
Supplementary information

The environmental impacts of palm oil in context

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The environmental impacts of palm oil in context – Supplementary materials

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SUPPLEMENTARY MATERIALS

SUPPLEMENTARY METHODS

The current study summarizes, and builds on, the findings from a review by the International Union for the Conservation of Nature (IUCN) Oil Palm Task Force¹ in response to IUCN Resolution WCC-2016-Res-061-EN requesting “a situation analysis of the implications for biodiversity conservation from the expansion of oil palm, and to review and define best practices in the industry”. The Situation Analysis primarily focused on oil palm in the context of biodiversity conservation based on literature published before 31 January 2018, and aimed to provide a more constructive pathway to addressing sustainability challenges in the palm oil industry. A draft version of the report was reviewed by 43 external reviewers from non-governmental organizations, academic institutions and people working in the palm oil industry, who provided some 600 comments that were then incorporated into a revised version (for comments and responses, see here: <https://www.iucn-optf.org/situation-analysis>). We updated the IUCN study with information from studies published subsequently, with an emphasis on other oil crops.

Comparative data on major vegetable oil crops

The estimates presented in Table 1 are best available estimates compiled from 18 data sources¹⁻¹⁸. The statistics presented are aggregated, and may include official, semi-official, estimated or calculated data. Where sources vary averages or ranges are given. The yield figures are most useful as comparative estimates.

The dataset is collated from a variety of sources, mostly based on statistics reported by countries. There is no information regarding sampling error available therefore it is difficult to estimate uncertainty. Therefore, it is not possible to assess the overall accuracy of the dataset. In the European

Union (EU), regulations mandate that the coefficient of variation shall not exceed 3% for the area of cultivation for main crops. However, for non-EU countries, the coefficient of variation may be larger. Further, we lack information regarding the magnitude of other errors which may occur as a result of different methods among the reporting organizations and countries.

To facilitate comparison between oil crops we have made some necessary simplifications. This includes the use of the gridded maps for crop distribution (see below), which provide rough estimates only for where crops, other than oil palm for which accurate global data are available, are grown. We also acknowledge that crop yield and other values may vary due to growing conditions, location, and other circumstances.

Description of methodology for species richness and range-size rarity in Table 1

We analysed the species richness and range-size rarity in the areas where oil palm, soybean, rapeseed, cotton, groundnuts and peanuts, sunflower, coconut, and maize are cultivated. The data used for this analysis derived from (1) SPAM 2010 (V2r0), which provides gridded maps that represent the estimated area of each crop globally at a spatial resolution of 10 km, and (2) the IUCN's species richness and range-size rarity maps for all assessed species of amphibians, birds and mammals (all Red List Categories) resampled to 10 km¹⁹. For the SPAM maps, we used the 'physical area' map, which represents the area in hectares where a crop is grown. The range-size rarity presents a high-positive skewed distribution and, thus, we reported the median as well as first and third quartiles to better represent the range of values of species richness and range-size rarity within each crop. These statistics were estimated using weighted percentiles²⁰ and considering the area of the crop in each pixel as weights in the calculation of the median and quartiles. In this way, pixels with high estimated crop area values had a major weight in the estimation of the statistics of species richness and range-size rarity. This approach takes the ordered values $\{x_1, x_2, \dots, x_n\}$, here representing the species richness and range-size rarity, with positive weights $\{w_1, w_2, \dots, w_n\}$ that sum up to 1 (summed crop area equal to 1). The p^{th} weighted percentile is the value x_k that satisfies the condition $\sum_{i=1}^{k-1} w_i = p$. For instance,

the weighted percentile 25th (or weighted first quartile) represents the value in which the summated weight is 0.25.

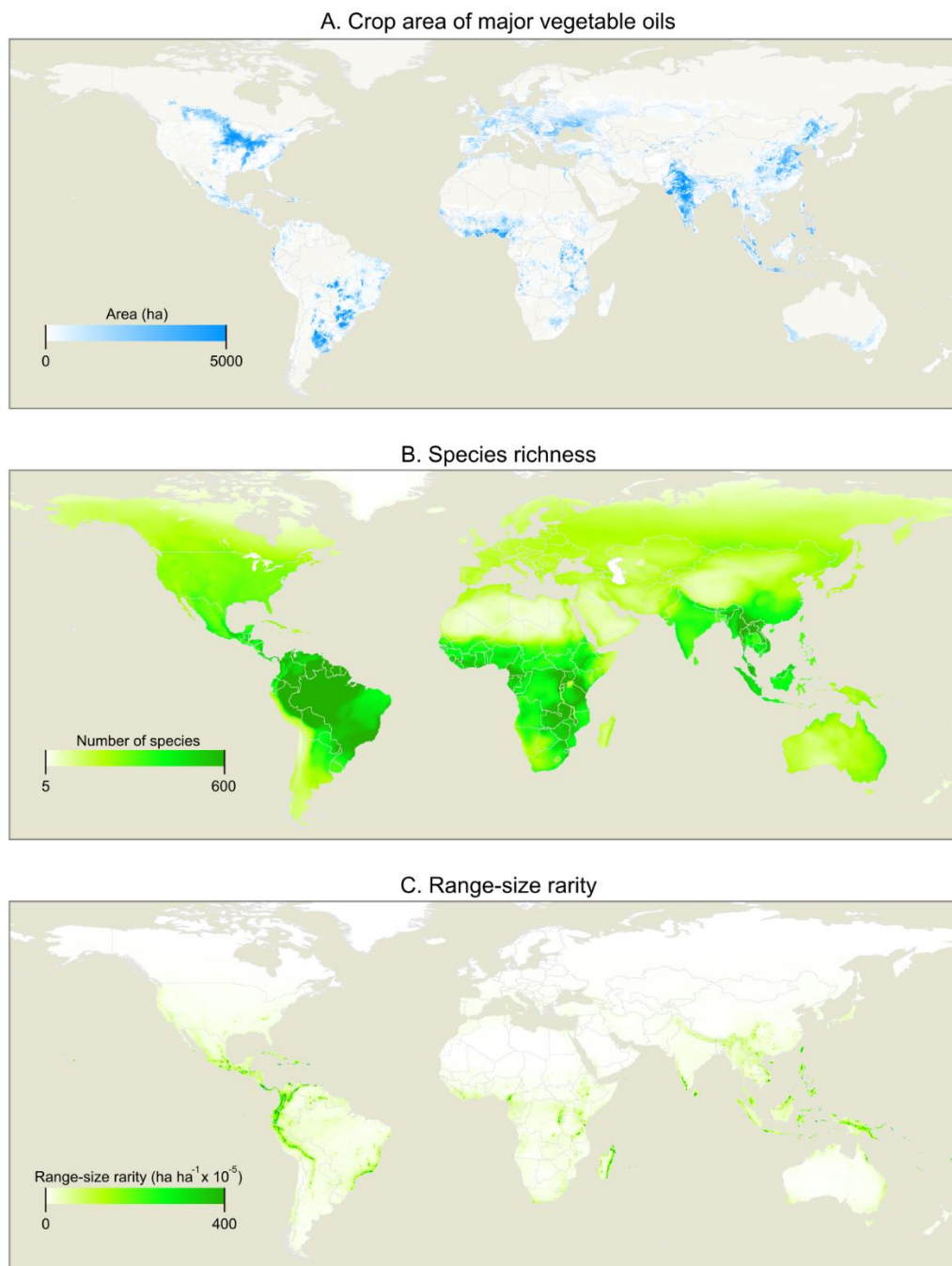


Figure S1. Maps of estimated crop area provided by SPAM 2010 (V2r0) (A) for oil palm, soybean, rapeseed, cotton, groundnuts and peanuts, sunflower, coconut, and maize, and species richness (B)

and range-size rarity (C) of all species assessed in the IUCN Red List. The crop area represents the estimated area in hectares where crop is grown within a 10-km pixel.

Oil Palm and deforestation

To determine how much global deforestation is due to palm oil we conducted a literature search. We initially used Google Scholar to identify peer reviewed articles focused on deforestation attributed to oil palm across actors, geographic location, and time. Example search terms are presented in Table S1. We read the abstracts of the first fifty titles returned for each search term and checked abstracts for relevance. Relevant papers were read in full. We identified additional potentially relevant papers from reference lists in these papers.

Criteria for inclusion: We selected peer-reviewed studies that reported land use or land cover change due to oil palm agriculture, or within government-allocated oil palm plantation leases Table S2). We filtered by method used to quantify oil palm expansion and land cover change, such that only studies that relied on geospatial data (e.g., remote sensing) were included.

Data collected: For each time-step in each article, we collected data on the total study area, initial and final forest area, area deforested due to oil palm, initial and final oil palm area, start and end year, actor responsible for oil palm expansion (i.e., smallholder versus industrial-scale company), methods (e.g., remote sensing), and geographic location. Where possible, we recorded forest cover quality (e.g., logged, intact) and ecosystem type (e.g., peat swamp forest, mangrove forest). We standardized all area metrics to hectares.

Definition of forest: We relied on the forest classifications presented in the original studies. “Forest” is considered any intact, primary, logged, or secondary forest of any kind, including mangrove, peat swamp, lower montane, and lowland forest. We excluded grasslands, savannas, and agroforests from our definition of forest, as this study focuses on natural forests.

Calculations: We calculated the percent of total deforestation in the study attributed to oil palm (i.e., deforestation from oil palm/total deforestation) as well as the percent of total oil palm expansion that cleared forest (i.e., oil palm expansion into forest/total oil palm expansion, Figure S2, Table S3). Means and medians were weighted by the study area times the number of years in a time period. Calculations were done with R software.

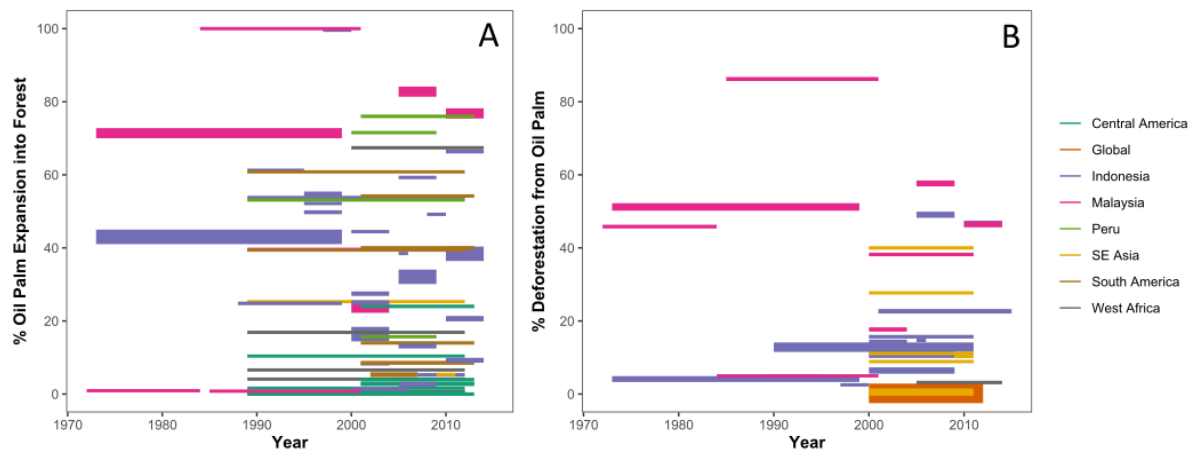


Figure S2. Percent of oil palm expansion into forest from 1972 to 2015 across regions and research investigations. Each bar represents the percentage of (A) total oil palm expansion that was due to deforestation or (B) total deforestation attributed to oil palm expansion (y axis) across two points in time (x axis) derived from an individual study. The height of the bar represents the sampled study area (ha) with taller bars indicating larger study areas. SE Asia excludes Indonesia and Malaysia, while South America excludes Peru.

Table S1. Search terms used in literature search. Combinations of above terms were entered into google scholar. The abstracts of the first fifty results were scanned for relevance, and relevant papers were downloaded and read in full. Citations within relevant papers were then obtained and followed using the “snowball method”.

Search Term
Land use change
Oil palm
oil palm” land use change Indonesia
“oil palm” land use change Malaysia
“oil palm” land use change Cameroon
“oil palm” land use change Ghana
“oil palm” land use change Dem. Republic of Congo
“oil palm” land use change Guatemala
“oil palm” land use change Peru
“oil palm” land use change Brazil
“oil palm” deforestation
“oil palm” smallholder
Tropical deforestation palm oil
Gabon oil palm expansion
Cameroon oil palm expansion
Kalimantan oil palm deforestation
Borneo oil palm deforestation
Oil-palm forest
Peru forest palm oil
Cover change forest oil palm
Oil palm forest loss
Oil palm forest cover loss
Humid tropics forest oil palm

Table S2. Articles used in study.

Period	Region	Study Area (ha)	Forest Type	Forest Quality	Resolution	Method	Actor	Author
2000- 2010	SE Asia	56,659,954	peat swamp forest, lowland forest, forest	Intact or logged	250 m	within concessions	Industrial	(Abood et al. 2015) ²¹
1972- 2002	SE Asia	130,000	forest	logged	80 m	wall to wall with mapped OP expansion	Industrial	(Hansen 2005) ²²
1984- 2002	SE Asia	5,821	forest	Intact	NA	wall to wall with mapped OP expansion	NA	(Sujaul et al. 2010) ²³
2000- 2010	S America	93,624,000	forest	Intact and secondary	250 m	mapped OP expansion	Industrial vs smallholders	(Gutiérrez-Vélez et al. 2011) ²⁴
1989- 2011	SE Asia	1,203,800	forest	Intact, logged, secondary	30 m	wall to wall with mapped OP expansion	Industrial	(Carlson et al. 2012) ²⁵
2000- 2010	SE Asia	2,143,000	peat swamp forest	Intact	28.5 m	mapped OP expansion	Industrial	(Miettinen et al. 2012) ²⁶
1990- 2010	SE Asia	539,346	peat swamp forest, forest	Intact, logged, agroforest	30 m	wall to wall with mapped OP expansion	Industrial	(Carlson et al. 2013) ²⁷
2002- 2008	S America	114,000,000	forest	Intact	30 m	mapped OP expansion	NA	(Castiblanco et al. 2013) ²⁸
2001- 2010	S America	215,700	forest	Intact	30 m, 250 m	mapped OP expansion	Industrial	(Gutiérrez-Vélez &

								DeFries 2013) ²⁹
2000- 2010	SE Asia	3,508,938	peat swamp forest, lowland forest, lower montane forest, mangrove	Intact	250 m	within concessions	Industrial, smallholders	(Lee et al. 2014) ³⁰
1988- 2013	SE Asia	324,058	forest	Intact	30 m	within concessions	NA	(Tarigan et al. 2015) ³¹
1990- 2012	SE Asia	11,300,600	forest	Intact	30 m, 250 m	wall to wall with mapped OP expansion	NA	(Wijaya et al. 2015) ³²
1973- 2015	SE Asia	7,370,101,100	forest	logged	30 m	wall to wall with mapped OP expansion	Industrial	(Gaveau et al. 2016) ³³
1990- 2015	SE Asia	15,667,300	peat swamp forest	Intact	30 m	wall to wall with mapped OP expansion	Industrial, smallholders	(Miettinen et al. 2016) ³⁴
2005- 2015	W Africa	70,000,000	forest	NA	30 m	wall to wall with mapped OP expansion	NA	(Okoro et al. 2016) ³⁵
2000- 2012	SE Asia	4,626,545	mangrove	Intact	0.9 ha	wall to wall with mapped OP expansion	NA	(Richards & Friess 2015) ³⁶
2000- 2009	SE Asia	1,345,000	peat swamp forest, forest, mangrove	Intact	30 m	wall to wall with mapped OP expansion	Industrial, smallholders	(Saswate et al. 2016) ³⁷
1989- 2013	Pan- Tropics	921,210	forest	Intact	30 m	mapped OP expansion	NA	(Vijayaraj et al. 2016) ³⁸

1995-2015	SE Asia	8,879,000	forest	Intact, secondary	250 m	mapped OP expansion	Industrial	(Austin et al. 2017) ³⁹
2001-2014	Latin America	538,433	forest	Intact	250 m	mapped OP expansion	Industrial, smallholders	(Furumo & Aide 2017) ⁴⁰
2000-2013	Global	1,280,000,000	intact forest landscape	Intact	30 m	sample-based mapped OP expansion	NA	(Potapov et al. 2017) ⁴¹
2000-2015	W Africa	12,416	forest	Intact and secondary	30 m	wall to wall with mapped OP expansion	Industrial, smallholders	(Ordway et al.) 2019 ⁴²
2001-2016	Indonesia	455,765	forest	natural forest	30 m	sample-based OP expansion within deforested areas	Industrial, smallholders	(Austin et al. 2019) ⁴³

Table S3. Global and regional deforestation from oil palm expansion. Southeast Asia excludes Indonesia and Malaysia, and South America excludes Peru. Mean and median were calculated for each study-time period and were weighted by study area times the number of years in the time period. Range indicates the range of values across study-time periods. N (studies) is the number of studies that were used to generate these observations.

Region	Deforestation from Oil Palm Expansion (%)				Oil Palm Expansion into Forest (%)			
	<i>Weighted mean</i>	<i>Weighted median</i>	<i>Range</i>	<i>N (studies)</i>	<i>Weighted mean</i>	<i>Weighted median</i>	<i>Range</i>	<i>N (studies)</i>
Indonesia	16	4.1	0-86%	8	38	43	1.4-100%	5
Malaysia	47	51	5.0- 86%	5	68	71	0.81- 100%	4
Peru	-	-	-	0	44	58	0-99%	3
West Africa	3.2	3.2	-	1	10	6.6	0.40-67%	2
Southeast Asia (excluding Indonesia and Malaysia)	11	10	0-40%	2	6.2	5.4	0-25%	2
South America (excluding Peru)	-	-	-	0	5.5	5.3	0-61%	3
Central America	-	-	-	0	5.6	1.6	0-24%	2
Global	0.20	0.20	-	1	-	-	-	0

IUCN Red List of Threatened Species and oil seed crops

The Red List of Threatened Species follows a standardised classification scheme to identify and quantify threats (<https://www.iucnredlist.org/resources/threat-classification-scheme>). The scheme is supported by a detailed narrative in the form of free text (threats details field in each assessment) which is included in each species assessment. There are 11 main threat categories which are then subdivided in over 50 subcategories. These threat categories however do not record threats from specific crops. To determine whether a species is threatened by a specific crop the threats details text needs to be read in full.

We downloaded the detailed threat texts for all assessed species from The Red List of Threatened Species website in June 2019. The .csv file retrieved included 101,017 species.

We developed an R code to i) filter the original table to retain assessments for threatened species only (Critically endangered, Endangered, and Vulnerable); ii) look, in each of these assessments, whether a series of key crops appeared in the threat texts. In this way, the code extracted a list with only those species for which the selected terms were found in the threats detailed text.

The terms searched were: palm oil, oil palm, palm plantation, maize, corn, coconut, coconuts, peanut, peanuts, groundnut, groundnuts, olive, olives, rapeseed, canola, soy, soybean, soybeans, and cotton. The search was not case sensitive and did not pick up these terms within a word (i.e. Oliveira). For full details of the R code see GitHub repository:

https://github.com/DiegoJuBi/R_codes/blob/master/species_threats_oil_crops

We obtained a list of 650 species for which the key words were present in the detailed threat texts.

We then read all those texts to confirm whether the species was actually threatened by that crop.

We ended up with 614 species. Most exclusions were due to common names of species including

the terms searched (e.g., New England Cottontail *Sylvilagus transitionalis*, or Autumn Olive

Elaeagnus umbellata). In other cases, although the selected crops were mentioned in the text, it was

not clear whether these posed a major threat to the species. Table S4 in these supplementary materials shows the 614 species analysed. This information was summarised in Table 1 and Figure 4 in the main text.

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