VU Research Portal

Operationalizing a land systems classification for Laos

Ornetsmueller, C.; Verburg, P.H.; Heinimann, Andreas

published in

Landscape and Urban Planning
2017

DOI (link to publisher)

[10.1016/j.landurbplan.2017.09.018](https://doi.org/10.1016/j.landurbplan.2017.09.018)

document version

Peer reviewed version

document license

CC BY-NC-ND

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Ornetsmueller, C., Verburg, P. H., & Heinimann, A. (2017). Operationalizing a land systems classification for Laos. *Landscape and Urban Planning*, 169, 229–240. [10.1016/j.landurbplan.2017.09.018].
<https://doi.org/10.1016/j.landurbplan.2017.09.018>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Manuscript Number: LAND-D-17-00117R1

Title: Operationalizing a land systems classification for Laos

Article Type: Research paper

Keywords: land cover; typology; mosaic; shifting cultivation; large scale
land acquisitions; agrarian transition

Corresponding Author: Ms. Christine Ornetsmüller,

Corresponding Author's Institution: VU University Amsterdam

First Author: Christine Ornetsmüller

Order of Authors: Christine Ornetsmüller; Andreas Heinemann, Dr.; Peter H
Verburg, Dr.

Abstract: Land cover data is widely used for the design and monitoring of land use policies despite the incapability of this type of data to represent multiple land uses and land management activities within the same landscape. In this study, we operationalized the concept of land systems for the case of the Lao PDR (Laos). Distinct land systems like shifting cultivation and plantations (land concessions) cannot be fully captured by land cover inventories alone, in spite of their relevance for land use policies. Using a decision tree and a matrix approach, we integrated several datasets for the period 2010/11, including land cover, an agricultural census and a land concession inventory. We selected thresholds for distinguishing land systems based on an expert survey. The resulting 17 land systems cover the whole territory of the Lao PDR and represents landscapes of 2x2 km pixel size. The largest area is occupied by smallholder agriculture land systems intertwined with forests. Only 27% of the territory are agriculturally undisturbed, dense forest systems. The assessment can serve as a basis to identify areas that could change shortly and locates the full range of land systems, from land concessions to smallholder systems, in one, integrated spatial assessment. The land system representation can help policy makers to link land systems to the diversity of different stakeholders and their backgrounds and support discussions about ecologic and socio-economic consequences of different land uses within a landscape.

1. Introduction

Land change and particularly the social dimensions of land change have repeatedly been identified as key leverage point to mitigate and adapt to global environmental change by designing sustainable and resilient landscapes (Davidson, 2016; Tscharntke et al., 2012; Turner, Janetos, Verburg, & Murray, 2013). Assessments of land change are important to identify unsustainable or vulnerable landscapes and monitor efficiency of adaptation and mitigation measures. The most common means of observation is remote sensing, therefore land cover is the most widely used type of data for land change assessments (Verburg, Neumann, & Nol, 2011; Verburg, Van de Steeg, Veldkamp, & Willemen, 2009). While remote sensing techniques are able to capture biophysical information at increasingly finer spatial resolutions and shorter time intervals, they insufficiently represent socio-economic aspects and differences in land use (Van Asselen & Verburg, 2012). A one-to-one translation is problematic since one type of land cover is in fact related to many functions and uses (Verburg et al., 2009). For instance, land covered with forest can be used for periodic timber extraction, wild food collection and recreation at the same time, while this cannot be inferred from satellite imagery. Furthermore, the same type of land cover (e.g. oil palm plantations) can be managed by different types of stakeholders (e.g. smallholders or large agribusinesses) who each are linked to different types of networks (kinship ties versus multinational corporate networks respectively). Again, this cannot be identified by remote sensing, or from already aggregated categories in land cover classifications. Thereby thematic and semantic inconsistencies propagate through to policy design if they are not taken into account in the interpretation of land change assessments (Comber, 2008; Comber, Wadsworth, & Fisher, 2008). Accompanying information is required to allow for a more

systemic representation of the multiple functions and actors related to land (Kruska, Reid, Thornton, Henninger, & Kristjanson, 2003; Verburg et al., 2009).

The land science community shifted its focus on analyzing *land systems*, a concept closely related with and often interchangeably referred to as coupled human-natural system, human environmental system (GLP, 2005) or socio-ecological system (SES) (Binder, Hinkel, Bots, & Pahl-Wostl, 2013; Lambin & Meyfroidt, 2010; McGinnis & Ostrom, 2014; Sakai & Umetsu, 2014). Broadly defined, land systems ‘*represent the terrestrial component of the Earth system and encompass all processes and activities related to the human use of land, including socioeconomic, technological and organizational investments and arrangements, as well as the benefits gained from land and the unintended social and ecological outcomes of societal activities*’ (Verburg et al. 2013, p. 433). In short, land systems capture the ecological and socio-economic characteristics of land but spatially explicit data describing land systems are not collected as a single dataset to date. Instead, to prepare a land systems classification several, independently collected datasets need to be integrated. In order to characterize land systems with their socio-ecologic characteristics and multifunctionality, data that is collected for different purposes needs to be integrated. Applications of concepts that better illustrate human-environment interdependencies have focused on the continental to global scale and include, among others, the Anthromes framework (Ellis & Ramankutty, 2008), a global mosaic land systems representation (Van Asselen & Verburg, 2012) and Land System Archetypes (Václavík, Lautenbach, Kuemmerle, & Seppelt, 2013).

Assessing land systems becomes especially critical at scales above the sub-national level (Boillat et al., 2015; Messerli, Bader, Hett, Epprecht, & Heinimann, 2015; Schmidt-Vogt et al., 2009). At these larger spatial scales land cover data often becomes aggregated to larger units, while losing

the mosaic of different, functionally important land use and land cover types (Verburg et al., 2011). Farming systems shape the diversity of land cover and land systems to a large degree (Van der Ploeg and Ventura 2014). However, the coarseness of global assessments often neglects the farming system diversity relevant within a country and may not address the types significant to national policy making. Typologies of farming systems have been created in the past (see Kruska et al. 2003 for an overview; and van de Steeg et al. 2010 for an application in Kenya) but as they focus on agricultural systems alone they often do not show the links of agriculture with forest systems or other land uses. For sustainable landscapes that are adapted to the politically relevant, socio-economic setting of an area, assessments are needed that include the types of land use relevant at the spatial scale of land change policies and land management (Moran, 2010). In other words, the land systems concept needs to be operationalized at a politically relevant scale to be effective in serving the creation and revision of land use policies beyond the information that land cover datasets and analyses can convey. Choosing an appropriate scale of analysis is not trivial because there may be a difference between the scales at which end users require spatially explicit information and the scales at which the processes take place (Van Delden, Van Vliet, Rutledge, & Kirkby, 2011). We argue, that for the land systems concept to be adopted in practice, the needs of end users (i.e. policy makers) should be the point of departure. Covering the spatial extent of their interest and the types of land uses occurring in this area is essential. What scale can be identified as politically relevant further depends on the governance structure of the respective place. For many locations, country scale assessments represent the highest level of autonomy and control regarding land use policies. This is also the case for the Lao People's Democratic Republic (Laos) where the socialist government form implies centralized planning

and policies, even if bottom-up, participatory planning has been part of local land governance too (Sandewall, Ohlsson, & Sawathvong, 2001).

In Laos, like in other tropical regions, there are specifically two land system types that are important for current land use policies but cannot be monitored fully with land cover information alone: shifting cultivation (Schmidt-Vogt et al., 2009), and land concessions (Schönweger et al. 2012). Land concessions are frequently large in area, granted to foreign investors and therefore referred to as large scale land acquisitions (LSLA). In shifting cultivation, active agricultural use of a plot alternates with periods of forest regrowth for sometimes more than ten years (Ducourtieux, Laffort, & Sacklokham, 2005). As it is a very dynamic land use, that requires wide areas for a full cropping cycle it normally requires a time series of comparable land cover data (Hurni, Hett, Heinimann, Messerli, & Wiesmann, 2012). Hurni et al. (2013) developed a texture-based technique using land metrics to identify the extent of shifting cultivation based on a single remote sensing dataset alone. However, this method is of limited accuracy in mountainous terrain, broad land cover categories and areas of heterogenous land uses (Hurni et al., 2013). Land cover classifications often lack a clear category on shifting cultivation, because it is challenging to identify it completely with remote sensing. Instead, shifting cultivation is scattered over several classes, which are named in a way that masks the (temporary) agricultural use of the respective area such as ‘unstocked forests’, ‘secondary forests’, ‘shrub’, or ‘open forest’. This is one of the reasons, why quantification of the extent and location of shifting cultivation landscapes is difficult with land cover data (Heinimann et al., 2013; Heinimann, Messerli, Schmidt-Vogt, & Wiesmann, 2007; Mertz, Leisz, et al., 2009; Padoch et al., 2007; Schmidt-Vogt et al., 2009). Likewise, land concessions are not easily and clearly captured in land cover assessments and it is challenging to distinguish their characteristics from smallholder

farming with similar crops or from forests. In Vietnam for example, recent reforestation occurred due to commercial tree plantations (Meyfroidt, Vu, & Hoang, 2013). While both natural reforestation and commercial tree plantations lead to a forest land cover they imply different management and biodiversity characteristics. Furthermore, land for which concessions were obtained does not necessarily exhibit immediate land cover change since some investors keep the land for speculation (Anseeuw et al., 2012). Yet, this land is unavailable to smallholders or other users.

For Laos, an assessment that includes both shifting cultivation and land concessions (LSLA) with information complementary to land cover is needed, since these land uses are part of two ongoing processes with long lasting effects: (i) the agrarian transition from subsistence to market oriented economy by an increase of cash cropping (Baird, 2009; Castella, Lestrelin, & Buchheit, 2012; Thongmanivong, Yayoi, Phanvilay, & Vongvisouk, 2009) and (ii) telecoupled land acquisitions (Friis, Nielsen, Otero, Haberl, & Hostert, 2015; Friis & Østergaard Nielsen, 2016; Liu et al., 2013).

The objective of this study is to operationalize the concept of land systems by developing a national scale representation of land systems for the case of Laos that captures different types of agricultural and forest systems. To achieve this, we integrated land cover data with an agricultural census and maps of land concessions from which we created a typology with 17 land systems. In this article, we present our data integration approach, describe the mapping result in relation to other land change assessment products and discuss the result as a basis for widening policy debates towards a systemic ‘land system’ view on land in Laos.

2. Material and methods

2.1.Data

The major land uses and land cover, that shape the largest part of Laos include forest cover, large scale land acquisitions (LSLA, hereafter called land concessions) and different forms of smallholder cropping systems (shifting cultivation, permanent cultivation and a mixed form of them labeled as transition from subsistence to cash cropping). Urban areas are taken into account as well, however, in Laos their size and influence relative to agricultural and forested areas is marginal, hence we did not focus on their role in this study. In order to create a typology of the major land systems we combined essentially three main datasets (land cover inventories, agricultural census, and land concessions inventory) and two auxiliary datasets (water bodies and accessibility in terms of travel time to next village) as listed in Table 1.

Together, the datasets reflect the land system situation for the period 2010 to 2012. The original datasets differed in their basic geometry and spatial units of reference. While forest cover, land concessions and water bodies (partly) had original geometries displaying physical units or plot level tenure information, the agricultural census data refers to ‘village polygons’ that have been created for the population, poverty and agricultural census due to a lack of official, clearly mapped administrative boundaries in Laos as explained in detail in Epprecht et al. (2008), Messerli et al. (2008), and Heinimann et al. (2013). This implies that information from the agricultural census represents village level aggregates, rather than individual plot level data. In order to improve the spatial accuracy of three particular land systems (further explained in section 2.2) we employed a derivate of accessibility (based on cost distance functions) indicating a travel time of less than 2 hours to the closest village. The location and extent of land

154 concessions were in the best case available as actual polygons of granted land concessions, in
155 many cases however, only the GPS points of the concession project was available around which
156 the granted area is shown as a buffer. We created the dataset ‘water bodies’ by merging
157 hydrological features of a Russian, digitized topographic map with reservoirs for hydropower
158 projects until the year 2012 that are greater than 500 hectares. Parts of the country borders are
159 under negotiation: at the northwestern border with Thailand and in the South with Cambodia.
160 The classification covers the area intersecting all versions of the country boundaries i.e. the least
161 common denominator. To correct for missing data for an area in the very South of Laos, we
162 complemented the 2010 forest cover with a corresponding dataset from 2002. We cleared the
163 land concession dataset from small holdings below 10 hectares, to only represent large scale land
164 acquisitions.

165 The guiding principle for this classification was to characterize land systems that reflect the
166 major agricultural and silvicultural land use practices in Laos. Next to representing land
167 concessions and dense forest we aimed at representing the two very distinct types of cropping
168 systems by smallholders: shifting cultivation and permanent cultivation. To represent shifting
169 cultivation, we selected the variable ‘upland rice’ (ur) from the agricultural census (village level
170 data) as a proxy, since the majority of slash-and-burn areas are used to grow this crop. The
171 census contains a direct question to farmers, whether they practice shifting cultivation. However,
172 this variable is questionable and loaded with uncertainty as farmers are aware of the
173 controversial practice and government strategy to eradicate shifting cultivation. In this study,
174 permanent cultivation describes the opposite of shifting cultivation as an umbrella term that
175 expresses smallholder farming for which the same plot of land is repeatedly used without fallow
176 periods and forest regrowth. It is thus a more intense form of land use. We assessed the

dominance of permanent cultivation within a village by subtracting shifting cultivation from the variable ‘total agriculturally used land’ (ta). To reflect the cropping system that is most dominant in a village, we built a ‘cropping system ratio’ (r) as a variable for the classification algorithm by calculating $r = ur/(ta - ur)$. High values of this ratio indicate a large proportion of shifting cultivation and low values direct towards a dominance of permanent cultivation in a village.

Table 1. Data integrated in land system classification

Data set	Components used	Year	Geometry	Source
Land cover	rock	2010*		GoL 2010*
	urban		original shapes	GoL 2002*
	forest cover	2010, 2002*		
Inventory of land concessions	mining		original shapes (polygons	Schönweger et al. 2012
	tree plantations	2012	and buffered	
	agricultural plantations		points)	
Village level census of agriculture	upland rice	2010/2011	village polygons	GoL 2012
	agriculturally used land			
Water bodies	large rivers and lakes	1980	original shapes	Russian topographic map 1:100k
	hydro power reservoirs	2012		World Bank 2010
Accessibility	travel time >2h from village center	2011	raster, 50m original resolution	CDE Bern, CH

Projection of all datasets: WGS84, UTM 48N.

* land cover 2010 based on ALOS/AVNIR (10-meter resolution), land cover 2002 based on SPOT 4 (10-meter resolution)

We harmonized the geometry of the remaining datasets by first converting them to raster format (cell size: 100 by 100 meters). In a second step, we calculated the percentage of land cover, land concessions and water components within a 2000 by 2000 meters cell (400 ha) by employing a

spatial aggregation function based on a weighted mean. This cell size was assumed to sufficiently address the small village structure within Laos while at the same time fulfilling the need of a landscape meso-level perspective required for the mosaic of land uses and covers that land systems contain. This way, the mosaic becomes effective by relating smaller land cover and land use components to each other within a larger unit.

2.2. Decision tree

The classification approach consists of a decision tree based on hierarchical, heuristic rules that identified land systems by their most dominant ecologic or socio-economic components. As illustrated in Figure 1, the decision tree includes a forest-cropping-system matrix (FCS matrix) to systematically define land systems with different degrees of forest cover (x-axis) and the ratio of cropping-systems (y-axis) that indicates whether the land system is dominated by shifting cultivation, a mix of shifting and permanent cultivation (often indicative for situations undergoing a transition of agricultural practices), or permanent cultivation. The cropping system ratio applies to the whole village area (see details in section 2.1.). However, in the remoter part of a village, permanent cultivation is unlikely to be practiced due to long transportation and travelling times. For shifting cultivation, in turn, this is not applied because the practice requires to include more land, often located on steep slopes (Castella, 2012). To be less limited by accessibility, farmers use temporary housing facilities similar to camps during times of work on remote plots. Hence, we only restricted the occurrence of permanent cultivation land systems to areas that are accessible within two hours of a village center.

We chose the classification thresholds in line with our objective to represent the different degrees of forest cover and types of agriculture in Laos that may shape the character of a landscape scale system ecologically and economically. We set a rather strict, high threshold for dense forests at more than 70% in order to capture systems and areas that are really covered mostly with forest. Land concessions influence the socio-economic characteristics of an area strongly. Smallholders may become laborers at a plantation, and/or harness the incentives provided by a closeby production unit such as farm inputs, logistics or processing plants and thereby facilitating smallholder cash crop booms (Cramb, Manivong, Newby, Sothorn, & Sujang, 2015); In a different trajectory, smallholders become displaced by large scale land acquisitions (Baird & Fox, 2015). While representing the exact implications of land concessions is beyond the scope of this study, we argue that land concessions should at least be recognized and visible in the classification given their different and substantial potential impacts. Likewise, we suggest that urban areas, waterbodies and rocky areas may be small in extent, but strongly influence the socio-ecologic character of a land system. The thresholds to represent these in our relatively large pixels, therefore, needed to be low. To guarantee graphical visibility on the classification map we (arbitrarily) chose 20-25% for land uses and land covers with small extent but high impact.

Figure 1. Forest-Cropping-System (FCS) matrix as part of the decision tree. Thresholds are expert verified.

2.3.Expert survey

Validation technically reflects on how far the outputs are appropriate regarding the intended purpose of the analysis rather than being an activity to test perfection (Van Vliet et al., 2016). For typologies, validation can only be an evaluation in how far the output represents the essential characteristics of the land systems and in how far it is recognizable and useable by those that are working on land systems in the region. The land systems defined by the FCS matrix in this study have proportionally the largest influence on the total classification output. Therefore, we conducted an expert based verification of the thresholds for the thresholds underlying the FCS matrix through a survey. This way we wanted to make sure that the identified land systems correspond with the general notion experts have of these systems. The experts addressed were researchers or land use professionals knowledgeable of land system change in Laos (n=15, response rate 66%). The survey included background information on the aim of the classification, the data and the concept of the FCS matrix. Six different threshold combinations were assessed based on the spatial outcomes of these combinations. The respondents evaluated six respective output options by seeing maps for the whole territory of Laos and one close up from the north and south of Laos each. The thresholds of the two variables (i) cropping system ratio and (ii) forest cover share were not provided in a numerical form in order to avoid bias and misunderstanding towards figures known by the experts from land cover assessments. Instead, the survey showed the relative proportion of the components in each land system visually next to the maps. The threshold combination ranked highest by all experts was finally selected and used as shown in the decision tree (Figure 1). This depicts the method underlying the final classification outcome.

3. Results

3.1. Land systems classification

The land systems (LS) map contains 17 classes of which 9 classes stem from the FCS matrix and are largely land systems dominated by smallholder agriculture and forest fractions (Figure 2).

The classification includes three LS categories that are neither silviculturally nor agriculturally dominated (rocky, bare systems; urban systems; systems dominated by water bodies). Three further LS categories are related to different land concession types (tree plantation, arable plantation and mining). One category denotes dense forest systems (>70% forest cover). The class '*other land systems*' contains very remotely located systems in rugged terrain, with uncertainty of a clear farm style and vegetation type. The '*other land systems*' often co-occur with permanent agriculture because in the decision tree they stem from the same tributary as permanent cultivation. These places are, however, further than 2 hours travelling time away from the village center, implying that the effort to permanently crop these is probably too high. We suspect that the other systems could be used for shifting cultivation and/or grazing areas for livestock in the outskirts of villages which are dominated by permanent agriculture.

The distribution and spatial patterns of land systems in the country are displayed in the maps of Figure 2 to Figure 4. The spatial patterns largely correlate with characteristics of the terrain and population density (Figure 2). While there are many shifting cultivation landscapes in the uplands of northern Laos, the center and South are dominated by permanent cultivation LS in the lowlands of the Mekong river and its tributaries. In the North, land concession LS (mining and tree plantations) are clustered towards the boundaries with China/Myanmar and Vietnam. In the

South, the land concession LS (arable and tree plantations) are also clustered but more widely scattered in the interior of the country. The land concession LS are both embedded with smallholder LS and occur directly adjacent to dense forest LS – they also sometimes reach into protected areas (Figure 3, Panel B). Protected areas (PA) largely contain dense forest LS, but contrary to common expectations also some permanent and shifting cultivation LS appear within their boundaries (Figure 3, Panel B and C). The category Other LS occurs in hotspots in the center (Figure 2) and largely appear in rugged terrain, adjacent to permanent cultivation LS and dense forest LS.

Focusing on quantitative distributions, Figure 4 and Table A.1 in the Appendix show how much space of the territory of Laos each land system occupies. The FCS matrix is by far the largest group of systems making up 95% of the area of Laos, composed by dense forest LS (27%) which imply little ‘human disturbance through agriculture’ and smallholder LS (58%) which imply a mixed silvi- and agricultural composition. Disentangling the smallholder LS further, we can see that the cropping system groups and forest coverage groups are almost equally distributed (Figure 4, Panel C and D). Only the group of transition LS is rather small. Overall though, the classification shows a similarly strong representation of the diverse land system groups.

Figure 2. Land systems classification for Laos based on agricultural census, land cover and land concession maps representing the year 2010/11.

Figure 3. Close-ups of the land system classification in northern (panel A) and southern Laos (B) and a stencil overlay covering the areas outside of national protected areas (NPA, panel B and C).

Figure 4. Distribution of land systems (LS) by area in percent. Panel A: all land systems and smallholder systems in detail. Panel B: Legend on the smallholder systems, dense forest and other LS. Panel C: area by forest coverage groups. Panel D: area by cropping system groups.

4. Discussion

4.1. Land systems classification

The land systems classification resulting from this study includes several land uses that previously were represented by separate datasets or not represented at all. It reflects land uses

such as shifting cultivation that have long prevailed in Laos but are difficult to assess with classic land cover maps. The approach used, systematically combines land cover, agricultural census data and a land concession inventory into one mapping product that offers opportunities to distinguish essential ecological and socio-economic dimensions of land and the different actors or land managers involved (e.g. smallholders or agribusinesses).

The problems to locate and monitor shifting cultivation have been widely discussed (Fox & Vogler, 2005; Mertz, Padoch, et al., 2009; Schmidt-Vogt et al., 2009). In land cover assessments, the full shifting cultivation system is divided between categories of agricultural land and categories of vegetation types associated with forests such as shrub, bush, unstocked forest or secondary forest that altogether are different stages of fallow. Bringing an agricultural census with forest cover together as put forward by Schmidt-Vogt et al. (2009), we assign shifting cultivation into dedicated classes, that also reflect different degrees of forest cover from shifting cultivation with less than 10% forest to forest-shifting cultivation with 30-70% forest cover.

In using the classification, it has to be kept in mind that it is a diagnostic, descriptive assessment of one snapshot in time. As Boillat et al. (2015) mentioned, meso-scale analyses are not capable to make statements about details of local conditions but they can lay out the scope of contexts for studies at finer scales. This typology can, therefore, be the basis for systematic selection of case study sites for more specific analyses e.g. of places that may be in transition from shifting cultivation to permanent cultivation or places that constitute a forest frontier. Many case studies on the agrarian transition in Laos (e.g. Vongvisouk et al., 2014) report that land use portfolios are mixed and shifting cultivation is still relatively dominant while permanent cropping (paddy rice, cash-cropping) has increased. This is reflected in the *transition LS* classes, where shifting and

permanent cultivation are almost equally present according to the cropping ratio that we calculated based on data from the agricultural census. These classes may signal places of socioeconomic change with related consequences for livelihoods and environment, e.g. higher incomes due to permanent cultivation and higher rates of permanent deforestation. Whether changes in land use have happened or will happen needs to be investigated with other methods and/or further data that are suited to make statements about change.

The land systems with high forest shares such as forest-shifting cultivation, forest-transition and forest-permanent cultivation may contain agricultural and forest frontiers i.e. places of tension and change of land use, social, political or economic conditions (Hirsch, 2009). The land systems with land concessions, in turn, indicate that large-scale land acquisitions by either foreign or domestic investors have taken place.

The overlay of the land systems assessment with areas where specific land policies apply, such as protected areas (Figure 3) can provide insight in the success of these land policies. It may, for example reveal the multiple purposes for which these areas are used, despite the restrictions on several land uses. Protected areas (PA) are not necessarily made up of undisturbed forests, neither in Laos nor in many other protected areas worldwide (Heino et al., 2015). If only analyzed with a land cover product, the state of deforestation in these areas could have been detected, but the diversity of ‘disturbing uses’ would have been invisible. Land cover categories would have masked the existence of land concessions within protected areas and the relevance of protected areas for the local livelihoods of shifting cultivators and permanent cultivators (Ducourtieux et al., 2005).

4.2. Accuracy and Validity

Conducting spatially explicit assessments of the validity of land systems classifications is hardly possible in the same way as in remote sensing and land use modelling (Malek & Verburg, 2017). On the one hand, each land system classification is slightly different because they are built for different purposes, scales and land use contexts (Van de Steeg et al., 2010; Verburg et al., 2011). On the other hand, land systems can be classified only based on the available data at the required spatial extent (Van der Zanden, Levers, Verburg, & Kuemmerle, 2016). While there are generally options for cross-checking the accuracy of the biophysical features e.g. forest cover, there are hardly any spatially explicit datasets covering wide areas that could serve to independently assess the functions, uses and other socio-economic dimensions implicit to the characteristic management type of a landscape. Despite these constraints, we provide alternatives to evaluate the land systems classification of this study by discussing the uncertainties of the input data, the impacts of spatial resolution and compare the classification result to a national mapping of mosaics by Messerli et al. 2009 and to remote sensing studies on shifting cultivation by Hurni et al., (2012) and Li & Feng (2016). Finally, we zoom in on two areas to see in how far the classification matches with examples of case study research on shifting cultivation and the agrarian transition.

The quality of the input data largely influences the quality of the outcome. Each dataset contains uncertainties inherent to the nature of the study subjects and the different methods with which they have been observed. The agricultural census and land concessions are declarative data and hence may be subject to underestimation, particularly shifting cultivation and land concessions. Spatial aggregation was necessary due to the different geometries of the input data, but it very

likely smoothened outliers and the value range within each dataset. Given the unit of representation at a 2x2 km pixel (i.e. 400 ha per cell), we consider most of these uncertainties to have a rather small influence on the overall outcome. If a coarser resolution was applied, it would have increased the sensitivity of thresholds for land systems determined by features of small extent but big impact (e.g. land concessions, urban area). These land systems would have been either represented as disproportionally large patches or not at all. This shows, that care must be taken when classification thresholds are applied to a different resolution. If a finer resolution was applied, small features and heterogeneity could be better represented but the land systems could become mistaken for actual land use/land cover on the plot level and complex land systems such as shifting cultivation misrepresented. Therefore, the unit of representation (2x2 km pixel) was chosen to support an integrated landscape perspective rather than detailed plot-level planning.

We compare the land systems classification to the approach and result by Messerli, Heinemann, & Epprecht (2009) who also aimed at characterizing landscapes of Laos at the meso-scale. Using land cover data of 2002, they first determined the composition of land covers surrounding a cell and found typical land cover combinations (patterns). In a second step, they interpreted the patterns as landscape mosaics of different agricultural intensity (from no use to permanent agriculture) and different levels of degradation of the vegetative land cover. Interestingly, despite their different approach and input data, they arrived at similar estimates for the extent of shifting cultivation landscapes (28.2%), permanent agricultural landscapes (29.6%) and (dense) forests (31%) as we found with 25%, 24% and 27% respectively. Both assessments contain categories

which the other one does not classify, e.g. grasslands in Messerli et al. (2009) versus systems in transition and concessions in our study. Consequently, an exact comparison is not possible.

Specific assessments of shifting cultivation show an overall fit of the spatial patterns of shifting cultivation in Laos. For example, Hurni et al.(2012) have assessed stability and change of shifting cultivation landscapes in northern Laos from 2002 to 2006. The spatial pattern resulting from their approach matches the shifting cultivation identified here. Only in the northwest, where Laos borders Myanmar, Hurni et al. 2012 find less shifting cultivation dominated areas than our study does. Li & Feng (2016) have recently estimated the extent of shifting cultivation in montane mainland southeast Asia with a remote sensing approach. Their estimates are very dependent on the delineation of mountainous area, however, the generous delineation (LER300) fits with the general predominance of shifting cultivation in northern Laos. A more detailed comparison would have been desirable but was hampered by the lack of statistics on the country level.

Another alternative to evaluate the classification is to use place based case studies (Malek & Verburg, 2017). We confront the classification with outcomes of a study by Vongvisouk et al. (2014), who collected perceptions of villagers in focus group discussions and interviews on current land use in 2010 and land use change from 2000-2010. They analyzed the places shown in Figure 5 with Sopxim and Thasae (=Namha) village in Nam Tha district and Keoxik and Houaymoun village in Hua Meuang district. The results in the study by Vongvisouk et al. (2014) are presented as summaries for the two villages, therefore the comparisons that can be made here indicate the sum of the two villages respectively. According to Vongvisouk et al. (2014), the land use portfolio of Sopxim and Thasae village together consists of roughly 70% shifting cultivation

(30% upland rice fields plus 26% young and 13% old fallow) while 24% of the agriculturally used land can be categorized as permanent cultivation (15% plantations, 7% paddy and 2% cash crops). Cumulated, this is roughly reflected in the land system classification, where Thasae village is characterized by forest-shifting cultivation and mainly forested areas. Sopxim village in turn, contains transition LS, shifting cultivation and shifting cultivation mosaic, forest-permanent cultivation and permanent mosaics indicating the influence of plantations as well as the importance of shifting cultivation for rice-self-sufficiency.

In Keoxik and Houaymoun villages, Vongvisouk and colleagues reported an almost equal share of shifting cultivation (44%) and permanent cultivation (43%) area. There is little fallow area left (38% upland rice, ca. 3% young fallow and 3% old fallow), suggesting that shifting cultivation is practiced intensely. Altogether, this matches with the types of land systems occurring in the land systems classification where Keoxik and Houaymoun villages are both characterized by the LS ‘permanent cultivation’ and ‘permanent cultivation mosaics’. The outskirts of the villages are covered by ‘transition mosaic’ and ‘other land systems’. These indicate that permanent cultivation and shifting cultivation are almost equally present.

Figure 5. Location of two case study areas by Vongvisouk et al. 2014 within the land system classification.

4.3. Comparison of land systems and land cover assessments

To illustrate the thematic difference a land system typology makes as compared to land cover typologies and point towards the caution needed when interpreting land (change) assessments, we compare the Land Systems assessment of this study (LS assessment) with other, global scale land cover assessments (Figure 6). The land cover products shown here (Panel A and C) operate at different spatial resolutions and partly different time steps than the LS assessment of this study (Panel B). Therefore, we only compare them in overall thematic resolution and how this affects the type of interpretation that is possible with these land assessments.

Figure 6. Comparison of land cover assessments GLOBCOVER 2009 (Panel A) and GLC 2000 (Panel C) with land system classification (Panel B, this study). For the legend of the land systems see Figure 2 or 3. To ease the comparison, the datasets with global coverage are displayed in Panel A and C only for the territory of Laos.

According to the GLOBCOVER 2009 assessment (Arino et al., 2012) (Panel A), Laos is mostly covered by '*Closed to open broadleaved evergreen or semi-deciduous forest*' (dark green), '*Closed to open shrubland*' (dark brown) and, to a smaller extent, by '*Rainfed Croplands*' (yellow) and '*Mosaic Croplands/Vegetation*' (very light green). In this representation, it is not possible to distinguish what type of farm style the forestlands or shrublands are used for. Hence, the degree or type of forest 'disturbance' by agriculture is not deductible and vice versa; not much can be said about the location and extent of 'pristine, undisturbed' forests.

The GLC 2000 assessment (Bartholomé & Belward, 2005) (regionally optimized version for Southeast Asia, Panel C) shows the land cover of Laos more nuanced in terms of forest cover and has overall a better thematic fit with the LS assessment. '*Tree cover closed and closed to open*' (dark green) reflects the quite strict '*dense forests*' of the LS assessment which signals low degree of human (agricultural) disturbance. Spatially, there are differences though. While the '*closed tree cover*' class of GLC 2000 largely covers similar areas of 'dense forest' in the south of the LS assessment, in the north, the GLC 2000 identified 'dense forest LS' as '*mosaic tree cover with other vegetation including very degraded tree cover*'. Here, it becomes apparent that the differences in type and quality of vegetation cover are not represented in the LS assessment in detail. The GLC 2000 does include several mosaics; it is however ambiguous and inconsistent in indicating sometimes the type of cropping system (shifting cultivation) or even a particular crop (shrimp farming, rice) and other times only generally refers to cropland. While both land cover assessments depict agricultural intensity by distinguishing irrigated or rainfed cropland, neither of the two represents plantations (often industrialized agriculture) nor areas of

agricultural transition in which extensive farming (shifting cultivation) is changing to intensive farming (permanent cultivation).

4.4 Potential use

This study provides the first, national scale assessment of major land systems including land concessions and shifting cultivation in the Lao PDR for the year 2010 given the dates of the main input data. It follows the call by Schmidt-Vogt et al. (2009) for more accurate analysis of shifting cultivation on country to regional scales by valorizing agricultural censuses and integrating it with land cover data. This work tackles the problem to assess the extent of shifting cultivation area, which is common to all tropical forest-agriculture frontiers globally (Van Vliet et al., 2012).

The land systems typology has potential to be a boundary object (Carlile, 2002) for policy debates, i.e. a concrete, tangible land assessment product to stimulate normative discussions about ecologic and socio-economic consequences of different land uses. It can bring scholars of agriculture, forestry, economics and socio-economic development together and provide one spatial product to facilitate a focused debate rather than distributing attention among three or more datasets. We provide a kml file for visualization e.g. in Google Earth, see Appendix B).

The use of integrated products that enable decision makers to account for multifunctionality and different actors involved in land systems is paramount for landscapes and land systems irrespective of the location of a study. Additionally, the land systems map enables to better model the multi-functionality of land. The LS classification has already been used for this purpose by Ornetsmüller et al. (2016). We encourage further analysis towards a quantification of

the ecosystem services each Land System can provide such as flood regulation, carbon sequestration or biodiversity.

5. Conclusions

The mapping of land systems in this paper advances the representation of land towards a socio-ecological systems perspective by operationalizing the land systems concept at the national scale.

We found that, from a land systems perspective, Laos is covered by less ‘undisturbed’ forest systems than most land cover maps suggest. Only 27% of the territory is made up of *dense forest land systems* in the sense of long time agriculturally undisturbed forests such as primary forests.

In turn, 58% of the country consists of land that is covered with varying degrees of forest and used for smallholder agriculture at the same time. This assessment contains three types of land systems, which indicate a land use composition signaling possible socio-ecologic changes: (i) those that belong to the transition subcategory could point towards hotspots of societal and economic change in the switch from subsistence towards market integration, (ii) all systems of the forest-mosaic subcategory may hint at agricultural and forest frontiers, and (iii) the areas within and around land concessions which are likely to expand if global or regional demand for the products produced in them continue to attract more of the same type of land use.

References

- Anseeuw, W., Boche, M., Breu, T., Giger, M., Lay, J., Messerli, P., & Nolte, K. (2012). *Transnational Land Deals for Agriculture in the Global South. Analytical Report based on the Land Matrix Database*. (T. Bending, Ed.). Bern, Montpellier, Hamburg: CDE/CIRAD/GIGA. Retrieved from landportal.info/landmatrix
- Arino, O., Ramos Perez, J. J., Kalogirou, V., Bontemps, S., Defourny, P., & Bogaert, E. Van. (2012). Global Land Cover Map for 2009 (GlobCover 2009). <http://doi.org/10.1594/pangaea.787668>
- Baird, I. G. (2009). Land, Rubber and People: Rapid Agrarian Changes and Responses in Southern Laos. *The Journal of Lao Studies*, 1(1), 1–47. Retrieved from www.laostudies.org
- Baird, I. G., & Fox, J. (2015). How Land Concessions Affect Places Elsewhere: Telecoupling, Political Ecology, and Large-Scale Plantations in Southern Laos and Northeastern Cambodia. *Land*, 4(2), 436–453. <http://doi.org/10.3390/land4020436>
- Bartholomé, E., & Belward, A. S. (2005). GLC2000: a new approach to global land cover mapping from Earth observation data. *International Journal of Remote Sensing*, 26(9), 1959–1977. <http://doi.org/10.1080/01431160412331291297>
- Binder, C. R., Hinkel, J., Bots, P. W. G., & Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. *Ecology and Society*, 18(4). <http://doi.org/10.5751/ES-05551-180426>
- Boillat, S., Dao, H., Bottazzi, P., Sandoval, Y., Luna, A., Thongmanivong, S., ... Giraut, F. (2015). Integrating Forest Cover Change with Census Data: Drivers and Contexts from Bolivia and the Lao PDR. *Land*, 4, 45–82. <http://doi.org/10.3390/land4010045>
- Carlile, P. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science*, 13(4), 442–455.
- Castella, J.-C. (2012). Agrarian transition and farming system dynamics in the uplands of South-East Asia. In *The 3rd International Conference on Conservation Agriculture in Southeast Asia - Conservation Agriculture an Sustainable Upland Livelihoods. Innovations for, with and by Farmers to Adapt to Local and Global Changes* (p. 20). Hanoi. Retrieved from www.conservation-agriculture2012.org
- Castella, J.-C., Lestrelin, G., & Buchheit, P. (2012). Agrarian transition in the northern uplands of Lao PDR : a meta-analysis of changes in landscapes and livelihoods. In *The 3rd International Conference on Conservation Agriculture in Southeast Asia - Conservation Agriculture an Sustainable Upland Livelihoods. Innovations for, with and by Farmers to Adapt to Local and Global Changes*.
- Comber, A. J. (2008). Land use or land cover? *Journal of Land Use Science*, 3(4), 199–201. Retrieved from

<http://www.tandfonline.com/doi/abs/10.1080/17474230802465140?journalCode=tlus20>

- Comber, A. J., Wadsworth, R. A., & Fisher, P. F. (2008). Using semantics to clarify the conceptual confusion between land cover and land use: the example of “forest.” *Journal of Land Use Science*, 3(2–3), 185–198. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/17474230802434187>
- Cramb, R., Manivong, V., Newby, J., Sothorn, K., & Sujang, P. (2015). Alternatives to Land Grabbing : Smallholder Engagement in Commodity Booms in Southeast Asia. In *Land grabbing, conflict and agrarian-environmental transformations: perspectives from East and Southeast Asia* (p. 26). Chiang Mai, Thailand.
- Davidson, D. (2016). Gaps in agricultural climate adaptation research. *Nature Climate Change*, 6(5), 433–435. <http://doi.org/10.1038/nclimate3007>
- Ducourtieux, O., Laffort, J., & Sacklokham, S. (2005). Land Policy and Farming Practices in Laos. *Development and Change*, 36(3), 499–526.
- Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, 6(8), 439–447. <http://doi.org/10.1890/070062>
- Epprecht, M., Minot, N., Dewina, R., Messerli, P., & Heinimann, A. (2008). *The Geography of Poverty and Inequality in the Lao PDR*. Swiss National Center of Competence in Research (NCCR) North-SouthSouth, University of Bern, and International Food Policy Research Institute (IFPRI), Bern: Geographica Bernensia.
- Fox, J., & Vogler, J. B. (2005). Land-use and land-cover change in Montane Mainland Southeast Asia. *Environmental Management*, 36(3), 394–403. <http://doi.org/10.1007/s00267-003-0288-7>
- Friis, C., Nielsen, J. Ø., Otero, I., Haberl, H., & Hostert, P. (2015). From teleconnection to telecoupling : taking stock of an emerging framework in land system science. *Journal of Land Use Science*, 4248(December), 1–23. <http://doi.org/10.1080/1747423X.2015.1096423>
- Friis, C., & Østergaard Nielsen, J. (2016). Small-scale land acquisitions, large-scale implications: Exploring the case of Chinese banana investments in Northern Laos. *Land Use Policy*, 57(36), 1–20. <http://doi.org/10.1016/j.landusepol.2016.05.028>
- GLP. (2005). *Science Plan and Implementation Strategy. IGBP Report No. 53/IHDP Report No. 19*. Stockholm. Retrieved from www.glp.colostate.edu
- GoL Government of Lao PDR. (2002). Land Cover Assessment 2002. Ministry of Agriculture and Forestry, Department of Forestry.
- GoL Government of Lao PDR. (2010). Land Cover Assessment 2010. Ministry of Agriculture and Forestry, Department of Forestry.

- GoL Government of Lao PDR. (2012). Results of the Lao census of agriculture 2010/2011. Steering Committee for the Agricultural Census Office. Retrieved from www.decide.la
- Heinimann, A., Hett, C., Hurni, K., Messerli, P., Epprecht, M., Jørgensen, L., & Breu, T. (2013). Socio-Economic Perspectives on Shifting Cultivation Landscapes in Northern Laos. *Human Ecology*, 41(1), 51–62. <http://doi.org/10.1007/s10745-013-9564-1>
- Heinimann, A., Messerli, P., Schmidt-Vogt, D., & Wiesmann, U. (2007). The Dynamics of Secondary Forest Landscapes in the Lower Mekong Basin. *Mountain Research and Development*, 27(3), 232–241. <http://doi.org/10.1659/mrd.0875>
- Heino, M., Kumm, M., Makkonen, M., Mulligan, M., Verburg, P. H., Jalava, M., & Räsänen, T. A. (2015). Forest loss in protected areas and intact forest landscapes: A global analysis. *PLoS ONE*, 10(10), 1–21. <http://doi.org/10.1371/journal.pone.0138918>
- Hirsch, P. (2009). Revisiting frontiers as transitional spaces in Thailand. *Geographical Journal*, 175(2), 124–132. <http://doi.org/10.1111/j.1475-4959.2009.00321.x>
- Hurni, K., Hett, C., Epprecht, M., Messerli, P., & Heinimann, A. (2013). A Texture-Based Land Cover Classification for the Delineation of a Shifting Cultivation Landscape in the Lao PDR Using Landscape Metrics. *Remote Sensing*, 5(7), 3377–3396. <http://doi.org/10.3390/rs5073377>
- Hurni, K., Hett, C., Heinimann, A., Messerli, P., & Wiesmann, U. (2012). Dynamics of Shifting Cultivation Landscapes in Northern Lao PDR Between 2000 and 2009 Based on an Analysis of MODIS Time Series and Landsat Images. *Human Ecology*, 41(1), 21–36. <http://doi.org/10.1007/s10745-012-9551-y>
- Kruska, R. L., Reid, R. S., Thornton, P. K., Henninger, N., & Kristjanson, P. M. (2003). Mapping livestock-oriented agricultural production systems for the developing world. *Agricultural Systems*, 77(1), 39–63. [http://doi.org/10.1016/S0308-521X\(02\)00085-9](http://doi.org/10.1016/S0308-521X(02)00085-9)
- Lambin, E. F., & Meyfroidt, P. (2010). Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy*, 27(2), 108–118. <http://doi.org/10.1016/j.landusepol.2009.09.003>
- Li, P., & Feng, Z. (2016). Extent and area of swidden in montane mainland Southeast Asia: Estimation by multi-step thresholds with Landsat-8 OLI data. *Remote Sensing*, 8(1), 1–17. <http://doi.org/10.3390/rs8010044>
- Liu, J., Hull, V., Batistella, M., Defries, R., Dietz, T., Fu, F., ... Naylor, R. (2013). Framing Sustainability in a Telecoupled World, 18(2).
- Malek, Ž., & Verburg, P. (2017). Mediterranean land systems: Representing diversity and intensity of complex land systems in a dynamic region. *Landscape and Urban Planning*, 165, 102–116. <http://doi.org/10.1016/j.landurbplan.2017.05.012>
- McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and

- continuing challenges. *Ecology and Society*, 19(2). <http://doi.org/10.5751/ES-06387-190230>
- Mertz, O., Leisz, S. J., Heinimann, A., Rerkasem, K., Dressler, W., Pham, V. C., ... Potter, L. (2009). Who Counts? Demography of Swidden Cultivators in Southeast Asia. *Human Ecology*, 37(3), 281–289. <http://doi.org/10.1007/s10745-009-9249-y>
- Mertz, O., Padoch, C., Fox, J., Cramb, R. A., Leisz, S. J., Lam, N. T., & Vien, T. D. (2009). Swidden change in Southeast Asia: Understanding causes and consequences. *Human Ecology*, 37(3), 259–264. <http://doi.org/10.1007/s10745-009-9245-2>
- Messerli, P., Bader, C., Hett, C., Epprecht, M., & Heinimann, A. (2015). Towards a spatial understanding of trade-offs in sustainable development: A meso-scale analysis of the nexus between land use, poverty, and environment in the Lao PDR. *PLoS ONE*, 10(7), 1–18. <http://doi.org/10.1371/journal.pone.0133418>
- Messerli, P., Heinimann, A., & Epprecht, M. (2009). Finding Homogeneity in Heterogeneity-A New Approach to Quantifying Landscape Mosaics Developed for the Lao PDR. *Human Ecology: An Interdisciplinary Journal*, 37(3), 291–304. <http://doi.org/10.1007/s10745-009-9238-1>
- Messerli, P., Heinimann, A., Epprecht, M., Phonesaly, S., Thiraka, C., & Minot, N. (Eds.). (2008). *Socio-Economic Atlas of the Lao PDR – an Analysis based on the 2005 Population and Housing Census*. Bern, Ventiane: Swiss National Center of Competence in Research (NCCR) North-South, University of Bern, Bern and Vientiane: Geographica Bernensia.
- Meyfroidt, P., Vu, T. P., & Hoang, V. A. (2013). Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam. *Global Environmental Change*, 23(5), 1187–1198. <http://doi.org/10.1016/j.gloenvcha.2013.04.005>
- Moran, E. F. (2010). *Environmental social science: human-environment interactions and sustainability*. Chichester, UK: John Wiley & Sons.
- Ornetsmüller, C., Verburg, P. H., & Heinimann, A. (2016). Scenarios of land system change in the Lao PDR : Transitions in response to alternative demands on goods and services provided by the land. *Applied Geography*, 75, 1–11. <http://doi.org/10.1016/j.apgeog.2016.07.010>
- Padoch, C., Coffey, K., Mertz, O., Leisz, S. J., Fox, J., & Wadley, R. L. (2007). The Demise of Swidden in Southeast Asia? Local Realities and Regional Ambiguities. *Geografisk Tidsskrift - Danish Journal of Geography*, 107(1), 29–41. <http://doi.org/10.1080/00167223.2007.10801373>
- Sakai, S., & Umetsu, C. (2014). *Social-Ecological Systems in Transition. Social-Ecological Systems in Transition, Global Environmental Studies*. <http://doi.org/10.1007/978-4-431-54910-9>
- Sandewall, M., Ohlsson, B., & Sawathvong, S. (2001). Assessment of Historical Land-use Changes for Purposes of Strategic Planning — A Case Study in Laos. *AMBIO: A Journal of*

- the Human Environment*, 30(1), 55. [http://doi.org/10.1639/0044-7447\(2001\)030\[0055:AOHLUC\]2.0.CO;2](http://doi.org/10.1639/0044-7447(2001)030[0055:AOHLUC]2.0.CO;2)
- Schmidt-Vogt, D., Leisz, S. J., Mertz, O., Heinimann, A., Thiha, T., Messerli, P., ... Dao, T. M. (2009). An Assessment of Trends in the Extent of Swidden in Southeast Asia. *Human Ecology*, 37(3), 269–280. <http://doi.org/10.1007/s10745-009-9239-0>
- Schönweger, O., Heinimann, A., Epprecht, M., Lu, J., & Thalongsechanh, P. (2012). *Concessions and Leases in the Lao PDR: Taking stock of Land Investments*. Bern, Vientiane: University of Bern: Geographica Bernensia.
- Struik, P. C., & Kuyper, T. W. (2014). Editorial overview: Sustainable intensification to feed the world: Concepts, technologies and trade-offs. *Current Opinion in Environmental Sustainability*, 8, vi–viii. <http://doi.org/10.1016/j.cosust.2014.10.008>
- Thongmanivong, S., Yayoi, F., Phanvilay, K., & Vongvisouk, T. (2009). Agrarian Land Use Transformation in Northern Laos: from Swidden to Rubber. *Southeast Asian Studies*, 47(3), 330–347.
- Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., ... Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, 151(1), 53–59. <http://doi.org/10.1016/j.biocon.2012.01.068>
- Turner, B. L., Janetos, A. C., Verburg, P. H., & Murray, A. T. (2013). Land system architecture: Using land systems to adapt and mitigate global environmental change. *Global Environmental Change*, 23(2), 395–397. <http://doi.org/10.1016/j.gloenvcha.2012.12.009>
- Václavík, T., Lautenbach, S., Kuemmerle, T., & Seppelt, R. (2013). Mapping global land system archetypes. *Global Environmental Change*, 23(6), 1637–1647. <http://doi.org/10.1016/j.gloenvcha.2013.09.004>
- Van Asselen, S., & Verburg, P. H. (2012). A Land System representation for global assessments and land-use modeling. *Global Change Biology*, 18(10), 3125–3148. <http://doi.org/10.1111/j.1365-2486.2012.02759.x>
- Van de Steeg, J. A., Verburg, P. H., Baltenweck, I., & Staal, S. J. (2010). Characterization of the spatial distribution of farming systems in the Kenyan Highlands. *Applied Geography*, 30(2), 239–253. <http://doi.org/10.1016/j.apgeog.2009.05.005>
- Van Delden, H., Van Vliet, J., Rutledge, D. T., & Kirkby, M. J. (2011). Comparison of scale and scaling issues in integrated land-use models for policy support. *Agriculture, Ecosystems & Environment*, 142(1–2), 18–28. <http://doi.org/10.1016/j.agee.2011.03.005>
- Van der Ploeg, J. D., & Ventura, F. (2014). Heterogeneity reconsidered. *Current Opinion in Environmental Sustainability*, 8, 23–28. <http://doi.org/10.1016/j.cosust.2014.07.001>
- Van der Zanden, E. H., Levers, C., Verburg, P. H., & Kuemmerle, T. (2016). Representing

- composition, spatial structure and management intensity of European agricultural landscapes: A new typology. *Landscape and Urban Planning*, 150, 36–49. <http://doi.org/10.1016/j.landurbplan.2016.02.005>
- Van Vliet, J., Bregt, A. K., Brown, D. G., van Delden, H., Heckbert, S., & Verburg, P. H. (2016). A review of current calibration and validation practices in land-change modeling. *Environmental Modelling and Software*, 82, 174–182. <http://doi.org/10.1016/j.envsoft.2016.04.017>
- Van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., ... Ziegler, A. D. (2012). Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. *Global Environmental Change*, 22(2), 418–429. <http://doi.org/10.1016/j.gloenvcha.2011.10.009>
- Verburg, P. H., Erb, K. H., Mertz, O., & Espindola, G. (2013). Land System Science: Between global challenges and local realities. *Current Opinion in Environmental Sustainability*, 5(5), 433–437. <http://doi.org/10.1016/j.cosust.2013.08.001>
- Verburg, P. H., Neumann, K., & Nol, L. (2011). Challenges in using land use and land cover data for global change studies. *Global Change Biology*, 17(2), 974–989. <http://doi.org/10.1111/j.1365-2486.2010.02307.x>
- Verburg, P. H., Van de Steeg, J., Veldkamp, A., & Willemsen, L. (2009). From land cover change to land function dynamics: A major challenge to improve land characterization. *Journal of Environmental Management*, 90(3), 1327–1335. <http://doi.org/10.1016/j.jenvman.2008.08.005>
- 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. *Applied Geography*, 46, 1–10. <http://doi.org/10.1016/j.apgeog.2013.10.006>

List of Tables

Table 1. Data integrated in land system classification

Data set	Components used	Year	Geometry	Source
Land cover	rock	2010*		GoL 2010*
	urban		original shapes	GoL 2002*
	forest cover	2010, 2002*		
Inventory of land concessions	mining		original shapes (polygons	Schönweger et al. 2012
	tree plantations	2012	and buffered	
	agricultural plantations		points)	
Village level census of agriculture	upland rice	2010/2011	village polygons	GoL 2012
	agriculturally used land			
Water bodies	large rivers and lakes	1980	original shapes	Russian topographic map 1:100k
	hydro power reservoirs	2012		World Bank 2010
Accessibility	travel time >2h from village center	2011	raster, 50m original resolution	CDE Bern, CH

Projection of all datasets: WGS84, UTM 48N.

* land cover 2010 based on ALOS/AVNIR (10-meter resolution), land cover 2002 based on SPOT 4 (10-meter resolution)

List of Appendices

Table A1. Detailed results of land systems classification

LS category	Land System (LS)	area (ha)	% of total	% of category
non-agricultural		590,000	2.5	100.0
	rocky, bare land	190,400	0.8	32.3
	water bodies	116,000	0.5	19.7
	urban area	48,800	0.2	8.3
	mining concession	234,800	1.0	39.8
concessions (agricultural)		457,600	1.9	100.0
	tree plantation	336,000	1.4	73.4
	arable plantation	121,600	0.5	26.6
dense forest and other land systems		8,726,400	37.0	100.0
	dense forest	6,439,600	27.3	73.8
	other land systems	2,286,800	9.7	26.2
smallholder agriculture		13,797,600	58.5	100.0
	permanent cultivation	2,243,600	9.5	16.3
	permanent cultivation mosaic	1,332,400	5.7	9.7
	forest-permanent cultivation	2,138,000	9.1	15.5
	transition	732,000	3.1	5.3
	transition mosaic	566,800	2.4	4.1
	forest-transition mosaic	856,400	3.6	6.2
	shifting cultivation	1,756,800	7.5	12.7
	shifting cultivation mosaic	1,646,800	7.0	11.9
	forest-shifting cultivation	2,524,800	10.7	18.3
Total		23,571,600	100.0	
cumulated smallholder agriculture by ratio		area (ha)	% of total	% of smallholder agriculture
	permanent (ratio <100)	5,714,000	24	41
	transition (ratio 100-300)	2,155,200	9	16
	shifting cultivation (ratio >300)	5,928,400	25	43
cumulated smallholder agriculture by forest share				
	low forest shares (<10%)	4,732,400	20	34
	medium forest shares (10-30%)	3,546,000	15	26
	high forest shares (30-70%)	5,519,200	23	40
		13,797,600		

Figure 1
[Click here to download high resolution image](#)

Figure 2

[Click here to download high resolution image](#)

Figure 3
[Click here to download high resolution image](#)

Figure 4
[Click here to download high resolution image](#)

Figure 5
[Click here to download high resolution image](#)

Figure 6
[Click here to download high resolution image](#)

GLOBCOVER 2009

- Irrigated croplands
- Rainfed croplands
- Mosaic Croplands/Vegetation
- Mosaic Vegetation/Croplands
- Closed to open broadleaved evergreen or semi-deciduous forest
- Open broadleaved deciduous forest
- Closed to open mixed broadleaved and needleleaved forest
- Closed to open shrubland
- Closed to open grassland

0 100 200 km

GLC 2000

- Artificial surfaces
- Bare Areas (Rock: Lime stone)
- Cultivated and managed, irrigated (flooded, rice, shrimp farms)
- Cultivated and managed, non irrigated (mixed)
- Mosaic of Cropland / Oth. natural vegetation (Shifting cultivation in mountains)
- Mosaic: Tree cover / Oth. nat. vegetation or Cropland (incl.very degraded & open tree cover)
- Mosaics & Shrub Cover, shrub component dominant, mainly deciduous
- Mosaics & Shrub Cover, shrub component dominant, mainly evergreen
- No Data
- Shrub cover, mainly deciduous, (Dry or burnt)
- Tree cover, broadleaved, deciduous, mainly open (incl. Dry Dipterocarpus)
- Tree cover, broadleaved, evergreen, closed and closed to open
- Water Bodies

Acknowledgments

Financial support for the research reported in this article was provided by the European Union's Seventh Framework Programme ERC Grant Agreement nr. 311819 – GLOLAND. We would like to acknowledge the Centre for Development and Environment (CDE), Bern, Switzerland for provision of data and especially thank the anonymous land use experts who took part in the expert survey for their expertise and two anonymous reviewers for their constructive feedback.

Interactive Map file (.kml or .kmz)

[Click here to download Interactive Map file \(.kml or .kmz\): Land_system_classification_Laos.kmz](#)