Simulating land-cover change in Montane Mainland Southeast Asia

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Abstract

We used the Conversion of Land Use and its Effects (CLUE-s) model to simulate scenarios of land-cover and land-use change (LCLUC) in Montane Mainland Southeast Asia (MMSEA), a region on the cusp of change due to projected rapid intensification of agriculture and expansion of regional trade markets. Simulated changes affected approximately 10% of the MMSEA landscape between 2001 and 2025 and 16% between 2001 and 2050. Roughly 9% of the current vegetation, which consists of native species of trees, shrubs, and grasses, is predicted to be replaced by tree plantations, tea, and other evergreen shrubs during the 50-year period. Importantly, 4% of this change would be due to the expansion of rubber, a tree plantation crop that may have important implications for local-to-regional scale hydrology because of its relatively high water use for leaf flushing during the driest part of the year.

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INTRODUCTION

Montane mainland Southeast Asia (MMSEA), 300 m elevation and above, is a large, ecologically vital region comprising about half of the land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province (Fig. 1) The region harbors a wealth of natural resources including globally important stocks of forest and biological diversity and the headwaters for several major river systems including the Mekong, Chao Praya, Irrawaddy, and Yuan-Hong. Much of MMSEA has only been reopened to outside influences within the last two decades, bringing profound and widespread changes to both its physical environment and to its local societies. Swidden agriculture, or swiddening (also called shifting cultivation), the dominant farming system in MMSEA where it has been practiced for at least a millennium, has greatly influenced land cover and land use throughout the region. Guo *et al.* (2002), however, recently asserted that, "from the mountains of Yunnan Province in southwestern China to the interior of Kalimantan," the ways of life of upland farmers throughout Southeast Asia are changing at rates and scales that "are unprecedented." They suggest that "hill farmers with their hundreds of rice landraces, and their cyclic secondary forest fallows are disappearing throughout the region,"

In addition to the land-cover and land-use change (LCLUC) driven by political and economic forces, the Asian Development Bank is funding the building and improvement of roads running throughout the region. The Chiang Mai-Kunming Highway (Fig. 1) provides the first reliable land-transport route connecting eastern China with central Thailand and the Malay Peninsula. This has created a "North-South Economic Corridor" through the heavily forested region (Maekawa 2002). Another new road, forming an "East-West Economic Corridor", will begin at Mawlamyine, Myanmar on the Andaman Sea, cross Thailand, Laos, Vietnam, and end at Da Nang on the South China Sea in central Vietnam (Thant and Nair 2002). In addition to the economic and social changes they produce, highways such as these, traversing forested regions, promote rapid LCLUC by providing access to formerly isolated areas and facilitating transport of timber and other products to market (Schneider 1994). Construction of major new highways through the region sets the stage for wholesale forest conversion in MMSEA.

While it has become all too apparent that MMSEA is on the cusp of a major new upsurge in LCLUC, there is much uncertainty about the direction of change and the impacts it will have on both people's livelihoods and environmental variables such as biodiversity, carbon sequestration, watershed hydrology, and climate. A great deal of recent literature suggests that swidden farming is rapidly giving way to commercial agriculture driven by domestic demand and by regional trade agreements (Fox and Vogler 2005, Xu *et al.* 2005, Thongmanivong *et al.* 2005, Padoch *et al.* 2007, Fox *et al.* 2008, Fujita and Phanvilay 2008). In Xishuangbanna (the most southern prefecture in Yunnan Province), China, both semi-privatized state farms and minority farmers are planting rubber at rates that threaten to transform the landscape between 300 and 1,000 m elevation into an unbroken carpet of rubber (Xu *et al.* 2005, Xu 2006, Li *et al.* 2007, Sturgeon in review). In northern Thailand, rural people are becoming increasingly divorced from farming, with education and consumerism creating a context where rural people are disintensifing, even abandoning their land, in favor of non-farm pursuits (Rigg and Nattapoolwat 2001, Rigg 2006). In Laos and Cambodia, entrepreneurs have contracted farmers to grow corn, bananas and sugar cane for the Chinese and Vietnamese markets (Thongmanivong *et al.* 2005, Fujita and Phanvilay 2008, Fox *et al.* 2008). In response to soaring prices for natural rubber, highlanders, usually ethnic minorities, are planting rubber trees on family plots. In Laos they are turning to relatives in China for advice; and in both countries, to merchants for seeds, grafts, and tapping tools (Thongmanivong *et al.* 2005, Fujita and Phanvilay 2008). In Vietnam researchers have reported the expansion of tree crops such as rubber, tea, and coffee in the Central Highlands (Thomas *et al.* 2008) and fast-growing species for pulp and timber in the northern part of the country (Sunderlin and Huynh 2005). An assessment of LCLUC in MMSEA, however, over the next few decades cannot merely be based on local case studies since case study location selection is often biased and results cannot be easily extrapolated to the broader region.

This project sought to determine what LCLUC has occurred in recent decades and what significant LCLUC is likely to occur in MMSEA in the coming decades. To answer this question, we developed a comprehensive, high-resolution database of land cover in MMSEA; sought expert opinions on future land cover and land use (LCLU) in the region; and simulated LCLUC in MMSEA to 2025 and 2050 based on expert knowledge.

METHODS

The conversion of land use and its effects (CLUE-s) model (Verburg *et al.* 1999a, Verburg *et al.* 2002, Verburg 2006) was used to simulate land-cover change in this work. Both CLUE-s and its predecessor, CLUE, have proven application and validation over a wide range of scales of analysis in several regions worldwide, including Asia (Verburg *et al.* 1999b), Central America (Wassenaar *et al.* 2007), and Europe (Verburg *et al.* 2006). In Southeast Asia, CLUE-s has been applied at the sub-national level in northern Vietnam (Castella and Verburg 2007, Willemen 2002) and Malaysia (Engelsman 2002, Verburg *et al.* 2002) and at the national and sub-national levels in the Philippines (Verburg and Veldkamp 2004, Soepboer 2001).

Baseline land-cover classification

A 2001 land-cover map was developed to serve as the model baseline. To do so, we first acquired a 1-km resolution global land cover map from the USGS Land Processes Distributed Active Archive Center that was generated from 2000-2001 MODIS/Terra observations (Friedl *et al.* 2002) and was made available in the 17-class International Geosphere-Biosphere Programme (IGBP) global vegetation classification scheme. The land cover dataset was then clipped to the simulation model domain, which removed areas of the “snow and ice” class. The IGBP classification was then reclassified to the 20-class Biosphere-Atmosphere Transfer Scheme (BATS) (Dickinson *et al.* 1993) to support regional climate modeling of the study area in a related work (Sen *et al.* in preparation). The resulting BATS class map for MMSEA excluded four BATS categories (tundra, ice caps and glaciers, water and land mixtures, and ocean categories) because they were not present in the study region. The BATS classification scheme does not recognize urban\built-up nor sparsely vegetated areas, therefore, we retained those areas from the IGBP class designation in the reclassified map. The final, 2001 BATS classification for the land cover simulation region included 16 land-cover types (Fig. 2).

CLUE-s model

CLUE-s employs an iterative spatial allocation procedure that involves parameterization of the following inputs to generate land-use/cover simulation maps at regular time steps: land-cover demands, location suitability, conversion characteristics, and location restrictions. MMSEA encompasses a region that extends into six countries and includes areas that lie above 300 m. (Fig. 1). These countries have unique social, political, and economic histories; and therefore, potentially unique land-cover change trajectories. Hence, we developed a separate model for the portion of each country that lies within MMSEA (henceforth called country domain), allowing independent simulation of land-cover changes within each domain. This modeling approach provided the flexibility to parameterize situations that affect some, but not all, countries. Model inputs and the spatial allocation procedure are described in the following sections.

Land-cover demands

Land-cover demands refer to the aggregate area occupied by each land-cover type at each simulation time step, in this case, annual time steps. To determine these demands, we first interviewed experts with knowledge of LCLUC in each country domain. Experts were shown the 2001 land-cover classification of their country and asked to estimate the percentage of change in each land-cover category in 2025 and 2050. By coupling these predictions with economic country profiles (Economic Intelligence Unit 2004a, b, 2005a, b, c, d), we determined the final domain-specific land-cover demand values for each intermediate year of the simulation for a total of 50 years (2001-2050) of demand values. Table 1 summarizes for each country domain the observed land cover in 2001 and expected demands for change (expressed as % of total country domain area) for simulation years 2025 and 2050. The percent change in land-cover demands from 2001 – 2050 is also indicated in Table 1.

Location suitability

Location suitability refers to how well a particular location, in this case a grid cell, is suited to a particular land-cover type. Land-cover conversions typically occur at locations that possess the highest suitability for a particular land-cover type at a particular point in time. Determining the suitability of each land-cover type at each cell location in the landscape requires 1) consideration of the biophysical, geographic, and socio-economic factors and processes hypothesized to be driving different land-cover conversions, 2) identifying a parsimonious set of factors influencing the locations of observed land-cover types and quantifying their relative influences by statistical means, and 3) combining actual factor location values (e.g., elevation, distance to road) and their relative influences in a function that empirically quantifies the probability of each land-cover type at each location on the landscape. The land-cover type with the highest probability, or suitability, for a particular location at a particular time, is then placed on the landscape at that location and for all grid cell locations, and a resulting land-cover pattern emerges in an output map. This section describes the spatial datasets (potential driving factors and land cover), their preparation for input into CLUE-s and statistical software, and the statistical modeling used to determine the total suitability of landscape locations for each of the modeled land-cover types.

Based upon the drivers of change highlighted by experts from each country domain, a set of 1-km resolution raster datasets, including the 2001 land-cover map described above, was developed in a geographic information system (GIS) and georeferenced to a common coordinate system. Table 2 lists the geospatial datasets, sources, years, and scales, and the type of variable (i.e. static, dynamic). It should be noted that the availability and scale of some datasets varied across the country domains, and some data layers were originally acquired in vector format (e.g., shapefile) and converted to raster grids. The raster grids were clipped to the country domains using administrative polygon boundaries.

A majority of the assembled datasets was stable in nature, that is, the grid cell values at each location represented a single snapshot in time and those values did not change over time during the simulations (e.g., elevation). To avoid a temporal mismatch of corresponding grid cell values across the assembled datasets, we attempted to obtain datasets that corresponded as closely as possible to the year of the baseline land-cover data, 2001. Two of the spatial variables, including the ‘distance to road’ accessibility layer and population density, were treated in the simulations as dynamic input variables that changed annually in the models. An updated distance to road layer was created for each model year and input at each annual time step, simulating annual step decreases in distance from each landscape grid cell to the nearest roads. In order to incorporate annual changing population density, we applied projected annual (2001-2050) growth rates, obtained from the US Census Bureau’s International Data Base (IDB), to the population density grid cell values of the baseline 2000 population density layer for each country domain and at each time step in the simulations.

CLUE-s uses a logit model to define a function that, for each modeled land-cover type, calculates a total probability (i.e., suitability) that a given land cover will occur in a grid cell based on a combination of factor (driver) values and their relative influences. For each country domain, we converted all raster grids to tables containing land-cover type presence/absence and corresponding location factors values. We used statistical software (SPSS) to run a series of binary logistic regressions in which each land-cover type was regressed against all potential driving/location factor values. A stepwise regression was performed on each land-cover type to identify a parsimonious set of the most significant, explanatory location factors for each type within each country domain.

For some land-cover types the probability of occurrence of that land-cover type at a particular location can be partially explained by the land-cover types found in the immediate surrounding area, or neighborhood, of the focal grid cell. Urban\built-up areas are a prime example where neighborhood interactions are important (Verburg et. al. 2003, Veldkamp and Fresco 1996, 1997a, b), with new urban growth typically developing at the edges of existing urban areas. Using the CLUE-s model we calculated an “enrichment factor” to describe the neighborhoods of urban cells and to enhance probability of new urban cells growing around existing urban cells by applying weights to neighboring cells during the land-cover simulations.

Conversion characteristics and restrictions

Land-cover conversion characteristics refer to the temporal transition behaviors for individual land-cover types. Transition behaviors are defined in part by a transition matrix of possible ‘from-to’ land-cover conversions. Transition matrices were created for each of the modeled country domains, specifying which land-cover conversions were permitted or restricted. An additional elasticity parameter quantifies how resistant or amenable each land-cover type is to change (Verburg *et al.* 1999b). Elasticity values ranged from 0 (easy conversion to other allowable types) to 1 (completely resistant, irreversible change). Values of 0 allow conversion without consideration of the current land cover or that in any adjacent cell. Values of 1 were typically assigned to land-cover types that are difficult or too costly to convert or revert to anything else (e.g., urban areas and forests).

Location restrictions define areas where land-cover conversions are either stimulated or restricted. We restricted land-cover change in our country domains in all areas designated as national parks and protected areas based on the World Database on Protected Areas (WDPA) 2005 spatial dataset (UNEP-WCMC 2005). The vector format dataset was acquired and polygon boundaries of all protected areas in the MMSEA region were converted to raster grids. Protected area grid cells were coded such that change was completely restricted during simulations. In order to satisfy the annual land-cover demands, changes were then limited to non-restricted cells.

Land-cover allocation

Land-cover spatial allocation is an automated, iterative process in CLUE-s that attempts to generate a spatial pattern of land cover that best satisfies the annual land-cover demands (scenario-based) for a given simulation year. Up to 20,000 iterations are allowed for any given simulation year to reach a satisfactory solution. When a solution is reached, the land-cover pattern is saved and used as the input land cover for the next simulation year. Land-cover demand values by themselves are non-spatial, and thus the spatial patterns are driven and shaped by the combination of land-cover location suitability at the grid cell level, allowable land-cover transitions and cover type elasticities, and geographic restrictions as described above. We performed multiple 50-year land-cover simulation runs per country domain, tested sensitivity of input parameters, and evaluated resulting land-cover patterns against country domain scenario demands. In the end, we selected the simulation having overall land-cover patterns that most accurately reflected the plausible scenarios envisioned by the experts.

RESULTS

Simulated land-cover change in years 2025 and 2050 generally reflects the role of small-scale diversified farming, monocropping (by both large operators and small holders), and establishment and strict maintenance of protected areas (national parks, state forests, and protected watersheds) in each country domain (Table 3). Across MMSEA, the following land covers are estimated to increase by 2050: diversified farming of crops and other mixed farming activities (2.45%, approximately 42,500 km^2); rubber and other deciduous broadleaf trees (2.46%, approximately 42,500 km^2); tea and other evergreen shrubs (1.63%, or approximately 28,300 km^2); urban and other built-up areas, such as those associated with peri-urbanization (1.62%, or approximately 28,300 km^2). These simulated increases take place largely at the expense of the following land-cover groups: (1) evergreen broadleaf trees, which are the most suitable habitat for rubber; and (2) mixed forests, forest/field mosaics and tall grass—land covers that are historically associated with swidden cultivation. The overall decline in these four land-cover categories is about 9% (approximately 155,300 km^2). The predicted decline in native tree cover is somewhat offset by a 4% increase in deciduous broadleaf trees (i.e., rubber), tree crops, tea, and other evergreen shrubs. Fig. 3 highlights the areas in the MMSEA region where simulated changes occur during the 2001-2025 and 2001-2050 time periods. Again, these results only include conversions between the modeled land-cover classes used in the study; other conversions that do not change the classification of land cover, e.g., among crop types or between residential and industrial areas, are not counted.

Among the six countries in MMSEA, Cambodia has the least amount of land within the region (59,579 sq km) and Myanmar the most (462,495 sq km). Laos, Thailand, and Vietnam, have roughly the same amount of land in the region (283,363 to 303,093 sq km) (Table 4). Model results suggest that Myanmar will undergo the least amount of change throughout the 50-year period (less than 10%). This is evident in the map of change/no change for the 2001-2050 time period in Fig. 3. This result, as well as that from Cambodia, however, should be interpreted cautiously as we were only able to interview one expert on the future of land-cover change in those countries. In Laos, Thailand and Vietnam, the model suggests that land-cover changes will range from 9.38 to 11.9 percent during the first 25-year period, and 14.46 to 19.17 percent of the landscape during the 50-year period. These robust results suggest land-cover experts in these countries see relatively similar futures. In Cambodia and Yunnan, the model suggests that land-cover change will affect approximately one-quarter of the upland landscape over the 50-year period. Overall, the model simulated change across the entire region of approximately 10 percent of the landscape over the first 25-year period and 16 percent over the 50-year period.

DISCUSSION AND CONCLUSIONS

This project used the CLUE-s model to simulate LCLUC patterns that might emerge in MMSEA in 2025 and 2050 based upon an amalgam of 1) expert knowledge of historical LCLUC; 2) expert knowledge and observations of current regional trends and narratives of land-cover change that included consideration of agricultural intensification, road development, and market growth in the region; and 3) economic forecasts. Land-change simulations are at best future explorations, and true validation of future projections is not possible (Wassenaar *et al.* 2007). We were not able to validate these models in a quantitative manner because of a lack of historical land-cover data at multiple time points using similar classification techniques and consistent land-cover types for MMSEA. Qualitative assessments by experts from each country indicated the simulated land-cover patterns we were reasonable representations of the scenario within each country domain. Visual inspection of the output maps revealed some localized anomalies in the location of individual grid cells of particular land-cover types. However, when the six country domain simulation maps were appended the resulting land-cover patterns along and across borders between domains were consistent with no artificial or unexpected abrupt changes in land-cover patterns at national borders.

We attribute the positive results we obtained to quality input datasets and model testing; plausible, scenario-based land-cover demands that reflect regional expert knowledge of historical, current, and future trends in policies (and how those policies influence land-cover change); expert consensus regarding the future of MMSEA; and the ability of the CLUE-s model to produce realistic, complex, non-linear land-cover patterns. While policies are not explicit inputs to the models, the exception being the change restrictions placed on parks and protected areas, policy is a primary consideration in determining the future land-cover demands.

Our estimates of total cumulative LCLUC in the 6 countries of the MMSEA simulation region ranged from 5.86 to 14.57 percent during the first 25-year period, and from 9.69 to 25.11 percent during the 50-year period from 2001-2050 (Table 4; Fig.3). These changes are 2 to 3 times greater than the 5 to 8 percent simulated change predicted to take place in Europe between 2000 and 2030 (Verburg *et al.* 2006). The models suggest that MMSEA may lose as much as 9 percent of native cover (secondary trees, shrub, and grass) by 2050, but this loss will be somewhat offset by the increase in rubber and other tree crops as well as tea and other evergreen shrubs (about 4% in total). These predicted changes in the composition of the tree cover have implications for watershed hydrology and regional precipitation patterns.

At the watershed level, Guardiola-Claramonte *et al.* (2008) showed that an increase in rubber cropping caused a decrease in soil water availability in Xishuangbanna Prefecture, China, during the dry season. While the root-water uptake of the other land covers (secondary forest, shrub, tea) declined throughout the dry season, water extraction in 1- and 2-m soil layers under rubber increased sharply in mid-February and remained high through March. This response to decreasing soil water availability coincided with the annual leaf shedding and new leaf-flushing period. Guardiola-Claramonte *et al.* (2008) suggest that conventional land-atmosphere models, which generally modulate evapotranspiration (ET) as a function of soil moisture, are not appropriate for predicting the hydrological impacts of expanding rubber cultivation.

At the regional scale, climate change models using these scenarios predict little change in regional participation patterns (Sen in preparation). Sen's work suggests that global warming-related effects will have a greater impact on precipitation than our predicted 16.41% changes in land cover. Much of the uncertainty regarding the hydrological impacts of tropical deforestation stems from a failure to develop and use realistic LCLU projections in climate simulations (Giambelluca *et al.* 1996). This study clearly demonstrates the need to integrate realistic LCLUC simulations based on expert opinion with climate change simulations.

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Table 1. Land cover (expressed as % of country domain) in 2001 and change demands as estimated from expert knowledge for 2025 and 2050.

	Cambodia				**Laos**				**Myanmar**			
	59579 km^2				283363 km^2				462495 km^2			
Land Cover Type	2001	2025	2050	**%ch**	2001	2025	2050	**%ch**	2001	2025	2050	**%ch**
Crops, Mixed Farming	1.4	4.5	7.5	**6.1**	1.3	2.0	3.0	**1.7**	2.7	4.0	5.0	**2.3**
Short Grass	0.9	1.0	1.0	**0.1**	1.7	3.0	3.0	**1.3**	2.1	3.0	3.0	**0.9**
Evergreen Needleleaf Trees	0.1	0.1	0.1	**0.0**	0.2	0.0	0.0	**-0.2**	0.2	0.2	0.2	**0.0**
Deciduous Needleleaf Trees	na[*]	na[*]	na[*]		na[*]	na[*]	na[*]		0.0	0.0	0.0	**0.0**
Deciduous Broadleaf Trees	9.1	8.5	6.0	**-3.1**	13.5	16.0	18.0	**4.5**	15.5	18.0	20.0	**4.5**
Evergreen Broadleaf Trees	44.5	41.0	37.0	**-7.5**	63.3	55.5	51.0	**-12.3**	34.4	31.5	29.5	**-4.9**
Tall Grass	7.0	6.0	5.0	**-2.0**	5.6	6.0	6.0	**0.4**	3.8	3.8	3.8	**0.0**
Urban/Built-Up	0.1	1.0	2.0	**1.9**	0.1	1.0	1.5	**1.4**	0.4	1.0	2.0	**1.6**
Irrigated Crops	3.9	6.0	11.0	**7.1**	2.2	2.3	2.5	**0.3**	12.6	13.0	13.0	**0.4**
Sparse Vegetation	0.3	0.3	0.3	**0.0**	0.2	0.2	0.2	**0.0**	1.1	1.1	1.1	**0.0**
Bogs and Marshes	0.0	0.0	0.0	**0.0**	0.1	0.1	0.1	**0.0**	0.1	0.1	0.1	**0.0**
Inland Water	1.5	1.5	1.5	**0.0**	0.6	0.6	0.6	**0.0**	0.8	0.8	0.8	**0.0**
Evergreen Shrubs	0.1	0.1	0.1	**0.0**	0.2	0.5	1.0	**0.8**	0.3	0.3	0.3	**0.0**
Deciduous Shrubs	0.1	0.1	0.1	**0.0**	0.1	0.1	0.1	**0.0**	0.3	0.3	0.3	**0.0**
Mixed Forest	0.8	3.5	6.0	**5.2**	0.9	0.9	0.9	**0.0**	2.4	3.0	3.0	**0.6**
Forest/Field Mosaic	30.3	26.0	22.0	**-8.3**	10.1	12.0	12.0	**1.9**	23.3	20.0	18.0	**-5.3**

	Thailand				**Vietnam**				**Yunnan (China)**			
	303093 km^2				285271 km^2				337532 km^2			
	2001	2025	2050	**%ch**	2001	2025	2050	**%ch**	2001	2025	2050	**%ch**
Crops, Mixed Farming	5.1	7.0	5.0	**-0.1**	6.7	10.0	11.0	**4.3**	4.5	8.0	7.0	**2.5**
Short Grass	3.4	4.0	5.0	**1.6**	1.5	2.5	2.0	**0.5**	5.2	2.5	4.5	**-0.7**
Evergreen Needleleaf Trees	0.1	0.1	0.1	**0.0**	0.7	1.0	1.5	**0.8**	0.5	1.0	0.0	**-0.5**
Deciduous Needleleaf Trees	1.0	1.0	1.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Deciduous Broadleaf Trees	9.7	13.0	15.5	**5.8**	8.9	8.0	7.0	**-1.9**	10.6	15.0	15.0	**4.4**
Evergreen Broadleaf Trees	22.7	25.0	27.0	**4.3**	42.2	38.0	35.0	**-7.2**	19.7	21.0	25.0	**5.3**
Tall Grass	7.3	7.3	7.3	**0.0**	5.2	7.0	8.0	**2.8**	7.2	4.0	2.5	**-4.7**
Urban/Built-Up	0.6	1.0	2.0	**1.4**	0.5	1.0	2.0	**1.5**	0.6	2.0	4.0	**3.4**
Irrigated Crops	27.2	24.0	22.0	**-5.2**	8.7	10.0	11.0	**2.3**	2.0	1.0	1.0	**-1.0**
Sparse Vegetation	0.5	0.5	0.5	**0.0**	0.8	0.8	0.8	**0.0**	0.9	0.9	0.9	**0.0**
Bogs and Marshes	0.1	0.1	0.1	**0.0**	0.2	0.2	0.2	**0.0**	0.1	0.1	0.1	**0.0**
Inland Water	0.9	0.9	0.9	**0.0**	0.4	0.4	0.4	**0.0**	0.3	0.3	0.3	**0.0**
Evergreen Shrubs	0.7	1.0	1.5	**0.8**	0.8	2.0	3.5	**2.7**	9.1	13.0	14.5	**5.4**
Deciduous Shrubs	0.2	0.2	0.2	**0.0**	0.6	1.0	1.0	**0.4**	2.0	2.0	2.0	**0.0**
Mixed Forest	0.5	1.0	1.0	**0.5**	3.9	3.0	2.5	**-1.4**	17.9	14.0	11.0	**-6.9**
Forest/Field Mosaic	21.0	15.0	12.0	**-9.0**	18.9	15.0	14.0	**-4.9**	19.2	15.0	12.0	**-7.2**

* Indicates land cover not type not present in model domain.

Table 2. Geospatial datasets used to derive location factors.

Variable	Data Source	Baseline Year	Scale or Resolution	Static or Dynamic
Land Cover - Land Use	LPDAAC at USGS[1] (MODIS/Terra Land Cover) (http://lpdaac.usgs.gov/)	2001	1 km	Dynamic
Population Density	SEDAC – CIESIN[2] (http://sedac.ciesin.org/gpw/)	2000	1 km	Dynamic
Distance to Populated Place	Derived from populated places UNEP-RRCAP[3] (http://www.rrcap.unep.org/)	2001	1:100k - 1:250k	Static
Distance to Domestic City (nearest domestic market)	Derived from cities GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Static
Distance to Foreign City (nearest foreign market)	Derived from cities GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Static
Distance to Major Road	Derived from roads GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Dynamic
Distance to Road	Derived from roads GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Dynamic
Distance to Major River	Derived from major river GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Static
Distance to River	Derived from rivers GIS layer UNEP-RRCAP	2001	1:100k - 1:250k	Static
Parks and Protected Areas	WDPA[4] (http://www.unep-wcmc.org/wdpa/)	2005	National - Global	Static
Elevation	SRTM at USGS[5] (http://srtm.usgs.gov/)	2000	1 km	Static
Slope	Derived from SRTM	2000	1 km	Static
Major Landform	ISRIC[6] (http://www.isric.org/)	1997	1:5M	Static
Human-induced Soil Degradation (major type and intensity)	ISRIC (http://www.isric.org/)	1997	1:5M	Static

Sources: 1 – Land Processes Distributed Active Archive, US Geological Survey; 2 – Socioeconomic Data and Applications Center, Center for International Earth Science Information Network; 3 – United Nations Environment Programme, Regional Resource Center for Asia and the Pacific Region; 4 – World Database on Protected Areas; 5 – Shuttle Radar Topography Mission, US Geological Survey; 6 – International Soil Reference and Information Centre.

Table 3. Land cover (expressed as % of region) in 2001 and simulation results aggregated to MMSEA region showing overall % change for 2001-2025 and 2001-2050 time periods.

	MMSEA 1,731,333 km^2		
Land-cover Type	**2001**	**2025**	**2050**
Crops, Mixed Farming	3.69	+2.29	+2.45
Short Grass	2.99	-0.06	+0.42
Evergreen Needleleaf Trees	0.31	+0.12	+0.01
Deciduous Needleleaf Trees	0.00	0.00	0.00
Deciduous Broadleaf Trees	12.82	+1.41	+2.46
Evergreen Broadleaf Trees	36.58	-2.96	-3.73
Tall Grass	5.70	-0.27	-0.44
Urban/Built-Up	0.69	+0.51	+1.62
Irrigated Crops	9.53	+0.56	+0.58
Sparse Vegetation	1.00	0.00	0.00
Bogs and Marshes	0.11	0.00	0.00
Inland Water	0.64	0.00	0.00
Evergreen Shrubs	2.30	+0.92	+1.63
Deciduous Shrubs	0.6	+0.07	+0.07
Mixed Forest	5.13	-0.66	-1.24
Forest/Field Mosaic	17.9	-1.67	-3.56

Table 4. Cumulative land-cover change for the six countries in MMSEA and the region in terms of area (sq. km.) and percent calculated in 5 year increments over the 25 and 50 year periods.

Country	Total upland area (sq. km)	2001-2025		2001-2050	
		Cumulative area change (sq. km)	Cumulative % change	Cumulative area change (sq. km)	Cumulative % change
Cambodia	59,579	6,142	10.31	14,963	25.11
Laos	283,363	26,589	9.38	40,982	14.46
Myanmar	462,495	27,096	5.86	44,819	9.69
Thailand	303,093	28,583	9.43	50,032	16.51
Vietnam	285,271	33,954	11.90	54,694	19.17
Yunnan	337,532	49,189	14.57	78,560	23.27
MMSEA	1,731,333	171,553	9.91	284,050	16.41

Fig. 1.

Fig. 1. Montane Mainland Southeast Asia with simulation model domains (blue boundaries), Chiang Mai to Kunming Highway Corridor (yellow lines) and East – West Corridor (red line). Areas shaded in green are 300m and above.

Fig. 2.

Fig. 2. Baseline (2001), 16-class land-cover map for the MMSEA simulation region.

Fig. 3.

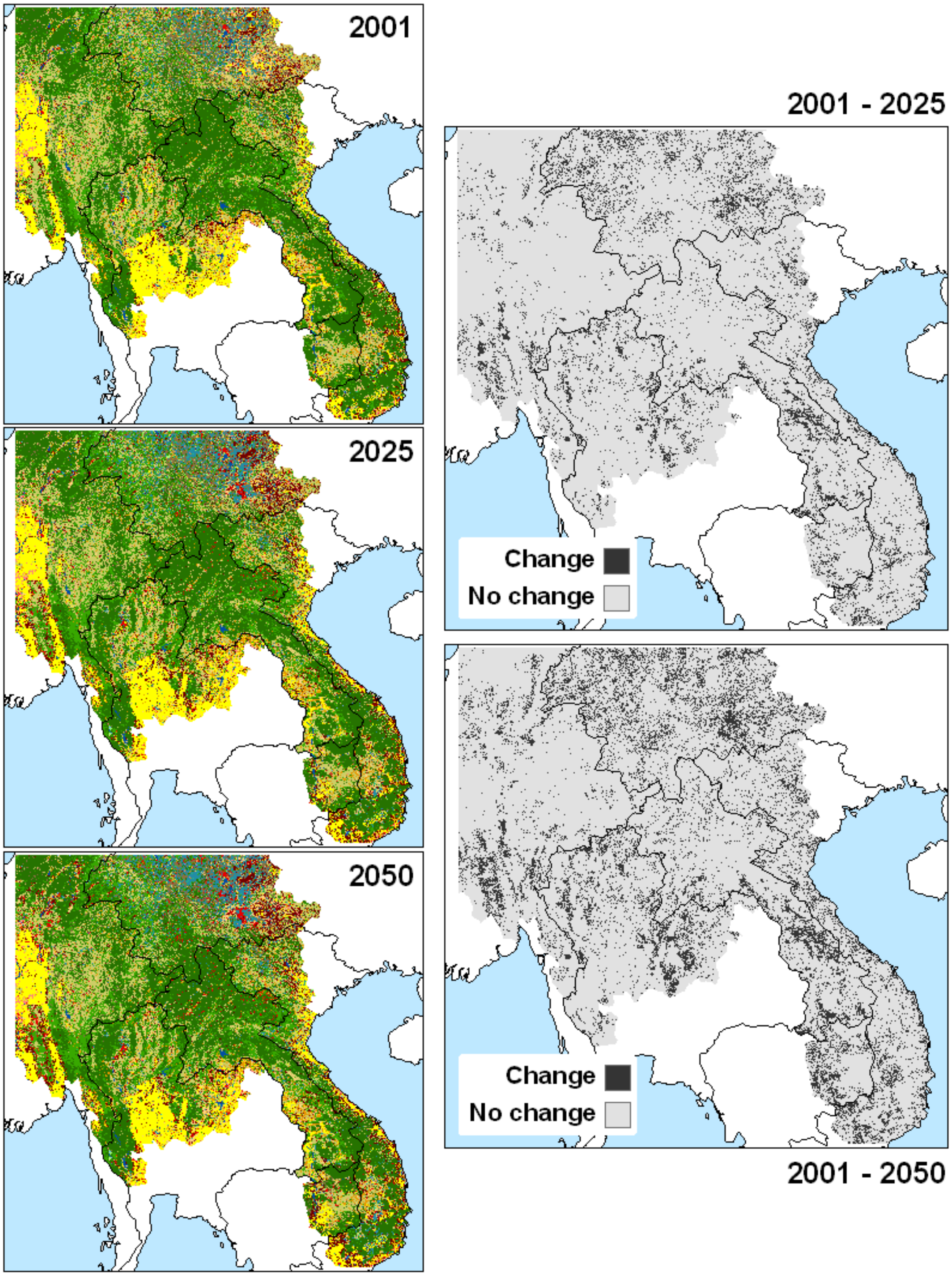

Fig. 3. Baseline land-cover map (2001), simulation output maps for years 2025 and 2050, and maps showing areas of change/no change for 2001-2025 and 2001-2050 time periods.