

Accelerated deforestation driven by large-scale land acquisitions in Cambodia

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Investment in agricultural land in the developing world has rapidly increased in the past two decades^{1–3}. In Cambodia, there has been a surge in economic land concessions, in which long-term leases are provided to foreign and domestic investors for economic development. More than two million hectares⁴ have been leased so far, sparking debate over the consequences for local communities and the environment⁵. Here we combined official records of concession locations^{4,6} with a high-resolution data set of changes in forest cover⁷ to quantify the contribution of land concessions to deforestation between 2000 and 2012. We used covariate matching to control for variables other than classification as a concession that may influence forest loss. Nearly half of the area where concessions were granted between 2000 and 2012 was forested in 2000; this area then represented 12.4% of forest land cover in Cambodia. Within concessions, the annual rate of forest loss was between 29% and 105% higher than in comparable land areas outside concessions. Most of the deforestation within concessions occurred after the contract date, and whether an investor was domestic or foreign had no effect on deforestation rates. We conclude that land acquisitions can act as powerful drivers of deforestation.

Large-scale land acquisitions have been at the centre of a debate between those who primarily see development opportunities in them and those concerned about the rights and livelihoods of local communities^{8,9}. Although promising an influx of technology and rural and economic development, land deals are often characterized by a lack of transparency and little or no involvement of previous land users^{2,10}. With only 13% of globally contracted area reportedly being put to productive use¹¹, many land acquisitions also seem to be speculative³, and, in a number of cases, have reportedly led to evictions, violations of human rights and the loss of livelihoods^{5,12}. In addition to the frequent economic and social impacts of land deals on local communities, there are concerns that the exclusion of previous land users can also represent a loss of environmental stewardship¹⁰. Proponents of these land deals in turn argue that these lands are 'empty', 'marginal', 'virgin' or 'degraded', and can therefore be put to productive use without affecting the livelihoods of local communities^{1,2,13}. Although knowledge of previous land use remains largely incomplete, the leasing of 'empty' lands raises another set of concerns on land-use change, deforestation and the associated environmental impacts^{13–15}.

As with potential impacts on previous land users, assertions about the environmental consequences of land acquisitions are often difficult to verify. Quantitative assessments of the previous land use (that is, cropland, forests, rangeland) and of the changes in land

cover are still missing^{16,17}. To that end, we focus on the case of Cambodia, where lands acquired by foreign and domestic investors at present total 2.05 million hectares⁴ (ha)—equivalent to 36% of the country's agricultural land¹⁸—and for which official government records of economic land concessions (ELCs) and their associated geographic locations exist^{4,6}. By combining this information with remotely sensed data on forest cover⁷, we determine the initial extent of forests in acquired lands for the year 2000 and analyse to what extent this forested area has changed annually through to 2012. Because deforestation does not occur randomly across a landscape, we also employ a covariate matching approach to control for characteristics that may make an area more likely to undergo forest loss (for example, distance from roads and cities). In doing so, we relate land acquisitions to deforestation and land-use change and investigate whether such land deals enhance deforestation and habitat loss. Our analysis provides much needed quantitative evidence for the environmental effects of land deals and highlights how spatial data on large-scale land acquisitions can be profoundly useful in informing future concessions and land tenure policies¹⁵.

Considerable deforestation has occurred across Cambodia since the start of the century, a disproportionate amount of which has taken place within ELCs (Fig. 1a). Although 12.4% of Cambodia's forests were contained in ELCs in 2000, 19.8% (or 0.26 Mha) of the country's forest loss through 2012 has been within these land concessions (Supplementary Table 1). In addition, the contribution of these acquired lands to Cambodia's annual forest loss rose from 12.1% in 2001 to 27.0% in 2012. However, although these differences seem stark (Fig. 1b), they do not directly address whether forested ELC areas are in fact more likely than non-ELC areas to experience forest loss, because deforestation is not a random process. Using a covariate matching approach, we controlled for characteristics that influence deforestation (see Supplementary Methods). Our analysis showed that although ELCs and non-ELC areas both experienced increases in the relative rate of deforestation from the initial $\sim 0.5\% \text{ yr}^{-1}$, forest removal was particularly aggressive within land concessions. As a result, the rate of forest loss on acquired lands increased to 4.3–5.2% yr^{-1} by the end of the study period (2010–2012 mean), 29–105% greater than that for matched non-ELC areas (Supplementary Table 2). Regardless of selection criteria—reporting of ELC contract date, distance from protected area, distance from ELC boundary (for non-ELC plots)—ELC areas consistently exhibited higher deforestation rates (Fig. 1c). These results were overall insensitive to hidden bias (see Supplementary Tables 15–18). Areas more distant ($>2 \text{ km}$) from ELCs with earlier contract dates (2001–2006) were slightly less likely to undergo deforestation (Fig. 1a,d); this suggests 'spillage'

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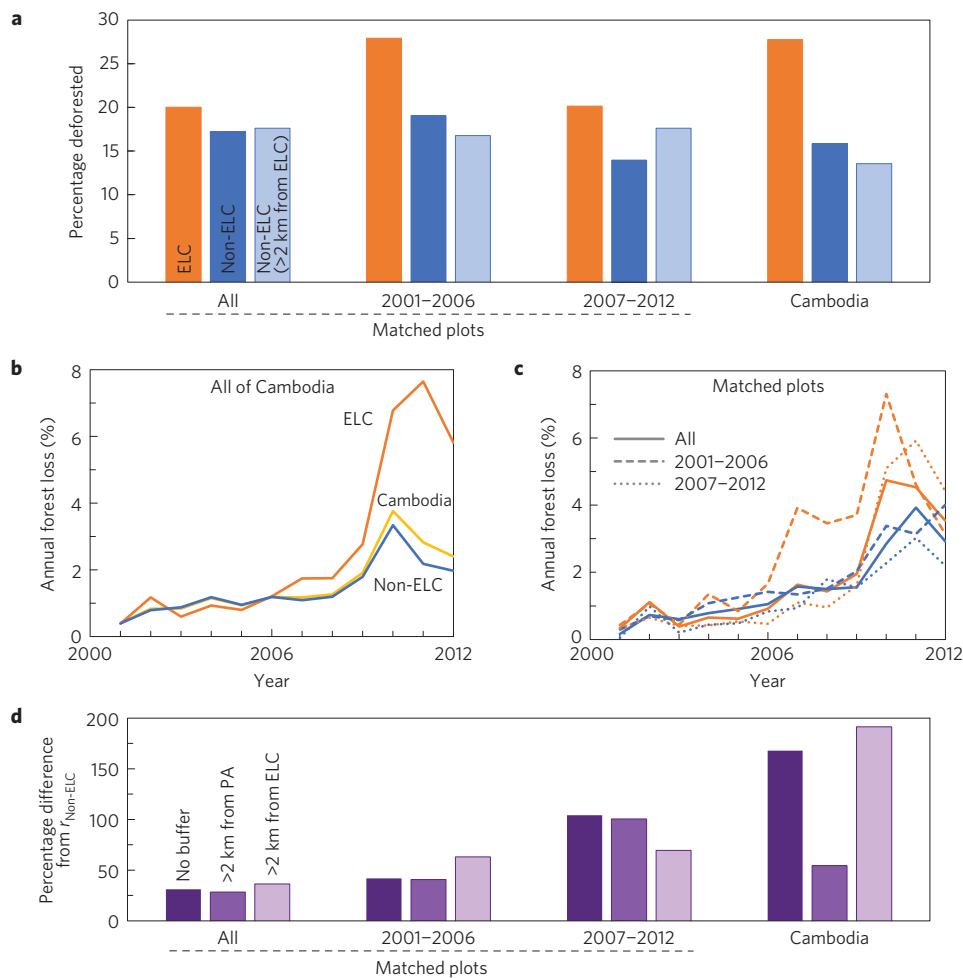


Figure 1 | Deforestation in Cambodia. **a**, Deforestation for matched plots and all of Cambodia. 'All'—all matched plots; '2001–2006' and '2007–2012'—only matched plots with an ELC contract date within specified years; 'Non-ELC (>2 km from ELC)'—excludes non-ELC plots within 2 km of ELC. **b,c**, Annual deforestation rates for Cambodia and for matched plots. **d**, Percentage difference between 2010 and 2012 average deforestation rates of ELC and non-ELC areas, calculated as $100(r_{\text{ELC}} - r_{\text{NonELC}})/r_{\text{NonELC}}$ (Supplementary Table 2). '>2 km from PA'—excludes plots within 2 km of protected area. '>2 km from ELC'—excludes non-ELC plots within 2 km of ELC.

in the areas immediately surrounding these ELCs, possibly as a result of investing companies exceeding their contract areas, from illegal logging and/or from the displacement of local communities to surrounding areas. The opposite was observed for the non-ELC areas matched with more recent (2007–2012) concessions, where more distant areas were more susceptible to forest loss and more proximal areas perhaps experienced an unintended protective effect.

Abrupt land-use change in ELCs is apparent when comparing the pattern of forest loss in acquired lands with that in other areas (Fig. 2). As opposed to the less targeted encroachment on forests generally observed throughout the country, large areas of forest within a number of ELCs were removed in a single year to make way for tree plantations and other crops. This clustered patterning of forest loss in ELCs probably explains why our random sampling underestimates the deforestation rate on ELCs (Fig. 1b,c). On average, 63% of cumulative forest loss on acquired lands has occurred after the date of the land deal contract (Supplementary Fig. 1). We found this post-contract increase in forest loss to be consistent regardless of investor origin (that is, foreign or domestic) and intended use. One requirement of any company that is granted an ELC contract is that it provide the State Land Management Committee with a detailed land-use plan for the entirety of the contract, a condition intended to prevent irresponsible land use and speculative investments. However, many investors granted

ELCs have not adhered to these land-use plans, and only recently has the Cambodian Ministry of Agriculture, Forest and Fisheries begun reviewing and cancelling contracts that are inactive or improperly used¹⁹. Combined with this general lack of monitoring and enforcement, our findings show that little lag typically exists between when an ELC contract is signed and when investors begin to modify the land for productive use. As a result, a large portion of forest (0.67 Mha remaining within ELCs) is now at a heightened risk of removal (Supplementary Table 1).

The recent surge in land concessions and the deforestation that has followed provide strong indications that shorter-term economic goals are trumping long-term sustainability and that serious environmental consequences are already occurring. With 28% of forests within ELCs removed since the start of the century, the rapid deforestation and conversion to commercial agriculture can produce various environmental impacts, including enhanced carbon emissions, biodiversity loss, soil erosion and nutrient runoff^{20–22}. In addition to the immediate effects of these land-use changes, the vast majority of ELCs considered in this study have a contract length of 70 years, and thus will continue to exert significant influence on land use and land-use change in Cambodia for most of this century. Furthermore, the potential for many of these environmental impacts to occur is made all the more likely given that many ELCs are intended for the production

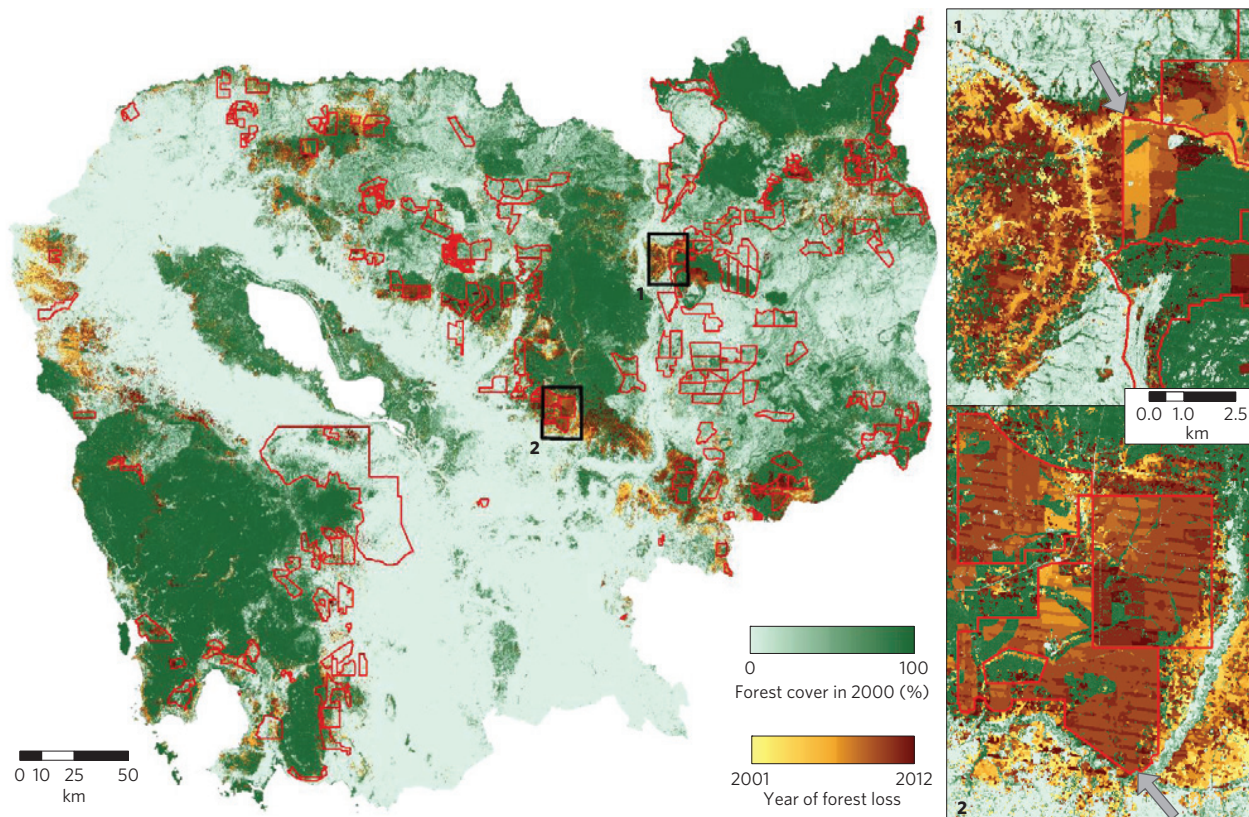


Figure 2 | Map of forest cover, forest loss and confirmed ELCs in Cambodia. The boxed areas in the main map are shown expanded in the corresponding local maps to the right. For the ELCs indicated by arrows, the establishment of tree plantations is also shown in Supplementary Figs 2 and 3. The ELC map is licensed under the Creative Commons Attribution-ShareAlike 3.0 Unported License.

and export of agricultural goods (86 of 191 deals for rubber alone). Foreign consumers of these export-oriented crops may unconsciously place a lower value on minimizing their impacts as they do not directly observe the environmental consequences of their choices^{10,23,24}.

Equivalent to a third of Cambodia's agricultural land, ELCs may also have important implications for domestic food security and the livelihoods of rural people^{10,25,26}—especially when the crops from these lands are mainly agroindustrial and intended for export¹³. With nearly half of the acquired areas initially forested in 2000 (Supplementary Table 1), what is apparent from the work here is that the areas targeted by ELCs were not entirely under crop cultivation before they were acquired and are continually undergoing rapid land-cover changes. Beyond this knowledge of forest location, information on the distribution of previous land use remains incomplete, although anecdotal evidence suggests that many areas were communally held (as farms, forest or conservation land) and that the livelihoods of many villagers are dependent on forests^{5,13}. Recent village census data^{4,27} (from the Cambodian Ministry of Planning) show that 277 villages—home to 213,000 people—fall within ELC boundaries. Further, despite a number of legal protections for indigenous people in Cambodia, by 2012 nearly 100 ELCs had been granted at least partially on indigenous lands²⁸. Dispossession, evictions and conflict have been reported impacts of ELCs on local communities^{13,19,29}. Whereas benefits from ELCs (for example, job creation, improved infrastructure) have been described¹⁹, quantitative studies examining the economic and social benefits and impacts of ELCs are still lacking. Systematic mapping, classification and registration of state public and private land in Cambodia have only partially taken place, and land-use plans have not been adopted by provincial or municipal land management committees¹⁹. These lines of evidence are representative of the recent situation in Cambodia, where a legal

framework for protecting local communities is well established but proper implementation and monitoring has been largely absent as a result of weak local and national governance bodies. That these institutions have been unable to ensure investors' adherence to ELC land-use plans has ultimately meant that many stakeholders are excluded from the potential benefits of ELCs. Efforts to address these issues include examples such as the adoption of Free, Prior, and Informed Consent as an operating principle and the requirement for sustainable palm oil certification by the Roundtable on Sustainable Palm Oil, a non-governmental certification body that includes industry members³⁰. In addition, a recent moratorium on ELCs as well as a new land titling initiative could clarify land ownership and associated benefits to the rural poor, distributing more than 200,000 land titles to households within the first year of the programme¹⁹. However, the enduring effectiveness of these actions remains to be seen.

The phenomenon of land acquisitions is especially fast-moving in Cambodia, where in just a few years a large area can go from a mixture of forests and smallholder farms to industrial plantation-style monocultures. Such rapid transitions in land use are also possible in other targeted countries where acquired land—much of which is not yet under production¹¹—can be quickly put to productive use. In these places there is urgent need for swift evidence-based action that better involves all stakeholders and integrates sustainability, so that the potential benefits of acquisitions might be enhanced and their human and environmental impacts minimized. However, these decisions are possible only if government agencies responsible for land tenure records make a concerted effort to improve access to the geographic coordinates of land deals. More open sharing of such information represents an important step towards improving the transparency of land acquisitions and—as evidenced by this study—will allow governments and

the international community to better assess the environmental impacts of the global land rush so far and to advance the related policy debate.

Methods

Methods and any associated references are available in the [online version of the paper](#).

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References

- Cotula, L., Vermeulen, S., Leonard, R. & Keeley, J. *Land Grab or Development Opportunity? Agricultural Investment and International Land Transactions in Africa* (IIED/FAO/IFAD, 2009).
- Deininger, K. & Byerlee, D. *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* (World Bank, 2011).
- Kugelman, M. & Levenstein, S. *Global Farms Race: Land Grabs, Agricultural Investment, and the Scramble for Food Security* (Island Press, 2012).
- ELC Government Data (Open Development Cambodia, 2014); http://www.opendevdevelopmentcambodia.net/download/maps/elc_government_data_complete.zip
- Montemayor, R. Q. in *Global Farms Race: Land Grabs, Agricultural Investment, and the Scramble for Food Security* (eds Kugelman, M. & Levenstein, S.) 135–152 (Island Press, 2012).
- Economic Land Concession* (Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, 2014); <http://www.elc.maff.gov.kh>
- Hansen, M. C. *et al.* High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–853 (2013).
- De Schutter, O. How not to think of land-grabbing: Three critiques of large-scale investments in farmland. *J. Peasant Stud.* **38**, 249–279 (2011).
- Cleveland, D. A. *Balancing on a Planet: The Future of Food and Agriculture* (Univ. California Press, 2014).
- D'Odorico, P. & Rulli, M. C. The land and its people. *Nature Geosci.* **7**, 324–325 (2012).
- Land Matrix Global Observatory *The Land Matrix Database* (ILC/CIRAD/CDE/GIGA/GIZ, 2015); <http://landportal.info/landmatrix>
- Golay, C. & Biglino, I. Human rights responses to land grabbing: A right to food perspective. *Third World Q.* **34**, 1630–1650 (2013).
- Neef, A., Touch, S. & Chiengthong, J. The politics and ethics of land concessions in rural Cambodia. *J. Agric. Environ. Ethics* **26**, 1085–1103 (2013).
- Borras, S. M. Jr & Franco, J. C. Global land grabbing and trajectories of agrarian change: A preliminary analysis. *J. Agrar. Change* **12**, 34–59 (2012).
- Messerli, P., Giger, M., Dwyer, M. B., Breu, T. & Eckert, S. The geography of large-scale land acquisitions: Analysing socio-ecological patterns of target contexts in the global South. *Appl. Geogr.* **53**, 449–459 (2014).
- Cotula, L. The international political economy of the global land rush: A critical appraisal of trends, scale, geography and drivers. *J. Peasant Stud.* **39**, 649–680 (2012).
- Messerli, P., Heinemann, A., Giger, M., Breu, T. & Schönweger, O. From 'land grabbing' to sustainable investments in land: Potential contributions by land change science. *Curr. Opin. Environ. Sustain.* **5**, 528–534 (2013).
- FAOSTAT Database (FAO, 2014); <http://faostat.fao.org>
- Oldenburg, C. & Neef, A. Reversing land grabs or aggravating tenure insecurity? Competing perspectives on economic land concessions and land titling in Cambodia. *Law Dev. Rev.* **7**, 49–77 (2014).
- Pimentel, D. *et al.* Environmental and economic costs of soil erosion and conservation benefits. *Science* **267**, 1117–1123 (1995).
- Brook, B. W., Sodhi, N. S. & Ng, P. K. L. Catastrophic extinctions follow deforestation in Singapore. *Nature* **424**, 420–426 (2003).
- Fargione, J., Hill, J., Tilman, D., Polasky, S. & Hawthorne, P. Land clearing and the biofuel carbon debt. *Science* **319**, 1235–1238 (2008).
- Zoomers, A. Globalisation and the foreignisation of space: Seven processes driving the current global land grab. *J. Peasant Stud.* **37**, 429–447 (2010).
- Lambin, E. F. & Meyfroidt, P. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl Acad. Sci. USA* **108**, 3465–3472 (2011).
- Rulli, M. C. & D'Odorico, P. Food appropriation through large scale land acquisitions. *Environ. Res. Lett.* **9**, 064030 (2014).
- Davis, K. F., D'Odorico, P. & Rulli, M. C. Land grabbing: A preliminary quantification of economic impacts on rural livelihoods. *Popul. Environ.* **36**, 180–192 (2014).
- Census 2008: Villages* (Open Development Cambodia, 2014); http://www.opendevdevelopmentcambodia.net/download/maps/census_2008_villages.zip
- United Nations Human Rights Council *A Human Rights Analysis of Economic and Other Land Concessions in Cambodia* (UN, 2012); http://cambodia.ohchr.org/WebDOCS/DocReports/2-Thematic-Reports/SR_report_on_land_concessions_in_Cambodia_Eng.pdf
- Neef, A. Law and development implications of transnational land acquisitions: Introduction. *Law Dev. Rev.* **7**, 187–205 (2014).
- 2014 *Impacts Report* (Roundtable on Sustainable Palm Oil Secretariat, 2014); <http://www.rspo.org/consumers/debate/blog/rspo-impact-report-2014#>

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Author contributions

K.F.D., M.C.R. and P.D'O. conceived the study; K.F.D. and K.Y. collected and analysed the data; K.F.D., K.Y., M.C.R., L.P. and P.D'O. wrote the paper.

Additional information

Supplementary information is available in the [online version of the paper](#). Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to K.F.D.

Competing financial interests

The authors declare no competing financial interests.

Methods

The database on ELCs was produced by Open Development Cambodia⁴. The database used government data provided directly by the Cambodian Ministry of Agriculture, Forestry and Fisheries (MAFF; ref. 6) for information on each deal, including coordinates, area, contract date, investors and intended use. Data on village location and population also came from Open Development Cambodia²⁷ and were originally produced by Cambodia's National Institute of Statistics and Ministry of Planning as a product of the 2008 national census. Data on annual forest loss came from a recent study that used detailed satellite imagery⁷. This data set provides the initial forest cover in the year 2000 (as a percentage of the pixel area) as well as the year in which a pixel (30 m × 30 m) gains or loses forest. For those initially forested pixels that undergo deforestation in a given year, we assume complete forest loss for that pixel in that year and all subsequent years. Forest gain from 2000 to 2012 was not considered in the calculation of deforestation rates because this was not reported on an annual basis. For all of Cambodia, the number of pixels experiencing apparent forest gain during this time was equivalent to 1% of initially forested pixels. Conversely, this value was 14% for ELCs, due in large part to the establishment of tree plantations, as our validation showed.

Validation of forest cover and tree plantations was carried out in two ways. The first approach was done using a new cropland cover map (1 km resolution)³¹—which was the product of fusing numerous published data sets on cropland extent and included oil palm areas as cropland—to evaluate the consistency between reported forest areas⁷ and non-crop areas. We resampled the 30 m forest cover data⁷ to 1 km resolution and classified a pixel as forest when its tree cover exceeded 90%. In 99% of the cases (and in the entire area of ELCs), forested areas coincided with areas with no cropland. As further validation of the forest cover data set, 29 land deals (15% of all ELCs) were randomly selected. Based on the Hansen data set, the average forest area (>30% tree cover) and tree cover of each of these deals was then calculated for the beginning of the year 2013 after accounting for tree loss. Then year 2013 high-resolution satellite images from Google Earth Pro (Imagery 2015 TerraMetrics) were imported to ArcGIS using the Arc2earth software³² for visually delineating areas of tree plantations, which stand as areas subdivided into regular rectangular (or, in general, polygonal) parcels or areas with trees growing in straight rows. These tree plantations were then digitized (for examples, see Supplementary Figs 2C,D) and used to calculate the percentage overlap with forest area after accounting for forest loss between the years 2001 and 2012. For the 29 randomly sampled ELCs, on average only 2.5% of forested areas occurred within tree plantations (Supplementary Table 20). However, in certain individual deals, this percentage was more substantial (in one case >25% of forested area). Some of these 'false positive' areas are probably a result of clearing for tree plantations or other intended crops during the year 2013, and may also have occurred in places where tree plantations were established before the year 2000—the start of the Hansen data set. From this analysis, we have demonstrated that our approach is overall sufficient for a national-scale analysis of deforestation in Cambodia and shown that our estimates of forest loss are conservative. For calculating average percent tree cover, the digitized tree plantations areas were subtracted from the ELC area before again calculating the tree cover. Linear regression analyses were used to compare average percentage tree cover within each randomly selected ELC both before and after accounting for the area of tree plantation ($R^2 = 0.99$). In this way, we were able to confirm that the effects of tree plantations on calculations of natural tree cover was minimal (Supplementary Fig. 3).

A number of factors may also influence the likelihood that an area will be deforested, regardless of whether or not it is located in an ELC. To control for these characteristic covariates, we employed a covariate matching approach similar to a recent study³³ that measured the effectiveness of protected areas in preventing forest loss. The goal of this approach is to establish 'balance', so that the covariate

distributions of ELC and non-ELC pixels are 'very similar'. It is then possible to compare ELC and non-ELC plots to examine the potential effect of land acquisition on deforestation. To this end, we randomly selected 179,347 initially forested pixels (30 m × 30 m)—28,439 of which were located within ELCs. Pixels in protected areas were not considered. For each pixel, we determined covariate information for distance from the nearest road, distance from the nearest waterway, distance from the nearest railway, distance from the nearest urban area (that is, population density greater than 300 people km⁻²), distance from forest edge, slope class, soil suitability and district area (Supplementary Tables 3–14). Distance from the nearest urban area was calculated using a year 2005 population density data set from CIESEN/CIAT (ref. 34). Classes for median terrain slope and agro-ecological suitability for rain-fed high-input oil palm (Supplementary Table 19) were assigned using data from the FAO/IIASA's Global Agro-Ecological Zones³⁵. Matching was performed in R using the 'Matching' package³⁶. We also examined the sensitivity of these results to hidden bias using Rosenbaum's sensitivity test³⁷. Matched ELC and non-ELC plots differ in their likelihood of being deforested by an unknown covariate by a factor of Γ , such that $\Gamma = 1$ means that ELC plots are equally as likely as their matched non-ELC plots to be deforested as a result of hidden bias. The more that gamma can be increased while the result still remains significantly different from zero, the more robust the results are to hidden bias. Results were overall insensitive to hidden bias, although it is important to note that this was not the case in the absence of selection criteria for ELC contract date. In cases where the results are not robust to hidden bias, we note that, although conclusions drawn from those results should be viewed with caution, this sensitivity does not guarantee the actual presence of an unobserved confounder. To determine the potential for leakage (for example, displacement of forest loss into neighbouring forests), we also considered the effect of a 2 km buffer (the same distance used by Andam and colleagues³³) around protected areas and ELCs. In adopting this distance for our analysis, we should note that leakage can occur at various distances and, given the indirect pathways by which it is often driven, can also be difficult to fully quantify. Complete results of matching and sensitivity analyses are presented in Supplementary Tables 2–19. In examining the amount of deforestation that occurred before and after the contract date of a land acquisition, only those deals with contract dates between January 2001 and December 2011 were used. Also, to prevent overestimation of the percentage of deforestation that occurred after the contract date, we assume that any deforestation occurring in the same year of the contract took place before the contract.

References

- Fritz, S. *et al.* Mapping global cropland and field size. *Glob. Change Biol.* **21**, 1980–1992 (2015).
- Arc2Earth software *Google Maps Data in ArcGIS* (Arc2Earth, 2015); <http://www.arc2earth.com>
- Andam, K. S., Ferraro, P. J., Pfaff, A., Sanchez-Azofeifa, G. A. & Robalino, J. A. Measuring the effectiveness of protected area networks in reducing deforestation. *Proc. Natl Acad. Sci. USA* **105**, 16089–16094 (2008).
- Center for International Earth Science Information Network (Columbia University) and Centro Internacional de Agricultura Tropical *Gridded Population of the World, Version 3 (GPW3: Population Density Grid, Future Estimates* (SEDAC, 2005); <http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density-future-estimates>
- Global Agro-ecological Zones (GAEZ)* v3.0 (IIASA/FAO, 2012).
- Sekhon, J. S. Multivariate and propensity score matching software with automated balance optimization: The Matching package for R. *J. Stat. Softw.* **42**, 1–52 (2011).
- Rosenbaum, P. *Observational Studies* (Springer, 2002).