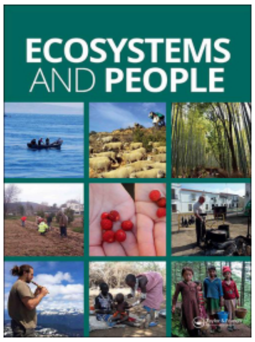

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RESEARCH

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Participatory mapping of ecosystem services across a gradient of agricultural intensification in West Kalimantan, Indonesia

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ABSTRACT

Agrarian change affects the supply and demand of ecosystem services (ES) by reducing the extent of natural ecosystems. Agricultural intensification can lead to changes in land covers and livelihood opportunities and it remains unclear how such changes align or misalign with the desires of local communities. Using participatry mapping, we assessed ES uses and desires of Indigenous people and local communities provided by different land cover types along a gradient of agricultural intensification (forest subsistence, agroforestry mosaic, and monoculture and market-dependence) in West Kalimantan, Indonesia. We found that mapped ES use diversity was highest in the forest-dependent zone and lowest near monoculture agricultural systems. The expressed ES uses and desires varied greatly among land cover types amidst loss of old-growth forest and greater reliance on secondary forest and shrub land. The spatial analysis showed that high priority areas of ES use was related to access in the landscape, demonstrating the importance of attending to place-based social values in ES assessments. From this study, we call for a people-centric spatial modelling approach to address the divergence of social and cultural ES values associated with land covers under different intensification contexts. Participatory mapping clarifies the ES desires of local communities, which state policy often fails to address. We recommend a place specific management strategy to reduce ES trade-offs of specific land use practices, which are currently apparent with agrarian change in Indonesia and relevant for other tropical developing countries.

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1. Introduction

Agrarian change in the form of a shift from forest subsistence to market-oriented agricultural and tree crops, has a dynamic effect on rural people's livelihoods, access and use of ES in tropical developing countries (Sunderland et al. 2017, Ahammad et al., 2021). Agricultural intensification that promotes homogenous land cover with the aim to maximize single commodities (e.g. palm oil, rubber and other commodity crops) engenders starkly different lifestyles and cultural values than those that encompass natural forests and agroforestry mosaics (Colchester and Chai 2011; Tscharntke et al. 2012; Cramb and McCarthy 2016; Rasmussen et al. 2018; Albizua et al. 2019; Yuliani et al. 2020). For instance, the modification of swidden agriculture to cash crops and industrial plantations has affected Indigenous people and local communities (IPLC) ability to access and maintain their traditional ecological knowledge, food sources, and cultural practices within diverse land uses in developing tropical regions (Orth 2007; van Vliet et al. 2012; Levang et al. 2016; Euler et al. 2017; Fantini et al. 2017; Pirard et al. 2017). The changes brought by intensification (e.g. increased tree plantations) can secure income for those with adequate capital, land rights and access to government support (Coomes et al. 2011;Vongvisouk et al. 2014; Edwards 2015; Thaler and Anandi 2017), at the expense of a socially equitable transition to ensure multiple benefits (e.g. D'amato et al. 2017; Dressler et al. 2017). The social and ecological effects of agrarian changes become place-specific due to historic uses of land, scale and configuration of the landscape, and land tenure arrangements (Laurance et al. 2014; Pingarroni et al. 2022). However, the extent that changing land use practices and landscape configurations will satisfy the needs and desires of IPLC depends on their values and preferences and how

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access to ES changes in the shifting landscape (Orth 2009; Feintrenie et al. 2010; Grass et al. 2020).

ES are classically conceived as being driven by land use and land cover changes, but attention has now shifted to the importance of recognizing the dynamic role of social practices as embedded within the culture of IPLC as critical drivers of ES changes (Raymond et al. 2009; Brown and Reed 2012; Chakib 2014; Palomo et al. 2014). Tracking both biophysical land cover changes and changes in social uses of ES are important in dynamic landscapes. Certain ES may become more desired by IPLC (i.e. food, fuel, carbon) due to increasing economic values associated with agrarian livelihoods that become available through increasing connectivity to factors of production and regional and global market. However, the importance and decline of many ES (i.e. regulating and cultural) in a multifunctional landscape, may go unseen in conventional land use planning that relies on coarse-scale biophysical mapping and excludes IPLC (Bennett et al. 2009; Eigenbrod et al. 2010; Power 2010; Chakib 2014; Howe et al. 2014; Freeman et al. 2015; Berbés-Blázquez et al. 2016; Fish et al. 2016; Bennett 2017; Reed et al. 2017; Chan and Satterfield 2020). Local people's experiences with ES trends associated with different land covers can help identify the occurrence and social implications of trade-offs as well as underlying drivers and needed interventions to achieve ecological sustainability at the landscape scale (Angelstam et al. 2018; Ahammad et al. 2019, 2022). Furthermore, incorporating Indigenous and local knowledge (ILK) and associated values of nature's contributions to people (Pascual et al. 2017; Díaz et al. 2018) in terms of ES uses and desires provides a deeper understanding of the way IPLCs perceive and interact within their landscape.

The participatory mapping approach provides an opportunity to assess local perceptions of landscape multi-functionality by incorporating ILK through place-based mapping (Sieber 2006; De Groot et al. 2010; Brown and Reed 2012; Boedhihartono et al. 2015; Brown and Fagerholm 2015; Ramirez-Gomez et al. 2017). This approach actively incorporates IPLC experiences of perceived landscape change and the spatial variation of ES supply to deliver a more equitable and collaborative landscape planning (Palomo et al. 2014; García-Nieto et al. 2015; Ramirez-Gomez et al. 2017). The approach can take into account the land uses and needs of IPLC, giving them a voice and democratizing the decision-making process of spatial planning over traditional biophysical mapping that faces social complexity and political negotiation (Andrew et al. 2014; Brown and Fagerholm 2015). While participatory mapping is applied in various social and ecological contexts, there have been limited studies on landscape gradients, particularly within the forest-agriculture frontiers (Palomo-Campesino et al. 2018). A limited understanding exists on how agrarian change meets local communities' desires for ES under different intensification gradients. Participatory mapping overcomes this by assessing IPLCs knowledge of ES trade-offs that may occur with agrarian change. At the same time, the approach could minimise conflicting goals among competing land uses and enhance synergistic opportunities within and across ES.

Given this context, this study aimed to assess ES use and desires of IPLCs across a gradient of agricultural intensification in the Kapuas Hulu Regency of West Kalimantan in Indonesia. The study region has experienced agrarian change that typifies a transition from forest land use and smallholder agriculture (primarily swidden farmer/shifting cultivators) through to mixed agroforestry (rubber plantation) and large-scale commercial oil palm planting (Lambin et al. 2003; Leonald and Rowland 2016; Yuliani et al. 2020). By applying participatory mapping techniques, we addressed the following two research questions: (1) what are the local perceptions of ES uses and desires of IPLCs across a gradient of agricultural intensification? and (2) where are the high priority areas of multiple ES that people have accessed across the three zones. The spatially explicit assessment of people's knowledge, use, and desires of ES across a gradient of land uses provides a context-specific understanding of ES trade-offs while bringing local stakeholders' connection to ES to the center-stage of landscape planning. In the context of agrarian changes, participatory mapping is beneficial to determine the perceived changes in ES flow around specific landscape gradients.

2. Materials and methods

2.1. Description of the study area

West Kalimantan is a region of high biodiversity in Indonesia, with a large amount of tropical forest covering over 70% of its total land. Kapuas Hulu is a district in West Kalimantan with the highest rate of remaining intact forests, and the subject area of this study. Over half (57%) of the forest in Kapuas Hulu is under some form of conservation protection, which is above the average in West Kalimantan (26%) (Shantiko et al. 2013). The two national parks, Betung Kerihun and Danau Sentarum, have a 30% forest cover and high biodiversity, including endemic and flagship species, i.e. Bornean orang-utan and the proboscis monkey. Most forests, including national parks and protected forests, are state owned and controlled by district administration, which restrict hunting and gathering of forest products. The IPLC are given special permission to extract non-timber forest products (NTFPs), hunt bushmeat, and perform swidden farming, but have only partial or no legal ownership of the forest lands.

Indonesia has experienced one of the highest rates of forest loss globally, driven largely by mining, subsistence agriculture, logging, and commodity expansion (Carlson et al. 2012; Hansen et al. 2013). Kalimantan is one of the most deforested areas in the country having lost one-third of its natural forests because of extractive industries for timber, oil and minerals. Almost all forested regions in Kalimantan outside of the protected areas are currently under some form of concession for planned oil palm or rubber plantations, or for mineral exploration and extraction. A major shift in agricultural practices occurred in Indonesia, transitioning from swidden farming to large-scale agribusiness operations in the form of oil palm estates. This was driven by state policies for transmigration, provision of land title and infrastructure development and led to additional forest clearing in the region. Over the past two decades, this pattern of agrarian change, i.e. the transition from swidden farming to smallholder and commercial palm oil became common in the Kapuas Hulu region. Forest cover has declined across the region 1990–2010 from a low of 0.2% per annum in remote areas up to 1.3% per annum in more intensified areas (unpublished landsat data). The transition is characterized as moving from forest-based livelihoods consisting of swidden farming, fishing and bushmeat hunting and use of NTFPs to use of agroforests (rubber production mixed with vegetables and nuts) and reduced access to natural forest to labouring commercial monocultures (palm oil plantations) that are either smallholder-owned or run by larger corporations (Yuliani et al. 2020).

2.2. Data collection and analytical approach

2.2.1. Selection of study sites

We identified the three zones (zone 1 – forest subsistence/zone, zone 2 – agroforestry mosaic/zone and zone 3 – monoculture and market-dependence/zone) by applying a set of criteria related to biophysical (forest cover, land use) and socio-economic conditions (market access, reliance on forests, agriculture commodities) and expert advice from researchers, NGOs, local institutions and key informant interviews (Deakin et al. 2016; Leonald and Rowland 2016; Sunderland et al. 2017). The three zones represent a gradient of agrarian change with each zone along the gradient represented by starkly different configurations of forest and agriculture land use (Deakin et al. 2016, Figure 1). Zone 1 consists of primarily natural forest and IPLCs rely on subsistence agriculture (mainly swidden farming), NTFP-based provisioning ES and fishing which are aided by transport across an extensive and largely intact river network. Zone 2 comprises agroforestry land use, where IPLCs rely on subsistence farming and occassional gathering of NTFPs, but are increasingly transitioning to rubber agroforestry as access to markets increases. In the monoculture and market-dependence zone (zone 3) local communities are engaged in rubber agroforestry or palm oil production and have limited access to intact forests to gather NTFP and other traditional ES (Figure 1).

2.3. Participatory mapping process

We randomly selected two villages (out of four), which represented the dominant characteristics of the intensification gradients per zone (see Leonald and Rowland 2016). In each village, we conducted one participatory mapping workshop (thus, two workshops per zone) representing a total of six workshops in the three zones from 2016 to 2017. Each workshop comprised four sub-groups, containing 3–5 participants in each sub-group depending on participant availability. One facilitator was assigned for each sub-group to coordinate the participants throughout the mapping process. The number of participants per sub-group did not affect the number of ES chosen by subgroup nor the number of ES mapped. Participants were selected within constraints of local socio-cultural obligations, which required first asking the village elder, who is knowledgeable about the landscapes, involved in forest management or highly engaged in agriculture, and then inviting further participants through snowball sampling. Due to daytime work engagements and busy farming activities of the IPLC, we arranged workshops in each village during the evening or on Sunday in Christian villages. Researchers from the Centre for International Forestry Research Organization (CIFOR) facilitated each workshop by introducing the participants to the purpose of the workshop, the mapping approach and guiding time management during each session. Given the workshop time constraints, data on participants age, socio-economic status, or occupation were not collected. Generally, participants were men with interest and expertise in aspects of land management.

Each workshop began with a focus group to present a pre-defined list of ES, followed by open discussion, and an ES mapping exercise. To ensure that the mapped ES were consistent and comparable across the three zones and to the broader ES literature, we adopted a pre-defined list of potentially relevant ES based on important local values identified during the scoping phase of this study (described in detail in Leonald and Rowland 2016). The list of

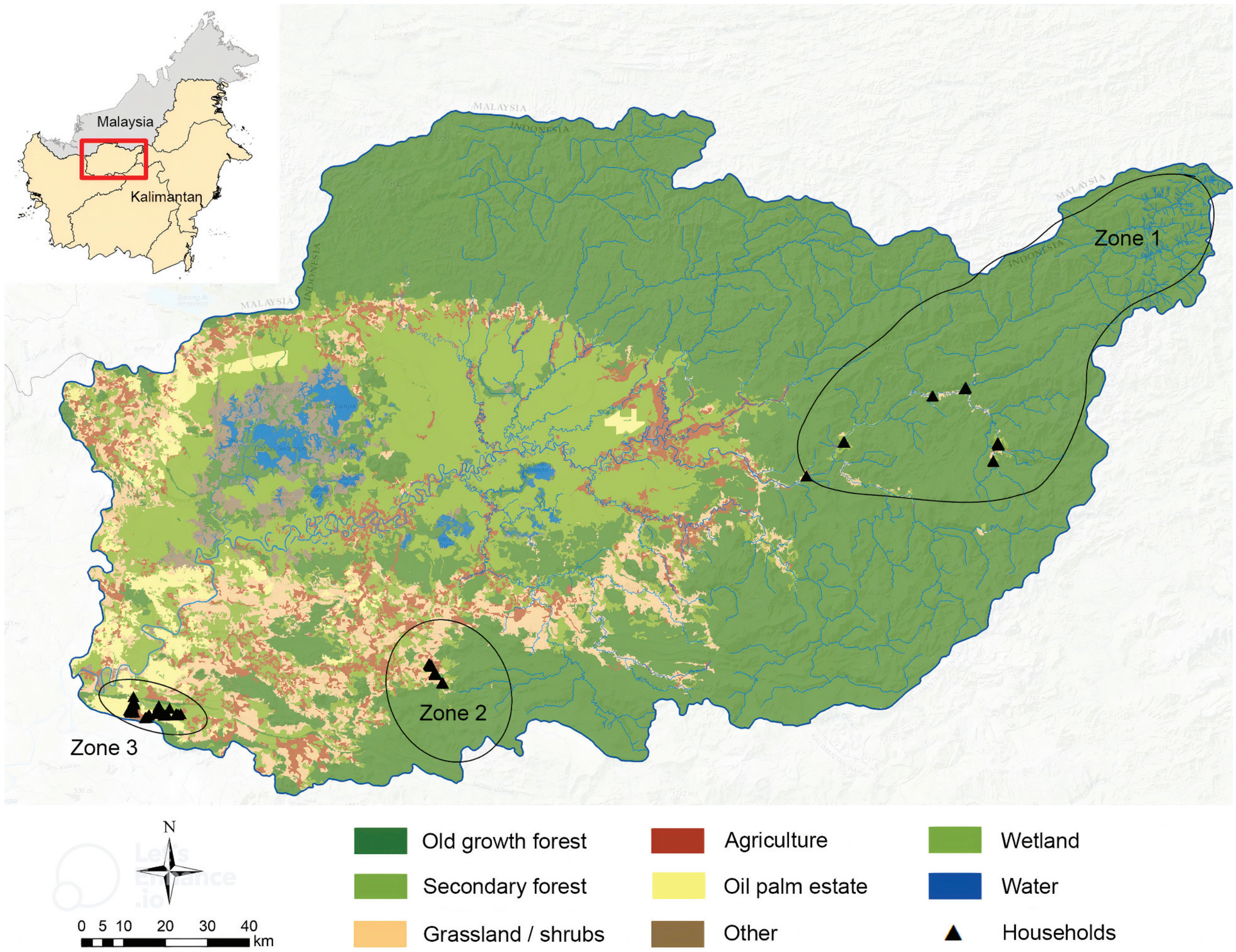

Figure 1. Study area shows three zones (zone 1: forest subsistence, zone 2: agroforestry mosaic, and zone 3: monoculture and market-dependence zone) of agricultural intensification gradient in the Kapuas Hulu of West Kalimantan region in Indonesia.

individual ES were categorized under the provisioning, cultural and regulating ES categories following the Millennium Ecosystem Assessment (MA, 2005). We assumed no prior knowledge of ES concepts among participants (a western scientific construct) and so sought to bridge the ES concept into their local worldviews by presenting the list of 25 ES alongside photographs and locally relevant examples for the participants to choose from (see Appendix 1, Leonald and Rowland 2016). For example, the cultural ES of 'landscape aesthetics' was presented as 'enjoyment of natural beauty' and shown as a photograph of a stream passing through an intact forest. Workshop subgroups then deliberated and chose the six ES uses that were most important to their wellbeing in the surrounding landscape and the six ES most desired in a future landscape. Here we define 'ES use' as the realization of ES at identifiable locations within a landscape, that is based on the biophysical supply and available access (Burkhard et al. 2014). 'ES desire' denotes where participants expressed a preference towards certain ES in a future landscape (which may or may not be the same as current ES uses).

Participants were then asked to spatially map the locations for the three most important ES uses and three most desired ES by placing buttons anywhere on a 1:50,000 scale paper map (as many points as desired) that showed topography (shaded ridges and river waterways) and their village locations. The maps used by the participants did not indicate land cover or land use, so as to not to bias their mapping. The mapping exercise was done using ES at a time and repeated based on each ES provision that was desired. Maps were photographed, then later digitized as point shapefiles in ArcGIS.

2.3.1. Land cover maps and ES assessment

We related the mapped ES points with land cover maps to assess how different land cover types influence the spatial distribution of ES currently used and desired by IPLC. The land cover maps were obtained for the year 2015 from the COLUPSIA project (CIFOR, 2013). The land cover classification was a simplified version of the COLUPSIA 1:50,000 scale vegetation map that combined computerized (ground truth data and supervised classification) and manual interpretation from Landsat satellite imagery at a spatial resolution of 30 m. The land

Table 1. Combination of landscape units applied in mapping of ES in Kapuas Hulu district of West Kalimantan, Indonesia.

Land cover type	Description
Old growth forest	Hill forest, lower montane forest, lowland forest, short and tall forest on sandstones (*Kerangas*), submontane forest, submontane depleted forest, upper montane forest, logged-over lowland forest, logged-over hill forest, logged-over fresh water swamp forest, mixed peat swamp forest
Secondary forest	Mosaic of old fallow secondary forest, mosaic of young fallow secondary forest, mosaic of secondary hill forest, mosaic of secondary mixed peat swamp forest
Shrub and low fallow regrowth	Shrub and low fallow regrowth, swamp grassland, swamp shrubs (*Semak rawa*)
Food crops field	Mixed garden/agroforestry, food crops field (shifting cultivation/*Ladang*), irrigated paddy field
Smallholder rubber plantation	Small holder rubber plantation mixed with secondary regrowth
Oil palm estate	Oil palm estate, newly open land for oil palm estate

cover maps were simplified into broad categories to represent landscape units typical of varying stages of forest transition and for which different ES uses were likely (Table 1). The final maps included the following land cover types: old growth forest, secondary forest, shrubs and low fallow regrowth, food crops field, small holder rubber plantations and oil palm estate.

The land cover maps were delineated within each zone boundary and a dominant land cover class was assigned to each of the spatial ES mapped across the region using ArcMap 10.6 (ESRI 2016). To compare the types and amounts of ES currently used or desired by local peoples in each land cover type, we calculated the proportion of ES points mapped for each land cover class across the three zones.

2.3.2. Kernel density analysis

To map areas with variation in the density of ES use and desires, we carried out kernel density analysis (Silverman 1986), a procedure that identifies hotspot areas where ES were particularly used or desired in the three zones. This widely used interpolation method uses point data to visually map intensities and spatial patterns of ES (Alessa et al. 2008; Brown and Fagerholm 2015). The approach calculates the density of ES in raster form by placing a circle with a given circumference (search radius) around each point and then calculating the number of overlapping search radii intersected at each raster cell (Brown and Fagerholm 2015). We set the kernel density search radius and output cell size to match the resolution of the survey maps for each of the three zones. Accordingly, a map resolution of 1:400,000 corresponded with a cell size of 400 m. We then overlaid the individual ES maps to produce a final map showing the degree of multifunctionality of ES. Hotspots are defined as areas with a high number of overlapping ES uses and desires points on the map. The final maps represent hotspots of overlapping ES, where multiple individual ES are reportedly used and desired by IPLC.

3. Results

The distribution of mapped ES points and land cover types across the three zones are presented in Figure 2. The total size of the forest subsistence zone (zone 1) is 299,221 ha with a land cover composed predominately of old growth forest (Table 2). In the agroforestry mosaic zone (zone 2), the total landscape area is 51338 ha, with the major land cover classes comprising old growth forest cover, shrubs and low fallow regrowth and secondary forest. The monoculture and market zone (zone 3) experienced the greatest agricultural intensification and had a total area of 14668 ha. The landscape in this zone is divided into a number of common classes, including oil palm estate, secondary forest cover, old growth forest and smallholder rubber plantations (Table 2). Among all the land cover types, old growth forest accounts for the largest proportion across zones 1 and 2, while secondary forest predominates zone 3.

3.1. Perceived ES use and desire across a gradient of agricultural intensification

In the forest subsistence zone, IPLCs mapped nearly all of their provisioning ES use and desire as occurring within the old growth forest, followed by shrubs, secondary forest and low fallow regrowth land (Table 3, Figure 3). Old growth forest account for 98% of the land cover in the subsistence zone. Timber construction, *Gaharu* (or agarwood *Aquilaria* spp.) a rare resource, but highly valued for its resin), hunting, agriculture and drinking water account the largest proportion of ES use sourced from old growth forest in this zone. Fish, fibre, drinking water and agriculture although limited in ES use, also occurred in shrubs and low fallow regrowth and secondary forests. *Gaharu* and drinking water are the most mapped desired ES from this old growth land cover. In total, the most frequently mapped ES uses were the provisioning ES of agriculture with 123 mapped points, timber construction (113), and drinking water (99) (Table 3). The most frequently mapped ES desire were agriculture (83) and fish (67). Interestingly, although no cultural ES uses were mapped in the subsistence zone, local people expressed a desire to increase these ES, including cultural and spiritual NTFPs (24), local environments

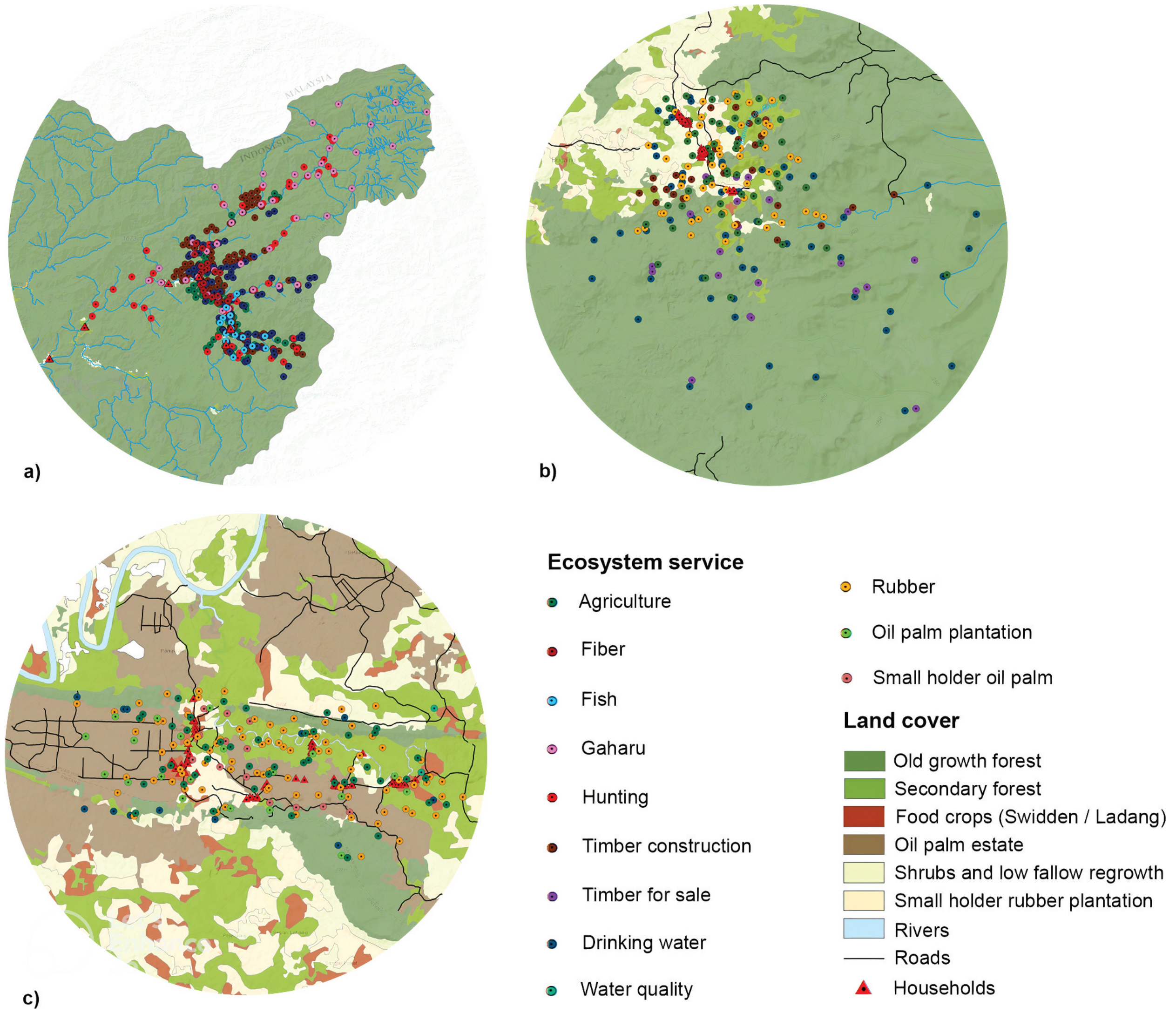

Figure 2. Distribution of used ecosystem service points mapped within land covers of (a) forest subsistence; (b) agroforestry mosaic; and (c) monoculture and market dependence zone. The geographic location of the three zones is displayed in Figure 1.

Table 2. Proportion (%) of land cover types within three zones (forest subsistence, agroforestry mosaic, and monoculture and market dependence zones).

	Zones		
Land cover types	Forest subsistence	Agroforestry mosaic	Monoculture and market dependence
Old growth forest	98	77	18
Secondary forest	1	8	28
Shrub and low fallow regrowth	1	13	5
Food crops field	0	0	5
Small holder rubber plantation	0	2	9
Oil palm estate	0	0	35

conducive to passing on traditional moral values to youth (19) and ecotourism (18).

The local community in the agroforestry mosaic zone mapped ES uses and desires over a broader range of land cover types compared to the subsistence zone (Table 4). The largest proportion of ES uses was concentrated in old growth forest (namely drinking water (61), timber for sale (68), rubber (45) and timber construction (43)). Similarly, the highest concentration of ES desires were located in the old growth forest followed by the shrub and low fallow regrowth land cover. These included ES desires for rubber, harvesting wild fruits and vegetables, fish and agricultural needs and to increase ecotourism in these areas. ES desires were also located in secondary forests, including *Gaharu*, harvesting wild fruits and vegetables and ecotourism. Among all ES, drinking water received the greatest number of mapped points for both ES use (61) and desire (65) (Table 4). Provisioning ES such as agriculture (51) and rubber plantations (55) also received a high number of mapped ES use points. No provisioning NTFP (i.e. *Gaharu*, harvest of wild fruits and vegetables and fish) were mapped for ES use, but there was an expressed desire for these ES by the respondents in this agroforestry mosaic zone.

In the monoculture and market dependence zone, IPLC considered almost all land covers to meet their

Table 3. Total numbers of mapped ES uses and ES desires locations and their proportional frequency in each land cover types in the forest subsistence zone.

Ecosystem service	Numbers of mapped ES points (Use/Desire)	Proportion (%) of ES by land cover (Use/Desire): Old growth forest	Secondary forest	Shrubs and low fallow regrowth	Food crops field
Provisioning service					
Agriculture	123/83	82/81	11/14	7/4	0/1
Timber construction	113/36	92/89	3/0	5/11	0/0
Fiber	19/34	79/85	0/9	21/6	0/0
Gaharu	46/31	91/100	0/0	9/0	0/0
Hunting	74/9	91/56	3/22	7/22	0/0
Fish	17/67	65/82	29/6	6/10	0/1
Drinking water	99/14	81/100	9/0	10/0	0/0
Cultural service					
Cultural/spiritual NTFP	0/24	0/96	0/0	0/4	0/0
Moral value	0/19	0/95	0/0	0/0	0/5
Ecotourism	0/18	0/67	0/17	0/17	0/0

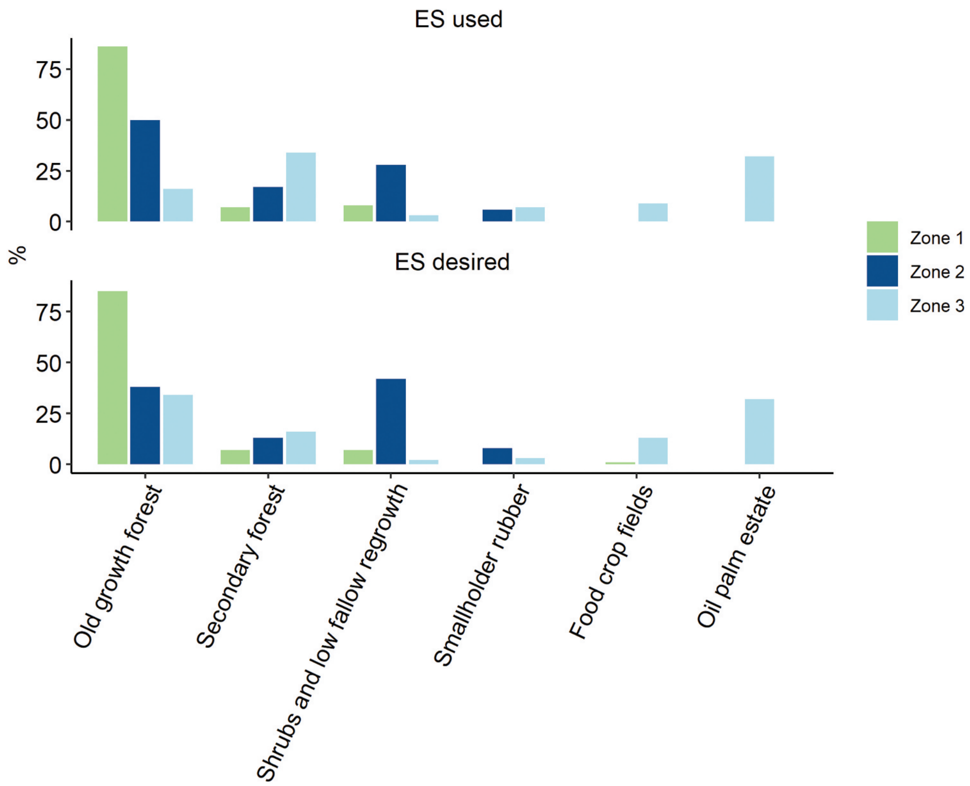

Figure 3. Percent of currently used and desired ecosystem services mapped by land cover for the forest subsistence (zone 1), agroforestry mosaic (zone 2) and monoculture and market dependence zone (zone 3) in Kapuas Hulu, West Kalimantan.

Table 4. Total numbers of mapped ES used and desired and their proportional frequency by land cover types in the agroforestry mosaic zone.

Ecosystem service	Numbers of mapped ES points (Use/Desire)	Proportion (%) of ES by land cover (Use/Desire): Old growth forest	Secondary forest	Shrubs and low fallow regrowth	Small holder rubber plantation
Provisioning service					
Agriculture	51/7	37/43	20/14	35/43	8/0
Timber construction	28/0	43/0	18/0	32/0	7/0
Timber for sale	22/0	68/0	9/0	18/0	5/0
Rubber	55/22	45/18	24/5	27/68	4/9
Gaharu	0/3	0/0	0/33	0/33	0/33
Harvest wild fruits & vegetables	0/3	0/0	0/33	0/67	0/0
Fish	0/11	0/27	0/9	0/45	0/18
Drinking water	61/65	61/54	10/11	25/28	5/8
Cultural service					
Ecotourism	0/9	0/0	0/33	0/67	0/0

Table 5. Total numbers of mapped ES used and desired and their proportional frequency by land cover type in the monoculture and market dependence zone.

Ecosystem service	Numbers of mapped ES point (Use/Desire)	Proportion (%) of ES by land cover (Use/Desire) Old growth forest	Secondary forest	Shrubs and low fallow regrowth	Small holder rubber plantation	Food crops field	Oil palm estate
Provisioning service							
Agriculture crops	45/0	18/0	27/0	4/0	9/0	11/0	31/0
Timber construction	0/21	0/48	0/14	0/5	0/10	0/0	0/24
Rubber	85/0	12/0	42/0	2/0	7/0	5/0	32/0
Oil palm plantation	20/0	15/0	20/0	0/0	10/0	5/0	50/0
Smallholder oil palm	13/25	0/24	46/12	0/0	23/20	0/0	31/44
Harvest wild fruits & vegetables	0/7	0/14	0/0	0/0	0/14	0/29	0/43
Drinking water	13/6	54/50	15/50	8/0	8/0	8/0	8/0
Cultural service							
Cultural/spiritual NTFP	0/3	0/33	0/33	0/0	0/0	0/0	0/33
Regulating service							
Water quality	2/0	0/0	50/0	0/0	0/0	50/0	0/0

use and desires for ES. The highest percentage of ES use were mapped in the secondary forest and oil palm estate as shown in Table 5 and Figure 3. These include provisioning ES such as smallholder oil palm (13), planted oil palm (20) and rubber (85). Secondary forest shares slightly more categories of ES use, with a quarter to half of them mapped in this land cover. An exception is that more than half (54%) of the drinking water use coincided within the few areas of remaining old growth forest land covers. Desired ES appeared predominately in the old growth forest and oil palm estate. Overall, rubber (85) use received the most mapped ES use points followed by agriculture (45). Timber construction (21), smallholder oil palm (25) and harvesting of wild fruits and vegetables (7) were the main desired ES that were mapped in the monoculture and market dependence zone.

3.2. Spatial distribution of high priority areas of ES across a gradient of agricultural intensification

The kernel density analysis revealed both clustered and dispersed distributions of multiple ES across the landscape (Figure 4). In general, hotspots of desired ES were smaller than those of ES use. In the forest subsistence and agroforestry mosaic zones, ES were clustered relative to the large size of the land area used by IPLC. ES were concentrated mainly close to village locations indicating hotspot areas where multiple ES are currently used or desired by IPLC (Figure 4). In comparison, ES were relatively more dispersed across the diverse landscape types used by local communities in market dependence zone 3. The locations of ES use hotspots in the forest subsistence zone 1 were located within the old growth forest in proximity to rivers and households. In contrast, more remote areas often had one or no mapped ES. Desired ES in the forest subsistence zone were slightly more dispersed within the old growth forest near rivers and households compared to ES use. A maximum of seven overlapping ES uses occurred, including agriculture, fish, *Gaharu*, hunting, timber construction, drinking water and fiber. For desired ES, a maximum of eight were found in the highest concentration areas and included provisioning ES such as agriculture, fish, fiber, drinking water, timber construction and *Gaharu* as well as cultural ES such as locations conducive to the generation of moral value in youth and NTFPs with cultural/spiritual importance.

In the agroforestry mosaic zone, ES occurred in lower densities than in the forest subsistence zone with a maximum of five overlapping ES, which were mainly distributed in proximity to roads and households. ES hotspots were mainly mapped within the shrub and low fallow regrowth with some also occurring in old growth and secondary forest. Desired ES were more clustered over a smaller area in zone 2, primarily within shrub and low fallow regrowth zone. The ES uses co-occurring in high-density areas included agriculture, timber construction, timber for sale, drinking water and rubber. A maximum of seven overlapping ES desires occurred, including agriculture, fish, water, harvesting of wild fruit and vegetables, *Gaharu*, rubber and ecotourism.

ES use was relatively more dispersed in the monoculture and market dependence zone compared to the other zones, although hotspots were still in proximity to village locations (Figure 4). These high-density ES locations occurred in a number of different land cover types, including old growth and secondary forest, smallholder rubber plantations and food crops fields (Figures 2, 4, Table 5). In comparison, desired ES were more dispersed with fewer hotspots compared to ES use. In contrast to the forest subsistence and agroforestry zones, desired ES were concentrated away from the village centers in the old growth, secondary forest and oil palm estates. A lower variation of ES were mapped in the market dependence zone, consisting of four provisioning ES, including agriculture, smallholder oil palm, oil palm plantations and rubber (Figure 4). A maximum of three overlapping desired ES were identified in this market dependence zone, including smallholder oil palm, timber construction and harvesting of wild fruits and vegetables.

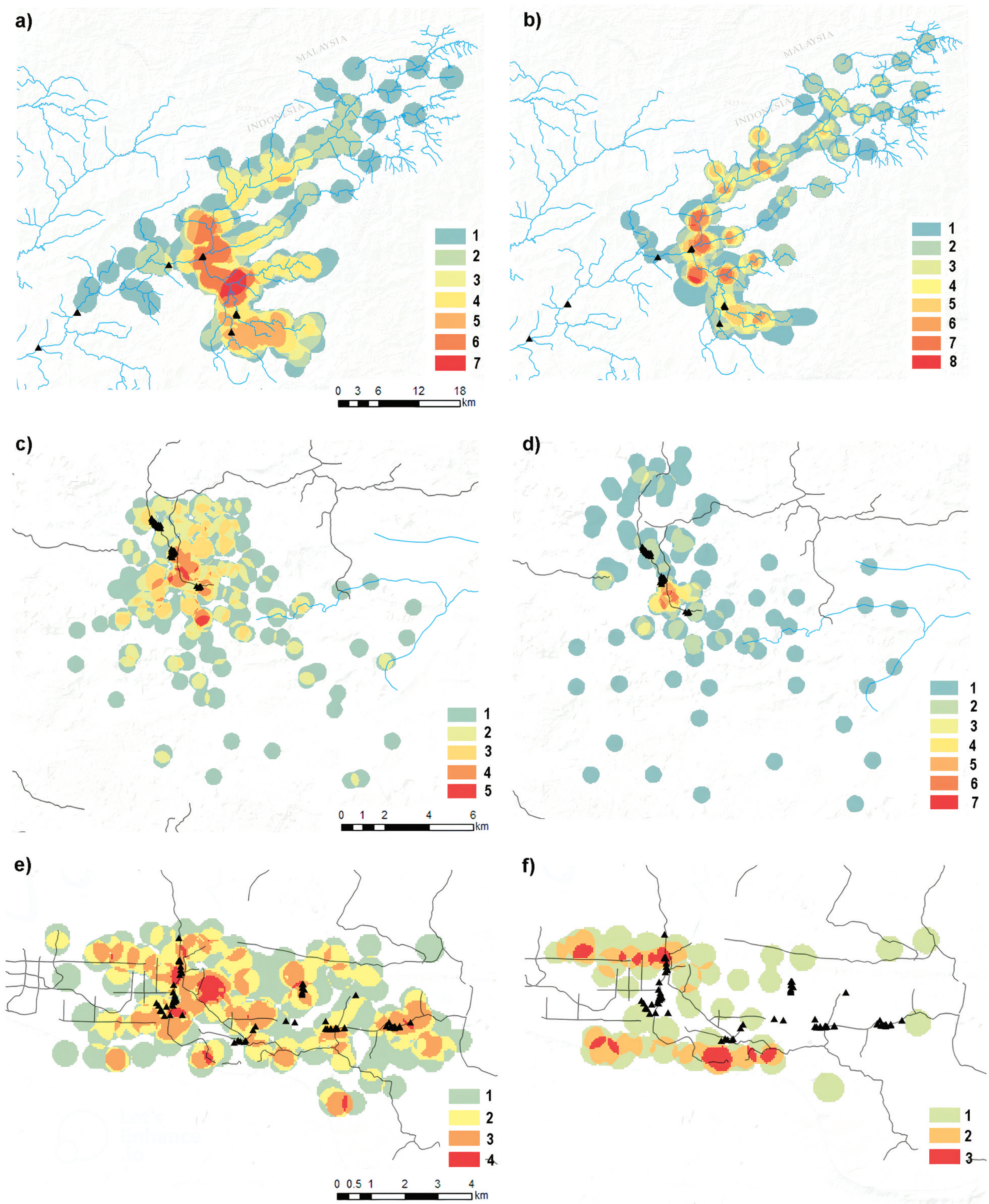

Figure 4. Hotspots in local people's ES use and desires detected from participatory mapped data. (a) ES use and (b) ES desire in the forest subsistence zone; (c) ES use and (d) ES desire in the agroforestry mosaic zone; and (e) ES use and (f) ES desire in the monoculture and market dependence zone. The colour codes represent the number of overlapping ES in each zone. Hotspots contain a high density of ES points and are depicted in red. Village locations are shown as black triangles, rivers as blue lines and roads as black lines. A geographic reference of the three zones is provided in Figure 1.

4. Discussion

Using participatory mapping with IPLC in West Kalimantan, Indonesia, our results showed a shift of their ES use and desire along a gradient of agricultural intensification. We found the highest frequency of ES use and desire mapped by IPLC in the forest subsistence zone in proximity to the forest, and a smaller selection in the more agriculturally modified landscape. This comparison of ES use and desire provides an understanding of how IPLC's aspiration and satisfaction change with ES access across different land covers along an intensification gradient. Our study exemplifies an improved understanding of ES desire of specific land covers in multifunctional landscapes and contributes to spatial planning that considers human livelihood and well-being (Cowling et al. 2008; Bryan et al. 2010; Reyers et al. 2013).

4.1. Shifting use and desire under agrarian change

Our study revealed a change of IPLC's use and desire for food, water and other NTFP-related ES across the three zones. In terms of food, we found that a transition occurred from a reliance on the forest for food and nutrition in the forest subsistence zone (zone 1) to an increased reliance on food production in the most agriculturally intensive zones (agroforestry mosaic/zone 2 and monoculture and market dependence/zone 3). Food was a highly desired ES in both the subsistence and agroforestry zone, originating from varying land covers. Accordingly, IPLCs acquired their provisioning food sources predominantly within the old growth forest, shrub and low fallow regrowth land and secondary forest in the forest subsistence and agroforestry zones. Such fallow lands have been reported as a valuable food source for nutrition in local diets (Ickowitz et al. 2019). Agricultural intensification has led to a loss of fallows in other regions and an associated reduction of ES such as wild fruit and vegetable as food sources (Broegaard et al. 2017). The economic benefits of agroforestry systems compared to swidden agriculture, as well as income and access to farm land can influence people's choice of whether a food source comes from subsistence use or through agricultural production (Kalaba et al. 2013; Angelsen et al. 2014; Rahman et al. 2014; Ahammad et al. 2019). In the context of Indonesia, such shifts to monoculture agricultural systems can lead to a loss in dietary diversity of IPLC with a greater consumption of processed foods (Ickowitz et al. 2019). In our study, agrarian change with an intensive production is leading to a declining overall role of the forest as an important food source for local livelihoods, nutrition and overall well-being within particular social-ecological contexts of a landscape.

Meanwhile, as the overall importance of the forest for providing ES declines, we observed a possible increase in the relative importance of the forest. Old-growth forests were relatively more important in zone 3 than they were in zone 1. In zone 1, old-growth forest covered 98% of the land but only provide 79% (fiber) or 65% (fish) of the ES. In zone 1, the secondary forest shared only 1% of land cover, but provided 29% fish. By contrast, the secondary forest remained in only 2% of land cover in zone 2, where it contributed 18% of timber construction material, exceptionally higher than other zones. This is likely suggesting that land covers become marginally more important for ES as those land covers become more scarce. This would caution that the value of some land covers (e.g. old growth forests) may not be readily apparent when they are still abundant and it also underscores the importance of doing place-based assessments that consider the actual abundance of land covers within a landscape.

Drinking water was the next most frequently mapped ES use and desire across all zones, in particular within the agroforestry mosaic zone, and within the forested land covers. The desire for drinking water within the forested areas of all three zones reveals the importance of the old growth and secondary forests to sustain this key ES, particularly within the more agriculturally developed landscape. Our finding supports previous studies that identified water as the most valuable ES, with an appreciation of the forests' contribution to healthy watersheds (Muhamad et al. 2014; Van Oort et al. 2015; Cuni-Sanchez et al. 2016; Grima et al. 2016). In this study, we demonstrate a clear desire of IPLC to have access to clean water in relative proximity to where they live. In the Kapuas Hulu Regency, a decline in water quality has been reported for downstream communities and those located near oil palm plantations (Anandi et al. 2020). Many communities explicitly identified drinking water as a core land use objective and have rejected proposals from oil palm corporations out of concern for their water in the past (Yuliani et al. 2018). Forest loss in highly intensive zones (monoculture and market zone) could cause a decline in water purification service (i.e. quality), leading to a greater vulnerability of these communities. There was a growing recognition of drinking water use and desire within the secondary forest of the monoculture zone, where the old growth forest had declined. Both in absolute terms and proportionally, drinking water seems to be a more important ES desire in the agroforestry systems than in the oil palm plantation. The high desire to increase this service (drinking water and water quality) indicates the need for old growth and secondary forest to be conserved for access to clean drinking water in the agriculturally modified landscapes.

NTFPs for provisioning use were mapped in the forest subsistence zone but were mostly absent in monoculture and agroforestry zones, indicating a move away from traditional forest uses toward a greater reliance on markets in the less forest-dependent communities. Our finding agrees with other studies that reported a reduced use of forest materials for subsistence and income in other parts of Borneo that had more developed infrastructure (Abram et al. 2014) and in the eastern upland Chittagong Hill Tracts region of Bangladesh (Ahammad et al. 2021). This reflects that IPLC living in forested landscapes are more dependent on forest products (Sunderlin et al. 2008) compared to communities living in agriculturally intensified areas, who may purchase their goods at markets. Nonetheless, in this study IPLC still clearly desired provisioning and cultural NTFPs in the agricultural frontier zones, expressing a desire for wild fruits and vegetables as well as *Gaharu*, an economically and culturally important resin derived from trees. So, the agrarian changes not only impacts the supply capacity of many NTFPs that has been available earlier but also the valuable knowledge and experiences held by IPLC in managing and conserving those resources on the landscape.

The desire to return to traditional forest products may indicate a preference for a wider range of livelihood and subsistence options as well as opportunities to restore traditional cultural identities (Tengberg et al. 2012). Our study did not observe any cultural ES use across all the zones at the time of the survey, but there was a high desire for these ES. Although we cannot explain this disparity observed for cultural ES, in zone 2 and zone 3, ecotourism is understood as an important future livelihood opportunity even if it not yet present. The limited response on the use of cultural ES can have several explanations. One is related to gender-biased participants, who focused more on provisioning services (this has already been reported in the literature for males: see Martín-López et al. 2012) and ES with economic value. There might also have been a not fully clear understanding of what cultural ES are in Zone 1. In general, the ongoing agrarian transformation may be seen as a brief sacrifice, and although participants in zone 3 may have lost access to culturally important NTFP during land cover change, it appears the participants are hopeful it may recover in the future. The desire for cultural/spiritual NTFPs and tourism ES was observed across diverse land covers (old growth forest, shrubs and low fallow regrowth, secondary forest and oil palm estate) and other studies have shown that spiritual and cultural values of the forest can be maintained despite the declines in forest interactions as landscape transitions occur (Plieninger et al. 2013; Abram et al. 2014). The results from this study demonstrate that despite continued desires for traditional NTFP's, opportunities are becoming limited in heavily transformed oil palm landscapes. This transition of cultural ES desire suggests a potential opportunity for considering conservation values of local communities in protecting secondary forests or restoration of shrub lands in agriculturally intensified zones.

The observed shifts in ES uses and desires reveal that there may be a range of transitional processes occurring where some ES are being slowly traded out for different ES as the gradient of agrarian change intensifies. Understanding ES losses and gains reflected in terms of use and desire remains challenging as the underlying processes do not happen at a single point in time and associated changes in ES use and desires do not necessarily preclude improved livelihood or conservation outcomes. Nonetheless, the observed shift in peoples' ES uses and desires across the gradient of agricultural intensification, gives insights of how the people are responding and coping with landscape change.

4.2. ES hotspot mapping

The ES hotspot maps produced from ILK revealed a decline in ES diversity across the three zones as the landscape transitioned away from old growth forest to a more modified landscape (Figure 4). The highly intensified market zone was dominated by ES such as rubber or oil palm, exemplifying an agricultural transition where the use of multiple ES gradually shifts to the reliance on a smaller range of ES in this modified landscape. A decline in ES multifunctionality with agricultural intensification has been reported in other studies that focused mainly on biophysical ES such as a biodiversity, water and soil formation processes (Loos et al. 2014; Allan et al. 2015; Rasmussen et al. 2018) without considering how these changes align with the spatial pattern of local communities' desires (Reed et al. 2016).

Spatial mapping of areas with high ES densities provides an opportunity to incorporate the land use desires of IPLC into landscape management plans, considering their cultural and livelihood values and thus accounting for multifunctionality of the landscape (Reyers et al. 2013; Ramirez-Gomez et al. 2016; Molin et al. 2018; Reed et al. 2020). The hotspot maps of socially valued ES from this study highlight areas that are most frequently used or desired by people in the surveyed villages. The location of identified hotspot areas near households and rivers in the forest subsistence zone, and accessible by roads in the agricultural zones, reflects the importance of access to determine ES use patterns. Areas with higher ES densities have also been described near riverine systems among indigenous groups in Suriname (Ramirez-Gomez et al. 2016). The findings from our study confirm that the spatial patterns of ES use are influenced by landscape configuration and that ES assessments benefit from combining knowledge on social values and access with biophysical data to promote human well-being by landscape management (Labrière et al. 2016; Tomscha and Gergel 2016; Pingarroni et al. 2022).

5. Conclusions and implications for management

This study leveraged participatory mapping as a means to incorporate the knowledge and aspirations of IPLC in explaining the patterns of ES use and desires across forest-agriculture gradients in Kapuas Hulu, Indonesia. Our study showed that agricultural intensification caused a decline in the availability and distribution of specific ES uses and desires of IPLC. Both ES used and desired decreased in both absolute and proportional terms with increasing agrarian change. Thus, the multifunctionality of the landscape decreased as it transitioned from forest subsistence use to market-oriented commodities. This finding confirms the importance of employing a place-based approach and community-involved measures of ES uses and desires for enhancing well-being of IPLC in multifunctional landscapes (Fagerholm et al. 2020).

By identifying hotspots of ES use and desires across a gradient of agriculture intensification, our ES mapping approach has the potential to greatly improve the quality of spatial planning that can benefit local communities, economic development and conservation objectives (Sumarga and Hein 2014). Integrating participatory ES mapping, as piloted here, could have additional benefits by providing IPLC a voice in decision-making directly, unmediated by governmental officials and other stakeholders with their own objectives and aims. Historically state land use mapping in the region has partly considered the claims of IPLC to permanent agriculture including, shifting cultivation. In contrast, state land use mapping allocates reserves with convertible forestland to the corporations for tree cropping (e.g. oil palm, rubber or pulp species). This plan only fits the state agency's purpose of controlling the land boundary without recognising the villagers' demand (including IPLC) for timber and non-timber provisioning ES in the old-growth forest and shifting (swidden) cultivation (Peluso, 1995). Recently, the counter-mapping (including participatory mapping approaches) developed by non-government organisations with the participation of local communities' oral histories and knowledge has emphasized how a customary resource use plan contributes to better social and ecological outcomes as long as government recognises the plan adequately. By applying a participatory approach, our study demonstrates that diverse set of ES values attached by IPLC to their protected forests regardless of their claims on lands adequately recognised within the state mapping. So, a successful participatory mapping may overcome this void with the state's recognition of the traditional, flexible and value-based resource use system allowing the space for negotiation and acceptance by IPLC.

The main methodological novelty of our work consisted in the comparison of the ES use and desire along a gradient of agricultural intensification. In contrast with previous participatory mapping studies, which focused mainly on the supply side or supply–demand (Palomo et al. 2014, Garcia-Nieto et al. 2015), we provided an assessment of the level of satisfaction of IPLC in terms of their perceptions of existing ES use and desire to maintain livelihoods and well-being under the circumstance of the changed resource allocation and exploitation around them. As we have shown in this work, the application of this approach provides key information on the level to which stakeholders′ ES preferences are met in different landscape configurations in the context of agrarian change. The participatory ES mapping provides a deeper social-ecological understanding of land currently used by local communities regardless of land classification on government maps. Decision-makers should consider this information when planning landscapes on both sides of the forest frontier, particularly the roles and value of forest reserves and other intensive land use held by IPLC.

This approach is particularly important in data-scarce, rural environments where IPLC still depend on ES from the forest (Abram et al. 2014) and where they are often marginalized in terms of land and resource use planning processes that can have direct impacts on their livelihoods and well-being (Gilmore and Young 2012; Mitchell et al. 2015; Van Oort et al. 2015). Improvements in the study can be made by involving a wide range of stakeholders or participant selection based on demographics (gender, age), social and economic contexts during the mapping process. Future research should consider a multi-level stakeholder involvement to assess the diverse perspectives of ES uses and desires from a landscape and identify the necessary land planning processes to achieve specific ES.

Landscape scale planning in Indonesia is a complex process that involves multiple stakeholders and multiple levels of governance (Brockhaus et al. 2012; Sayer et al. 2013; Law et al. 2015; Sahide and Giessen 2015). In theory, decision-making processes required for the conversion of forests to oil palm should include IPLC' consultation and consent. However, in reality elite capture, and systems of incentives and coercions result in little to no local consultation over land use planning arrangements (Ardiansyah et al. 2015; Prabowo et al. 2017; Hasudungan and Neilson 2020; Yuliani et al. 2020). Therefore, our study shows that the use of land cover alone excludes information about local perceptions of ES uses and desires, which can lead to disagreements with existing land management strategies under agrarian change. Instead, by incorporating IPLC's desires for their landscapes within the participatory mapping process, our study demonstrates that important insights can be gained over IPLC's visions for development and their concerns over perceived current land use trajectories.

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