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Predicting Land-use and Land-cover Patterns Driven by Different Scenarios in the Emerald Triangle Protected Forests Complex

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ABSTRACT

The Emerald Triangle is the largest, extensive intact block in the Greater Mekong Sub-region, which still remains along the tri-national borders between Thailand, Lao PDR and Cambodia. The remaining habitats are very important for the survival of wide-ranging species in this area. This research aimed to assess land-use change in recent years and to predict land-use patterns across the Emerald Triangle landscape. The current land-use map was visually interpreted from satellite images and the rate of reduction was calculated accordingly. Future land-use patterns were predicted using the Dyna-CLUE model based on different land-use scenarios in 2030 defined by multi-stakeholders from the three countries. The model results indicated that dry dipterocarp forest in the north of Dong Khanthung proposed National Biodiversity Conservation Area in Lao PDR and to the west of Pha Taem National Park in Thailand would be threatened by encroachment for agriculture and rubber plantation. If no restriction policy, parts of the Preah Vihear protected forest in Cambodia and Phou Xiang Thong National Biodiversity Conservation Area in Lao PDR would be converted to arable land in 2030. Evergreen forests were predicted to be relatively intact, as at the current stage, because they are found either inside protected areas or in steep terrains, thus become natural barriers for human-intervention.

Keywords: CLUE-s model, Emerald Triangle, Land use scenarios, Trans-boundary biodiversity conservation

INTRODUCTION

The Southeastern Indochina Dry Evergreen Forests ecoregion is situated across northern and central Thailand, Lao PDR, Cambodia and Vietnam. However, about two-thirds of the original forest of this eco-region has been converted or seriously degraded (Wikramanayake *et al*., 2000). The largest, extensive intact block still remains along the tri-national borders between Thailand, Lao PDR and Cambodia, the so-called the Emerald Triangle Forests Complex (ETFC). It is recognized globally as outstanding for biodiversity conservation and important habitats for the large vertebrates in the Greater Mekong Sub-region (Office of Environmental Center, 2005). According to Bhumpakphan (2003), there are more than 50 species listed as IUCN threatened status, and more than 10 species are categorized as critically endangered or endangered species found in the ETFC, such as, Asian elephant (*Elephans maximus*), banteng (*Bos javanicus*), *Eld's* deer (*Cervus eldi*i), Clouded leopard (*Neofelis nebulosa*) and Siamese crocodile (*Crocodylus siamensis*).

The ETFC landscape contains heterogenuous landscape patterns and hydrological conditions. The general topography in Thailand is mountaineous and slopes gently towards the southeast. In contrast, the areas in Lao PDR and Cambodia are generally flat and part of the forested areas are inundated during the wet season. As a result of the highly heterogenuous landscape, wide-ranging species seasonally migrate across the tri-national boundaries and are dependent on very limited resources, including permanent waterbodies and lowland forest patches that are scattered in protected areas in the dry season (Bhumpakphan, 2003, 2006). Residual forests outside the reserves are vulnerable to disturbance.

Besides the diverse natural feaures, the disparities of conservation efforts and human capacity are clearly noted among the three countries. Cambodia and Lao PDR have some of the most extensive intact natural forests, but they lack sufficient capacity to effectively maintain the remaining forest cover and conserve biodiversity at all levels (Galt *et al*., 2000). In contrast, the Government of Thailand has deployed many park rangers and fac ilities to manage and to protect biological resources, but Thailand's protected areas contain relatively less biodiversity than in Lao PDR and Cambodia (Trisurat, 2003). In addition, a recent study on land-use change in Thailand between 2002 and 2008 indicated that deforestation was continuing in the buffer zones (Trisurat, 2009).

Therefore, long-term persistence of trans-boundary biodiversity in the ETFC is largely dependent on the cooperation between the three countries to safeguard the remaining habitats and to reduce anthropogenic pressures both inside and in the buffer zones of the protected forests. To address some of these issues, the Government of Thailand with technical suport from the International Tropical Timber Organization (ITTO) and financial support from Japan, Switzerland and USA has initiated the framework of trans-boundary biodiversity conservation in cooperation with Cambodia and Lao PDR since 2001 (Kalyawongsa and Hort, 2010). The current ITTO project phase III (2012-2015) aims at strengthening the protection of trans-boundary habitats of protected wide-ranging wildlife species in the ETFC landscape.

In this context, it is important to understand present and future land-use/land-cover patterns because deforestation is considered as having an important effect on wildlife distribution and biodiversity (Sodhi *et al*. 2004; Corlett 2012). This is due to the fact that deforestation does not only cause habitat loss, but also it results in habitat fragmentation, diminishing patch size and core area, and isolation of suitable habitats (MacDonald, 2003). Trisurat and Duengkae (2011) indicated that the predicted occurrence of Black-crested Bulbul (*Pycnonotus melanicterus*) in the Sakaerat Man and Biosphere Reserve in Nakhon Ratchasima Province, Thailand would significantly decrease if forest cover slightly declined from 45.3% to 42% of the reserve and intact habitats would be severely fragmented.

Various models have been developed to forecast future land-use patterns, which range from simple system representations including a few driving forces to simulation systems based on a profound understanding of situation-specific interactions among a large number of factors (Verburg and Veldkamp, 2004; Pontius *et al*., 2008). The Markov Chain Model is a simple land use model that uses previous land use trends to predict what will happen in the future. However, it is not capable of addressing land suitability, land demands and government policies in the model (Pontius *et al*., 2008). A Cellular Automata incorporates spatial component in the traditional Markov Chain Model and it can address dynamics with simple rules (Baker, 1989), and has been applied in a wide range of land-use change applications (Houet and Hubert-Moy, 2006; Ballestores and Qiu, 2012). Recently, agent-based model was developed to allow the influence of human decision-making on the environment to be incorporated in a mechanistic and spatially explicit way, also taking into account social interaction, adaptation and decision-making at different levels (Matthews *et al*., 2007).

The current research used the Dyna-CLUE (Conversion of Land Use and its Effects) model (Verburg and Overmars, 2009) to assess future land-use at the ETFC. The Dyna-CLUE model was chosen for this study because it explicitly addresses the dynamics of the different future land demands. In addition, it has been used at both local level (Trisurat *et al*., 2010) and regional level (Verburg and Veldkamp, 2004) and has been proven to be as capable as other popular land-use change models (Pontius *et al*., 2008). Specific objectives of this research were (1) to quantify rate of land-use/land-cover change in recent years, and (2) to allocate land-use change and land-use patterns across the ETFC based on different demand scenarios of stakeholders from the three participating countries.

MATERIALS AND METHODS

Study area

The ETFC comprises the Pha Taem Protected Forests Complex (PPFC) in Thailand, the Preah Vihear Protected Forest for the Conservation of Genetic Resources of Plants and Wildlife (PVPF) in Cambodia and two national biodiversity conservation areas (NBCA) in Lao PDR. The PPFC located in Ubon Ratchathani province includes five protected areas, namely, Pha Taem National Park, Kaeng Tana National Park, Phu Jong-Na Yoi National

Park, Yot Dom Wildlife Sanctuary and Bun Thrarik-Yot Mon Wildlife Sanctuary. The collective area of the complex is approximately 1,736 km^2.

The PVPF is located in Preah Vihear Province, Cambodia. It adjoins the south of the Yot Dom Wildlife Sanctuary and to the west of the Mekong River, covering an area of approximately 1,900 km^2. To the northeast, it borders to Dong Khanthung proposed NBCA, which covers 1,828 km^2. Another protected area in Lao PDR situated in the ETFC is the Phou Xiang Thong NBCA, which is located east of Pha Taem National Park, and has an area of approximately 1,015 km^2. Therefore, the entire protected areas encompass approximately 6,500 km^2. The study area of this research also included surrounding protected areas located within a defined rectangular perimeter covering altogether approximately 25,800 km^2 (Figure 1).

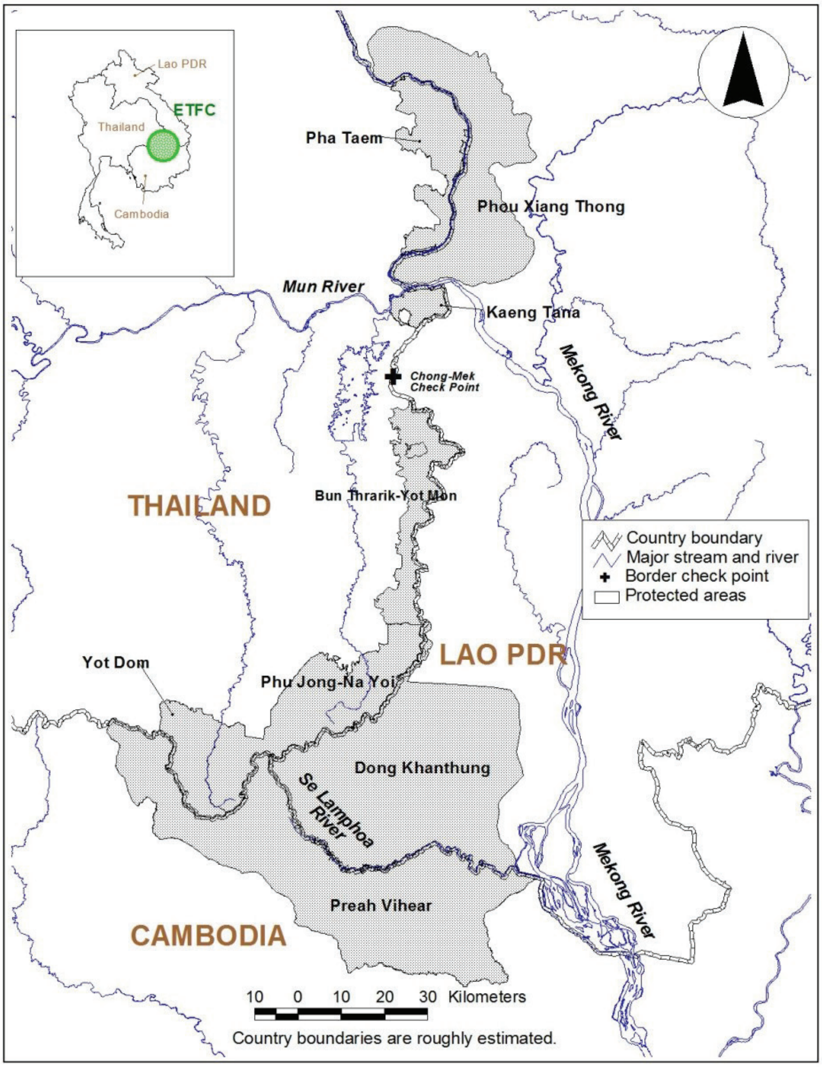

Figure 1 Location of the Emerald Triangle protected forests complex along the borders of Thailand, Lao PDR and Cambodia.

Land-use/land-cover Change Detection

Basically, there are three main steps to detect land-use/land-cover (LU/LC) change. These steps are described as follows:

a) ***Gathering past land-use/land-cover map***

The raster LU/LC map in 2003 with a resolution of 250 m covering the entire study area was obtained from the Mekong River Commission Secretariat (MRC). The original LU/LC map comprised 14 classes, namely 1) moist evergreen forest, 2) dry evergreen forest, 3) hill evergreen forest, 4) mixed deciduous forest, 5) dry deciduous forest, 6) forest plantation, 7) rubber plantation, 8) oil palm plantation, 9) cash crop, 10) paddy field, 11) settlement and infrastructure, 12) bare soil and miscellaneous land uses, 13) rock outcrop, and 14) water body. The original 14 LU/LC classed were generalized to 9 classes by combining some classes and renaming them as evergreen forests (moist, dry and hill evergreen forests), arable land (paddy, cash crop and oil palm), and bare soil and rock outcrop. This is due to the current Dyna-CLUE version is applicable not more than 11 classes (Verburg and Overmars, 2009), for land-use transitions at landscape level. During field reconnaissance, it was found that oil palm was recently introduced and mainly planted in paddy field in small patch (less than 250-m resolution). Thus, both classes show similar image signatures and they are difficult to discriminate.

b) ***Preparing current land-use/land-cover map***

The current LU/LC map in 2013 was interpreted from satellite images. The relatively cloud-free Landsat-8 TM imageries were downloaded from USGS (United States Geological Survey Department - http://earthexplorer.usgs.gov/). A sub-scene of images path/row 126/49 and 126/50 dated 8 October 2013 and 26 October 2013, respectively, was extracted and geometrically registered to the UTM coordinate system WGS Zone 48 using the topographic map at scale 1:50,000. Then, these two sub-scenes were made into a mosaic using ERDAS Imagine software and false color composite images (band combination 4 5 3 – R G B) were produced for visual interpretation based on tone, shape, size, pattern, texture, shadow and association (Lillesand et al., 2004). Due to unavailability of reference data from the NBCAs in Lao PDR, key image features of LU/LC types were sampled from the PPFC in Thailand and the PVPF in Cambodia.

The current research used a contingency table or classification matrix to quantify the agreement between the interpreted classes and the known classes of LU/LC map (Foody, 2002). Omission and commission errors for each LU/LC class, overall accuracy, and the kappa statistic were calculated (Jensen, 1996). The number of samples classified in preliminary LU/LC classes were selected using stratified random sampling scheme. The total number of sample locations for arable land, rubber plantation, forest plantation, dry dipterocarp forest, mixed deciduous forest, dry evergreen forest, settlement and others classes were 238, 38, 14, 43, 42, 61, 53 and 19, respectively.

c) ***Assessing annual change rate***

The annual rate of LU/LC change was determined by using the deforestation rate (DR) equation from year P (start) until year N (end year) (Trisurat, 2009), as below:

$$\text{DR (\%)} = -\left[1-\left(\frac{N}{P}\right)^{1/t}\right]\times 100$$

where

DR = Annual rate of change

N = Land-use of end year

P = Land-use of start year

t = Time period; $t_2 - t_1$ (10 years)

Land-use Change Modeling

The Dyna-CLUE model requires four inputs to allocate a set of conditions and possibilities of LU/LC patterns: (1) land-use requirements, (2) location characteristics, (3) spatial policies and restrictions and (4) land-use type-specific conversion settings (Verburg and Overmars, 2009). Land use requirements were calculated at the aggregate level jointly defined by 50 multi-stakeholders of the three participating countries attending the Joint Training Workshop on GIS Modeling for Forest Land Use Planning during 10-15 March 2014 in Cambodia. There were superintendents of protected areas, government officials, NGOs representatives and lecturers from universities.

Using a two-dimensional matrix to develop the LU/LC scenarios (Van der Heijden, 1996), the workshop participants identified *population growth as an important factor,* and *economic growth* as a result of the *ASEAN Economic Community (AEC) in 2015 scheme as a critical uncertainty,* to drive four LU/LC. In addition, they jointly defined four LU/LC scenarios for the period from 2013 to 2030 (Figure 2). The definitions of the scenarios are detailed as below.

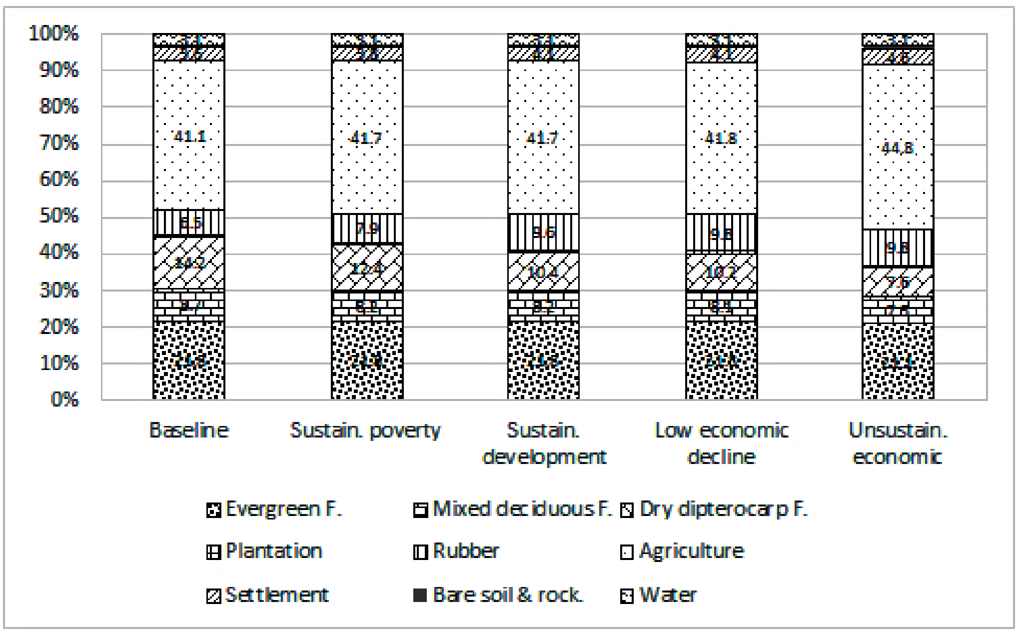

Figure 2 Land allocations for four scenarios in 2030.

a) Low economic decline and localized resource degradation (business as usual): a continuation of land transformation of recent years (2003-2013) is foreseen. The recent land-use change detection revealed that only limited encroachment was observed inside the

PPFC (Protected Areas Region 9, personal communication). Therefore, this scenario defines the PPFC as restriction areas.

b) Unsustainable economic development and serious resource degradation scenario: it is predicted that the continuous high rubber prices and high population growth make it profitable to transform large forest land and bare soil to paddy field and economic crops.

c) Sustainable poverty and stable resources scenario: a lower rate of land conversion is assumed due to low population growth and the delay of the AEC scheme, meaning limited deforestation. In addition, this scenario anticipates effective protection of remaining forest in all existing and proposed protected areas.

d) Sustainable development and limited resources degradation scenario: a relative land conversion rate applies for rubber plantation. Limited forest encroachment for agriculture outside protected areas and along inner and outer buffer zones of Dong Khanthung is assumed due to low population growth.

The Dyna-CLUE model determines the location preferences of the different LU/LC classes based on logistic regression models (Verburg and Veldkamp, 2004), which define the relation between occurrence of a particular LU/LC type and the physical and socio-economic conditions of a specific location (location factors):

$$Log(p_i) = \ln (p_i)/(1-p_i) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$$

where, p_i is the probability of a grid cell for the occurrence of the considered LU/LC type and the X_i parameters are the explanatory factors. The coefficients (β_i) are estimated through logistic regression using the occurrence of the LU/LC in 2013 as the dependent variable.

The physical factors to indicate the preference for a specific type of land use were altitude, slope, aspect, distance to available water, annual rainfall, rainfall in wettest quarter, rainfall in the driest quarter and soil characteristics. In addition, the socio-economic factors influencing land-use change were distance to district, population density and distance to main road. Topographic variables of 100-m resolution were gathered from Advanced Space Thermal Emission and Reflection Radiometer (ASTER) archive (http://asterweb.jpl.nasa.gov/data.asp). Road and stream networks and district location were updated from topographic maps at scale 1:50,000 and Landsat-8 TM, and later they were interpolated to obtain proximity to road, proximity to stream and proximity to city.

Climatic variables of approximately 1-km resolution were downloaded from the World climate database (http://www.worldclim.org/download), while soil map and population density were obtained from the MRC. The pixel resolution of 250 m was selected for this research because it was suitable for landscape scale and relevant to original LU/LC map in 2003 and the driving factors. In addition, the goodness-of-fit of a logistic regression model was evaluated using the receiver operating characteristic (Hosmer and Lemeshow, 2000). The value of the area under curve (AUC) ranged between 0.0 (completely unfit) and 1.0 (perfect fit), where AUC 0.5 is completely random.

Generally, elasticity is estimated based on capital investment and expert judgment, ranging from 0 (easy conversion) to 1 (irreversible change) (Verburg and Veldkamp, 2004). In this study, the elasticity values were obtained from the probability transition matrix of land-use between 2003 and 2013. In addition, water body and settlement and infrastructure classes were assigned "not possible to be transformed". In addition, a minimum of 10 years was assigned in the transition-setting as a requirement for the natural succession of reforestation to forest class and 20 years was specified for succession from abandoned agriculture back to forest cover, based on a previous study (Sahunaru *et al*., 1993) and image signature.

When all inputs were provided, the Dyna-CLUE model calculated the total probability for each grid cell of each land use type based on the suitability of location derived from the logit model, the conversion elasticity and the competitive advantage of the location. The total allocated area of each land use equals the total land requirements specified in the scenario (Verburg and Veldkamp, 2004).

Assessing Landscape Configuration Features

The FRAGSTATS ver. 3.0 software (McGarigal and Marks, 1995) was used to assess landscape structure and fragmentation indices of forest classes, arable land and rubber plantation in 2013 and 2030 in terms of total area, number of patches, mean patch size, largest patch index, shape index, total core area and mean core area. An eight-neighbor rule was used to identify patch in the landscape. In addition, a core area was assigned from 1 km from the perimeter. These landscape indices imply direct and indirect impacts of forest fragmentation on biodiversity (Turner *et al*., 2001; Trisurat and Duengkae, 2011).

RESULTS AND DISCUSSION

Land-use/Land-cover Change between 2003 and 2013

The classification matrix (Table 1) shows that five sample locations of arable land class were misclassified as dry dipterocarp forest. This is because some small woodlots still remain in new paddy fields, particularly in the northern plains of Cambodia. In addition, seven locations of dry dipterocarp forest were interpreted as mixed deciduous forest due to similar image signatures of these two classes. This effect was also found during field survey of young rubber plantation that was incorrectly interpreted as arable land. All sample locations of evergreen forest, water body and human settlement and infrastructure were correctly classified. The overall accuracy for the classified LU/LC map in 2013 was 94% and kappa statistic value was 0.91, which was highly reliable and acceptable for most remote sensing scientists (Jensen, 1996).

Table 1 Contingency table resulting from field validation

	LU/LC class	Interpreted class											
		Arable land	**Rubber plantation**	**Plantation**	**Bare soil**	**Dry ipterocarp forest**	**Mixed dipterocap forest**	**Dry Evergreen forest**	**Water**	**Settlement & infra.**	**Total**	**Producer's Accuracy (%)**	**Omission error (%)**
Known class	Arable land	224				5					229	98	2
	Rubber plantation	7	35	1							43	81	19
	Plantation		3	13							16	81	19
	Bare soil				8					1	9	89	11
	Dry diptercarp forest	7				38	2				47	81	19
	Mixed deciduous forest						40	7			47	85	15
	Evergreen forest							54			54	100	0
	Water								10		10	100	0
	Settlement & Infra.									53	53	100	0
	Total	238	38	14	8	43	42	61	10	54	508		
	User's accuracy (%)	94	92	93	100	88	95	89	100	98	94		
	Commission error (%)	6	8	7	0	12	5	11	0	2			

The spatial analysis and change detection indicated the extent of LU/LC classes as shown in Table 2 and their distribution patterns are as follows:

Evergreen forest: In the ETFC, moist evergreen forest is found along stream network where soil moisture is high all year round (Marod, 2003). In addition, dry evergreen forest is dominant among evergreen forest classes mainly found in Phu Jong-Na Yoi, Yot Dom and the core area of Dong Khanthung (Figure 3). In 2003, evergreen forest covered 21.36% of the ETFC, and it slightly increased to 21.71%, or approximately 9,000 ha, in 2013. This may be due to more rainfall as was recorded in 2013 (Department of Meteorology) or, may be because the LU/LC map in 2013 was interpreted from Landsat-8 TM taken in October 2013, which was early dry season. Therefore, there were commission errors from the signature of dense mixed deciduous forest (Table 1) and flooded dry dipterocarp forest situated in Dong Khanthung. Approximately 60% of the total evergreen forest was found inside protected areas.

Mixed deciduous forest: This forest type exists in Phou Xiang Thong, Pha Taem, Kaeng Tana and along the escarpment between Thailand and Lao PDR. Small patches were scattered in the southern part of the ETFC landscape. This forest type covered 245,412 ha in 2003 and substantially declined to 226,573 ha in 2013. The reduction rate was 7.68% in 10 years or 0.80% annually. Table 2 shows that the deforestation rate of mixed deciduous forest in protected areas was greatly lower than the entire ETFC landscape due to protection measures.

Dry dipterocarp forest: This forest type usually occurs on dry shallow and lateritic soils. It is now dominant in Pha Taem, Kaeng Tana, PVPF and Dong Khanthung. In Thailand, it used to be abundant along the buffer zone of PPFC (Trisurat, 2003). In 2003, the dry dipterocarp forest covered an area of 540,678 ha or 20.92% of the ETFC landscape. Approximately 30% of dry dipterocarp forest shrunk during 2003-2013 and large-scale conversion was observed both inside the PVPF and the Phou Xiang Thong NBCA and in the buffer zones. This finding was consistent with the result of forest cover assessment in PVPF that indicated that the total forest cover declined from 97.62% in 2002 to 95.33% in 2010, equivalent to 4,353 ha (Sobon *et al*., 2014). The primary manifestation of that change was concentrated in deciduous forest.

Forest plantation: Establishment of forest plantations has been mainly conducted in Thailand by the Forest Industrial Organization and Department of National Parks, Wildlife and Plant Conservation, for economic purposes and natural rehabilitation, respectively. *Eucalyptus* sp. is a common plantation species and most plantations were situated along the buffer zone of Bun Thrarik-Yot Mon Wildlife Sanctuary. Although the annual increment rate of forest plantations during 2003-2013 was greater than 3% in the entire ETFC landscape and greater than 6% in protected areas, it covered less than 1% of the total study area.

Para rubber plantation: This is a new cultivation practice in the ETFC landscape. However, it has increased rapidly in the last decade in Thailand and now expanded to Lao PDR and Cambodia. In 2003 rubber plantation covered 85,456 ha, but in 2013 it increased to 164,225 ha or 92% during this period. In addition, the annual increment rate (6.75%) was the highest among nine LU/LC classes. Most plantations were situated in the buffer zone of Bun Thrarik, Phu Jong-Na Yoi and Yot Mon. A few patches were observed inside Bun Thrarik-Yot Mon. The result of the LU/LC transformation matrix revealed that some paddy fields and cash crop areas were converted to rubber plantation due to the increasing rubber prices in the last decade.

Arable land: Arable land, including paddy field, cash crop and oil palm, is widespread in the ETFC landscape. Although oil palm was introduced as a new economic crop recently, it is anticipated that the extent of oil palm will not cover large area as rubber or other cash crops due to the constraints of soil characteristics and climatic conditions. In 2003, arable land constituted about 37% and slightly increased to 41% in 2013. Table 2 shows that the arable land inside protected areas greatly increased from 4% to 12.7% during the same period as a result of forest destruction in Phrea Vihear (Figure 2).

Bare soil and rock outcrop: This includes a drawdown zone along the river banks and rock outcrops in the marginal land or unfertile soil. The area of over 2,000 of this class was changed to other classes, particularly arable land, rubber plantation and settlement. There are 82 villages situated within a 3-km buffer of the PPFC and 4 villages are located inside the PPFC (Trisurat, 2007). In the last 10 years

(2003–2013), *human settlement areas* had expanded and the number of local residents increased from 49,324 to 65,016 individuals. *Water body* class includes reservoirs, ponds and major rivers. The total area of water body was virtually stable between 2003 and 2013. A few hundreds has increased in the ETFC landscape and less than 100 ha decreased in protected areas due to the fluctuation of water level during wet and dry seasons.

Projected Land-use/Land-cover in 2030

The significant factors and coefficients of the logistic regression models that determine the location suitability of the eight LU/LC classes are shown in Table 3. Water body was excluded because it was determined as stable in the land demand scenarios (Figure 2). It is noted that each driving factor contributed to different LU/LC types. High altitude, steep slope, high annual rainfall and further distance from city and stream, as well as difficulty to access by road were positively correlated with remaining evergreen forest. In contrast, areas that were close to the stream and main city, situated on fertile soil, accessible from main roads, and at low altitude, were a prime target for agriculture. Aspect is a considerable factor only for rubber plantation in the logistic regression model. In general, rubber tree can grow in all aspect directions (Ranst *et al*., 1996) but the model results indicated that the greater the degrees in a clock-wise direction, the more suitable the aspect is for rubber. This is due to the fact that most existing rubber plantation areas are situated in the buffer zones of the PPFC (Figure 3). The areas to the east of PPFC are mountainous landscape.

Table 2 LU/LC classes in 2003 and 2013 in the Emerald Triangle landscape and protected areas (ha) and changes.

Type of land-use	2003		2013		Change	Change in %	
	ha	%	ha	%	ha (+/-)	10 yrs.	Yearly
Evergreen forest	552,112[1]	21.36	561,104	21.71	8,992	1.63	0.16
	320,813[2]	49.39	325,719	50.16	4,906	1.53	0.15
Mixed deciduous forest	245,412	9.49	226,573	8.77	-18,839	-7.68	-0.80
	106,563	16.41	103,856	15.99	-2,707	-2.54	-0.26
Dry dipterocarp forest	540,687	20.92	374,337	14.48	-166,350	-30.77	-3.61
	179,731	27.67	121,788	18.75	-57,943	-32.24	-3.82
Forest plantation	9,850	0.38	13,475	0.52	3,625	36.80	3.18
	119	0.02	231	0.04	112	94.12	6.86
Para rubber	85,456	3.31	164,225	6.35	78,769	92.18	6.75
	4,381	0.67	3,856	0.59	-525	-11.98	-1.27
Arable land	965,087	37.34	1,058,836	40.96	93,749	9.71	0.93
	26,575	4.09	82,756	12.74	56,181	211.4	12.03
Settlement	77,700	3.01	80,365	3.11	2,665	3.43	0.34
	913	0.14	1,500	0.23	587	64.29	5.09
Bare soil & rock outcrop	25,549	0.99	23,293	0.90	-2,256	-8.83	-0.92
	6,075	0.94	5,288	0.81	-525	-11.98	-1.27
Water body	83,050	3.21	82,697	3.20	-353	-0.43	-0.04
	4,356	0.67	4,419	0.68	63	1.45	0.14
Total: Emerald Triangle	2,584,903	100.00	2,584,903	100.00	0.00	0.00	0.00
Protected areas	649,413	100.00	649,413	100.00			

Remarks: [1]Entire Emerald Triangle landscape; [2] within protected areas.

Table 3 Beta values of significant location factors for regression models related to each land use type.

Variables	Evergreen forest	Mixed deciduous forest	Dry dipterocarp forest	Plantation	Rubber	Arable land	Settlement	Bare soil
DEM (m)	0.002	ns	-0.013	0.015	0.011	-0.003	0.003	0.007
Slope (%)	ns	0.103	ns	-0.096	-0.118	-0.120	ns	-0.035
Aspect	ns	ns	ns	ns	0.001	ns	ns	ns
Population density (person/km2)	-0.039	-0.001	<-0.001	-0.001	-0.001	<-0.001	0.002	ns
Annual rainfall (mm)	0.009	-0.006	-0.003	0.019	-0.006	-0.007	0.008	-0.015
Rainfall in the wettest quarter (mm)	-0.007	0.008	0.007	-0.023	0.008	0.006	-0.011	0.016
Rainfall in the driest quarter (mm)	-0.045	0.152	0.290	-0.384	-0.179	-0.102	-0.122	ns
Distance to road (m)	<0.001	8.9E-05	5.7E-05	-0.001	-0.001	-0.0003	-0.003	<-0.001
Distance to stream (m)	8E-05	0.6E-05	5.1E05	<-0.001	-0.001	<-0.001	<-0.001	ns
Distance to city (m)	3.8E 05	-0.3.2E-05	1.1E-05	ns	ns	1.6E-05	-3.0E-05	-3.4E-05
Acrisol soil	3.222	0.437	2.332	0.763	0.667	1.590	-0.366	0.744
Arenosol soil	1.503	ns	1.311	0.735	ns	2.174	-0.513	ns
Cambisol/Plinthosol soil	3.503	0.572	2.446	ns	-1.594	1.383	-0.628	ns
Ferralsol soil	3.554	ns	Ns	-1.836	0.834	1.161	ns	ns
Gleysol/Fluvisol soil	2.168	0.929	1.916	ns	ns	1.836	-1.161	ns
Leptosol soil	4.786	ns	2.099	ns	ns	1.933	ns	ns
Lixixol soil	2.893	ns	ns	ns	1.664	1.673	ns	ns
Luvisol/Solonetz soil	2.495	ns	3.001	ns	-2.447	1.777	ns	ns
Slope complex	2.475	ns	4.245	ns	1.736	ns	-0.740	2.222
Rock	3.660	ns	3.512	-3.355	-1.326	Ns	-1.718	0.997
Constant	-11.252	-0.232	-8.307	-5.176	4.120	7.532	1.489	8.008
AUC	0.902	0.758	0.767	0.837	0.802	0.815	0.903	0.797

Notes: AUC = area under curve; ns = not statistically significant

Table 4 Landscape indices of remaining forest types, rubber plantation and arable land under different LU/LC scenarios.

Scenarios	Total area (km2)	No. of patches	Mean patch size (ha)	Largest patch index (%)	Shape index	Total core area (ha)	Mean core area (ha)
Baseline (2013)							
Evergreen	5,474	5,678	120	13.80	1.21	69,768	15
Mixed Dec. For.	2,169	7,588	29	1.94	1.15	119	<1
Dry Dip. For.	3,569	7,541	47	1.58	1.25	50	<1
Rubber plt.	1,617	3560	45	0.70	1.22	0	<1
Arable land	10,308	5415	190	27.84	1.24	68,887	13
Low economic decline							
Evergreen	5,277	3,497	151	13.79	1.25	70,125	20
Mixed Dec. For.	1,938	5,584	35	2.31	1.17	75	<1
Dry Dip. For.	2,637	4,692	56	0.73	1.28	50	<1
Rubber plt.	2,348	4713	50	1.03	1.22	737	<1
Arable land	10,733	5080	211	28.55	1.24	79,575	16
Unsustainable economic							
Evergreen	5,278	3,300	160	14.3	1.25	73,206	22
Mixed Dec. For.	1,881	5,409	35	2.24	1.17	75	<1
Dry Dip. For.	1,912	3,414	56	0.63	1.27	25	<1
Rubber plt.	2,459	4700	52	1.01	1.21	743	<1
Arable land	11,218	4664	240	28.67	1.24	86,500	18
Sustainable poverty							
Evergreen	5,473	4,237	130	13.95	1.22	72,068	17
Mixed Dec. For.	2,053	6,694	31	1.95	1.16	100	<1
Dry Dip. For.	3,101	5,492	56	1.57	1.29	50	<1
Rubber plt.	1,969	4,350	45	0.91	1.22	12	<0
Arable land	10,449	5,311	197	28.31	1.24	75,856	14
Sustainable development							
Evergreen	5,462	3,649	146	14.24	1.25	78,906	22
Mixed Dec. For.	2,053	6,438	32	1.96	1.16	100	<1
Dry Dip. For.	2,614	4,605	57	0.74	1.29	37	<1
Rubber plt.	,2404	4,911	49	1.09	1.22	1,781	<1
Arable land	10,448	5,208	201	28.05	1.24	7,290	14

According to Hosmer and Lemeshow (2000), the predicted models were outstanding for evergreen forest and settlement (AUC>0.9), excellent for forest plantation, rubber plantation and agriculture (0.8≤AUC<0.9), and acceptable for mixed deciduous forest, dry dipterocarp forest and bare soil & rock outcrop (0.7≤AUC<0.8). This is because evergreen forest and human settlement were mainly restricted and clustered in certain areas, while other classes were widely distributed in the ETFC landscape. The gradient of AUC values showed similar agreement with the accuracy assessment of the interpreted LU/LC classes (Table 2).

The simulated LU/LC maps in 2030 for the four scenarios are shown in Figure 4. The results of the *low economic decline and localized resource degradation (business as usual)* scenario with restriction policy in the PPFC show that future deforestation for agriculture was predicted in the remnant forests situated in the buffer zones of the PPFC and areas close to the Chong-Mek border check point (Figure 4a). In addition, substantial amount of forest cover in the Phou Xiang Thong and to the north of Dong Khanthung were predicted to be converted to rubber plantations. In Thailand, expansion of rubber plantations was predicted in the west outside the Pha Taem national park and close to road network currently covered by cash crop and mixed deciduous forest.

The *unsustainable economic development and serious resource degradation* scenario predicted a lot of land conversion to arable land and rubber plantation. The area of mixed deciduous and dry dipterocarp forests was predicted to decline from 22.9% of the entire ETFC in 2013 to 15.1% in 2030. In contrast, rubber plantation area was anticipated to increase 50% from the current status (Figure 2). Figure 4b shows that new arable land is also predicted in the west of PVPF, which is close to the Preah Vihear Temple cultural world heritage site.

The *sustainable development and limited resources degradation* scenario (Figure 4d) predicted similar land-use patterns as the *business as usual* scenario (Figure 4a). High deforestation was found in the north of Dong Khanthung and to the west of Pha Taem, but limited areas in all protected areas. Finally, the *sustainable poverty and stable resources scenario* showed different land-use patterns than other scenarios. This scenario assumed less demand for agriculture and rubber plantations due to low population growth and the delay of AEC implementation scheme, leading to limited deforestation. A small amount of land conversion to rubber plantation was expected outside all existing and proposed protected areas (Figure 4c).

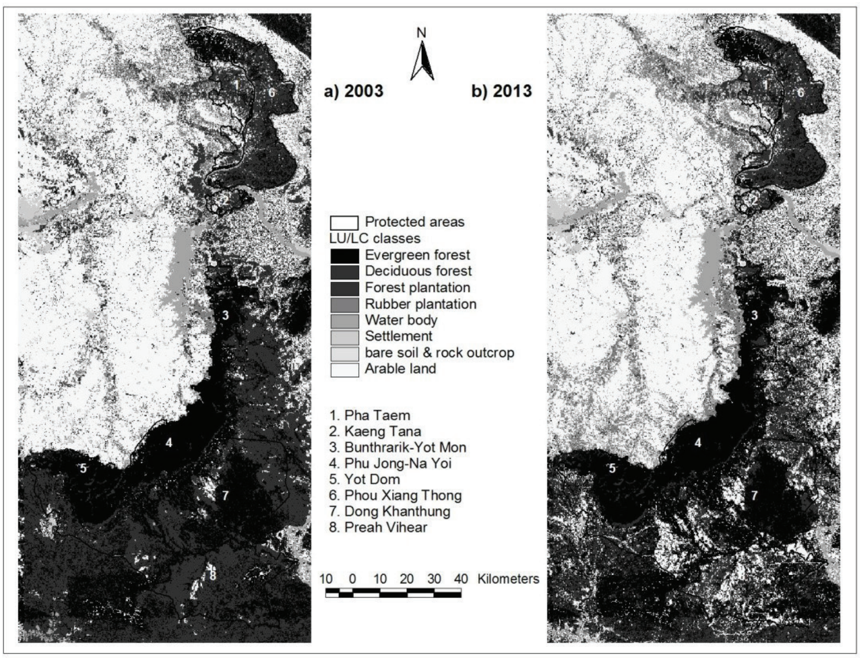

Figure 3 Location of the Emerald Triangle protected forests complex along the borders of Thailand, Lao PDR and Cambodia.

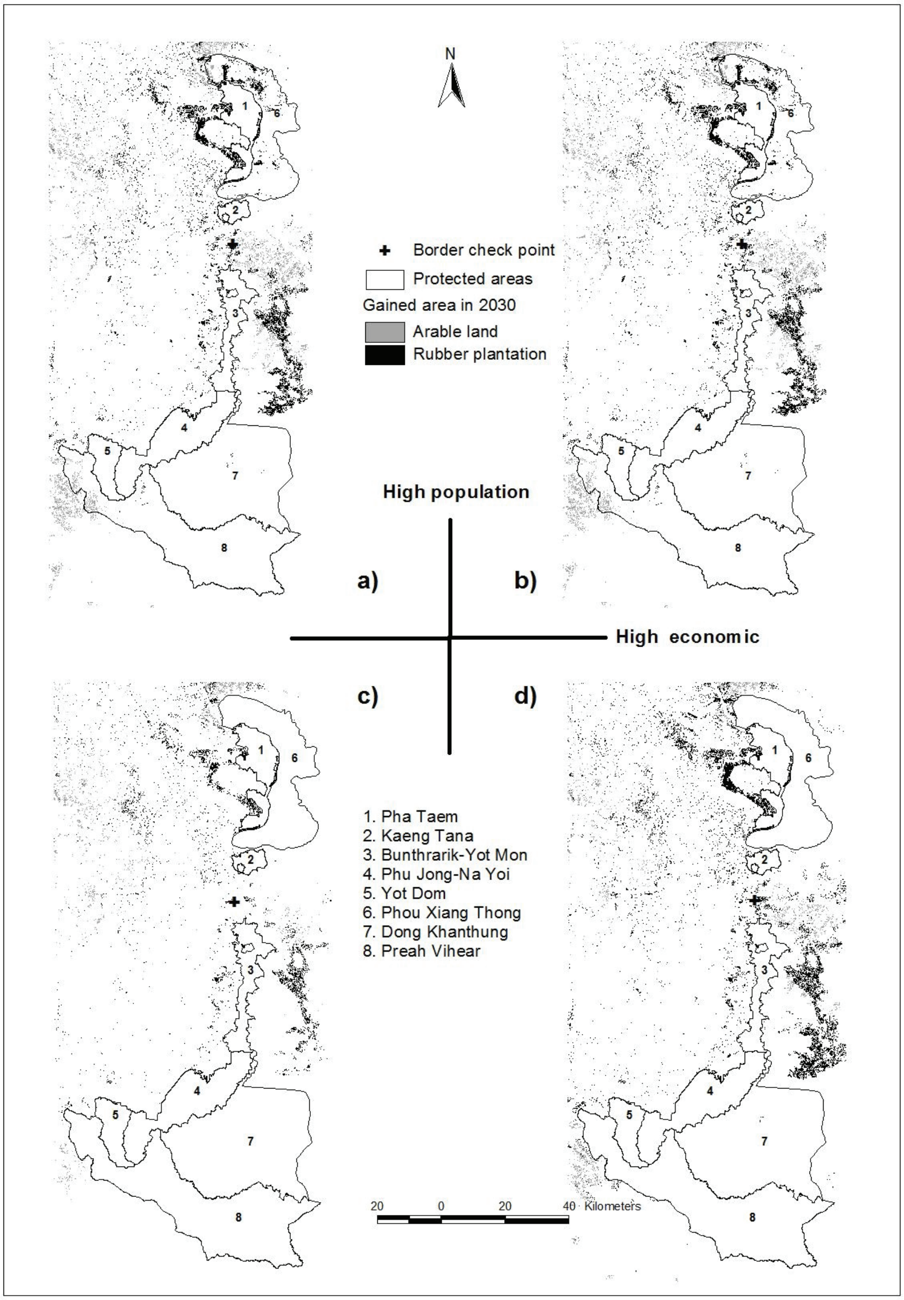

Figure 4 Predicted new areas for arable land and rubber plantation in 2030.

Implications for Trans-boundary Biodiversity Conservation

Land-use conversion as a result of expansion of human settlements and permanent crops does not only diminish suitable habitats for wildlife species, but also it causes habitat fragmentation, reduced patch size and core area, and isolation of suitable habitats (Turner *et al.,* 2001; MacDonald, 2003; Trisurat and Duengkae, 2011). These consequential effects were very clear for dry dipterocarp forest in which the total area was predicted to decrease from 3,569 km^2 in 2003 to 2,637 km^2 in 2013. The number of threatened patches was over 4,000 and most of these were remnant patches distributed outside protected areas across the ETFC landscape (Table 4).

In addition, the results of landscape analyses revealed that the total core area of dry dipterocarp forest declined from 50 ha in 2003 to 25 ha in 2013. In contrast to these results, evergreen forest was less threatened under all scenarios because the remaining areas are situated either in protected areas or in high steep slope, which become barriers for encroachment for agriculture (Trisurat, 2007). In addition, Table 4 also shows that the extent and average patch size of arable land and rubber plantation are greater in 2030 for all modeled scenarios, except the *sustainable poverty* scenario where small landholder subsistence farmers practice agriculture for their daily livelihood not driven by market prices.

The destruction of lowland dry deciduous forest situated in Lao PDR and Cambodia will cause significant impacts to iconic wildlife species (e.g., *Eld's* deer, giant ibis, Sarus crane), large herbivores (Asian elephant, banteng, gaur) and medium-to-large sized mammals in the ETFC landscape. Population densities and diversity of large herbivores are greater in seasonal dry forest habitats than in rain forests that are characterized by closed canopies and tall grasses (Sukumar, 2003; McShea and Baker, 2011). Round (1998) found that the lowland dry diptercarp forest in the Dong Khanthung forest reserve supports more wildlife species than evergreen forest. The results of land-use modeling are being used as explanatory variables in the distribution modeling of wide-ranging species and as important input for preparation of collaborative framework for trans-boundary biodiversity conservation in the ETFC landscape.

CONCLUSION

The LU/LC change assessment between 2003 and 2013 indicated that approximately 30% of remaining dry dipterocarp forest both inside protected areas and the entire ETFC landscape was converted to other land-use classes. Rubber plantation expanded substantially in the buffer zones of the PPFC. Future LU/LC in the ETFC landscape would be driven by population growth and the implementation of the AEC scheme.

The *sustainable poverty and stable resources scenario* predicted a small amount of rubber and arable land expansion. All protected areas are secured from future deforestation. The *low economic decline and localized resource degradation* scenario indicated future deforestation for agriculture in the remnant forests in the buffer zones of the PPFC and in Lao PDR close to the border check point (Figure 4a). The two remaining scenarios, *unsustainable economic development and serious resource degradation* and *sustainable development and limited resources degradation*, showed similar land-use patterns but greater extent of new arable land and rubber plantation, especially for the *unsustainable economic development.* Large conversion of dry dipterocarp forest in the PVPF was expected as the result of land allocation program and infrastructure development for tourism activities.

It is important to note that the projected LU/LC patterns should not be interpreted to be the actual predictions of where a land-use type will be in the future, because of some limitations and uncertainties in the models used for the predictions (e.g., scale dependent, future socio-economic conditions). However, the general patterns emerging from the projections are very useful to inform policy makers and stakeholders of the three participating countries to proactively formulate collaborative framework to prevent future deforestation in risk areas and to put more efforts for conserving important habitats and migratory routes of trans-boundary species. The modeled outputs are being employed to predict the distributions of wide-ranging species in the ETFC landscape as outlined in the objective of ITTO project phase III.

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