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# High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon

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## Abstract

High-yield agriculture potentially reduces pressure on forests by requiring less land to increase production. Using satellite and field data, we assessed the area deforested by industrial-scale high-yield oil palm expansion in the Peruvian Amazon from 2000 to 2010, finding that 72% of new plantations expanded into forested areas. In a focus area in the Ucayali region, we assessed deforestation for high- and smallholder low-yield oil palm plantations. Low-yield plantations accounted for most expansion overall (80%), but only 30% of their expansion involved forest conversion, contrasting with 75% for high-yield expansion. High-yield expansion minimized the total area required to achieve production but counter-intuitively at higher expense to forests than low-yield plantations. The results show that high-yield agriculture is an important but insufficient strategy to reduce pressure on forests. We suggest that high-yield agriculture can be effective in sparing forests only if coupled with incentives for agricultural expansion into already cleared lands.

**Keywords:** agricultural intensification, yield, land use change, remote sensing, tropical forests, deforestation, conservation, biofuels

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Competition between agricultural expansion and forest conservation for carbon storage, biodiversity, and watershed protection is increasing in the tropics as rising global population and affluence create demands for agricultural

commodities [1–3]. Projections estimate a 14% increase in global agricultural land between 2010 and 2030 [4], potentially representing higher pressure on forests [5]. Increasing yields from already cultivated areas is one

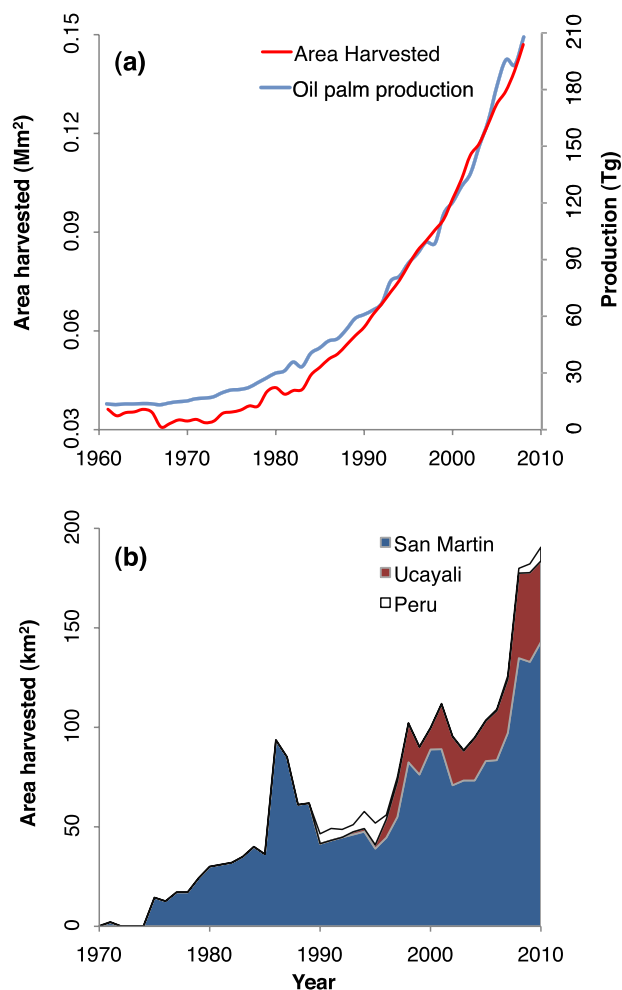
proposed approach to achieve both forest conservation and agricultural production [6–8]. This approach has been questioned because higher yields increase production efficiency and profitability, constituting an incentive to expand into forests [9]. We examine oil palm expansion in the Peruvian Amazon to address a further consideration that assesses whether higher yields in new agricultural lands reduce pressure on forests. We argue that if high- and low-yield agriculture expand in different proportions into forested and already cleared lands, forest loss relative to production can be greater for high-yield agriculture even though less total land is consumed.

Global oil palm production more than doubled between 1999 and 2009, accounting for more than the total increase during the previous 38 years. Despite nearly constant increments in yield, agricultural expansion explains most of the historical increase in oil palm production in the world (figure 1(a)). Most of the global area suitable for oil palm is currently within tropical forests [10]. Oil palm expansion has already led to the conversion of extensive areas of tropical forests, particularly in Southeast Asia [11] and is an emerging peril to the conservation of Amazon forests [12].

Rising global demand for palm oil, along with national political support and economic incentives for oil palm production, constitute increasing threats to forest conservation in countries such as Peru, which still retains a high proportion of forest cover and with low historic deforestation rates [15]. Peru has the second largest forest area suitable for oil palm plantations among Amazonian countries [10]. In addition, the Peruvian government declared oil palm cultivation to be in the national interest and put in place legal incentives for its cultivation [16]. Incentives include tax exemptions for investments in oil palm production in the Amazon and a mandate to mix 5% biodiesel in diesel oil by 2011 [17, 18]. Oil palm in Peru is mostly concentrated in two Amazonian regions where plantations have expanded dramatically in recent years (figure 1(b)).

Two models of oil palm expansion occur in the Peruvian Amazon. The first, defined here as high-yield expansion, is typically operated by private companies. These companies have access to sufficient capital and technology to invest in infrastructure and agricultural inputs and to apply farming techniques aimed towards optimizing yields in relatively large extensions. Low-yield plantations are usually owned by smallholders that operate either individually or as cooperative associations. Owners have restricted access to capital and land that limits expansion and the full application of technology to maximize yields. These constraints translate into smaller plantations with relatively low productivity (table S2 available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

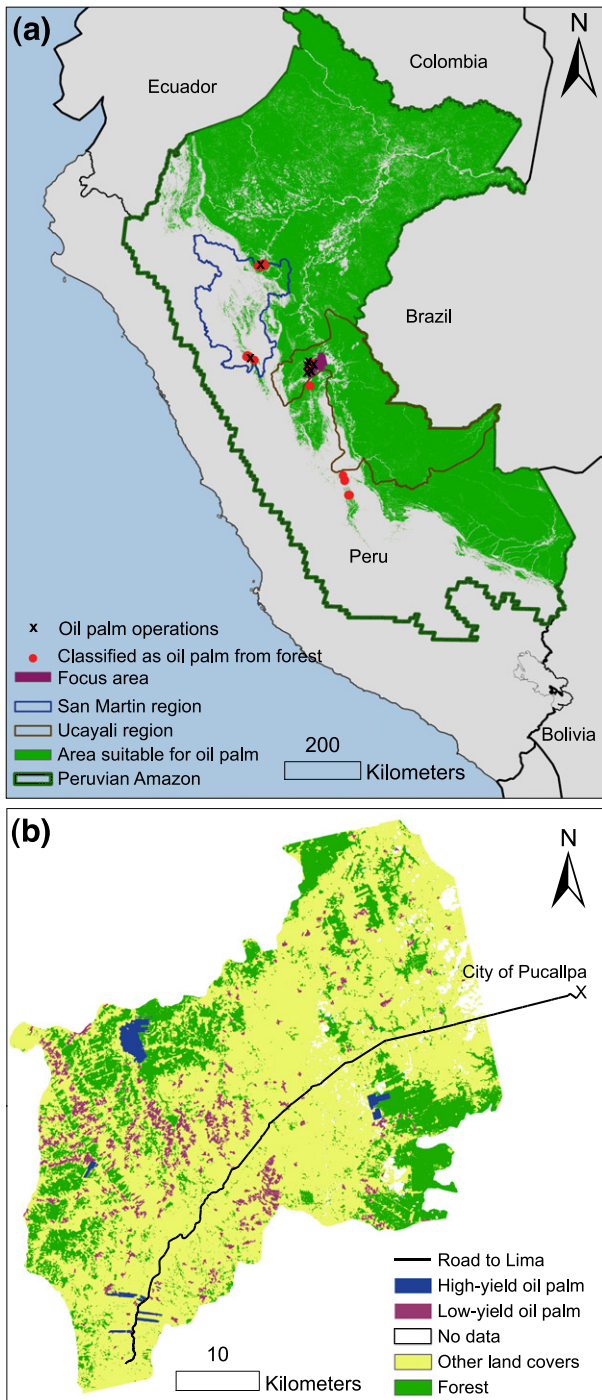
We used remote sensing data and field information to quantify the contribution of oil palm expansion to deforestation from 2000 to 2010 at two scales: the entire Peruvian Amazon (936 240 km<sup>2</sup>) and a smaller focus area (2157 km<sup>2</sup>) located in the Ucayali region, near the city of Pucallpa where both high- and low-yield oil palm plantations are actively expanding. In the Peruvian Amazon, we identified the contribution of industrial-scale high-yield



**Figure 1.** (a) Global increase in oil palm production is closely related to changes in harvested area (data from [13]). (b) Total harvested area in the regions of San Martin and Ucayali has increased considerably in recent years, following global trends. These regions are responsible for 98% of the total harvested area in Peru (data from [14]).

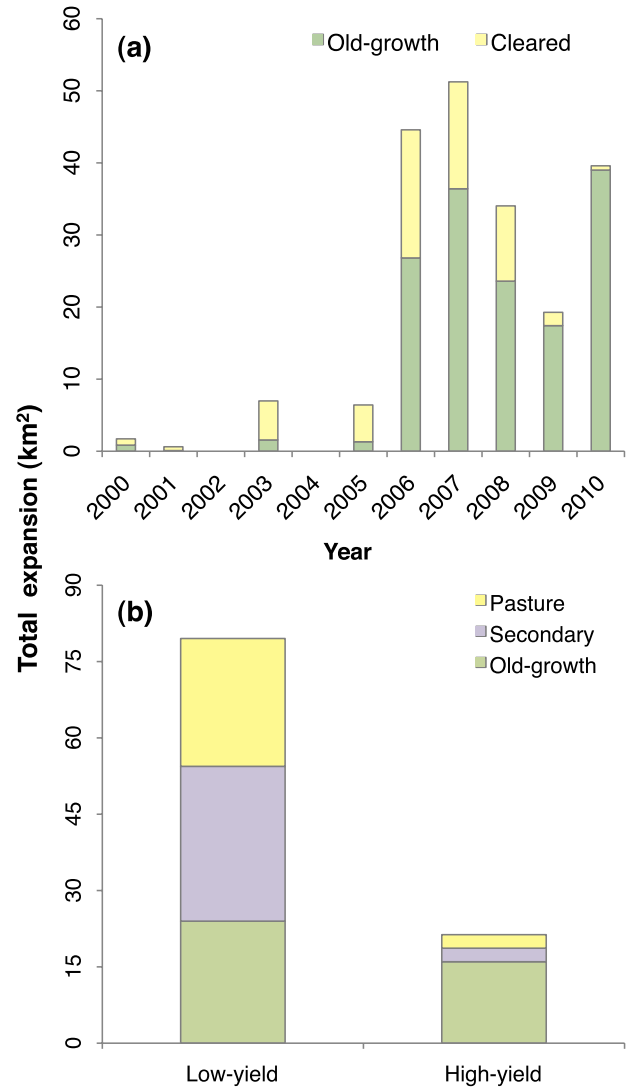
oil palm expansion to deforestation (figure 2(a)). In the focus area, we assessed the contribution of high-yield and small-scale, low-yield oil palm expansion to deforestation (figure 2(b)). Using the proportions of high- and low-yield expansion into forest and already cleared land, we assessed whether high-yield oil palm expansion effectively reduces the amount of forest converted relative to low-yield expansion to achieve the same amount of production (a detailed description of methods is available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

We mapped deforestation attributed to high-yield oil palm expansion in the Peruvian Amazon by analysing temporal changes in vegetation greenness using data from the satellite MODIS [19] (figure S1 available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)). We identified events of forest conversion to oil palm and quantified total annual oil palm expansion into forests and already cleared land visually using data from the satellite Landsat with 96.3% accuracy. Accuracy was assessed using forest/non forest maps created for land change analysis in the focus area as reference (available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).



**Figure 2.** (a) Location of high-yield oil palm plantations in the Peruvian Amazon and operations detected in this analysis using data from the satellite MODIS [19]. (b) High- and low-yield plantations identified in the focus area using data from Landsat and ALOS/PALSAR [20, 21].

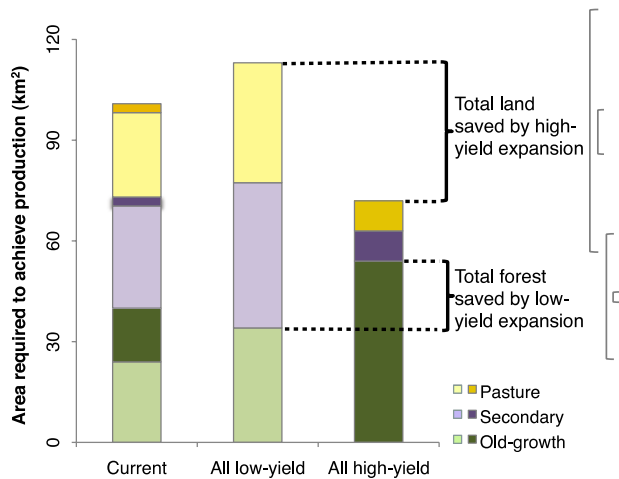
ERL/6/044029/mmedia). Total high-yield oil palm expansion between 2000 and 2010 was 204.5 km<sup>2</sup>. Seventy-two per cent of the expansion occurred at the expense of forests, representing about 1.3% of total deforestation in Peru during the same period. Ninety-two per cent of the total expansion and 97% of the deforestation occurred between 2006 and 2010. Before 2006, expansion was considerably lower and



**Figure 3.** (a) Total area expanded by high-yield oil palm plantations into old-growth forest and cleared lands in the Peruvian Amazon between 2000 and 2010. (b) Area expanded into pastures, secondary, and old-growth forests by low- and high-yield plantation in the focus area during the same period. Area estimates for different land cover in (b) were corrected to account for bias in land cover classification (available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

mostly occurred in already cleared areas (figure 3(a)). The method detected forest conversion to oil palm with 91% accuracy in terms of area (figure S3 and a detailed description of methods are available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

We identified oil palm expansion in the focus area by classifying oil palm plantations ten years old or younger and other land covers in 2010 using satellite data from Landsat and ALOS/PALSAR [20, 21]. Then we estimated area of pastures, secondary and old-growth forests converted to oil palm from 2000 to 2010. Secondary vegetation consisted of tree-dominated areas that were previously cleared but with significantly lower tree stocking than old-growth forests (figure S4 available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)). Total oil palm expansion between 2000 and 2010 in the focus area was 102.3 km<sup>2</sup> (figure 3(b)). Low-yield oil palm



**Figure 4.** High-yield oil palm expansion would require less land to achieve production than low-yield plantations but at greater expense of old-growth forests. Lighter colours refer to land covers converted to low-yield plantations and darker colours represent conversion to high-yield plantations. Grey brackets on the right side indicate the minimum and maximum difference in total and forest area required by high- and low-yield plantations considering uncertainty in yield estimates (table S2 available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)). Estimates are based on corrected land cover areas shown in figure 3(b).

plantations accounted for 80% of the total new-planted areas but only 30% of their expansion resulted from conversion of old-growth forest. In contrast, 75% of the expansion by high-yield plantations occurred into old-growth forests. Overall accuracy was 98% for the 2010 oil palm classification and 88% for the classification of land covers in 2000 converted to oil palm from 2000 to 2010 (table S3 and a detailed description of methods are available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

Finally, we calculated the hypothetical amount of land and old-growth forest that could potentially be saved if all estimated annual production in the focus area had been reached following the typical yields and percentages of forest converted by low- or high-yield plantations. High-yield plantations would require 64% less land than low-yield plantations to achieve the same amount of production. However high-yield plantations would require 58% more forestland to meet production levels (figure 4). In summary, expansion of high-yield oil palm resulted in overall land saving relative to low-yield expansion but the former led to greater loss of old-growth forest relative to production because high-yield oil palm converted a larger proportion of forest (a detailed description of methods is available at [stacks.iop.org/ERL/6/044029/mmedia](http://stacks.iop.org/ERL/6/044029/mmedia)).

Our research did not permit us to determine with certainty why high-yield industrial-scale plantations expand mostly into old-growth forest, while low-yield plantations are more apt to expand onto already cleared land in the focus area. Conversations with residents, researchers and oil palm producers, however, suggest strongly that the large areas needed for high-yield plantations lead owners to avoid land previously cleared, which is frequently under uncertain

and disputed tenure; it is simpler to establish tenureship over forests, officially owned by the State. Moreover, many high-yield plantations are owned by large, extra-local entities that choose not to engage with the local social and political complications that any land disputes might entail. Smaller holdings avoid such difficulties partly because they need smaller spaces, and because local, family owners are usually willing to take on the uncertainties of local tenure systems.

Industrial-scale, high-yield oil palm plantations are just beginning to be important drivers of deforestation in Peru. Strong political support and legal stimuli for the cultivation of this crop in the country, along with extensive suitable areas and increasing global demand for palm oil, suggest that expansion will continue. Incentives for cultivating new high-yield oil palm plantations in already cleared land or increasing productivity in existing low-yield plantations would promote both forest conservation and agricultural production. Policy-making on this matter requires consideration of multiple issues including land tenure, governance and equity, as well as potential environmental impacts associated with intensive agricultural production.

This analysis did not assess the conservation status of the forests converted into oil palm. Some plantations might be expanding into previously logged old-growth forests. Yet, logged forests provide a habitat for numerous species and can store considerable amounts of carbon that would otherwise be released to the atmosphere [22–24]. On the other hand, biodiversity in oil palm plantations is considerably lower, and carbon stored is much less than forests [11, 25–27]. Thirty-eight per cent of low-yield plantations expanded into secondary forests in the area of Pucallpa (figure 3(b)). The conversion of secondary forests into oil palm might represent an impact for conservation since they provide habitats and other ecosystem services but their conservation value does not compare with that of old-growth forests [28].

Expanding high-yield oil palm plantations minimizes the total land required for a given amount of production compared to low-yield expansion. Counter-intuitively however, our results suggest that expansion by high-yield oil palm plantations in the study area from 2000 to 2010 occurred at greater expense of forest than low-yield cultivations to achieve the same amount of production because the former is more likely to occur through expansion into forest. Higher productivity in new agricultural areas can increase efficiency in the use of land, but incentives for expanding cultivations outside of the forest are essential to achieve simultaneous goals of agricultural production and forest conservation.

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