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

Authors:

- [a,b,k]Prof. Dr. Julie G. Zähringer (Corresponding author); julie.zaehringer@unibe.ch; +41 79 646 43 88
- [a,b,k]Clara L. Diebold; clara.diebold@students.unibe.ch
- [a,b]Madlaina Michelotti; madlaina.michelotti@unibe.ch
- [a,c,d]Dr. Jorge C. Llopis; jorge.llopis@faculty.unibe.ch
- [k]Katharina Nydegger; nydegger-katharina@bluewin.ch
- [l]Aung Myin Htun; aungmyinhtut511@gmail.com
- [c]Nicolas Stenger; stenger.nicolas@outlook.com
- [e]Souliyaphon Kommadam; s.kommadam@nuol.edu.la
- [f]Paul-Clément Harimalala; iaritours@gmail.com
- [a,g]Dr. Mélanie Feurer; melanie.feurer@bfh.ch
- [b,e]Phokham Latthachack; phokhaml@gmail.com
- [a]Dr. Lara Lundsgaard-Hansen; lara.lundsgaard@unibe.ch
- [f]Dr. Ntsiva Andriatsitohaina; ntsiva.andriatsitohaina@wyssacademy.org
- [b,k]Prof. Dr. Peter Messerli; peter.messerli@wyssacademy.org
- [a,h,i,j] Prof. Dr. Flurina Schneider; flurina.schneider@isoe.de

Affiliations:

[a]Centre for Development and Environment, University of Bern, Switzerland
[b]Wyss Academy for Nature at the University of Bern, Switzerland
[c]Institute of Geography and Sustainability, University of Lausanne, Switzerland
[d]Institut de Ciència i Tecnologia Ambientals (ICTA - UAB). Edifici ICTA-ICP, Carrer de les Columnes s/n, Campus de la UAB, 08193, 08193 Cerdanyola del Vallès, Universitat Autònoma de Barcelona
[e]NUOL – National University of Laos, Vientiane, Laos
[f]ESSA-Forêts, University of Antananarivo, Antananarivo, Madagascar
[g]BFH-HAFL, Bern University of Applied Sciences, Switzerland
[h]Institute for Social-Ecological Research (ISOE), Frankfurt am Main, Germany
[i]Faculty of Biosciences, Goethe University Frankfurt, Frankfurt am Main, Germany
[j]Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt am Main, Germany
[k]Institute of Geography, University of Bern, Bern, Switzerland
[l]Environmental Care and Community Security Institute, Yangon, Myanmar

Preprint statement:

This manuscript version is a non-peer reviewed preprint submitted to EarthArXiv. This preprint has also been submitted to the journal Land Systems.

Abstract

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

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

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

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

1. Introduction

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

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

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

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

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

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

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

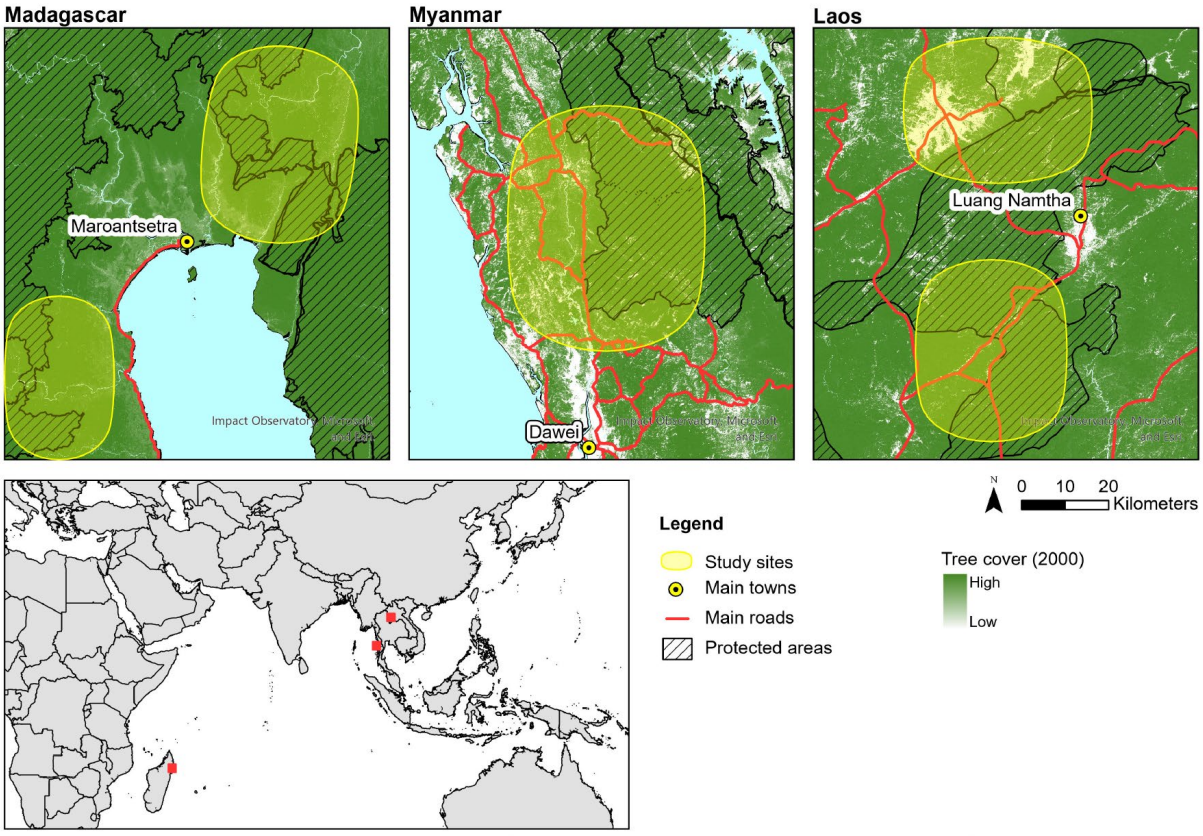
This study combines the application of the capabilities approach as a heuristic tool to assess multidimensional well-being together with the ecosystem services framework to examine: 1) to what extent human well-being is dependent on specific land use types and the provision of ecosystem services linked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

3. Methodological approach

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

3.1 Study areas

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



Source: ArcGIS.com. Layers from ArcGIS.com: madagascarPrimaryRoads, Myanmar Road Network (Myanmar Information Management Unit, 2025), Laos Roads, WDPA - World Database of Protected Areas (UNEP-WCMC and IUCN, 2025, Protected Planet: The World Database on Protected Areas (WDPA) [On-line], [November 2025], Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net).

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

3.2. Land use change assessment

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

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

3.3 Workshop discussions

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

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**

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

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

3.4 Household-level interviews

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

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

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

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

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

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

Table 4. Nussbaum's central capabilities and contextualized well-being components (see step 1 of the workshops) 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

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

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

4. Results

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

4.1 The most prevalent land use changes

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

Table 5. Share of the three most prevalent land use changes in each study area in terms of total share of mapped 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	

4.2 Human well-being across different forest frontiers

Perceptions of human well-being across the three countries were multidimensional and nuanced. Health emerged as both an intrinsic value and as a prerequisite for fulfilling work, 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

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

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

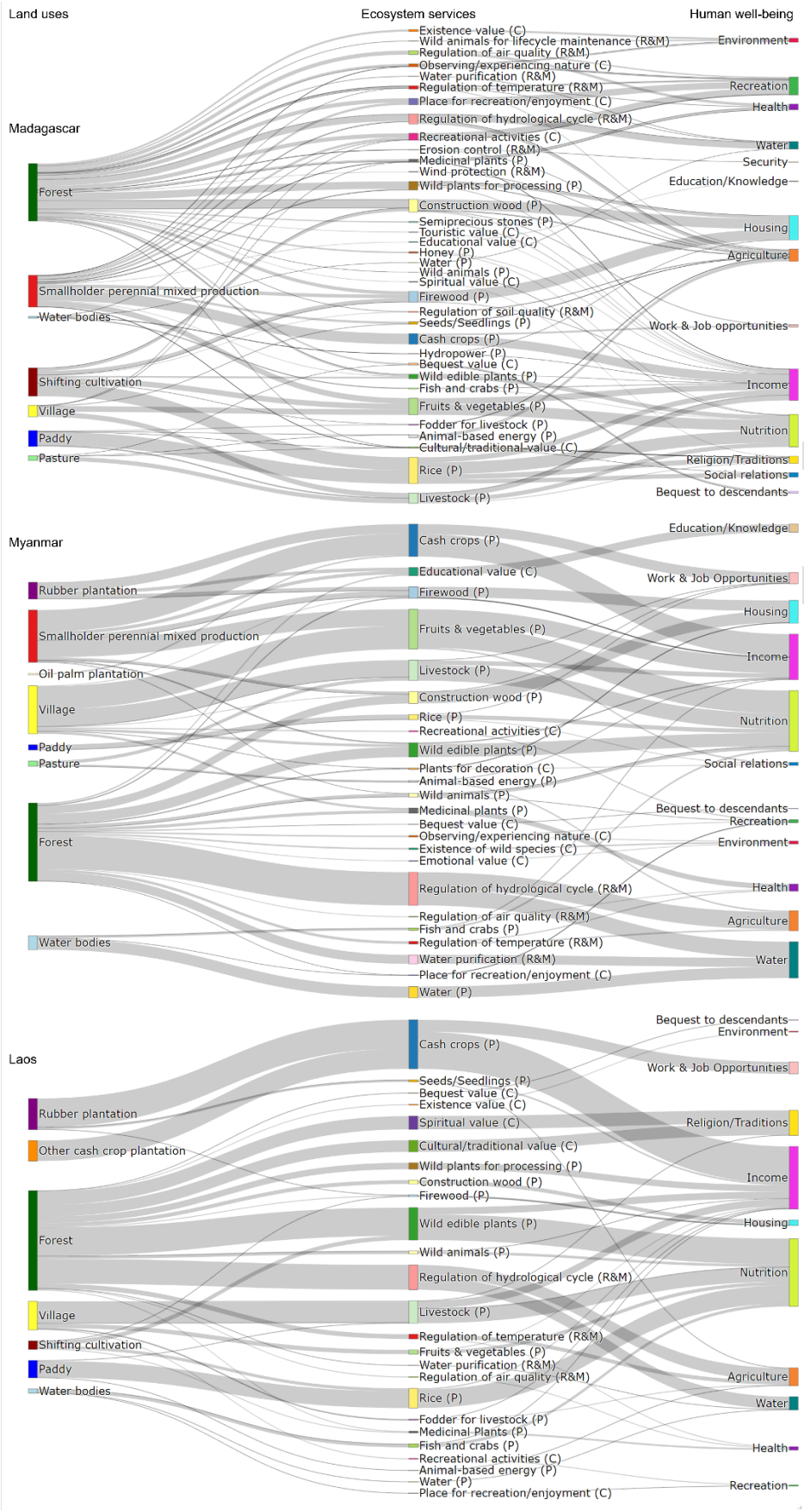


Figure 2. Links between land use and human well-being components via ecosystem services for Madagascar, Myanmar and Laos. (P) refers to provisioning ecosystem services, (R&M) refers to regulation and maintenance services, and (C) refers to cultural services.

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

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

4.4.1. Forests to mixed perennial systems

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

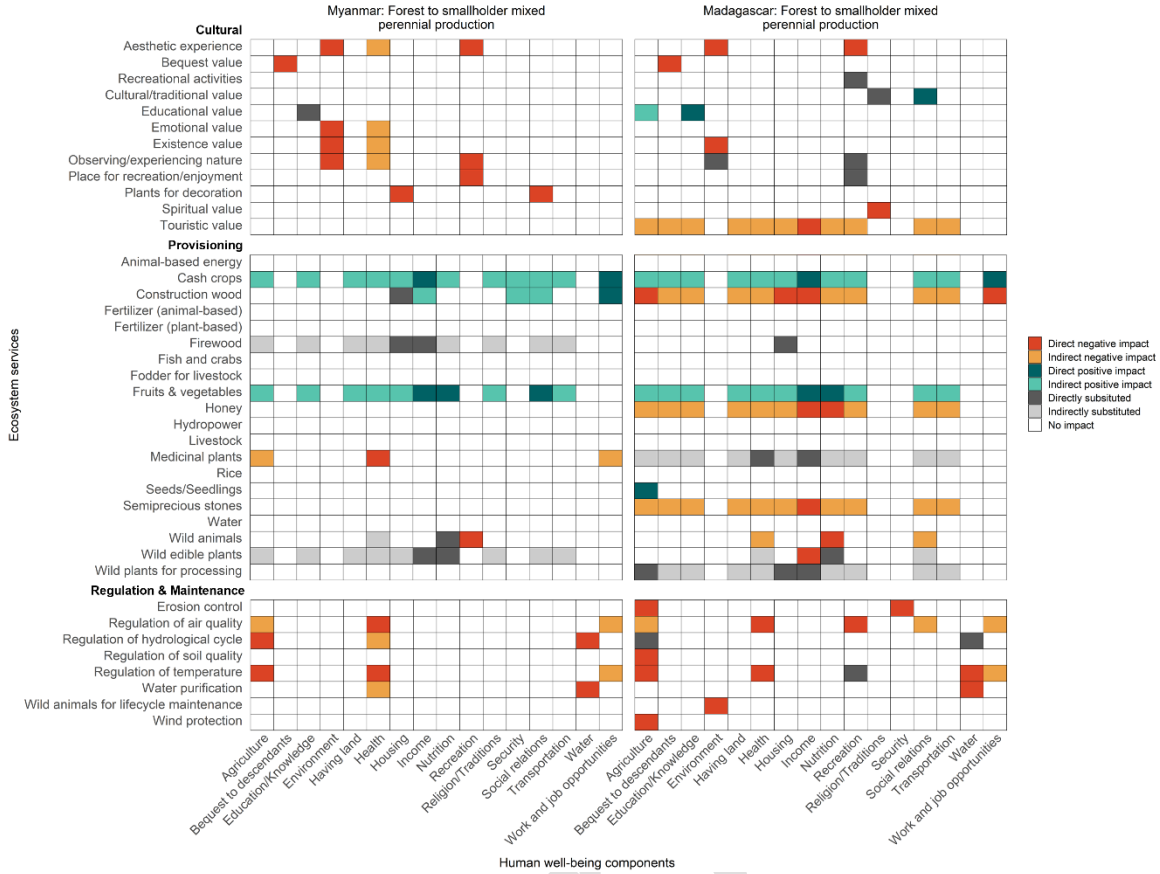


Figure 3. Impacts of the land use change forest to smallholder mixed perennial production systems on ecosystem services and their consequences for human well-being components in Myanmar and Madagascar. Direct impacts refer to changes in human well-being components caused by changes in ecosystem services.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

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

Regulation and maintenance ecosystem services did not experience any positive changes. In Myanmar, declines in air quality, the hydrological cycle, temperature and water purification were observed. In Madagascar, further negative impacts were perceived on erosion control, regulation of soil quality, wild animals for lifecycle maintenance and wind protection. These declines primarily negatively affected health, water and agriculture. Only hydrological and 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

components. In Laos, the new rubber plantations also offered seeds and seedlings, directly supporting agriculture and income, with numerous further indirect benefits. In Laos, the loss of shifting cultivation led to reductions in medicinal plants, rice, and wild edible plants, thereby affecting health and nutrition. Nevertheless, in the Laos study site overall access to healthcare improved, as stated by one respondent: “There was no health care center or hospitals in the past. You had to walk for 4 hours from the upland to go to Namtha for care. It’s easier now”.

Only a few impacts on regulation and maintenance ecosystems were observed in Madagascar and none in Laos. The regulation of soil processes was negatively impacted, which worsened agriculture. Regulation of the hydrological cycle and temperature could both be substituted, thus the well-being components recreation and water were both maintained.

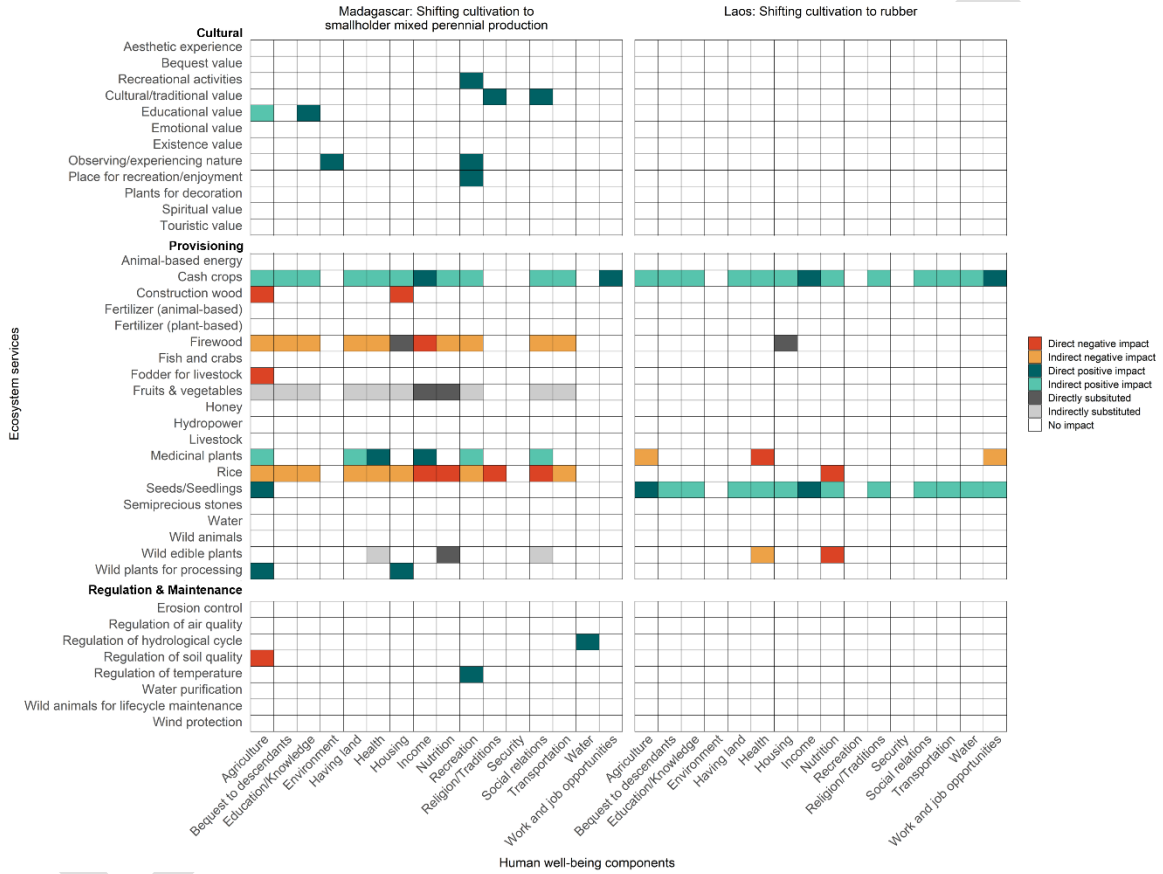


Figure 5. Impacts of a decline in shifting cultivation on ecosystem services and their consequences for human well-being components in Madagascar and Laos. An explanation for how direct and indirect impacts are defined is provided in the caption of Figure 3.

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

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

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

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

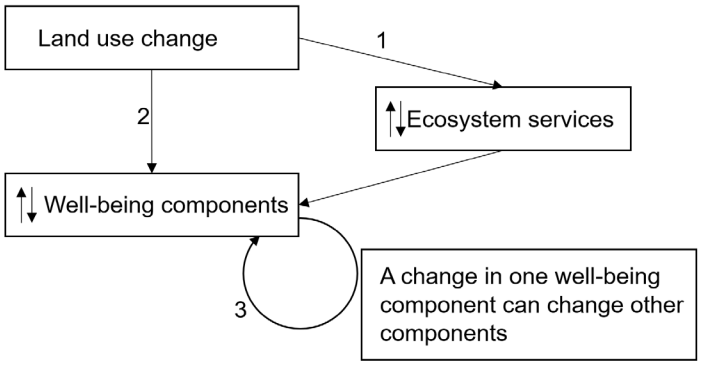


Figure 6. Mechanisms between land use change, ecosystem services and human well-being. Numbers refer to the type of mechanism: mechanism 1 occurs when a land use change affects the supply of one or more ecosystem services, which in turn affects one or more well-being components; mechanism 2 occurs when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

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

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

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

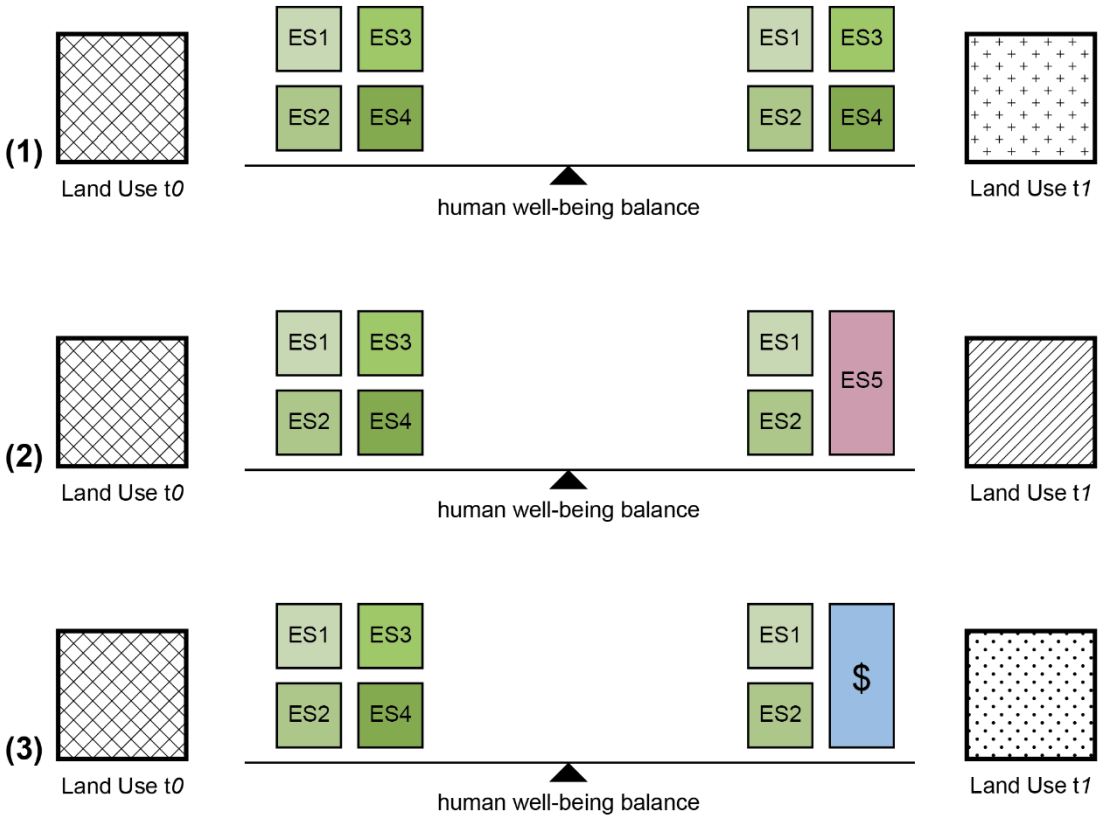


Figure 7. Three mechanisms through which ecosystem services (ES) could be substituted when land use changed. (1) "land use-based substitution"; (2) "ecosystem services-based substitution"; and (3) "alternative income-based substitution". Figure created by Svitlana Lavrenciuc.

5. Discussion

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

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

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

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

5.1.2. The decline of shifting cultivation and its impacts

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

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

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

Our study sites in Laos and Myanmar experienced a significant rise in rubber and other cash crop plantations. These plantations contributed to income generation, but otherwise negatively 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

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

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

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

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

5.3. Substitution mechanisms for lost ecosystem services

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

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

5.4. Reflection on our methodological approach: novelty and limitations

Our study offers a novel methodological contribution by empirically examining the multidimensional nature of human well-being in the context of land use change, using a deductive and contextually grounded application of Nussbaum's capability approach. While this theoretical framework is widely recognized, it has rarely been operationalized—particularly in Global South contexts—due to challenges related to contextualization and because impact 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 (Millenium 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.

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

Acknowledgments

This study is an output of the *Managing Telecoupled Landscapes* project at the *University of Bern*, funded through the *Swiss Programme for Research on Global Issues for Development* (*r4d programme*; Grant number 400440 152167), JCL was funded by the *Swiss National Science Foundation* (Grant number PZ00P1_223766). This study contributes to the Global Land Programme (https://glp.earth/). Special thanks to Svitlana Lavrenciuc who designed Figure 7.

Author contributions

Julie G. Zaehringer: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review and editing. Supervision: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team. Project administration: Management and coordination responsibility for the research activity planning and execution. **Clara L. Diebold:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. **Madlaina Michelotti:** Visualization, Writing – original draft, Writing – review and editing. **Jorge C. Llopis:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. **Katharina Nydegger:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. **Aung Myin Htun:** Investigation, Writing – review and editing. **Nicolas Stenger:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. **Souliyaphon Kommadam:** Investigation, Writing – review and editing. **Paul-Clément Harimalala:** Investigation, Writing – review and editing. **Mélanie Feurer:** Investigation, Writing – review and editing. **Phokham Latthachack:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. **Lara Lundsgaard-Hansen:** Investigation, Writing – review and editing. **Ntsiva Andriatsitohaina:** Investigation, Writing – review and editing. **Peter Messerli:** Conceptualization, Methodology, Writing – review and editing. Funding acquisition: Acquisition of the financial support for the project leading to this publication. **Flurina Schneider:** Conceptualization, Methodology, Formal analysis, Writing – review and editing. Supervision: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team. Funding acquisition: Acquisition of the financial support for the project leading to this publication.

Bibliography

Abunge, C., Coulthard, S., Daw, T.M., 2013. Connecting Marine Ecosystem Services to Human Well-being: Insights from Participatory Well-being Assessment in Kenya. AMBIO 42, 1010–1021. https://doi.org/10.1007/s13280-013-0456-9

Agarwala, M., Atkinson, G., Fry, B.P., Homewood, K., Mourato, S., Rowcliffe, J.M., Wallace, G., Milner-Gulland, E.J., 2014. Assessing the Relationship Between Human Well-being and Ecosystem Services: A Review of Frameworks. Conserv. Soc. 12, 437. https://doi.org/10.4103/0972-4923.155592

Ahammad, R., Stacey, N., Sunderland, T.C.H., 2019. Use and perceived importance of forest ecosystem services in rural livelihoods of Chittagong Hill Tracts, Bangladesh. Ecosyst. Serv. 35, 87–98. https://doi.org/10.1016/j.ecoser.2018.11.009

Alfonso, A., Zorondo-Rodríguez, F., Simonetti, J.A., 2017. Perceived changes in environmental degradation and loss of ecosystem services, and their implications in human well-being. Int. J. Sustain. Dev. World Ecol. 24, 561–574. https://doi.org/10.1080/13504509.2016.1255674

Alkire, S., 2002. Dimensions of Human Development. World Dev. 30, 181–205. https://doi.org/10.1016/S0305-750X(01)00109-7

Andriatsitohaina, R.N.N., Laby, P., Llopis, J.C., Martin, D.A., 2024. Agroforestry in Madagascar: past, present, and future. Agrofor. Syst. 98, 1659–1680. https://doi.org/10.1007/s10457-024-00975-y

Appelt, J.L., Garcia Rojas, D.C., Verburg, P.H., van Vliet, J., 2022. Socioeconomic outcomes of agricultural land use change in Southeast Asia. Ambio 51, 1094–1109. https://doi.org/10.1007/s13280-022-01712-4

Arowolo, A.O., Deng, X., Olatunji, O.A., Obayelu, A.E., 2018. Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. Sci. Total Environ. 636, 597–609. https://doi.org/10.1016/j.scitotenv.2018.04.277

Baumann, M., Gasparri, I., Buchadas, A., Oeser, J., Meyfroidt, P., Levers, C., Romero-Muñoz, A., Le Polain De Waroux, Y., Müller, D., Kuemmerle, T., 2022. Frontier metrics for a process-based understanding of deforestation dynamics. Environ. Res. Lett. 17, 095010. https://doi.org/10.1088/1748-9326/ac8b9a

Beauchamp, E., Woodhouse, E., Clements, T., Milner-Gulland, E., 2018. “Living a good life”: conceptualizations of well-being in a conservation context in Cambodia. Ecol. Soc. 23. https://doi.org/10.5751/ES-10049-230228

Beban, A., Gironde, C., 2023. Surviving cassava: smallholder farmer strategies for coping with market volatility in Cambodia. J. Land Use Sci. 18, 109–127. https://doi.org/10.1080/1747423X.2023.2190744

Bennett, E.M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B.N., Geijzendorffer, I.R., Krug, C.B., Lavorel, S., Lazos, E., Lebel, L., Martín-López, B., Meyfroidt, P., Mooney, H.A., Nel, J.L., Pascual, U., Payet, K., Harguindeguy, N.P., Peterson, G.D., Prieur-Richard, A.-H., Reyers, B., Roebeling, P., Seppelt, R., Solan, M., Tschakert, P., Tscharntke, T., Turner II, B., Verburg, P.H., Viglizzo, E.F., White, P.C., Woodward, G., 2015. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain., Open Issue 14, 76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Bentley Brymer, A.L., Toledo, D., Spiegal, S., Pierson, F., Clark, P.E., Wulfhorst, J.D., 2020. Social-Ecological Processes and Impacts Affect Individual and Social Well-Being in a Rural Western U.S. Landscape. Front. Sustain. Food Syst. 4. https://doi.org/10.3389/fsufs.2020.00038

Blanco, J., Rasambo, N., Durand-Bessart, C., Randriamalala, J.R., Queste, J., Becker, N., Sarron, J., Razafimandimby, H., Zafitody, C., Carrière, S.M., Rafidison, V.M., 2025. Strategies to engage local communities in forest biodiversity conservation had limited effectiveness in Madagascar: Lessons from the literature. Biol. Conserv. 309, 111332. https://doi.org/10.1016/j.biocon.2025.111332

Boillat, S., Gerber, J.-D., Oberlack, C., Zaehringer, J.G., Ifejika Speranza, C., Rist, S., 2018. Distant Interactions, Power, and Environmental Justice in Protected Area Governance: A Telecoupling Perspective. Sustainability 10, 3954. https://doi.org/10.3390/su10113954

Borma, L.S., Costa, M.H., da Rocha, H.R., Arieira, J., Nascimento, N.C.C., Jaramillo-Giraldo, C., Ambrosio, G., Carneiro, R.G., Venzon, M., Neto, A.F., van der Hoff, R., Oliveira, B.F.A., Rajão, R., Nobre, C.A., 2022. Beyond Carbon: The Contributions of South American Tropical Humid and Subhumid Forests to Ecosystem Services. Rev. Geophys. 60, e2021RG000766. https://doi.org/10.1029/2021RG000766

Brandon, K., 2014. Ecosystem Services from Tropical Forests: Review of Current Science. SSRN Electron. J. https://doi.org/10.2139/ssrn.2622749

Breslow, S.J., Sojka, B., Barnea, R., Basurto, X., Carothers, C., Charnley, S., Coulthard, S., Dolšak, N., Donatuto, J., García-Quijano, C., Hicks, C.C., Levine, A., Mascia, M.B., Norman, K., Poe, M., Satterfield, T., Martin, K.St., Levin, P.S., 2016. Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management. Environ. Sci. Policy 66, 250–259. https://doi.org/10.1016/j.envsci.2016.06.023

Carmenta, R., Zaehringer, J.G., Balvanera, P., Betley, E., Dawson, N.M., Estrada-Carmona, N., Forster, J., Hoelle, J., Lliso, B., Llopis, J.C., Menon, A., Moeliono, M., Mustin, K., Pascual, U., Rai, N.D., Schleicher, J., Shelton, C., Sigouin, A., Sterling, E.J., Steward, A.M., Tauro, A., White, C., Woodhouse, E., Yuliani, E. l., 2023. Exploring the relationship between plural values of nature, human well-being, and conservation and development intervention: Why it matters and how to do it? People Nat. 5, 1720–1738. https://doi.org/10.1002/pan3.10562

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Díaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J., Whyte, A., 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proc. Natl. Acad. Sci. 106, 1305–1312. https://doi.org/10.1073/pnas.0808772106

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosyst. Serv. 28, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

Cramb, R.A., Colfer, C.J.P., Dressler, W., Laungaramsri, P., Le, Q.T., Mulyoutami, E., Peluso, N.L., Wadley, R.L., 2009. Swidden Transformations and Rural Livelihoods in Southeast Asia. Hum. Ecol. 37, 323–346. https://doi.org/10.1007/s10745-009-9241-6

Dave, R., Tompkins, E.L., Schreckenberg, K., 2017. Forest ecosystem services derived by smallholder farmers in northwestern Madagascar: Storm hazard mitigation and participation in forest management. For. Policy Econ., Forest, Food, and Livelihoods 84, 72–82. https://doi.org/10.1016/j.forpol.2016.09.002

DeFries, R.S., Rudel, T., Uriarte, M., Hansen, M., 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nat. Geosci. 3, 178–181. https://doi.org/10.1038/ngeo756

Dewi, S., van Noordwijk, M., Ekadinata, A., Pfund, J.-L., 2013. Protected areas within multifunctional landscapes: Squeezing out intermediate land use intensities in the tropics? Land Use Policy 30, 38–56. https://doi.org/10.1016/j.landusepol.2012.02.006

Dong, X., Ren, J., Zhang, P., Jin, Y., Liu, R., Wang, X.-C., Lee, C.T., Klemeš, J.J., 2021. Entwining ecosystem services, Land Use Change and human well-being by nitrogen flows. J. Clean. Prod. 308, 127442. https://doi.org/10.1016/j.jclepro.2021.127442

Dressler, W.H., Wilson, D., Clendenning, J., Cramb, R., Keenan, R., Mahanty, S., Bruun, T.B., Mertz, O., Lasco, R.D., 2017. The impact of swidden decline on livelihoods and ecosystem services in Southeast Asia: A review of the evidence from 1990 to 2015. Ambio 46, 291–310. https://doi.org/10.1007/s13280-016-0836-z

Edwards, D.P., Socolar, J.B., Mills, S.C., Burivalova, Z., Koh, L.P., Wilcove, D.S., 2019. Conservation of Tropical Forests in the Anthropocene. Curr. Biol. 29, R1008–R1020. https://doi.org/10.1016/j.cub.2019.08.026

Edwards, G.A.S., Reid, L., Hunter, C., 2016. Environmental justice, capabilities, and the theorization of well-being. Prog. Hum. Geogr. 40, 754–769. https://doi.org/10.1177/0309132515620850

European Environment Agency, 2013. CICES. Towards a common classification of ecosystem services. [WWW Document]. CICES Common Classif. Ecosyst. Serv. URL http://cices.eu/ (accessed 11.16.15).

Fagerholm, N., Oteros-Rozas, E., Raymond, C.M., Torralba, M., Moreno, G., Plieninger, T., 2016. Assessing linkages between ecosystem services, land-use and well-being in an agroforestry landscape using public participation GIS. Appl. Geogr. 74, 30–46. https://doi.org/10.1016/j.apgeog.2016.06.007

Friis, C., Nielsen, J.Ø., Otero, I., Haberl, H., Niewöhner, J., Hostert, P., 2016. From teleconnection to telecoupling: taking stock of an emerging framework in land system science. J. Land Use Sci. 11, 131–153. https://doi.org/10.1080/1747423X.2015.1096423

Gardner, C.J., Nicoll, M.E., Birkinshaw, C., Harris, A., Lewis, R.E., Rakotomalala, D., Ratsifandrihamanana, A.N., 2018. The rapid expansion of Madagascar's protected area system. Biol. Conserv. 220, 29–36. https://doi.org/10.1016/j.biocon.2018.02.011

Gasper, D., 2007. Human Well-being: Concepts and Conceptualizations, in: McGillivray, M. (Ed.), Human Well-Being: Concept and Measurement. Palgrave Macmillan UK, London, pp. 23–64. https://doi.org/10.1057/9780230625600_2

Grêt-Regamey, A., Sirén, E., Brunner, S.H., Weibel, B., 2017. Review of decision support tools to operationalize the ecosystem services concept. Ecosyst. Serv., Putting ES into practice 26, 306–315. https://doi.org/10.1016/j.ecoser.2016.10.012

Haines-Young, R., 2023. Common International Classification of Ecosystem Services (CICES) V5.2 Guidance on the Application of the Revised Structure.

Hallaj, Z., Bijani, M., Karamidehkordi, E., Yousefpour, R., Yousefzadeh, H., 2024. Forest land use change effects on biodiversity ecosystem services and human well-being: A systematic analysis. Environ. Sustain. Indic. 100445. https://doi.org/10.1016/j.indic.2024.100445

Hasan, S.S., Zhen, L., Miah, Md.G., Ahamed, T., Samie, A., 2020. Impact of land use change on ecosystem services: A review. Environ. Dev., Resources Use, Ecosystem Restoration and Green Development 34, 100527. https://doi.org/10.1016/j.envdev.2020.100527

Heinze, A., Bongers, F., Ramírez Marcial, N., García Barrios, L., Kuyper, T.W., 2020. The montane multifunctional landscape: How stakeholders in a biosphere reserve derive benefits and address trade-offs in ecosystem service supply. Ecosyst. Serv. 44, 101134. https://doi.org/10.1016/j.ecoser.2020.101134

Holland, B., 2014. Allocating the Earth: A Distributional Framework for Protecting Capabilities in Environmental Law and Policy. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199692071.001.0001

Horcea-Milcu, A.-I., Leventon, J., Hanspach, J., Fischer, J., 2016. Disaggregated contributions of ecosystem services to human well-being: a case study from Eastern Europe. Reg. Environ. Change 16, 1779–1791. https://doi.org/10.1007/s10113-016-0926-2

Hunt, G., Leonard, S.N., 2023. The struggle for forest tenure in Myanmar: voices from the 2019 forest rules consultation. J. Land Use Sci. 18, 296–314. https://doi.org/10.1080/1747423X.2023.2241456

Junquera, V., Grêt-Regamey, A., 2019. Crop booms at the forest frontier: Triggers, reinforcing dynamics, and the diffusion of knowledge and norms. Glob. Environ. Change 57, 101929. https://doi.org/10.1016/j.gloenvcha.2019.101929

Kenney-Lazar, M., Wong, G., Baral, H., Russell, A.J.M., 2018. Greening rubber? Political ecologies of plantation sustainability in Laos and Myanmar. Geoforum 92, 96–105. https://doi.org/10.1016/j.geoforum.2018.03.008

Ketema, H., Wei, W., Legesse, A., Wolde, Z., Endalamaw, T., 2021. Quantifying ecosystem service supply-demand relationship and its link with smallholder farmers' well-being in

contrasting agro-ecological zones of the East African Rift. Glob. Ecol. Conserv. 31, e01829. https://doi.org/10.1016/j.gecco.2021.e01829
Khaine, I., Woo, S.Y., Kang, H., 2014. A study of the role of forest and forest-dependent community in Myanmar. For. Sci. Technol. 10, 197–200. https://doi.org/10.1080/21580103.2014.913537
King, M.F., Renó, V.F., Novo, E.M.L.M., 2014. The Concept, Dimensions and Methods of Assessment of Human Well-Being within a Socioecological Context: A Literature Review. Soc. Indic. Res. 116, 681–698. https://doi.org/10.1007/s11205-013-0320-0
Kusakabe, K., Chanthoumphone, C., 2021. Transition From Subsistence Agriculture to Rubber Plantations in Northern Laos: Analysis of Household Livelihood Strategies by Ethnicity and Gender. Sage Open 11, 21582440211011463. https://doi.org/10.1177/21582440211011463
Kusakabe, K., Myae, A.C., 2019. Precarity and Vulnerability: Rubber Plantations in Northern Laos and Northern Shan State, Myanmar. J. Contemp. Asia 49, 586–601. https://doi.org/10.1080/00472336.2018.1554161
Leakey, R.R.B., 2020. A re-boot of tropical agriculture benefits food production, rural economies, health, social justice and the environment. Nat. Food 1, 260–265. https://doi.org/10.1038/s43016-020-0076-z
Lessmann, O., Rauschmayer, F., 2013. Re-conceptualising Sustainable Development on the basis of the Capability Approach: a model and its difficulties. J. Hum. Dev. Capab. 14, 95–114.
Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., Hertel, T.W., Izaurralde, R.C., Lambin, E.F., Li, S., Martinelli, L.A., McConnell, W.J., Moran, E.F., Naylor, R., Ouyang, Z., Polenske, K.R., Reenberg, A., de Miranda Rocha, G., Simmons, C.S., Verburg, P.H., Vitousek, P.M., Zhang, F., Zhu, C., 2013. Framing Sustainability in a Telecoupled World. Ecol. Soc. 18.
Liu, L., Fang, X., Wu, J., 2022. How does the local-scale relationship between ecosystem services and human wellbeing vary across broad regions? Sci. Total Environ. 816, 151493. https://doi.org/10.1016/j.scitotenv.2021.151493
Liu, L., Wu, J., 2021. Ecosystem services-human wellbeing relationships vary with spatial scales and indicators: The case of China. Resour. Conserv. Recycl. 172, 105662. https://doi.org/10.1016/j.resconrec.2021.105662
Lliso, B., Arias-Arévalo, P., Maca-Millán, S., Engel, S., Pascual, U., 2022. Motivational crowding effects in payments for ecosystem services: Exploring the role of instrumental and relational values. People Nat. 4, 312–329. https://doi.org/10.1002/pan3.10280
Llopis, J.C., Chastonay, J.F., Birrer, F.C., Bär, R., Andriatsitohaina, R.N.N., Messerli, P., Heinimann, A., Zaehringer, J.G., 2021. Year-to-year ecosystem services supply in conservation contexts in north-eastern Madagascar: Trade-offs between global demands and local needs. Ecosyst. Serv. 48, 101249. https://doi.org/10.1016/j.ecoser.2021.101249
Llopis, J.C., Diebold, C.L., Schneider, F., Harimalala, P.C., Andriamihaja, O.R., Messerli, P., Zaehringer, J.G., 2022. Mixed impacts of protected areas and a cash crop boom on human well-being in North-Eastern Madagascar. People Nat. n/a, 1–18. https://doi.org/10.1002/pan3.10377
Llopis, J.C., Diebold, C.L., Schneider, F., Harimalala, P.C., Patrick, L., Messerli, P., Zaehringer, J.G., 2020. Capabilities Under Telecoupling: Human Well-Being Between Cash Crops and Protected Areas in North-Eastern Madagascar. Front. Sustain. Food Syst. 3. https://doi.org/10.3389/fsufs.2019.00126
Mandle, L., Shields-Estrada, A., Chaplin-Kramer, R., Mitchell, M.G.E., Bremer, L.L., Gourevitch, J.D., Hawthorne, P., Johnson, J.A., Robinson, B.E., Smith, J.R., Sonter, L.J., Verutes, G.M., Vogl, A.L., Daily, G.C., Ricketts, T.H., 2021. Increasing decision relevance of ecosystem service science. Nat. Sustain. 4, 161–169. https://doi.org/10.1038/s41893-020-00625-y
Martin, A., 2017. Just Conservation: Biodiversity, Wellbeing and Sustainability. Routledge, London. https://doi.org/10.4324/9781315765341

Martin, D.A., Llopis, J.C., Raveloaritiana, E., Coomes, O.T., Andriamihaja, O.R., Bruun, T.B., Heinimann, A., Mertz, O., Rakotonarivo, O.S., Zaehringer, J.G., 2023. Drivers and consequences of archetypical shifting cultivation transitions. People Nat. 5, 529–541. https://doi.org/10.1002/pan3.10435

Martin, D.A., Pham-Truffert, M., Gillham, L., Andriamihaja, O.R., Andriatsitohaina, R.N.N., Diebold, C.L., Fulgence, T.R., Kellner, E., Llopis, J.C., Messerli, P., Rakotomalala, A.A.N.A., Raveloaritiana, E., Wurz, A., Zähringer, J.G., Heinimann, A., 2024. Interactive visual syntheses for social-ecological systems understanding. Socio-Environ. Syst. Model. 6, 18637–18637. https://doi.org/10.18174/sesmo.18637

McMichael, A., Scholes, R., Hefny, M., Pereira, E., Palm, C., Foale, S., 2005. Linking Ecosystem Services and Human Well-being, in: Ecosystems and Human Well-Being.

Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well-being. A Framework for Assessment. [WWW Document]. URL http://www.millenniumassessment.org/en/Framework.html (accessed 5.20.16).

Morgan, D.L., Hoffman, K., 2018. Focus Groups, in: The SAGE Handbook of Qualitative Data Collection. SAGE Publications Ltd, London, United Kingdom.

Muche, M., Yemata, G., Molla, E., Adnew, W., Muasya, A.M., 2023. Land use and land cover changes and their impact on ecosystem service values in the north-eastern highlands of Ethiopia. PLOS ONE 18. https://doi.org/10.1371/journal.pone.0289962

Müller, D., Sun, Z., Vongvisouk, T., Pflugmacher, D., Xu, J., Mertz, O., 2014. Regime shifts limit the predictability of land-system change. Glob. Environ. Change 28, 75–83. https://doi.org/10.1016/j.gloenvcha.2014.06.003

Mutoko, M.C., Hein, L., Shisanya, C.A., 2015. Tropical forest conservation versus conversion trade-offs: Insights from analysis of ecosystem services provided by Kakamega rainforest in Kenya. Ecosyst. Serv. 14, 1–11. https://doi.org/10.1016/j.ecoser.2015.03.003

Nanhthavong, V., Oberlack, C., Hett, C., Messerli, P., Epprecht, M., 2021. Pathways to human well-being in the context of land acquisitions in Lao PDR. Glob. Environ. Change 68, 102252. https://doi.org/10.1016/j.gloenvcha.2021.102252

Nussbaum, M., 2007. Human rights and human capabilities. Harv Hum Rts J 20, 21.

Nussbaum, M., 1992. Human Functioning and Social Justice: In Defense of Aristotelian Essentialism. Polit. Theory 20, 202–246. https://doi.org/10.1177/0090591792020002002

Nussbaum, M., Sen, A. (Eds.), 1993. The Quality of Life. Oxford University Press. https://doi.org/10.1093/0198287976.001.0001

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Cáceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gómez-Baggethun, E., González-Jiménez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., van den Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Curr. Opin. Environ. Sustain. 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Polishchuk, Y., Rauschmayer, F., 2012. Beyond "benefits"? Looking at ecosystem services through the capability approach. Spec. Sect. Planet. Boundaries Glob. Environ. Gov. 81, 103–111. https://doi.org/10.1016/j.ecolecon.2012.06.010

Rasmussen, L.V., Coolsaet, B., Martin, A., Mertz, O., Pascual, U., Corbera, E., Dawson, N., Fisher, J.A., Franks, P., Ryan, C.M., 2018. Social-ecological outcomes of agricultural intensification. Nat. Sustain. 1, 275–282. https://doi.org/10.1038/s41893-018-0070-8

Raudsepp-Hearne, C., Peterson, G.D., Tengö, M., Bennett, E.M., Holland, T., Benessaiah, K., MacDonald, G.K., Pfeifer, L., 2010. Untangling the Environmentalist's Paradox: Why Is Human Well-being Increasing as Ecosystem Services Degrade? BioScience 60, 576–589. https://doi.org/10.1525/bio.2010.60.8.4

Robeyns, I., 2017. Wellbeing, Freedom and Social Justice: The Capability Approach Re-Examined. Open Book Publishers. https://doi.org/10.11647/obp.0130
Rodríguez-Loinaz, G., Alday, J.G., Onaindia, M., 2015. Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. J. Environ. Manage. 147, 152–163. https://doi.org/10.1016/j.jenvman.2014.09.001
Sangha, K.K., Le Brocque, A., Costanza, R., Cadet-James, Y., 2015. Application of capability approach to assess the role of ecosystem services in the well-being of Indigenous Australians. Glob. Ecol. Conserv. 4, 445–458. https://doi.org/10.1016/j.gecco.2015.09.001
Santillán-Carvantes, P., Tauro, A., Balvanera, P., Requena-Mullor, J.M., Castro, A.J., Quintas-Soriano, C., Martín-López, B., 2025. Impact of land transformation, management and governance on subjective wellbeing across social–ecological systems. Sustain. Sci. 20, 469–483. https://doi.org/10.1007/s11625-024-01584-5
Schleicher, J., Schaafsma, M., Burgess, N.D., Sandbrook, C., Danks, F., Cowie, C., Vira, B., 2018. Poorer without It? The Neglected Role of the Natural Environment in Poverty and Wellbeing. Sustain. Dev. 26, 83–98. https://doi.org/10.1002/sd.1692
Schlosberg, D., 2007. 4 Environmental Justice and Global Movements, in: Schlosberg, D. (Ed.), Defining Environmental Justice: Theories, Movements, and Nature. Oxford University Press, p. 0. https://doi.org/10.1093/acprof:oso/9780199286294.003.0004
Schneider, F., Feurer, M., Lundsgaard-Hansen, L.M., Win Myint, Cing Don Nuam, Nydegger, K., Oberlack, C., Nwe Nwe Tun, Zähringer, J.G., Aung Myin Tun, Messerli, P., 2020. Sustainable Development Under Competing Claims on Land: Three Pathways Between Land-Use Changes, Ecosystem Services and Human Well-Being. Eur. J. Dev. Res. 32, 316–337. https://doi.org/10.1057/s41287-020-00268-x
Sen, A., 1979. Equality of what? The Tanner lectures on human values; delivered at Stanford University, 22 May, published in 1980., in: McMurrin, S.M. (Ed.), Tanner Lectures on Human Values. University of Utah, Salt Lake City.
Smith, H.E., Ryan, C.M., Vollmer, F., Woollen, E., Keane, A., Fisher, J.A., Baumert, S., Grundy, I.M., Carvalho, M., Lisboa, S.N., Luz, A.C., Zorrilla-Miras, P., Patenaude, G., Ribeiro, N., Artur, L., Mahamane, M., 2019. Impacts of land use intensification on human wellbeing: Evidence from rural Mozambique. Glob. Environ. Change 59, 101976. https://doi.org/10.1016/j.gloenvcha.2019.101976
Song, W., Deng, X., 2017. Land-use/land-cover change and ecosystem service provision in China. Sci. Total Environ. 576, 705–719. https://doi.org/10.1016/j.scitotenv.2016.07.078
Thanasack, P., Michelotti, M., Epprecht, M., Heinimann, A., Zaehringer, J.G., 2026. Exploring household preferences for ecosystem services as a basis for strategic land use and conservation planning. Ecosyst. People 22, 2611227. https://doi.org/10.1080/26395916.2025.2611227
Van Der Meer Simo, A., Kanowski, P., Barney, K., 2019. Revealing environmental income in rural livelihoods: evidence from four villages in Lao PDR. For. Trees Livelihoods 28, 16–33. https://doi.org/10.1080/14728028.2018.1552540
van Eeuwijk, P., Angehrn, Z., 2017. How to...Conduct a Focus Group Discussion (FGD), Key Area of Activity (KAA-10): “Society, Culture and Health.” Swiss Tropical and Public Health Institute.
van Noordwijk, M., 2021. Agroforestry-Based Ecosystem Services. Land 10, 770. https://doi.org/10.3390/land10080770
van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., Adams, C., Schmidt-Vogt, D., Messerli, P., Leisz, S., Castella, J.-C., Jørgensen, L., Birch-Thomsen, T., Hett, C., Bech-Bruun, T., Ickowitz, A., Vu, K.C., Yasuyuki, K., Fox, J., Padoch, C., Dressler, W., Ziegler, A.D., 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. Glob. Environ. Change, Adding Insult to Injury: Climate Change, Social Stratification, and the Inequities of Intervention 22, 418–429. https://doi.org/10.1016/j.gloenvcha.2011.10.009

Vezina, B.I., Ranaivoson, A., Razafimanahaka, J.H., Andriafidison, D., Andrianirina, H., Ahamadi, K., Rabearivony, J., Gardner, C.J., 2020. Understanding Livelihoods for Protected Area Management: Insights from Northern Madagascar. Conserv. Soc. 18, 327. https://doi.org/10.4103/cs.cs_19_144

Voget-Kleschin, L., 2013. Employing the Capability Approach in Conceptualizing Sustainable Development. J. Hum. Dev. Capab. 14, 483–502. https://doi.org/10.1080/19452829.2013.827635

Vongvisouk, T., Broegaard, R.B., Mertz, O., Thongmanivong, S., 2016. Rush for cash crops and forest protection: Neither land sparing nor land sharing. Land Use Policy 55, 182–192. https://doi.org/10.1016/j.landusepol.2016.04.001

Vongvisouk, T., Mertz, O., Thongmanivong, S., Heinimann, A., Phanvilay, K., 2014. Shifting cultivation stability and change: Contrasting pathways of land use and livelihood change in Laos. Appl. Geogr. 46, 1–10. https://doi.org/10.1016/j.apgeog.2013.10.006

Wang, X., Dong, X., Liu, H., Wei, H., Fan, W., Lu, N., Xu, Z., Ren, J., Xing, K., 2017. Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China. Ecosyst. Serv. 27, 113–123. https://doi.org/10.1016/j.ecoser.2017.08.013

Wolff, N.H., Masuda, Y.J., Meijaard, E., Wells, J.A., Game, E.T., 2018. Impacts of tropical deforestation on local temperature and human well-being perceptions. Glob. Environ. Change 52, 181–189. https://doi.org/10.1016/j.gloenvcha.2018.07.004

Yee, S.H., Paulukonis, E., Simmons, C., Russell, M., Fulford, R., Harwell, L., Smith, L.M., 2021. Projecting effects of land use change on human well-being through changes in ecosystem services. Ecol. Model. 440, 109358. https://doi.org/10.1016/j.ecolmodel.2020.109358

Zaehringer, J.G., Llopis, J.C., Latthachack, P., Thein, T.T., Heinimann, A., 2018. A novel participatory and remote-sensing-based approach to mapping annual land use change on forest frontiers in Laos, Myanmar, and Madagascar. J. Land Use Sci. 13, 16–31. https://doi.org/10.1080/1747423X.2018.1447033

Zaehringer, J.G., Schwilch, G., Andriamihaja, O.R., Ramamonjisoa, B., Messerli, P., 2017. Remote sensing combined with social-ecological data: The importance of diverse land uses for ecosystem service provision in north-eastern Madagascar. Ecosyst. Serv. 25, 140–152. https://doi.org/10.1016/j.ecoser.2017.04.004

Supplementary Material

Supplementary Material S1. Nussbaum's central capabilities list (Nussbaum 2000) .

Central capabilities	**Definition**	**Probing components**
Life	Being able to live to the end of a human life of normal length; not dying prematurely, or before one's life is so reduced as to be not worth living.	Have a long life
Bodily Health	Being able to have good health, including reproductive health; to be adequately nourished; to have adequate shelter.	Good health
		Enough food
		House
Bodily Integrity	Being able to move freely from place to place; having one's bodily boundaries treated as sovereign, i.e. being able to be secure against assault, including sexual assault, child sexual abuse, and domestic violence; having opportunities for sexual satisfaction and for choice in matters of reproduction.	Security
Senses, Imagination, and Thought	Being able to use the senses, to imagine, think, and reason – and to do these things in a ''truly human'' way, a way informed and cultivated by an adequate education, including, but by no means limited to, literacy and basic mathematical and scientific training. Being able to use imagination and thought in connection with experiencing and producing self-expressive works and events of one's own choice, religious, literary, musical, and so forth. Being able to use one's mind in ways protected by guarantees of freedom of expression with respect to both political and artistic speech, and freedom of religious exercise. Being able to search for the ultimate meaning of life in one's own way. Being able to have pleasurable experiences, and to avoid non-necessary pain.	Express criticism
		Education
		Practice a religion
Emotions	Being able to have attachments to things and people outside ourselves; to love those who love and care for us, to grieve at their absence; in general, to love, to grieve, to experience longing, gratitude, and justified anger. Not having one's emotional development blighted by overwhelming fear and anxiety, or by traumatic events of abuse or neglect. (Supporting this capability	Family

	means supporting forms of human association that can be shown to be crucial in their development.)	
Practical Reason	Being able to form a conception of the good and to engage in critical reflection about the planning of one's life. (This entails protection for the liberty of conscience.)	Plan your own life
Affiliation	A. Being able to live with and toward others, to recognize and show concern for other human beings, to engage in various forms of social interaction; to be able to imagine the situation of another and to have compassion for that situation; to have the capability for both justice and friendship. (Protecting this capability means protecting institutions that constitute and nourish such forms of affiliation, and also protecting the freedom of assembly and political speech.) B. Having the social bases of self-respect and non-humiliation; being able to be treated as a dignified being whose worth is equal to that of others. This entails, at a minimum, protections against discrimination on the basis of race, sex, sexual orientation, religion, caste, ethnicity, or national origin. In work, being able to work as a human being, exercising practical reason and entering into meaningful relationships of mutual recognition with other workers.	Good social relations Be respected
Other Species	Being able to live with concern for and in relation to animals, plants, and the world of nature.	Nature / environment
Play	Being able to laugh, to play, to enjoy recreational activities.	Laugh / enjoy Free time
Control Over One's Environment	A. Political. Being able to participate effectively in political choices that govern one's life; having the right of political participation, protections of free speech and association. B. Material. Being able to hold property (both land and movable goods), not just formally but in terms of real opportunity; and having property rights on an equal basis with others; having the right to seek employment	Participate in decision-making in the village Have land Secure income Trust in the government

	on an equal basis with others; having the freedom from unwarranted search and seizure.	

References

Nussbaum, Martha C. 2000. *Women and Human Development: The Capabilities Approach*. Vol. 3. Cambridge university press.

Supplementary Material S2. Detailed workshop outline.

At the start of each workshop, we explained the goals and sought verbal consent for participation, audio recordings, and photographs.

(1) As a means of conceptualizing well-being, participants were asked to offer examples of how they define a "good life" in their village, with the aim of capturing “well-being components” needed to support such a good life locally. Recognizing potential methodological limitations in attempting a comprehensive identification of all crucial components for human well-being through entirely open questions (Abunge et al. 2013), we subsequently used additional probing questions derived from Nussbaum’s list of ten central capabilities.

(2) In Madagascar and Laos, after incorporating all the components deemed essential by participants for sustaining a good life in the village, we directed participants to assign relevance scores to these well-being components. Each participant was provided with five stickers and instructed to place them on the well-being components that they perceive as being the most important. This prioritization exercise defined which well-being components would be discussed in the subsequent phase. Due to time limitations, only five to eight well-being components could be discussed during each workshop, with the higher-ranked components being discussed first. In Myanmar, no such prioritization was done and all well-being components were discussed.

(3) During the in-depth discussions about the most important well-being components, participants were prompted to elucidate why a specific well-being component held significance for a good life in the village, exploring the value this component added to their well-being. Participants provided responses, which were recorded on a dedicated flipchart with distinct columns for each question. To delve deeper into the fundamental reasons behind the perceived importance of a particular component, we employed "iterative questioning" techniques (Schleicher et al. 2018), e.g. asking participants the "why of the why" (Alkire 2002; Finnis 2011) until further detailed explanations could no longer be provided.

(4) Next, the discussion shifted to have participants articulate the requirements for fulfilling the identified well-being component. (5) Participants were then prompted to deliberate on whether meeting a specific component's requirements was currently more, less, both more and less, or equally challenging compared to recent decades. Participants were asked to envision the well-being situation approximately 20 years ago, sometimes using well-known local and/or national events to help make sense of this time span, e.g., the moment that Masoala National Park was created in Madagascar (1997). (6) In order to complete the final column on the flip chart, participants were prompted to articulate and elucidate the reasons behind any change in their satisfaction with specific well-being components. (7) Finally, the workshop concluded by distributing three red and three green stickers to each participant. These stickers were designated for placement on the components deemed "most difficult to satisfy at the present time" and those currently perceived as "most satisfied at the present time", respectively red and green stickers.

References

Abunge, Caroline, Sarah Coulthard, and Tim M. Daw. 2013. “Connecting Marine Ecosystem Services to Human Well-Being: Insights from Participatory Well-Being Assessment in Kenya.” *AMBIO* 42 (8): 1010–21. https://doi.org/10.1007/s13280-013-0456-9.

Alkire, Sabina. 2002. “Dimensions of Human Development.” *World Development* 30 (2): 181–205. https://doi.org/10.1016/S0305-750X(01)00109-7.

Finnis, John. 2011. *Natural Law and Natural Rights*. OUP Oxford.

Schleicher, Judith, Marije Schaafsma, Neil D. Burgess, et al. 2018. “Poorer without It? The Neglected Role of the Natural Environment in Poverty and Wellbeing.” *Sustainable Development* 26 (1): 83–98. https://doi.org/10.1002/sd.1692.

Supplementary Material S3: Additional land use changes.

Land use change forest to shifting cultivation in Madagascar

In Madagascar, the land use change forest to shifting cultivation had a negative effect on eight out of 19 well-being components. Only the well-being components of social relations was positively affected. Four well-being components experienced a trade-off with both positive and negative effects from the land use change: nutrition, religion/traditions, agriculture, and income. The land use change thereby most negatively affected regulating ecosystem services and cultural ecosystem services, followed by provisioning ecosystem services. No direct impacts of the land use change on well-being were recorded.

This land use change negatively affected all regulation and maintenance ecosystem services, except for the regulation of soil quality. The most pronounced negative effect was on agriculture through decrease in erosion control, regulation of the hydrological cycle, temperature regulation, and wind protection. Nevertheless, the change also had a positive effect on agriculture by increasing the provision of fodder for livestock. Another important negative effect was on water, through the decrease in regulation of the hydrological cycle, temperature and water purification. Regulation of air quality and temperature negatively affected both health and recreation. Furthermore, the environment was negatively affected through the decline of wild animals for lifecycle maintenance and security was negatively affected through a reduction in erosion control. The land use change negatively affected provisioning ecosystem services linked to income through a decline in construction wood, firewood, honey, medicinal plants, wild animals, and wild animals for processing. The decline of medicinal plants also affected health, and the decline of honey affected nutrition, which was in turn affected by the decline of wild animals. Furthermore, the decrease in the availability of construction wood impacted on work and job opportunities. However, trade-offs were observed as nutrition and income were positively affected through an increase in fruits, vegetables, and rice. Four well-being components worsened due to a decline in the supply of cultural ecosystem services. This was mostly the case for the environment, through the decline in bequest value, existence value, aesthetic experience, and observing/experiencing nature, as well as for recreation through the latter two ecosystem services, as well as through a decline in recreational activities and places for recreation/enjoyment. Furthermore, religion/traditions were negatively affected through the declining cultural/traditional and spiritual value, and the bequest to descendants was negatively affected through a decline in bequest value.

Land use change paddy rice fields to other cash crops in Laos

Only a few impacts on well-being were recorded via ecosystem services for the land use change paddy rice fields to other cash cop plantations (commercial banana and sugar cane plantations) in Laos. Three dimensions were clearly negatively affected, one positively, and one mixed. Income experienced a trade-off as on the one hand, a decrease in rice had a negative effect (as rice from paddy fields is also commercialized), while an increase in cash crops had a positive effect (the latter is also true for work opportunities). A negative effect occurred on agriculture as livestock declined. Due to this decline in rice and livestock, nutrition also worsened. The increased use of fertilizers, pesticides, and herbicides negatively affected health, environment and agriculture (as soil quality strongly decreases in intensive monoculture banana plantations). Additionally, air pollution from burning plastic waste (banana

wrappings) worsened health and degraded the environment. As with the land use change shifting cultivation to rubber, the decrease of available agricultural land and increase in land rent negatively affected the well-being component of having land. The opportunity to lease out land to investors for banana plantations had a positive effect on income (additional income from lease) and recreation (less labor had to be invested). Similarly, land users who turned paddy rice fields into sugarcane plantations, which they continued to plant themselves, also observed positive effects on income and recreation (as lower labor inputs are required compared to paddy rice).