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands

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ABSTRACT

Ecosystem service (ES) assessments, which make an explicit link between nature and people’s well-being, can support the management of natural protected areas that face complex and persistent sustainability challenges. We present a case study of ES supply in a biosphere reserve community in southern Mexico. We aimed to identify stakeholder-relevant ES and to analyse trade-offs between them. After engaging local stakeholders, we conducted a biophysical assessment of ES supply and associations across four different land uses. Closed forests and riparian areas, which occurred in different parts of the landscape, supplied high levels of multiple ES. Furthermore, co-produced farming goods and services that supported local livelihoods and conservation-oriented ecosystem services coincided in these four habitats. Together, these habitats provided a diverse array of ES across the landscape, indicating that stakeholders benefited from a multifunctional landscape. At the same time significant trade-offs were found in the supply of forage cover against most other ES, especially tree-based goods and services. These trade-offs revealed conflicts between agricultural land and neighbouring open forests and riparian areas, as well as opposed service demands among beneficiary groups. To address these trade-offs, stakeholders agreed on enhancing forest benefits in order to support both local livelihoods and conservation goals.

1. Introduction

The benefits that people derive from ecosystems (ecosystem services, hereafter ES) are vital for human existence and quality of life. ES decline across the world at an unprecedented rate in human history (IPBES, 2019). Food, freshwater and other vital ES are provided by land, and human land use affects more than 70% of the Earth’s ice-free land surface (IPCC, 2019). Indeed, land use activities have increased the immediate supply of material goods but have at the same time undermined ecosystems and their capacity for sustained ES, both regionally and globally (Foley et al., 2005).

Biosphere reserves designated under UNESCO’s Man and the Biosphere Programme (MAB) have for over four decades served as learning sites for sustainable development. They are examples for local solutions to global environmental problems. Biosphere reserves seek to safeguard their natural and managed ecosystems and concomitantly improve human livelihoods and equitable sharing of benefits (UNESCO, 2017). In southern Mexico these reserves face complex and persistent challenges: eradication of rural poverty and vulnerability (CBM, 2002), and countering the negative impacts of agricultural activities that have reduced, fragmented and degraded forests (García-Barrios et al., 2009; Jackson et al., 2012; Ramírez-Mejía et al., 2017).

To overcome these challenges, ES assessments that recognise social-ecological interactions have been proposed as a way to manage protected areas and their surrounding landscapes (Palomo et al., 2014; Hummel et al., 2019). ES assessments make the important link between nature and people, oriented to human well-being and quality of life (Díaz et al., 2015; Bennett, 2017). They can also support biodiversity conservation efforts (Armsworth et al., 2007; Reyers et al., 2012). Moreover, they are consistent with Latin America’s long trajectory of...
integrated landscape management approaches, which formally began with the establishment of MAB reserves (Estrada-Carmona et al., 2014). In this paper we present an ES assessment of a biosphere reserve community in southern Mexico. Our aims were to identify stakeholder relevant ES and to analyse trade-offs between them.

Essential groundwork and priority research in the sustainable use of natural resources include assessing ES across a range of habitat types in the landscape (Chazdon et al., 2009; Bennett et al., 2015). Landscapes are naturally heterogeneous and multifunctional (Forman and Godron, 1986). ES underpin the concept of multifunctional landscapes, and ES assessments can be used as a tool to explore and understand these multifunctional landscapes (O’Farrell and Anderson, 2010). Multifunctionality allows for a broader portfolio of ES beyond food production and biodiversity (Bennett, 2017). Furthermore, multifunctional landscapes make ES available to a wider range of beneficiaries, especially to local beneficiaries and practitioners who directly experience the services and manage the landscape (Fischer et al., 2017).

By further identifying and characterizing co-occurrences of ES in the landscape, relationships among ES can be determined (Cord et al., 2017). This includes the analysis of supply trade-offs, which are evident when one ES increases while the other decreases (Mouchet et al., 2014). When coupled to information on ecosystem management, the analysis of associations among ES can support decisions regarding trade-offs in land use management (de Groot et al., 2010).

There is a pressing need for stakeholder participation in ES research and engagement in the decision-making processes (Cowling et al., 2008; Seppelt et al., 2011; Fish et al., 2016). Stakeholder engagement addresses the need to understand the diversity of beneficiaries and their associated values (Bennett et al., 2015). Moreover, stakeholder involvement leads to more inclusive assessments that recognise a broad range of worldviews and integrate diverse sources of knowledge (Pascual et al., 2017; Díaz et al., 2018). Specific knowledge gaps in ES research in Latin America also need to be addressed. First, as ES research is often limited to a few services, a more diverse array of ES needs to be considered (Balvanera et al., 2012; Perevotchikova et al., 2019). Emphasis should be especially placed on locally relevant services (Balvanera et al., 2012). Second, the analysis of ES associations is not well developed; only in a few case studies have trade-offs resulting from different land uses been explored (Balvanera et al., 2012).

In this study, we conducted a biophysical assessment of ES supply across different land uses, including analyses of spatial co-occurrence and trade-offs in ES supply. From the outset, local stakeholders were taken into account to identify relevant ES. This user-inspired assessment of ES has not commonly been performed in rural communities of Mexico. When coupled to information on ecosystem management, the analysis of associations among ES can support decisions regarding trade-offs in land use. After consulting with key informants in the community, having an interest in the landscape, and influencing land use decisions. Stakeholders were identified by the authors’ long-term involvement in participatory research in the area (García Barrios et al., 2012) and a sense of actors there present (Brunel and García-Barrios, 2011; Braasch et al., 2018). Researchers, merchants and other actors that had marginal interest or influence on the landscape were not included in this study. Stakeholders were grouped into two main beneficiary groups.

The first beneficiary group was the farmers from the California ejido, the people living directly on and off the land. Although communities are not homogeneous entities (Leach et al., 1999), we focused on farmers to identify ES supplied to the community. Farmers regularly interact with and manage the landscape. They make the ultimate decisions on land use. After consulting with key informants in the community, we interviewed 12 seasoned farmers. Semi-structured interviews (Geilfus, 2008) were conducted using vernacular terms around the topic of “benefits, goods and problems of the landscape/terrain” (interview guide in Sup. Mat., Tab. SM1). Although the interviews focused on ES, ecosystem disservices were also considered, goods and services that undermine or harm human well-being (Shackleton et al., 2016). Visual representations like farm maps with satellite images and photos of the landscape were provided during the interview. Additionally, we engaged as participant observers in the community (Geilfus, 2008) during our frequent visits to the study site (> 90 days on site). We participated in field activities (crop cultivation, resin and timber harvests), local reunions (farmer group reunions, meetings between farmers and conservation institutions), and workshops (on capacity building in resin extraction). This participation provided relevant information on local people's views of ES.

The second beneficiary group was composed of diverse institutions with different characteristics, goals and strategies but having the shared mission of conserving biodiversity and natural habitats in the reserve (henceforth ‘conservation institutions’). These institutions interacted directly with farmers and indirectly via their programs, and influenced farmer’s land use decisions. Dialogues with key respondents (Geilfus, 2008) of conservation institutions were conducted: three staff from the National Commission of Natural Protected Areas (CONANP), the reserve’s official administrator; one from the National Forestry

1 Refer to the Supplementary Material (Sup. Mat) for numbering with prefix ‘SM’.
Commission (CONAFOR), manager of federal support programs for forest landowners; and two from a regional civil society organisation (Pronatura Sur, A.C.), which has carried out many on-site programs. Dialogues focused on promoted programs and activities in relation to ES and their values. Additionally, the reserve’s official Management Plan (INE, 1999), which guides CONANP’s management strategy, as well as documents associated to CONAFOR’s support programs (found in its official website (CONAFOR, 2019) were studied.

We used existing ES classifications based on landscape functions and land use (de Groot et al., 2002; Groot, 2006; de Groot et al., 2010) to guide the integration of reported goods, materials, resources, and services (both positive and negative contributions to human well-being) into a set of generalised ES and disservices. The focus was on ES with assigned values (values of objects), like instrumental and economic values (Chan et al., 2018). Only ES and disservices that were mentioned by at least four farmers were considered. We collated and synthesised information from conservation institutions into main ES with local relevance; global ES and disservices were not included. Ultimately, fourteen ES and one ecosystem disservice were identified as relevant by the two groups of beneficiaries.

2.3. Assessment of ES supply

State indicators and appropriate measure(s) were selected to assess the supply of ES and disservices (Table 1). State indicators and measures represent biophysical properties and conditions supplying the service and indicate how much of the service is present (de Groot et al., 2010). The assessment was limited to a selected sampling area in the study site (Section 2.3.1), and involved a forest inventory consisting of two sampling phases (Section 2.3.2).

2.3.1. Sampling area

A representative sampling area for the ES supply assessment was selected after farmer consultation (Fig. 2). The area combined multiple productive activities, was close to the village and hence more intensively used, and had been farmed for over two decades. It was surveyed on the ground with a GPS by following the boundary wire fencing, which enclosed eight neighbouring properties totalling 123 ha or 11% of the community’s territory. The elevation for the sampling area ranged from 965 to 1175 m.a.s.l.

2.3.2. Biophysical assessment

Land (ES 1, Table 1) was considered a spatial resource upon which productive activities could take place. For this purpose we developed a land use classification (Sup. Mat., Meth. SM1). Land use was characterised in a systematic horizontal point sampling (HPS) (Fig. 2), in which tree basal area and terrain properties were measured (Husch et al., 2003). Four main land use types were identified: riparian areas, agricultural land, open forests and closed forests (Sup. Mat., Figs. SM1, SM2). Their extension in the landscape was calculated as their relative share of the sampling area. Water and staple crops (ES 2 & 3) were similarly assessed by the spatial extent of the land use types that provide these ES, riparian areas and agricultural land respectively.

In the second sampling phase, supply of the remaining services and disservice (ES 4–15) was assessed in the four land use types. 82 sampling units were selected using a stratified random sampling design (Husch et al., 2003), with land use types as strata (plots, Fig. 2). Sample size was determined by optimum allocation: the number of sampling units in each stratum was proportional to its standard error (of HPS basal area estimates) weighed by area. Sample units were then randomly selected for each stratum (Sup. Mat., Tab. SM2). Plots were sampled from August to October 2017 following standard forest inventory methods (Husch et al., 2003) and laboratory analysis for soil and forage samples. These methods, including procedures to determine supply measures, are described in detail in the Supplementary Material (Meth. SM2). Finally, to obtain one value of ES supply per land use type, we estimated the survey group mean of indicators (b–l).

All statistical computing was performed in the R environment (R Core Team, 2019): group (and population) means were estimated using the ‘survey’ package (Lumley, 2019), and flower diagrams built with ‘ggplot2’ (Wickham, 2016).

2.4. ES associations

Consistent ES co-occurrence and trade-offs in the landscape were
identified and characterised using pairwise correlations and clustering methods (Mouchet et al., 2014; Cord et al., 2017). Spearman’s rank correlation coefficients ($r_s$) (Zuur et al., 2007) were tested for all pairwise associations between ES supply indicators (b–l) using plot-level data ($n=82$). The same supply measure per indicator as for the flower diagrams was used. A dissimilarity matrix was then built with the correlation coefficients, and a hierarchical cluster analysis performed to find discrete groups of ES supply with different degrees of (dis)similarity (Buttigieg and Ramette, 2014). Positive associations and clusters indicated co-occurrence of ES supply, whereas negative associations and distance in clustering indicated trade-offs.

Consistent associations in ES supply were analysed in relation to land use, and additionally regarding stakeholder interests. ES supply and demand trade-offs were analysed using ordination methods (Mouchet et al., 2014). Non-metric multidimensional scaling (NMDS) was used to represent the pairwise dissimilarity between objects (Buttigieg and Ramette, 2014). We carried out a NMDS using the same set of supply indicators (b–l) as objects, and inventory plots ($n = 82$) as sites. The position of ES supply associations relative to land use sites was examined in the resulting ordination plot. Distanced objects and sites pointed to trade-offs in ES supply. These ES supply and land use combinations were additionally examined from the demand perspective or interests of the two beneficiary groups.

Correlations and multivariate analyses (clustering, ordination) using mixed data types without identifiable distributions were analysed with rank-based approaches (Zuur et al., 2007). Statistical analyses were carried out in the R environment (R Core Team, 2019). The correlation matrix was built with the ‘corrplot’ package (Wei and Simko, 2017). The hierarchical cluster analyses were performed with the average-linkage method using the ‘stats’ package (R Core Team, 2019), its distance matrix computed with the ‘Hmisc’ package (Harrell et al., 2018). The NMDS was run and plotted with the ‘vegan’ package (Oksanen et al., 2019) resulting in an appropriate ordination: the algorithm was run iteratively using 3 dimensions and reached two convergent solutions with a stress value of 0.065 (< 0.1 indicates a fair fit (Buttigieg and Ramette, 2014)).

### Table 1
Supply indicators and their measure(s) for the identified ES and disservices (see Table 2 and Sup. Mat., Meth. SM2 for full description). * Land use is both an indicator (a) and a landscape classification upon which other indicators (b–l) are assessed.

| ES and disservices | Indicator | Measure |
|--------------------|-----------|---------|
| 1. Land            | a) Land use * | Land use types |
| 2. Water           | b) Soil quality | Extension of riparian areas |
| 3. Staple crops    | c) Forage cover | Extension of agricultural land |
| 4. Fertile soil    | d) Forage nutritional value | Quality index: composite of soil organic matter, total N, cation-exchange capacity, and pH |
| 5. Livestock forage| e) Firewood stocks | Available P |
| 6. Firewood        | f) Timber stocks | Forage grasses |
| 7. Timber          | g) Resin capacity | Muhlenbergia spp. |
| 8. Pine resin      | h) Toppled pines | Creeping-climbing grasses |
| 9. Windthrow (disservice) | i) Tree cover | Forbs & shrubs |
| 10. Forest habitat | j) Woody plant diversity | For grasses and forbs-shrubs separately: |
| 11. Water regulation| k) Epiphyte habitat | Crude protein |
| 12. Gene pool protection | l) Downed coarse woody debris (DCWD) | Digestibility index: composite of fibre content (NDF, ADF) and pH |

**Fig. 2.** Sampling area and sampling points to assess ES supply. A representative managed landscape, 123 ha covering 11% of the California territory, was selected as the sampling area (inset map: sampling area in black within the California polygon). A regular grid of 281 points was set up for horizontal point sampling (HPS), from which 82 points were randomly selected to establish forest inventory plots (Plot).

3. **Results**

#### 3.1. Relevant ES

The most recognised ES by farmers were goods, resources and services produced in their farms, those that supported their family and community’s livelihood (Table 2). Agriculture-related benefits were usually mentioned first, including the land for cultivation, staple foods, mainly maize and beans, livestock and forage, and ‘good’ soil to support agricultural production. Water was also considered a vital resource for
the community. All household and drinking water originated “up from the mountain”: clean water was piped to the village (ca. 3 km) from an upstream river in the core zone of the biosphere reserve. Water supply for livestock and crop irrigation in farms was also important, although there was minimal water infrastructure for it. Lastly, people bathed in river pools and cherished the recreational use of freshwater. Farmers also valued raw materials and semi-domesticated foods consumed in the household, such as firewood to cook food and nourish, timber to occasionally repair house structures, and available seasonal fruits and herbs. Resin extracted from pine trees was an important raw forest material that provided a highly appreciated income to farmers. Likewise, pine timber was increasing in economic value after it was commercialised. The community also valued forests for the indirect benefits provided by institutional programs, such as income and other goods from sustainable forest management programs and payments for environmental services. As stated by farmers, most benefits were “a fruit of hard labour”, derived from their work in cultivation, harvest, transport, etc. In summary, local farmers valued a production landscape that provided food, water, raw materials and an income to support their livelihoods.

For conservation institutions, the montane ecosystem provided a vital habitat for wildlife and the conservation of biodiversity, as well as water regulation services (Table 2). The biosphere reserve was originally established for the purpose of biodiversity conservation and hydrological services. Thus for government institutions (CONANP and CONAFOR) who worked in the context of an officially-protected area, the mission and mandate were to manage the landscape to safeguard these ES. Montane forests, pine-oak and evergreen cloud forests, were highly valued ecosystems in which biodiversity, water regulation and other ES naturally occurred. Well-conserved forests provided a suitable living space and reproductive habitat for important wildlife, and played a fundamental role in hydrological processes that benefited downstream beneficiaries. Hence, conservation institutions considered forests the proxy for habitat and water regulation functions, and forest cover the overall indicator of forest health and integrity. Furthermore, conservation institutions focused their biodiversity values in specific animal and plant species of conservation concern and status. Relevant to the study site were plants of high conservation, aesthetic and commercial value, epiphytes including orchids and bromeliads. Trees were also valued. Different tree species were important as (micro-) habitat to other species, notably downed and decaying trees and snags, and host trees for epiphytes (Table 2).

Conservation institutions considered ES in a broader geographic scale, including the interests of society at large regarding nature protection. Conservation institutions recognised ES in the context of the whole biosphere reserve, the regional connectivity across the mountain range and to the lowland valleys (water supply for downstream agricultural beneficiaries), and a national agenda (protecting Mexican endangered species and forests).

3.2. ES supply

Fig. 3 provides a synthesis of ES supply in the different land use types, whereas original values of all supply measures are provided in the Supplementary Material (Tab. SM5–SM7). Accompanying rarefaction and extrapolation curves of Hill diversity numbers are included (Figs. SM3–SM6), as well as a list of woody plant species recorded in the forest inventory with their estimated tree cover. A description of ES supply across land use types follows.

Riparian areas stood out for their woody plant diversity, epiphyte habitat, and the quality of soils and forage. Riparian areas were rich in woody plants ($^{13}D_{obs}$: 29 out of a total of 42 species were recorded there. The observed typical ($^{13}D_{obs} = 12.0$) and dominant ($^{13}D_{obs} = 6.4$) species diversity were 3–4 times that of forest land uses. Broadleafed species (other than oaks) were dominant, accounting for 82% of total tree cover. Epiphyte-harbouring trees were also abundant (25.6 trees/ha) in riparian areas. Tree cover was notably low (7.4 m²/ha total basal area) as was the supply of tree-based materials such as timber and resin. Firewood stocks were substantial (18.6 t/ha) but mainly of Inga vera, a less favoured fuelwood. Soil quality parameters were the highest in total N (2.8 g/kg) and organic matter (42.1 g/kg), as well as in available P (4.32 mg/kg). Likewise, forage nutritional values like crude protein and digestibility index of grasses, forbs and shrubs, were the highest in riparian areas.

Agricultural land had a high supply of forage grasses, with an average 63% ground cover and in some open pasture plots above 90%. Agricultural land presented relatively good forage nutritional and soil quality values compared to forests. Tree cover (2.5 m²/ha total basal

Table 2

| ES and disservices | Beneficiary group | Relevance/importance of ES |
|-------------------|-------------------|----------------------------|
| Land              | Fa                | Land is a fundamental resource base for the peasant family and farm. Land provides space and supporting resources for agricultural and silvicultural activities that allow farmers to make a living. |
| Water             | Fa                | Water is a vital resource to the community. An upstream river provides all drinking water for household consumption. Streams and rivers in the landscape supply water for crops (irrigation) and livestock. Natural river pools are used for bathing and recreation. |
| Staple crops      | Fa                | Staple crops, maize and beans, are the community’s most daily consumed. Under average years, maize (Zea mays) and beans should cover at least 60% of the food need of the community. |
| Fertile soil      | Ci                | Native maize varieties are valued and promoted by CONANP. |
| Livestock forage  | Fa                | Cattle ranching is very important to local livelihoods. Equines are also raised as mounts and/or pack animals. Livestock usually graze and forage extensively in the farm’s open pastures and forests. |
| Firewood          | Fa                | Firewood is the main source of cooking fuel in the community. Oakes (Quercus spp.) are the preferred species. |
| Timber            | Fa                | Local timber demand for building and fencing material, as well as a growing commercial interest, is supplied by abundant native pine trees (Pinus oocarpa). |
| Pine resin        | Fa                | Resin extracted from natural stands of pine (P. oocarpa) is gathered and traded, providing a valuable income to farmers. |
| Windthrow (disservice) | Fa          | Strong winds and gusts frequently topple trees. Pines are particularly vulnerable, their loss mostly affects resin production. |
| Forest habitat    | Ci                | The conservation of montane forests that provide habitat for wild species and biodiversity, is a core value and objective of the biosphere reserve and related conservation institutions. |
| Water regulation  | Ci                | Water regulation in the mountain’s upper watershed (which includes the study site), is important for freshwater supply to downstream regional beneficiaries. This hydrological service is a main value and objective of the biosphere reserve. |
| Genepool protection| Ci            | Biodiversity in lifeforms, species, genes, etc. maintains and is maintained by ecological and evolutionary processes. Conservation institutions strive to protect biodiversity. |
| Minor forest resources | Fa          | A variety of wild and semi-domesticated woody plants are used by locals. Plants provide tool/building materials, edible fruits, herbal medicine, livestock forage, etc. These are secondary resources compared to major tree products. |
| Ornamental plants | Ci                | Epiphytes, orchids (Orchidaceae) and bromeliads (Bromeliaceae) have a high aesthetic and conservation value. They are protected by conservation institutions and appreciated by locals. |
| Decaying trees    | Fa                | Conservation institutions value dead and decaying trees, as they offer habitat for myriad species during their decomposition. |


area) was very low and the supply of tree-based materials practically null. There was little firewood (1.9 t/ha), hardly any DCWD (0.3 m³/ha) and few trees hosting epiphytes (6.5 trees/ha). Tree cover was evenly distributed among pines (38% of total basal area), oaks (25%) and other broadleaved species (37%). Hence, agricultural land exhibited some relatively high plant diversity measures, particularly those sensitive to relative frequencies: $D_{obs} = 9.3$ and $D_{obs} = 6.3$.

Forest land uses were dominated by pine-oak forests. Closed forests had the highest tree cover (20.7 m²/ha total basal area) and were composed almost entirely (99%) of one pine (*Pinus oocarpa*) and a few oak (*Quercus* spp.) species. These forests presented low woody plant diversity (by all $D$ measures). Closed forests contained the highest supply of tree-based materials: large timber stocks (147.7 m³/ha), high resin capacity (149.3 faces/ha), and important firewood stocks (18.4 t/ha) consisting almost entirely of oaks, the preferred fuelwood. Open forests had the most downed trees, up to 4 pine logs/ha and over 4 m³/ha of DCWD, and provided suitable habitat for epiphytes (= 23 trees/ha). Both open and closed forests had poor soils, as shown by low soil quality parameters. Forage nutritional values, especially crude protein content, were also low for both grasses and forbs-shrubs in forests. As for forage ground cover, the understory vegetation presented low values in forage grasses (30% and 18% cover in open and closed forests respectively), but maintained a relatively high supply of forbs and shrubs (39% and 34% cover in open and closed forests respectively).

### 3.3. ES associations

Combined analyses of ES supply correlations are presented in Fig. 4. The strongest positive associations among all ES indicators were: first, the triad of timber stocks, resin capacity and tree cover ($r_s(82) = 0.85$–0.98, $p < .001$); second, toppled pines and DCWD ($r_s(82) = 0.77$, $p < .001$); and third, firewood stocks and epiphyte habitat ($r_s(82) = 0.63$, $p < .001$). For these associations, the distances resulting from the cluster analysis were all below a low threshold ($D_{obs} = 6.3$). In contrast, the strongest negative associations were those of the (above-mentioned) triad of timber stocks, resin capacity and tree cover, in relation to forage cover ($r_s(82) = -0.54$ to $-0.66$, $p < .001$).

Overall, three clusters of ES co-occurrence were identified (threshold distance of 0.400). The first cluster combined five ES, namely timber stocks, resin capacity, tree cover, toppled pines and DCWD. The second cluster grouped firewood stocks, epiphyte habitat and woody plant diversity. Associations within these two clusters consisted of strong (previous paragraph) and more moderate positive correlations ($r_s(82) = 0.39$–$0.52$, $p < .001$). On the other hand, associations between these two clusters were for the most part non-significant, apart from the correlation of woody plant diversity with both timber stocks and resin capacity ($r_s(82) = -0.32$ & -0.33 respectively, $p < .01$). The third cluster consisted of soil quality, forage nutritional value and forage cover. The positive associations within this group were weak: the highest correlation occurred between soil quality and forage nutritional value ($r_s(82) = 0.35$, $p < .01$). Associations between the third and first cluster were mostly significantly negative (Fig. 4).

The ordination of ES supply indicators (Fig. 5) represents the location or co-occurrence of ES supply across the landscape, especially in relation to the different land use types. Timber stocks, resin capacity and toppled pines, three pine-based indicators, were located close to each other, and relatively near to tree cover and DCWD as well. These five ES co-occurred and generally coincided in forest land uses. At the opposite end in the NMDS graph was forage cover in agricultural land plots and also in some riparian areas. Adjacent were indicators of soil quality, forage nutritional value and woody plant diversity, the three more positioned in relation to riparian areas than to agricultural land. The last two indicators, epiphyte habitat and firewood stocks, were distanced and orthogonal to the rest. These two indicators were found alongside a few marginal plots of riparian areas and open forests with an abundance of oak trees.

The ordination of ES further located the occurrence of ES supply regarding the different interests of the two beneficiary groups (Fig. 5). For ES relevant to local farmers, ES supply was distributed across the whole landscape, as ES supply indicators were not apparently

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**Fig. 3.** ES supply in the four land use types. Flower diagrams are based on supply indicators (a–l) and their corresponding measures. Numbers (percentages) correspond to the estimated means of land use types in relation to the highest recorded value (excluding outliers: data points beyond 1.5 x interquartile range). The exception is for woody plant diversity, in which the percentage corresponds to the observed diversity in relation to the extrapolated diversity of riparian areas (the highest asymptote of all land use types).
concentrated in a specific land use. In the case of ES valued by conservation institutions, ES supply was likewise distributed and not restricted to a single land use: tree cover and DCWD were mainly positioned in forest land uses while woody plant diversity and epiphyte habitat mainly occurred in riparian areas. No ES valued by conservation institutions occurred in agricultural land. The closest occurring indicator was woody plant diversity, positioned around the group’s periphery.

4. Discussion

4.1. Relevant ES

For local farmers, relevant ES were mostly co-produced goods and services that supported their livelihood and that of the community, benefits that also allowed them to make a living. Peasant family farms contain the resource base that lets families engage in primary production and thus earn a living (Van der Ploeg, 2014). Hence, the landscape had a production and livelihood-sustaining function. Even the variety of trees and plants in the landscape was defined in terms of their usefulness. As argued by Swift et al. (2004), farmers prefer farm biodiversity with direct-use purposes. Our results are similar to other studies that found that rural farmers highly appreciate provisioning services linked to their productive activities (Cáceres et al., 2015; Garrido et al., 2017; Tauro et al., 2018). In addition, farmers in our ejido asserted that farm goods and services were the result of hard labour, multiple resource investments and land interventions. ES are frequently co-produced through people’s interaction with the landscape (Fischer and Eastwood, 2016; Palomo et al., 2016), and especially in farming, the close interaction is constant and mutually transforming (Van der Ploeg, 2014). In the course of this research, farmers expressed and revealed this special relation to nature. The reported goods and services were interwoven with other value concepts like relational values, preferences, principles and virtues about human-nature relationships (Chan et al., 2018).

Conservation institutions were mainly interested in biodiversity, habitat and regulation services of montane forest ecosystems at larger geographic scales (Table 2). This was consistent with the institutions’ mission of protecting biodiversity and ecosystems. Compared to local people, stakeholders operating at higher scales show more appreciation of regulating and supporting services, including biodiversity and nature conservation (Hein et al., 2006; Garrido et al., 2017). Still, conservation institutions were quite aware of local livelihoods and ES supporting the
community. They acknowledged the ejido’s demand of provisioning ES and worked in parallel to improve the living conditions of local communities. In fact, many of their programs actually aimed to enhance agricultural and forest-based goods and services. As a result, farmers’ values around forests changed in response to these programs. So, although this study reported different sets of ES identified by the two beneficiary groups, they were neither opposing nor incompatible. Cáceres et al. (2015) found that extension officers from conservation-oriented organisations working closely with subsistence farmers, resonated with their interests and thus perceived and valued similar ES. In a protected areas in southwestern Spain, traditional provisioning services and regulating services shared low monetary value compared to other ES provided outside the protected area’s borders (Martín-López et al., 2011). A notion of social interactions between the different beneficiary groups, and broader social-ecological interactions and context, provided valuable insight into local stakeholders’ views and preferences of ES and how they influenced each other.

4.2. ES supply

Closed forests and riparian areas presented a high supply of multiple ES: both land use types had the highest values in four ES supply indicators (Fig. 3). These areas can be considered ES hotspots, areas containing high values of a single service or areas where multiple services occur (Schröter and Remme, 2016). Moreover, these land uses strongly contributed to both conservation and local livelihood-supporting ES, combining high-valued ES of interest to both beneficiary groups. Spatial overlap of biodiversity conservation values and diverse ES has been reported in other study areas (Egoh et al., 2009; Bai et al., 2011). In spatial assessment where multiple ES are identified, biodiversity and ecosystem services can be integrated into conservation planning and resource management decisions (Chan et al., 2006; Nelson et al., 2009; Schröter and Remme, 2016).

The present state of ES supply across the landscape further showed the effects of local land use decisions. Management choices may alter the type, magnitude and relative combination of ES provided by the landscape (Rodríguez et al., 2006). Reduced tree cover and supply of tree-based goods such as oak firewood, pine timber and resin in agricultural land, open forests and riparian areas, were the likely result of agricultural expansion and forest degradation that had advanced from valleys upslope into hillsides (farmer comments; see also Braasch et al., 2017). Agricultural land had lower soil quality than the riparian areas they had spatially displaced through land use change, a possible indication of land degradation. Soil quality degradation in farmlands has indeed been identified in the study site (Jackson et al., 2012). Yet, the relatively high presence of downed trees in open forests could not be clearly explained by farmers, only that windthrow occurred in strong storm events and specific zones. Multiple factors contribute to windthrow, including recurrent extreme winds, topographic exposure, soil and stand conditions (Mitchell, 2013). More relevant however, were the consequences of toppled trees for ES supply: a decrease in resin capacity for resin farmers, a ready source of firewood or timber for locals, and woody debris providing wildlife habitat.

4.3. ES associations and trade-offs

The ES hotspots closed forests and riparian areas contrasted in their ES supply. Closed forests presented a consistent set of ES involving tree cover, pine timber and resin, which were gradually traded-off against ES provided in riparian areas of woody plant diversity, soil quality and forage nutritional value (Figs. 4 and 5). Still, this divergence in ES supply was not clear-cut. Firewood and epiphyte habitat were provided in forests (closed and open) as well as riparian areas, because these ES relied on a variety of oaks and other broadleaved species.

Although closed forests and riparian areas differed in ES supply, they were complementary at the landscape level. Complementarity arises because these ES hotspots occurred in different parts of the landscape: closed forests were present in mountain ridges and hillsides whereas riparian areas were found in valley bottoms. Thus for local stakeholders, there was no conflict in ES supply between these land uses. Moreover, both beneficiary groups derived multiple benefits from the multifunctional landscape in which their valued ES were distributed (Fig. 5). Even production activities of farmers benefited from a diverse landscape. In cattle ranching several goods and services were supplied to animals in agricultural land and riparian areas (Table 2, Fig. 3), but livestock also had access to the large foraging area in forests. Local forests constitute a sort of silvopastoral system in which a wide variety of forage plants can be found (Dechnik-Vázquez et al., 2019). As peasant farmers are well-adapted to a diversification-multifunctionality strategy (Van der Ploeg, 2014), farmers in California had extended this strategy onto an already heterogeneous landscape. Farmers had shaped and adapted to a multifunctional landscape to provide a diverse array of...
benefits in different parts of the landscape.

There were significant trade-offs in the supply of forage cover (forage grasses) and other ES (Fig. 4), epitomised in the forage vs. tree cover trade-off. This revealed conflicts between agricultural land and neighbouring land uses, namely open forests and riparian areas (Fig. 5), as well as opposed demands in service supply and potential conflicts among the two beneficiary groups. Trade-offs between the provision of agricultural goods and other ES, especially regulating and supporting services, are common and occur at different scales (DeFries et al., 2004; MEA, 2005; Rodríguez et al., 2006).

To address these trade-offs, local stakeholders had agreed on enhancing forest benefits. Institutional programs in California and other ejidos in the reserve aimed to increase the provision of forest-based goods and services, and thus maintain forest cover and concomitantly allow farmers to make a living off their forests. A working landscape should maintain a mosaic landscape composed of different land use patches, each with a balanced array of ES, so that diversity, resilience and multifunctionality are enhanced (Kremen and Merenlender, 2018). For peasant farmers who constantly seek to convert land into a productive resource and intensify production in their farms (Van der Ploeg, 2014), the integration of forests into their resource base constitutes a viable strategy. As these benefits provided an income to California farmers through pine resin and timber trade, this could serve as an incentive to manage and protect their forests.

5. Conclusions

Local farmers valued goods and services co-produced in farms and the landscape that supported livelihoods and allowed them to make a living. In comparison, conservation institutions were mainly interesting in biodiversity conservation and the protection of natural habitat and regulation services of montane forest ecosystems at larger geographic scales. Despite the apparent differences in relevant ES, local stakeholders interacted in a social-ecological system and influenced each other’s views and preferences of ES.

Closed forests and riparian areas supplied high levels of multiple ES of relevance to both beneficiary groups. Hence conservation and local livelihood-supporting ES coincided in these ES hotspots. The current state of ES supply across the landscape also revealed land use decisions in the study site. Agricultural expansion and forest degradation had apparently reduced tree cover and supply of tree-based goods throughout the landscape.

Closed forests and riparian areas contrasted in their ES supply. However, as they occurred in different parts of the landscape, their supply was complementary and together provided a diverse array of ES at the landscape level. Thus, both beneficiary groups benefited from a multifunctional landscape in which their valued ES were distributed in different land uses. This is especially relevant for peasant farmers, who are well-adapted to a diversified production strategy.

Important trade-offs were found in the supply of forage cover against most other ES, especially tree cover. This trade-off revealed conflicts between agricultural land and neighbouring open forests and riparian areas, as well as opposing ES demands among farmers and conservation institutions. Local stakeholders agreed on enhancing forest benefits as a way to address these trade-offs, through institutional programs aimed to increase the provision of forest goods and services. Through this approach, both local livelihoods and conservation goals were supported.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2020.101134.

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