Exploring trade-offs between development and conservation outcomes in northern Cambodia

Emilie Beauchamp^{1&3}, Tom Clements², and E.J. Milner-Gulland³

¹ 14 Princes Gardens, Centre for Environmental Policy and Department of Life Sciences, Imperial College London, UK

² Wildlife Conservation Society, Bronx, New York, USA

³ Department of Zoology, University of Oxford, UK

Corresponding author:

Emilie Beauchamp
New Radcliffe House
Zoology Department,
University of Oxford,
Oxford OX2 6AE
emilie.beauchamp@zoo.ox.ac.uk

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Abstract

Trade-offs between different land use outcomes are inevitable to meet both development and conservation agendas, especially in developing countries where aspirations for development take place within the world's most biodiversity-rich areas. Reports at the national or subnational levels about how trade-offs between conservation and development outcomes materialize once implemented are limited and regionalized analyses are required to understand how they materialize spatially once policies are executed. We take the case study of northern Cambodia, where both protected areas (PAs), as a conservation policy, and Economic Land Concessions (ELCs), as a developmental agricultural intensification strategy, have been implemented. We explore the influences on placement of ELCs and the extent to which they overlap with protected areas, using mixed effect models. We then determine the predictors of deforestation in the study area between 2008 and 2013, including presence of ELCs and PAs. ELC placement does not respond to expected socio-environmental factors related to implementation criteria in policy documents, and is not influenced by the presence of PAs. ELCs represent the most significant driver of deforestation of the factors considered. PAs limit deforestation but only if well-managed. This failure to achieve the balanced trade-off between conservation and development outcomes which policies intend points to development impacts compromising environmental sustainability in the long-run.

Keywords: Economic Land Concessions; deforestation; trade-offs; conservation policy; Cambodia

Highlights

- Spatial correlates of Economic Land Concession (ELC) placement and deforestation in northern Cambodia are modelled
- ELC placement does not respond to implementation criteria stated in policy documents
- Deforestation is more likely to occur in ELCs, and less likely in managed protected areas
- Results point to discrepancies in the implementation of the Land Law
- Development impacts may compromise long-term environmental sustainability

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1. Introduction

Land as a global resource has become the focus of intensified demands from a variety of users over the past decades (Lambin & Meyfroidt 2011). In an industrializing and globalized world, reconciling land use policies to achieve aspirations for economic development, food production and biodiversity protection is a tricky task (Tscharntke et al. 2012). Several studies now emphasize that trade-offs between different land uses are inevitable to meet both development and conservation agendas (Cardinale et al. 2012; Halpern et al. 2013; McShane et al. 2011). This is especially the case for developing countries, which are expected to support the bulk of development pressures from now until 2050, but which also host most biodiversity-rich areas of the planet (Balmford et al. 2002; Baudron & Giller 2014b; Phalan et al. 2013). Notwithstanding the challenge of designing adequate development policies, governments must also devise appropriately matching conservation strategies.

Land use change and deforestation follow complex dynamics, with agriculture as a central feature. More than half of the new agricultural land across the tropics was carved out from intact forests between 1980 and 2000 (Gibbs et al. 2010). This trend continued into the new millennium, with conversion of forests to agricultural plantations being considered the main cause of forest loss since 2000 (DeFries et al. 2010; Gibbs et al. 2010; Stibig et al. 2014). The increased competition for finite land resources entails trade-offs between preserving biodiversity and meeting food demand, yet several configurations exist for the integration of both agricultural and environmental aims (Balmford et al. 2012). Two contrasting alternatives are land sharing, which integrates both objectives on the same land, or land sparing, which separates high yield farming zones from conserved high biodiversity areas (Phalan, Onial, et al. 2011; Phalan, Balmford, et al. 2011). Over the years, several studies have pointed to the oversimplicity of the land sharing/sparing discourse, arguing land use planning should consider combinations of sharing and sparing strategies in order to address the integrated challenges related to land scarcity, food security and land governance (Fischer et al. 2014; Grau et al. 2013; Tscharntke et al. 2012).

Nonetheless, agricultural intensification has been adopted by several countries across the tropics as a policy for reducing pressure on forest from extensive farming over the past decades (Phelps et al. 2013; Green et al. 2005). Proponents argued the strategy can satisfy agricultural demand and growth in the face of rising population (Angelsen 2010; Phalan, Balmford, et al. 2011; Shively & Pagiola 2004; Ziegler et al. 2012). Intensification also offers potential reductions in carbon emissions from deforestation, but also from mitigation when reduced farmland areas can be actively restored into natural habitats (Green et al. 2005). In theory, agricultural intensification aims to maximize synergies between development and conservation; increasing national yields and reducing carbon emissions by transitioning from small-holder slash-and-burn agriculture to larger-scale commercial agriculture, increasing employment for local labour, and facilitating

investment in already degraded areas rather than new unconverted areas (Foley et al. 2004; Foley et al. 2011; Lambin & Meyfroidt 2011b; Tilman et al. 2011).

The potential economic benefits of agro-industrial projects are huge, yet major concerns have arose around the poor adaptation to local conditions of certain preferred plantation crops such as rubber, and the economically volatile and unsustainable conditions this creates for the future livelihoods of local farmers (Ahrends et al. 2015; Gironde & Peeters 2015). The opportunity cost of these investments represent a passive disinvestment in financing development and better access to markets for small land holders, and a failure to deliver poverty reduction in rural communities (De Schutter 2011; Sperfeldt et al. 2012; Vrieze & Naren 2012). Critiques of agro-industrial plantations additionally point to the lack of standardized sustainability assessments of the plantation projects, the displacements which often result from the corporate takeover of local community land, and lack of power that communities have over such decisions (Feintrenie 2014; Gerber 2011; McCarthy & Zen 2010). Recent research has further highlighted that large-scale agro-industrial conversion can drastically alter landscape soil and hydrological functions by clearing high-biodiversity value land for single species plantation (Fox et al. 2014; Ziegler et al. 2009).

Reports at the national or subnational levels about how trade-offs between conservation and development interventions materialise once implemented are limited, but point to the influence of a multiplicity of local geographical and historical contexts (Ferraro & Hanauer 2010; Pender et al. 2004; Gurney et al. 2014). These include land conversion drivers such as illegal logging, infrastructure construction, large-scale agricultural plantations, smallholder clearance by farmers and by resettlements (Stibig et al. 2014; Baird 2014a; Lambrick et al. 2014; Michinaka et al. 2013). The nature of specific attributes related to agro-industrial development policy in Cambodia including soil fertility, accessibility and population density, are also key in determining trade-offs between different land uses (Peeters 2015). Hence regionalized analyses are required to better understand how land use trade-offs materialise spatially once policies are executed (Geist & Lambin 2002; Rudel et al. 2009).

Here we explore influences on the spatial placement of large-scale agro-industrial development interventions, their outcomes in terms of deforestation rates, and the extent to which development interventions trade off against conservation goals. While the overlap between development and conservation interventions can be observed in several developing countries, Cambodia presents an interesting case study for the analysis of the impacts of trade-offs between development and conservation on land cover change in a context of growing and industrialising economy. The Cambodian context reflects similar situations in developing countries where large-scale land acquisitions have been taken place on a background of weak governance and insecure customary tenure rights (Clements et al. 2010; Sekiguchi & Hatsukano 2013). Yet overlaps between ELCs and other land uses such as small-scale agriculture and different levels of conservation activities highlight the importance of a regional-scale analysis using accurate data (Milne & Mahanty 2015; Messerli et al. 2015; Edelman 2013).

2. Background

2.1. Development and conservation policy in Cambodia

Both conservation and development are stated as priorities of the Royal Government of Cambodia (RGC)'s long-term development 'Rectangular Strategy' and the related National Strategic Development Plans (NSDP 2014). The Cambodian protected area network, designed in 1993, includes 23 protected areas covering 3.3 million hectares, or 18.3% of Cambodia's total area (MRC 2003). In 2010, forests covered about 55% of the country, representing a substantial source of its natural wealth and contribution to local livelihoods (USAID 2012). Political commitments to biodiversity conservation in Cambodia have been sustained in recent years, with policy objectives of the country's forest cover reaching 59% of its total area by 2013. Despite these statements, Cambodia recorded the world's fifth highest national deforestation rate between 2000 and 2012, with a 7% loss of its official forest cover during that period (Hansen et al. 2013). Deforestation proves additionally tricky to identify under large scale land conversions to plantations such as rubber, which has similar spectral characteristics compared to natural tropical forest and can change seasonally (Dong et al. 2013; Li & Fox 2011). Moreover, the RGC's official forest classification which considers mature plantations as forest, including plantations such as rubber, oil palm, teak, acacia and eucalyptus in which trees are higher than five meters, covering at least 0.5 ha and with a canopy of more than 10% (RGC 2010).

In parallel, Cambodia has also seen rapid economic progress, registering annual GDP growth of almost 10% per year between 1998 and 2008, along with an average annual population growth rate of 1.7% between 2000 and 2013 (World Bank 2011; World Bank 2013). More specifically, the RGC has increased the number of Economic Land Concessions (ELCs) being granted per year over the past decade. While Cambodia had already started granting land to private companies for investment in plantations and large-scale agriculture in the 1990s, ELCs as a process for agro-industrial development became formalized through the 2001 Cambodia Land Law and the subsequent Sub-decree n°146 (RGC 2001; RGC 2005). According to RGC's strategic policy documents, ELCs respond to the national impetus for economic development by boosting agricultural production and generating work for local communities (Arias et al. 2012; MAFF 2015; Phelps et al. 2013).

Cambodia recognizes five categories of land tenure; privately owned land, state-owned public land, state-owned private land, common property, and indigenous land. State land, both public and private, accounts for 75-80% of Cambodia's total land area (GTZ 2006; Thiel 2009; USAID 2011). State-owned private land can be leased, granted as a concession or held in usufruct. In turn, state-owned public land is classified as land that contains property of 'natural origin' which carries a public interest use and which may not be sold or transferred. For example, state-owned public land includes land designated under the protected area network (Bolin 2013).

The 2001 Land Law and sub-decree decree n°146 on ELCs outlines the criteria against which proposed ELC projects must be evaluated (Article 5). First, the law requires ELCs to be located in

state-owned private land, which is considered to be 'free' or 'non-use' land. This is in contrast with state-owned public land under which protected areas are designed (MAFF 2015; NSDP 2014; RGC 2005). ELCs must primarily generate state revenues and increase agricultural production. Additionally, they must: create local employment to diversify livelihoods in rural areas; promote living standards of the people and avoid or minimize adverse social impacts; and perpetuate environmental protection and natural resource management (Article 5).

Lastly, sub-decree n°146's Article 4 also mentions that comprehensive environmental protection provisions must be development within the concession management plan. Towards this, proposed ELCs must by law complete an environmental and social impact assessment and develop a sustainable land use plan, both of which have to be put to public consultation before getting final approval from provincial authorities (MAFF 2015; RGC 2005).

2.2. Rising concerns: deforestation and ELCs

In 2008, a review of the Protected Areas Law opened up for ELCs to be conceded within Cambodia's Protected Areas network (RGC 2008). Already existing concerns about the negative environmental impacts of ELCs increasing threats in under-funded protected areas increased as the review introduce a new system of zoning allowing to convert public land into private land (Sperfeldt et al. 2012; WWF 2007). Since 2008, several sub-decrees have been passed degazetting sections of conservation areas, and reclassifying them as "sustainable use zones" which allows economic activities in these areas according to its Art. 11 III (RGC 2008). For example, Sub-Decree 206 rezoned 9,237 hectares as sustainable use zones in Kulen Prumtep Wildlife Sanctuary, and granting the land for agro-industry investment to Cambodia Dawn Plantation Ltd (RGC 2008; RGC 2011)

The granting of ELCs also increased apace, along with rising foreign direct investments in agriculture (Arias et al. 2012; LICADHO 2014; Ullenberg 2009b). According to MAFF (2014), 118 companies were granted ELCs over a total land area of 1,204,750 hectares by the beginning of 2013. The figure is contested by several local and international NGOs, claiming that over 2 million hectares, covering almost half of Cambodia's total arable land, have been granted (LICADHO 2014; Neef et al. 2013; Peeters 2015). In recent years, communities, local and international organisations have increasingly raised concerns about the impacts of the widespread granting of ELCs and the lack of adherence to the established legal criteria in the granting process (BICP 2012; GW 2009; 2012; LICADHO 2005; 2014). Issues have arisen specifically around unfair eviction from land, human rights abuses, rapid deforestation rates, and ELCs being granted over high value forests and protected areas (Bues 2011; Hor et al. 2014; Sperfeldt et al. 2012; Subedi 2012; Subedi 2014; Ullenberg 2009a; Vrieze & Naren 2012).

Partly in response to external pressures and with looming national elections, the RGC introduced a moratorium on the granting of new ELCs and a systematic review of all ELCs in May 2012 (Bolin 2013; LICADHO 2014; RGC 2012). However, recent reports indicate that at least 16 new concessions have been granted since the ban was announced in 2012, totalling over 80,000 hectares. Amongst these, 35,000 hectares of land have been granted within the protected area network since the moratorium (LICADHO 2014). Additionally, field reports have shown that most

ELCs, once cleared of forest, remain largely unexploited for agriculture, hence not contributing to agricultural productivity in Cambodia (CEA 2009; GW 2009; GW 2012).

Bickel (2011) states that ELCs remain mostly unproductive because of the lack of access to finance (both equity and loans), the lack of access to skilled labour, slow net cash inflows in agriculture for tree crops or due to the political nature of ELCs. Contributions to local rural economies come further into question with studies showing that most ELC workers are migrants coming from outside the province (Sperfeldt et al. 2012) and that little is done by the private investors to collaborate with local farmers, or to provide technical or financial support (Ullenberg 2009b). Due to a continuing lack of transparency in the granting of ELCs, the mechanism has been implicated as primarily serving the interests of elite wealth accumulation through land grabbing for high value timber logging, instead of the legally stated provisions of development and agricultural goods (Neef & Touch 2012; Biddulph 2010; Vrieze & Naren 2012; Un & So 2011).

Qualitative accounts of ELCs impacts are numerous, with detailed analysis of processes and meta-analysis of case studies now available (Messerli et al. 2015; Sperfeldt et al. 2012). However, spatial analyses have focused on providing a visualization of the location of ELCs to grant insights into their characteristics, for example the type of concession and their implementation stage, rather than spatial analysis for a large scale inference (Diepart & Schoenberger 2016; LICADHO 2014; Peeters 2015; Schönweger et al. 2012). The lack of larger scale study is partly due to issues with data transparency and reliability of geospatial data about forest cover and ELC location at the national level (Dwyer 2013; Frewer & Chan 2014; Scoones et al. 2013). A few studies have highlighted the negative influence of ELCs on deforestation (Clements & Milner-Gulland 2015; Rainey et al. 2010; Hor et al. 2014). Recently, Davis et al. (2015) have investigated the contribution of ELCs to deforestation at the national level using covariate matching, however they have not enquired into the spatial patterns of their location and evaluated the scale of their influence in relation to environmental change in a regionalized context.

Deforestation drivers often vary spatially, thus untangling the socio-ecological contributing factors and analysing the spatial overlaps between ELCs and protected areas requires a regionalized approach. Here we use regression models to investigate two issues. First, what are the correlates of ELC placement as implemented within Cambodia's stated development policy? Second, what are the correlates of recent deforestation, and specifically, what is the role of ELCs in deforestation, in the context of other factors?

3. Materials and Methods

3.1. Study area

This analysis focuses on Northern Cambodia, more specifically the provinces of Preah Vihear and Kampong Thom, as well as the provinces of Stung Treng and Kratie up to the Mekong river (Figure 1). The 3,333,486 hectare study area contains several ecosystems including an evergreen dry forest home to 80% of Cambodia's economically valuable and endangered endemic tree

species, hence of considerable biodiversity value (Olsson & Emmett 2007; Strange et al. 2007). The landscape contains 50 ELCs and 4 protected areas, at times overlapping (Table 1; see Appendix A for detailed list). The study area was bounded by the availability of triangulated spatial data for land cover change between 2008 and 2013 (CI 2013; Hansen et al. 2013).

Figure 1: Location of the study area showing villages and administrative boundaries at the provincial, district and commune level as included in the analysis

Amongst the four protected areas, three have been actively managed by the RGC since the beginning of the 2000s. The Kulen Promtep Wildlife Sanctuary (KPWS), which was established in 1993, is managed by the Ministry of Environment, and the Preah Vihear Protected Forest (PVPF), declared in 2002, is managed by the Forestry Administration (FA) of the MAFF. The section of KPWS located in the Preah Vihear province and the PVPF are part of the Northern Plains landscape, where international non-governmental organization Wildlife Conservation Society (WCS) has been supporting the the MoE and FA's conservation efforts since 2005 (Clements et al. 2010; Clements & Milner-Gulland 2015). The Preah Vihear Temple, a Unesco World Heritage Site since 2008, is managed by the Ministry of Tourism. The Boeng Per Wildlife Sanctuary (BPWS) is by law under the management of the MoE, yet has seen insufficient law enforcement activities and was identified by Lacerda et al. (2004) as the protected area second most threatened by land encroachment in Cambodia.

Three other intervention types present in the landscape and that may have had additional effects on deforestation include Community Forests (CFs), Community Protected Areas (CPAs), and Social Land Concessions (SLCs). They have not been included in this study due their size of less than 5 hectares in average.

Table 1. Area of the study site under PA and ELC land use designations, not mutually exclusive

Intervention status	Area (ha)	% of total area
Outside of PAs	2,690,481	80.7%
Inside PAs	643,005	19.3%
Boeng Per Wildlife Sanctuary	213,340	6.4%
Kulen Promtep Wildlife Sanctuary (East)	236,109	7.1%
Preah Vihear Protected Forest	189,978	5.7%
Preah Vihear Temple	3,578	0.1%
Inside ELC	476,049	14.3%
Outside ELCs	2,857,437	85.7%
Total study area	3,333,486	100.0%

The landscape is also home to 1088 villages, which contain between 18 and 1002 households each. The main livelihoods revolve around small-scale rice farming, non-timber forest product harvesting and fishing (Clements et al. 2014; USAID 2011b). While the aggregated impacts of human activities such as small-scale illegal logging and farming are recognized to contribute to deforestation, the limited extent of each activity makes local community livelihoods a relatively small contributor to deforestation in Cambodia (DeFries et al. 2010; Milne & Chervier 2014; Schneider 2011; Vrieze & Naren 2012).

3.2. Statistical models

We first present a mixed-effects generalized linear model with binomial errors of the presence and absence of ELCs to explore the spatial patterns of ELC placement across the landscape, followed by a zero-altered negative binomial (ZANB) model to identify the importance of predictors of deforestation in the study area between 2008 and 2013.

The ELC model's response variable is the presence or absence of a new ELC in a pixel in 2013 when compared to a 2008 baseline, which marks the start of the legal granting of ELCs in the protected area network and of a recorded increase in the number of concessions granted (Arias et al. 2012; LICADHO 2014; Ullenberg 2009b). The location of ELCs was based on national data from LICADHO (May 2014) and externally confirmed by local experts and through field visits. While we recognize that ELC characteristics can influence the dynamics of land use change and ELC effects, many of such decisive indicators are difficult or impossible to capture fully using spatial explicit data, with factors such as time of investment or characteristic of land allocation being rarely publicly available (Messerli et al. 2015). Several data sources about ELCs are also often inaccurate and incomplete (Dwyer 2015; Edelman 2013; Oya 2013). Without this level of

accuracy available for the 50 ELCs present in the landscape, we thus chose to use the conservative indicator of ELC presence/absence only.

The distribution of the percentage of a given pixel deforested between 2008 and 2013 was zero-inflated, non-negative and bounded between 0 and 100, hence was treated as count data. Overdispersion was found in the distribution of the data, indicating a negative binomial error structure. A zero-altered negative binomial (ZANB) model, also called hurdle or two-part model, was fitted to the data (Hardin et al. 2007; Hilbe 2011; Zuur et al. 2009). This first entailed fitting a generalized linear model with binomial errors for the absence or presence of deforestation as a response variable, in order to explain the absence of deforestation (hurdle model). Then we fitted a negative binomial model with percentage deforestation as the zero-truncated, or positive count, part of the data as a response variable (count model). The distribution of the binary response variable used in the hurdle model was 5490 pixels with no deforestation and 4510 pixels with deforestation values above zero, the latter forming the data for the count model.

Deforestation data were obtained from two sources: a land cover change private dataset from Conservation International (CI) (2013) categorizing 2011 land cover across the study area, including patches deforested between 2008 and 2011; and Hansen *et al* (2013)'s global forest change data between 2012 and 2013 (CI 2013; Hansen et al. 2013). The CI dataset was selected as the basis for work as it included a consolidation of all available historic deforestation data over the area, including the RGC Forestry Administration land cover data, and WCS's private spatial cover data, which was compiled for a project pre-feasibility study. The methodology used by CI included accuracy assessments against high resolution imagery as well as ground truth data from biomass surveys (see Appendix B). Deciduous and evergreen forest classifications from the CI dataset were aggregated for the analysis to enable the overlay with Hansen's dataset (see Appendix B). The Hansen dataset identified deforested patches on a yearly basis, thus deforested areas for 2012 and 2013 were mapped over the 2011 land cover data using conditional formatting in ArcGIS, in order to identify total deforestation between 2008 and 2013.

This approach was deemed superior to using only the Hansen dataset given the superiority of localised quality checks performed over the CI dataset. The CI dataset used two Landsat scenes to cover the study site (125/051 and 126/51), which were aligned with other data sources including RGC Forestry Administration land cover data and WCS private datasets, and classified as multi-temporal pairs. The two change classifications were then consolidated to produce the analysed time-window between 2008 and 2011, capturing the long term and most recent forest cover changes with a better temporal resolution. Further quality checks included accuracy assessments using ancillary data, Google Earth and ground truth data from a biomass survey (see Appendix B for details).

A limitation is that under CI's forest cover analysis, which follows the RGC's National Forest Programme forest classification system, agro-industrial plantations with a height of at least five meters on an area of at least 0.5 hectares with a canopy of more than 10 per cent are also

classified as forests. Afforestation has not been included in this analysis, thus it is not possible to differentiate potential deforestation of an agro-industrial plantation from natural forest if the plantation was mature prior to 2008. Further data quality checks were performed to confirm the validity of overlaying the two datasets and to ensure that conversion into plantations was not analysed as forest post-2008. This suggested that the analysis was correctly interpreting natural forest as forest, and other land-use types as non-forest. For example, no pixel showed an increased percentage of forest in 2012 and 2013, compared to prior years, which would have been expected if plantation trees were being counted as forest cover. Additionally, the percentage of deforestation recorded in pixels in 2012 and 2013 was always equal to or lower than the remaining percentage of forest in a pixel in 2011.

3.3. Predictor variables

Predictor variables for each model were selected based on previous literature and local expertise concerning their relevance to the placement of ELCs, and as drivers of deforestation (Table 2). The following variables were evaluated for every pixel: protected area status; carbon values; proportion of non-forest in surrounding area; soil quality; elevation; slope; distance to village; distance to major road; distance to river; and population density per commune (Table 3). As different levels of conservation efforts can be a factor that affects deforestation in PAs, the four protected areas were included separately in the deforestation model.

Spatial data for each variable was first mapped with ArcGIS and, when required, resampled using a 1 kilometre square grid. This was judged an appropriate size given the resolution of the data and the scale of interventions analysed. It is also computationally tractable for the construction of non-parametric models over a large area. Only pixels completely inside or outside an intervention, either ELCs or PAs, were used; hence leaving 26 945 pixels for analysis over the landscape. A sample of 3000 pixels was then randomly subset to limit spatial autocorrelation (Lichstein et al, 2002).

Collinearity between predictor variables was tested and led to the exclusion of forest cover within the pixel as a variable. Carbon values were considered a better proxy for the mix between quantity and quality of forest present in a pixel, which is relevant when looking at patterns of deforestation across different land uses. Carbon data was factorized in three categories to reflect the multinomial distribution of carbon values across forest types. An interaction between carbon values and proportion of non-forest in surrounding area was introduced to reflect differences in forest fragmentation around a pixel depending on the forest type. Continuous predictor variables were scaled using the interquantile range and median instead of standard deviation to account for the skewed distribution of spatial data (Babyak, 2009).

Table 2: Hypothesis supporting the selection of variables included

Variable	Hypothesized correlation to ELC presence in 2013	Hypothesized correlation to deforestation between 2008-13
ELC presence 2013	ELCs are expected to be located in non-used, low forest-value areas yet that are suitable for commercial agriculture. Location of ELCs taken after the implementation of the Moratorium in January 2013.	<i>Not used in model; post-hoc</i>
Deforestation 2008-2013	<i>Not used in model; assumed outcome not driver.</i>	Deforestation is expected to occur close to development factors: infrastructures, villages, in easily accessible areas for timber transport and trade.
ELC presence 2008	<i>Not used in model; self-predictive.</i>	Negative: ELCs to be located in areas with high proportion of non-forest in already degraded and fragmented areas rather than in non-converted forests.
Protected Area status in 2008	Negative: ELCs to be located in the private state domain primarily; while PAs to be located in public state domain. ELCs to follow criteria of “perpetual environmental protection and natural resources management”.	<i>Not used in model; "Protected Area identity in 2008" used to allow differentiating between the level of conservation management effort between the different protected areas.</i>
Protected Area identity in 2008	<i>Not used in model; "Protected Area status in 2008" variable used as per legislation all protected areas are in public state domain and no need to differentiate</i>	Negative but PA-dependent: Protected Areas prevent deforestation through management of natural resources and enforcement of protection laws.
Carbon values in 2008	Negative: Variable used as a proxy for the extent and type of forest present in a pixel. ELCs should follow criteria of “perpetual environmental protection and natural resources management”; hence located in areas with lower carbon values.	Positive: Carbon values, as a proxy for the extent of forest present in a pixel, are expected to be targeted for deforestation of high value timber; except in managed Protected Areas.
Proportion of non-forest in surrounding area in 2008	Positive: ELCs likely to be located in areas with high proportion of non-forest in already degraded and fragmented areas rather than in non-converted forests.	Positive: Deforestation likely to occur where timber is easily accessible in areas surrounded by high proportion of non-forest.
Soil quality in 2008	Positive: Soil quality linked to agricultural suitability and hence to greater potential for land conversion and ELC presence.	Positive: Soil quality linked to agricultural suitability and higher rate of land conversion.
Elevation	Negative: ELCs less likely to be located on high elevation as less suitable for agriculture.	Negative: High elevation linked to less accessibility and lower rate of land conversion.
Slope	Negative: ELCs are less likely to be located on high slopes as less suitable for agriculture.	Negative: High slopes linked to less accessibility and lower rate of land conversion.
Distance to village in 2008	Positive: ELCs aim at creating rural local employment; should be located far from settlements.	Negative: Areas close to villages are more likely to be converted or logged due to accessibility, transport and trade.
Population density in 2008	Negative: ELCs aim at creating rural local employment; should be located in low population density areas.	Positive: Areas with high population are more likely to be converted or logged due to accessibility, transport and trade.
Distance to road in 2008	Negative: ELCs more likely to be located close to a road for accessibility of rural employment and large-scale agriculture operations	Negative: Areas close to roads are more likely to be converted or logged due to accessibility and transport.
Distance to river in 2008	Negative: Areas with access to water are better suited for commercial agriculture; ELCs should be located close to rivers.	Negative: Areas close to river are more likely to be converted or logged due to accessibility and transport.
Sources	De Schutter, 2011; Lambrick et al, 2013; MAFF, 2014; NSDP, 2014; Schönweger, 2012; RGC Land Law, 2001; RGC Protected Area Law, 2008;	Angelsen & Kaimowitz, 2001 ; Clements, 2012 ; Etter et al, 2006 ; Lambin et al, 2003 ; Liu et al, 2009 ; Muller et al, 2011 ; RGC 2008 ; Veldkamp et al, 1992

1 **Table 3: Description of selected variables and their sources**

Variable	Type / units	Methodology (source)
ELC presence 2013	Binary: 0= absence 1= presence	Location of ELCs as of January 2013 after the implementation of the Moratorium (MAFF, 2014; RGC-NSDP, 2014; RGC – Green Growth, 2012). Absence or presence of an ELC as 100% of a pixel (WCS 2013, LICADHO 2014)
Deforestation 2008-2013	Continuous & Binary 0 = absence 1= presence	Area deforested between 2008 and 2013 in hectares per pixel / Absence or presence of deforestation in a pixel (CI 2013, Hansen et al 2014).
ELC presence 2008	Binary 0= absence 1= presence	Absence or presence of an ELC as 100% of a pixel (WCS 2013, LICADHO 2014)
Protected Area status in 2008	Binary 0= absence 1= presence	Absence or presence of a Protected Area as 100% of a pixel (WCS, 2014).
Protected Area identity in 2008	Categorical: 1 = Boeng Per 2= KPWS 3= PVPF 4= PVT	Absence or presence of each Protected Area as 100% of a pixel (WCS, RECOFT 2014)
Carbon values in 2008 (in (Mg/ha)	Categorical: 1= Low (0-100) 2=Medium (100-200) 3= High (>200)	Carbon values in a pixel in 2008 as Above Ground Biomass, obtained by applying average carbon value per land cover type to 2008 land cover change map (CI 2013, Baccini et al. 2012).
Proportion of non-forest in surrounding area in 2008	Percentage	Proportion of non-forest in the 4 nearest neighbour levels of pixels (48 surrounding pixels), reflecting average forest fragmentation surrounding a pixel. This excludes the central pixel's value as latter is better captured under carbon values. (CI 2013).
Soil quality in 2008	Categorical: 1=Low 2= Medium 3= High	Category of soil fertility as 100% of a pixel (WCS, 2013)
Elevation	Continuous (meters)	From digital elevation model (WCS, 2013)
Slope	Continuous (degrees)	From digital elevation model (WCS, 2013)
Distance to village in 2008	Continuous (km)	Distance to nearest village in 2008 (WCS, 2013)
Population density in 2008	Continuous (ppl/sqkm)	Population density on a commune basis in 2008 (Atlas of Cambodia, 2008)
Distance to road in 2008	Continuous (km)	Distance to 'all weather' road in 2008 (WCS, 2013)
Distance to river in 2008	Continuous (km)	Distance to river in 2008 (WCS, 2013)
Communes	Categorical (278)	Added as random effect to account for data hierarchy and spatial autocorrelation structure (WCS, 2013)
Districts	Categorical (19)	Added as random effect to account for data hierarchy and spatial autocorrelation structure (WCS, 2013)

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3.4. Model selection and validation

All statistical analysis was done in R. 3.20 and models were fitted using the function 'glmer' in R package 'lme4' version 1.1-7 (Bates et al. 2014). The ELC model was fitted with administrative units as nested random effects (communes within districts) to account for structure of the data and to account for spatial autocorrelation. This spatial autocorrelation structure was preferred to a longitude and latitude structure which resulted in convergence and rescaling errors. This reflects the scale at which ELCs are implemented spatially across administrative boundaries and the levels at which ELC impacts are observed. The corrected Akaike information criterion (AICc) was used to select and rank the most parsimonious models. Inclusion of final variables was confirmed by comparing model weightings from dredging (Barton 2015) and computing the variable relative importance using the top models selected based on AICc >4 (see A1).

Model selection for the two-step deforestation model was done at both stages, with models being fitted first with all *a priori* variables. The models were validated by using changes in AICc when dropping non-significant variables (see A2). Excluding variables did not lead to an AICc change higher than four hence all variables were kept in the final model. The random selection of 3000 pixels affects model selection and coefficients. To confirm that the final model results are robust to sampling error, we ran the final model 100 times on different sets of 3000 randomly sampled pixels and extracted the coefficient estimates. We plotted the distribution of these coefficients as well as their mean, median and mode. We then plotted the bootstrapped confidence intervals for 10,000 replicates. The plots confirm the validity of the final model coefficients presented.

All three models were tested for spatial autocorrelation by testing model residuals using variograms ('gstat' version 1.0-23). The Best Linear Unbiased Predictors (BLUPs) (Pinheiro & Bates 2006) of the random effects extracted from the ELC model were also plotted, to graphically check the random effects associated with each commune. BLUPs are given by the ordinary least squares estimator, giving the lowest variance of the estimate, as compared to other unbiased, linear estimators (Wang & Liu 2013). All graphical outputs from both tests showed minimal spatial autocorrelation effects in the models.

3.5. Average Predictive Comparisons

Parameter estimates derived from mixed effect models are difficult to interpret directly because of the presence of interactions and, in the case of binomial regressions, nonlinearity. We therefore present regression coefficients, which allow interpretation of the direction of correlation between response and predictor variables, as well as average predictive comparisons (APCs) of focal variables for each model. APCs allow for the interpretation of the expected difference in outcomes associated with changes in individual inputs of interest. This helps clarify the interplay between individual predictors for the hierarchical models and also illustrates the relative size of effects (Gelman & Pardoe 2007). We do so by calculating the means and confidence intervals of responses simulated from the fitted models to evaluate their predictions at different values for one variable at a time, holding all others constant (Gelman & Hill 2007; Gelman & Pardoe 2007). Key explanatory variables were predicted at both low and high values

to reflect realistic scenarios according to each predictor. Low and high values for continuous variables were calculated respectively as the first and third quartile ranges in the data distribution, rounded up to the tenth decimal (see Table 4).

Table 4: Descriptive statistics for predictor variables and values used in Average Predictive Comparisons

Predictor variable	Min	Median	Mean	Interquartile range	Max	Low predicted value	High predicted value
ELC presence 2008	-	-	-	-	-	0 (absence)	1 (presence)
Protected Area status in 2008	-	-	-	-	-	0 (absence)	1 (presence)
Protected Area identity in 2008	-	-	-	-	-	0 (absence)	1 (presence)
Carbon values in 2008	-	-	-	-	-	Low	High
Proportion of non-forest in surrounding area in 2008 (%)	0.0	8.9	24.6	38.4	100.0	1.7	40.1
Soil quality in 2008	-	-	-	-	-	1 (Low)	3 (High)
Elevation (meters)	5.8	79.8	79.4	57.1	550.0	48.5	105.0
Slope (degrees)	0.0	1.1	1.5	0.8	23.5	1.0	2.0
Distance to village in 2008 (km)	0.0	5.5	6.6	6.6	25.3	3.0	10.0
Population density in 2008 (ppl/sqkm)	1.8	10.9	25.0	24.2	297.6	6.0	30.0
Distance to road in 2008 (km)	0.0	1.0	1.8	2.1	18.6	0.5	3.0
Distance to river in 2008 (km)	0.0	5.1	6.2	7.2	23.8	2.0	10.0

4. Results

4.1. Factors influencing ELC placement

In 2008, there were 7 ELCs covering 114,808 hectares (3.4%) over the study area, with no overlap between ELCs and protected areas. This increased to 50 ELCs in 2013, covering 1,018,321 hectares (30.5%) of the landscape and more specifically 14% (91,366 hectares) of the overall protected areas (Figure 2a and 2b). ELC overlap with PAs is concentrated in Boeng Per Wildlife Sanctuary (25% of its area), where there is no enforcement of the Protected Area Law, as well as in Eastern KPWS (16% of its area; Table 5).

Table 5. Overlap between ELCs and Protected Areas in 2013

Protected Area	PA under ELC (ha)	PA under ELC (%)
Boeng Per Wildlife Sanctuary	54,274	25
Kulen Promtep Wildlife Sanctuary (East)	37,092	16
Preah Vihear Protected Forest	0	0
Preah Vihear Temple	0	0

Interventions 2008

- Protected Areas
- Economic Land Concessions

Forest Cover 2008

- Water
- Non Forest
- Forest
- Cleared 2001-08

1
2 **Figure 2a: Protected Areas and Economic Land Concessions over land cover in 2008**

Interventions 2013

- Protected Areas
- Economic Land Concessions

Forest Cover 2013

- Water
- Non Forest
- Forest
- Cleared 2001-08
- Cleared 2008-13

3
4 **Figure 2b: Protected Areas and Economic Land Concessions over land cover in 2013**

The top model for the influence of predictor variables on the placement of ELCs between 2008 and 2013 included all variables hypothesised as important *a priori*. Model selection led to the exclusion of slope, distance to road, distance to river and distance to village in the final model (Table 6; A1).

Table 6: Parameter estimates from the selected 2013 ELC placement generalized linear mixed model, with ELC presence/absence as a binary response variable to predictor variables at a 2008 baseline. Pseudo R-squared = 0.42. Model selection table is shown in Appendix C1. Significance values: 'ns' = non-significant; '.' = $P < 0.1$; '*' = $P < 0.05$; '' = $P < 0.01$; '***' = $P < 0.001$.**

Variable	Estimate	SE	P-value
Intercept	-4.19	0.68	***
Protected Area presence in 2008	0.14	0.16	ns
Carbon values in 2008: medium	1.04	0.28	***
Carbon values in 2008: high	1.07	0.3	***
Proportion of non-forest in surrounding area in 2008	-0.95	0.23	***
Soil fertility in 2008: medium	-0.04	0.16	ns
Soil fertility in 2008: high	-0.42	0.11	***
Elevation in 2008	-1.23	0.13	***
Population density in 2008	-1.18	0.27	***
Proportion of non-forest in surrounding area * Carbon values: medium (2008)	-1.03	0.27	***
Proportion of non-forest in surrounding area * Carbon values: high (2008)	1.17	0.31	***
Random effect	Variance	SD	
Commune	8.18	2.86	
Districts	3.13	1.77	

ELCs are more likely to be located in pixels with high and medium carbon value. The interaction between proportion of non-forest surrounding area and carbon values suggest that ELCs are also more likely to be located in areas that contain high values, compared to medium or low carbon values, but that are generally surrounded by non-forest. In other words, ELCs are more likely to be found in easily accessible high value carbon areas. ELCs are also less likely to be placed in pixels substantially surrounded by non-forest, at high elevation, high soil fertility and in highly populated areas. According to the model exploring factors driving ELC placement (Table 6), there is no evidence of an effect of protected area status on ELC placement.

The average predictive comparison found that the mean probability of ELC presence in a pixel was 0.12. With all other variables held constant, the probability of ELC presence was substantially increased by high carbon values (by 57%; Fig. 3). In line with regression results, the APC shows that high soil fertility and low population density increase the probability of ELC presence (both by 27%), with high population density greatly reducing the probability of ELC presence (by 94%). Low carbon values and low soil fertility were also influential in decreasing ELC presence, by 30% and 21% respectively. A high proportion of non-forest in the surrounding area

1 slightly decreased the probability of ELC presence (by 13%). The APC indicates that presence of a
 2 Protected Area (21%) increases the probability of ELC presence, which supports the conclusion
 3 that the probability of ELC presence increases rapidly with every additional pixel containing a PA
 4 in the landscape. Thus while PA presence is non-significant within the random subsampled
 5 model shown in Table 6, the APCs confirm that PA presence increases the presence of ELCs.

7 **Figure 3: Average predictive comparisons illustrating the effect of each predictor variable (on their interquartile range and median scale) on the probability of ELC presence. The red vertical line indicates the predicted overall mean response for the original dataset. The diamond points indicate the predicted mean and standard error response for the sample dataset when variables are set at different values (see Table 4 for scenario values).**

12 4.2.Factors influencing deforestation between 2008 and 2013

14 Raw data analysis indicated that total forest loss over the study area between 2008 and 2013
 15 was 181,587 ha, at an average annual rate of 1.77% (Table 7). Deforestation rates were higher
 16 outside protected areas, with the exception of the Boeng Per Wildlife Sanctuary which recorded
 17 a 3.95% deforestation rate over the period. Higher still was the forest loss rate under the
 18 presence of ELCs, which reached on average 5.19% per year. Overall forest loss is computed at
 19 8.85% over the period, which is higher than the 7% national forest loss rate between 2000 and
 20 2012 (Hansen et al. 2013).

21 **Table 7: Forest area and deforestation between 2008 and 2013 per intervention status**

Intervention status	Forested area in 2008	Forested area in 2013	Deforestation 2008-13 (ha)	Average annual deforestation rate 2008-13
Outside of PAs	1,555,545	1,404,669	150,876	1.94%
Inside PAs	496,677	465,967	30,710	1.24%
Boeng Per Wildlife Sanctuary	143,561	115,226	28,335	3.95%
Kulen Promtep Wildlife Sanctuary	193,866	192,276	1,590	0.16%
Preah Vihear Protected Forest	157,451	156,690	761	0.10%
Preah Vihear Temple	1,800	1,775	25	0.28%
Inside ELC	285,205	211,124	74,081	5.19%
No ELCs	1,767,017	1,659,512	107,505	1.22%
Total forest in study area	2,052,223	1,870,636	181,587	1.77%

These observations are confirmed by the second two-part model which looks at predictors of deforestation in the study area between 2008 and 2013. Both the hurdle and the truncated count models show similar results suggesting that the same processes are at play with regards to predicting the presence or absence of deforestation as well as the degree of deforestation if present. Analytically, this confirms that the high occurrence of zeros is not part of a structural design nor observation failures, in other words are not false negatives. There are three exceptions to this. High and medium values and population density are negatively correlated to the presence of deforestation initially but are positively correlated with extent of deforestation once a pixel is deforested (Table 8a and 8b). Arguably this represents how deforestation over an area is likely to start in an accessible and degraded location but extends towards richer biomass zones afterwards. Additionally, this shows how deforestation can increase rapidly in the early stages of new settlements, such as the establishment of an immigrant labour force (Sodhi et al. 2004).

High deforestation is likely to occur in ELCs (Table 8b). High deforestation, similar to predictors of ELC placement, is also more likely to occur in high and medium carbon value areas, especially when such areas are surrounded by a high proportion of non-forest. While both presence and extent of deforestation show a significant negative correlation with two of the four Protected Areas, it is more likely to occur in Boeng Per Wildlife Sanctuary, which is the only unmanaged PA of the four. Deforestation is less likely to happen at high elevation, far from villages and from roads. According to the APCs and in line with the ZAMB model, the most important variables influencing deforestation were high carbon values and the presence of an ELC. The probability of deforestation in a pixel increased respectively by 2.88 and 2.75 times, while all other variables were held at their mean values. The APCs also showed that deforestation was more likely to occur in areas with high proportions of non-forest, outside PAs and in BPWS. Keeping all else equal, predicted probabilities of deforestation decreased in the other three managed protected areas, as well as in areas far from roads.

1 **Table 8a: Parameter estimates from the final zero hurdle deforestation model. Presence or absence of**
2 **deforestation between 2008 and 2013 in 1 km² pixel as a binary response variable to predictor variables at a 2008**
3 **baseline. Model selection table is shown in Appendix C2. Significance values: 'ns' = non-significant; '.' = P <0.1; '*'**
4 **= P <0.05; '**' = P <0.01; '***' = P <0.001.**

Variable	Estimate	SE	P-value
Intercept	1.41	0.13	***
ELC presence	1.35	0.16	***
Protected Area: Boeng Per Wildlife Sanctuary	0.32	0.1	**
Protected Area: Kulen Promtep Wildlife Sanctuary	-1.82	0.09	***
Protected Area: Preah Vihear Protected Forest	-2.3	0.15	***
Protected Area: Preah Vihear Temple	-13.52	110.47	n.s.
Carbon values: medium	-0.83	0.13	***
Carbon values: high	-0.52	0.15	***
Proportion of non-forest in surrounding area	-1.81	0.09	***
Soil fertility medium	-0.21	0.16	n.s.
Soil fertility high	-0.05	0.02	n.s.
Elevation	-0.46	0.05	***
Slope	0.05	0.01	***
Distance from village	-0.46	0.04	***
Population density	-0.1	0.03	***
Distance from road	-0.23	0.03	***
Distance from river	-0.32	0.23	n.s.
Proportion of non-forest in surrounding area	2.09	0.12	***
* Carbon values: medium			
Proportion of non-forest in surrounding area	5.15	0.28	***
* Carbon values: high			

5
6 **Table 8b: Parameter estimates from the zero-altered negative binomial deforestation model. Area of**
7 **deforestation between 2008 and 2013 per 1 km² pixel as a continuous response variable to predictor variables at**
8 **a 2008 baseline. Model selection table is shown in Appendix C2. Significance values: 'ns' = non-significant; '.' = P**
9 **<0.1; '*' = P <0.05; '**' = P <0.01; '***' = P <0.001.**

Variable	Estimate	SE	P-value
Intercept	-3.05	0.35	***
ELC presence	1.75	0.14	***
Protected Area: Boeng Per Wildlife Sanctuary	0.64	0.14	***
Protected Area: Kulen Promtep Wildlife Sanctuary	-1.99	0.38	***
Protected Area: Preah Vihear Protected Forest	-1.81	0.52	***
Protected Area: Preah Vihear Temple	-12.05	316.75	n.s.
Carbon values: medium	0.13	0.36	n.s.
Carbon values: high	1.38	0.36	***
Proportion of non-forest in surrounding area	-1.56	0.29	***
Soil fertility medium	0.35	0.29	n.s.
Soil fertility high	-0.51	0.31	n.s.
Elevation	-0.37	0.08	***
Slope	-0.63	0.55	n.s.
Distance from village	-0.17	0.07	*
Population density	0.16	0.06	***
Distance from road	-0.4	0.06	***
Distance from river	0.13	0.07	***
Proportion of non-forest in surrounding area	1.27	0.31	.
* Carbon values: medium			
Proportion of non-forest in surrounding area	2.31	0.33	***
* Carbon values: high			

Figure 4: Average predictive comparisons illustrating the effect of each predictor variable (on their interquartile range and median scale) on deforested area in a pixel. The red vertical line indicates the predicted overall mean response for the original dataset. The dots indicate the predicted mean response for the sample dataset when variables are set at different values, based on the zero-altered negative binomial deforestation model (see Table 4 for scenario values).

5. Discussion

In this study, we examined the patterns of ELC placement across northern Cambodia by first using a logistic mixed effects model to detect the importance of different socio-economic and environmental factors in determining the location of ELCs. Second, we used a zero-altered negative binomial model to examine the influence of different regional drivers on deforestation across the study site. We used spatial overlays to provide underlying data about the factors considered in models, and APCs to further understand the relative importance of each predictor on the response variable’s mean outcome.

5.1. ELC location and policy goals

Overall, results reveal that both drivers of ELC placement and drivers of deforestation between 2008 and 2013 mostly do not correspond to the initial hypotheses assumed in this study, which were based on the RGC's criteria for placement of ELCs (Table 9). Our first model refutes the

1 assumption that drivers of ELC placement reflect the objectives and implementation criteria
2 stated in Cambodia's development policies.

3 **Table 9: Correlation between response variable and individual predictor variables for each model and resulting**
4 **response with regards to a priori hypothesis of correlation (Table 2).**

Variable	Correlation with ELC presence	Accepted (✓) or refuted (X)	Correlation with area deforested	Accepted (✓) or refuted (X)
ELC presence 2008	N/A	N/A	Positive	X
Protected Area status in 2008	N/A	X	Negative & positive	X
Carbon values in 2008	Positive	X	Positive	✓
Proportion of non-forest in surrounding area in 2008	Negative	X	Negative	X
Soil quality in 2008	Negative	X	N/A	N/A
Elevation	Negative	✓	Negative	✓
Slope	N/A	N/A	N/A	N/A
Distance to village in 2008	N/A	N/A	Negative	✓
Population density in 2008	Negative	✓	Negative	X
Distance to road in 2008	N/A	N/A	Negative	✓
Distance to river in 2008	N/A	N/A	Negative	✓
Proportion of non-forest in surrounding area * Carbon values: medium (2008)	Negative	N/A	Positive	N/A
Proportion of non-forest in surrounding area * Carbon values: high (2008)	Positive	N/A	Positive	N/A

5
6 There is no evidence that ELCs are more or less likely to be in PAs. This is in line with the raw
7 data measuring the overlap of ELCs with 14% or 91,366 hectares of the total protected area
8 territory in the study area. Overall, this suggests ELC placement is not related to whether the
9 land has a Protected Area designation, despite the criterion that ELCs should be located in the
10 private state land and not public state land.

11 ELCs are more likely to be placed in areas with high carbon values yet surrounded by high
12 proportions of non-forested land, instead of in non-used low carbon value land. In fact, other
13 studies have suggested that ELCs are not implemented in already-degraded land, but rather in
14 high timber value yet accessible forest land (Neef et al. 2013). This is additionally supported by
15 the negative correlations between ELC locations and elevation, which makes access to an area
16 more difficult and falls in line with the observation that ELCs are mostly located in fairly
17 accessible areas (Peeters 2015).

18 When it comes to providing for rural employment, our model reveals that ELCs are more likely to
19 be located in areas with low population density. This is not surprising as companies are legally
20 expected to provide employment and diversification of livelihoods in rural areas which are less
21 populated. However, there is no evidence that distance to village, the presence of road or river,
22 or the suitability of soils influence the placement of ELCs; all of which are specific attributes
23 related to agro-industrial development policy in Cambodia. In short, the first model suggests that
24 ELC placement does not respond to expected socio-environmental factors that are related to
25 implementation criteria in policy documents.

5.2. Drivers of deforestation in Northern Cambodia

Furthermore, our second model points to the negative environmental outcomes correlated with ELCs. ELCs represent the most significant driver of deforestation of the factors considered. Their substantial contribution to deforestation highlights again the failure to abide by the environmental criteria stated in the 2001 Land Law and sub-decree decree n°146. These results are in line with multiple qualitative reports over the past years identifying ELCs as a driver of deforestation and a national study of the impact of ELCs on deforestation rates (GW 2009; LICADHO 2014; Davis et al. 2015).

Other significant drivers of deforestation include the presence of high carbon values and a high proportion of non-forest in surrounding areas, suggesting there is targeted deforestation of easily accessible high value forests. While probability of deforestation is lower than average in PVPF and KPWS, it is higher than average in the only protected area which is not actively managed. This suggests that level of biodiversity conservation management is potentially an important driver of deforestation. In fact, research has shown that deforestation rates within the KPWF and PVPF have significantly decreased after the increased PA management in collaboration with WCS in 2005 (Clements & Milner-Gulland 2015). Additional potential factors at play when observing deforestation patterns are linked to the types of ELCs granted over BPWS. Namely, the investor nationality, the time of investment and the stated type of crop have been shown to be key patterns in the implementation process of ELCs (Messerli et al. 2015). In such, this study confirms results from Peeters (2015) highlighting that recent granting of ELCs in North Cambodia have primarily been focused on rubber plantations; the development of which can have accentuated deforestation in the area (see Appendix A).

On the other hand, results support the idea that small-scale farming and local timber harvesting around villages are not the primary driver of deforestation initially, yet becomes more influential once an area starts being cleared. In fact, households' response to the delimitation of an ELC close to their village often includes clearing in order to assert their informal customary right on a piece of land (Gironde & Peeters 2015). The APCs confirmed that distance to village did not have a major influence on probability of deforestation. Deforestation is much less likely to occur far from roads.

5.3. Agro-industrial concession and conservation goals in Cambodia

Market-driven intensification policies have attracted criticism as a means of addressing both reduced deforestation and rising food demand (Angelsen 2010; Lamb et al. 2016), with studies pointing to a mix of alternatives such as small-scale technology-driven intensification as better and more realistic options (Byerlee et al. 2014; Grau et al. 2013). In fact, intensification mechanisms must be directly linked to compensated habitat protection measures to avoid incentivising agricultural expansion (Phalan et al. 2016). However it is questionable to what extent RGC policies truly aim to achieve any type of agricultural intensification policy, given the lack of alignment between their stated goals and realised ELC placement.

1 The variables that most influenced ELC placement and deforestation were similar when
2 comparing results between the models and the APCs. Both ELCs and deforestation are positively
3 correlated with, and significantly influenced by, the interaction between high carbon value and
4 low proportion of surrounding non-forest. In short, factors driving decision-making about where
5 ELCs and deforestation occur are closely related, making ELCs are a prominent driver of the high
6 deforestation rates that have occurred across the study landscape.

7 This supports research suggesting that ELC placement is in fact driven by timber extraction
8 through the use and abuse of legal mechanisms to profit Cambodian political elite's interest,
9 rather than towards agricultural intensification (Baird 2014b; Le Billon 2007; Milne 2015). While
10 existing policies prescribe a balance in trade-offs between the development and conservation
11 agendas, results point to discrepancies in the implementation of the Land Law and a lack of
12 synergies between development and conservation. The intensification of granting Economic
13 Land Concessions (ELCs) in recent years is testament to what Biddulph (2010) has tagged
14 "Geographies of Evasion": the weak outcomes from development intervention policies due to
15 their evasive focus on geographies located away from the main problems which they were
16 stated to address.

17 The governance systems under which land use decisions are made and implemented play a
18 pivotal role in shaping land use outcomes (Messerli et al. 2015). For example, the case of Boeng
19 Per Wildlife Sanctuary shows that protected area designations can be meaningless without an
20 associated law enforcement capacity. The challenge of balancing trade-offs between
21 conservation and development in Cambodia thus extends much further than biophysical
22 attributes and policy documents. In fact, the issues primarily relate to the wider political and
23 institutional reforms necessary to achieve better transparency in land use decisions, increased
24 security of land tenure and respect for the stated environmental and social impact assessments
25 written into the law (Diepart & Schoenberger 2016; Neef et al. 2013). These changes are further
26 challenged by the lack of transparency in the political process and lack of access to information
27 about the mechanisms underlying ELC decision-making. Consequently, this study has not
28 addressed the adverse effects of ELCs on local people's livelihoods as raised by several reports
29 (Bues 2011). This is because understanding the social impacts of ELCs on human well-being
30 requires a more complex and grounded mixed method evaluation (Scoones et al. 2013;
31 Woodhouse et al. 2015).

32 **Conclusion**

33 Overall, this study corroborates qualitative reports suggesting that ELCs are mechanisms for the
34 Cambodian ruling elite to enable land grabbing, clear-cutting and selling of high value timber
35 under the pretext of an agricultural intensification strategy (Biddulph 2010; Neef et al. 2013; GW
36 2012; Oldenburg et al. 2014). In such a case, ELCs would affect not only forest retention, but also
37 impede future positive development in northern Cambodia and impact negatively local
38 communities.

39 Quantitative research about the potential future effects of ELCs on rural development and
40 occurring trade-offs is seriously hampered by the unavailability of information about concessions

1 in Cambodia. Better records of large-scale land deals, especially with regards to qualitative,
2 comprehensiveness and accessible sources about ELC characteristics and for spatially explicit
3 data are necessary for unbiased policy recommendations (Davis et al. 2015). This study shows
4 that regionalized and contextualized analyses are required to explore land use dynamics and the
5 trade-offs between development and conservation, and supports that interventions are more
6 often than not results of politicized implementation processes rather than primarily driven by
7 pre-existing socio-economic and environmental conditions (Biddulph 2010; Messerli et al. 2015).
8

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16

1 **References**

- 2 Ahrends, A. et al., 2015. Current trends of rubber plantation expansion may threaten biodiversity
3 and livelihoods. *Global Environmental Change*, 34, pp.48–58.
- 4 Angelsen, A., 2010. Policies for reduced deforestation and their impact on agricultural
5 production. *Proceedings of the National Academy of Sciences of the United States of*
6 *America*, 107(46), pp.19639–44.
- 7 Arias, P. et al., 2012. *Trends and impacts of foreign investment in developing country agriculture*
8 *– Evidence from case studies*, Rome.
- 9 Baccini, A. et al., 2012. Estimated carbon dioxide emissions from tropical deforestation improved
10 by carbon-density maps. *Nature Climate Change*, 2(3), pp.182–185.
- 11 Baird, I.G., 2014a. Reduced Emissions from Deforestation and Forest Degradation (REDD) and
12 Access and Exclusion: Obstacles and Opportunities in Cambodia and Laos. *Southeast Asian*
13 *Studies*, 3(3), p.643.
- 14 Baird, I.G., 2014b. The Global Land Grab Meta-Narrative, Asian Money Laundering and Elite
15 Capture: Reconsidering the Cambodian Context. *Geopolitics*, 19(2), pp.431–453.
- 16 Balmford, A. et al., 2002. Economic reasons for conserving wild nature. *Science (New York, N.Y.)*,
17 297(5583), pp.950–3.
- 18 Balmford, A., Green, R. & Phalan, B., 2012. What conservationists need to know about farming.
19 *Proceedings. Biological sciences / The Royal Society*, 279(1739), pp.2714–24.
- 20 Barton, K., 2015. MuMIn: Multi-Model Inference v 1.14.0.
- 21 Bates, D. et al., 2014. Linear Mixed-Effects Models using “Eigen” and S4. *R package version*, 1(7).
- 22 Baudron, F. & Giller, K.E., 2014. Agriculture and nature: Trouble and strife? *Biological*
23 *Conservation*, 170, pp.232–245.
- 24 Bickel, M., 2011. Pro-poor land distribution in Cambodia. *Rural 21 - International Platform*,
25 45(May), pp.33–35.
- 26 BICP, 2012. *The Biodiversity of the Proposed Western Siem Pang Protected Forest Stung Treng*
27 *Province, Cambodia*, Phnom Penh, Cambodia.
- 28 Biddulph, R., 2010. *Geographies of Evasion. The Development Industry and Property Rights*
29 *Interventions in Early 21st Century Cambodia*.
- 30 Le Billon, P., 2007. The Politics of Forest Exploitation in Cambodia. In *Conflict and Change in*
31 *Cambodia*. New York: Routledge.
- 32 Bolin, A., 2013. Big agribusiness at the Cambodian forest frontier: will REDD+ be able to
33 compete? *Global Canopy Programme*. Available at:
34 [http://www.globalcanopy.org/updates/blogs/big-agribusiness-cambodian-forest-frontier-](http://www.globalcanopy.org/updates/blogs/big-agribusiness-cambodian-forest-frontier-will-redd-be-able-compete)
35 [will-redd-be-able-compete](http://www.globalcanopy.org/updates/blogs/big-agribusiness-cambodian-forest-frontier-will-redd-be-able-compete) [Accessed June 22, 2015].
- 36 Bues, B.A., 2011. *Increasing Pressure for Land - Implications for Rural Livelihoods in Developing*
37 *Countries : The Case of Cambodia*,
- 38 Byerlee, D., Stevenson, J. & Villoria, N., 2014. Does intensification slow crop land expansion or
39 encourage deforestation? *Global Food Security*, 3(2), pp.92–98.
- 40 Cardinale, B., Duffy, J. & Gonzalez, A., 2012. Biodiversity loss and its impact on humanity. *Nature*.
- 41 CEA, 2009. *Does Large-Scale Agricultural Investment Benefit the Poor ?*, Phnom Penh, Cambodia.
- 42 CI, 2013. Land Use and Forest Cover Change in Cambodia 2001-2011.

- 1 Clements, T. et al., 2010. Payments for biodiversity conservation in the context of weak
2 institutions: Comparison of three programs from Cambodia. *Ecological Economics*, 69(6),
3 pp.1283–1291.
- 4 Clements, T. & Milner-Gulland, E.J., 2015. Impact of payments for environmental services and
5 protected areas on local livelihoods and forest conservation in northern Cambodia.
6 *Conservation biology : the journal of the Society for Conservation Biology*, 29(1), pp.78–87.
- 7 Clements, T.O.M., Suon, S. & Wilkie, D.S., 2014. Impacts of Protected Areas on Local Livelihoods
8 in Cambodia. *WORLD DEVELOPMENT*, xx, pp.1–10.
- 9 Davis, K.F. et al., 2015. Accelerated deforestation driven by large-scale land acquisitions in
10 Cambodia. *Nature Geoscience*, 8(10), pp.772–775.
- 11 DeFries, R.S. et al., 2010. Deforestation driven by urban population growth and agricultural trade
12 in the twenty-first century. *Nature Geoscience*, 3(3), pp.178–181.
- 13 Diepart, J. & Schoenberger, L., 2016. Concessions in Cambodia: governing profits, extending state
14 power and enclosing resources from the colonial era to the present. In S. Springer & K.
15 Brickell, eds. *Handbook of contemporary Cambodia*. Routledge.
- 16 Dong, J. et al., 2013. Mapping deciduous rubber plantations through integration of PALSAR and
17 multi-temporal Landsat imagery. *Remote Sensing of Environment*, 134, pp.392–402.
- 18 Dwyer, M.B., 2013. *The Formalization Fix? Land titling, state land concessions, and the politics of*
19 *geographical transparency in contemporary Cambodia*, UK.
- 20 Dwyer, M.B., 2015. *Trying to follow the money: Possibilities and limits of investor transparency in*
21 *Southeast Asia’s rush for “available” land*. Vol 177.,
- 22 Edelman, M., 2013. Messy hectares: questions about the epistemology of land grabbing data.
23 *Journal of Peasant Studies*, 40(3), pp.485–501.
- 24 Feintrenie, L., 2014. Agro-industrial plantations in Central Africa, risks and opportunities.
25 *Biodiversity and Conservation*, 23(6), pp.1577–1589.
- 26 Ferraro, P.J. & Hanauer, M.M., 2010. Protecting Ecosystems and Alleviating Poverty with Parks
27 and Reserves: “Win-Win” or Tradeoffs? *Environmental and Resource Economics*, 48(2),
28 pp.269–286.
- 29 Fischer, J. et al., 2014. Land Sparing Versus Land Sharing: Moving Forward. *Conservation Letters*,
30 7(3), pp.149–157.
- 31 Foley, J.A. et al., 2004. Solutions for a cultivated planet.
- 32 Foley, J.A. et al., 2011. Solutions for a cultivated planet. *Nature*, 478(7369), pp.337–42.
- 33 Fox, J.M. et al., 2014. Rubber plantations expand in mountainous Southeast Asia: What are the
34 consequences for the environment? *Asia Pacific Issues*, (114).
- 35 Frewer, T. & Chan, S., 2014. GIS and the “Usual Suspects”-[Mis]understanding Land Use Change
36 in Cambodia. *Human Ecology*, 42(2), pp.267–281.
- 37 Geist, H.J. & Lambin, E.F., 2002. Proximate Causes and Underlying Driving Forces of Tropical
38 Deforestation. *BioScience*, 52(2), p.143.
- 39 Gelman, A. & Hill, J., 2007. *Data Analysis Using Regression and Multilevel/Hierarchical Models* R.
40 M. Alvarez, N. L. Beck, & L. L. Wu, eds., Cambridge University Press.
- 41 Gelman, A. & Pardoe, I., 2007. Average predictive comparisons for models with nonlinearity,
42 interactions, and variance components. *Sociological Methodology*, 37(1), pp.23–51.

- 1 Gerber, J.F., 2011. Conflicts over industrial tree plantations in the South: Who, how and why?
2 *Global Environmental Change*, 21(1), pp.165–176.
- 3 Gibbs, H.K. et al., 2010. Tropical forests were the primary sources of new agricultural land in the
4 1980s and 1990s. *Proceedings of the National Academy of Sciences of the United States of*
5 *America*, 107(38), pp.16732–7.
- 6 Gironde, C. & Peeters, A., 2015. Land Acquisitions in Northeastern Cambodia: Space and Time
7 matters. *LDPI conference in Chiang Mai University*.
- 8 Grau, R., Kuemmerle, T. & Macchi, L., 2013. Beyond “land sparing versus land sharing”:
9 Environmental heterogeneity, globalization and the balance between agricultural
10 production and nature conservation. *Current Opinion in Environmental Sustainability*, 5(5),
11 pp.477–483.
- 12 Green, R.E. et al., 2005. Farming and the fate of wild nature. *Science*, 307(5709), pp.550–5.
- 13 GTZ, 2006. *Overview of Major Legal Categories of Lands and Waters in Cambodia*, Phnom Penh,
14 Cambodia.
- 15 Gurney, G.G. et al., 2014. Poverty and protected areas: An evaluation of a marine integrated
16 conservation and development project in Indonesia. *Global Environmental Change*, 26,
17 pp.98–107.
- 18 GW, 2009. *Country for sale: How Cambodia’s elite has captured the country’s extractive*
19 *industries*, London.
- 20 GW, 2012. *Dealing with disclosure: Improving transparency in decision-making over large-scale*
21 *land acquisitions, allocations and investments*, London.
- 22 Halpern, B.S. et al., 2013. Achieving the triple bottom line in the face of inherent trade-offs
23 among social equity, economic return, and conservation. *Proceedings of the National*
24 *Academy of Sciences of the United States of America*, 110(15), pp.6229–34.
- 25 Hansen, M.C. et al., 2013. High-resolution global maps of 21st-century forest cover change.
26 *Science (New York, N.Y.)*, 342(6160), pp.850–3.
- 27 Hardin, J., Hilbe, J. & Hilbe, J., 2007. *Generalized linear models and extensions*, Stata Press.
- 28 Hilbe, J., 2011. *Negative binomial regression*, Cambridge University Press.
- 29 Hor, S. et al., 2014. The Impact of Agricultural Expansion on Forest Cover in Ratanakiri Province,
30 Cambodia. *Journal of Agricultural Science*, 6(9), pp.46–59.
- 31 Keane, A. et al., 2011. Evidence for the effects of environmental engagement and education on
32 knowledge of wildlife laws in Madagascar. *Conservation Letters*, 4(1), pp.55–63.
- 33 Lacerda, L. et al., 2004. *Management effectiveness assessment of the system of protected areas*
34 *in Cambodia using WWF’s RAPPAM methodology*, Phnom Penh, Cambodia.
- 35 Lamb, A. et al., 2016. The potential for land sparing to offset greenhouse gas emissions from
36 agriculture. *Nature Climate*.
- 37 Lambin, E.F. & Meyfroidt, P., 2011. Global land use change, economic globalization, and the
38 looming land scarcity. *Proceedings of the National Academy of Sciences of the United States*
39 *of America*, 108(9), pp.3465–72.
- 40 Lambrick, F.H. et al., 2014. Effectiveness of community forestry in prey long forest, Cambodia.
41 *Conservation Biology*, 28(2), pp.372–381.
- 42 Li, Z. & Fox, J.M., 2011. Integrating Mahalanobis typicalities with a neural network for rubber
43 distribution mapping. *Remote Sensing Letters*, 2(2), pp.157–166.

- 1 LICADHO, 2015. Economic Land Concession Spatial Dataset.
- 2 LICADHO, 2005. *Harmful effects of Economic Land Concessions on Poor Cambodians*, Phnom
3 Penh, Cambodia.
- 4 LICADHO, 2014. Year 2013 in Review: Land, a Country in Crisis.
- 5 MAFF, 2015. Economic Land Concession. Available at: <http://www.elc.maff.gov.kh/> [Accessed
6 May 18, 2015].
- 7 McCarthy, J. & Zen, Z., 2010. Regulating the oil palm boom: Assessing the effectiveness of
8 environmental governance approaches to agro-industrial pollution in Indonesia. *Law and*
9 *Policy*, 32(1), pp.153–179.
- 10 McShane, T.O. et al., 2011. Hard choices: Making trade-offs between biodiversity conservation
11 and human well-being. *Biological Conservation*, 144(3), pp.966–972.
- 12 Messerli, P. et al., 2015. Marginal Lands or Marginal People? Analysing Key Processes
13 Determining the Outcomes of Large-Scale Land Acquisitions in Lao PDR and Cambodia.
14 *Revue internationale de politique de développement*, (6.1).
- 15 Michinaka, T. et al., 2013. Factors Affecting Forest Area Changes in Cambodia: An Econometric
16 Approach. *Journal of Sustainable Development*, 6(5), p.p12.
- 17 Milne, S., 2015. Cambodia's Unofficial Regime of Extraction: Illicit Logging in the Shadow of
18 Transnational Governance and Investment. *Critical Asian Studies*, 47(2), pp.200–228.
- 19 Milne, S. & Chervier, C., 2014. *A Review of payments for environmental services (PES) experiences*
20 *in Cambodia*, Bogor, Indonesia: Center for International Forestry Research (CIFOR), Bogor,
21 Indonesia.
- 22 Milne, S. & Mahanty, S., 2015. *Conservation and Development in Cambodia: Exploring Frontiers*
23 *of Change in Nature, State and Society*, Routledge.
- 24 MRC, 2003. *State of the Basin Report*, Phnom Penh, Cambodia.
- 25 Neef, A. & Touch, S., 2012. Land Grabbing in Cambodia: Narratives, Mechanisms, Resistance. In
26 *International Conference on Global Land Grabbing*. Ithaca, NY.: Department of Development
27 Sociology at Cornell University, p. 23.
- 28 Neef, A., Touch, S. & Chiengthong, J., 2013. The Politics and Ethics of Land Concessions in Rural
29 Cambodia. *Journal of Agricultural and Environmental Ethics*, 26(6), pp.1085–1103.
- 30 NSDP, 2014. *National Strategic Development Plan 2014-18*,
- 31 Oldenburg, C., Neef, A. & Andreas, N., 2014. Reversing Land Grabs or Aggravating Tenure
32 Insecurity? Competing Perspectives on Economic Land Concessions and Land Titling in
33 Cambodia. *The Law and Development Review*, 7(1).
- 34 Olsson, A. & Emmett, D.E., 2007. *A floral and faunal biodiversity assessment of Prey Long*, Phnom
35 Penh, Cambodia: Conservation International, Forest & Landscape, University of
36 Copenhagen, and Forestry Administration.
- 37 Open Development Cambodia (ODC), 2016. Economic Land Concessions. Available at:
38 <http://www.opendevdevelopmentcambodia.net/briefing/economic-land-concessions-elcs/>
39 [Accessed January 1, 2016].
- 40 Oya, C., 2013. Methodological reflections on “land grab” databases and the “land grab”
41 literature “rush.” *Journal of Peasant Studies*, 40(3), pp.503–520.
- 42 Peeters, A., 2015. Disclosing recent territory-lift and rural development contributions of
43 Cambodian large-scale land acquisitions. *LDPI conference in Chiang Mai University*.

- 1 Pender, J. et al., 2004. Development Pathways and Land Management in Uganda. *World*
2 *Development*, 32(5), pp.767–792.
- 3 Phalan, B. et al., 2013. Crop Expansion and Conservation Priorities in Tropical Countries. *PLoS*
4 *ONE*, 8(1).
- 5 Phalan, B. et al., 2016. How can higher-yield farming help to spare nature? *Science*, 351(6272),
6 pp.450–451.
- 7 Phalan, B., Balmford, A., et al., 2011. Minimising the harm to biodiversity of producing more food
8 globally. *Food Policy*, 36, pp.S62–S71.
- 9 Phalan, B., Onial, M., et al., 2011. Reconciling food production and biodiversity conservation:
10 land sharing and land sparing compared. *Science (New York, N.Y.)*, 333(6047), pp.1289–91.
- 11 Phelps, J. et al., 2013. Agricultural intensification escalates future conservation costs.
12 *Proceedings of the National Academy of Sciences of the United States of America*, 110(19),
13 pp.7601–6.
- 14 Pinheiro, J. & Bates, D., 2006. *Mixed-effects models in S and S-PLUS*, Springer Science & Business
15 Media.
- 16 Rainey, H.J., Heng, B. & Evans, T., 2010. *Forest cover trends in the Northern Plains*,
17 RGC, 2001. *Land Law*, Royal Government of Cambodia.
- 18 RGC, 2010. *National Forest Programme 2010-2029*, Phnom Penh.
- 19 RGC (Royal Government of Cambodia), 2008. *Law on Nature Protection Area (Protected Areas*
20 *Law)_080104_080104*,
- 21 RGC (Royal Government of Cambodia), 2005. *Sub-Decree #146 on Economic Land Concessions*,
22 Cambodia.
- 23 Royal Government of Cambodia (RGC), 2012. *Directive 01 on Measures to Strengthen and*
24 *Foster the Effectiveness of the Management of Economic Land Concessions*, Phnom Penh.
- 25 Royal Government of Cambodia (RGC), 2011. *Sub-decree on determining management zone in*
26 *nature protection area as sustainable use zone*,
- 27 Rudel, T.K. et al., 2009. Changing drivers of deforestation and new opportunities for
28 conservation. *Conservation biology : the journal of the Society for Conservation Biology*,
29 23(6), pp.1396–405.
- 30 Schneider, A., 2011. What shall we do without our land? Land Grabs and Resistance in Rural
31 Cambodia. In *International conference on Global land grabbing*. pp. 1–35.
- 32 Schönweger, O., Heinimann, A. & Epprecht, M., 2012. *Concessions and Leases in the Lao PDR:*
33 *Taking stock of land investments*, Centre for Development and Environment (CDE),
34 University of Bern, Bern and Vientiane.
- 35 De Schutter, O., 2011. How not to think of land-grabbing: three critiques of large-scale
36 investments in farmland. <http://dx.doi.org/10.1080/03066150.2011.559008>.
- 37 Scoones, I. et al., 2013. The politics of evidence: methodologies for understanding the global
38 land rush. *Journal of Peasant Studies*, 40(3), pp.469–483.
- 39 Sekiguchi, M. & Hatsukano, N., 2013. Land conflicts and land registration in Cambodia. *Land and*
40 *Post-conflict Peacebuilding*.
- 41 Shively, G. & Pagiola, S., 2004. Agricultural intensification, local labor markets, and deforestation
42 in the Philippines. *Environment and Development Economics*, 9(2), pp.241–266.

- 1 Sodhi, N.S. et al., 2004. Southeast Asian biodiversity: an impending disaster. *Trends in Ecology &*
2 *Evolution*, 19(12), pp.654–660.
- 3 Sperfeldt, C., Tek, F. & Tai, B.C.L., 2012. *An Examination of Policies Promoting Large-scale*
4 *investments in farmland in Cambodia*,
- 5 Stibig, H.-J. et al., 2014. Change in tropical forest cover of Southeast Asia from 1990 to 2010.
6 *Biogeosciences*, 11(2), pp.247–258.
- 7 Strange, N. et al., 2007. Integration of species persistence, costs and conflicts: An evaluation of
8 tree conservation strategies in Cambodia. *Biological Conservation*, 137(2), pp.223–236.
- 9 Subedi, S.P., 2012. *A Human Rights Analysis of Economic and Other Land Concessions in*
10 *Cambodia: Report of the Special Rapporteur on the Situation of Human Rights in Cambodia*,
11 Cambodia.
- 12 Subedi, S.P., 2014. *Report of the Special Rapporteur on the situation of human rights in*
13 *Cambodia*,
- 14 Thiel, F., 2009. Law for State Land Management in Cambodia. *Rural* 21, 43(3), pp.34–36.
- 15 Tilman, D. et al., 2011. Global food demand and the sustainable intensification of agriculture.
16 *Proceedings of the National Academy of Sciences of the United States of America*, 108(50),
17 pp.20260–4.
- 18 Tscharntke, T. et al., 2012. Global food security, biodiversity conservation and the future of
19 agricultural intensification. *Biological Conservation*, 151(1), pp.53–59.
- 20 Ullenberg, A., 2009a. *Foreign Direct Investment (FDI) in Land in Cambodia*,
- 21 Ullenberg, A., 2009b. *Foreign Direct Investment (FDI) in Land in Cambodia*,
- 22 Un, K. & So, S., 2011. Land Rights in Cambodia: How Neopatrimonial Politics Restricts Land Policy
23 Reform. *Pacific Affairs*, 84(2), pp.289–308.
- 24 USAID, 2012. *Cambodia Country Profile: Rights and Resource Governance*,
- 25 USAID, 2011a. *Property Rights and Resource Governance Country Profile: Cambodia*,
- 26 USAID, 2011b. *Rapid Socio-Economic and Hydrological Assessment of Prey Lang Forest*,
27 Cambodia.
- 28 Vrieze, P. & Naren, K., 2012. Carving Up Cambodia: One concession at a time. *Cambodia Daily*
29 *Weekend*.
- 30 Wang, Q.-W. & Liu, X., 2013. The Equalities of BLUPs for Linear Combinations Under Two General
31 Linear Mixed Models. *Communications in Statistics - Theory and Methods*, 42(19), pp.3528–
32 3543.
- 33 WCS, 2013. Northern Plains spatial dataset.
- 34 Woodhouse, E. et al., 2015. Guiding principles for evaluating the impacts of conservation
35 interventions on human well-being. *Philosophical transactions of the Royal Society of*
36 *London. Series B, Biological sciences*, 370(1681).
- 37 World Bank, 2013. Cambodia Overview. Available at:
38 <http://www.worldbank.org/en/country/cambodia/overview>.
- 39 World Bank, 2011. The World Bank and Aid Effectiveness. , (November).
- 40 WWF, 2007. *Addressing the Environmental and Social Challenges Resulting from Large-Scale*
41 *Agricultural Land Concessions in Cambodia and Lao PDR*,
- 42 Ziegler, A.D. et al., 2012. Carbon outcomes of major land-cover transitions in SE Asia: Great

- 1 uncertainties and REDD+ policy implications. *Global Change Biology*, 18(10), pp.3087–3099.
- 2 Ziegler, A.D., Fox, J.M. & Xu, J., 2009. Agriculture. The rubber juggernaut. *Science (New York,*
- 3 *N.Y.)*, 324(5930), pp.1024–5.
- 4 Zuur, A. et al., 2009. *Mixed effects models and extensions in ecology with R*, Springer.

5

Appendices

Appendix A – Economic Land Concession characteristics

Table A1. Characteristics of the 50 ELC located in the study area. Data sources for spatially explicit data from LICADHO (2015); data about ELC characteristics from ODC (2016).

Source (GIS data, ELC data)	ODC Data classification	Concessionaire name	Size (ha)	Province(s)	Investment intension	Purpose	Investor country	Contract date	Sub- decree date	Issue ministry	Protected Area name(s)
LICADHO, ODC	Government data complete	Am Phal Focus (Cambodia)	8000	Preah Vihear	Rubber plantation	Agro-industry	Not found	Not found	40963	Not found	Not found
LICADHO, ODC	Government data complete	Kol Veasna Investment Co., Ltd. (previously An Mady Group)	9863	Kampong Thom	Agro-industrial crops and animal husbandry	Agro-industry	Cambodia	09/05/2005	Not found	MEF	Not found
LICADHO, ODC	Government data complete	An Mady Group Co., Ltd.	9993	Preah Vihear, Kampong Thom	Rubber and other plantations	Agro-industry	Cambodia	Not found	40038	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	An Sophy Farming (Cambodia) Co., Ltd.	967	Kampong Thom	Agro-industrial crops and animal husbandry	Agro-industry	Cambodia	09/07/2009	Not found	Not found	Not found
LICADHO, ODC	Government data complete	BNA (Cam) Corp	7500	Kampong Thom	Rubber and cassava plantation	Agro-industry	Korea	25/09/2009	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	Best Royal (K) Co., Ltd.	6500	Oddar Meanchey, Preah Vihear	Agro-industrial crops and rubber plantation	Agro-industry	Not found	Not found	40870	Not found	Kulen Promtep Wildlife Sanctuary
LICADHO, ODC	Government data complete	Bean Heach Investment Co., Ltd.	4385	Kampong Thom	Agro-industrial crops	Agro-industry	Vietnam	Not found	40207	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	Bean Heach Investment Co., Ltd.	5095	Kampong Thom, Preah Vihear, Siem Reap	Not found	Agro-industry	Vietnam	Not found	40623	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	Cambodia Dawn Plantation Ltd.	9237	Preah Vihear	Agro-industrial crops	Agro-industry	Singapore	Not found	40890	Not found	Kulen Promtep Wildlife Sanctuary
LICADHO, ODC	Government data partial	Cambodia Blue Haven Ltd.	9129	Preah Vihear	Rubber and Other crops	Agro-industry	Not found	Not found	41067	Not found	Kulen Promtep Wildlife Sanctuary

Source (GIS data, ELC data)	ODC Data classification	Concessionaire name	Size (ha)	Province(s)	Investment intension	Purpose	Investor country	Contract date	Sub- decree date	Issue ministry	Protected Area name(s)
LICADHO, ODC	Government data complete	Caoutchouc Mekong	7541	Kampong Thom	Rubber plantation	Agro-industry	Not found	Not found	40304	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	C C V Co., Ltd.	5730	Kampong Thom	Acacia plantation	Agro-industry	Cambodia	05/05/2010	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	Chhun Hong Rubber Better	8202	Kratie	Rubber plantation	Agro-industry	Cambodia	29/01/2010	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	China Great Cause (Cambodia) Investment	5980	Preah Vihear	Rubber plantation	Agro-industry	Not found	06/06/2012	40963	MEF	Not found
LICADHO, ODC	Government data complete	C R C K Rubber Development Co., Ltd.	6155	Kampong Thom	Rubber plantation	Agro-industry	Vietnam	05/05/2010	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	C R C K Rubber Development Co., Ltd. II	7289	Kampong Thom	Rubber plantation	Agro-industry	Vietnam	Not found	40186	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	C R C K Rubber Development Co., Ltd. II	2183	Kampong Thom, Siem Reap	Rubber plantation	Agro-industry	Vietnam	Not found	40623	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	C X P B Development	8202	Kratie	Rubber plantation	Agro-industry	Cambodia	29/01/2010	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	Distinct Harvest (Cambodia) Co., Ltd.	7960	Preah Vihear	Rubber plantation and agro-industry	Agro-industry	Malaysia	Not found	41124	Not found	Not found
LICADHO, ODC	Government data complete	Eminent Elite (Cambodia) Co., Ltd.	5973	Preah Vihear	Rubber plantation and other agro- industrial crops	Agro-industry	Malaysia	Not found	41124	Not found	Not found
LICADHO, ODC	Government data complete	F P Malaysia (Cambodia) Plantation Co., Ltd.	8200	Preah Vihear	Rubber plantation and other agro- industrial crops	Agro-industry	Not found	Not found	40934	MEF	Not found
LICADHO, ODC	Government data complete	(Cambodia) Farming Investment Co., Ltd.	901.22	Kampong Thom	Agro-industrial crops	Agro-industry	Cambodia	09/07/2009	Not found	MAFF	Not found
LICADHO, ODC	Other data	Gold Foison	5534	Kampong Thom	Not found	Not found	Not found	13/11/2007	Not found	Not found	Not found
LICADHO, ODC	Government data complete	Golden Farming Investment Co., Ltd.	925	Kampong Thom	Agro-industrial crops	Agro-industry	Cambodia	09/07/2009	Not found	Not found	Not found

Source (GIS data, ELC data)	ODC Data classification	Concessionaire name	Size (ha)	Province(s)	Investment intension	Purpose	Investor country	Contract date	Sub- decree date	Issue ministry	Protected Area name(s)
LICADHO, ODC	Government data complete	Green Choice (Cambodia) Co., Ltd.	6424	Preah Vihear	Rubber plantation and other agro- indrial crops	Agro-industry	Malaysia	Not found	41124	Not found	Not found
LICADHO, ODC	Government data complete	Heng Nong (Cambodia) International Company Limited	6488	Preah Vihear	Rubber, acacia and sugar cane plantation	Agro-industry	China	Not found	40730	MEF	Not found
LICADHO, ODC	Government data complete	Heng Ruy (Cambodia) International Company Limited	7607	Preah Vihear	Rubber, acacia and sugar cane plantation	Agro-industry	China	Not found	40730	MEF	Not found
LICADHO, ODC	Government data complete	Heng You (Cambodia) International Company Limited	8860	Preah Vihear	Rubber, acacia and sugar cane plantation	Agro-industry	China	Not found	40730	MEF	Not found
LICADHO, ODC	Government data complete	H.M.H Co., Ltd.	5914	Kampong Thom	Acacia and other plantation	Agro-industry	Cambodia	17/03/2006	41047	MAFF	Not found
LICADHO, ODC	Government data complete	Kim Chea Toun Group	8846	Preah Vihear	Rubber and acacia plantation	Agro-industry	Not found	Not found	40730	Not found	Not found
LICADHO, ODC	Government data complete	Lan Feng (Cambodia) International Company Limited	9015	Preah Vihear	Rubber, acacia and Sugar cane plantation	Agro-industry	China	Not found	40730	MEF	Not found
LICADHO	N/A	Lun Agritech Invesment company Ltd.	400	Oddor Meanchey , Preah Vihear					2012		
LICADHO, ODC	Government data complete	Ly Chhung Construction and Import Export	6000	Siem Reap, Preah Vihear	Agro-industrial crops and rubber plantation	Agro-industry	Not found	Not found	41022	Not found	Kulen Promtep Wildlife Sanctuary
LICADHO, ODC	Government data complete	Phoeuk Va Kampong Thom Rubber Development (previously Mean Rithy Co. Ltd.)	9784	Kampong Thom	Agro-industrial crops	Agro-industry	Cambodia	Not found	Not found	MAFF	Not found
LICADHO	N/A	Metri Peap Kase-Ousahakam Co.,Ltd	8441	Preah Vihear				2013			
LICADHO	N/A	N & Y Co.Ltd., Limited	9485	preah Vihear				2013			
LICADHO	N/A	Phureang	5534	Kampong Thom				2013			
LICADHO, ODC	Government data complete	P N T Co., Ltd.	7900	Preah Vihear	Rubber plantation	Agro-industry	Vietnam	05/05/2010	Not found	MAFF	Not found

Source (GIS data, ELC data)	ODC Data classification	Concessionaire name	Size (ha)	Province(s)	Investment intension	Purpose	Investor country	Contract date	Sub- decree date	Issue ministry	Protected Area name(s)
LICADHO, ODC	Government data complete	Rethy Granite (Cambodia) Co., Ltd.	2036	Preah Vihear	Not found	Agro-industry	Not found	Not found	40623	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	Ruy Feng (Cambodia) International Company Limited	8841	Preah Vihear	Rubber, acacia and Sugar cane plantation	Agro-industry	China	Not found	40730	MEF	Not found
LICADHO	N/A	Se Hong Plantation Company Limited	4337	Oddor Meanchey, Preah Vihear				2012			
LICADHO	N/A	Serymony Transpotation & Construction	2030	Preah Vihear				2011			
LICADHO, ODC	Government data complete	Siv Guek Investment Co., Ltd.	601	Kampong Thom	Agro-industrial crops and animal husbandry	Agro-industry	Cambodia	09/07/2009	Not found	MAFF	Not found
LICADHO, ODC	Government data complete	Sovannaphum Viniyok Kase- Usahakam	9913	Preah Vihear	Rubber plantation	Agro-industry	Not found	Not found	40742	Not found	Boeng Per Wildlife Sanctuary
LICADHO, ODC	Government data complete	Ta Bien Kampong Thom Rubber Development	8100	Kampong Thom	Rubber plantation and constructing processing factory	Agro-industry and processing factory	Vietnam	18/07/2007	Not found	MAFF	Not found
LICADHO	N/A	Think Biotech	34133	Kratie				2011			
LICADHO, ODC	Government data complete	Thy Nga Development and Investment Co., Ltd.	6060	Preah Vihear	Rubber plantation	Agro-industry	Cambodia	25/09/2009	Not found	MAFF	Not found
LICADHO	N/A	Timas Resources	57363	Kratie				2008			
LICADHO, ODC	Government data complete	Try Pheap Import Export Co., Ltd.	9916	Preah Vihear	Rubber plantation	Agro-industry	Cambodia	Not found	40682	Not found	Boeng Per Wildlife Sanctuary
LICADHO	N/A	Tumring Rubber	6200	Kampong Thom				2011			

Appendix B –Methodology for historical deforestation analysis by Conservation International dataset

Classification using Landsat products

The deforestation classification of two Landsat scenes was updated to include deciduous forests and temporal resolution was improved. The Landsat scenes classified were 125/051 and 126/051, as defined by the world reference system of paths and rows for Landsat imagery. The methodology used identifies change detection within co-registered multi-temporal images.

The classification goes back 10 years and includes 4 time periods namely circa 2001, c.2005, c.2008, c.2011. The 4 time periods also align with other data sources such as population census (c.2008), forest cover mapping (c.2002, c.2006), CALMS Forest trends (c.2001, c.2005, c.2008 and c.2010) and Eastern Plains forest cover (c.1998, c.2002, c.2008 and c.2010). The change between c.2001 and c.2011 and the change between c.2005 and c.2008 were classified as multi-temporal pairs. The 2 change classifications were then consolidated to get a single 4 period deforestation product which capture the long term and latest forest cover changes with a better temporal resolution. A 3x3 majority filter was used to reduce small variations and a final classified product with a minimum mapping unit of 1 hectare was created.

Accuracy Assessment using ancillary data and Google Earth and ground truth data from biomass survey

Generally the accuracy of the last classified image is tested against the latest available high resolution imagery. However, given the lack of high resolution imagery for 2011 a spatio-temporal accuracy of the classified product was assessed using available forest cover mapping from the FA for c.2002, c.2006, c.2010. It should be noted that the minimum mapping unit for the FA's forest cover mapping is 20 ha and has been updated for the various years using heads-up digitization as opposed to a classified product which picks up a lot more change.

The classification within the four provinces of Kampong Thom, Kratie, Stung Treng and Preah Vihear were assessed. A 5km grid was used over this area and a random sample point was generated for each grid cell. The points were checked to see whether the FA's 2010 forest cover matched with the 2011 classification. Where the 2010 forest cover data did not cover the 2005 classification, the points were validated against the RGC Forestry Administration's 2006 forest cover data. Areas classed as non-forest in FA'S 2002 data were considered to be non-forest in the later years and the areas classed as deforestation between c2005 and c2008 were also validated against what FA had classed as being deforested between c2002 and c2006. Further to this, the UN FAO land use classification provided additional information to assess the water class against areas of water or flooded vegetation and also to verify shrubby areas which were classed as "Other forest" in FA's forest cover data. The overall accuracy of pixel following this accuracy test is 81% of pixels are correctly classified.

The accuracy was also tested against the plot survey data (50%) that was available at the time of writing this. The validation only included the Project Area and a 10km buffer. All ground truth points that were considered semi-evergreen are classed as evergreen, and biomass surveys considered plots that had forest in the centre-plot of each cluster but may include non-forest in other plots for a cluster. The overall accuracy of pixel following this accuracy test is 82% of pixels are correctly classified.

Consolidation of historical deforestation datasets

The study area, initially chosen as a reference region included the 4 provinces of Kampong Thom, Kratie, Stung Treng and Preah Vihear. The classified Landsat imagery does not cover this entire reference region; however, the data gaps were filled using data from other studies in the region. These studies include data from the *Forest cover trends in the Northern Plains of Cambodia 2002-2010* (WCS 2010) and the *Eastern Plains REDD pilot study* (WCS2011). The historic deforestation classification based on consolidation of the

various data sources was used to calculate the baseline deforestation values. The calculations were performed for 1) A reference region which includes only the 4 provinces initially chosen for the analysis and 2) A reference region which also includes north-western Kampong Champ where data was available. The consolidated product map and tables with deforestations rates for evergreen and deciduous forests are shown below.

Figure B1. Map of the original historical deforestation raster layer verified by Conservation International.

Aggregation of classification in current analysis

Classifications of CI's final deforestation dataset were re-classified for the purpose of this analysis as shown below.

Table B1. Reclassification of CI symbology for the current analysis

CI symbology	Beauchamp et al. symbology
Cloud over Deciduous	Forest
Cloud over Evergreen	Forest
Clouds	No data
Deciduous cleared (01-05)	Non forest
Deciduous cleared (05-08)	Forest
Deciduous cleared (08-11)	Forest
Deciduous Forest	Forest
Evergreen cleared (01-05)	Non forest
Evergreen cleared (05-08)	Forest
Evergreen cleared (08-11)	Forest
Evergreen Forest	Forest
Non Forest	Non forest
Water	Non forest

Appendix C – Model selection and validation of ELC placement model

Table C.1. Generalized linear mixed effect model of ELC placement in 2013

Set of models selected based on AICc for ELC placement using ‘dredge’ function in MuMIn v.1.14.0 (Barton, 2015). A full model with a priori variables was first fitted as a generalized linear mixed model with a binomial error structure and administrative units as random effect using ‘glmer’ function in lme4 v1.7-7 (Bolker, 2015). Final model coefficients presented in Table 6. The number of parameters in the model (k), the log-likelihood (log(L)), the information criterion value (AICc), the AICc difference (Δ AICc) and AICc weight are given for each model. Selected model scored 95% confidence interval and AICc<4.

(Intercept)	PA status	Carbon values	% non-forest	Soil fertility	Elevation	Slope	Population density	Distance to village	Distance to river	Distance to road	Carbon values + % non-forest	df	logLik	AICc	Δ AICc	weight
-3.15	+	+	-1.99	+	-1.17		-1.08				+	13	-736	1497.6	0.00	0.10
-3.05		+	-2.06	+	-1.22		-1.10				+	12	-737	1497.8	0.20	0.09
-3.06	+	+	-2.11	+	-1.104		-1.06	-0.17			+	14	-735	1498.4	0.76	0.07
-3.03		+	-2.13	+	-1.153		-1.06	-0.16			+	13	-736	1498.7	1.04	0.06
-3.10	+	+	-2.00	+	-1.095	-0.05	-1.08				+	14	-735	1499	1.38	0.05
-3.07	+	+	-2.05	+	-1.113		-1.07		-0.10		+	14	-736	1499.1	1.53	0.05
-3.03		+	-2.04	+	-1.137	-0.05	-1.11				+	13	-737	1499.2	1.63	0.04
-3.12	+	+	-2.00	+	-1.15		-1.09			-0.06	+	14	-736	1499.3	1.64	0.04
-3.02		+	-2.07	+	-1.212		-1.10			-0.06	+	13	-737	1499.4	1.83	0.04
NA	1.00	1.00	1.00	1.00	1.00	NA	1.00	NA	NA	NA	NA

Figure C.1.1 Best Linear Unbiased Predictors of the random effects of communes

Figure C.1.2. Variogram of EL placement model shows minimal spatial autocorrelation effects (<10 kilometre square)

C.2 Deforestation two-step model selection and validation

C2.1. Zero-altered negative binomial model of deforestation between 2008 and 2013

Set of models selected based on AICc for deforestation between 2008 and 2013. Model selection for the two-steps deforestation model was done at both stages, with models being fitted first with all *a priori* variables. The models were reduced to a more parsimonious model by dropping non-significant variables one by one, using changes in AICc change to determine the final model. Final model coefficients presented in Tables 8a and 8b.

Table C.2.1a. – Hurdle model selection

Model	D.f.	AICc
Full model - distance to river - soil fertility	16	10926
Full model - soil fertility	17	10926
Full model - distance to river	18	10928
Full model	19	10929

Table C.2.1b. Zero-truncated count model selection

Model	D.f.	AICc
Full model - soil fertility - slope	16	2342
Full model - soil fertility	17	2342
Full model - slope	18	2343
Full model	19	2343
Full model - distance to river	18	2346
Full model - soil fertility - slope - distance to river	15	2347