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RESEARCH



Tapping into nature's benefits: values, effort and the struggle to co-produce pine resin

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ABSTRACT

The concept of ecosystem services (ES) and related conceptual frameworks like the cascade model, can be relevant to explore the ways through which people and nature are connected and how the benefits of nature, upon which people depend, are realised. An integrated cascade framework was used to study the ES pathway of pine resin, a traded forest product, in a rural mountain community in Mexico. We conducted mixed-methods research, combining participatory tools with measures of service capacity, resin yield, and key farmer endowments. Resin was co-produced by an intricate interaction between the human and natural components of the social-ecological system. Substantial human inputs and coordinated efforts were required to realise resin benefits, and people's appreciation and plural values emerged along the whole service pathway. Though there were stark differences in natural resource endowments, working farmers gained a high share of resin's income through labour, labour relations and social networks. But most social conflicts and struggles also occurred over labour relations and organisation, revealing power dynamics. Furthermore, external actors controlled different mechanisms of access, and exerted power over the community's ability to derive benefits from resin. In resin co-production, values connect people to the landscape, while labour and power mediate the access to nature's benefits.

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1. Introduction

People are dependent on Earth's ecosystems and the benefits, goods and services they provide (Daily 1997; MEA 2005; Kumar 2011). Nature provides a variety of materials, often co-produced with people, that are vital to people's existence and their physical well-being; nature supports all dimensions of human health and contributes to intangible aspects of quality of life and cultural integrity (IPBES 2019). Moreover, prosperity and poverty reduction, particularly in rural areas, rely on maintaining the benefits that flow from ecosystems (TEEB 2010). Modern neoliberal societies have failed to recognise and appreciate this life-supporting character and value of nature. This failure could be one of the factors responsible for the often negative human impacts on the environment (Daily 1997; Potschin and Haines-Young 2017). Indeed, human drivers of change have accelerated in the past five decades, with the consequences that ecosystems and biodiversity are declining rapidly, and that nature and her vital contributions to people are deteriorating across the globe (IPBES 2019).

The ecosystem services (ES) and related concepts of nature's benefits or contributions to people (Díaz et al. 2015; Pascual et al. 2017), emphasise and explore the

ways in which people are connected to nature (Potschin and Haines-Young 2017). Although there are multiple meanings and perspectives on ES, they overall convey the importance that nature has for people. ES can be understood as a stepwise pathway that links ecological structures and processes to the well-being of people (Potschin and Haines-Young 2016). ES bridge the natural and human spheres and are thus viewed as an integral part of broader social-ecological systems (Carpenter et al. 2009; Loft et al. 2016). In exploring the multiple steps and feedbacks involved in nature's delivery of benefits to people, we can better understand what these services really are and the roles they play in society and nature relationships (Potschin and Haines-Young 2017). Here, we present a case study that aims to unravel and better understand a whole ES pathway.

The idea of a stepwise pathway can be represented in the ES cascade proposed by Haines-Young and Potschin (2010). This conceptual framework identifies the steps that lead from the structural and functional characteristics of ecosystems that generate services, to the benefits that contribute to human well-being and the values they support (Potschin and Haines-Young 2017). The framework gives the sense of a production line (Potschin and Haines-

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Young 2016) in which ES are placed in the production boundary, where the biophysical and socio-economic elements of the social-ecological system intersect (Potschin and Haines-Young 2017). Conceptual frameworks like the ES cascade can serve as organising structures that elucidate complex relationships, re-frame societal challenges (e.g. people's reliance on nature, sustainable management of ecosystems, governance issues), and offer an analytical template for empirical research (Potschin-Young et al. 2018).

Human interactions and interventions are often necessary to realise benefits derived from ES (Potschin and Haines-Young 2017), with human inputs occurring across different stages of the co-production pathway (Van Oudenhoven et al. 2012; Palomo et al. 2016). Human agency and inputs are as important to service co-production, as the underlying ecosystems that give rise to these services (Spangenberg et al. 2014a). Moreover, social and ecological factors facilitate, hinder or are necessary for the provision and delivery of ES (Reyers et al. 2013; Fedele et al. 2017). Likewise, institutions play a critical role in the control, regulation and access of ES and their associated benefits (Leach et al. 1999; Hicks and Cinner 2014; Berbés-Blázquez et al. 2016).

The ES cascade has been applied in several place-based studies to understand human-nature relationships (Potschin-Young et al. 2018). However, there are few instances in which the different steps, feedback loops, and social-ecological interactions along the entire service pathway have been characterised and measured (Spangenberg et al. 2014a, 2014b; Fedele et al. 2017). An integrated ES cascade can thus be used to address key challenges in ES research, namely to understand how ES are co-produced and the way in which social interactions and institutions influence the supply and distribution of these services (Bennett et al. 2015).

We conducted mixed-methods research to study the ES cascade of a traded non-timber forest product, pine tree resin, in a rural mountain community in Mexico. The local context of a natural protected area and a broad set of social actors and institutions was taken into account in the social-ecological system analysis. We aimed to examine the whole resin ES cascade that links people's well-being to forests, and thus to better understand how ES are realised. To this end, we had three research questions: (1) How is resin co-produced? (2) How do social interactions and institutions influence the supply of resin and the distribution of benefits? (3) How does resin connect local people to their landscape? The practical applications of this study serve to inform sustainable forest management programs and socio-environmental innovation processes in landscapes that support people and biodiversity.

2. Methods

2.1. The study site and the Resin Project

California is a rural community located in the mountains of the Sierra Madre of Chiapas, southern Mexico, with a territory (here the local scale) of approximately 1120 ha (WGS 84, 16°13'41"–16°16'18" N, 93°34'53"–93°37'10" W). California is an *ejido* since 1985, a special type of social land tenure and sub-municipal settlement organisation that is formed both by a group of peasant farmers and the rural land they hold (UN-HABITAT 2005). Though *ejidos* are social land holdings, part of a post-revolutionary land distribution and reform system in Mexico, the California *ejido* presently is mostly comprised of individual parcels with few communal holdings in the village and no forest commons. California is situated in the buffer zone, a sustainable use area, of La Sepultura Biosphere Reserve, a federal natural protected area established in 1995 (Figure 1).

Around 400 people live in California (*Ejido* president, personal communication, 12 January 2019), mostly *ejido* members with farms but also landless villagers and recent settlers. The *ejido* promotes the use of its natural resources for the community's benefit: farmers cultivate valleys, let livestock graze extensively, extract materials from forests, and obtain household water from streams. Domestic units in California and neighbouring communities follow a diversified strategy strongly based on primary production, including maize, bean, coffee and vegetable cultivation, cattle ranching, resin extraction and forestry. They also depend on government transfers, remittances and non-agricultural activities for their income. Staple crops, notably maize and beans, are grown for self-consumption, and excess production is commercialised alongside livestock (mostly calves), resin and coffee, products with a higher exchange value (Meza Jiménez et al. 2020). Various traders frequently visit the community. California lies within the Villaflores Municipality and 65 km away (about 1.5 h) from the city of Villaflores, a region famous for its rich agricultural valleys and strong farming and ranching identity.

Located at 850–1535 m.a.s.l., California has a semi-warm and humid climate (INE 1999). Mean annual temperature is 22°C and mean annual precipitation around 1,000 mm (Fick and Hijmans 2017). Summers are hot and rainy in contrast to winters with scarce rains, with the wet season from May to October and the dry season from November to April. Montane pine-oak forests dominate, made up mainly of *Pinus* (Pinaceae) and *Quercus* (Fagaceae) species (González-Espinosa et al. 2006). The most abundant pine species is the ocote or eggcone pine, *Pinus oocarpa* Schiede ex Schltdl. var.

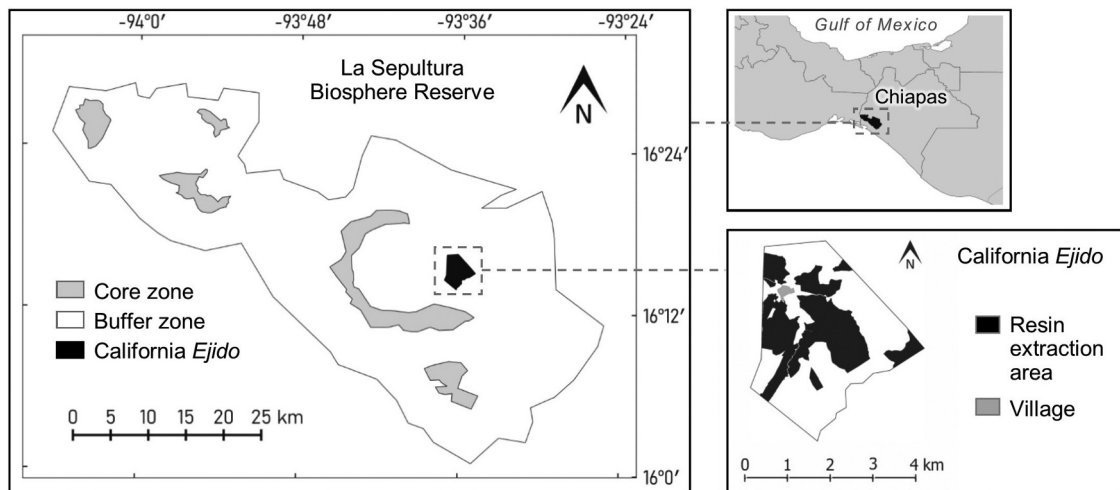


Figure 1. Study site location and map. The California *ejido* is situated within the buffer zone of La Sepultura Biosphere Reserve (left map), in the State of Chiapas, southern Mexico (top-right map). The resin extraction area presently encompasses around 40% of the total *ejido* territory (bottom-right map).

ocarpa, from which raw resin is extracted. *Pinus oocarpa* is the most common pine in Mesoamerica (Dvorak et al. 2009).

Pine resin is a non-timber forest product (NTFP). NTFP are biological products of wild species harvested from ecosystems, with benefits from their use that accrue to local livelihoods and well-being (Shackleton et al. 2011a). Pine resin, used as a raw material to obtain turpentine and rosin (colophony), is one of the most important NTFP in Mexico and its production has steadily increased in the last decade (CONAFOR 2013; SEMARNAT 2020). Resin extraction and commercialisation, like many NTFP in Mexico, is federally regulated and thus requires an official forestry permit. Resin production in the region has entailed a long development process coordinated by multiple stakeholders. California has been involved in this process (the ‘Resin Project’) from the start and delivered the first batch of raw resin together with other *ejidos* in 2012. California has been the only community to maintain production (Pronatura Sur 2018). Resin farmers in California have organised themselves into a cooperative known as the ‘Resin Group’ that manages production and its own assets. The Resin Group presently consists of around 20 members and other farmers (3–5) are irregularly active in production. There are no membership fees, though members share small administration expenses. Members are expected, as stated in the group’s bylaws, to produce resin consistently, cooperate in the group’s delivery to the buyer, and attend occasional meetings.

2.2. Unpacking the ES cascade

An integrated ES cascade was used as an analytical template for this study (Figure 2). The five steps in the

cascade, based on Potschin and Haines-Young (2016), were adapted to the resin provisioning service: (1) the *landscape*, the forest or habitat type where resin is supplied; (2) specific *function(s)*, the subset of ecological structures and processes that underpin or determine resin production and are useful to resin farmers; (3) the *service* or final output from the ecosystem, the extracted pine resin, that directly contributes to products or conditions valued by local people (4) the *benefits* from resin extraction that can change people’s well-being; and (5) the *values* that people assign to these benefits. Values were differentiated into values of nature, namely the importance, worth or usefulness of nature (Díaz et al. 2015), and basic human values, which are people’s beliefs, motivations, criteria and priorities (Schwartz 2012). The ten motivationally distinct values identified by Schwartz (2012) include self-direction, stimulation, hedonism, achievement, power, security, conformity, tradition, benevolence and universalism. Alongside benefits, we also took into account the detriments or negative contributions to people’s well-being (Díaz et al. 2018). People’s interventions and interactions were integrated to the framework by identifying mediating mechanisms (management, mobilisation, allocation-appropriation, and appreciation) that connect the cascade steps, and mediating factors (rules, assets, space-time, and values) that influence these mechanisms (Spangenberg et al. 2014a; Fedele et al. 2017).

We conducted mixed-methods research in a yearlong study, from March 2018 to February 2019. To examine benefits, detriments and values of the resin cascade, as well as mediating mechanisms and factors, qualitative data were obtained through participatory tools (Geilfus 2008). We conducted 15 semi-structured interviews (guide in Table S1)¹ with resin producers (12 Resin Group members) who had been

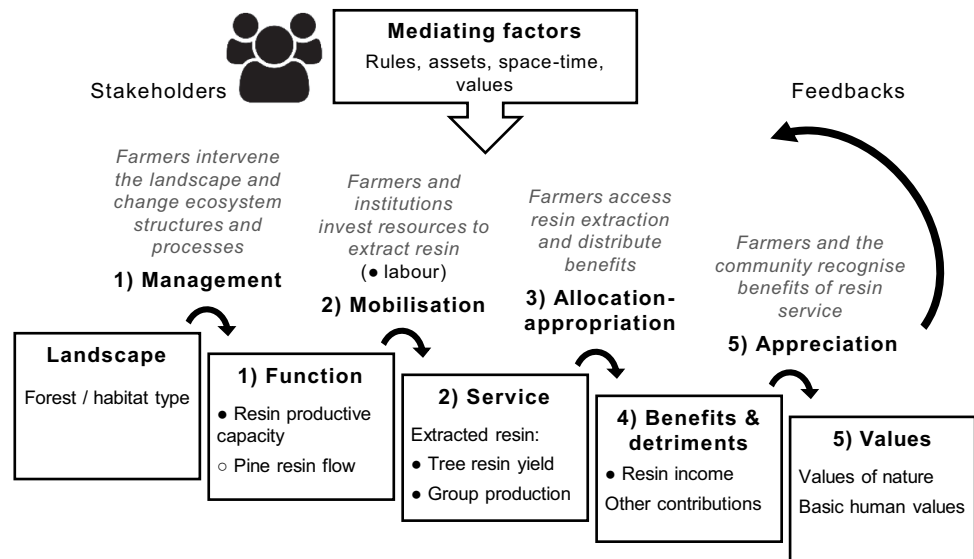


Figure 2. Cascade framework to study pine resin extraction in California. The resin cascade is a stepwise pathway that links ecological structures and processes in the landscape to local people's well-being. Cascade steps are connected by mediating mechanisms, and mediating factors influence these mechanisms. Specific measures along the cascade were quantified (black circles), and key relationships in the social-ecological system examined. Pine resin flow (white circle), which includes tree secretory canals as well as resin synthesis, storage and exudation (Neis et al. 2019), was identified as an important function but not analysed in this study. Numbers (ordinals 1–5) correspond to Results subsections. Framework mainly adapted from Haines-Young and Potschin (2010), Spangenberg et al. (2014a), and Fedele et al. (2017)

involved in the Resin Project for at least four years. We also carried out frequent informal dialogues with key respondents, including other resin farmers, ten community residents, and two representatives of a civil-society organisation (*Pronatura Sur, A.C.*) that works on integrated development projects in the region. Finally, we participated as observers during six resin delivery events that also served as group meetings, as well as a local capacity building workshop and two community visits from government officials in relation to the Resin Project.

2.3. Quantifying measures along the cascade

To complement qualitative data, the following measures along the cascade were quantified (Figure 2): farm and landscape resin productive capacity (Section 2.3.1), the actual service provided in one year, i.e. raw resin extracted and produced throughout the study period (Section 2.3.2), and income from resin extraction and its relationship to key farmer endowments (Section 2.3.3).

2.3.1. Resin productive capacity

Resin faces are regarded as the basic supply unit in the landscape's capacity to deliver resin (Figure S1). A face consists of an open wound installed on the pine trunk, where the bark has been removed and the outer xylem, which contains resin secretory canals, is reached. The exposed area is about 10 cm wide, with increasing height as tapping progresses upwards. When farmers can no longer reach the top of the

face, up to 2.5–3 m high, the face is abandoned. Hence, faces are only productive for 3–5 years. According to Mexican pine resin extraction regulations (SEMARNAT 2006), a single face can be installed on a pine with a minimum dbh of 25 cm. Bigger trees can support two and occasionally even more parallel faces. Consistent with ES concepts of potential supply and capacity (Mouchet et al. 2014; Cord et al. 2017), we here refer to resin productive capacity as the maximum amount of faces that can be installed on existing pine trees, whether in a plot, farm, landscape, or area unit (per hectare).

To measure resin productive capacity as well as resin tree density and basal area, we carried out a forest inventory in the community's present resin extraction area (Figure 1). This 442 ha sampling area, ca. 40% of the *ejido* territory, consisted of a mountainous landscape with slopes averaging 25° and up to 51°, and an elevation of 900–1220 m.a.s.l. The 33 farms that comprised the extraction area were mapped with a GPS. The forest inventory followed a double-sampling design (Husch et al. 2003a). Detailed methods can be consulted in the Table S2.

2.3.2. Resin service

Pine trees are tapped by scratching the top of faces with a specialised axe, making an arc-shaped wound, each wound slightly higher than the previous (Figure S1). Skilled resin-tappers aim to make a small superficial wound, ideally ≤ 1 cm higher, to progress slower up the trunk and tap the tree for more years.

Trees are tapped regularly to maintain resin flow, every eight days is recommended. Resin drips down to a collecting cup at the bottom of the face. Cups gradually fill up, are replaced when necessary, and full cups are normally left on the ground next to trees. Farmers continue to tap and accumulate resin in the field until they agree on a date to collectively deliver resin to the buyer. Deliveries are irregular and depend on the amount of accumulated resin, farmer's income demand and the buyer's schedule. To harvest resin, all cups are emptied and resin is poured into containers (40 kg). These are carried to a village warehouse, the Resin Collection Centre, where each farmer's resin is weighed. All produced resin is then placed into barrels ready to be shipped.

To measure resin yield, the amount of raw resin extracted per face per year, we carried out an empirical study in collaboration with three experienced resin farmers. We first identified a small resin extraction area, where each farmer worked and easily harvested in a 6 h work day, and tagged around 90 pine trees therein. During the study additional trees were tagged to replace harvested or fallen individuals. We measured resin yield alongside farmer resin harvests. For each tagged tree, we recorded the net weight of accumulated resin with a spring scale [Pesola® Medio line, 1000 g, d = 10 g], and the number of actively tapped faces. We obtained tapping frequency by asking farmers the amount of times trees had been tapped in the period. We measured and harvested resin six times during the yearlong study. Finally, monthly and annual estimates of resin yield were calculated (details in Table S3).

We calculated the Resin Group's total production for the last 5 years (2015–2019), alongside other performance indicators like the amount of annual deliveries and number of active producers, i.e. those supplying resin in each delivery event. This information was obtained from the group's records (California Resin Group, personal communication, 1° March, 2019).

2.3.3. Resin income

The trade of raw resin provides a direct cash income to farmers involved in resin production. According to them this income depends mostly on two key farmer endowments, understood as the resources and rights that social actors have (Leach et al. 1999). First are the pine trees in their farms. Based on Mexico's federal agrarian laws, farmers with usufruct rights to land in the *ejido*, here farm owners, also have the right to exploit the natural resources therein. Thus, farmers have different productive capacities based on their farm's stand structure, specifically the density and size of pine trees. Second is the labour resource needed to produce resin.

We quantified income and key endowments of all resin farmers (N = 25) during the study period. Net income was calculated as gross income obtained from payment records, minus paid wages and rents. Resin productive capacity consisted of the farmer's total productive capacity of his/her farm(s) (estimated means, from Section 2.3.1). Labour comprised the reported working hours by the farmer and his/her family in resin extraction, including tapping, harvesting and carrying resin (from semi-structured interviews, Table S1). We recognised three different types of resin farmers: non-working farm owners (O), who did not work on resin extraction themselves; working farm owners (OL); and labourers (L), who extracted resin but did not own farms.

We explored the relationship between income and key endowments using a multiple regression model:

$$\begin{aligned} \text{Net income} = & \beta_0 + \beta_1 \text{productive capacity} \\ & + \beta_2 \text{labour} + \beta_3 \text{productive capacity} \\ & \times \text{labour} + \varepsilon \end{aligned}$$

All statistical computing for this study was performed in the R environment (R Core Team 2020). The model were checked for normality and homoscedasticity ($\alpha = 0.05$) using the 'olsrr' package (Hebbali 2018). Variables were first square-root transformed to normalise them, then standardised to z-score (subtracting sample mean and dividing by the standard deviation) to reduce multicollinearity between predictors, detected with variance-inflation factors in the 'car' package (Fox and Weisberg 2019).

3. Results

3.1. Landscape functions and management

Landscape resin productive capacity was 56.4 ± 10.3 faces $\cdot \text{ha}^{-1}$ (95% CI). There was considerable variation among farms in their productive capacity, which ranged from 156 to 2860 estimated faces. About half of the farms had less than 500 faces. This broad range was due to a tenfold range in farm size, 4.6–47.6 ha, and a threefold range in pine basal area, 4.1–11.6 $\text{m}^2 \cdot \text{ha}^{-1}$ (full results in Table S4).

Not all potential faces were installed and tapped simultaneously. The fraction of faces installed on tapping-size pines (n = 460 trees, 58 sampling plots in eight farms) was 51% of full productive capacity, i.e. about half of the potential number of faces were presently installed on resin trees. Face installation required substantial work with costly wages as well as materials that were not always readily available. More important, farmers decided on the amount and timing of faces, either due to labour constraints, e.g. farm owners working alone, or as a resource use strategy that took into account the face's limited productive period (< five years at most). In addition,

it took pines in California 30 years on average to reach the minimum tapping size (25 cm dbh), but this size varied considerably with stand characteristics and management (Egloff 2019). Thus, a single-face pine had an economic lifespan of up to 35 years, after which it was felled for timber or left to grow until a second face could be installed, usually ≥ 40 cm dbh (Table S2c). Farmers were not explicitly concerned about the abundance of pine trees in the landscape with an actual density of tapping-size trees of 45.3 ± 8.4 trees \cdot ha⁻¹ (95% CI). Extensive pine forests remained untapped, up to 60% of the territory was still not used for resin extraction (Figure 1). Farmers were of the opinion that smaller pine trees would grow and replenish tapping pine stocks. In fact, in the eight subsampled farms, there were 3.5 times more juvenile (5 to < 25 cm dbh) than tapping-size pine trees (dbh ≥ 25 cm) in forested areas, 194.5 vs 54.8 individuals \cdot ha⁻¹ respectively (diameter class distribution in Figure S2).

In their own farms, however, farmers actively promoted pine regeneration mainly by weeding around seedlings and saplings and excluding cattle from regeneration areas. Farmers also performed forest management practices, including litter raking, tree pruning and thinning, occasionally supported with wages and tools from institutional programmes. Other practices like maintaining firebreaks and controlling agricultural burns were aimed at reducing the risk and impact of forest fires, a threat to resin extraction. As a result, 4–5 m tall pine trees were growing in several farms, usually within designated regeneration areas (Figure 3).

Farmers allowed livestock to graze extensively in forests where resin extraction took place. A frequently reported benefit was that livestock kept understory vegetation low, which allowed farmers to move faster among resin trees. Steep and open forest areas overgrown with dense grass and shrubs posed a real challenge, and as mentioned by a couple farmers, they preferred to extract resin elsewhere. On the downside, cattle tipped over filled cups placed on the ground, which for farmers was a minor but recurring and annoying problem. Cattle also trampled pine seedlings and damaged small trees (< 2 m tall), which affected pine regeneration efforts.

3.2. Resin service and mobilisation

Resin farmers mobilised regularly and effectively to extract resin. They installed faces, tapped pines, harvested and carried resin to the Resin Collection Centre, where they weighed, stored and loaded the resin onto transport vehicles. Resin farmers worked alone, summoned the help of able family members, and cooperated with co-workers through different arrangements, e.g. shared profit, barter or wages.

Farmers had devoted considerable amounts of work and time to the Resin Project, especially at the start, and in the words of a study participant, without knowing if the project would succeed or eventually pay them back. Farmers had e.g. provided their labour to build the Resin Collection Centre, met with external stakeholders on multiple occasions, and frequently travelled to the state's capital to deal with government institutions, which they pointed out was costly and time-consuming.

Annual tree resin yield was 2.59 kg \cdot face⁻¹ (SD = 1.41 kg \cdot face⁻¹), a median value of 2.34 kg \cdot face⁻¹. Considering the landscape's mean productive capacity, this amounted to 146 kg \cdot ha⁻¹. Resin production was irregular throughout the year, and resin farmers recognised different production periods. The high production period, February to May, contributed with 54% (1.39 kg \cdot face⁻¹) of annual yield; the low production period, June to September during the height of the rainy season, with 17% (0.45 kg \cdot face⁻¹); and the intermediate production period, October to January, with 29% (0.75 kg \cdot face⁻¹) (Figure 4, values in Table S3).

Tapping frequency for the three farmers who collaborated in the resin yield study was roughly one tapping session every 11 days on average. Tapping frequency varied alongside production periods, with tapping on average every 9, 14 and 10 days during the high, low and intermediate production periods respectively. Farmers tapped pine trees less often during the low production period because the small resin yields were not worth the effort. They attributed this to the rain, which they claimed reduced resin flow, and torrential storms that flushed the accumulated resin out of collecting cups. There was also labour constraint in this period, as agricultural fields demanded a lot of work and farmers prioritised their staple crops.

Local and external institutions were essential for the Resin Project (Figure 3). The Resin Group managed total resin production, traded with the buyer(s), and was the point of contact with civil-society organisations promoting capacity building. The *ejido*, in which the Resin Group and community were embedded, constituted the legal entity with the rights and responsibilities to manage official government programmes. To build the Resin Collection Centre, the *ejido* managed the government-funded building materials and organised collective work, to which community residents were obliged to participate or contribute – up to eight workdays by some accounts. It was also the *ejido's* legal obligation to obtain the forestry permit, valid for either five or ten years, which entailed a challenging procedure. The permit had been granted on two occasions owing to the support of multiple external actors, which had formally and informally collaborated to this end. The

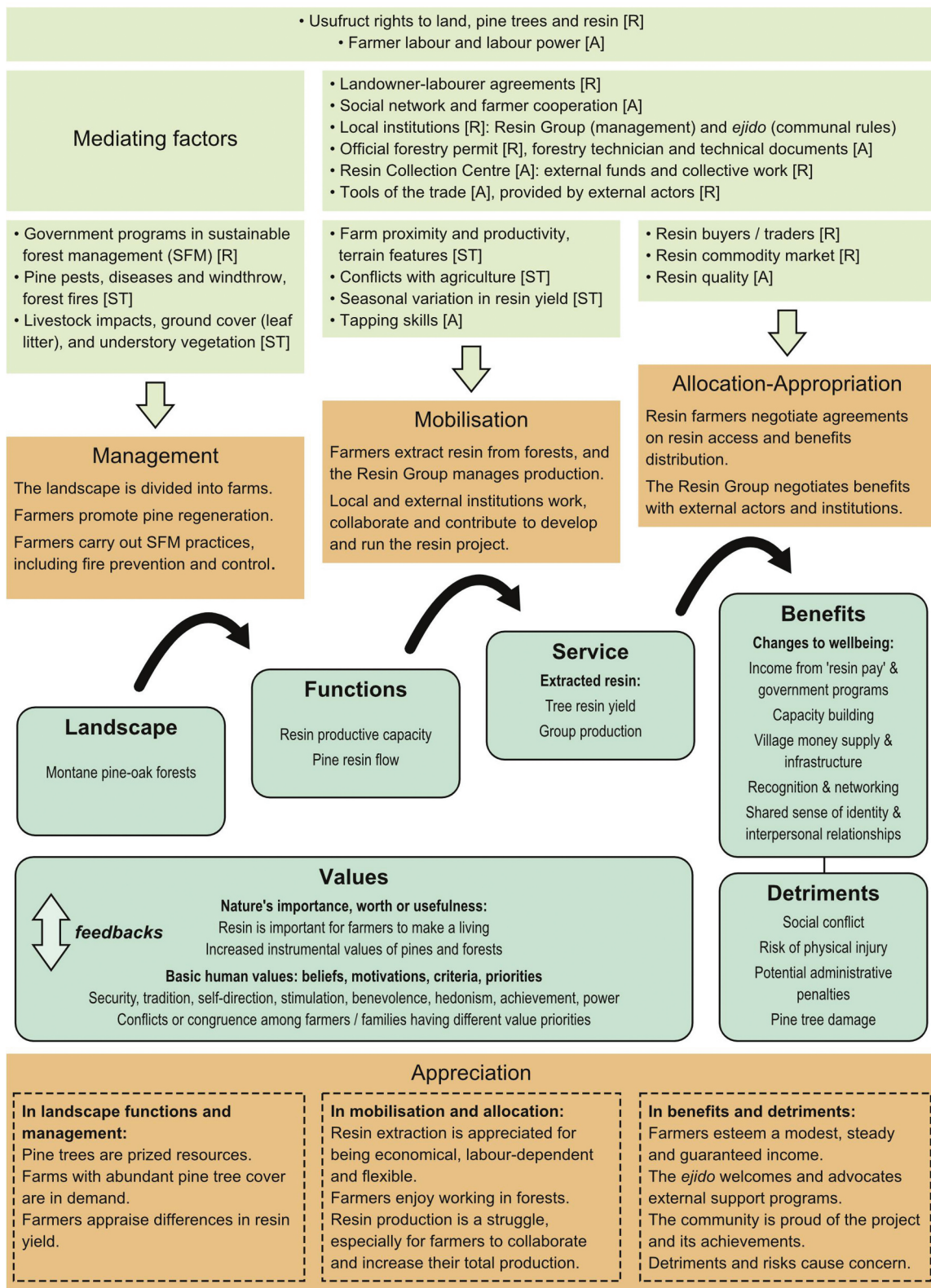


Figure 3. ES cascade of pine resin in California, connecting the forested landscape to local people's well-being. The step-wise pathway flows upwards to depict the multiple human inputs and social interactions needed to co-produce resin and derive benefits. Mediating mechanisms (management, mobilisation, allocation-appropriation and appreciation) connect the steps, and these mechanisms are influenced by numerous contextual factors (mediating factors) including assets [A], rules [R], space-time [ST], and values. Values underlie many aspects of resin extraction, resulting in feedback loops throughout the cascade. This framework is based on the cascade model (Potschin and Haines-Young 2016) and the mediating mechanisms-factors framework (Fedele et al. 2017).

forestry technician, a certified professional, was responsible for the technical studies, paperwork and permitting process, and served as a liaison between

the *ejido* and environmental authorities. The Resin Group and resin buyers arranged a compensation scheme consisting of a percentage on future resin

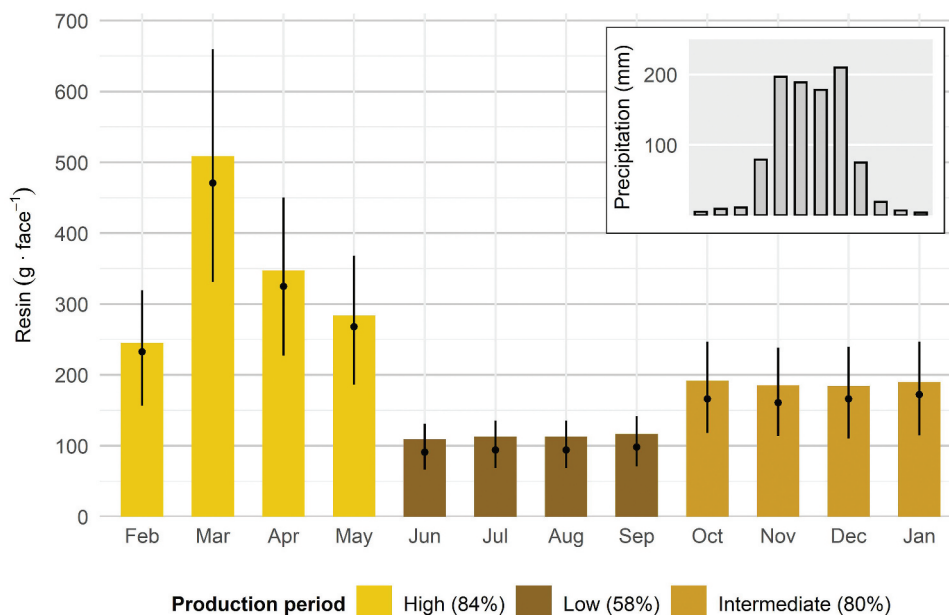


Figure 4. Tree resin yield throughout the study period (Mar. 2018–Feb. 2019). Mean monthly estimates include the median and interquartile range (black points and lines respectively) to represent data dispersion. Average tapping frequency for each production period is shown in parenthesis (legend). Rain pattern in the study site (inset graph) is based on historical monthly climate data for precipitation (Fick and Hijmans 2017).

sales to pay for the technician's professional services. In addition, the civil-society organisation counselled the *ejido* throughout the process. These external actors, with different goals and expectations in the Resin Project, e.g. financial returns in the case of the resin buyers, had made considerable resource investments and were crucial to resin co-production.

For the Resin Group, total production, deliveries and active producers were highest in 2015 and 2016. Many resin farmers regarded this period, even back to 2014, as the most successful in the project's history, after which overall performance declined (Table 1). More than half of the original group members abandoned the project, including a few big farm owners with high productive capacity that accounted for a large share of total production. There were many reasons cited for this drop: not enough income from resin extraction, unrealised project expectations such as receiving additional funds or wages, the

physical challenge of resin extraction, conflict among members, insecurity around the forestry permit, and out-migration. Still, current members asserted that production had stabilised, and preferred less frequent but substantial deliveries (group and individual production per delivery, Table 1). As remarked by a civil-society organisation representative, the more determined and committed resin farmers had remained and the Resin Group was consolidating.

3.3. Allocation-appropriation

Labour relations between farmers endowed with pine trees and those endowed with skilled labour were a central aspect in service allocation and benefits distribution (Figure 5). Out of 14 farmers who worked on resin extraction, including those with farms, nine tapped resin in properties they did not

Table 1. Resin group performance indicators of raw resin production (California Resin Group, personal communication, 1 March, 2020).

	2015	2016	2017	2018	2019	5-year average
Group deliveries	8	11	7	6	5	7.4
Total group production tonnes	34.9	42.1	29.3	15.9	21.2	28.7
[tonnes · delivery ⁻¹]	[4.4]	[3.8]	[4.2]	[2.7]	[4.2]	[3.9]
Active producers on average	31.4	28.8	22.1	13.5	15.0	22.2
No. producers · delivery ⁻¹						
Individual production on average	136.0	130.4	183.5	181.6	308.9	188.1
kg · delivery ⁻¹						

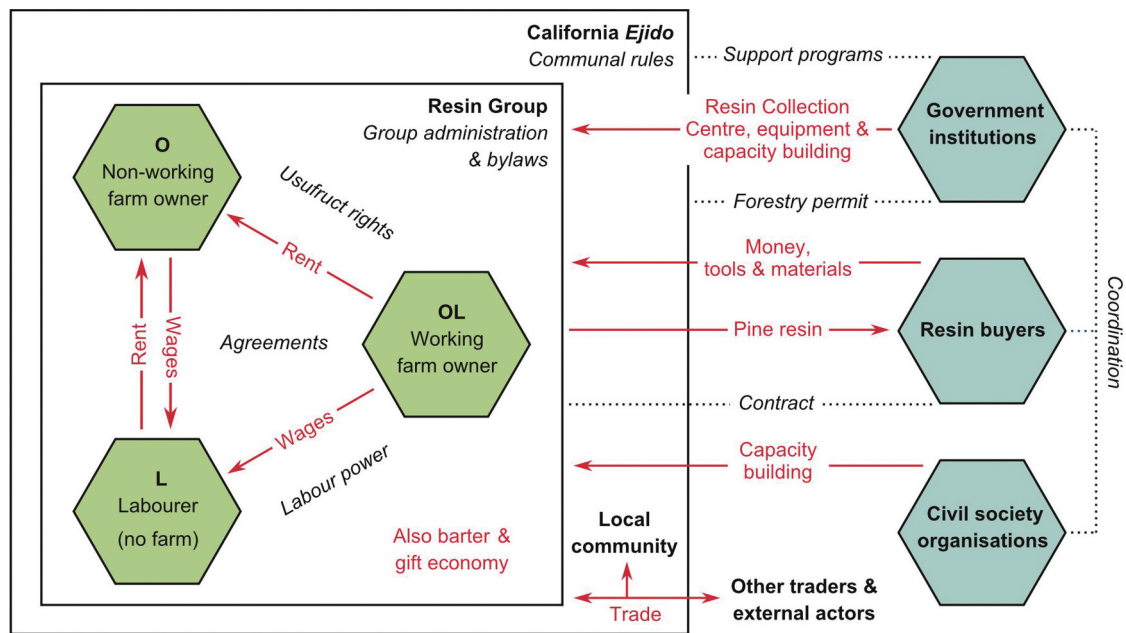


Figure 5. Allocation-appropriation of tangible benefits derived from pine resin. Goods and products flow (arrows) among resin farmers (green hexagons) and the community, local institutions like the Resin Group and the *Ejido* in which they are embedded, and external actors-institutions (blue hexagons). Diverse rules and interactions (*in italics*) among social actors mediate the access and distribution of benefits, notably agreements between different types of resin farmers.

own, on occasions in three or four. Hence, farm owners and resin workers interacted and negotiated an agreement, typically an oral contract, to extract resin. The agreements could specify a rent paid to the owner, usually $\approx 25\%$ of gross income (a production-rate basis of \$100 MXN rent per 40 kg container delivered),² or paid wages. Resin workers were thus able to negotiate a high benefit share, up to 75% when renting. Other agreements included the barter of goods or services, e.g. sawed wood, wire fencing, or labour, and a gift culture between family members and friends. For instance, five farm owners allowed their properties to be tapped without charging rent. Social networks were thus important for resin workers to access pine trees in farms and likewise for farm owners to find trustworthy workers.

Social interactions among resin farmers and between local and external institutions involved in the Resin Project were for the most part positive. According to stakeholders, the relative success of the project was the outcome of farmer cooperation, stakeholder collaboration, and concerted efforts (Figure 3). Nonetheless, raw pine resin was a traded commodity in national and global markets that integrated external actors, especially buyers, and the Resin Project in a broader economic context. The initial buyer in the Resin Project, an important Mexican company interested in developing resin production in Chiapas, abandoned the project and its regional presence as soon as its contract ended, without giving notice nor explanations. The farm gate price of resin (\$10 MXN per kg, for most of the

study period) caused tensions and constant negotiations between the Resin Group and buyers, and low prices threatened the whole Resin Project to end abruptly. In addition, the project had not progressed without social conflict. There were power struggles in resin access, e.g. constantly changed or broken working agreements, and in benefits distribution, e.g. disputes over a differential resin pay (price per kg) and the use of the Resin Group's assets (truck and equipment). Outstanding issues in the group's management were that bylaws were neither respected nor enforced through penalties, and the lack of member participation beyond infrequent meetings and resin deliveries. The bulk of the work was done by the 3–5 Resin Group administrators, who worked without being paid. As noted by two former Resin Group presidents, the volunteer work load was substantial and the burden fell mostly on them.

3.4. Resin benefits and detriments

Farmers valued resin's contribution to their livelihood, mainly the resin pay from trade that helped them make a living by earning money (Figure 3). Resin provided a modest but reliable source of income, and for some even their main livelihood, which according to a few farmers was enough to subsist. This income was especially important from February to May, when resin production was highest (Figure 4) and demand for hired labour in agriculture, and hence alternative sources of income, lowest. Resin gave farmers a sense of security through

income stability and safety to their family and livelihood. One farmer asserted, ‘Resin guarantees our food,’ while another was appreciative of pine trees that ‘feed me and my family.’ Pine trees had become esteemed resources – their instrumental value had increased significantly in a few years – and as stated by many farmers, they now carefully reconsidered cutting down a pine tree. Similarly, farms with abundant pine cover were worth more, as evidenced by the fact that the selling price to land rights had increased, because of their added value from resin production.

Annual net income from resin averaged \$7,428 MXN (SD = \$7,690 MXN) for farmers. Non-working farm owners (O), the group with largest productive capacity, earned less on average (Table 2). They were physically unable to extract resin and busy in other productive activities, so most (9 of 10) received only minor rents and one hired a worker, expending 63% of gross income on labour. In comparison, working resin farmers (L & OL) generated a high net income; their daily earnings, considering a 6 h workday, were higher than local agricultural wages of \$100–120 MXN (Table 2, Figure 6a).³ Resin productive capacity among farm owners (O & OL)

varied broadly, a range of 78 to 4184 faces, with an average of 1204 faces (SD = 1063). Labour was likewise wide-ranging: working resin farmers (L & OL) invested between 80 to 1311 h of family labour during the study period, an average of 427 h (SD = 323 h) or $\approx 8 \text{ h} \cdot \text{week}^{-1}$. Based on the reported tapping frequency (Section 3.2), this varied from 9.3 to 6.4 $\text{h} \cdot \text{week}^{-1}$ in the high and low production periods respectively. The highest earning farmer (\$30,030) invested considerably more labour, $\approx 25 \text{ h} \cdot \text{week}^{-1}$ on average (outlier, Figure 6a), by having a family of four able workers.

Net income of all resin farmers was significantly explained by labour ($\beta = 0.98, p < .001$), productive capacity ($\beta = 0.22, p = .024$), and their interaction ($\beta = -0.17, p = .049$); the whole model $F(3,21) = 39.5, p < .001$, explained 84.9% of the variance (regression Table S5). For non-working farm owners (O), productive capacity significantly predicted net income ($F(1,8) = 8.4, p = .020$), and explained 51.3% of the variance (Figure 6b). In the case of working farm owners (OL), only labour significantly predicted net income ($F(1,9) = 38.0, p < .001$), explaining 80.9% of the variance (Figure 6a). For labourers (L), most

Table 2. Income and endowment profile of resin farmers for the study period (Mar. 2018–Feb. 2019). Values are estimated means (SE in parentheses). Workdays are considered 6 h long.

Resin farmer type	Net income MXN	Daily earnings MXN $\cdot \text{workday}^{-1}$	Productive capacity Faces	Labour Hours
Non-working farm owner (O) n = 10	\$1,583 (\$765)	-	1398 (411)	0
Working farm owner (OL) n = 11	\$10,914 (\$2,384)	\$174 (\$17)	1027 (246)	407 (101)
Labourer (L) n = 4	\$12,455 (\$3,709)	\$165 (\$23)	0	483 (165)

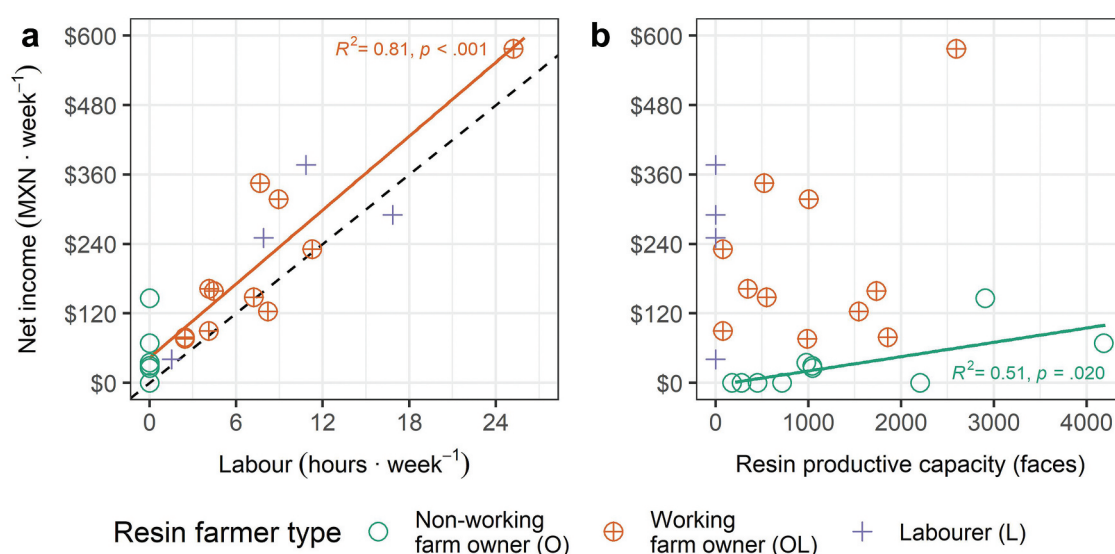


Figure 6. Bivariate analyses between farmer income and key endowments in resin extraction for the study period (Mar. 2018–Feb. 2019). (a) Labour is a significant predictor of net income to working farm owners (OL), and resin extraction generates higher daily earnings on average (solid regression line) than the local upper wage for hired labour (\$120 MXN per 6 h workday, dashed line). (b) Resin productive capacity alone is a significant predictor of net income to non-working farm owners (O). Net income and labour are annual averages scaled to per-week values.

variance (78.9%) was explained by labour, however due to low sample size ($n = 3$) the relation was not significant ($F(1,2) = 7.5, p = .112$).

The community valued resin's contribution to its well-being (Figure 3). With the resin pay, the village's money supply increased and there was a noticeable surge in local trade and credit, as observed in stores around resin delivery days. One store owner commented that resin benefited the whole community, and that resin brought a monetary stimulus to the village. Besides the Resin Collection Centre, which was used by the Resin Group and the broader community for multiple purposes, farmers had obtained, at practically no cost to them, several tangible goods from project interventions by external actors (Figure 5). Farmers received free tools and equipment as well as capacity building, e.g. farmers participated in resin extraction workshops, where all expenses were paid. Skilled resin farmers later became instructors in subsequent workshops for which they were remunerated. Resin also brought intangible goods such as a shared sense of identity for the community and stronger interpersonal relationships within the Resin Group. The community was proud of the Resin Project and its achievements, and had gained respect and networking opportunities with key social actors. For example, California's Resin Project was touted by multiple government officials as one of the most successful integrated development projects in Chiapas, a recognition the *ejido* used to claim more government support programmes and subsidies.

Resin extraction could also negatively affect people's well-being (Figure 3). Farmers had injured themselves when carrying heavy resin containers across the steep and slippery terrain. Farmers also felt uncomfortable about dangerous viper snakes and wildlife encountered in the high mountain areas. Another source of concern was the forestry permit, particularly potential administrative penalties for non-compliance. Finally, resin tapping caused an evident damage to the pine trunk, and farmers worried that the loss of protective bark left trees more vulnerable to forest fires. But beyond this, people voiced little concern about the impact of resin extraction on pine population biology.

3.5. People's appreciation and values

People not only valued the benefits gained from resin, but appreciated also non-monetary aspects of resin extraction (Figure 3). Farmers enjoyed working up in the mountain forests away from the village. One study participant said he was fond of working under the cool shade of trees, and another expressed how he could get some fresh air and clear his mind. Spending time in forests was a respite from agricultural activities.

Overall, resin extraction was valued for being economical, in the sense that farmers needed to invest little to no money to produce. This was especially relevant when compared to cattle ranching or maize and bean cultivation, which incurred in considerable upfront costs (see Figure S3). Resin workers occasionally bought cooking oil used as thinner to clean resin, and replaced their clothes because resin stained and ruined them. The highest costs were incurred when installing new faces, but only if based on hired labour. In contrast, agricultural production required a suite of expensive agrochemicals and other inputs. Though some of these were subsidised, one farmer claimed he usually spent \$15,000 MXN on fertiliser, pesticide and seeds for his 2 ha of cultivated maize, and around \$800 MXN every month on cattle tick treatments. Resin extraction was also considered a flexible activity that could be temporarily abandoned, then taken up again if income was needed. As stated by a resin farmer, pine trees were resources waiting to be tapped. Despite some timing conflicts with agriculture, e.g. during crop cultivation (June–September and December–January), many regarded resin extraction a compatible and supplementary farming practice. Farmers also had a good grasp of the requirements for adequate resin extraction: it demanded diligence, i.e. being constant and hardworking, the capacity to schedule multiple productive activities, and special tapping skills.

Human values underlay many aspects of resin extraction, they were a central component in the resin cascade (Figure 3). Values were often expressed or suggested in the multiple exchanges with farmers, e.g. security, achievement and hedonism values already referred to. Resin farmers including landless labourers cherished the self-direction offered by resin production, many of them claimed they were independent and could make their own decisions. Farmers liked to rely on their own labour, a traditional value in peasant farming. A couple of farmers experienced stimulation from resin extraction, they saw it as a novel activity that challenged them, and a project they could further develop. Values of benevolence were expressed by three farm owners who allowed their properties to be tapped because of kinship and in support of fellow farmers. In parallel, there were many references to power values related to the control of resources, social status and recognition. Values were ubiquitous, present e.g. in the Resin Project's appraisal, Resin Group's bylaws and (non-) compliance, tapping frequency, and pine reforestation efforts. People's values both shaped resin extraction and were also shaped by it: working and spending more time in forests had influenced how farmers related to forests, and resin allowed people to further recognise and value their

dependence on forest resources. This was evident in resulting feedbacks, in changes in the landscape's management (Section 3.1) to protect and promote pine regeneration and forest cover.

4. Discussion

4.1. How resin is co-produced

People interacted strongly with their landscape to co-produce resin. Constant and considerable resource investments, as well as coordinated efforts, were necessary to transform key functions of montane pine-oak forests into a satisfactory and legitimate production of commercial resin. Hence, the resin pathway moves upwards (Figure 3) to represent the multiple human inputs and the struggle farmers experience to attain the benefits that contribute to their well-being. The assumption that ES simply 'trickle-down' from the landscape to people has been contested (Berbés-Blázquez et al. 2016; Wieland et al. 2016). Different conceptual frameworks of ES co-production (Costanza et al. 2014, 2017; Jones et al. 2016; Palomo et al. 2016) show that services are realised by combining the natural with human-derived capital, like built and manufactured goods, knowledge and skills, and financial capital. In rural areas, landscapes are managed and provisioning services depend heavily on human inputs (ESP 2020). In California, farmer mobilisation and especially labour were key in resin co-production: work was essential to extract resin from pines and to generate a meaningful income. Indeed, peasant farmers rely on on-farm family labour to earn a living (Van Der Ploeg 2014). Labour is often mentioned in general terms and alongside other human inputs that contribute to ES co-production (Lele et al. 2013; Spangenberg et al. 2014b; Díaz et al. 2015; Palomo et al. 2016), but few studies in ES research actually detail or highlight the important role of labour in ES delivery (Spangenberg et al. 2014a; Berbés-Blázquez et al. 2016). Peluso (2012) and Berbés-Blázquez et al. (2016) argued that ES can distort the boundaries between ecological and natural inputs and thus hide the role of human labour behind them, a commodification problem that can additionally obscure the importance of nature (Peterson et al. 2010).

Co-production also entailed impacts to the natural resources that supplied the resin and feedbacks that shaped the landscape. Resin faces wounded pine trunks and left scars, which can take decades to heal (Génova et al. 2014). The resinous ocote pine (*P. oocarpa*) is a species adapted and dependent on forest fires (Rodríguez-Trejo and Fulé 2003; Dvorak et al. 2009) due to its thick bark that protects it from frequent surface fires (Keeley 2012). Thus, removing the bark and exposing more delicate tissues likely left trees vulnerable to fire. Still, the effects from resin extraction were part of a more complex social-ecological system in which fire, pine biology, resin

production and other land uses interacted (Braasch et al. 2017). Furthermore, forest fires, fire use and the underlying perception of fire have changed repeatedly in California and in the Biosphere Reserve; presently, the use of fire is restricted and forest fires are suppressed – in part due to a perceived threat to resin activities – though more flexible and informed fire management policies and practices are being introduced (Huffman 2010; Gutiérrez Navarro et al. 2017; García-Barrios et al. 2020). Interestingly though, one of the most important attributes associated to historically tapped pine forests in Spain, is that they reduce the risk of dangerous wildfires because they are better managed and people are more present (Soliño et al. 2018).

People were not fully aware of the potential impacts of resin extraction on pine biology and its population. Pine trees have evolved resin, complex mixtures of terpene-rich oleoresins, as a chemical and physical defence mechanism against pathogens and herbivores (Celedon and Bohlmann 2019). This constitutes a considerable investment of photosynthetic resources and a trade-off in other important physiological processes, especially if resin production is being mechanically induced (Zas et al. 2020). Resin extraction in other countries has had a negative effect on the growth of different pine species (Papadopoulos 2013; Génova et al. 2014; Chen et al. 2015), though these effects are inconsistent (Tomusiak and Magnuszewski 2009; Van Der Maaten et al. 2017). Furthermore, though abundant pine trees remained for future use, the sustainability of resin extraction was uncertain. Braasch et al. (2017, 2018) questioned if sufficient tree recruitment could sustain long-term resin extraction in California, more importantly, they showed that multiple factors were interacting and affecting recruitment, including grasses, cattle, fire and incongruent stakeholder interventions. Still, pines were regenerating across the California landscape. Forests were being co-restored as farmers nurtured the natural pine ingrowth. In the context of forest restoration, this could be considered an assisted natural regeneration approach, whereby natural succession is hastened by reducing barriers, like weed competition and constant disturbances, to natural forest regeneration (Shono et al. 2007; Chazdon and Uriarte 2016). In addition, the active management and restoration of forests brought further co-benefits, as other forest-based ES were being enhanced. Local people stood to benefit from other material, e.g. pine timber, and non-material contributions, e.g. inspiration and recreation, that directly influenced their quality of life. Moreover, regulating contributions to freshwater quantity and quality, climate, soil protection, and habitat creation among other – services for which the Reserve was established – were being restored, with joint benefits to local livelihoods and conservation, downstream beneficiaries,

and society at large (categories based on Díaz et al. 2018). Not only was resin co-produced, but the impacts and feedbacks in the resin cascade were likewise co-produced, by the interaction of people and their landscape, and the combination of human and natural capitals.

4.2. How social interactions and institutions influence resin supply and benefits distribution

Based on Ribot and Peluso's (2003) notion of access to natural resources, access to resin can be understood as the ability of local people to derive benefits from resin. This brings the attention to a range of social and power relations that affect this ability. Though access to capital is often a basic factor and form of power that defines who gets access to resources and benefits (De Janvry et al. 2001; Ribot and Peluso 2003; Sikor and Lund 2010), in our case study resin access was not fully determined by the farm owners' control over the land and pines. Despite stark contrasts in farmer's access to resin productive capacity, this endowment had a relatively small effect on net income. On the other hand, resin workers entered into working relations and gained access to resin, employment, and the ability to labour for themselves. Access to labour and labour opportunities can shape how and who benefits from natural resources (Ribot and Peluso 2003; Faye and Ribot 2017; Spierenburg 2020). In the sense of environmental entitlements (Leach et al. 1999), resin workers gained legitimate effective command over resin and its benefits in order to improve their well-being. Local labour relations, especially between farm owners and workers, were thus fundamental to resin access. It is in the relation between actors who own capital and control access and actors who labour to gain and maintain access, so-called capital-labour relationships, that the distribution of benefits is negotiated (Ribot and Peluso 2003).

Resin farmers employed their social network to derive benefits from resin. Workers extracted resin in other properties, cooperated and reciprocated with co-workers, and came together in negotiations with external actors. High social capital in collective resource management, including relations of trust, reciprocity, and connectedness in networks and groups, are essential to improved social and economic community well-being (Katz 2000; Pretty 2003). Moreover, the observed working relations among family and friends based on barter and a gift economy were in agreement with Ribot and Peluso (2003), who highlight the importance of kinship and the negotiation of other social relations to resource access and the relative share of benefits. These benevolent exchanges occurred in part because the modest resin pay was more important to farmers with

fewer income opportunities, than to wealthier farmer with more land for whom resin represented a complementary income. As documented for other NTFP, whereas more affluent households can often access alternative income opportunities, poorer households that face economic barriers to entry are more motivated to trade in forest products (Shackleton et al. 2011b).

Resin extraction involved diverse, intricate and dynamic relations among resin farmers. Labour relations and organisation in particular, evidenced power struggles and the different and often conflicting value priorities among farmers and families. Relations of access include negotiation, cooperation, competition and conflict (Peluso and Ribot 2020), and power dynamics are exceptionally revealed by labour relations that shape the social interactions between and within social groups (Berbés-Blázquez et al. 2016). Similar social and organisational challenges have been documented for various projects in other *ejidos* of the Biosphere Reserve (García Barrios et al. 2012), other natural protected areas in Chiapas (Cruz Morales and García Barrios 2017), the Villaflores Municipality and southern Mexico, e.g. small coffee producers and indigenous forestry communities in Oaxaca (neighbouring state), identified the rupture of rules, excessive workloads on leaders, low participation, and poor administration as major challenges (Lazos-Chavero 2013). All efforts to control, gain and maintain access to natural resources are fundamentally struggles in the sphere of social relations (Peluso and Ribot 2020).

Finally, different structural and relational mechanisms of access controlled by external institutions were revealed in this study, including access to technology in tools of the trade, access to capital in support programmes, access to authority in the forestry permit, and access to markets in resin trade, among others (after Ribot and Peluso 2003). Hence, external actors with vested interests in the Resin Project had power over the locals' capacity to benefit from resin, power understood as the ability of social groups to control or influence the behaviour of other social groups in ecosystem governance (Berbés-Blázquez et al. 2016). Development and conservation interventions, like the Resin Project and other projects promoted by external actors in the Biosphere Reserve, are embedded in power structures that frame and fit the decisions of actors from the international down to the local scale (Meza Jiménez et al. 2020). These semi-coherent set of rules, so-called socio-technical regimes, orientate and coordinate the activities of different social groups and perpetuate the existing system (Geels 2002, 2011). Moreover, farmers and their families in the Biosphere Reserve have had to reconstruct their social relations many times and in response to the varied interactions with external

actors and institutions, which dispute local territories and the benefits that communities can derive from the landscape (García-Barrios et al. 2020). The Resin Project was considered a socio-environmental innovation success that used endogenous bioresources to support local livelihoods (see e.g. Bello Baltazar et al. 2012). Nevertheless, the project was heavily directed and dependent on external actors, and additionally influenced by multiple external factors. In a sense, resin farmers were employed by the Resin Project, limited to receiving economic compensation for producing resin.

4.3. How pine resin connects people to their landscape

For Van Der Ploeg (2014), land, trees and other natural assets constitute the resource base of the peasant farm, the family capital that lets farmers engage in production and make a living off the land. Traded pine resin was mainly appreciated for its economic contribution and the sense of security it provided. Resin income played different roles to households in the community, including livelihood diversification, risk reduction e.g. as a safety net, and income smoothing when on-farm labour was in low demand, as reported for other traded NTFP (Shackleton et al. 2011b). Daily earnings from resin extraction were relatively high, and total annual income amounted to 32% of the rural poverty line for one person in Mexico (estimated at \$23,428 MXN for the study period, based on CONEVAL 2020). Though this can be considered a minor economic contribution to households, it was evident that resin's diverse benefits were highly appreciated by local people. In fact, even with a diversified strategy of productive activities, households in California fail to achieve their basic economic objectives (Meza Jiménez et al. 2020). In Latin America, NTFP do not usually make people rich, but the income is commonly used to build household assets and pay children's school fees, supporting quality of life and better opportunities for future generations (Shackleton et al. 2011b). In seeking economic security and a family legacy, farmers use the land to create a safe place and livelihood for their family; the farm provides security and farmers develop a deep place attachment and connection to their land (Quinn and Halfacre 2014).

Appreciation and values in the delivery of resin were essential to the link between people and their landscape. People's values were found in relation to the steps and mediating mechanisms in the resin pathway, they were pervasive and not just placed at the end of the cascade as is commonly portrayed (e.g. Potschin and Haines-Young 2016). In the view of environmental pragmatism (Parker 1996; Rosenthal

and Buchholz 1996), values are dynamic, situation-dependent properties that emerge from people's interactions with their environment and the natural sphere in which they are embedded. Values were thus ubiquitous in resin extraction and production, social interactions within and between social groups, and in relation to pines, resin and its contributions. As described by Schwartz (2012), values underlie attitudes, norms, and behaviours in people's action and communication. ES values can thus be understood as 'the multiple means and incommensurable ways in which ES are important to people' (Arias-Arévalo et al. 2018). Here, basic values were listed and a few examples noted, but as in other ES valuation studies e.g. in and around protected areas (Martín-López et al. 2014), watersheds (Arias-Arévalo et al. 2017), and farms (Hervé et al. 2020), plural values emerged. Values were a central component in the ES resin cascade. This resonates with calls to put people's values central and above objects of value (i.e. the service) in ES valuation frameworks (Kenter 2018), to include relational values of and about nature grounded in particular contexts (Chan et al. 2018), and to integrate the diverse set of values of nature in resource and land management decisions and actions (Jacobs et al. 2016).

5. Conclusions

By exploring an integrated ES cascade, we gained a better understanding of how ES are realised and the role a NTFP plays in connecting local people's well-being to their forested landscape. The co-production of resin, which extends to the impacts and feedbacks in the cascade, was made possible by an intricate interaction between the human and natural components of the California social-ecological system. An upward resin cascade shows that human inputs, effort and struggle were required to realise the benefits of resin, and especially to highlight the often-obscured role of labour in ES delivery. Moreover, resin extraction was coupled to people's appreciation and values, especially values in peasant farming, social relations, and a closer interaction with forests. People's values were central in the resin cascade; the societal importance ascribed to resin was as important as the resin itself.

Social relations were essential to access resin and its benefits. In particular, local labour relations and social networks enabled working farmers to access a high share of the resin income. However, most social conflicts occurred over labour relations and organisation as well, revealing power struggles in the access to resources. In addition, external actors, most of them stakeholders in the Resin Project, mediated the access to capital, technology, authority and markets, and thus had power and control over

the community's ability to derive benefits from the landscape. In California, resin provided an appreciated income and forests were being restored, but the success of this socio-environmental innovation project in delivering sustained and substantial ES benefits is questioned.

Notes

1. Refer to the Supplemental material for table and figure numbering with prefix 'S'.
2. For the study period \$1.00 MXN \approx \$0.05 USD.
3. National minimum wages adjusted for geographic area were \$88.36 and \$102.68 MXN for 2018 and 2019 respectively (CONASAMI 2020).

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Disclosure statement

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Data availability statement

The authors confirm that summarised data supporting the findings of this study are available within the article and its supplemental materials (<https://doi.org/10.1080/26395916.2021.1892827>). Full data are available on request from the corresponding author [AH], and are not publicly available due to containing information that could compromise the privacy of individual research participants.

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