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Future governance options for large-scale land acquisition in Cambodia: Impacts on tree cover and tiger landscapes

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ABSTRACT

This paper investigates how large-scale land acquisitions (LSLAs) can be governed to avoid underuse and thereby spare room for other land claims, specifically nature conservation. LSLA underuse occurs when land in LSLAs is not converted to its intended use. Taking Cambodia as a case, we map converted and unconverted areas within LSLAs using remote sensing. We develop three scenarios of alternative LSLA policies until 2040, and use a land system change model to evaluate how governing the underuse of LSLAs affects overall land use. Specifically, we evaluate the impact of these policies on future tree cover, the size and spatial integrity of natural areas, and the potential these natural areas can offer to meet the conservation target of a successful tiger reintroduction. In 2015, only 32% of LSLA area was converted. Simulations suggest that both interventionist (reclaim unconverted areas) and preventive (avoid non-conversion) policies dramatically reduce underuse. Interventionist policies perform best in limiting tree cover loss and in preserving natural areas, but preventive measures lead to significantly less fragmentation. Noninterventionist policies (no enforced policies) make tiger reintroduction in the Eastern Plains impossible. Preventive policies with well-enforced protected areas succeed in creating the largest potential for tiger reintroduction. Our results suggest that Cambodia can reconcile LSLAs with tiger reintroduction in the Eastern Plains only when using preventive land use policies. In the absence of such policies, tiger survival in the Eastern Plains is unlikely and only the Cardamom or Virachey forest may offer such potential.

1. Introduction

Following the 2007-08 crises in food, fuel, and finance, demand for the control over land resources has surged (Arezki et al., 2011). Large-scale land acquisitions (LSLAs) are the prime manifestation of this demand, resulting in the reported acquisition of over 49 million hectares of land globally, predominantly in developing countries (International Land Coalition (ILC), 2018). The rapid proliferation of LSLA has spurred societal and academic debate on the desirability of these investments.

Some dismiss the idea that LSLAs can provide benefits that outweigh the negative social and environmental effects and the opportunity costs they incur and argue against optimizing land governance as it will not solve the fundamental problems with LSLA (Borras and Franco, 2010; De Schutter, 2011). Others argue that LSLA is a necessary way to meet growing agricultural commodity demands. In this line of reasoning, LSLAs hold the potential to close yield gaps and increase labor productivity by bringing technological improvements to rural areas that have hitherto seen little rural innovation (Collier and Dercon, 2009). Countries with large land endowments may benefit from LSLAs provided that they streamline the process in a transparent way and with sufficient land governance guardrails (Deininger and Byerlee, 2012).

The fundamental discourse legitimizing LSLA, the notion that ‘unused’ or ‘waste’ land should be allocated to more efficient (large-scale) producers to boost global agricultural production, is scrutinized in a number of ways (De Schutter, 2011; Scoones et al., 2018). Firstly, the existence of ‘unused’ land is doubted, because often such land is in common use (Eitelberg et al., 2015; D’Odorico et al., 2017). Marking land as ‘waste’ land is an underappreciation of the many services land can supply (Borras et al., 2011). Second, the alleged higher efficiency of larger-scale farm units is not supported by empirical evidence. Instead, small owner-producers outperform corporate farms in all but a few crops, and even for crops where e.g. post-harvest processes warrant large-scale supply, it can suffice to organize smallholders in cooperatives (Deininger and Byerlee, 2012; Holden and Otsuka, 2014). Third, the local livelihood and land system impacts of LSLAs are often deemed unacceptable (Friis et al., 2016). Fourth, the secondary positive

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effects that are claimed to accrue from land investments, such as employment, poverty reduction, or food security, often do not materialize or are insufficient to compensate for lost opportunities (Rulli and D'Odorico, 2014; Oberlack et al., 2016; Nolte and Ostermeier, 2017;). The core of this debate is a choice between two development pathways: a pathway of smallholder enablement or a pathway of scale enlargement and foreign investment. While LSLAs can be an engine of agricultural production growth, the enablement of small farmers has the same potential while also providing stronger gains in rural poverty alleviation and development. From this perspective, LSLA is loaded with a high opportunity cost (De Schutter, 2011).

Amidst this debate, a less discussed aspect is the governance and functioning of granted LSLAs. While LSLAs are granted as large, contiguous areas intended for commercial agriculture, a significant share of areas claimed by LSLAs is not converted to its intended use. This is problematic as land resources are becoming scarcer and more contested. Underuse of LSLAs is caused by a host of factors. Often, land is acquired for its speculative value. Although the extent of mere speculative land acquisition is unknown, it has global significance (De Schutter, 2011). In other cases, investors lack agronomic or logistic capacity and knowhow, or meet effective opposition from local land users (Buxton et al., 2012; Schönweger and Messerli, 2015). Agronomical challenges become especially significant when new crops are pioneered (Pearce, 2012; Wendimu, 2016).

The implication of LSLA underuse is a potentially inefficient land use distribution. Unproductive LSLA areas could instead be farmed by smallholder farmers or designated as natural areas. While the full extent of underuse is unknown, the Land Matrix reports 7.5 million hectares of failed LSLA deals globally. For 918 deals, the productive use is known, revealing that only 56% of the area of those deals is converted to its intended use, and only 24% of LSLAs converted all area they acquired (International Land Coalition (ILC) et al., 2017). More reliable figures of LSLA underuse are not available, highlighting the need for empirical research to inform policy. Even when unconverted LSLA areas are still being farmed by smallholders, the LSLA creates insecure land tenure conditions for these land users. This means that the original land use/cover (e.g. forest, smallholder agriculture) persists, but land ownership and tenure become highly insecure. This insecurity is problematic in its own right, but also potentially creates second-order negative effects such as lower land productivity (Higgins et al., 2018). Large tracts of land are effectively locked in by high transaction costs (Deininger and Byerlee, 2012), and cannot easily be rededicated to e.g. smallholder agriculture or nature conservation.

Countries hosting LSLAs are now faced with the challenge of governing these novel land tenure arrangements. This is a pertinent, yet rarely addressed issue: new tenure systems demand new regulatory frameworks, and effective management may have the potential to maximize LSLA benefits while minimizing its negative impacts. Most academic work on LSLA has scrutinized the discourses by which LSLAs are (un)justified (e.g. De Schutter, 2011; Scoones et al., 2018), the motives of stakeholders in the global network of land buyers and sellers (e.g. Zoomers, 2010), or the impacts of LSLAs on local and national socio-ecological systems (e.g. Oberlack et al., 2016; Davis et al., 2015). Such studies tell a precautionary tale and warn against the undesirable outcomes and missed opportunities associated with an LSLA pathway. We do not argue against these analyses, but depart from this debate by considering governance options for those countries that, despite the abovementioned issues, have already embarked on an LSLA pathway nonetheless. Such countries must deal with a different problem set: how to govern novel land tenure arrangements and deal with a new type of land user. This challenge has two interrelated sides: first, policy makers may wish to grant more land as LSLAs, raising questions concerning the amount, size, and location of new projects. Second, effective regulation of existing LSLAs can be challenging in the absence of best practices. Because land resources are limited and claimed for a multitude of purposes, the management of LSLA has often come at the cost of other land users (Messerli et al., 2014), and competitive interactions with smallholder farmers at the national level have been identified (Debonne et al., 2018). Moreover, as LSLA is having an impact on forests and natural habitats (Davis et al., 2015), countries with an environmental policy agenda should reconcile their LSLA policies with their environmental policies, and have the tools to do so.

Countries have established a number of governance approaches to manage the amount of new LSLAs and regulate existing LSLAs. In terms of amount of new LSLAs, policies range from moratoria on all or specific types of LSLAs, to active stimulation of new LSLA (Debonne et al., 2018; Sperfeldt et al., 2012). Those countries accepting and/or stimulating LSLA are using various regulatory frameworks to control location and use of existing and new LSLAs, which we group into three categories. First, some host countries opt for a *noninterventionist* policy, where land acquirers do not need (or are not enforced) to meet any requirements. There are no prior checks on the suitability of the granted land for the intended purpose or the overall feasibility of the project, and LSLA underuse is not penalized. Noninterventionist governance has for example been reported in Myanmar and Zambia where existing regulations are only rarely enforced because responsible administrations are underfinanced and legal pluralism (the co-existence of formal and customary law) undermines formal regulations (Byerlee, 2014; Nolte, 2014). Second, *interventionist* policies demand from land acquirers that they present a plan detailing the intended land use conversions and their timing. Failure to adhere to these plans can result in the revocation of the contract. This policy is for example used in Madagascar and Mozambique, where the LSLA performance and adherence to land use plans is checked after 5 years and 2 years, respectively, and the contract can either be extended or voided (Andriamanalina and Burnod, 2014). Such policies are especially implemented to avoid speculative use of the acquisitions (Nolte et al., 2016). Third, as host governments become more experienced with LSLA and land is becoming scarcer, there are signs that countries are increasingly considering local populations and biophysical suitability of the land for the intended use (Messerli et al., 2015). This creates the perspective for a *preventive* policy style, where host governments allocate LSLAs on land suitable for the intended purposes, and only when the aspiring investors can present solid business plans.

Cambodia is one of the countries where the governance challenges instigated by LSLA have become pertinent. Land is claimed for commodity production by domestic and international producers, but also for biodiversity conservation and urban expansion. Cambodia has granted approximately 2.3 million hectares of agricultural LSLAs, using the Economic Land Concessions system (LICADHO, 2017). LSLAs are intended for the production of, among others, rubber, sugar cane, cassava, fast-growing tree species and palm oil (Sophal, 2015). The de jure policies regulating LSLAs theoretically contain safeguards against LSLA underuse and excessive environmental damage. Among others, a maximum size of 10,000 ha per LSLA is set, environmental and social impact assessments should be conducted, protected areas are off-limits, and contracts can be revoked. However, the de facto policies before 2012 have been implemented less stringently. LSLAs have been granted in protected areas, maximum areas have been exceeded, and LSLAs were often used only to extract timber. Underuse of LSLAs is reported to be a large problem (Löhr, 2011; Neef et al., 2013; Oldenburg and Neef, 2014). This has lead the Government of Cambodia to launch Order 01 in 2012, which includes a full review of currently existing LSLAs and a ban on new LSLAs (Sophal, 2015). Meanwhile, Cambodia hosts a large stock of tree cover, often within large, contiguous natural areas. These natural areas contain a wide range of globally endangered species (WWF, 2018). 34% of Cambodia's territory is officially protected (World Bank, 2018), although this protection is often not effective (Souter et al., 2016). In the context of the WWF Tx2 project, which aims to double the global population of wild tigers (*Panthera Tigris*) by 2022 (Wikramanayake et al., 2011), Cambodia has committed itself to reintroduce the currently extirpated tiger. This reintroduction requires, among other factors, a large contiguous habitat and therefore constitutes a large claim on land resources (Gray et al., 2017).

The objective of this paper is to assess to what extent and how Cambodian LSLA policies can be reconciled with their nature conservation ambitions. This assessment is carried out using a forward-looking land system change model, able to project future land use under different policy scenarios. We assess the impacts of projected land system changes to future tree cover, area and integrity of natural areas, and the ensuing potential of a successful tiger introduction. Land change models are valuable tools to explore the possible impacts of land policies in the future, and find out which policies may succeed in reaching stated targets. Currently, some LSLAs have been revoked or downsized following Order 01, but there are currently no protocols or guidelines on the management or use of the land of reclaimed LSLAs (Grimsditch and Schoenberger, 2015). With such large areas of land in the balance, Cambodia's policies on these issues will likely have a highly significant effect on land use and the environment, with perpetuating effects in the future.

2. Methods

To assess how LSLA policies will shape future land system patterns in Cambodia by 2040, we use CLUMondo, a land system change model that can explicitly address LSLA (Debonne et al., 2018; van Asselen and Verburg, 2013). The model is described in detail in Supplementary Information (SI) 5. In the following sections, we first develop a land system map for 2015, distinguishing the productive use of LSLAs. Next we explain the modeling of future land system changes until 2040. Lastly, we present and parameterize three LSLA policy scenarios.

2.1. Mapping large-scale land acquisitions as land systems in Cambodia

We characterize Cambodian land systems based on their land cover composition as well as their land management regime. Land systems combine information on land cover, land use, and land management. They capture the different purposes land has and to what extent specific combinations of land cover, use, and management can fulfill demands for these purposes (van Asselen and Verburg, 2012). Land systems are classified at a spatial resolution of 1000 m, because this best captures the land change processes of interest and the detail of available data. The starting land system map depicts the situation in 2015 for mainland Cambodia. We operationalized the classification using a decision tree that combines a 2015 land cover map (Miettinen et al., 2016), a forest classification (Open Development Cambodia, 2016a), and the spatial delineation of LSLAs (Open Development Cambodia, 2016b). The resulting land systems are defined in Table 1. A detailed procedure is presented in SI-1A and 1B.

To be able to reflect differences between LSLAs, we used the Cambodian LSLA spatial database by Open Development Cambodia (2016a,b), and mapped the areas that are converted into a plantation. We interpreted LSLAs to be 'converted' when (1) it falls within a mapped LSLA area (Open Development Cambodia, 2016b) (2) a plantation-like land cover pattern is present (large-scale monocultures planted in a noticeably structured way), and (3) the land was converted after the contract date of the LSLA. We used high resolution Google Earth data and Landsat time series with yearly images to perform the visual interpretation. We further subdivided converted LSLAs into annual crops, forestry, and perennial crops, based on their intended production as stated in the LSLA database. Unconverted LSLAs are subdivided into forested and other unconverted LSLAs, based on forest cover (Table 1). Other unconverted LSLAs may be fallow, or in use for smallholder agriculture, but this was not classified in more detail.

2.2. Modelling land system changes in response to multiple demands for commodities and services

The CLUMondo model (van Asselen and Verburg, 2013) is used to simulate future land system changes until 2040. CLUMondo combines information on local suitability for different land systems, conversion rules, and future demands for land system commodities and services, and uses an iterative procedure to allocate land systems in order to meet these demands. Conceptually, the model assumes that if there is an increase in demand for a commodity or service, land systems producing this commodity or service will appear where the biophysical and socio-economic context is most suitable for those land systems. Suitability is quantified using logistic regressions performed with eighteen socio-economic and biophysical factors (SI-4B to 4C). Importantly, because land system can produce zero to many commodities and services, and any single commodity or service can be produced by multiple land systems, they drastically increase the complexity of the model. Each time step, the model essentially aims to supply all the land-based goods and services that are provided as exogenous inputs while maximizing the total allocation likelihood defined by the suitability and conversion resistances. The resulting land system changes (e.g. the choice between agricultural intensification or expansion pathways) are the result of a numerical optimization procedure balancing these demands, constraints, suitability and other specifications (van Vliet and Verburg, 2018). Within each time step (year), land use changes are simulated in an iterative procedure. Each cell is initially given the land system that is (1) allowed in that location (depending on original land system and location) and (2) has the highest transition potential (suitability) on that location. Then, the amount of commodities and services this new landscape produces is calculated, and based on the imbalance between demand and supply, land systems producing undersupplied demands are given a higher transition potential and vice versa. This is repeated until all demands are fulfilled within a margin of 5%, while the overall average deviation is below 1%.

Table 1
Land systems and explanation. The decision tree and specific data sources are provided in SI-1.

Land system	Description
Water	Rivers and lakes
Floodplain/Mangrove	Floodplains or mangroves
Urban	Cities and towns based on Miettinen et al. (2016)
Converted annual crops LSLA	Plantations located within an LSLA and intended for the production of annual crops (cassava, sugar cane, maize, and others)
Converted forestry LSLA	Plantations located within an LSLA and intended for the production of timber (acacia and teak) or paper pulp
Converted perennial crops LSLA	Plantations located within an LSLA and intended for the production of rubber or palm oil
Forested unconverted LSLA	Areas claimed as LSLA but not currently in use as a plantation, covered with forest
Other unconverted LSLA	Areas claimed as LSLA but not currently in use as a plantation, not covered with forest
Evergreen forest	Tropical evergreen forest
Deciduous forest	Deciduous dipterocarp forest, also known as tropical dry forest
Cropland	Smallholder cropland dominantly used for paddy rice cultivation and to lesser extent for the production of annual and perennial crops or timber
Cropland – Evergreen forest mosaic	Variant of the Cropland system in mosaic with evergreen forest
Cropland – Deciduous forest mosaic	Variant of the Cropland system in mosaic with deciduous forest

In our application, each land system produces, in varying quantities, five defined commodities and services: annual cash crops (cassava, sugar cane, and others), timber, perennial crops (predominantly rubber, but also palm oil), and rice. 'Urban' is a land system service grouping all urban functions such as residential functions. LSLAs are assumed to specialize in one of three commodity groups (annual cash crops, perennial cash crops or forestry). Smallholder systems also produce these commodities, but focus mostly on rice. Furthermore, smallholders are assumed to experience increasing yields, representing partial closures of the yield gap. We control the area of new LSLAs added each year by defining a specific policy demand for LSLA, and allocate LSLAs using a multi-cell allocation algorithm to represent them as large contiguous entities (SI-5). A detailed description of the quantification of demands and productivities is given in SI-2A until 2C.

2.3. LSLA policy scenarios towards 2040

We developed three scenarios to address alternative LSLA governance options for Cambodia and their possible consequences. We explain these scenarios with storylines and present model parameters that differ among scenarios in Table 2. The first scenario assumes no reform or no implementation of a reform and is therefore noninterventionist, while the next two scenarios assume a policy reform towards an interventionist and a preventive LSLA policy, respectively.

2.3.1. Hands-off

In this scenario, a noninterventionist approach towards LSLAs is assumed. No restrictions are in place to regulate LSLA. Upon acquiring land, there is no penalization if the investor does not develop a plantation, making it possible to leave the land undeveloped. We assume that each year, between 40,000 and 60,000 ha of new LSLAs are granted, and each individual LSLA is between 8000 and 12,000 ha large. In the last 15 years, the average yearly area of new LSLA amounted to 111,239 ha. Our estimates are therefore conservative, because (1) since 2012, Cambodia has signaled a less expeditious LSLA policy (Oldenburg and Neef, 2014), and (2) we assume the already high pressure on land in Cambodia (Löhr, 2011) makes a continuation of past trends unlikely. In this scenario, LSLA contracts are permanent and cannot be revoked or downsized. This scenario resembles a continuation of the LSLA policies prior to the 2012 Order 01, where LSLAs were granted without any effective management efforts (ADHOC, 2014; Dwyer et al., 2015).

2.3.2. Penalization

In this scenario, land acquirers are required to develop the acquired land within three years after the LSLA was granted. If they fail to do so, the contract is voided for the unconverted areas. These areas will convert to a non-LSLA land system. This scenario simulates a continuation of the interventionist policy effectively introduced by Order 01 in 2012, when the revision of granted LSLAs resulted in the downsizing or outright revocation of unconverted LSLAs. These areas where then granted to smallholders as Social Land Concessions, or (re-)integrated into protected areas (Oldenburg and Neef, 2014; Schoenberger, 2017). As LSLA contracts are revoked, we assume that the demand for commodities produced by LSLAs in Cambodia (timber, annual and perennial cash crops) decreases. This process mimics the globalized nature of the markets for these commodities: if land is not available or used in Cambodia, we assume production will move elsewhere. Specifically, the expected demand for LSLA area instigated by the three commodities in the next simulation year cannot exceed 50% of the total unconverted LSLA area. If this threshold is exceeded, the demands for the three commodities are evenly lowered until the criteria is met.

2.3.3. Proactive granting

In this scenario, Cambodia takes a preventive stance by granting smaller concessions on highly suitable land only. New LSLAs cannot be allocated within protected areas. Furthermore, new LSLAs are only granted if there is sufficient market demand for the commodities LSLAs produce. Specifically, only when the expected demand for LSLA area instigated by commodity demands in the next year exceeds 50% of the current LSLA stock new LSLAs can be granted. Note that in this scenario LSLA availability is adjusted upward based on commodity demand, while in the Penalization scenario commodity demand is adjusted downward based on LSLA availability.

2.4. Scenario impact assessment

2.4.1. Impact on tree cover

We quantify the total tree cover change during the simulated period. Conceptually, a land system is composed of various land covers, among which is tree cover. We quantify average tree cover for each land system and assume this will remain constant. This is operationalized using overlay analysis of the initial land system map with a tree cover map by Open Development Cambodia (2016a). We analyze total tree cover at the end of the simulation to assess the effectiveness of different policies. We also break down total tree cover into tree cover situated in natural, LSLA, and other land systems.

2.4.2. Impact on core natural areas and tiger reintroduction potential

We assess how land system changes impact core natural areas by defining a core area as a forested area (evergreen or deciduous land system) that is at least 5 km away from any large (> 300 ha) unnatural disturbance. Non-core natural areas are defined as edge areas, and we assume that disturbance and edge effects pose a threat to biodiversity there. 5 km is frequently used as a distance to define core areas (Thatte et al., 2018). Further details on core area delineation are presented in SI-3.

In a next step, we evaluate the impact of the modeled natural area dynamics on the potential of a tiger reintroduction. Tiger reintroduction success depends, amongst other factors, on the availability of a sufficiently large contiguous natural area. For a reintroduction to be

Table 2

Scenario parameters. Maximum vacancy time is the number of years an LSLA is allowed to be unconverted before its contract is revoked. The LSLA size and minimum suitability are controlled by the multi-cell allocation algorithm described in SI-5.

	Hands-off	Penalization	Proactive granting
Protected areas	None or not effective	None or not effective	No LSLA in protected areas as delineated by Open Development Cambodia (2018)
Maximum unconverted time	Indefinite	3 years	3 years
LSLA size	8000– 12,000 ha	8000–12,000 ha	600–900 ha
LSLA minimum suitability	Very low (0.3)	Very low (0.3)	High (0.5)
New LSLA area yearly	40,000– 60,000 ha	40,000– 60,000 ha	Matching commodity demand
Total cash crop demand increase until 2040	100%	Depending on LSLA availability	100%
Total Timber demand increase until 2040	100%	Depending on LSLA availability	100%
Total Perennial cash crop demand increase until 2040	152%	Depending on LSLA availability	152%

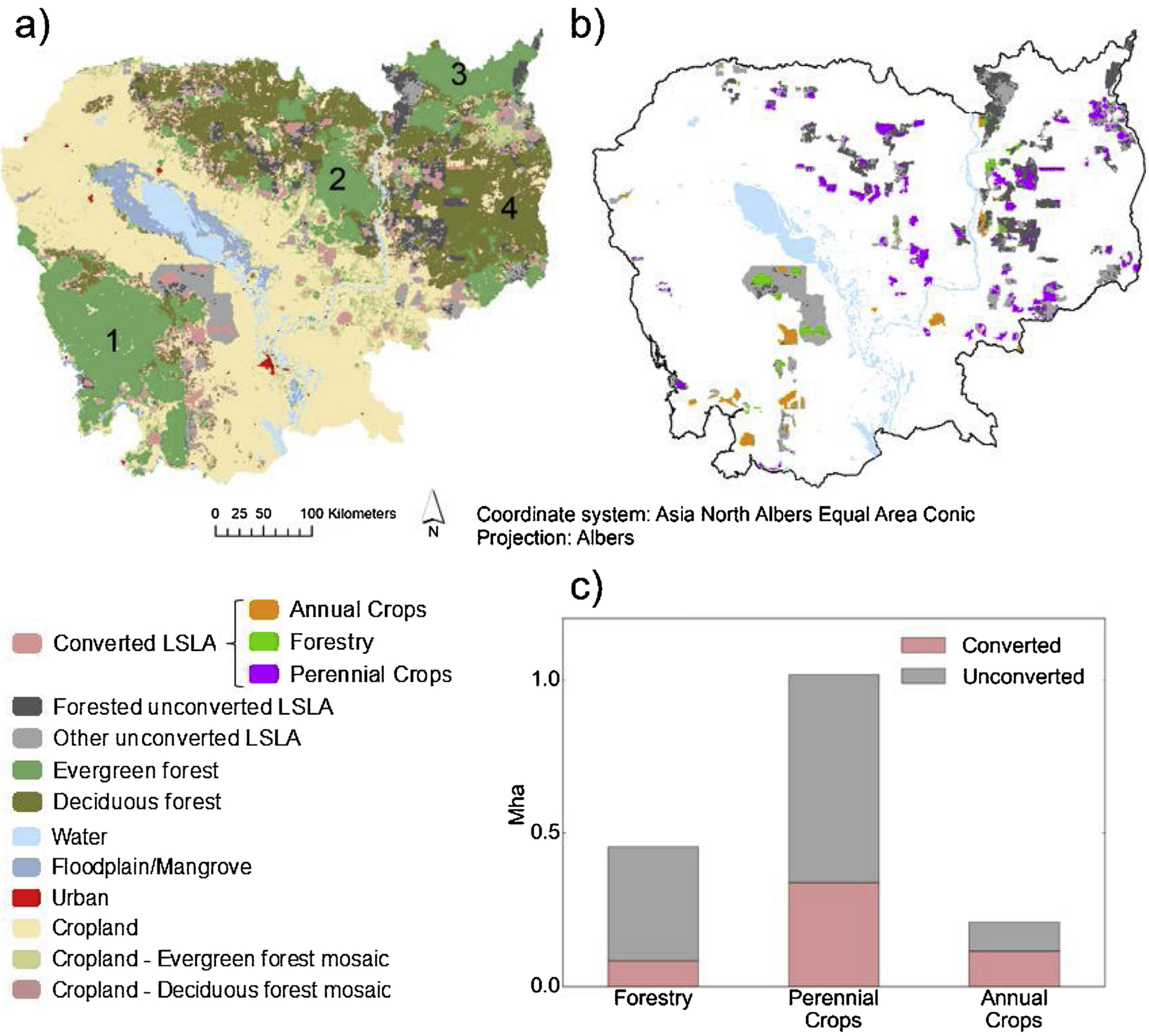

Fig. 1. a) Cambodian land systems in 2015. Numbers mark the Cardamom forest (1), Prey Lang Forest (2), Virachey Forest (3), and the Eastern Plains Deciduous Forest (4). b) LSLA areas detailing the c) Productive use of LSLAs. Production group is determined by the stated intention in the LSLA database.

successful, it is estimated that a habitat must be at least 0.2 Mha. The risk for human-tiger conflict is high in Cambodia, with low support rates reported for coexistence with tigers in potential tiger reintroduction sites (Gray et al., 2017). Therefore, we assume that tiger reintroduction is only feasible within the core natural areas, as defined above. Evergreen and deciduous forest systems can sustain 3 and 10 tigers/10,000 ha, respectively (Wikramanayake et al., 2011). Using these figures, we quantify how many tigers can potentially be sustained by the remaining core areas larger than 0.2 Mha in 2040, in case other inhibiting factors (poaching, human-wildlife conflict, adequate prey densities; see Gray et al., (2017)) are dealt with.

3. Results

3.1. Cambodian land systems and large-scale land acquisitions in 2015

In 2015, Cambodia consists of a central valley of cropland systems, and a number of large and relatively intact patches of evergreen or deciduous forests (Fig. 1a). The Eastern Plains have been fragmented by a number of LSLAs, mostly for perennial crop production. Other natural areas marked in Fig. 1a form relatively undisturbed core areas.

The majority of the land included in LSLAs in the year 2015 is not in use for their intended production (Fig. 1b-c). Only 32% of all LSLA area is used productively, while the other 68% remains in its original state. Yet, the fractions differ between LSLAs, and according to the intended use. Only 18% of forestry LSLAs, 33% of perennial cash crops LSLAs, and 55% of annual cash crops LSLAs were in use. The total area of undeveloped LSLAs is 1.15 Mha.

3.2. Cambodian land systems from 2015 to 2040 under different LSLA policies

Fig. 2 shows the evolution of LSLA productive use in the three scenarios, and Fig. 3 shows the scenario results for the year 2040.

In the Hands-off scenario, the total area of LSLA rises from 1.95 Mha to 3.03 Mha by 2040. 2.06 Mha (68%) of these LSLA areas are converted to plantations. The fraction of LSLAs converted to plantations rises over time as a consequence of the parameterization assumptions: the yearly area of new LSLAs is lower than the area required to meet yearly commodity demands. The LSLA areas present in 2015 are fully preserved, because there is no mechanism to cancel LSLAs. 0.83 Mha, or 43% of the unconverted LSLA areas in 2015 are never converted,

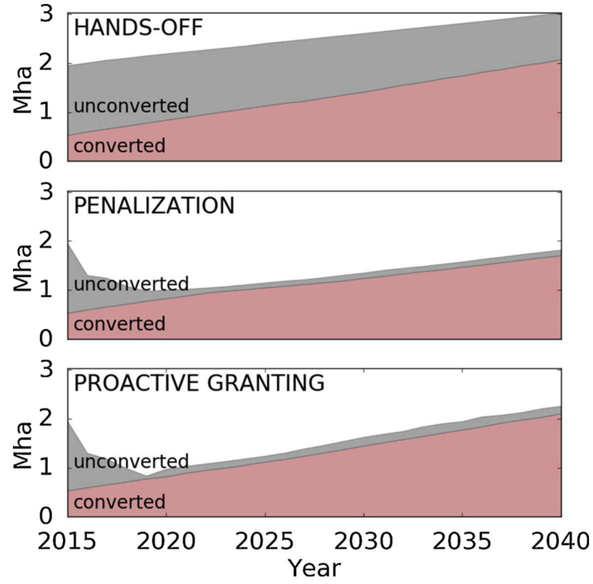

Fig. 2. Evolution of vacant and used economic land concessions.

because these areas are not very suitable for the growth of any of the commodity types. Furthermore, new LSLAs are allocated mostly in lowland forests, such as the Prey Lang National Park, which is almost completely converted to perennial LSLA, and large parts of the Easter Plains.

In the Penalization scenario, the total area of LSLA decreases to 1.8 Mha in 2040. Fig. 2 shows that the area of LSLA decreases sharply until 2022, when the area of unconverted LSLAs stabilizes at about 0.1 Mha (6%), while the area of converted LSLA increases steadily. The policies simulated in this scenario manage to remove surplus LSLA areas that are not suitable for plantation use. However, because of the assumed feedback on the commodity demands, the total area of converted LSLAs is lower than in the other two scenarios (1.7 Mha in this scenario versus 2.1 Mha in the other two scenarios). As in the Hands-off scenario, large parts of protected areas are lost to LSLA.

In the Proactive Granting scenario, the total area of LSLA increases slightly, to 2.3 Mha, of which 0.16 Mha (7%) is unconverted. Because the area of granted LSLAs is parameterized to match closely the area needed for the production of demanded commodities, the converted LSLA area is higher in this scenario as compared to the Penalization scenario. The same quantities of commodities are produced as in the Hands-off scenario, but the amount of unconverted LSLA is significantly lower. The results further show that commodity demands can be met while protecting 34% of the Cambodian territory. In the other two scenarios, LSLA encroachment into protected areas leads to the conversion of Prey Lang Forest, as well as large areas of the Eastern Plains, into plantations (see Fig. 3). The assumed effective nature protection in this scenario moves plantation development outside of protected areas.

3.3. Scenario impact assessment

3.3.1. Impact on tree cover

Table 3 shows the impacts in terms of tree cover. We present tree cover in three categories: (1) tree cover in LSLA systems, (2) tree cover in natural systems (deciduous and evergreen forest systems), and (3) tree cover in all other systems. The highest area of total tree cover is achieved under Penalization scenario (7.6 Mha), 0.4 Mha more than under the Hands-off scenario. The fraction within natural land systems differs more starkly. In the Proactive Granting scenario, 20% more tree cover resides within natural systems as compared to the Hands-off scenario, and this difference increases to 26% under the Penalization scenario. Tree cover within LSLA systems is minimal under the Penalization scenario, where 50% less tree cover is in LSLA systems as compared to the Hands-off scenario.

3.3.2. Impact on core natural areas and tiger reintroduction potential

The three policies impact the core natural areas and the ensuing potential for a tiger reintroduction differently (Tables 4, 5). The Hands-off scenario results in a 19% loss of total natural area, and a 46% loss of core natural areas. The decline in average and median core patch size indicate that this scenario results in reduced extent and integrity of natural areas. The Penalization scenario results in the highest total natural area, but 74% of this natural area is situated at edges and 35% of core natural areas is lost. The Proactive Granting scenario limit core natural area loss to 19%, and average and medium patch sizes increase due to the loss of smaller, unprotected patches, leaving a smaller number of large core areas.

In 2015, there was sufficient core natural area for 956 tigers, spread over four potential areas. The Eastern Plains deciduous forest, which has been identified as the main candidate for tiger reintroduction (Launay et al., 2012), is the landscape with the highest tiger carrying capacity, supporting up to 481 tigers.

Our simulation results show that, while the total core natural area faces significant drops, the size of individual patches of core area declines even more rapidly, making many too small to be viable tiger landscapes (Fig. 3; Table 5). In all scenarios, a few core natural areas remain able to support a tiger population. However, all scenarios have less suitable tiger habitat conditions then what is found in the year 2015, as a result of a net loss in natural land systems. The potential for reintroduction in the Eastern Plains disappears in the Hands-off scenario and significantly shrinks in the Penalization scenario, due to strong fragmentation (Fig. 3).

4. Discussion

4.1. Cambodian land systems in 2015

We present the first rigorous national-scale effort to estimate LSLA productive use. In 2015, 68% of mapped LSLAs are not used productively. Üllenberg (2009) reports 90% non-use in Cambodian land concessions in 2009, but no clarity is given on how this number was calculated. This underuse of LSLAs represents a major problem for Cambodian land governance. If the previous land users were small farmers it may mean that these farmers were evicted or live in a precarious land tenure situation. In other cases, LSLAs claim forested areas, which has been proven to form a high risk of deforestation even if they are not used productively (Davis et al., 2015). In 2015, 0.9 Mha of forest systems, 12% of all Cambodian forests, are therefore at higher risk of loss. Non-use is particularly problematic as it defeats the purpose of the Economic Land System policy, i.e. *"to use land more optimally"* (Oldenburg and Neef, 2014). If Cambodia anticipated positive economic effects to accrue from these investments, underuse may significantly scale back the expected benefits. The underuse problem is currently being addressed following the issuance of Order 01 in 2012, which, among others, aims to seize undeveloped parts of ELCs (Grimsditch and Schoenberger, 2015).

4.2. Scenarios of large-scale land governance

Our objective was to assess the potential conflict between Cambodian LSLA policies and its nature conservation ambitions, thereby confronting two disparate large-scale land claims. The policy options embedded in the presented scenarios do not constitute an exhaustive list of all policy interventions. Their storylines are designed to be contrasting in terms of policy approaches, thereby demarcating the option space for countries aiming to govern existing LSLAs and allocate new LSLAs. Each scenario is associated with several governance issues, which we briefly discuss here.

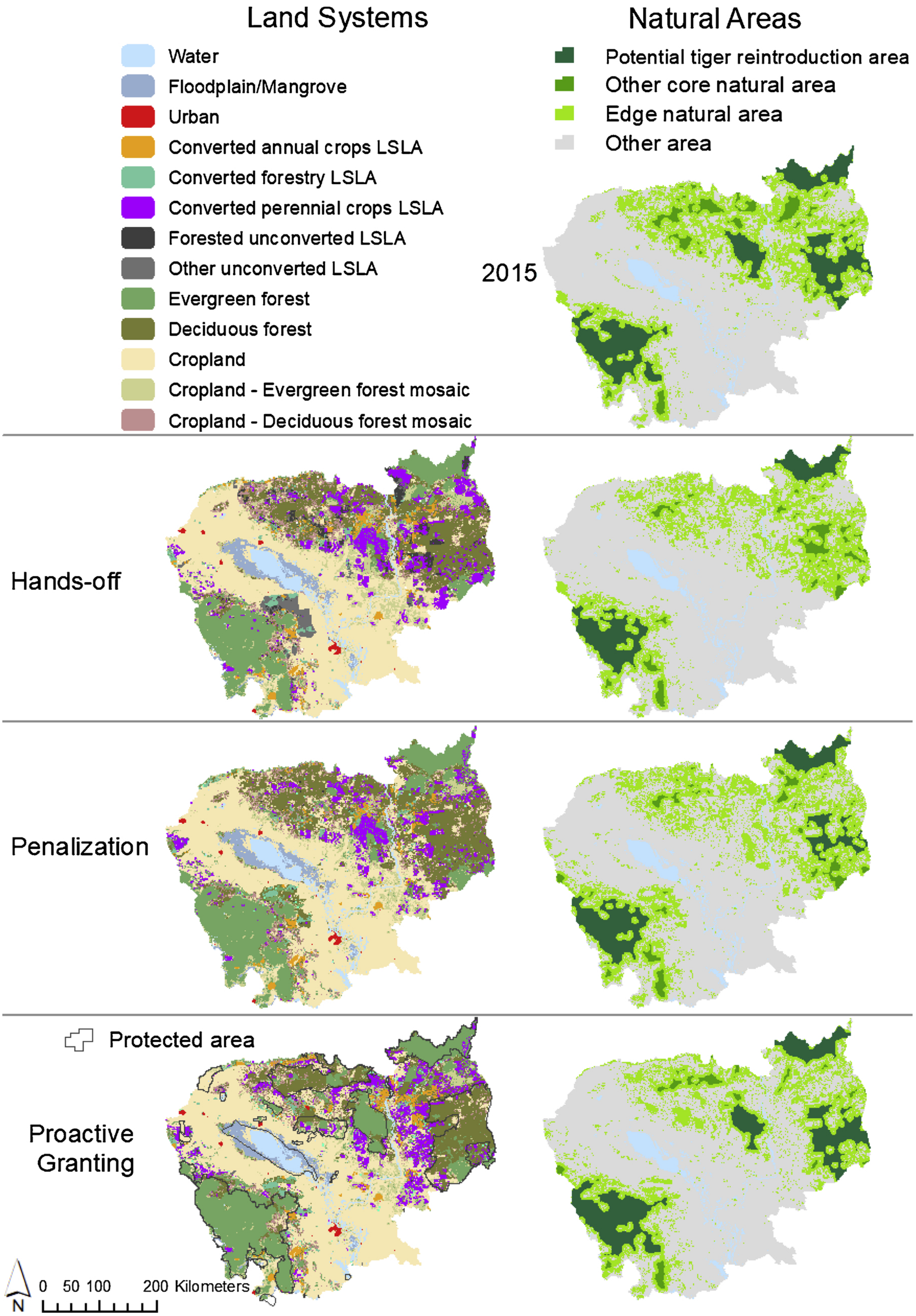

Fig. 3. (left) Land system projections for 2040 in three scenarios. In the Proactive Granting scenario, the mapped protected areas are effective. (right) Impact on natural areas and tiger reintroduction candidate areas.

Table 3
Tree cover (Mha) in 2015 and 2040 under three simulation scenarios broken down into three categories: (1) LSLA land systems, (2) natural land systems, which is evergreen and deciduous forest systems, and (3) all other land systems.

Situation / scenarios	Tree cover area included in different land systems			
	Natural systems (Mha)	LSLA systems (Mha)	Other systems (Mha)	Total (Mha)
2015	5.6	1.0	1.2	7.8
2040 - Hands-off	4.6	1.2	1.4	7.2
2040 - Penalization	5.8	0.6	1.2	7.6
2040 - Proactive Granting	5.5	0.8	1.1	7.4

Table 4
Core, edge and total natural (evergreen and deciduous forest systems) area (Mha).

Situation / scenario	Core (Mha)	Edge (Mha)	Natural area		
			Average core patch size (ha)	Median core patch size (ha)	Total (Mha)
2015	2.6	4.4	49394	1583	7.0
2040 - Hands-off	1.4	4.3	28513	980	5.7
2040 - Penalization	1.7	4.9	37375	1526	6.6
2040 - Proactive Granting	2.1	4.3	78542	4522	6.4

Table 5
Tiger carrying capacity in potential tiger landscapes in 2015 and in 2040 under three alternative scenarios. Location of natural areas are given in Fig. 1.

Situation / scenarios	Tiger carrying capacity in core natural areas				
	Cardamom Forest	Prey Lang	Virachey Forest	Eastern Plains	Total
2015	265	95	115	481	956
2040 – Hands-off	203	0	107	0	310
2040 - Penalization	225	0	111	250	586
2040 - Proactive Granting	287	68	106	459	920

The policy option to neither penalize nor prevent LSLA underuse, captured in the Hands-off scenario, has been prevalent in many countries because it benefits elites and requires little state capacity. In a penalty-free playing field, land acquirers are inclined to clear-cut acquired land for valuable timber, or simply leave land vacant for its speculative future value (Grimsditch and Schoenberger, 2015). This often means that land acquirers can profit without investing in cultivation. However, a noninterventionist governance style may be hard to sustain as popular protest organizes and international pressure mounts. This is why many countries have had to curb the freedom with which LSLAs operate (Hall et al., 2015).

The Penalization scenario contains mechanisms to void contracts for the LSLA areas that have not been converted to productive use. This is indeed a policy on paper in many countries, including Cambodia since 2012 (Oldenburg and Neef, 2014). However, considerable difficulties can arise in the implementation of such a policy. Sunken costs and transaction costs are often too high. The state and judicial capacity to administer and judge disownments is frequently not in place (Deininger and Byerlee, 2012; Burnod et al., 2013). In Cambodia, as in many LSLA-targeted countries, domestic elites with a vested interest in maintaining a noninterventionist approach make a full-fledged interventionist LSLA governance unlikely (Beban and Gorman, 2015). Still, public protest, combined with oftentimes disappointing gains in e.g. employment and tax revenue from underused LSLAs can garner support for intervention and disownment on a case by case basis, as exemplified by Schoenberger (2017).

The Proactive Granting scenario assumes that there is foreknowledge about future commodity demands. The implementation of Proactive Granting takes the form of sincere vetting of business plans prior to the allocation of land. Theoretically, Cambodia grants LSLAs using competitive solicited proposals which should guarantee that land is granted to the most capable investor. However, in reality this regulation may never have been applied (Oldenburg and Neef, 2014). Proactive Granting requires skilled state capacity, not hampered by conflicts of interest. Even if such capacity exists, the volatility of commodity markets will create uncertainties for the aspiring land owner as well as for the granting agency. The limitation imposed in the model, stating that only highly suitable land should be granted, will require agro-ecological knowledge. Furthermore, while our model assumes perfect protection of protected areas, the level of protection may range from 'paper park' to strict no-go zones (Ferraro et al., 2013). However, because of the rather low number of LSLAs, a ban of LSLAs in protected areas is likely relatively feasible by coordinating between responsible agencies. This step has been taken by the Cambodian government, as the Ministry of the Environment was ordered to cease granting LSLAs and is now coordinating with the Ministry of Agriculture to align their land policies (Souter et al., 2016).

In all scenarios, it is assumed that LSLAs will be present in the future, and new LSLAs will be granted (this is our point of departure). Scenario model results for Laos suggest that, if smallholders sufficiently diversify towards export commodity production, the country can meet both domestic and world market demands, making LSLAs superfluous (Debonne et al., 2018). This result is corroborated by historical analyses for Southeast Asia that situate LSLA as a trend-breaking phenomenon in a region characterized by a transition from plantations to smallholder systems since the end of the colonial times (Byerlee, 2014; Bissonnette and De Koninck, 2017). Furthermore, the Penalization and Proactive Granting scenarios have redistributive mechanisms, as unconverted LSLAs are assumed to be reclaimed by either smallholder or natural land systems. However, LSLAs that have been converted to their intended use as a plantation are not assumed to be returned to smallholders or natural areas. Cancelling and redistributing all LSLAs is an interesting though experiment, but falls beyond our scope for a model-based approach.

4.3. Impacts of LSLA policy scenarios

4.3.1. Impacts on LSLA underuse

Scenario results suggest that, if not penalized or prevented, LSLAs will be left underused. The majority of unconverted land in the Hands-off scenario (87%) has been unconverted since the beginning of the simulation in 2015. This is because of the relatively low suitability of these lands for any plantation agriculture, and in retrospect these areas should likely never have been granted. Penalization measures, to some extent active under Order 01 since 2014 (Grimsditch and Schoenberger, 2015), manage to minimize LSLA underuse until 2040 in our scenarios. However, while penalization of existing, unconverted LSLAs may return land to the land market, avoiding underuse altogether is preferable as this can abate negative impacts of LSLAs. The Proactive Granting scenario shows that when LSLAs are only granted if there is demand for the commodities they intent to produce, underuse can be avoided. By granting smaller LSLAs with higher minimum requirements in terms of suitability, non-use is further avoided.

4.3.2. Impacts on tree cover

The impacts on tree cover indicate that Penalization measures perform best to limit tree cover loss, saving 0.4 Mha more tree area then under Hands-off policies. This is partly because, in this scenario, commodity demands are lowered in response to LSLA revocations, ultimately easing the pressure on land in Cambodia. However, because we assume this demand will leak to other countries, these leakage effects may cancel out the tree cover savings in Cambodia (Lambin et al., 2014), making the result uncertain on a larger scale. Overall, tree cover losses remain limited because the yield increases by smallholders instigate a land sparing effect (Phalan et al., 2011). Furthermore, the tree cover loss from natural areas is partly compensated by tree cover gain within agricultural mosaics. However, this assumes that these mosaics are appropriately managed. Importantly, the Hands-off scenario not only results in the lowest tree cover, but the share of tree cover residing in (unconverted) LSLA land systems is highest in both absolute and relative terms. Davis et al. (2015) have found that Cambodian LSLA areas are characterized by accelerated deforestation, making our estimates of tree cover optimistic.

The preservation of tree cover is important for global climate change mitigation (Schlamadinger et al., 2007). At the regional level, the loss of tree cover can severely alter weather patterns. In Southeast Asia, rapid deforestation has been found to lead to declines in precipitation and a significant rise in average and maximum temperature (Tölle et al., 2017). These regional climate changes can have repercussions on the agricultural potential of the region in the near future.

4.3.3. *Impacts on natural areas and tiger reintroduction potential*

Changes in natural areas differs more strongly between scenarios. While a Penalization scenario results in more natural areas, these areas are more fragmented compared to Proactive Granting. This indicates that, while the penalization measures are able to maximize natural areas, the integrity of natural areas can only be preserved by effective protection measures. We found that, currently, a tiger reintroduction is feasible in terms of habitat, as has also been found by Gray et al. (2017). In addition, while all scenarios yield a possibility to accommodate tigers in 2040, the number of tigers that can be sustained in core natural areas ranges from 310 in the Hands-off scenario to 920 in the Proactive Granting scenario. Hence LSLA policies considerably affect the potential size of the tiger population and the chance of a successful reintroduction. This assessment of reintroduction potential is modest by design, and only evaluates habitat size and integrity. The Virachey, Eastern Plains, and Cardamom natural areas extend across the border, and therefore may host more tigers than estimated here. Oppositely, because we only mapped known LSLAs and did not include plantations outside of official LSLA areas, the tiger estimates may be too high. These biases are consistent across scenarios, making comparisons between scenarios valid. More detailed assessment frameworks, relying on landscape genetics (Thatte et al., 2018) or population viability analysis (Tian et al., 2011), can serve to fine-tune this assessment.

4.3.4. *Impacts on local livelihoods*

Lastly, while we did not assess livelihood impacts of our scenarios, we note that such impacts exist and are significant (Dell’Angelo et al., 2017b). Cambodian LSLAs have been associated with brutal evictions (Schoenberger, 2017). Furthermore, LSLA can intensify competition over land resources and instigate loss of commonly used land is (Friis et al., 2016; Dell’Angelo et al., 2017a). Such consequences might be more dire under the Proactive Granting scenario, because LSLAs move outside of protected areas and into smallholder agricultural areas. This is another leakage effect (Meyfroidt and Lambin, 2009) that intensifies competition between smallholder and LSLA systems. Whether and to what extent such competition leads to dispossession and other undesirable social effects is dependent on a large number of factors and processes in the livelihood context of the target population (Oberlack et al., 2016). Because of the range of potential livelihood consequences, as well as the myriad of contextual factors that moderate the relation between our land use scenarios and their socioeconomic impacts (Messerli et al., 2015), these could not be quantified with sufficient certainty. Therefore, we focused our analyses on the landscape impacts only while acknowledging the importance of establishing further insight in the livelihood impacts.

4.4. *Implications for land use policies*

The connection made here between two largely disparate areas of governance (forest and wildlife conservation versus LSLA) showcases that integrated land management is needed to reconcile multiple large-scale claims on land. The goal to reintroduce tigers in Cambodia is jeopardized by LSLA development. While the reintroduction plan is specifically aimed at the Eastern Plains deciduous forests, there are three other viable candidate areas (Cardamom forest, Prey Lang Wildlife Sanctuary, and Virachey National Park). In the absence of protection measures, our scenarios show that Prey Lang is almost fully converted to plantations, and the Eastern Plains deciduous forests fragments to the point that the sustenance of a tiger population is unlikely. The Cardamom forest and Virachey National Park show a remarkable stability in the absence of protection, because these areas are not very suitable for commodity production. This in turn is caused by their poor accessibility, rough terrain and/or poor soil drainage. For protecting the other areas the current capacity of responsible agencies to enforce protection has been too low to be effective in the past, and the additional funding that is necessary for capacity building is not on the agenda (Souter et al., 2016). This leads to two options: (budget for) protection capacity could be significantly increased, as is also suggested by Launay et al. (2012). Alternatively, the Cardamom Forest and Virachey National Park could be the target areas for reintroduction of tigers instead of the Eastern Plains. These areas are less suitable for reintroduction at face value, because they consist of evergreen tropical forests which have a lower tiger carrying capacity. However, as a consequence of their agricultural unsuitability, they are more stable reintroduction zones in the longer term.

Habitat availability is only one factor contributing to the potential for tiger reintroduction. A sufficiently large habitat will still require enough prey animals, and will have to be protected from poaching and other threats (Gray et al., 2017). These factors are not included in our assessment, making the reported tiger carrying capacities theoretical upper limits. Our assumption that only core natural areas are suitable habitat may be contested by reports that tigers are observed to roam in sparsely populated areas (Thatte et al., 2018). However, human-tiger conflict is likely in Cambodia (Gray et al., 2017), making the restriction to core areas necessary for social acceptability.

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Appendix A. Supplementary data

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