Environmental Research Letters

Environmental Research Letters

Deforestation risks posed by oil palm expansion in the Peruvian Amazon[*]

Varsha Vijay[1,2] ⓘD, Chantal D Reid[1], Matt Finer[3], Clinton N Jenkins[4] and Stuart L Pimm[1]

Author affiliations

[1] Nicholas School of the Environment, Duke University, Durham, NC 27708, United States of America

[2] National Socio-Environmental Synthesis Center (SESYNC), 1 Park Place, Suite 300, Annapolis, MD 21401, United States of America

[3] Amazon Conservation Association, Washington, DC 20005, United States of America

[4] IPÊ—Instituto de Pesquisas Ecológicas, Nazaré Paulista, São Paulo 12960-000, Brazil

Abstract

Further expansion of agriculture in the tropics is likely to accelerate the loss of biodiversity. One crop of concern to conservation is African oil palm (*Elaeis guineensis*). We examined recent deforestation associated with oil palm in the Peruvian Amazon within the context of the region's other crops. We found more area under oil palm cultivation (845 km²)

than did previous studies. While this comprises less than 4% of the cropland in the region, it accounted for 11% of the deforestation from agricultural expansion from 2007–2013. Patches of oil palm agriculture were larger and more spatially clustered than for other crops, potentially increasing their impact on local habitat fragmentation. Modeling deforestation risk for oil palm expansion using climatic and edaphic factors showed that sites at lower elevations, with higher precipitation, and lower slopes than those typically used for intensive agriculture are at long-term risk of deforestation from oil palm agriculture. Within areas at long-term risks, based on CART models, areas near urban centers, roads, and previously deforested areas are at greatest short-term risk of deforestation. Existing protected areas and officially recognized indigenous territories cover large areas at long-term risk of deforestation for oil palm (>40%). Less than 7% of these areas are under strict (IUCN I-IV) protection. Based on these findings, we suggest targeted monitoring for oil palm deforestation as well as strengthening and expanding protected areas to conserve specific habitats.

Introduction

The demand for commodity crops has driven the global expansion of agriculture, often at the expense of natural habitats and biodiversity. Most of the world's biodiversity hotspots are in tropical regions [1, 2]. In these regions, agricultural expansion may accelerate deforestation and threaten biodiversity and associated ecosystem services.

The African oil palm (*Elaeis guineensis*) is a commodity crop of

singular concern to conservation, as it grows almost exclusively in areas that were once tropical moist forests. Oil palm production has doubled in the recent past [3], with demand projected to drive further expansions [4, 5]. If oil palm expands into all biophysically suitable areas, it may affect more than half of all threatened birds and mammals globally [6].

Palm oil, derived from the oil palm fruit and seeds, is the most widely consumed vegetable oil in the world. Processed foods, cosmetics, biofuels, household cleaners and industrial lubricants all use it. Oil palm is expanding rapidly in South America, driven by economic incentives, international investments, and large areas suitable for its production [7]. Although estimates of deforestation for oil palm vary throughout South America, prior studies in Peru suggest that at least half of current oil palm is on land deforested in the past two decades [8–10].

We consider the recent deforestation impacts of oil palm within the context of general agricultural development and protected areas in the Peruvian Amazon. We examined the extent and spatial pattern of oil palm plantation development and its distribution relative to the physical environment, human population, and accessibility. From these analyses, we projected long-term and short-term risks of deforestation from oil palm development. We then explored the distribution of such risks relative to administrative regions, ecoregions, recognized indigenous territories, and currently and formerly protected areas.

We asked the following questions: (1) what is the current extent of oil palm compared to other crops in the Peruvian Amazon, how has it changed over time, and how much of it came from recent deforestation? (2) Do oil palm plantations differ in size, spatial distribution, or biophysical characteristics from sites occupied by other crops? (3) Do human population and the ease of forest access predict the location of oil palm plantations within bounds set by site characteristics? (4) How well do the currently protected areas and recognized indigenous territories

conserve forests predicted to be at risk of deforestation for oil palm? (5) How could the expansion of oil palm agriculture impact specific habitats and biological communities in the Peruvian Amazon?

Despite the inaccessibility of much of the Amazonian region, human activities have fragmented the forests near population centers and provided markets for agricultural products. Agricultural expansion in this region concentrates along roads and rivers that provide access to these markets [11]. Common subsistence crops in the Amazon basin include maize, rice, cassava, beans, and fruit trees, while commercial crops include soybean, coffee, cacao, and beef [12]. Thus, oil palm is part of a diverse and rapidly changing agricultural sector in the Amazon basin and this trend mirrors that of South America as a whole, where agriculture is a primary driver of deforestation [13, 14]. In 2005, pasture and commercial cropland accounted for 96% of agricultural land in South America, while tree crops such as oil palm accounted for only 0.5% [15]. However, in the past decade, regional studies show marked expansion of tree crops including cacao [16] and coffee [17].

Away from population centers and the roads and rivers connecting them, much of the Peruvian Amazon is still intact. It is one of the most biodiverse areas in the world [18, 19] and contains large areas of contiguous primary forest [20]. Extensive areas of forest are legally protected from development in some manner, with protected areas as the primary tool for conservation [21]. Compared to equivalent areas without protection, protected areas and indigenous territories reduced deforestation in the Peruvian Amazon [22−24] and studies in the Brazilian Amazon showed that both are barriers for land clearing associated with 'slash and burn' agriculture [25, 26].

The placement of protected areas, however, does not always align with broader goals of conservation, but rather with residual areas of human land uses [27, 28]. In this analysis, we considered not just the context of

agricultural areas and existing human population centers, but also the coverage of currently protected areas and officially recognized indigenous territory. Our focus was their possible role in limiting the future expansion of oil palm agriculture should global demand drive its continued expansion.

Methods

Our analyses proceeded in five parts. (1) We mapped the extent of deforestation for oil palm and other crops in the study area. (2) Using climatic and edaphic factors, we modeled the risk of future deforestation from oil palm expansion ('long-term risk'). (3) We refined the forests at long-term risk using population and accessibility factors to identify those most immediately threatened ('short-term risk'). (4) We examined the distribution of protected areas and indigenous territories, as well as their overlap with at-risk forests. (5) We then evaluated these areas by ecoregion, representing risk to the region's major habitats.

Mapping deforestation

Our focus was the tropical moist forest biome of Peru, an area that occupies 53.9% of the country. We defined our study area as the monitoring area for the forest change dataset [29] generated by Peruvian Government agencies, primarily the Servicio Nacional Forestal y de Fauna Silvestre (SERFOR), the Ministry of the Environment (MINAM), and the Ministry of Agriculture and Irrigation (MINAGRI). Using this dataset, we assessed yearly forest and non-forest areas from 2000–2015 at 30 m spatial resolution. A known problem in the dataset is that river meanders and oxbow lakes contribute substantial false positives to deforestation detection. To account for such errors, we further refined these data by removing all pixels identified as surface water at any time

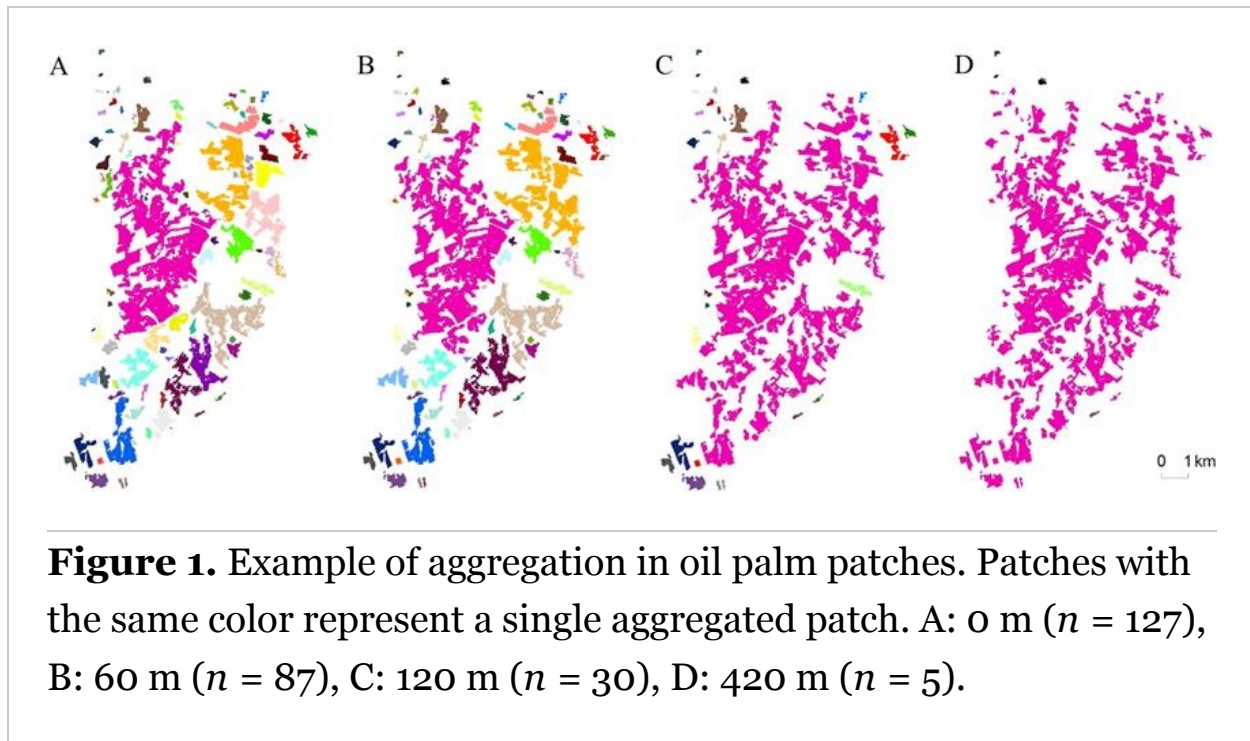between 2000–2015 in the JRC Global Surface Water Occurrence dataset [30].

Within areas classified as non-forest in 2015, we identified oil palm and other cropland areas. To visually identify patterns of oil palm monoculture, we used high-resolution (⩽0.5 m spatial resolution) Worldview-02 and Worldview-03 imagery for 2014–2016 obtained from DigitalGlobe (NextView License). Where possible we corroborated our identification of oil palm plantations with news and scholarly articles, government and company records, and geotagged photos.

We defined cropland as areas with active or fallow cultivation of annual or plantation crops other than oil palm. To identify cropland, we used an unsupervised classification implemented in Google Earth Engine, based on Landsat 8 2015 data (SI: Addl. Methods). Pastures were excluded from our analysis because they face different biophysical constraints than areas of crop production, including oil palm cultivation. Many of the region's agricultural areas are mixed-use farms that do not conform to the large-scale monoculture typical of industrial agricultural practices, increasing the likelihood of underestimating cropland extent [31].

Using the binary forest cover layers for 2000–2015, we conducted a change analysis within current oil palm and other cropland to determine the percent forested in any given year. We then determined the size of contiguous oil palm or other crop patches in 2015, and repeated this analysis again for 2000 to determine the size of non-forest patches within the 2015 sample areas.

Short distances may separate small patches of deforestation, so a cluster of such patches may be appropriately viewed as a single patch in terms of habitat fragmentation. To address this possibility, we also evaluated the spatial clustering of oil palm and other crop deforestation patches at different aggregation distances, from Euclidean distances of

0–600 m at 60 m intervals (figure 1). We examined how mean patch size increased with aggregation distance for oil palm and other crops to indicate a relative degree of clustering in both types of agricultural deforestation.

Figure 1. Example of aggregation in oil palm patches. Patches with the same color represent a single aggregated patch. A: 0 m ($n = 127$), B: 60 m ($n = 87$), C: 120 m ($n = 30$), D: 420 m ($n = 5$).

Long-term and short-term risk modeling

To estimate the areas at long-term risk of deforestation for oil palm, we calculated the biophysical envelope for oil palm growth. By this, we mean the current distributions of climatic and edaphic variables for current oil palm plantations in the region. We examined physical and climatic variables likely to influence the planting of crops: mean annual precipitation, minimum monthly temperature, elevation, slope, and soil depth (SI: Addl. Methods). Using these distributions, we identified other forested areas likely suitable for oil palm.

Within forest areas at long-term risk of deforestation, we used a

classification and regression tree model (CART) to determine areas of short-term, i.e. more immediate, risk of deforestation (SI: Addl. Methods). Here, explanatory variables describe population centers and accessibility for development: large urban areas, villages, distance to roads and navigable rivers.

Evaluation of protected areas

Within areas determined at long-term risk of deforestation for oil palm, we assessed the extent of protected areas and officially recognized indigenous territories (henceforth just 'indigenous territories') by administrative region (department). Data on protected areas, including information on IUCN categories, were from MINAM and data on indigenous territories from Rede Amazônica de Informação Socioambiental Georreferenciada (RAISG) [32]. We also assessed National Forest areas degazetted in 1996 and 2000 based on data from the Protected Area Downgrading, Downsizing and Degazettement (PADDD) dataset, as well as the extent of oil palm and oil palm risk classes found within these areas [33].

We evaluated long-term and short-term risk by ecoregion as well as protected areas and indigenous territories coverage for each ecoregion. A lack of fine-scale data on species abundance and ranges in this region makes it difficult to assess the impact of deforestation on biodiversity. When such data are lacking, ecoregions [34] serve as useful proxies for the habitat and community types required to sustain biodiversity [35, 36].

Results

Mapping deforestation

We identified 845 km² of oil palm plantation area and 21 997 km² cultivated for other crops in the Peruvian Amazon (figure 2). In 2000, deforested areas within current oil palm and cropland areas showed a similar distribution of sizes with a median patch size of 0.81 km² and 0.99 km² respectively (figure 3). By 2015, we observed a highly divergent pattern for the median size of oil palm deforestation (4.50 km²), more than six times the size of cropland deforestation (0.72 km²). The statistical distributions in patch size of both the oil palm and cropland patches are long-tailed. The top 5% of patches deforested for both oil palm and cropland cultivation account for 82% and 76% of the area deforested for each land use, respectively. The distribution of patch sizes for oil palm is also bimodal, with many small patches in addition to the large ones.
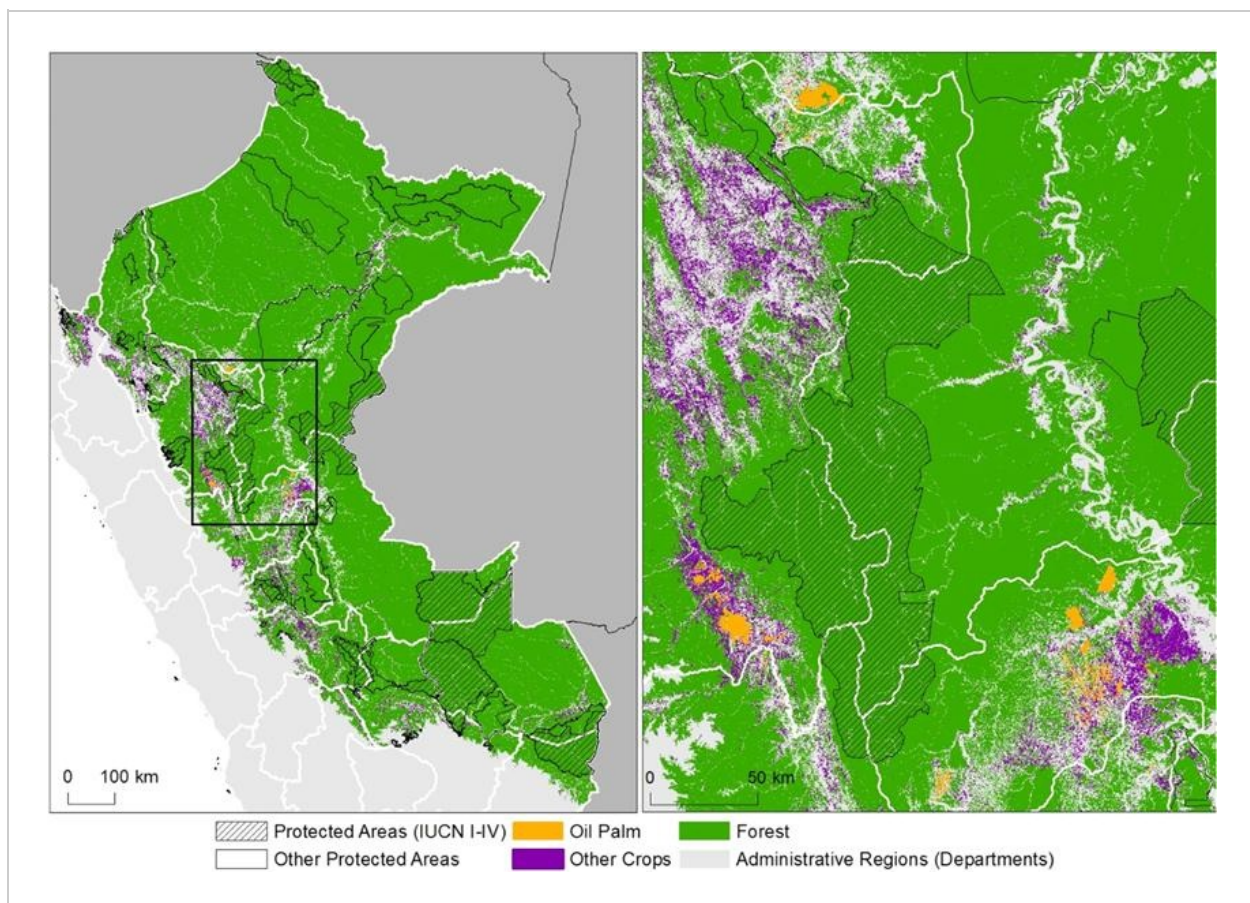
Figure 2. Map of forest and deforestation for oil palm and other crops (gray inside the study area represent pixels not included in our analysis: either water or non-agricultural deforestation). Inset map shows the primary zone for oil palm cultivation.
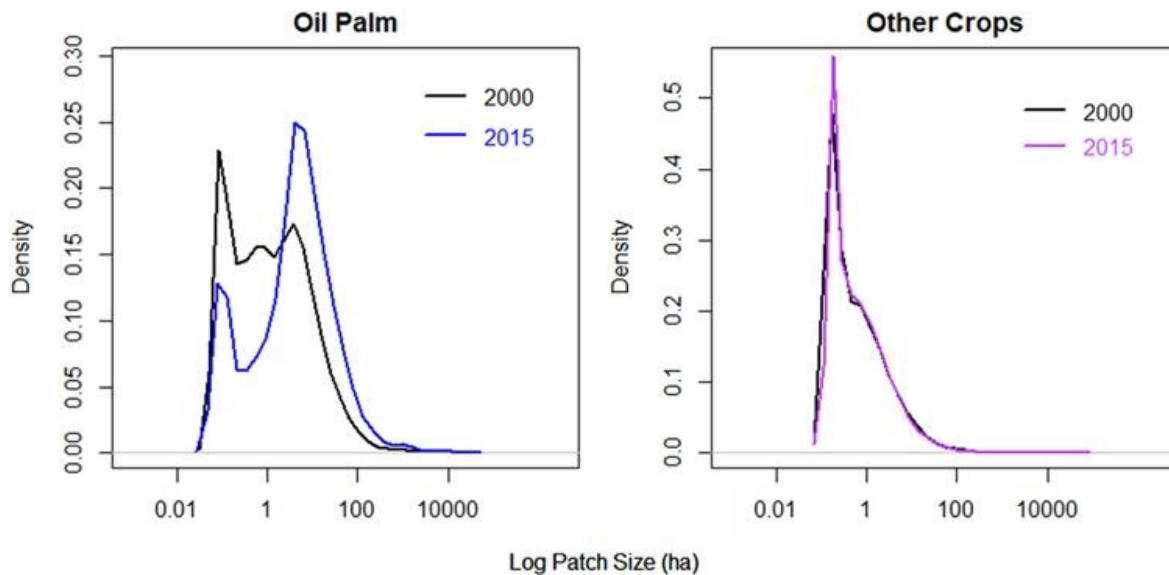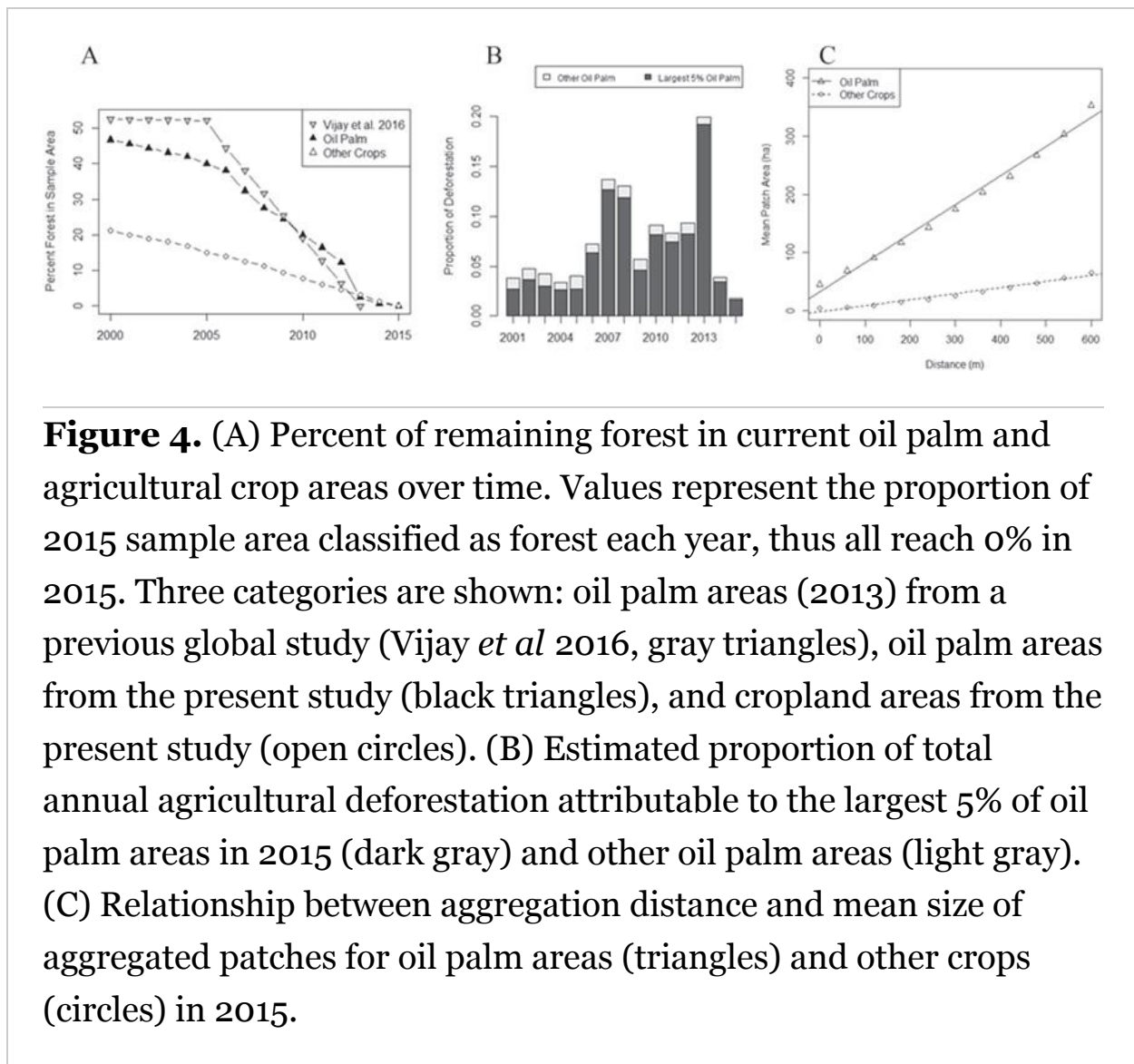

Figure 3. Log transformed distributions of deforested patch size for oil palm in 2000 and 2015 (left panel) and other crops in 2000 and 2015 (right panel).

The pace of forest transformed to oil palm or cropland, as a percent of that cover type in 2015, varied. In the 2015 oil palm area, 47% was forested in 2000 (figure 4(A)). About 1.4% was deforested each year from 2000–2005. This accelerated to ~5% per year from 2006–2012. While the rate of deforestation appears to decrease dramatically in 2013–2015, this is at least partially an artifact of the difficulty of verifying the presence of oil palm seedlings within the first year of planting. Some of

the deforested areas may indeed be oil palm, but it is too soon to confirm using remote sensing. In the area planted in other crops in 2015, 21% was forest in 2000, with an average of 1.4% of this area converted from forest each year between 2000–2015.

Figure 4. (A) Percent of remaining forest in current oil palm and agricultural crop areas over time. Values represent the proportion of 2015 sample area classified as forest each year, thus all reach 0% in 2015. Three categories are shown: oil palm areas (2013) from a previous global study (Vijay *et al* 2016, gray triangles), oil palm areas from the present study (black triangles), and cropland areas from the present study (open circles). (B) Estimated proportion of total annual agricultural deforestation attributable to the largest 5% of oil palm areas in 2015 (dark gray) and other oil palm areas (light gray). (C) Relationship between aggregation distance and mean size of aggregated patches for oil palm areas (triangles) and other crops (circles) in 2015.

The exact contribution of oil palm to overall agricultural deforestation fluctuated over the study period, reaching 20% in 2013, assuming current
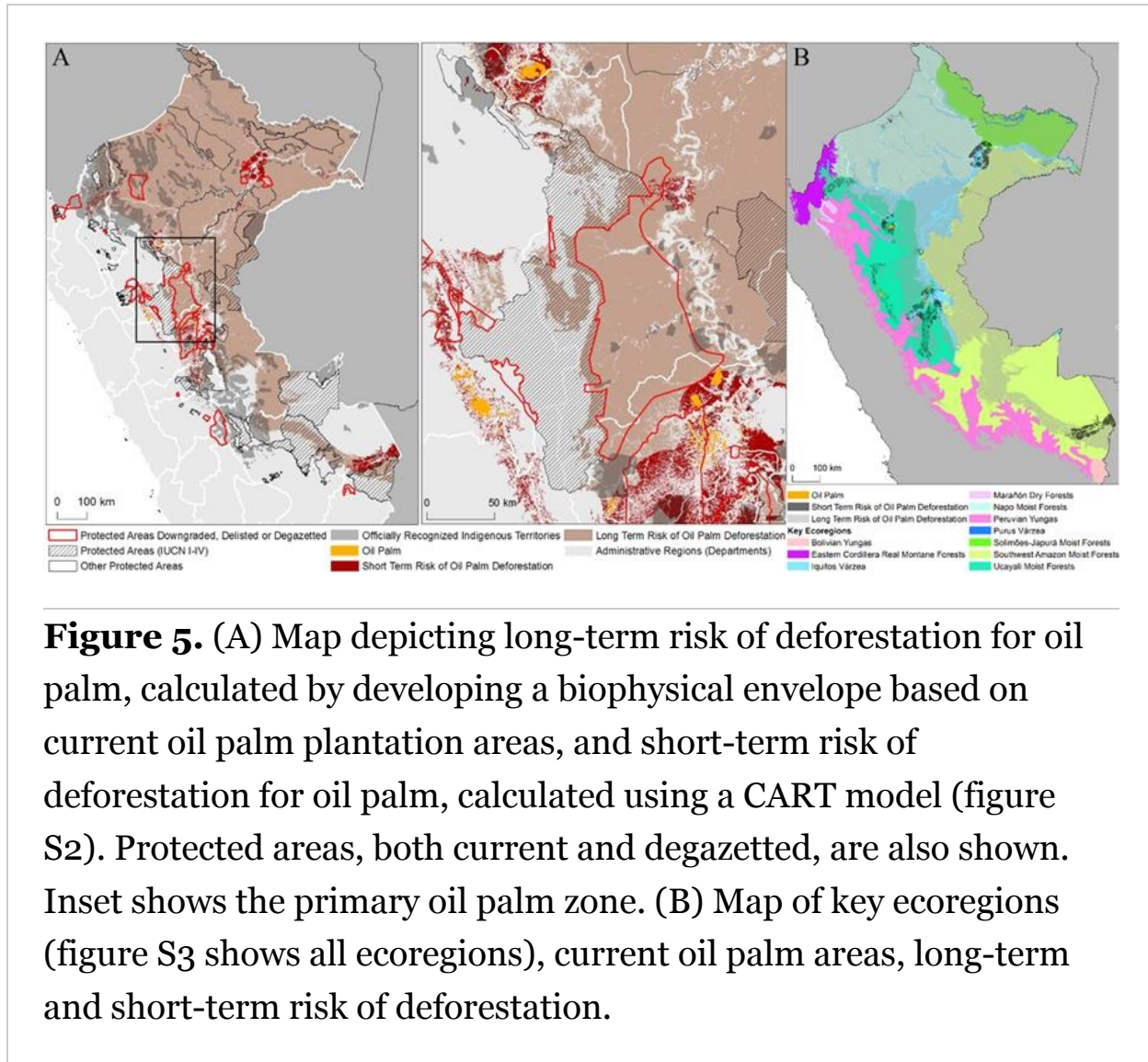
oil palm areas deforested since 2000 were converted directly to oil palm from forest (figure 4(B)). From 2001–2006, oil palm accounted for an average of 5% of annual agricultural deforestation, in the second part of the study period, from 2007–2013, oil palm accounted for an average of 11% of annual agricultural deforestation. The same detection difficulties mentioned above affected the final two years evaluated for this metric. Over the entire study period, deforestation within the largest oil palm patches accounted for 88% of total oil palm deforestation.

We considered how patches of oil palm and other cropland deforestation would aggregate at distances up to 600 m. Using a linear regression of aggregation distance (d_A) to mean patch area after aggregation (figure 4(C)), we found that the rate of increase in mean patch area was five times greater for oil palm patches ($0.50\,d_A + 32.0$, $R^2 = 0.99$) than for cropland patches ($0.10\,d_A - 2.22$, $R^2 = 0.97$), indicating a much greater degree of clustering for oil palm.

Long-term risk modeling

The distributions of oil palm and other crop patches were different with respect to minimum monthly temperature, mean annual precipitation, elevation, slope, and soil depth (Kolmogorov–Smirnov test, $p < 0.001$; figure S1 is available online at stacks.iop.org/ERL/13/114010/mmedia). Although the ranges of oil palm and other crops for each environmental factor examined overlap, oil palm tended to occupy a narrower biophysical niche. We determined threshold values that included all the variability in oil palm patch values for each explanatory variable: $\geqslant 1678$ mm mean annual precipitation, $\geqslant 17.9\ °C$ for minimum monthly temperature, $\leqslant 705$ m for elevation, $\leqslant 30°$ for slope, and $\geqslant 1$ m for soil depth. Forest areas meeting all these conditions are considered at long-term risk of deforestation for oil palm plantations (figure 5(A), table S1).

Most of these areas were in Loreto (75%) and Ucayali (14%). None of the other regions contained more than 5% of the area at long-term risk.

Figure 5. (A) Map depicting long-term risk of deforestation for oil palm, calculated by developing a biophysical envelope based on current oil palm plantation areas, and short-term risk of deforestation for oil palm, calculated using a CART model (figure S2). Protected areas, both current and degazetted, are also shown. Inset shows the primary oil palm zone. (B) Map of key ecoregions (figure S3 shows all ecoregions), current oil palm areas, long-term and short-term risk of deforestation.

Short-term risk modeling

Based on cross-validated error, we selected a tree with five terminal nodes for the CART model representing the short-term risk of deforestation for oil palm in unprotected forests within the long-term risk areas (figure S2). The rarity of oil palm deforestation in the area sampled

for this model (0.1%) impacts the precision of the model, 92.6%. Two scenarios emerged for short-term risk of deforestation for oil palm within the long-term vulnerable forest areas: (1) forest that occur close to roads (<23 km) and urban areas (<104 km) and (2) forests that are further from urban areas, but even closer to roads (<12 km) and near previously deforested areas (>1.3% of the area within 300 m radius deforested). The greatest proportions of forest at short-term risk are in the Loreto (31%), Ucayali (15%), Huánuco (6%), and Madre de Dios (5%) regions (figure 5(A), table S1).

Evaluation of protected and indigenous areas

Protected Areas cover 19 2988 km² (24.6%) of the Peruvian Amazon (figure 5(A)). Officially recognized indigenous territories cover another 12 4626 km². No oil palm is within current protected areas and <0.1% is within indigenous territories. We determined that 107 102 km² (23.6%) of forests at long-term risk are protected. Of these, 30 636 km² are within IUCN I-IV protected areas (6.7%). Another 75 589 km² (16.7%) of forest at long-term risk was within indigenous territories. We determined that 2708 km² of forest would be at short-term risk but for its protected areas status. Another 16% of forest at short-term risk is located within indigenous territories.

    Peru removed the National Forest designation from its protected areas system in 2000 (SI: appendix B). These areas formerly covered 34 594 km² of the study area. In areas formerly protected by the Humboldt and Iparía National forests, we found 96 km² of oil palm, 11.3% of total estimated Peruvian oil palm. Some 81 of 100 random samples of oil palm in the former Humboldt and Iparía National forests were established after 2005. Later plantation establishment occurred within the interior of the formerly protected areas (SI: appendix B). We found 16 810 km²

(3.7%) of forests at long-term risk and 2381 km² (12.6%) of forests at short-term risk of deforestation for oil palm are within degazetted National Forest areas. Some 19.2% (6654 km²) of these former National Forests became officially recognized indigenous territory.

Status of ecoregions

Some 99.9% of oil palm deforestation is within two ecoregions, Ucayali Moist Forest (80.9%) and Iquitos Várzea (19.0%) (table S2, figure 5(B)). This reflects the two types of ecoregions most at risk of long-term development for oil palm: moist forests (Napo, Solimões-Japurá, Ucayali and Southwest Amazon) and floodplain forests known as várzea (Iquitos and Purus). Higher elevation forests (E. Cordillera Real Montane Forests, Marañón Dry Forests, Peruvian and Bolivian Yungas) have 7% or less of their area at risk. The greatest amount of forests at short-term risk occur in the Southwest Amazon Moist Forests (35.9%), Ucayali Moist Forests (34.8%), and Iquitos Várzea (18.0%) ecoregions.

In each of the six moist forest and várzea ecoregions, 38%–43% of the long-term risk area is under some form of protection or within indigenous territories. However, these differ among those that have primarily protected areas (Iquitos Várzea, Solimões-Japurá and Southwest Amazon Moist Forests), indigenous territories (Ucayali Moist Forest and Purus Várzea) or a nearly equal amount of both (Napo Moist Forest). Less than 7% of the area at long-term risk is under strict (IUCN I-IV) protection.

Discussion

Oil palm covers a small area, but one expanding rapidly at the expense of forests

Between 1990 and 2010, demand for palm oil resulted in an expansion of plantation area from 60 000–160 000 km² globally [3]. As suitable land becomes limited in Southeast Asia, producers are targeting expansion in tropical areas, including in South America [37]. The impacts of such expansion are of concern when viewed in conjunction with those of mining, logging, petroleum extraction, infrastructure development and urban expansion in the Peruvian Amazon [38–46].

We identified 845 km² of oil palm plantation area in the Peruvian Amazon (figure 2). The area is greater than reported in previous studies and nearly twice the FAO estimate of harvested oil palm area in 2015 (431 km²) [3]. Almost half of the oil palm plantations we mapped were forest in 2000, compared to about 21% of other crops (figure 4(A)). Oil palm has become a major source of agricultural deforestation in the Peruvian Amazon, accounting for 11% of agricultural deforestation from 2007–2013, while occupying less than 4% of the agricultural area. These results support general trends from previous studies suggesting recent deforestation for oil palm [9–11], including increases in the rate of deforestation since 2006 (figure 4).

The spatial pattern of deforestation for oil palm differs from other crops in terms of scale, organization, and physical characteristics

The spatial pattern of oil palm agriculture differed from other crops, with larger and more clustered deforestation patches (figures 3 and 4). Most oil palm cultivation comes from a small number of large plantations. However, the bimodal nature of oil palm patch distribution suggests both smallholder and large industrial actors are responsible for plantation establishment. A recent study of deforestation in the Peruvian Amazon noted that small patch deforestation is not always attributable to smallholder or subsistence agriculture but to a diversity of actors [47]. This motivates a need for further field surveys in the region. A greater

percentage (50%) of large plantations came from deforestation since 2000 than small ones (30%). This is in broad agreement with earlier studies of this region [9, 11]. The dramatic shift we observed in median patch sizes from 2000–2015 suggests a fundamental change in the scale of deforestation within areas currently occupied by oil palm.

While small plantations may each have a limited impact, oil palm plantations were also more spatially clustered than cropland areas (figure 4(C)). Clustering of oil palm plantations may result from the need to transport oil palm fruits to mills soon after harvest. Rapid processing of the fruit is needed to prevent a rapid rise in free fatty acids that reduces the quality of the crude palm oil produced [48]. Such aggregation possibly leads to larger effective patches of oil palm deforestation, when we consider the effects of fragmentation on the remaining forest between patches. Studies indicate that increasingly fragmented forest areas support fewer species in the long-term and affect the function of forest areas [49–53].

Oil palm occupies sites at lower elevations, higher precipitation, lower slopes, and greater soil depths than many crops in this region (figure S1). Such habitat envelope differentiation suggests that oil palm development leads to deforestation in different areas than for other crops. If oil palm agriculture continues to expand, it could greatly change the distribution of agriculture on this landscape.

Population and accessibility factors predict the location of current oil palm development within the bounds set by climate and soils

Large areas of forest are biophysically suitable for oil palm. We do not suggest that the entirety of this area will convert to oil palm. Rather we suggest that deforestation for oil palm could become a substantial part of overall deforestation within this region, given the extent of suitable forest area. Within the area determined suitable for oil palm, approximately

13% are seasonally or permanently flooded wetlands, including lowland peatlands [54]. We have not observed conversion of wetlands for oil palm in Peru, though logging, agriculture, and grazing activities increasingly degrade and convert these systems [55]. Peatland conversion for oil palm is an issue in Southeast Asia [56] and in the flooded savannah ecosystems of the Colombian Llanos [57]. Because of the uncertainty around future oil palm development scenarios in the Peruvian Amazon, we include wetlands in our areas projected to be at risk of development.

We highlight a subset of the biophysically suitable envelope as under short-term threat due to population and accessibility factors. In the short-term, the proximity of urban areas, roads and previous deforestation increase the risk of deforestation from oil palm (figure 5(A)). Another important factor is the proximity to existing oil palm plantations, as evidenced by the spatial clustering of oil palm plantations (figure 4(C)). Other studies find similar factors to be important in other regions of the world [58–60].

Frequent satellite images are few in areas of active oil palm expansion. Thus, the exact sequence of events in deforestation for new plantations and the development of infrastructure to bring palm oil to market requires further investigation. Our fieldwork near Pucallpa supports the idea that, while major road infrastructure is predictive, the establishment of large-scale plantations involves construction of new roads and improvement of existing ones. Our short-term risk analyses suggest that monitoring should continue throughout this region, including areas where there is no oil palm currently. A notable example is the province of Madre de Dios, which shares many of the biophysical, population and accessibility factors with areas that already have oil palm development.

Existing protections are working, but few areas are strictly protected

Less than 7% of the area at long-term risk is under strict (IUCN I-IV) protection. Although Peru's forestry laws mandate preservation of vegetation cover and forestry resources, agricultural deforestation has occurred under the 'best land use capacity' exemption to them [61]. This highlights the importance of protected areas and indigenous territories. A new governmental resolution, signed by the Vice-Minister of Culture in 2017, mandates consultation with communities in indigenous territories (Resolution 014-2017-VMI-MC). Recent news items indicate that some indigenous communities are vocal in their concern about development within their territories [62].

It is also important to maintain long-term protections. From 1996–2000, Peru degazetted National Forests from their protected area system. This reduced the total protected areas in the study region by 12.3%. After degazetting, former National Forests opened to commercial logging and agriculture. From 2000–2010, deforestation rates exceeded those in both protected areas and areas that were never protected [63]. Most of the oil palm we identify in the former Humboldt and Iparía National Forests was planted after 2005 (SI: appendix B). Maintaining and enforcing protections preventing agricultural deforestation in National Forests could have reduced the areas at long-term and short-term risk of deforestation for oil palm by 3.7% and 12.6% respectively. While our findings support the conclusion that protected status prevents development of protected lands, it could displace development to other areas and, therefore, may not reduce overall risk of deforestation.

Oil palm expansion could heavily impact certain habitats and biological communities

The two ecoregions currently containing oil palm (Ucayali Moist Forest and Iquitos Várzea) also contain much of the area at short-term risk of oil palm deforestation. In the long term, all six ecoregions of low elevation

moist forests and várzea have large areas at risk. Little of these are under strict protection (<7%), though indigenous territories and other categories of protection cover ~40% of each. This suggests that increasing protections of already designated areas could be a major component of conservation in this region. Indigenous territories are critical to the protection of the Purus Várzea, Napo Moist Forests and Solimões-Japurá Moist Forests, which have more than 90% of their area at long-term risk. Eighty percent of at-risk area currently under IUCN I-IV protection lies within the Southwest Amazon Moist Forest. It has considerable area under short-term risk despite containing no oil palm currently.

The role of policy and voluntary commitments in the future of oil palm expansion in Peru

Peru's recent National Oil Palm Plan [64] indicates that an area of more than 14 000 km² may be suitable for oil palm development, a claim that conflicts with the goal of reducing deforestation within the Amazonian region. In recent years, companies have experienced increasing pressure to purchase responsibly produced palm oil, certified through the Roundtable on Sustainable Palm Oil (RSPO) [65]. RSPO certified palm oil now accounts for about 20% of global oil palm production. A recent study of RSPO certification effectiveness in Indonesia found it to be insufficient in reducing deforestation for oil palm [66].

In a recent instance of RSPO activity in Peru, the Native Community of Santa Clara de Uchunya made a formal complaint regarding the activities of one of its member companies: plantations of Pucallpa. An RSPO investigation ruled the company guilty of land clearing within traditional forest lands, violating the code of conduct for member companies [67]. Although Plantations of Pucallpa withdrew from the RSPO prior to the verdict, the Peruvian government fined it for compliance issues related to the case. Outside of the RSPO framework, a

combination of societal pressure and legal action prevented deforestation of 230 km² of primary forest by Grupo Romero, a Peruvian producer in 2015 [61].

Voluntary commitments form an important part of deforestation regulation in Peru, but their effectiveness is limited when unaccompanied by policy interventions. Plantations will likely continue to expand in the coming years with a combination of international and national producers active in the region. As evidence of this, after the end of our study period in 2016 and 2017, deforestation occurred to establish a large plantation in Northern San Martin and for smaller plantations in the Ucayali and Huánuco regions.

Conclusions

This study proposes an approach to limit deforestation from oil palm expansion and to consider its implication for conservation in the Peruvian Amazon. Deforestation monitoring programs, like the newly established National System of Monitoring and Control in Peru, can target the unique spatial patterning associated with oil palm development within areas shown to be at risk. The implementation of real-time monitoring using satellite imagery enhances this approach [68]. In habitats disproportionately at risk of oil palm deforestation and with little protected area coverage, it may be advisable to establish new protected areas, increase protection levels in existing ones, and effectively implement consultation with indigenous communities. These strategies, along with regulation on infrastructure expansion such as road construction, could be essential to reduce the impacts of oil palm expansion to biodiversity.

Acknowledgments

ORCID iDs

Varsha Vijay https://orcid.org/0000-0002-2665-7866

References

[1] Jenkins C N, Pimm S L and Joppa L N 2013 Global patterns of terrestrial vertebrate diversity and conservation Proc. Natl Acad. Sci. 110 E2602–10
Crossref

[2] Joppa L N, Visconti P, Jenkins C N and Pimm S L 2013 Achieving the convention on biological diversity's goals for plant conservation Science 341 1100–3
Crossref

[3] FAO (Food and Agriculture Organization of the United Nations) FAOSTAT database. Rome (Italy). c2017

[4] Corley R H V 2009 How much palm oil do we need? Environ. Sci. Policy 12 134–9
Crossref

[5] FAPRI (Food and Agricultural Policy Research Institute) World Agricultural Outlook. Ames (IA). c2012

[6] Meijaard E et al (ed.) 2018 Oil Palm and Biodiversity. A Situation Analysis by the IUCN Oil Palm Task Force (Gland: International Union for Conservation of Nature and Natural Resources) pp 116

[7] Butler R A and Laurance W F 2009 Is oil palm the next emerging threat to the Amazon? Tropical Conservation Sci. 2 1–0
Crossref

[8] Gutiérrez-Vélez V H, et al 2011 High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon Environ. Res. Lett. 6 044029
Crossref

[9] Vijay V, Pimm S L, Jenkins C N and Smith S J 2016 The impacts of oil palm on recent deforestation and biodiversity loss PLoS One 11 e0159668
Crossref

[10] Furumo P R and Aide T M 2017 Characterizing commercial oil palm expansion in Latin America: land use change and trade Environ. Res. Lett. 12 024008
Crossref

[11] Alvarez N L and Naughton-Treves L 2003 Linking national agrarian policy to deforestation in the Peruvian Amazon: a case study of Tambopata, 1986–1997 AMBIO: J. Human Environ. 32 269–74
Crossref

[12] FAO (Food and Agriculture Organization of the United Nations) AQUASTAT database. Rome (Italy). c2015

[13] Gibbs H K, et al 2010 Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s Proc. Natl Acad. Sci. 107 16732–7
Crossref

[14] Hosonuma N, et al 2012 An assessment of deforestation and forest degradation drivers in developing countries Environ. Res. Lett. 7 044009
Crossref

[15] De S V, et al 2015 Land use patterns and related carbon losses following deforestation in South America Environ. Res. Lett. 10 124004
Crossref

[16] Schroth G, Garcia E, Griscom B W, Teixeira W G and Barros L P 2016 Commodity production as restoration driver in the Brazilian Amazon? Pasture re-agro-forestation with cocoa (Theobroma cacao) in southern Para Sustain. Sci. 11 277–93

[17] Jones K W, et al 2017 Forest conservation incentives and deforestation in the Ecuadorian Amazon Environ. Conservation 44 56–65
Crossref

[18] Finer M, Jenkins C N, Pimm S L, Keane B and Ross C 2008 Oil and gas projects in the western Amazon: threats to wilderness, biodiversity, and indigenous peoples PLoS One 3 e2932
Crossref

[19] Hoorn C, et al 2010 Amazonia through time: Andean uplift, climate change, landscape evolution, and biodiversity Science 330 927–31

Crossref

[20] Potapov P, et al 2017 The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013 Sci. Adv. 3 e1600821
Crossref

[21] Watson J E, Dudley N, Segan D B and Hockings M 2014 The performance and potential of protected areas Nature 515 67
Crossref

[22] Oliveira P J, et al 2007 Land-use allocation protects the Peruvian Amazon Science 317 1233–6
Crossref

[23] Miranda J J, Corral L, Blackman A, Asner G and Lima E 2016 Effects of protected areas on forest cover change and local communities: evidence from the Peruvian Amazon World Dev. 78 288–307
Crossref

[24] Schleicher J, Peres C A, Amano T, Llactayo W and Leader-Williams N 2017 Conservation performance of different conservation governance regimes in the Peruvian Amazon Sci. Rep. 7 11318
Crossref

[25] Nepstad D, et al 2006 Inhibition of Amazon deforestation and fire by parks and indigenous lands Conservation Biol. 20 65–73
Crossref

[26] Adeney J M, Christensen N L, Jr and Pimm S L 2009 Reserves protect against deforestation fires in the Amazon PLoS One 4 e5014
Crossref

[27] Pressey R L, et al 2000 Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia Biol. Conservation 96.1 55–82
Crossref

[28] Joppa L N and Pfaff A 2009 High and far: biases in the location of protected areas PLoS One 4 e8273
Crossref

[29] MINAM (Ministerio del Ambiente). Lima; 2016 http://minam.gob.pe/

[30] Pekel J F, Cottam A, Gorelick N and Belward A S 2016 High-resolution mapping of global surface water and its long-term changes Nature 540 418
Crossref

[31] Loker W 1993 The human ecology of cattle raising in the Peruvian Amazon: the view from the farm Human Organ. 52 14–24
Crossref

[32] RAISG (Rede Amazônica de Informação Socioambiental Georreferenciada). Indigenous Territories – RAISG (Amazon Region) c2012. (Accessed: 15 March 2017)

[33] World Wildlife Fund & Conservation International 2016 PADDDtracker.org Data Release Version 1.1 (January 2017). Washington, DC: World Wildlife Fund; Arlington, VA: Conservation International

[34] Dinerstein E, et al 2017 An ecoregion-based approach to protecting half the terrestrial realm BioScience 67 534–45
Crossref

[35] Jenkins C N and Joppa L 2009 Expansion of the global terrestrial protected area system Biol. Conservation 142 2166–74
Crossref

[36] Butchart S H, et al 2015 Shortfalls and solutions for meeting national and global conservation area targets Conservation Lett. 8 329–37
Crossref

[37] Pirker J, Mosnier A, Kraxner F, Havlík P and Obersteiner M 2016 What are the limits to oil palm expansion? Glob. Environ. Change 40 73–81
Crossref

[38] Mäki S, Kalliola R and Vuorinen K 2001 Road construction in the Peruvian Amazon: process, causes and consequences Environ. Conservation. 28 199–214
Crossref

[39] Perz S G, Aramburú C and Bremner J 2005 Population, land use and deforestation in the Pan Amazon Basin: a comparison of Brazil, Bolivia, Colombia, Ecuador, Perú and Venezuela Environ., Dev. Sustain. 7 23–49
Crossref

[40] Finer M and Orta-Martínez M 2010 A second hydrocarbon boom threatens the Peruvian Amazon: trends, projections, and policy implications Environ. Res. Lett. 5 014012
Crossref

[41] Swenson J J, Carter C E, Domec J C and Delgado C I 2011 Gold mining in the Peruvian Amazon: global prices, deforestation, and mercury imports PLoS One 6 e18875
Crossref

[42] Oliveira L J, Costa M H, Soares-Filho B S and Coe M T 2013 Large-scale expansion of agriculture in Amazonia may be a no-win scenario Environ. Res. Lett. 8 024021
Crossref

[43] Perz S G, et al 2013 Trans-boundary infrastructure and land cover change: Highway paving and community-level deforestation in a tri-national frontier in the Amazon Land Use Policy 34 27–41
Crossref

[44] Lawrence D and Vandecar K 2015 Effects of tropical deforestation on climate and agriculture Nat. Clim. Change 5 27
Crossref

[45] Maxwell S L, Fuller R A, Brooks T M and Watson J E 2016 Biodiversity: the ravages of guns, nets and bulldozers

Nature 536 143–5
Crossref

[46] Asner G P and Tupayachi R 2017 Accelerated losses of protected forests from gold mining in the Peruvian Amazon Environ. Res. Lett. 12 094004
Crossref

[47] Ravikumar A, Sears R R, Cronkleton P, Menton M and Pérez-Ojeda del Arco M 2017 Is small-scale agriculture really the main driver of deforestation in the Peruvian Amazon? Moving beyond the prevailing narrative Conservation Lett. 10 170–7
Crossref

[48] Hai T C 2002 The Palm oil Industry in Malaysia (WWF, Malaysia)

[49] Laurance W F, et al 2011 The fate of Amazonian forest fragments: a 32-year investigation Biol. Conservation 144 56–67
Crossref

[50] Ferraz G, et al 2003 Rates of species loss from Amazonian forest fragments Proc. Natl Acad. Sci. 100 14069–73
Crossref

[51] Newmark W D, Jenkins C N, Pimm S L, McNeally P B and Halley J M 2017 Targeted habitat restoration can reduce extinction rates in fragmented forests Proc. Natl Acad. Sci. 114 9635–40
Crossref

[52] Halley J M, Monokrousos N, Mazaris A D, Newmark W D and Vokou D 2016 Dynamics of extinction debt across five taxonomic groups Nat. Commun. 7 12283
Crossref

[53] Broadbent E N, et al 2008 Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon Biol. Conservation 141 1745–57
Crossref

[54] Hess L L, Melack J M, Affonso A G, Barbosa C C, Gastil-Buhl M and Novo E M 2015 LBA-ECO LC-07 Wetland Extent, Vegetation, and Inundation: Lowland Amazon Basin. ORNL DAAC

[55] Hergoualc'h K, Gutiérrez-Vélez V H, Menton M and Verchot L V 2017 Characterizing degradation of palm swamp peatlands from space and on the ground: an exploratory study in the Peruvian Amazon Forest Ecol. Manage. 393 63–73
Crossref

[56] Koh L P, Miettinen J, Liew S C and Ghazoul J 2011 Remotely sensed evidence of tropical peatland conversion to oil palm Proc. Natl Acad. Sci. 108 5127–32 201018776

[57] Romero-Ruiz M H, Flantua S G, Tansey K and Berrio J C 2012 Landscape transformations in savannas of northern South America: Land use/cover changes since 1987 in the Llanos Orientales of Colombia Appl. Geogr. 32 766–76
Crossref

[58] Austin K G, Kasibhatla P S, Urban D L, Stolle F and Vincent J 2015 Reconciling oil palm expansion and climate change mitigation in Kalimantan, Indonesia PLoS One 10 e0127963
      Crossref

[59] Euler M, Schwarze S, Siregar H and Qaim M 2016 Oil palm expansion among smallholder farmers in Sumatra, Indonesia J. Agric. Econ. 67 658–76
      Crossref

[60] Castiblanco C, Etter A and Aide T M 2013 Oil palm plantations in Colombia: a model of future expansion Environ. Sci. Policy 27 172–83
      Crossref

[61] Environmental Investigation Agency 2015 Washington, DC Deforestation by definition: the Peruvian government fails to define forests as forests

[62] Miller A E 2017 Resistance and Risk in the Peruvian Amazon: Oil Palm Plantations Threaten Rights and Rainforests (Washington, DC: Amazon Watch)

[63] Forrest J L, et al 2015 Tropical deforestation and carbon emissions from protected area downgrading, downsizing, and degazettement (PADDD) Conservation Lett. 8 153–61
      Crossref

[64] MINAG. Plan Nacional de la Palma Aceitera (Peru, 2000–2010)

[65] Lambin E F, et al 2018 The role of supply-chain initiatives in reducing deforestation Nat. Clim. Change 8 109–16

[66] Carlson K M, Heilmayr R, Gibbs H K, Noojipady P, Burns D N, Morton D C, Walker N F, Paoli G D and Kremen C 2017 Effect of oil palm sustainability certification on deforestation and fire in Indonesia Proc. Natl Acad. Sci. 115 121–26 201704728

[67] Roundtable on Sustainable Palm Oil 2017 RSPO Complaints Panel's Decision on Plantaciones de Pucallpa (6 April 2017)

[68] Finer M, et al 2018 Combating deforestation: from satellite to intervention Science 360 1303–5
      Crossref

[*] Data associated with this letter are available at: https://doi.org/10.5061/dryad.kk7hq10.