



1 Land-use change impacts on multidimensional well-being: insights from tropical forest
2 frontiers in Madagascar, Myanmar and Laos

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36

37 **Abstract**

38 Tropical forest frontiers are undergoing rapid land use change due to expanding global
39 demands for agricultural commodities and conservation efforts. These changes profoundly
40 affect the well-being of local populations, yet the pathways linking land use, ecosystem
41 services, and well-being remain underexplored. This study examines these links across three
42 forest frontier landscapes in Madagascar, Laos, and Myanmar. Using Nussbaum's capabilities
43 framework, we conducted 14 workshops and 154 household interviews to assess how land
44 use change influences diverse well-being components via ecosystem services.

45 We identify three key findings. First, land use change impacts well-being both directly and
46 indirectly via shifts in ecosystem service supply. Forests provide the broadest range of services
47 that support essential components of well-being, including nutrition, income, housing, and
48 spiritual values. Second, we find three generic mechanisms through which well-being is
49 affected, often involving trade-offs within or between well-being components. For example,
50 gains in income can coincide with losses in cultural identity or environmental quality. Third, we
51 identify three substitution processes that can mitigate ecosystem service loss' impact on well-
52 being. However, these processes often fail to maintain relational and collective components of
53 well-being and it might be that ecosystem services are often not substituted to the same level.

54 Our findings highlight the need for a multidimensional, context-sensitive understanding of well-
55 being in land system science. Development and conservation interventions should move
56 beyond narrow economic framings and support multifunctional landscapes that sustain both
57 ecosystem services and the full spectrum of human well-being in tropical forest frontiers.

58 **Key words:** land use change, ecosystem services, human well-being, trade-offs, telecoupling,
59 deforestation, conservation, capabilities approach

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63 1. Introduction

64 Landscapes across the tropics are undergoing rapid transformations through crop booms and
 65 other forms of agricultural expansion and commercialization (e.g. Carmenta et al., 2023;
 66 Junquera and Grêt-Regamey, 2019) along with increased efforts into globally driven protected
 67 areas expansion (Edwards et al., 2019; Gardner et al., 2018). Tropical deforestation, largely
 68 driven by global consumer demands for a variety of agricultural products, remains a major
 69 source of concern for sustainable development (Alfonso et al., 2017; Baumann et al., 2022;
 70 DeFries et al., 2010; van Vliet et al., 2012). Such changes in forest frontiers are increasingly
 71 due to telecoupled land use change processes, where local, social-ecological systems are
 72 becoming more influenced by distant systems, through flows of products, finance, information
 73 and people (Boillat et al., 2018; Friis et al., 2016; Liu et al., 2013). Dynamic land use changes
 74 in forest frontiers often lead land systems to shift to new regimes, characterized by a
 75 dominance of commercial over subsistence agriculture, that have very different economic and
 76 ecological characteristics; these land system regime shifts are associated with trade-offs
 77 between social-ecological outcomes (Baumann et al., 2022; Müller et al., 2014; Nanhthavong
 78 et al., 2021). While land use change drivers are increasingly stemming from outside the local
 79 context, those affected the most by the short- and long-term consequences of those changes
 80 are people inhabiting these landscapes (Carmenta et al., 2023).

81 Ecosystem services (the benefits people obtain from ecosystems, classified as provisioning,
 82 regulation and maintenance, and cultural services (Haines-Young, 2023)), or more recently
 83 Nature's Contributions to People (Pascual et al., 2017), are the most widely used concepts to
 84 demonstrate how people's well-being depends on nature, healthy ecosystems or land and sea
 85 in the wider sense. Since the Millenium Ecosystem Assessment (Millenium Ecosystem
 86 Assessment, 2005), the first has become widely applied (Bennett et al., 2015), including as a
 87 valuable framework for assessing the links and feedbacks between drivers of change,
 88 biodiversity, ecosystem processes, ecosystem services, human well-being and human
 89 responses (Carpenter et al., 2009; Grêt-Regamey et al., 2017). Ecosystem services are
 90 closely linked to human well-being and contribute to people's capabilities (Costanza et al.,
 91 2017; McMichael et al., 2005; Polishchuk and Rauschmayer, 2012). Links between ecosystem
 92 services and human well-being exist in both directions, are multidimensional, complex and
 93 may change over time (Costanza et al., 2017; Horcea-Milcu et al., 2016; McMichael et al.,
 94 2005; Schleicher et al., 2018). The decline in tropical forest cover leads to a reduction in the
 95 availability of critical ecosystems services (Alfonso et al., 2017; Brandon, 2014), diverse and
 96 profound impacts on human well-being (Alfonso et al. 2017) and changes in the relationships
 97 people have with these landscapes through emotions and experiences (Carmenta et al., 2023;
 98 Schneider et al., 2020).

99 In contrast, a phenomenon that has been termed "the environmentalist's paradox", refers to
 100 the situation where human well-being, especially in material terms, increases as ecosystem
 101 services degrade (Raudsepp-Hearne et al., 2010). One reason for this paradox is the positive
 102 impact an increase in food production has on human well-being, with increased food
 103 production often being achieved through the expansion of agricultural land, at the expense of
 104 natural habitats such as forest (Ketema et al., 2021; Raudsepp-Hearne et al., 2010).
 105 Nevertheless, through such a land use change, other ecosystem services decline, while the
 106 implications for broader human well-being are not sufficiently understood. This is the case
 107 because both ecosystem services and human well-being are multidimensional and how they



108 affect each other is not only context specific but dynamic in space and time (Agarwala et al.,
 109 2014; Beauchamp et al., 2018; Ketema et al., 2021; Liu and Wu, 2021; Raudsepp-Hearne et
 110 al., 2010).

111 The concept of human well-being has greatly evolved over the past decades and is now
 112 understood to be person- and culture-specific, and thus subjective (King et al., 2014). The
 113 capabilities approach, developed by Amartya Sen in the late 1970s (Sen, 1979), was influential
 114 in pioneering a people-centered understanding of well-being (King et al., 2014). It came about
 115 as a response to the predominant, primarily monetary, methods of assessing human welfare,
 116 centering instead on the freedoms that individuals possess to shape their lives in ways they
 117 find meaningful (Sen, 1979). This marked a significant departure from the contemporary
 118 paradigms of evaluating human welfare and development (Sen, 1979). Martha Nussbaum
 119 further developed the capabilities approach, advocating for a universal set of ten central
 120 capabilities or "rights" that any government should endorse and safeguard: life; bodily health;
 121 bodily integrity; senses, imagination, and thought; emotions; practical reason; affiliation; other
 122 species; play; and control over one's environment (Nussbaum, 1992; Nussbaum and Sen,
 123 1993) (refer to Table 4 and Supplementary Material S1 for a detailed definition). This list serves
 124 as a valuable theoretical and practical tool for evaluating individual or group well-being (Alkire,
 125 2002). Acknowledging the context-specific nature of well-being, Nussbaum maintains that her
 126 list must be further refined, allowing individual countries and their populations to specify the
 127 central capabilities differently (Nussbaum, 2007). The capabilities approach has, for example,
 128 been applied to conceptualize sustainable development (Lessmann and Rauschmayer, 2013;
 129 Voget-Kleschin, 2013) and investigate the role of ecosystem services on human well-being
 130 (Polishchuk and Rauschmayer, 2012; Sangha et al., 2015).

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 132 Yet, there are only a few studies that explore the links between different types of land use,
 133 ecosystem services and multiple well-being components (e.g. Dong et al., 2021; Fagerholm et
 134 al., 2016; Schneider et al., 2020; Wang et al., 2017; Wolff et al., 2018; Yee et al., 2021);
 135 understanding which part of human well-being is dependent on which land uses and
 136 ecosystem services remains a challenge. On the one hand, ecosystem service supply is
 137 usually modelled based on spatially explicit land cover or land use information as a proxy (e.g.
 138 Arowolo et al., 2018; Llopis et al., 2021; Muche et al., 2023; Song and Deng, 2017). On the
 139 other hand, since the Millenium Ecosystem Assessment (Millenium Ecosystem Assessment,
 140 2005), there has been a body of literature evolving in the investigation of how ecosystem
 141 services affect human well-being (Agarwala et al., 2014; Breslow et al., 2016; Polishchuk and
 142 Rauschmayer, 2012). While ecosystem service supply assessments are done mainly by
 143 natural scientists with biophysical modelling expertise, well-being studies are often rooted in a
 144 more integrative social science approach. Therefore, the full exploration of the impact chain
 145 from land use change to human well-being via ecosystem service supply is rare.

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 147 However, without a better understanding of these links, how changing environmental
 148 conditions and management interventions affect the different human well-being components,
 149 and what this means in return for any attempts towards more sustainable land use and
 150 management remains unclear (Breslow et al., 2016). More in-depth assessments are therefore
 151 required to understand how the rapidly advancing transformation of landscapes in tropical
 152 forest frontiers affect peoples' well-being. Additionally, measuring the supply of ecosystem
 153 services and how they contribute towards human well-being is one of the key elements that
 154 would enable ecosystem service research to effectively inform decisions (Mandle et al., 2021).



155 This study combines the application of the capabilities approach as a heuristic tool to assess
156 multidimensional well-being together with the ecosystem services framework to examine: 1)
157 to what extent human well-being is dependent on specific land use types and the provision of
158 ecosystem services linked to those; and 2) how land use changes have affected human well-
159 being via changes in ecosystem services (and beyond), and 3) the mechanisms by which
160 declines in one or more ecosystem services can be substituted in forest frontier landscapes in
161 Madagascar, Laos and Myanmar.

162 **3. Methodological approach**

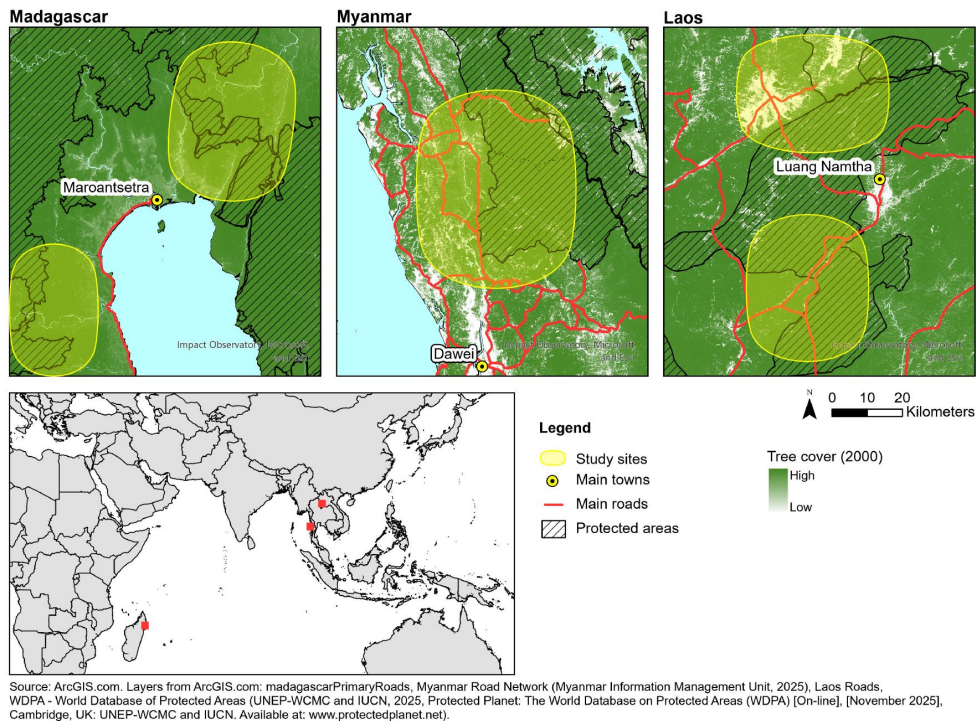
163 Our methodological approach is based on a comparison of three different case studies in forest
164 frontier landscapes: north-eastern Madagascar, north-western Laos and southern Myanmar
165 (Figure 1). In each case study site, we drew upon spatially explicit participatory land use
166 mapping to identify the most prevalent land use change trends. To assess what well-being
167 means in each context, we conducted workshops and structured interviews with households
168 in the case study areas. The data thus obtained also allowed us to identify relevant ecosystem
169 services and then to establish the links between land use change, ecosystem services, and
170 well-being. Some results from the workshops and interviews have already been published for
171 Madagascar (Llopis et al., 2020, 2022) and Myanmar (Schneider et al., 2020).

172 173 **3.1 Study areas**

174 While embedded in different socio-cultural and political systems, our three case study sites
175 (Figure 1) have many commonalities. They are inhabited by smallholder farmers, who have
176 traditionally produced rice for subsistence through shifting cultivation. Over the last decades,
177 these farmers have transformed their livelihoods and most of them are now also producing
178 crops for domestic or international markets. In terms of land use, these are typical
179 multifunctional landscapes (e.g. Martin et al., 2024) with a mosaic of different land uses
180 including smallholder mixed perennial production systems (from here on referred to as mixed
181 perennial systems), paddy rice to various extents, shifting cultivation, rubber plantations, oil
182 palm plantations and various types of forest under different management regimes.



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185 *Figure 1. Overview of case study sites in Madagascar, Myanmar, and Laos.*

186 **3.2. Land use change assessment**

187 The land use categorization was developed in close collaboration between researchers with
188 expertise in the land systems present in the three countries and in a nested way that allowed
189 for aggregation and comparison (Table 1). Land use changes were assessed through
190 participatory mapping, supported by very-high resolution satellite imagery. The detailed
191 methodology is explained in (Zaehringer et al., 2018). For the present study, we consider the
192 three most prevalent (i.e., widespread, by area affected) land use changes in each site
193 respectively and establish links to ecosystem services and well-being components using the
194 data from the workshops and interviews.

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201 *Table 1. Land use category per case study site.*

Land use category	in Madagascar	in Myanmar	in Laos
Rubber plantation	none	rubber	rubber
Smallholder mixed perennial production systems	clove, vanilla, coffee	betelnut, cashew, cocoa	none
Oil palm plantation	none	oil palm	none
Other cash crop plantation	none	none	sugarcane, cucumber, watermelon, pumpkin, banana, cardamom
Paddy	paddy rice	paddy rice	paddy rice
Forest (primary & secondary)	primary & secondary forest	secondary forest/fallows	primary & secondary forest
Shifting cultivation	(young) fallows & hill rice fields	none	(young) fallows & hill rice fields
Pasture	pasture	pasture	none
Water bodies	river	river	river, fishponds
Village	home gardens, village surroundings	home gardens, village surroundings	home gardens, village surroundings
Land use category	in Madagascar	in Myanmar	in Laos

202 **3.3 Workshop discussions**

203 In total, we conducted 14 workshops, four in Madagascar, four in Myanmar, and six in Laos
204 (Table 2). Workshops included between four and 19 participants and separate groups were
205 organized for women and men to foster open dialogue (Morgan and Hoffman, 2018; van
206 Eeuwijk and Angehrn, 2017). In all three countries, the research teams ensured informed
207 consent for participation in workshops as well as for the interviews. Prior to the workshops and
208 interviews, we introduced ourselves, explained the purpose of the research and its context
209 within a broader academic project, and emphasized the voluntary nature of participation.

210



211 *Table 2. Overview of workshops and interviews conducted in the three study areas*

Madagascar			Myanmar			Laos		
Villages	Workshops	Interviews	Villages	Workshops	Interviews	Villages	Workshops	Interviews
Village MA1	2	20	Village MY1	2	16	Village LA1	2	15
Village MA2	2	24	Village MY2	2	35	Village LA2	2	15
						Village LA3	2	14
						Village LA4	0	15
TOTAL	4	44		4	51		6	59

212 Workshops consisted of seven distinct steps as set out in Table 3. Additional workshop details
 213 are outlined in Supplementary Material S2.

214 *Table 3. Workshop discussion structure.*

Step	Discussion topic	Data gathered
1.	How do you define a “good life” in your village?	Conceptualizing well-being components
2.	Which well-being components are most important for you?	Prioritization of well-being components
3.	Why is [well-being component] important for sustaining a “good life”?	Exploration of the value a component adds to their well-being
4.	What do you need so that [well-being component] is satisfied?	Understanding what is needed for well-being components
5.	How has the ability to fulfill [well-being component] changed compared to 20 years ago?	Understanding of how satisfaction with well-being has changed
6.	What are the reasons for changes in how satisfied you are with [well-being component]?	Understanding of reasons for changes in satisfaction with well-being
7.	Which three well-being components are the most difficult to satisfy and which are the most satisfied at the present time?	Ranking of perceptions regarding which well-being components are the most difficult and easiest to satisfy

215 **3.4 Household-level interviews**

216 In total, our study draws on 154 household interviews from eight villages (Table 2) that were
 217 conducted between 2017 and 2018. Interviews were conducted in the local language in pairs



218 of foreign researchers and nationals from the respective study countries, ensuring both
 219 linguistic and cultural fluency during data collection. Consent from respondents was asked in
 220 the same way as for the workshops. The same components investigated in the workshops
 221 were further explored at an individual level using a structured interview guide. We employed
 222 follow-up questions to delve deeper into components pertinent to this study. From the
 223 interviews, we also collected data on the socio-economic characteristics of each household
 224 and perceptions on the links between land use change and ecosystem services. The
 225 interviews concluded with respondents specifying the three well-being components that they
 226 found most satisfying and the three that were deemed most challenging to attain at the present
 227 time.

228 ***3.5 Data analysis: Linking results on well-being to ecosystem services and land use***

229 To prepare for data analysis, the flipchart notes from the workshop were translated into English
 230 (Laos and Myanmar) or French (Madagascar). In case some data were missing or unclear,
 231 the flipcharts were complemented with notes taken during the workshop, and/or information
 232 from the audio recordings. For the interviews, the full audio recordings were transcribed and
 233 translated into English or French.

234 We then analyzed the data using qualitative content analysis approach with the aim to elicit
 235 any reported links between well-being components, ecosystem services affecting those, and
 236 land uses supporting ecosystem services. To link ecosystem services to land use, we
 237 considered those land uses identified as the most prevalent ones in each case study site
 238 (Table 1) and considered any direct connection made between land use and ecosystem
 239 service by the workshop participants or interview respondents.

240 Well-being components were framed according to the capabilities approach, resulting in 19
 241 distinct well-being components (Table 4). The central capability of “Life” was not
 242 operationalised with separate well-being components as it was considered to be covered
 243 sufficiently by other capabilities like bodily health and bodily integrity. We used the Common
 244 International Classification of Ecosystem Services (CICES) to categorize ecosystem services
 245 from the interviewees and workshop participants’ responses (European Environment Agency,
 246 2013; Haines-Young, 2023). The ecosystem services mentioned included 25 provisioning
 247 ecosystem services, 15 regulation and maintenance, and 23 cultural ones.

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255 *Table 4. Nussbaum's central capabilities and contextualized well-being components (see step 1 of the workshops)*
 256 *for our case study sites.*

Central Capability (Nussbaum)	Operationalized well-being components	Countries
Bodily Health	Health	Laos, Myanmar, Madagascar
	Nutrition	Laos, Myanmar, Madagascar
	Water	Laos, Myanmar, Madagascar
	Housing	Laos, Myanmar, Madagascar
Bodily Integrity	Security	Myanmar, Madagascar
	Transportation	Laos, Myanmar, Madagascar
Senses, Imagination, and Thought	Education/Knowledge	Myanmar, Madagascar
	Religion/Traditions	Laos, Myanmar, Madagascar
Emotions	To express your emotion without fear	Laos
	To have a household/family	Madagascar, Myanmar
Practical Reason	To be able to plan your own life	Laos, Madagascar
Affiliation	Social relations	Myanmar, Madagascar
	Bequest to descendants	Laos, Madagascar
Other species	Environment	Laos, Myanmar, Madagascar
Play	Recreation	Laos, Myanmar, Madagascar
Control over one's environment	Agriculture	Laos, Myanmar, Madagascar
	Income	Laos, Myanmar, Madagascar
	Work & Job opportunities	Laos, Myanmar, Madagascar
	Having land	Laos, Myanmar, Madagascar

257 For each country, an excel table was established containing a sheet for: (a) links between
 258 ecosystem services and well-being components, including the respective land use supporting
 259 the ecosystem services; (b) direct effects of land use changes on well-being components; (c)
 260 interactions among well-being components; and (d) the substitution mechanisms that enabled
 261 ecosystem services and human well-being to be supported when land use changed. We then
 262 filled the tables with all corresponding mentions that could be detected in the interviews and
 263 workshop transcripts. For the changes in well-being components affecting other well-being
 264 components (c), only immediate effects that were mentioned in the data were considered. For
 265 example, if it was mentioned that an increase in income increased the ability to send children



266 to school, only this link was included in the analysis and possible further effects such as a link
 267 between better education and better work and job opportunities were not included.

268 4. Results

269 In this section, we begin by characterizing the most important land use changes across the
 270 different case studies. We then describe the multidimensional and nuanced perceptions of
 271 human well-being. Next, we illustrate the links between land use and human well-being via
 272 ecosystem services, followed by an assessment of the impacts of land use change on human
 273 well-being through changes in ecosystem service provision. Subsequently, we outline generic
 274 mechanisms linking land use change, ecosystem services, and human well-being and lastly,
 275 we portray three substitution mechanisms through which alternative ecosystem services or
 276 livelihood strategies have continued to support well-being during land use change.

277 4.1 The most prevalent land use changes

278 Different land use changes were observed across the three countries; however, the most
 279 common changes were transitions from forest to a different land use (Table 5). The most
 280 prevalent resulting land uses after the conversion of forest were mixed perennial systems in
 281 Myanmar, rubber plantations in Laos and shifting cultivation in Madagascar. The transition
 282 from forest to rubber plantations was observed in both Laos and Myanmar. It is important to
 283 note that the quality of forest differed across countries: in Madagascar and in Laos, the term
 284 “forests” refers primarily to primary old-growth forests, whereas in Myanmar it refers to highly
 285 degraded or secondary forests. Mixed perennial systems and shifting cultivation are practiced
 286 by smallholders and represent forms of low-input agriculture. In contrast, rubber plantations—
 287 although also managed by smallholders—are high-input systems, while oil palm cultivation is
 288 dominated by large-scale private plantations and similarly characterized by high input
 289 requirements.

290
 291 *Table 5. Share of the three most prevalent land use changes in each study area in terms of total share of mapped*
 292 *area (%) between 1990 and 2017 (2000-2017 in Laos).*

Land use change	Laos	Madagascar	Myanmar
Forest to smallholder mixed perennial production systems		4.4	33.8
Forest to rubber plantations	22.9		18.6
Forest to oil palm plantation			12.6
Shifting cultivation to rubber plantations	12.4		
Shifting cultivation to smallholder mixed perennial production systems		2.5	

293 4.2 Human well-being across different forest frontiers

294 Perceptions of human well-being across the three countries were multidimensional and
 295 nuanced. Health emerged as both an intrinsic value and as a prerequisite for fulfilling work,
 296 planning for the future, caring for family, maintaining mobility and participating in social



relations. In Laos, maintaining good health entailed nutritious food, clean water, good sleep, adequate sanitation, and a pollution-free environment. In Myanmar, additional emphasis was placed on needing good quality and access to health care services and infrastructure. Nutrition was frequently identified as foundational because food was perceived to be a crucial factor for survival, good health and to have the strength to work. Social relations and relationships with family, encompassing solidarity, mutual respect and communal assistance, were widely recognized as integral to well-being. Similarly, income was consistently emphasized in all three case studies, closely interconnected with many other well-being components. For example, financial resources facilitated access to material goods and well-being components that depend on income, and they contributed to the social status of a person. Land played a pivotal role in supporting income given the reliance on agricultural livelihoods, with land ownership and associated tenure securement holding particular significance in Myanmar. A respondent exemplified this point by explaining that “in this village, if you do not own land, it is hard to work on anything else”. Housing extended beyond having any kind of shelter to include aspirations for beautiful and comfortable houses. For example, in Madagascar, ongoing enhancement of one’s house was deeply embedded in local tradition and considered essential to life satisfaction and progress in one’s life, as exemplified by a respondent stating that “it is the house that makes a person”. Education and job opportunities were perceived to be important across all countries; in Myanmar and Laos, a special focus was placed on having more job opportunities in villages so that people are not forced to migrate for education or jobs. In Laos, one respondent highlighted how “now, [they] have more choice[s] to earn income than [previously]. We have more cash crops and sometimes, when we need money, we just go work for the Chinese company at the watermelon plantation”. Gender equality was underscored in Myanmar, where women’s participation in decision-making, access to education, and equal employment opportunities were highlighted as important determinants of well-being.

4.3 Links between land use and human well-being via ecosystem services

The greatest number of links between land uses and well-being components mediated through specific ecosystem services were reported in Madagascar (103 links supported by seven land uses), followed by Myanmar (67 links supported by eight land uses) and Laos (45 links supported by seven land uses) (Figure 2). Nutrition and income emerged as the well-being components with the most links to different land uses in all three countries. In Madagascar, nutrition had the most links to shifting cultivation through the provision of rice, fruits, vegetables and wild edible plants. In contrast, nutrition had the most links to forests in Laos (via wild edible plants and animals), while in Myanmar, villages contributed mainly through livestock, fruits and vegetables. Many respondents cultivated their own vegetables in Myanmar: “I mostly eat vegetables from my own cultivation next to the stream [...]” Across all countries, nutrition consistently depended on paddy fields (primarily for rice), village areas (mainly for livestock and produce from home gardens) and forests (providing wild edible plants and animals, as well as honey in Madagascar). However, certain links were absent: nutrition was not associated with shifting cultivation in Myanmar, nor with waterbodies in Madagascar or other cash crop plantations in Laos. Regarding income, forests in Madagascar supplied the most diverse set of ecosystem services, supporting livelihoods through provisioning services (such as construction wood, wild plants for processing like leaves for making mats and baskets, and honey) and the cultural ecosystem service of tourism. In contrast, in Laos, rubber plantations played a central role in generating income, offering both cash crops and seeds/seedlings. In



343 Myanmar, mixed perennial systems contributed significantly to income through the production
344 of betel nut, cashew nut, cocoa and coffee. The well-being component housing had many links
345 to land uses in Madagascar and Myanmar, with forests providing construction wood in both
346 countries and additionally firewood (for cooking and boiling water) and wild plants for
347 processing in Madagascar. Shifting cultivation and mixed perennial systems in Madagascar,
348 as well as rubber plantations in Myanmar, were also central to obtaining firewood and
349 construction materials.

350 While most land uses contributed to income generation, primarily via provisioning ecosystem
351 services, and to a lesser extent via cultural services such as tourism, many benefits they
352 offered were intangible. Forests, in particular, played a critical role in supporting numerous
353 well-being components in all three countries. For instance, forests were valued for recreation
354 in Madagascar, and to a lesser extent in Myanmar, primarily for cultural ecosystem services,
355 such as a place for recreation, enjoyment and recreational activities. For example, in
356 Madagascar one respondent explained: "I go for walks in the forest; it is nice to see the
357 vegetation. The big trees (...) are beautiful". Instead, in Laos, villages and water bodies
358 facilitated recreational activities, enabling (vegetable) gardening and recreational fishing,
359 respectively. Forests in Laos were the most important land use supporting religion/traditions
360 through their provision of spiritual, cultural and traditional values, whereas in Myanmar, they
361 contributed to water via regulation and hydrological cycle maintenance and water purification.
362 Forests also provided bequest value across all study sites. Agriculture in all countries relied
363 on forests mainly for hydrological cycle regulation and maintenance, and in Laos, additionally
364 for temperature maintenance. Medicinal plants were sourced from forests in each country, as
365 well as from village areas in Myanmar and Madagascar, from shifting cultivation areas in Laos,
366 and from mixed perennial systems in Madagascar.

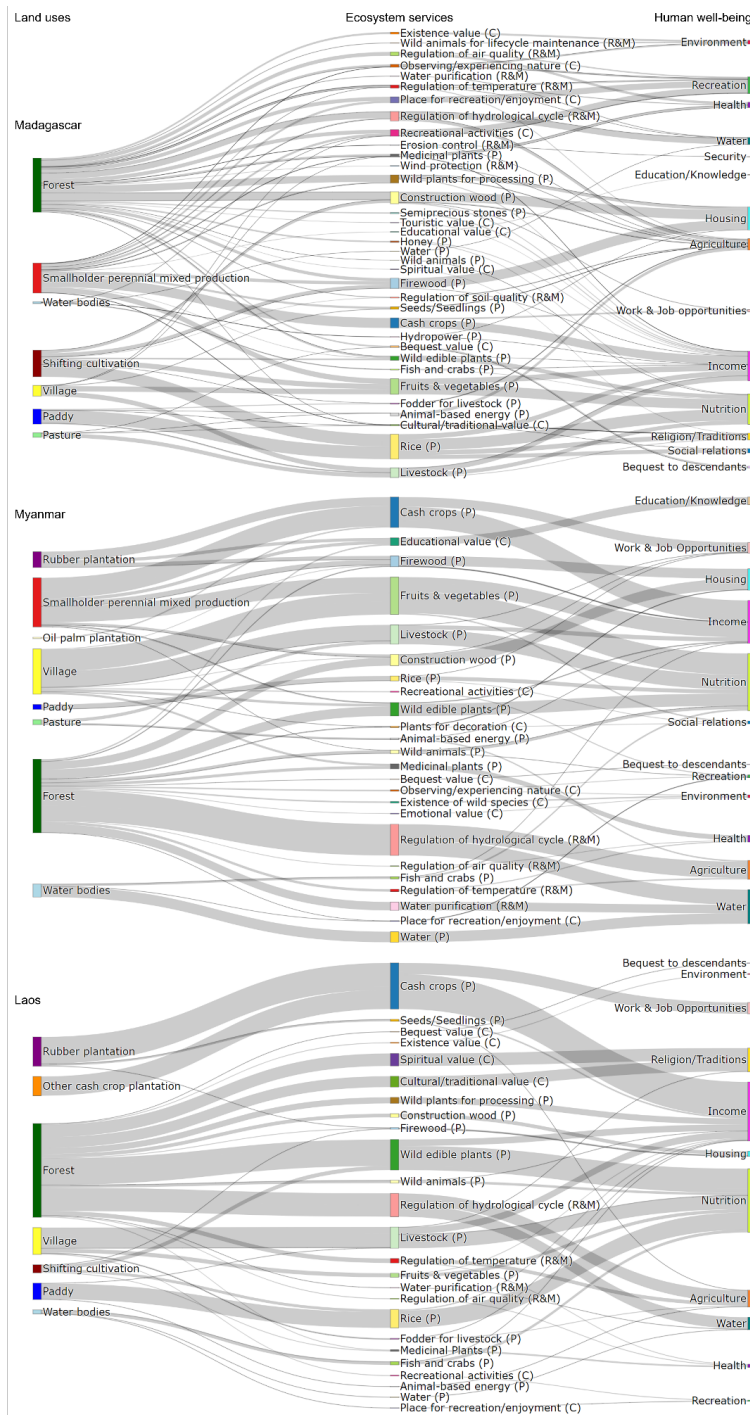


Figure 2. Links between land use and human well-being components via ecosystem services for Madagascar, Myanmar and Laos. (P) refers to provisioning ecosystem services, (R&M) refers to regulation and maintenance services, and (C) refers to cultural services.

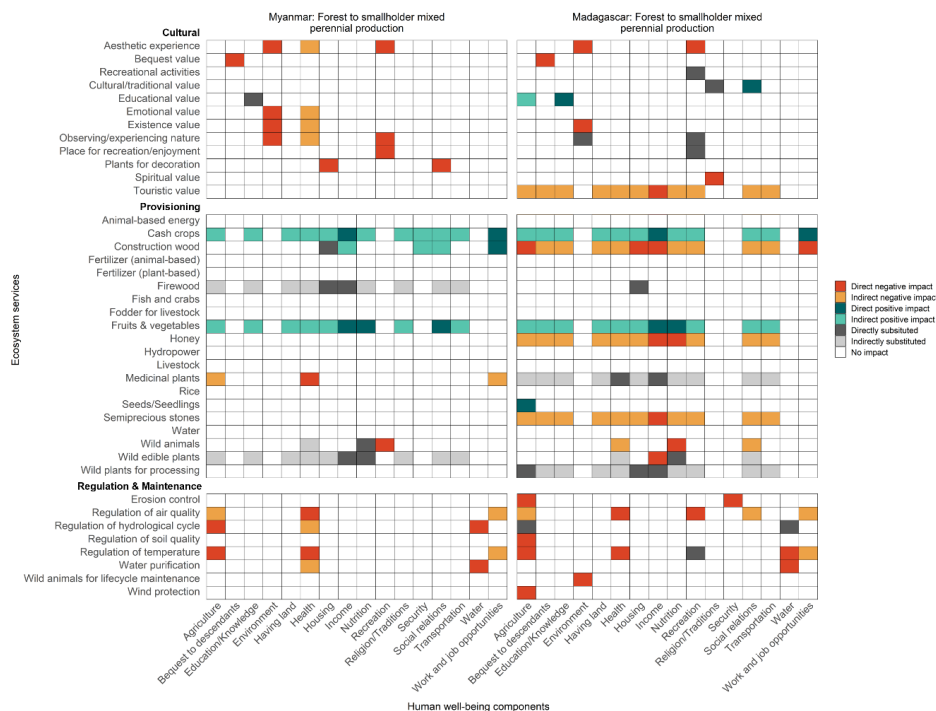


371 4.4 Impacts of land use change on human well-being via ecosystem services

372 In the following, we shed light on the impacts of those land use changes, which held potential
 373 for comparison across at least two of the forest frontiers. The land use changes from forest to
 374 shifting cultivation (in Madagascar) and paddy rice fields to other cash crops (in Laos) and
 375 their impacts on human well-being via ecosystem services are described in Supplementary
 376 Material S3.

377 4.4.1. Forests to mixed perennial systems

378
 379 The transition from forest to mixed perennial systems was observed in both Madagascar,
 380 mainly to produce vanilla and clove as cash crops, and in Myanmar, mainly for cashew and
 381 betelnut. This change was perceived to have predominantly negative impacts on cultural
 382 ecosystem services (Figure 3). For example, in Myanmar, these mixed perennial systems were
 383 associated with decreases in aesthetic experience and the value of observing and
 384 experiencing nature, which negatively affected the well-being components environment and
 385 recreation. In Madagascar, they partially substituted for the cultural and traditional values
 386 formerly associated with forests; for example, respondents associated both forests and mixed
 387 perennial systems with recreational value. Positive impacts were perceived on social relations
 388 in the sense that cultivating vanilla and clove increases one's social status in the village.
 389 However, an increase in the significance of money negatively impacted overall social relations
 390 directly (not related to changes in ecosystem services). Mixed perennial systems further
 391 provided educational value in Madagascar, positively impacting on education/knowledge yet
 392 they negatively impacted religion/traditions by decreasing the landscape's spiritual value. In
 393 addition, negative effects on touristic value were observed, which impacted income and
 394 through that a range of other well-being components. No positive impacts of this land use
 395 change on any cultural ecosystem services.
 396



397

398 *Figure 3. Impacts of the land use change forest to smallholder mixed perennial production systems on ecosystem*
399 *services and their consequences for human well-being components in Myanmar and Madagascar. Direct impacts*
400 *refer to changes in human well-being components caused by changes in ecosystem services. Indirect impacts refer*
401 *to changes in one human well-being component resulting from changes in another. Direct substitution indicates*
402 *that the ecosystem service affected by the land use change is also provided by the new land use, thereby*
403 *maintaining the associated well-being component unchanged. Indirect substitution follows the same pathway as*
404 *indirect impact, with the well-being component being influenced by another (directly substituted) component.*

405 The impacts of this land use change on provisioning ecosystem services were mixed, with
406 Madagascar experiencing more pronounced losses than Myanmar. Cash crops, fruits and
407 vegetables grown in the new mixed perennial systems contributed to income, employment and
408 nutrition, generating further indirect benefits across multiple well-being components. However,
409 in Madagascar, rising vanilla prices (grown in mixed perennial systems) increased the cost of
410 living and directly undermined nutrition. Firewood remained accessible in both contexts,
411 ensuring continued support for housing; in Myanmar, its availability also supplemented
412 income. Wild edible plants and plants for processing were also provided by the new land use.
413 In Madagascar, with this land use change the availability of honey and construction wood was
414 reduced, which had negative impacts on income, nutrition, housing, agriculture and work
415 opportunities. These direct impacts in turn were linked to many negative, indirect impacts on
416 most other well-being components.

417

418 Regulation and maintenance ecosystem services did not experience any positive changes. In
419 Myanmar, declines in air quality, the hydrological cycle, temperature and water purification
420 were observed. In Madagascar, further negative impacts were perceived on erosion control,
421 regulation of soil quality, wild animals for lifecycle maintenance and wind protection. These
422 declines primarily negatively affected health, water and agriculture. Only hydrological and
423 temperature regulation could be substituted by the new land use in Madagascar.



4.4.2. Transitions to high-input plantations: rubber and oil palm

Land use changes from forest to rubber and oil palm plantations in Laos and Myanmar led to predominantly negative impacts on ecosystem services and well-being components (Figure 4). Cultural services were uniformly negatively affected, particularly bequest and existence values, reduced the possibility to satisfy the well-being components of bequest to descendants and environment. Myanmar experienced a greater number of cultural losses than Laos. At the time of data collection, respondents expressed an interest in knowledge about cultivating rubber plantations and received agricultural training on cultivating rubber. Educational value was therefore partially maintained under rubber plantations in Myanmar, but this was not the case for oil palm plantations.



Figure 4. Impacts of the land use change forest to high-input plantations (rubber and oil palm) on ecosystem services and their consequences for human well-being components in Laos and Myanmar. An explanation for how direct and indirect impacts are defined is provided in the caption of Figure 3.

Provisioning services also declined in both countries under these land use changes. The availability of construction wood and medicinal plants declined, thus negatively impacting housing and health (timber, bamboo and medicinal plants used to be collected from the forest). In Myanmar, reduced availability of wild animals and plants led to direct impacts on nutrition and income, and many indirect impacts on other well-being components. One respondent in Myanmar found that “In the past I also got more fish, and other animals from the forest. I think it is due to too much use [over-exploitation] that the situation of the forest became the way it is now.”

Despite these declines, some provisioning services increased under these land use changes. For example, rubber plantations in Laos and Myanmar, and oil palm plantations in Myanmar positively contributed to cash crop production, leading to improvements in income and employment opportunities. For conversions to rubber plantations, improvements generated additional indirect, positive impacts on most other well-being components. The only other



positive impacts observed in oil palm plantations were indirect and occurred by cash crop income improving security and social relations. In Laos, rubber plantations also improved the availability of seeds/seedlings and increased cash crop production, supporting income and agriculture directly, and most other well-being components indirectly. Firewood availability was maintained under rubber plantations in Laos and Myanmar, continuing to support housing, and in Myanmar, income. This substitution did not occur under oil palm plantations in Myanmar, which reduced firewood and thereby negatively affected housing and income, with subsequent indirect impacts on most other well-being components.

Regulating and maintenance ecosystem services experienced only negative impacts from these land use changes. Regulation of air quality, the hydrological cycle, temperature and water purification declined with direct, negative consequences for health, water and agriculture. In Laos and Myanmar, health and the environment also experienced additional direct negative impacts (not via ecosystem services) due to an increase in the use of fertilizers, pesticides and herbicides in rubber and oil palm plantations. One respondent in Myanmar explained that “by using chemicals [...] animals such as butterflies, grasshoppers and so on are also killed. At first I did not know about such side-effects, and I did not wear any protection, but then I made those observations and I also had pain in my whole body.”

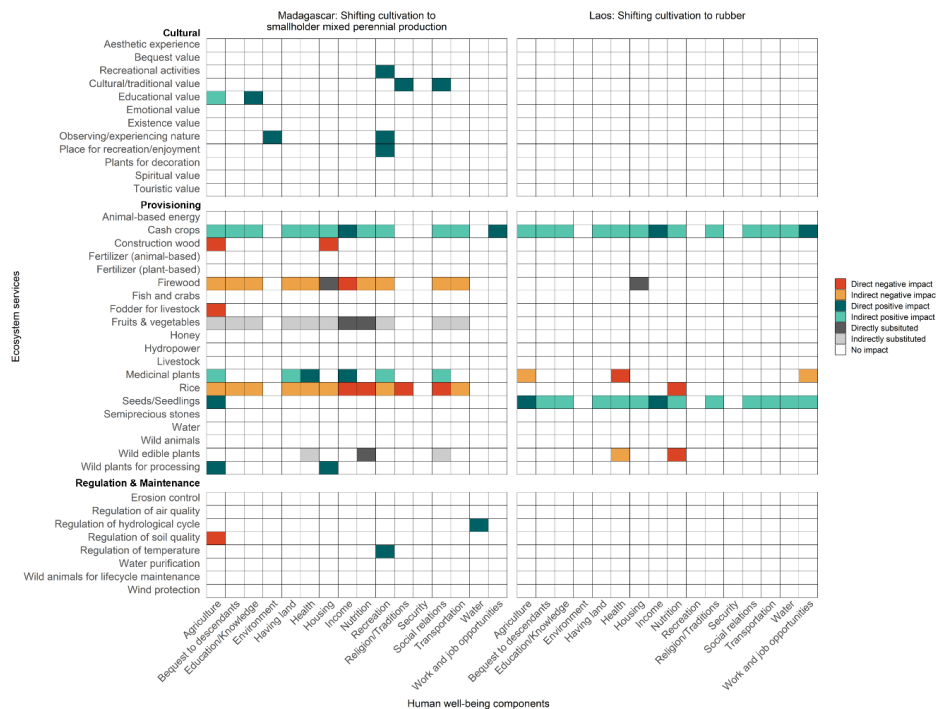
4.4.3. Decline of shifting cultivation

The decline of shifting cultivation—replaced by rubber plantations in Laos and mixed perennial systems in Madagascar—had contrasting effects on ecosystem services and human well-being components (Figure 5). No impacts on cultural ecosystem services were perceived in Laos, whereas positive impacts on recreational activities and spaces, cultural/traditional value, educational value, and experiencing nature were supported by the new land use in Madagascar.

Under both land use changes, the reduced provision of rice directly worsened nutrition. In Madagascar, a decline in rice also directly negatively impacted income, religion/traditions, and social relations, as well as indirectly negatively impacting most other well-being components. In Laos, the shift to rubber cultivation brought farmers physically closer to the village, as rubber plantations established on former shifting cultivation fallows are typically not as far from homesteads (while actively cultivated shifting cultivation plots are often hidden in the forest). This proximity allowed for more frequent interactions with family and neighbors, thereby strengthening social ties. Working in rubber plantations was also perceived as being “[...] comfortable. You just need to cut some grass and do some cleaning. It is a lot less work than upland rice [...]”. In contrast, in Madagascar, the transition from subsistence-oriented shifting cultivation to income-generating mixed perennial systems coincided with a growing emphasis on monetary value and individual gain, e.g. voiced as “Life has become difficult, people have become materialistic, selfish, and in love with money”. This shift contributed to a weakening of social relations, as these mixed perennial systems are largely managed at the household level and lack the collaborative labor arrangements—such as reciprocal labor exchanges—that are central to shifting cultivation systems. Firewood for housing could be directly substituted in both countries, but in Madagascar, a decline in available firewood negatively impacted income, which had indirect consequences for most other well-being components. Similar to the previous land use changes, the provision of cash crops directly increased income and the availability of job opportunities which provided further indirect benefits to most other well-being



503 components. In Laos, the new rubber plantations also offered seeds and seedlings, directly
504 supporting agriculture and income, with numerous further indirect benefits. In Laos, the loss of
505 shifting cultivation led to reductions in medicinal plants, rice, and wild edible plants, thereby
506 affecting health and nutrition. Nevertheless, in the Laos study site overall access to healthcare
507 improved, as stated by one respondent: “There was no health care center or hospitals in the
508 past. You had to walk for 4 hours from the upland to go to Namtha for care. It’s easier now”.
509
510 Only a few impacts on regulation and maintenance ecosystems were observed in Madagascar
511 and none in Laos. The regulation of soil processes was negatively impacted, which worsened
512 agriculture. Regulation of the hydrological cycle and temperature could both be substituted,
513 thus the well-being components recreation and water were both maintained.
514



515
516 *Figure 5. Impacts of a decline in shifting cultivation on ecosystem services and their consequences for human well-being components in Madagascar and Laos. An explanation for how direct and indirect impacts are defined is*
517 *provided in the caption of Figure 3.*
518

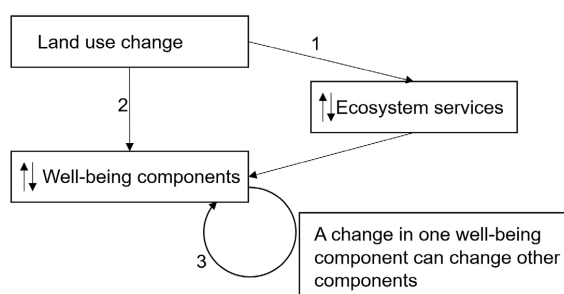
519 **4.5 Generic mechanisms between land use change, ecosystem services and human** 520 **well-being**

521 Our results highlight that changes in human well-being can occur via three generic
522 mechanisms (Figure 6). The first mechanism (mechanism 1), which was at the center of our
523 analysis, occurs when a land use change affects the supply of one or more ecosystem
524 services, which in turn affects one or more well-being components. We found that land use
525 changes often simultaneously affected provisioning, regulation and maintenance, and cultural
526 ecosystem services, which in turn affected 14 out of the 19 well-being components
527 (transportation and having land were the only well-being components that were not impacted



528 directly). As the impacts from land use change to well-being can be mediated by ecosystem
 529 services, there can even be trade-offs within the same well-being components. For example,
 530 the change from forest to mixed perennial systems on the one hand negatively affected income
 531 because people could no longer rely on income associated with the touristic value of forests,
 532 nor the construction wood, honey, or wild edible plants that were found in forests. On the other
 533 hand, the new land use produces cash crops and fruits and vegetables that provide an
 534 alternative source of income.

535 Land use change can also affect well-being directly (mechanism 2); for example, in Laos,
 536 people had more free time when they transitioned from shifting cultivation to rubber
 537 plantations. Improvements in well-being components like income and employment, often have
 538 many positive, indirect impacts on most other well-being components, as was observed in the
 539 transition from forest to mixed perennial systems in Myanmar and Madagascar (mechanism
 540 3).



541

542 *Figure 6. Mechanisms between land use change, ecosystem services and human well-being. Numbers refer to the*
 543 *type of mechanism: mechanism 1 occurs when a land use change affects the supply of one or more ecosystem*
 544 *services, which in turn affects one or more well-being components; mechanism 2 occurs when land use change*
 545 *directly affects well-being components; and mechanism 3 occurs when a change in one well-being component, in*
 546 *turn, affects other well-being components.*

547 **4.6 Substitution processes whereby ecosystem services continued to support well-** 548 **being during land use change**

549 Our data indicate that shifts in ecosystem services driven by land use change do not
 550 necessarily lead to changes in human well-being. Changes in ecosystem services can be
 551 substituted so that well-being components are still supported and maintained by the new land
 552 use or the new opportunities the land use brought. Three substitution processes can be
 553 described: (1) “land use-based substitution”; (2) “ecosystem services-based substitution”; and
 554 (3) “alternative income-based substitution” (Figure 7).

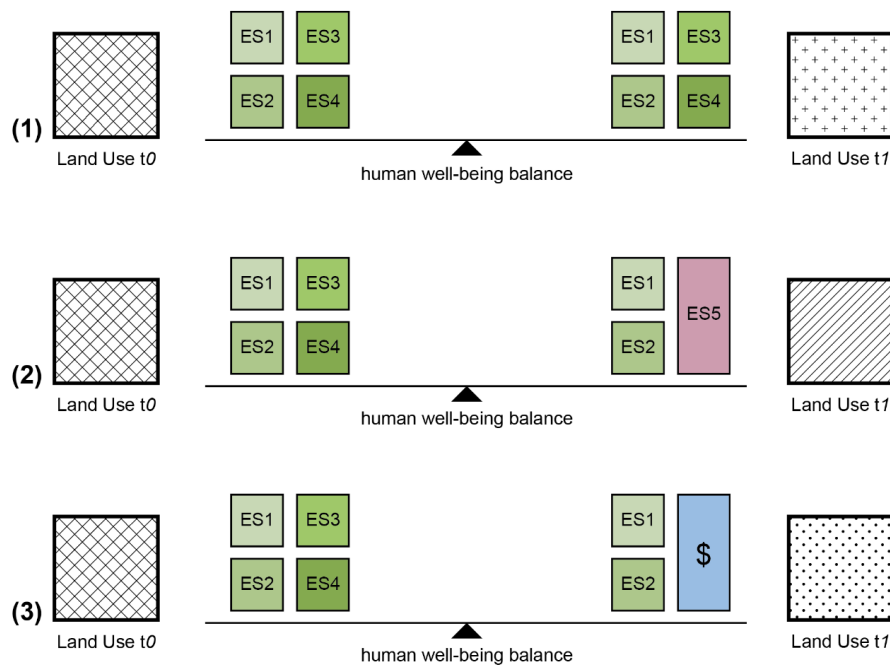
555 “Land use-based substitution” refers to instances when a new land use can provide ecosystem
 556 services comparable to those delivered by the previous land use. When both the former and
 557 the replacing land uses sustain similar ecosystem services, they can continue to support
 558 equivalent components of human well-being. In such cases, these well-being components are
 559 perceived as being substituted. For example, the collection of edible plants, construction wood
 560 and firewood may take place in shifting cultivation fallows or in mixed system plots as well as
 561 in forests, thereby maintaining the positive impact on nutrition or housing. As one respondent
 562 in Madagascar stated “I am satisfied when I go to our agroforest to collect firewood. There is



nothing I want in the natural forest.” In Madagascar, mixed perennial systems have demonstrated the capacity to substitute for many ecosystem services, including the provision of spaces for recreational activities and the regulation of the hydrological cycle and temperature.

The second substitution process, “ecosystem services-based substitution”, occurs when unaffected ecosystem services substitute those that decline or are lost as a result of the land use change, thereby maintaining the link to the respective well-being component. Across all three countries, the well-being component income remains supported by new ecosystem services provided by the new land use. For example, in Myanmar, income generated from rubber plantations substitutes for the income previously obtained from forests (non-timber forest products and rice). Similarly, in Laos, income from rubber plantations and other cash crops replaces income formerly derived from forests (through the sale of wild animals and plants) and paddy fields (through commercialization of rice). In Madagascar, income from shifting cultivation (selling fruits, vegetables and rice) and mixed perennial systems (selling cash crops, fruits and vegetables) substitutes for income once obtained from forests (through the sale of construction wood, medicinal plants, honey, and other non-timber forest products). Additionally, in Laos and Myanmar, vegetable gardens and mixed perennial systems substitute for the lost opportunity to collect edible plants in the forest, supporting nutrition. In Myanmar, poultry substitutes for wild animals that were previously hunted in forests, maintaining a positive contribution to nutrition.

Through “alternative income-based substitution”, ecosystem services lost due to a land use change are substituted by alternative, equal or higher incomes generated from new ecosystem services linked to the new land use. This alternative income enables households to purchase previously available ecosystem services from elsewhere. In Laos and Madagascar, for example, people maintain their nutritional intake by buying (often imported) food from markets rather than relying on collecting edible plants, hunting wild animals or producing subsistence rice through shifting cultivation or paddy rice fields (the latter only in Laos). As one respondent from Laos stated: “It is easier now thanks to the market, you just need money. There are also shops and restaurants. You had to find and cook all by yourself in the past, there was no market”. Similarly, declines in water provision are offset by purchasing bottled water in Laos and Myanmar. In Laos, cement and bricks substitute for forest-derived construction wood, while in Myanmar, construction wood is sourced from markets. Health is also maintained through improved access to hospitals (Laos) and medicines (Laos, Myanmar and Madagascar), substituting for the loss of medicinal plants. In Myanmar, electricity or gas stoves substitute for declining firewood availability, supporting housing.



598

599 *Figure 7. Three mechanisms through which ecosystem services (ES) could be substituted when land use changed.*
600 *(1) "land use-based substitution"; (2) "ecosystem services-based substitution"; and (3) "alternative income-based*
601 *substitution". Figure created by Svitlana Lavrenciuc.*

602 5. Discussion

603 5.1. Dependence of human well-being on land use and the consequences of land use 604 change

605 5.1.1. Forests as key providers of ecosystem services and well-being

606 In all three countries, forests provided the most varied set of ecosystem services and
607 contributed to many well-being components. This aligns with existing literature on the
608 multifunctionality of tropical forests, which highlights their role in supporting cash income,
609 nutrition, as well as regulating and cultural ecosystem services (e.g. Ahammad et al., 2019;
610 Borma et al., 2022; Mutoko et al., 2015; Zaehring et al., 2017). Forests contributed to
611 peoples' cash income via various provisioning ecosystem services, such as the provision of
612 firewood, construction wood, wild edible plants, and medicinal plants, showing how amidst
613 rapid land use change processes, livelihoods are still partly forest dependent. This reliance on
614 subsistence, forest-dependent income is consistent with other studies that explored
615 community livelihood strategies in forest frontiers (Hunt and Leonard, 2023; e.g. Khaine et al.,
616 2014; Van Der Meer Simo et al., 2019; Vezina et al., 2020).



617 Mixed perennial systems in Madagascar and Myanmar were also linked to several well-being
 618 components, confirming their importance in tropical multifunctional landscapes, not only for
 619 their ecological benefits, but also for their social impacts (e.g. Dewi et al., 2013; Leakey, 2020;
 620 van Noordwijk, 2021). Transitions from forest (in Madagascar and Myanmar) to mixed
 621 perennial systems had mixed effects, with many ecosystem services being substituted and
 622 well-being continued to be supported. A recent review of agroforestry systems (a type of mixed
 623 system) in Madagascar highlights that agroforestry systems do not provide regulation and
 624 maintenance ecosystem services at the same level as forests but they do support many
 625 provisioning ecosystem services (Andriatsitohaina et al., 2024). This pattern was reflected in
 626 our findings in Madagascar and Myanmar, where mixed perennial systems maintained or
 627 enhanced provisioning ecosystem services but diminished regulation and maintenance
 628 ecosystem services.

629 5.1.2. The decline of shifting cultivation and its impacts

630 Nutrition and income also depended on other land uses, especially shifting cultivation, which
 631 was linked to multiple well-being components in Madagascar and Laos. Yet both countries are
 632 experiencing a decline in this land system. During the study period (2000 – 2017), shifting
 633 cultivation disappeared entirely in the study site in Laos and was mainly replaced by rubber
 634 plantations. Indeed, others have documented more widely that in northern Laos, shifting
 635 cultivation is decreasing in areas where rubber is expanding and increasing where maize is
 636 expanding (Vongvisouk et al., 2014). Similar trends were observed in Madagascar, where
 637 large tracts of land once used for shifting cultivation were converted to mixed perennial
 638 systems; in this case vanilla plantations. However, this change in Madagascar was driven by
 639 an increase in vanilla prices, so when vanilla prices dropped, shifting cultivation increased
 640 again. The decline of shifting cultivation made food security more difficult to achieve,
 641 particularly because rice production was not substituted by the new land use and access to
 642 forest land for conversion to shifting cultivation fields was reduced (Llopis et al., 2020).
 643 Although the new land uses enabled land users to obtain income from vanilla or clove, rice is
 644 not always available on local village markets, making it risky to completely give up subsistence
 645 rice production.

646 In Southeast Asia's upland regions, transitions from shifting cultivation to cash crop plantations
 647 have been shown to increase household income, however this increase often comes at a
 648 significant cost, such as reductions in customary practices, well-being, livelihood options and
 649 stable yields (Dressler et al., 2017). Similarly, a systematic review of agricultural land change
 650 in Southeast Asia found that while such changes benefitted income and employment, they led
 651 to mixed outcomes on health, and had negative consequences for food security, gender
 652 equality, and economic equality (Appelt et al., 2022). Our findings are consistent with patterns
 653 observed across tropical forest-agriculture frontiers, where the intensification of agriculture
 654 often produces complex trade-offs rather than uniformly positive outcomes (Martin et al., 2023;
 655 van Vliet et al., 2012).

656 5.1.3. Landscape simplification and trade-offs in well-being

657 Our study sites in Laos and Myanmar experienced a significant rise in rubber and other cash
 658 crop plantations. These plantations contributed to income generation, but otherwise negatively
 659 impacted most ecosystem services and well-being components. The reliance on volatile cash



crop markets increases household vulnerability (Beban and Gironde, 2023; Cramb et al., 2009). This risk extends to mixed perennial systems when they are overly dependent on cash crop production (Andriatsitohaina et al., 2024). Studies have also shown that cash crop expansion can lead to high levels of inequality and can damage ecological integrity, resulting in wide-spread consequences on ecosystem services and well-being (e.g. Kenney-Lazar et al., 2018; Kusakabe and Chanthoumphone, 2021; Kusakabe and Myae, 2019).

Changes in landscapes, such as through landscape simplification and land use intensification, can have mixed impacts on well-being (e.g. Dressler et al., 2017; Rasmussen et al., 2018; Smith et al., 2019) because changes are complex and result in various trade-offs. We observed this, for example, in Myanmar with the expansion of palm oil at the expense of forest, and in Laos with the expansion of rubber plantations at the expense of forest. In these transitions, most well-being components were negatively affected due to a deterioration in the ecosystem services which underpinned those well-being components. The only positive impacts experienced were on agriculture, income, and work opportunities. These findings are aligned with Rasmussen's et al. (2018), who argue that agricultural intensification rarely leads to win-win outcomes for ecosystem services and well-being. This complexity also challenges the premise of the environmentalist's paradox – the idea that well-being increases even as ecosystems services decline (Raudsepp-Hearne et al., 2010). Our results suggest that this paradox is only valid when focusing narrowly on provisioning services.

Our findings support the hypothesis that there is a time lag between the decline in ecosystem services and a subsequent decline in human well-being (Raudsepp-Hearne et al., 2010). While the well-being components of income and work opportunities need to be satisfied in the short term, impacts of land use change on other components, such as health, might only be felt in the long term (Schneider et al., 2020). This hypothesis may be particularly relevant in Laos, where the current benefits of cash crop plantations outweigh the potential long-term damages to peoples' health due to pesticide exposure. The environmentalist's paradox's narrowly constructed view on the relationship between ecosystem services and human well-being also fuels the still dominant focus of conservation and development interventions to slow agricultural expansion into natural habitats by reducing poverty through income generation (Carmenta et al., 2023). This narrow framing of well-being may obscure the many non-material links between people and land and, in the worst case, lead to motivational crowding out, as a focus on economic value undermines intrinsic motivations for environmental stewardship (Lliso et al., 2022).

5.1.4. Cross-country comparisons and contextual specificities

Although the most dominant land use changes were not the same across Madagascar, Myanmar and Laos, there were some common changes (e.g., forest to mixed perennial systems in Madagascar and Myanmar and forest to rubber plantation in Myanmar and Laos). Among these common land use changes, there were many similarities with regards to how the change impacted ecosystem services and well-being but there were also important, context-related differences. For example, a negative impact on wild animals and wild edible plants had much fewer indirect negative consequences in Myanmar than in Laos when looking at the land use change from forest to rubber plantation. This may suggest a greater reliance on forests for non-timber forest products in Laos than in Myanmar. In Madagascar, forests are important for honey production and the honey is either consumed at home (e.g., for nutrition or for



704 medicinal purposes) or sold as a commodity (Dave et al., 2017). This reliance on forests for
 705 honey production was only observed in Madagascar and transitions to mixed perennial
 706 systems and shifting cultivation negatively impacted honey production. Furthermore, the
 707 demise of shifting cultivation due to the advance of commercial agriculture in these forest
 708 frontier landscapes is playing out differently depending on local customs around labor
 709 arrangements and other social parameters. This might also mean that interventions designed
 710 to curb the extent of shifting cultivation, such as those undertaken by conservation actors,
 711 need to take local specificities into account to avoid unintended consequences for human well-
 712 being, which might backfire and hamper the success of conservation interventions.

713 **5.2. Mechanisms between land use change, ecosystem services and human well-being**

714 Our results highlight different mechanisms through which land use change, ecosystem
 715 services and human well-being interact and impact each other, suggesting greater complexity
 716 than previously described. For example, Hallaj et al. (2024) conducted a systematic analysis
 717 on the effects of forest land use change on biodiversity ecosystem services and human well-
 718 being, relying on Wang's et al. (2017) framework, which shows a unidirectional, cyclical
 719 relation between the three elements. We found that a change in one ecosystem service often
 720 affects several well-being components at once. This was often the case when income was
 721 positively impacted by an ecosystem service, as income was able to indirectly improve most
 722 other well-being components. In Laos, an increase in income from cash crops supported
 723 transport and agriculture, by using vehicles to transport agricultural products from the field to
 724 home and to markets, and by buying motorbikes so that children can travel to and from school
 725 more quickly to have more time available for agricultural work (Vongvisouk et al., 2016). This
 726 signifies that it is not sufficient to only consider ecosystem services when assessing land use
 727 change impacts on people. Instead, it is key to explicitly consider how changes in ecosystem
 728 services can indirectly and directly impact well-being components, as well as how changes in
 729 well-being components can impact other well-being components. These impacts should also
 730 be explored across different spatial scales because whether the relationship between
 731 ecosystem services and human well-being is positive, negative or non-existent is scale-
 732 dependent (Liu et al., 2022).

733 Our results also suggest that well-being outcomes of land use change can differ not only
 734 across well-being components but also across social scales. In several instances, we found
 735 that income improvements at the individual level were associated with enhanced capabilities,
 736 such as increased ability to support family members or participate in religious life—thereby
 737 improving personal relations and spiritual fulfillment. However, it remained unclear whether
 738 these improvements translated into strengthened community-level well-being. For example,
 739 greater financial means enabled individual donations to religious institutions or more frequent
 740 participation in events, yet it was less evident whether this strengthened or weakened the
 741 broader social fabric and religious cohesion in the village. Similarly, while income was seen to
 742 support personal relationships, the increasing monetization of social interactions was also
 743 linked to reduced collective reciprocity and social cohesion in some cases. These divergent
 744 outcomes illustrate how changes in land use can reconfigure not only economic practices but
 745 also the social fabric of rural communities, highlighting the need for assessments that are
 746 sensitive to the relational scale of well-being and that distinguish between personal gains and
 747 communal well-being (Bentley Brymer et al., 2020; Santillán-Carvantes et al., 2025).



748 **5.3. Substitution mechanisms for lost ecosystem services**

749 When land use change occurs, the original ecosystem services are lost (Hasan et al., 2020).
 750 However, we identified three distinct mechanisms by which these lost ecosystem services can
 751 be substituted. Nevertheless, our study did not address the conversion factors that influence
 752 how these substituted ecosystem services are translated into actual improvements in well-
 753 being. The ability of individuals to convert ecosystem services into well-being depends on their
 754 personal, social and environmental conversion factors (Polishchuk and Rauschmayer, 2012).
 755 Therefore, the extent to which human well-being will really have been substituted by the new
 756 land use remains uncertain. Differences in the number of ecosystem services that could be
 757 substituted across the three countries may also be due to the different assets and
 758 characteristics of the individuals living across the different villages and countries (e.g. gender,
 759 age, education, etc.) and their specific environment (e.g. climate). For example, the agency of
 760 the actors and the ruling governance system were found to impact well-being outcomes in
 761 Myanmar, where positive well-being effects were more likely to be observed in villages where
 762 people had at least a certain amount of power in land use decision-making (Schneider et al.,
 763 2020).

764 Whether income, through for example alternative livelihood activities, can adequately
 765 substitute for lost ecosystem services and support human well-being components also remains
 766 unclear. A recent literature review on the effects of Madagascar's conservation actions found
 767 inconclusive results regarding whether alternative activities contribute to people's well-being
 768 in Madagascar and such activities are often not suited to local contexts (Blanco et al., 2025).
 769 Furthermore, we generally do not know whether land users are satisfied with the respective
 770 substitution, e.g., eating imported rice they can buy from the market, instead of the rice they
 771 produce themselves. However, although not captured systematically, some findings point
 772 towards this situation, like in Madagascar, where a few interviewees mentioned that they are
 773 less satisfied eating imported rice from Asia instead of their own rice varieties. Substituting for
 774 the loss of nature's benefits through imported or manufactured products somehow constitutes
 775 the end of a chain of possibilities of substitution and could also be seen as a type of spillover
 776 from land use change in a specific location. In the end, if all forest frontier landscapes around
 777 the globe become similarly homogeneous in terms of land use, it may no longer be possible
 778 to source the lost benefits in one place from another one. It is therefore imperative to maintain
 779 a certain level of land use diversity in each landscape to avoid such a dead end where
 780 substitution is no longer possible. Conserving and promoting multifunctional landscapes
 781 should therefore be a priority, as they provide multiple ecosystem services that contribute
 782 towards human well-being (Rodríguez-Loinaz et al., 2015; Thanasack et al., 2026), they can
 783 reduce trade-offs and conflicts (Heinze et al., 2020), and are important for coping with risk (van
 784 Vliet et al., 2012).

785 **5.4. Reflection on our methodological approach: novelty and limitations**

786 Our study offers a novel methodological contribution by empirically examining the
 787 multidimensional nature of human well-being in the context of land use change, using a
 788 deductive and contextually grounded application of Nussbaum's capability approach. While
 789 this theoretical framework is widely recognized, it has rarely been operationalized—particularly
 790 in Global South contexts—due to challenges related to contextualization and because impact
 791 assessments to trace well-being often rely on simplified metrics that are easier to implement,



as well as to aggregate for policy making (Carmenta et al., 2023). Unlike previous studies, which often center ecosystem services and treat their link to well-being as secondary or vague, such as in the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005), our research takes well-being as the analytical entry point. We trace back from well-being to land use change via ecosystem services in a comprehensive manner, which remains rare in the literature. By doing so, we address the empirical and methodological gap of capturing the complex, context-specific, and evolving components of well-being, and shed light on their interlinkages with the land people depend on.

While our study provides valuable insights into the links between land use change and human well-being, several limitations should be acknowledged. First, although ecosystem services served as a crucial bridging concept in our analysis, they were not the central focus; thus, the identification and assessment of ecosystem services are not fully comprehensive. In particular, the same ecosystem service outcome can result from different land use change pathways due to the aggregated nature of certain ecosystem services (e.g. medicinal plants comprising multiple species) or differences in quantity, which our study did not disentangle. Additionally, we did not explore intra-community differences, such as those based on gender or other social dimensions, which may influence both ecosystem service access and well-being outcomes (Abunge et al., 2013). Second, while we did consider land use change over time, temporal dynamics in terms of how well-being perceptions could shift rapidly in response to changing circumstances were also not addressed (Gasper, 2007; Llopis et al., 2022). Third, the strength of effects might vary considerably depending on the magnitude of the change in the well-being component. Finally, while the study design was harmonized across countries, slight adaptations to the questionnaire were made to ensure local relevance. This may have resulted in certain themes being more prominently represented in one context than another, potentially affecting cross-case comparability.

6. Conclusion

This study set out to unravel the complex interlinkages between land use change, ecosystem services, and human well-being in tropical forest frontier contexts of Madagascar, Laos, and Myanmar. Our findings reaffirm that while certain components of well-being may appear to improve in the short-term following land use change, most notably income and employment, these improvements are often accompanied by the degradation of critical ecosystem services, especially cultural and regulating services. This reinforces the environmentalist's paradox on the one hand, but on the other hand also calls for a rethinking of its premises: human well-being has not decoupled from the health of ecosystems if we account for the multidimensional nature of well-being, as well as the temporal and spatial scales at which trade-offs manifest. We show that land use changes, such as from forest to mixed perennial systems or to high-input plantations, can affect well-being directly or indirectly via changes in ecosystem supply, and that the resulting impacts are often felt across multiple well-being components. Moreover, well-being components themselves influence one another, compounding both positive and negative effects. Crucially, we identify three distinct substitution mechanisms that allow ecosystem service losses to be mitigated: land use-based, ecosystem service-based, and alternative income-based substitution. While these mechanisms can sustain satisfaction with well-being components in the short term, they are not without limitations. Material substitution, for instance, cannot substitute for lost relational values to land, and income-based strategies expose households to market volatility, eroding long-term resilience.



837 These insights underline that it is no longer sufficient to assess land use change impacts
838 through a narrow focus on provisioning ecosystem services or economic metrics alone. Well-
839 being is inherently plural, relational, and context specific. Therefore, a more integrative and
840 people-centered lens is needed—one that foregrounds local conceptualizations of a “good life”
841 and embraces subjective, relational, and place-based values. Our study contributes
842 methodologically to this task by applying Nussbaum’s capabilities approach (Nussbaum, 2007)
843 in a harmonized, yet context-sensitive way, capturing nuanced, grounded understandings of
844 what matters to people in forest frontier landscapes. Policy makers, development practitioners,
845 and conservation actors must move beyond a simplistic “win-win” framing of land use
846 interventions and instead engage with the real trade-offs and transformations that shape local
847 lives. Future interventions should aim to preserve the multifunctionality of landscapes,
848 maintain land use diversity, and enhance the conditions under which ecosystem services can
849 be equitably accessed. Without this, even well-intentioned interventions risk undermining
850 important components of human well-being and ecological systems they aim to support. In
851 sum, tropical forest frontiers are rapidly transforming under global pressures, but the
852 consequences for human well-being are complex, uneven, and contingent. In-depth, empirical,
853 and participatory assessments, such as the one presented here, are essential to anticipate the
854 cascading effects of land use changes and to design interventions that foster both ecological
855 sustainability and multidimensional human well-being.



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888 Competing interests

889 The authors declare no competing interests.

890 Code and data availability

891 Data and code will be made available, we are working on making them publicly available via
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