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ORIGINAL ARTICLE

Use, value, and desire: ecosystem services under agricultural intensification in a changing landscape in West Kalimantan (Indonesia)

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Abstract

A fundamental challenge is to understand and navigate trade-offs between ecosystem services (ES) in dynamic landscapes and to account for interactions between local people and broad-scale drivers, such as agricultural intensification. Many analyses of ES trade-offs rely on static mapping and biophysical indicators while disregarding the multiple uses, values, and desires for ES (UVD-ES) that local people associate with their changing landscapes. Here, a participatory UVD-ES framework was applied to assess differences in the use, values, and desire of ES between three zones with different land-use intensities (with pre-frontier, frontier, and post-frontier landscapes) in West Kalimantan (Indonesia). The analysis revealed that (1) almost the full suite of ES uses has become destabilized as a result of agricultural intensification; (2) ES more closely associated with agricultural intensification were largely desired by local people yet they still valued a diversity of traditional ES, such as those derived from the provision of non-timber forest products, fish, and other ES associated with non-material aspects including those tied to traditional culture; (3) the mismatch in used ES versus valued ES increased with agricultural intensification due to a decrease in the flow of non-timber forest products, aquatic, regulating, and non-material (cultural) ES. Together, exploring UVD-ES patterns in a participatory way helped to reveal locally relevant social-ecological drivers of ES and a multidimensional perspective of ES trade-offs. Our UVD-ES framework offers an opportunity to foster participation as a way to reconnect global environmental research agendas with local and regional landscape contexts.

Keywords Deforestation · Feedbacks · Landscape dynamics · Landscape transition · Participatory mapping · Social-ecological system

Introduction

Agricultural intensification is pursued in many regions around the world and supported by international policy as it can increase yields, free up land to set aside for conservation, and, potentially, improve the lives of local people (Rockström et al. 2017, Rasmussen et al. 2018). However, simplifying landscapes and reducing multifunctionality (e.g. by favouring monocultures) degrades biodiversity and erodes the diversity of ecosystem services (ES), especially regulating ES (Sharma et al. 2019, Watson et al. 2021). Likewise, it often leads to a decline in dietary diversity which has direct effects on people's health (Friant et al. 2019, Ickowitz et al. 2019). Hence, it is questionable whether and to what extent agricultural intensification can sustainably support local people's needs and wants (Ickowitz et al. 2019, Jiren et al. 2020). One opportunity to better contextualize the outcomes of agricultural intensification is through analysis of how locally important ES are affected by agricultural intensification. The ES that local people *desire* to have access to, currently *value*, and actually make *use* of are determined by complex interrelationships among many variables including landscape features (e.g. biodiversity), people's objectives and worldviews, including visions of what constitutes well-being (e.g. food security, health, freedoms), and the institutions (norms and rules) that influence land management (Selomane et al. 2019, Friant et al. 2019, Meyfroidt et al. 2022, Pascual et al. 2022a, b).

To date, many discussions over how to reduce environmental impacts of agricultural intensification while still

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managing to feed an expanding human population have been taken up in highly stylized academic debate. For example, the land sharing/land sparing debate (Phalan et al. 2011) created a powerful discursive framing but has continuously and largely ignored the complex interrelationships between local people's values, desires, and actual uses of ES in local landscapes (Jiren et al. 2018, Reyers and Selig 2020). There are emerging calls for more inclusive social-ecological systems–based approaches that recognize multiple values and ES interactions (synergies and trade-offs) at the landscape level (e.g. Bennett 2017, Ellis et al. 2019, Reyers and Selig 2020, Guibrunet et al. 2021, Pascual et al. 2021).

Trade-offs between agriculture and non-agricultural ES have traditionally been portrayed to mechanistically follow changes in land use, such as when multifunctional natural forests are converted into high-intensity agricultural systems that primarily provide food (Foley et al. 2005). Recent research has attempted to better identify complex drivers and their trade-offs among multiple ES within and across regional landscapes (Renard et al. 2015, Rieb and Bennett 2020). Analysis of ES bundles, defined as sets of ES provided by a given landscape, has emerged as an important heuristic in ES research to assess the drivers and outcomes of alternative landscape configurations (Raudseppe-Hearne et al. 2010, Spake et al. 2017). However, research on ES trade-offs and bundles has typically relied on static assessments or assumed narrow and primarily biophysical definitions of ES (i.e. ES supply). There are relatively few studies that focus on the dynamics of ES bundles and how they are driven by a range of social-ecological mechanisms (but see, Renard et al. 2015, Sutherland et al. 2016, Jaligot et al. 2019). Thus, a remaining knowledge gap is to understand how mismatches arise in dynamic landscapes between what landscape can provide and what ES local communities want or desire (Winkler et al. 2021). Addressing this gap is important to a core aim of sustainability research, which is to understand how the outcomes of biophysical landscape changes align with the needs, wants, and values of people at the landscape level (Cord et al. 2017, Albizua et al. 2019, Schirpke et al. 2019, Aryal et al. 2022). Manning et al. (2018) suggest that comparing bundles of ES supply to those ES desired by local actors can move forward general questions concerning the level of landscape multifunctionality desired in local landscapes.

Here, we investigate differences in ES across landscapes with varying agricultural intensities by means of a participatory mapping and ES evaluation approach. Participatory mapping and ES evaluation involve a process that allows studying the interconnections between local communities and the flow of ES at the landscape level. To leverage this approach, we disaggregate ES into three dimensions to study the dynamics of (a) ES use, (b) ES values, and (c) ES desires, at the landscape level during agricultural intensification. 'ES use' refers to the realization of ES at identifiable locations within a landscape, which is enabled by preconditions of biophysical supply and access being met (Burkhard et al. 2014). 'ES values' are interpreted here through an anthropocentric perspective as the perceived importance of ES for the well-being of local people and that lead people to prioritize some ES over others (Pascual et al. 2022b). 'ES desires' in turn, reflect people's preferences towards certain ES flows in the future, which may or may not be the same as the ES currently used (Wolff et al. 2015). Eliciting the *use of*, *values about*, and *desires for* multiple ES (UVD-ES) from the perspectives of local people can offer a window into how local people interact with and respond to their changing environments at the landscape level. Using a framing centred around UVD-ES can help understand what triggers and what impacts arise in landscapes at different stages of agricultural intensification and provide an analytical framework to help understand the complex ES trade-offs occurring during landscape change (Spangenberg et al. 2014, Wei et al. 2017, Reyers and Selig 2020).

To understand the effect of agricultural intensification on ES bundles, we examine a landscape transitioning from baseline (natural forest) to a forest frontier zone with land sharing characteristics (mixed agroforestry and natural forest) to rapid agricultural intensification (palm oil plantations). A landscape transition describes the sequence of non-linear changes to land covers and local livelihoods that result from interactions and feedbacks between social systems, ecosystems, and institutions (Lambin and Meyfroidt 2010). By incorporating local perceptions of ES across a landscape transition, we build insight into how local people's uses, values, and desires for multiple ES change during at different stages of agricultural intensification. Our broad objective is to enrich a nuanced understanding of how landscape changes brought by deforestation and subsequent agricultural intensification are aligning or misaligning with local people's needs and values in dynamic landscapes. Specifically, we aim to (1) identify and compare differences in the bundles of ES uses, values, and desires across an experimental gradient of increasing agricultural intensity; (2) survey local people's perceptions of ES trends and stability; and (3) examine how well agricultural intensification is aligning with local people's desires for their hypothetical future.

This study is part of the Agrarian Change Project, a multi-country research initiative that examined landscape change to assess the implications of landscape transitions for biodiversity conservation, livelihoods, and food security (Baudron et al. 2017, Sunderland et al. 2017). The use of spatial aspects within experimental designs is relatively nascent in ES research (Sutherland et al. 2016, Spake et al. 2017, Dade et al. 2019, Mitchell and Devisscher 2022) but here allows us to address how the widespread global process of agricultural intensification is driving differences in ES across a landscape transition.

Methods

We analyze the use, values, and desires for ES in the rapidly changing landscapes of West Kalimantan, Indonesia. We selected sites across three zones representing an experimental gradient of agricultural intensity, the 'pre-frontier' zone 1, 'frontier' zone 2, and 'post-frontier' zone 3. We then collected data using participatory workshops in each of the targeted zones to elicit estimates of ES-UVD and also ES trends in each zone. We then plotted ES bundles and used descriptive statistics and other statistical analyses to confirm and explore the differences in ES between zones and to identify mismatches between ES-UVD. Finally, we combined the insights from each of these methods toward a multidimensional assessment of ES trade-offs occurring under each of the three zones with varying agricultural intensities. The methods are summarized in Fig. 1.

Study area

The province of Kapuas Hulu is a region undergoing rapid landscape change as natural forests are being converted to smallholder agriculture plots or rubber agroforests, and eventually to palm oil plantations (Leonald and Rowland 2016, Gaveau et al. 2018), which support far lower biodiversity and diversity of ES than natural forests (Fitzherbert et al. 2008). An increase in rubber agroforestry and palm oil production since the early 2000s has driven this region to have the highest deforestation rates in Indonesia (Rudel et al. 2009, Leonald and Rowland 2016, Yuliani et al. 2018).

Study system experimental design

Sites were selected to approximate a landscape transition from forest and river-based to market-oriented livelihoods in West Kalimantan, Indonesia (described in Leonald and Rowland (2016) and Sunderland et al. (2017)). Three zones were selected to represent different stages of a typical landscape transition occurring in the region thus forming an experimental gradient of increasing agricultural intensity (Fig. 2). The three zones were selected by scoping biophysical data (e.g. forest cover, land use, and soil type; Laumonier and Setiabudi 2013), socio-economic factors (e.g. market access, reliance on forests, diets), and expert advice from researchers, NGOs, and other local organizations. A full description of data sources used in study site selection is provided in Leonald and Rowland (2016) (also see supplementary information [SI] Table 1 and Sunderland et al. 2017).

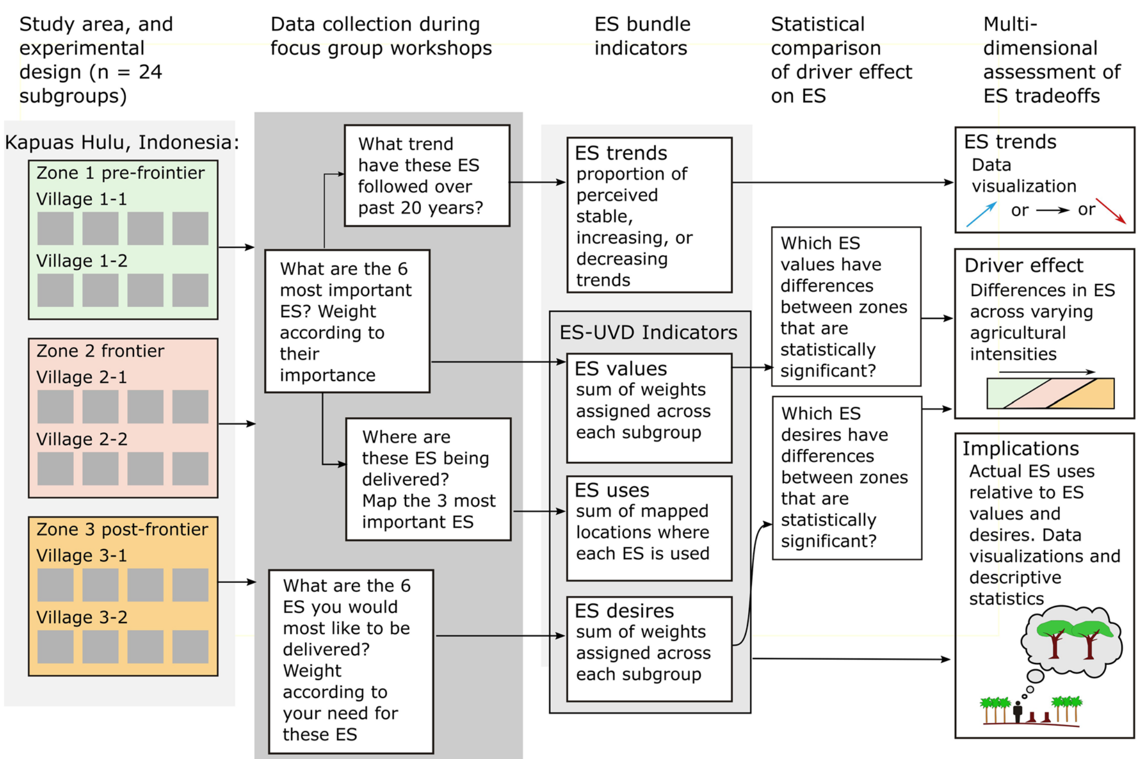

Fig. 1 Summary of methods for estimating ecosystem services (ES). The sample size of $n = 24$ subgroups includes 4 subgroups per village, two villages per zone, and three zones ($4 \times 2 \times 3 = 24$)

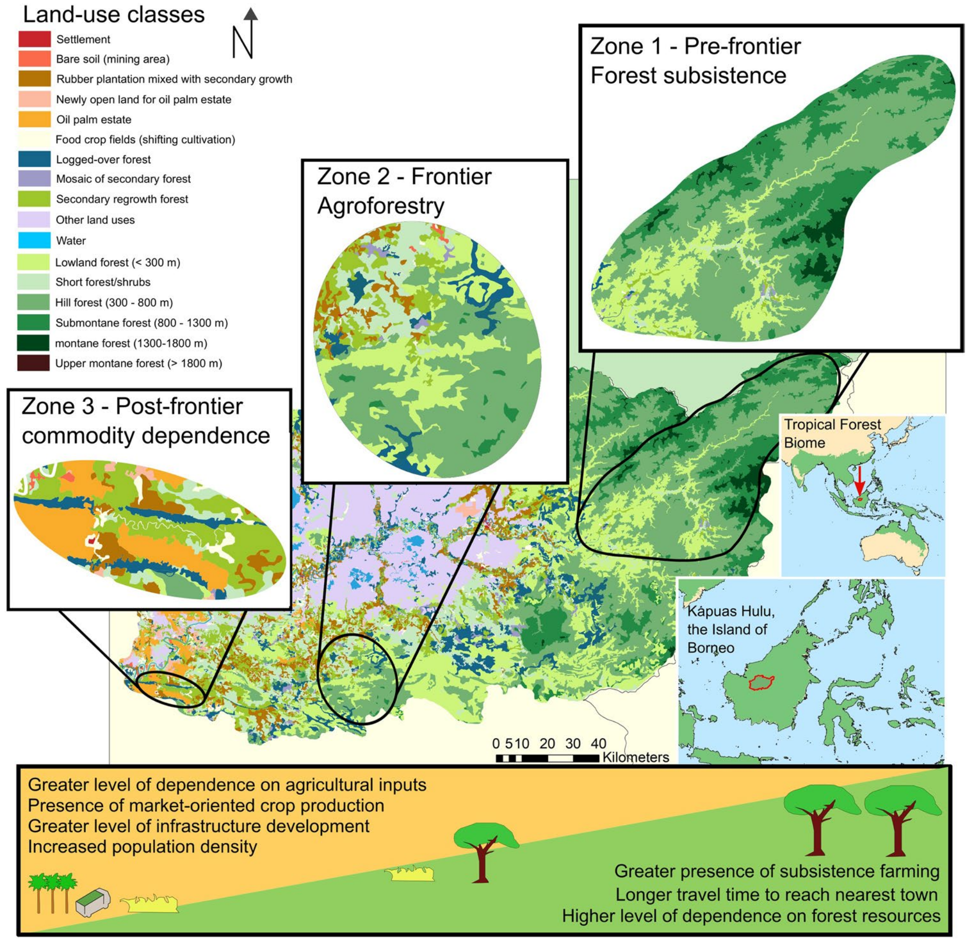

Fig. 2 Study area (approximate) in Kapuas Hulu, West Kalimantan, Indonesia. The three zones were selected to represent a gradient of agricultural intensity. See SI Table 1 or Leonald and Rowland 2016 for a detailed comparison of social and biophysical factors between zones

Figure 2 depicts the varying landcovers across this intensification gradient, which includes the three zones named according to the dominant ES and their position relative to the forest frontier. In 'pre-frontier forest subsistence' zone 1, local communities rely on river access and practice swidden agriculture, forest-based subsistence hunting, and fishing, alongside gathering of non-timber forest products (NTFPs). In 'frontier agroforestry' zone 2, access to markets increases as local people work in rubber agroforests (mixed with fruit and nut trees) but still practice subsistence-based swidden agriculture and rely on traditional forest uses. Access to forests, especially primary forests, is decreasing, requiring further travel to access traditional forest uses. In "post-frontier commodity dependence" zone 3, primary forests are significantly diminished but some forest uses (e.g. NTFPs collection) persist. In this zone, local communities increasingly rely on cash crops through labouring on oil palm plantations, or participating in company-smallholder oil palm schemes, or through developing independent smallholder oil palm plantations.

Data collection during workshops and participant selection

We selected two villages per zone based on scoping (semi-structured) interviews and focus groups held in 2014 to best exemplify the regional landscape transition (Leonald and Rowland 2016, Sunderland et al. 2017). In 2015, we held one workshop in each of the six villages. Each workshop included four self-organized subgroups of three to five participants, leading to a total sample size of 24 participant subgroups and about 96 participants. Workshop protocols were subject to internal institutional review for scientific validity and ethics (SI text 1.2). Participant selection was conducted within the constraints of local social-cultural obligations to invite village elders and dignitaries, which skewed the participants towards a closely connected and male-only gender demographic profile. This uneven participant representation was not desired by the workshop planners, and happened unintentionally out of the snow-balling participant gathering approach and necessity to accomplish the remote fieldwork as discussed in the "Limitations and research challenges for valuing regulating ES" section later on. The general demographic profile of participants was consistent across the three zones.

During the workshops, we solicited participants to express their perceptions on multiple ES. In anticipation that local people might be unfamiliar with the ES concept (a western scientific construct), we framed the ES using examples and photographs identified during the scoping research of different ways that local people interact with the landscape (Supplementary Information [SI] Table 2; Leonald and Rowland 2016). In total, we presented a list of 31 broad and easily identifiable ES according to local people's views for the participants to choose from, which is a common practice in participatory ES mapping approaches (Palomo et al. 2013). These included nine regulating ES, 13 provisioning ES, and nine cultural ES, which were presented during a plenary at the start of each workshop (Leonald and Rowland 2016; SI Table 2). The ES were distinguished based on the direct or indirect ways they are important to local people as regulating ES, cultural ES, and provisioning ES (MA 2005). To further refine the nuanced differences in how local people relate to ES in this landscape, we identified three categories of provisioning ES: NTFPs provisioning ES, aquatic provisioning ES, and commodity-based provisioning ES. These three categories of provisioning ES were distinguished to reflect differences among the material and non-material benefits each category contributes (e.g. Rasmussen et al. 2018, Gergel et al. 2020), as well as the types of social, financial, and built capital involved in their co-production (Palomo et al. 2016, Costanza et al. 2017; Díaz et al. 2018), which likely change during a landscape transition. Although traditional practices associated with co-producing some provisioning ES are inherently cultural (Díaz et al. 2018), we define cultural ES here as non-material benefits (MA 2005) to help distinguish broader patterns occurring among different types of ES across the transition.

Questionnaires consisted of the four questions shown in Fig. 1, which guided the workshop and were answered using deliberation, where participants in subgroups worked through questions with help from the workshop organizers (see SI text 1.1 for the full questionnaire). This allowed participants to collectively rank ES values and desires, map locations of ES use, and express perceived ES trends (increasing/decreasing/stable) over the past 20 years (1995–2015). Eliciting values through deliberation encourages collective understanding and sharing of participants' knowledge, beliefs, and norms (Kenter 2016, Hejnowicz and Rudd 2017, LLiso et al. 2020)—a process particularly appropriate when individuals do not hold preconceived and fixed values for ES (Hejnowicz and Rudd 2017). Thus, each subgroup addressed the use, values, and desires (UVD)—related questions via within-group deliberation aiming at reaching consensus. They listed on paper up to a maximum of the six ES currently most important for well-being in general (ES values) and six ES most desired in a hypothetical future (ES desires). Each subgroup then distributed a total of 20 points to their chosen ES values and 20 points to their chosen ES desires as a means to assign weights of subjective importance, preference, and needs associated with each of their choices. These points represent the ES indicators for ES values and ES desires (described further below). Participants mapped the locations where the three most valued ES were currently being used (ES uses). Mapping was done by placing buttons at any location where participants use the ES on 1:50,000 scale paper maps as described in Mathys et al. (2023). From the six most valued ES identified by each subgroup, participants were then asked to assess the trends (ES trends) in those ES over the past 20 years.

Ecosystem services bundle indicators

We summarized the results from the focus groups by plotting ES bundles for each zone to visually compare ES across the three zones. An ES bundle depicts the set of individual ES occurring within a landscape for a given indicator type. Thus, we plotted three bundles per landscape including one for each of ES use, values, and desires. For ES values and ES desires, the indicator plotted is the sum of subjective (i.e. perceived) importance scores assigned to that ES by each subgroup standardized relative to the maximum potential score that could be assigned. For ES use, it is the sum of locations mapped by subgroups that show where each ES is used standardized relative to the number of locations of the most frequently mapped ES. We also plotted ES bundles to depict the proportion of subgroups perceiving stable, increasing, or decreasing ES trends.

We described ES bundles using descriptive statistics including a dominance index (ES dominance) to indicate mono-functionality (Brown and Reed 2012) for comparison against a diversity index (ES diversity), defined as the effective number of ES (SI Eq. 1; Jost 2006), which ranges from 1 ES up to (theoretically) 31 evenly distributed ES and reflects multifunctionality. The ES dominance index (SI Eq. 2) is bounded between 0 and 1 and compares differences between the highest and second highest ranked ES (SI Eq. 1) relative to the highest ranked ES. Thus, a dominance index of 0 indicates that no ES dominates and 1 indicates total dominance (only one ES is present). Together the dominance and diversity are used to help describe the broader differences in ES observed across the gradient.

Data analysis

To analyze if observed differences in ES were non-random, we statistically analyzed for a driver effect by detecting differences in ES across zones using a generalized linear model (GLM). The explanatory variable was zones (comparing for differences between zones 1, 2, and 3). The response variable was the ES indicators (ES values and ES desires) for each ES (e.g. fish) and also for each category of ES (e.g. aquatic provisioning ES), which summed all the indicators in that category. Because response variables are proportions—scores assigned out of a maximum score of 20—they are not normally distributed. Thus, we analyzed the effect of zones on ES using GLMs with a binomial distribution (Zuur et al. 2009). Each subgroup represents one out of a n=24 sample (4 subgroups per village × 2 villages per zone × 3 zones). Because each subgroup could choose only a limited subset out of a possible set of 31 ES, many ES received a zero score (i.e. not chosen). For ES with very few non-zero data points, and for all 'ES use' data (which had the most zeros), statistical models were often invalid as assessed by residual plots. Thus, during model validation, we decided to exclude 'ES use' from the statistical analysis and only report statistical results for ES values or ES desire categories that were chosen by a minimum of two subgroups per zone.

Multidimensional assessment of ecosystem services trade-offs

Insights from each of the methods described thus far contributed to a multidimensional assessment of ES trade-offs occurring within these landscapes. First, we observed ES over time by surveying participants' perception of ES trends, which allowed us to identify if different ES are changing in parallel or in opposition (e.g. one ES is increasing as the other decreases). Second, we assessed differences in each of ES-UVD bundles across the experimental gradient of agricultural intensity. Here, we assume that differences in ES-UVD across the landscape gradient have been caused primarily by agricultural intensification. This assumption is supported by the scoping work and experimental design but is interpreted cautiously because each zone has its own unique place-based landscape history (Leonald and Rowland 2016). Finally, to explore the implications of trade-offs between agricultural intensification and other ES (Manning et al. 2018, Schirpke et al. 2019), we compared mismatches between ES-UVD to understand if differences between the zones were desired or undesired. If an ES is valued and desired but not used in a given zone, then a mismatch is identified that may affect people's well-being as a result. Together, these three dimensions (perceived trends, driver effect, and ES-UVD outcome) offer complimentary insight into the processes and implications of trade-offs occurring for multiple ES in a landscape undergoing transition towards greater agricultural intensification.

Results

Shifts in bundles of ecosystem services use, value, and desire between zones

ES use differed the most between zones among the UVD-ES indicators and was the only indicator to exhibit a directional shift from diverse ES use bundles in zone 1 with multiple and different categories of ES (NTFPs, cultural ES, and aquatic ES, yet low regulating ES) and high diversity (5.80 effective number of ES) to bundles dominated by one or two commodity-oriented ES uses (namely rubber and palm oil) with lower diversity in zone 3 (3.97 effective number of ES) (Fig. 3). Differences among ES values between zones were less directional: ES values narrowed from a highly diverse bundle in zone 1 (12.25 effective number of ES) to zone 2 (7.46 effective number of ES) due to greater values for commodity-oriented provisioning ES in zone 2 (namely rubber). Comparing between zone 2 and zone 3, diversity in ES values was higher in zone 3 (8.87 effective number of ES values). Diversity in ES desires was also higher in zone 3 compared to zone 2 due to higher desires for cultural and regulating ES in zone 3, as well as traditional NTFPs, which had been lost during agricultural intensification in their local landscapes. Nonetheless, NTFPs were less valued in zone 2 and zone 3 compared to zone 1 (both are $p<0.0001$, Table 1).

When visually comparing the ES values to ES use bundles, it was apparent that in zone 1 participants' ES values match closely what ES participants do use (Fig. 3). In zone 2, the similarity is still strong but reduced as many ES values, including all NTFPs and fish are no longer used. In zone 3, participants' ES values are decoupled from what they use: people expressed value for regulating ES, cultural ES, NTFPs provisioning ES, yet are limited to ES uses associated with agriculture.

Perceived trends in ecosystem services availability

The observation that bundles of ES use become less diverse in zones with higher agricultural intensity was supported by participants' perception (reported from memory) of widespread ES declines over the past 20 years for most ES (Fig. 4 and data displayed are given in SI Table 4). Among the three zones, the greatest declines in ES flows were perceived amidst rising oil palm production in zone 3: many ES other than provision of palm oil (60%; referring to the number of subgroups perceiving the modal trend) were perceived to be decreasing, led by timber extraction (100% - every subgroup perceived timber to be decreasing), surface drinking water (83%), smallholder

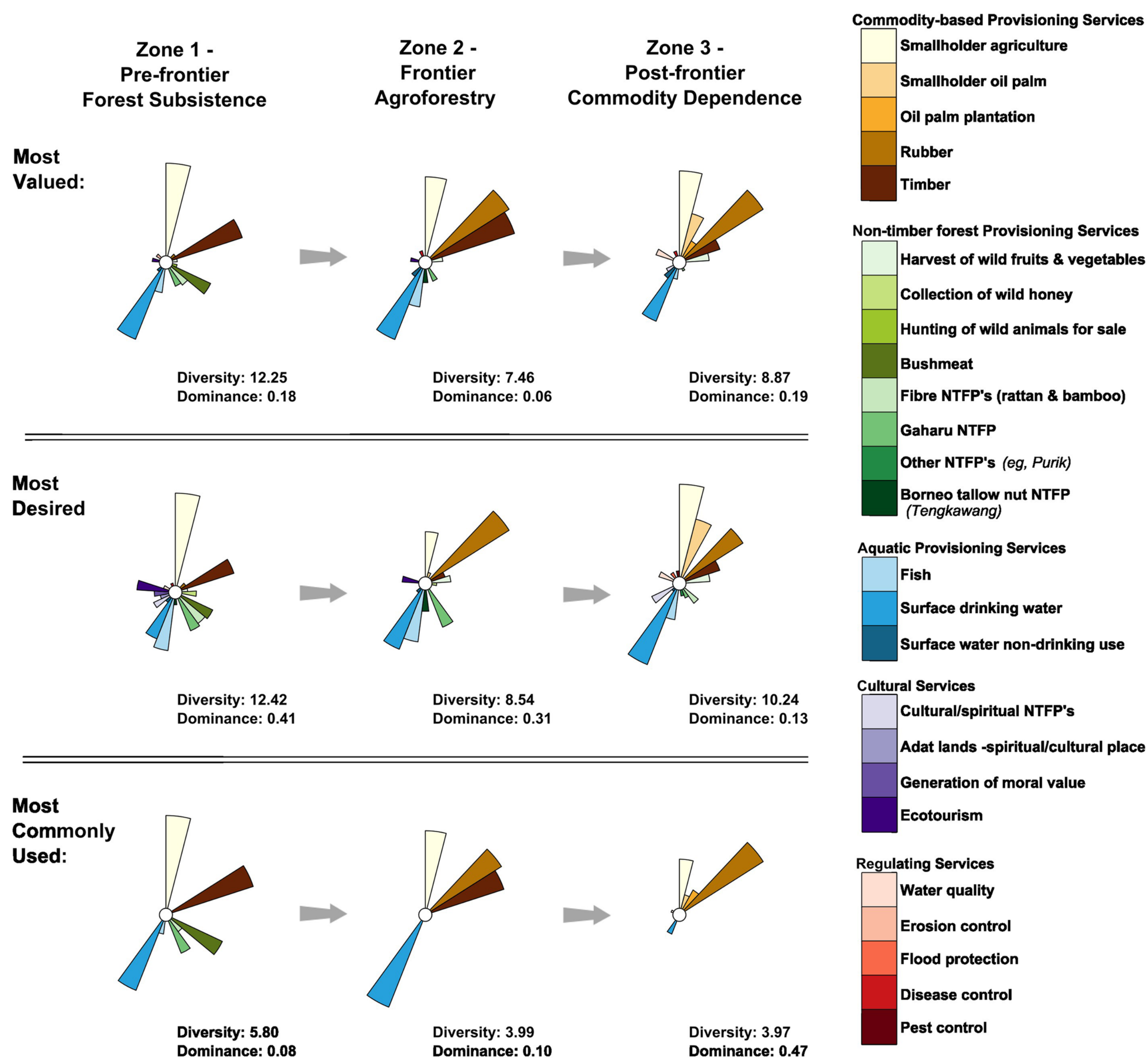

Fig. 3 Ecosystem services (ES) bundles across the three stages of agricultural intensity. Bundles for ES values and ES desires depict the sum of importance scores each subgroup of participants assigned to each ES. Bundles for ES use depict the sum of locations each subgroup mapped for each ES, and thus represent the geographic frequency of ES use. Diversity is the effective number of ES use, values, and desires (SI Eq 1)—a higher number indicates greater diversity. Dominance indicates the degree that any single ES use, value, or desire is more prevalent than all other ES combined—a high number indicates greater dominance (SI Eq 2)

agriculture (75%), and rubber agroforestry (63%; Fig. 4). In zone 2, 52% of ES were decreasing led by decreases in several ES perceived as important to their food security, including fish (83%), timber (75%), smallholder agriculture (71%), and drinking water (50%; Fig. 4). Zone 1 was the most stable with 60% of ES perceived as remaining stable. The most consistently observed increases perceived in ES were in agricultural commodity–oriented ES: smallholder palm oil in zone 3 (80%) and increases in rubber in zone 2 (75%; Fig. 4).

A few ES were relatively stable even in the most dynamic zone 3. For example, although only seven out of 24 subgroups chose wild fruits and vegetables (a relatively low sample), this ES was considered stable by all groups that chose it in zone 1 and zone 2, as well as two out of the four subgroups that chose it in zone 3 (Fig. 4). Surface water for non-drinking use was considered stable by all subgroups that chose it. Surface water for drinking was stable in zone 1, stable to decreasing in zone 2, and mostly decreasing (but 1 subgroup perceived an increase) in zone 3. Several ES were

Table 1 Comparison of ecosystem services (ES) between zones for ES values and ES desires based on participatory workshop results and GLM model fits (p <0.05). Average relative weight is the average subjective importance score subgroups assigned to ES values (i.e. importance) and ES desires (i.e. are important for the future) as a proportion of the total 20 importance score points they could have assigned. See SI Table 3 for sample sizes and standard deviation between subgroups. Sparsely chosen ES produced invalid models and are not shown so rows may not sum to 1

	Average relative weight of subjective importance assigned to each ES			GLM results	
Ecosystem services (ES)	Zone 1	Zone 2	Zone 3	Zone 1–zone 2 *p*-value	Zone1–zone3 *p*-value
ES values					
Aggregate by ES category					
Commodity-based provisioning ES	0.45	0.59	0.67	**0.010***	**<0.001***
NTFP provisioning ES	0.24	0.09	0.06	**<0.001***	**<0.001***
Aquatic provisioning ES	0.28	0.29	0.19	0.804	0.0875
By individual ES					
Smallholder agriculture	0.24	0.18	0.21	0.173	0.422
Surface drinking water	0.20	0.18	0.14	0.567	0.138
Timber	0.19	0.20	0.09	0.888	**0.008***
Fish	0.06	0.09	0.03	0.398	0.113
Gaharu NTFPs[b]	0.05	0.03	0.01	0.400	NA[a]
ES desires					
Aggregate by ES category					
Commodity-based provisioning ES	0.33	0.41	0.54	0.133	**<0.001***
NTFPs provisioning ES	0.28	0.23	0.12	0.302	**<0.001***
Aquatic provisioning ES	0.22	0.32	0.24	**0.045***	0.690
Regulating ES	0.02	0.00	0.06	0.994	0.0926
Cultural ES	0.16	0.04	0.05	**0.002***	**0.003**
By individual ES					
Smallholder agriculture	0.20	0.12	0.19	**0.049***	0.888
Surface drinking water	0.09	0.17	0.17	**0.0498***	**0.0498***
Fish	0.11	0.14	0.06	0.500	0.118
Timber	0.12	0.04	0.08	**0.010***	0.18938
Gaharu NTFPs[b]	0.08	0.11	0.02	0.333	NA[a]

[a]NA indicates that the ES was chosen by a fewer than two subgroups in a zone so no stats were performed

[b]*Gaharu* is a dark resinous wood collected for use in incense and perfume

stable in zone 1 that showed intensifying decreases across zone 2 and zone 3, including the ES of timber, fish, smallholder agriculture, and surface drinking water.

Among these ES trends, variation in perceived trends was relatively high among subgroups (Fig. 4): some ES were simultaneously perceived to be increasing (outward bars in Fig. 4), decreasing (inward bars), or stable (size of circles). This likely reflects the subgroups' individual experiences within the landscape as well as biophysical heterogeneity in the ES (e.g. surface drinking water arises from many springs across the landscape). This variation was highest in zone 3 (and to a lesser extent zone 2) and lowest in zone 1 where subgroups tended to agree and predominantly perceive ES as either increasing, decreasing, or stable (Fig. 4).

Desired ecosystem services transitions

In zone 1, participants desired more ES of what is already being used and valued (e.g. the desire bundle roughly mimicked the ES use and ES values bundle; Fig. 3), whereas participants in zones 2 and 3 desired a more diverse bundle of ES, including increased NTFPs provisioning ES. All zones desired more cultural ES. Desire for cultural ES was highest in zone 1 (16%), and these differences were significantly higher based on GLM comparison than in zone 2 ($p = 0.002$) and zone 3 ($p = 0.003$; Table 1), primarily driven by desire for more ecotourism, traditional *adat* lands (i.e. traditional spiritual/cultural places), and places suitable to transfer intergenerational learning and moral values to youth (Table 1). Desire for NTFPs provisioning ES was significantly less in zone 3 (0.12) than in zone 1 (0.28; $p < 0.001$) and zone 2 (0.23; $p = 0.013$; Table 1). In contrast, desire for commodity-based provisioning ES was highest in zone 3 (54%), being significantly higher than those in zone 1 (33%; p<0.001) and zone 2 (41%; p=0.026; Table 1). Zone 2 participants expressed high desire for rubber (24%), significantly more than zone 3 (14%; $p = 0.025$; Table 1). Interestingly, zone

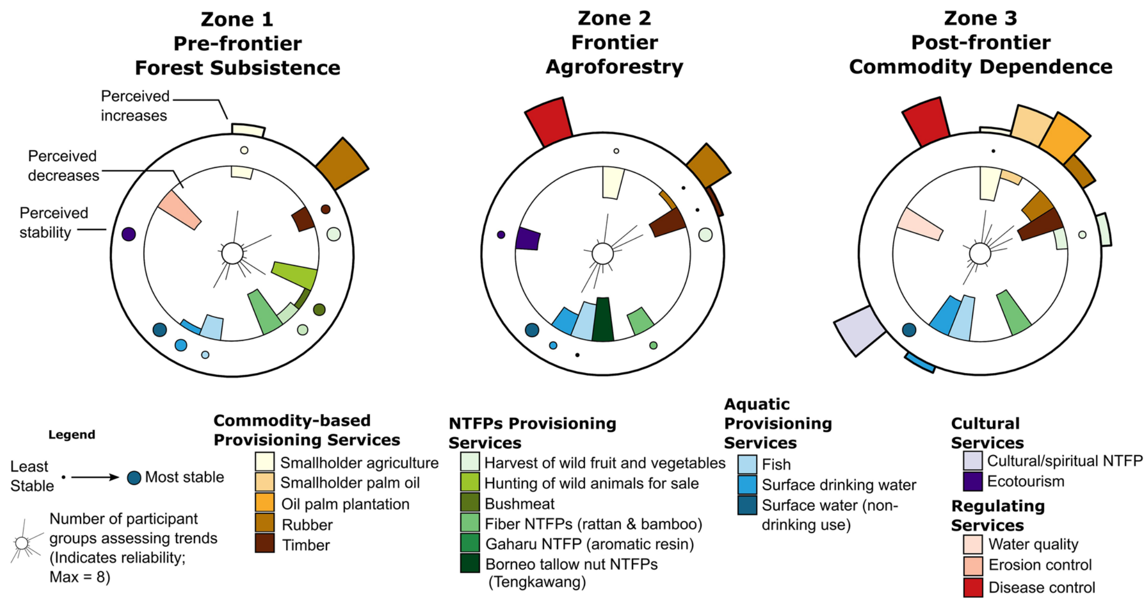

Fig. 4 Perceived trends by local communities in ecosystem services (ES) across the three stages of agricultural intensity. Outward bars indicate the proportion of workshop subgroups (from a max of 8 per zone) perceiving an increase from 1995 to 2015, and inward bars a decrease. Large circles within the ring indicate perceived stability. Inner spokes indicate the number of subgroups that assessed trends for each ES, and as such, longer spokes indicate greater reliability in the estimate. These results are given in numerical form in SI Table 4

1 did not express desire for rubber or any other commodity-based ES associated with agriculture.

Discussion

Our results are aligned with previous studies showing that commodity-based provisioning ES are trading off with multiple other ES: first timber, then rubber, and finally palm oil are trading off with nearly all other ES categories (Rasmussen et al. 2018, Sharma et al. 2019). Our analysis provides nuanced insight into the trade-offs at each stage of landscape transition towards agricultural intensification. First, this trade-off is evidenced by the rising dominance of commodity-based provisioning ES uses from 8% in zone 1, to 10% in zone 2, and up to 47% in the most intensified zone 3. Second, perceived trends suggest that commodity-based provisioning ES are increasing from 33% in zone 1, to 52.1% in zone 2, and up to 60.4% in zone 3 amidst concomitant declines in NTFPs provisioning ES, aquatic ES, and cultural ES. Finally, insight into the social implications of these trade-offs brought by agricultural intensification is elucidated by the ES-UVD approach, which reveals a growing mismatch between ES-UVD particularly with respect to what ES are used versus what ES are most valued and desired. Although agricultural commodity production is also desired by local people in zone 2 and zone 3, it is desired alongside other ES, suggesting an overall desire for the best of both worlds: while local people may desire some benefits of intensification they are not willing to forgo other ES that are desired and valued as being important for their well-being. Thus, multifunctional landscapes combining some agricultural intensification alongside other, more traditional land uses may be optimal from the perspective of aligning with peoples' values and desires and decreasing the emergence of these trade-offs. Below we draw on insights from these three approaches (trends, driver effect, and UVD-ES) to elaborate a more holistic perspective of the trade-offs that result from agricultural intensification.

Our approach of using (workshop based) participatory mapping and evaluation of ES (Brown and Fagerholm 2015) is deemed adequate as a first step to capture a good level of understanding regarding the perceptions of local communities with regard to their collective uses, expressed values, and emerging desires for ES and how these might change along a landscape transition.

Trade-offs of agricultural intensification

The Indonesian government vigorously promotes palm oil production, and many regions to the south and north of this study site as well as elsewhere in Indonesia have been almost entirely converted into palm oil production (Austin et al. 2017). As agricultural intensification is still underway in Kapuas Hulu, some highly valued and desired ES uses persist while others are steadily declining or already lost. Identifying the diverse ES used and valued by local people and how ES are impacted by intensification could inform opportunities on which ES are likely to be lost and which can preserved during agricultural intensification.

Some ES uses remain stable even under moderate intensification. For example, water for non-drinking use remained 100% stable, which was expected because this ES is stable whether polluted or not. Meanwhile, wild fruits and vegetables remained 100% stable in zone 1 and zone 2 and 50% stable in zone 3, which was surprising, and occurred possibly because wild fruits and vegetables can be opportunistically protected and cultivated in moderately developed landscapes (Leonald and Rowland 2016, Gergel et al. 2020). Stability theory posits that ES that rely on diverse species may be more likely to persist during landscape change (Renard and Tilman 2019). Furthermore, response diversity theory suggests that stability will be highest in instances where the assemblage of different species has disparate responses to disturbance and land cover change (Biggs et al. 2012, Gergel et al. 2020). Stability theories rarely account for ES, let alone social factors such as desire for ES. In Kapuas Hulu, wild fruits and vegetables were perceived by local people to have remained relatively stable possibly because they are partially cultivated, whereas all other NTFPs, such as bushmeat (also highly diverse species mix), rattan, and *Gaharu*, associated with natural forests use declined. The decline in these NTFP ES may reflect three of three potential explanations: (1) the quality and abundance of ecosystems that provide these ES diminished (Mathys et al. 2023); (2) local people have less time to harvest them (as NTFP become harder to access and people are occupied in their market-based livelihoods, e.g. Gergel et al. 2020); or (3) people no longer need or desire them (Spangenberg et al. 2014). The ES-UVD approach helps ruling out the third, by showing that although use of NTFPs was very low in zone 3, local people continued to value and desire NTFPs, perhaps, because they perceive them as option values to fall back on in case their farming livelihoods are not successful. The ability of ES uses to persist during agricultural intensification will depend on complex interactions between the biophysical landscape (see Dislich et al. 2017) and local people's values and their capabilities to maintain these ES (Fischer and Eastwood 2016). The social-ecological ES-UVD approach used here offers nuanced insight to understand the types of ES most valued, those being lost due to agricultural intensification, and which ES can be actionably preserved during landscape change. Many other desired ES may continue to decline unless intentional efforts are made to safeguard them, such as the case with regulating ES.

Spatial-temporal lags obscure trade-offs with regulating ecosystem services

Regulating ES provide critical feedbacks that maintain biodiversity and all other ES, yet regulating ES are rarely assessed in studies on agricultural intensification (Rasmussen et al. 2018). A concerning observation in this landscape is that as fish and drinking water (two of the most important ES to local food security in this study) have become destabilized, the losses in these two ES were not matched by a desire for increased regulating ES to prevent their declines. Based on empirical research from this region and elsewhere, we assume that the decline in drinking water and fish is at least partially attributable to a declining aquatic environmental quality brought about by agricultural intensification (Power 2010, Comte et al. 2012, Yuliani et al. 2018, Kropp et al. 2019). The lesser desire expressed for regulating ES despite the apparent need for it likely reflects the complex spatial-temporal nature of regulating ES which make them hard to cognitively prioritize (Sutherland et al. 2018), a dissonance exacerbated with increasing spatial and temporal lags (Pascual et al. 2017, Olander et al. 2018). Only in zone 3 did some participants express desire for water quality, yet in this zone fish and drinking water had already decreased beyond a usable condition (i.e. there was zero ES use, yet ES desires for these ES remained high). In contrast, several studies in other (typically affluent regions) have detected a proactive and consistent appreciation for regulating ES (e.g. Martín-López et al. 2012, Bernués et al. 2019), especially when framed in terms relevant to their socio-economic well-being. We acknowledge that our stakeholder sample (unfortunately biased towards male participants) might affect the lower proportion of regulating and cultural ES perceived as important and being impacted during the landscape transition.

Institutions and desired ecosystem services transitions

Desire for particular ES may interact with exogenous land-use drivers (Meyfroidt et al. 2018, 2022), allowing ES desires to emerge rapidly in step with arising economic opportunities (Lambin et al. 2001). In Kapuas Hulu and in other regions undergoing a landscape transition, ES desires for provisioning ES spill over from within or adjacent landscapes. This pattern can be magnified by broader-scale dynamics such as financing and state agricultural policies that promote intensification (Meyfroidt et al. 2018, Verburg et al. 2019, Yuliani et al. 2020). In this study, agricultural commodity production is vigorously supported by the Indonesian state and large corporations, especially through subsidies and financing schemes (Pramudya et al. 2017), a pattern seen in production landscapes worldwide (Nyström et al. 2019). Situated within this context, this study offers insight to how top-down policy drivers foster trade-off dynamics that interact with bottom-up desires among local people for new development opportunities (Lambin et al. 2001) and demonstrates what the ES concept can bring to these complex landscape contexts. Local people may have an impossible set of ES desires and this situation is made vulnerable to the addition of external system components and incentives (new markets, oil palm financing). If left unchecked by local institutions, such offerings of 'a better life' may increase economic revenues, but it can also decouple people's livelihoods from what they value and desire, thereby trapping them with ever narrowing dietary diversity, lost livelihood opportunities, food insecurity, and loss of regulating and cultural ES (Ickowitz et al. 2019).

Meanwhile, ES values were relatively persistent (no differences across the experimental gradient) in comparison to ES uses and ES desires suggesting that ES values may be a potent latent opportunity, which if surveyed and given agency through judicious landscape planning, could guide the right amount of agricultural intensification to occur while still preserving at least some locally valued ES. ES values reflect local worldviews, beliefs, and norms (Hejnowicz and Rudd 2017, Pascual et al. 2017, 2021) and can be understood as leverage points for sustainable transitions (Chan et al. 2020) and yet are slow to change because they evolve over long timeframes embedded within local socio-cultural and environmental contexts (Walker et al. 2012). Thus, ES values can influence the choices of individual households and communities and can potentially dampen landscape change if given agency through local institutions. In contrast, rapid emergence of social conventions and ES desires can spread through globalization and may outpace the ability of communities to fully grasp such compromises (Fischer 2018). Feedbacks that help preserve local ES, such as planning efforts that systematically link local participation into adaptive planning (e.g. Armitage et al. 2009, Bodin et al. 2019), can potentially be strengthened by placing power back in the hands of the communities (Zimmerer 2013, Fischer and Eastwood 2016, Friant et al. 2019). Below, we discuss the importance of participatory processes and how such an approach could potentially be scaled up to interact with institutions at the global scale, such as the setting of global policy agendas.

Participatory approaches to mitigate trade-offs of agricultural intensification

This study exemplifies the need to study trade-offs and synergies between agricultural intensification and other land-use objectives within the context of dynamic local landscapes and how local people rely on multiple ES. Considering that local communities desire both increased commodity production and maintenance of cultural, NTFPs, and aquatic ES, which we refer to as 'the best of both worlds hypothesis', brings forth a question to guide research of agriculture-conservation trade-offs: what level of commodity production can be obtained, and how, while minimizing trade-offs with other locally valued ES now and in the future?

Participatory approaches alongside landscape spatial analyses that include multiple ES (e.g. Qiu et al. 2018, Grass et al. 2019) can help answer this question. Studies that only address a too narrow set of ES or that rely on biophysical proxies to assess ES greatly abstract from the rich social-ecological interdependencies between local people and their surrounding landscapes (Lee and Lautenback 2016, Wei et al. 2017, Aryal et al. 2022). Participatory approaches ask local people what matters to them, and can thus gather information on multiple ES simultaneously as well as information about the spatial distribution of those ES in relation to their local landscapes (e.g. Brown and Fagerholm 2015, Brown et al. 2020, Mathys et al. 2023).

Reconnecting global land system discussions (e.g. land sharing and land sparing) with local landscapes requires broadening the focus from food production toward the incorporation of multiple ES (Bennett 2017, Grass et al. 2019), the plurality of values held for ES (Pascual et al. 2017, Pascual et al. 2021, Zafra-Calvo et al. 2020), and their complex dynamics in changing landscapes. In this study, we contribute to calls asking for a multidimensional assessment of trade-offs (Reyers and Sigel 2020) and contribute to an emerging understanding of how ES vary across alternative landscape contexts. Policies that focus on commodity-based provisioning ES (the only stable and increasing ES globally; Díaz et al. 2018) without considering the needs and desires of local people obscure real declines in a bundle of other ES that may be highly desired and valued, such as for dietary diversity (Ickowitz et al. 2019), non-material contributions from nature (Ellis et al. 2019, Díaz et al. 2019), and insurance during times of crisis (Tscharntke et al. 2011, Koffi et al. 2016). Thus, we argue that policy arenas such as those linked to landscape planning must incorporate participatory approaches. The ES-UVD approach introduced here can both help monitor social-ecological outcomes of suggested policies and to proactively identify future ES synergies and trade-offs and how they align with local needs and desires.

Limitations and research challenges for valuing regulating ecosystem services

This study has several limitations. The experimental design was used in combination with survey of ES trends to gain insight into how ES respond to agricultural intensification. However, each of these zones has a unique place-based landscape history and changes in ES-UVD are likely driven by agricultural intensification alongside other social processes and life circumstances that participants may find themselves in. Tracking the same participants and surveying their ES-UVD over time would have potentially yielded a more valid and nuanced understanding of how various social processes, behaviours, and power dynamics shape ES-UVD in real landscapes. Thus, for future studies considering to use a similar approach, it will be important that they use rigorous site selection to reduce confounding variables (Leonard and Rowland 2016) and survey of participants perceived trends, so that results can be triangulated and interpreted cautiously.

Another limitation stems from the non-representativeness of the (workshop based) participatory process, which may lead to underestimating the trade-offs of agricultural intensification on other ES and over-emphasize the local importance of commodities. Sociocultural obligations encountered while in the fieldwork component of this research resulted in men alone participating in the workshops. Female gender roles in this region include as caretakers of the water (Yuliani et al. 2018). We would have greatly preferred to include their values and desires, which may differ substantially from the reported ones by male participants. Thus, the uneven gender participation in our workshops, which has occurred in participatory work elsewhere in South East Asia (e.g. Zaehringer et al. 2018), may partly explain why regulating ES and non-material (i.e. cultural) ES were somewhat less valued and desired in comparison to commodity-based provisioning ES, which often men value more (Muhamad et al. 2014, Yang et al. 2018, García-Llorente et al. 2020).

Finally, we acknowledge that the questions we used to elicit ES-UVD may have caused local people to prioritize provisioning ES, which have direct material instrumental values over regulating ES and cultural ES. The deliberative evaluation approach we used is argued to better bridge different types of values into ES assessments (Kenter et al. 2011, Lliso et al. 2020). However, ethnographic studies in this region have elucidated a much higher appreciation for regulating ES in the landscape (Yuliani et al. 2018, Yuliani et al. 2020). Future studies can try to address this limitation by seeking better gender representation, eliciting expert opinion for regulating ES, using ethnographic work (Paudyal et al. 2015, Dawson et al. 2017), or designing questions that do not require local people to prioritize between cultural, regulating, and provisioning categories.

Conclusion

Landscapes are dynamic social-ecological systems influenced by drivers across multiple scales, including national and regional institutions, and local variables, such as the underlying values and desires of local people (Pascual et al. 2022). Through our workshops in six rural villages, we found that local people value and desire multiple provisioning, cultural, and regulating ES in different ways depending on their landscape context. When comparing the ES values bundles to ES use bundles, it is apparent that in zone 1 (pre-frontier forest subsistence) local people's ES values match closely what they have and use. In zone 2 (frontier agroforestry), the similarity is still strong but reduced as many ES values, including all NTFPs and fish are no longer used. In zone 3 (post-frontier commodity dependence), people's ES values are decoupled from what they have and use: people express value for regulating ES, cultural ES, and NTFPs, yet are limited to ES uses associated with commodities and agriculture. Of particular concerns, fish and drinking water remain highly valued in zone 3 but have declined steeply, and yet their decline is not matched by an increased desire for regulating ES, suggesting a cognitive disconnect among the locals who participated in this study and the regulating ES that sustain the fish and drinking water they value.

Overall, our multidimensional assessment reveals that commodity-based provisioning ES have driven trade-offs in ES traditionally used by local people. By surveying ES trends, sampling across an agricultural intensity gradient, and doing ES-UVD analysis, we have begun to disentangle a suite of complex interactions governing the dynamics of ES important to local people. This research thus crystallizes the necessity of local participation and experimenting with novel and multidimensional approaches to understand ES trade-offs in changing landscapes.

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Data Availability Contact the corresponding author concerning data availability.

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