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Impact of palm oil sustainability certification on village well-being and poverty in Indonesia

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The Roundtable on Sustainable Palm Oil has emerged as the leading sustainability certification system to tackle socioenvironmental issues associated with the oil palm industry. However, the effectiveness of certification by the Roundtable on Sustainable Palm Oil in achieving its socioeconomic objectives remains uncertain. We evaluate the impact of certification on village-level well-being across Indonesia by applying counterfactual analysis to multidimensional government poverty data. We compare poverty across 36,311 villages between 2000 and 2018, tracking changes from before oil palm plantations were first established to several years after plantations were certified. Certification was associated with reduced poverty in villages with primarily market-based livelihoods, but not in those in which subsistence livelihoods were dominant before switching to oil palm. We highlight the importance of baseline village livelihood systems in shaping local impacts of agricultural certification and assert that oil palm certification in certain village contexts may require additional resources to ensure socioeconomic objectives are realized.

Oil palm cultivation has expanded tremendously in response to global demand for oils and fats over the past three decades. In 2018, the crop covered around 19 million hectares of land across the tropics, and a further 10–14 million hectares is probably needed in this region to satisfy projected global demand in 2050[1]. Indonesia was the world's largest palm oil producer in 2018, supplying more than 40 million tonnes of crude palm oil, or 56% of global production[2]. The country's oil palm plantation area has tripled since 2000 and now covers 14 million hectares, greater than the area of Java[2]. Unlike other key agricultural commodities in Indonesia, where farms are largely managed by smallholders, the ownership of Indonesian oil palm plantations is mostly through private corporations[2] (Extended Data Fig. 1).

The continuing expansion of oil palm across tropical countries has prompted fierce national and international debate[3,4]. While governments, industry lobbies and companies have pointed to regional economic development and rural poverty alleviation to justify expansion of the oil palm sector[4–6], numerous social and environmental costs of the industry have also been reported. These include land conflicts[7–9], loss of forest[10], biodiversity[1] and traditional livelihoods and culture[8,11], water scarcity and pollution[12–14], increased flooding[15], and heightened risk of fire and concomitant emissions, especially due to expansion of plantations on peatland[16–19]. In response to these sustainability concerns, the Roundtable on Sustainable Palm Oil (RSPO) was formed in 2004 as a multistakeholder participatory body that promotes more-sustainable production, in part by offering a sustainability certification system[20]. In 2019, around 4 million hectares of oil palm plantations had been certified, equating to ~20% of the global area cultivated[21]. Certified plantations are predominantly managed by companies (90%[21]), although there have been efforts by the RSPO to enable greater smallholder participation[22].

Despite 15 years of promoting more-sustainable production practices, the effectiveness of RSPO certification in delivering social and environmental benefits to local communities in producing areas remains uncertain[23,24]. Mixed impacts of certification have been reported by several studies on the basis of counterfactual evidence comparing the performance of certified and similar non-certified concessions[25–29]. Few, if any, such robust evaluations have addressed social aspects beyond basic financial measures, mainly because of a lack of systematic socioeconomic data availability over large spatial and temporal scales. In addition, past social evaluations have not fully accounted for the substantial heterogeneity in baseline village conditions, such as socioeconomic and sociocultural characteristics, which may result in misleading assessments of certification outcomes[30,31]. Indeed, numerous sociology and development studies provide evidence for the widespread failures of development programmes based on modernization approaches and technologies applied to agriculture without adequately considering resource barriers to local communities, institutional and infrastructural constraints, and cultural values[32,33] (see Supplementary Methods 1 for further discussion).

Here we evaluate the impact of RSPO certification on village well-being across the main oil palm-producing regions of Indonesia: Sumatra (land area of 470,000 km^2; comprising 24,259 villages or *desa*), Kalimantan (540,000 km^2; 7,095 villages) and

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Papua (420,000 km^2; 4,957 villages) (Fig. 1). Of the total 36,311 villages sampled across the three islands, we identified 2,602 villages with large-scale non-certified oil palm plantations (those with at least 10% of the land area allocated to non-certified industrial plantations—the median amount across the whole region) and 794 villages with large-scale RSPO-certified plantations (≥10% of the village land area allocated to RSPO-certified plantations). We define village-level well-being in line with the Sustainable Livelihood Approach[34,35] in terms of the socioeconomic (living conditions, infrastructure and income support) and socioecological (security, social equity and natural hazard prevention) capabilities of people to function in society (Supplementary Table 1 and Supplementary Methods 2). Poverty arises when these capabilities break down[36]. We applied rigorous counterfactual analysis based on statistical matching methods to address three research questions: (1) How have oil palm and RSPO certification expanded in Indonesia in the context of ongoing rural development and agrarian transition? (2) What have been the impacts of oil palm and subsequent RSPO certification on village-level well-being? (3) What lessons can be learned from how these impacts have been generated in relation to changing land use, livelihoods and community composition?

To answer these questions, we tracked changes in 18 socioeconomic and socioecological well-being indicators throughout the certification process, from before plantations were first established to several years after plantations were certified. We derived these well-being indicators together with information on primary livelihood sectors from a large longitudinal dataset of village-level censuses—*Potensi Desa* (PODES) or 'Village Potential'—collected by Indonesia's Bureau of Statistics (BPS) roughly every three years between 2000 and 2018[37]. By incorporating the latest census in 2018, we evaluated poverty change in 587 villages 5–11 years after the development of industrial oil palm plantations and 500 villages 5–11 years after the issuance of RSPO oil palm certificates, thereby providing insights on how impacts manifest as land is first converted to oil palm and then later certified. This nuanced assessment of how the characteristics of the oil palm industry evolve over time in a particular location is rarely addressed in other studies.

Regional variation in oil palm and RSPO certification

The pace of development in Indonesia's oil palm industry has been unevenly distributed. Most development has occurred in Sumatra (now 81,200 km^2) (Fig. 1a and Extended Data Fig. 2), with the island being the oldest centre of oil palm production. The industry then expanded eastward across the major regions of Kalimantan (53,300 km^2) (Fig. 1b and Extended Data Fig. 3) and more recently Papua (2,100 km^2) (Fig. 1c and Extended Data Fig. 4). In Sumatra, the extent of oil palm plantations nearly doubled since 2000, while Kalimantan and Papua experienced a near-fourfold increase in production area over the same period (Fig. 1 and Extended Data Figs. 2–4). The three regions can be viewed as being at advanced, intermediate and early stages of oil palm development, respectively. These distinct development stages are broadly reflective of the expansion of the crop pan-tropically. For example, Malaysia and Thailand are also at an advanced stage of oil palm development, while the industry is still in its infancy across Latin America[1].

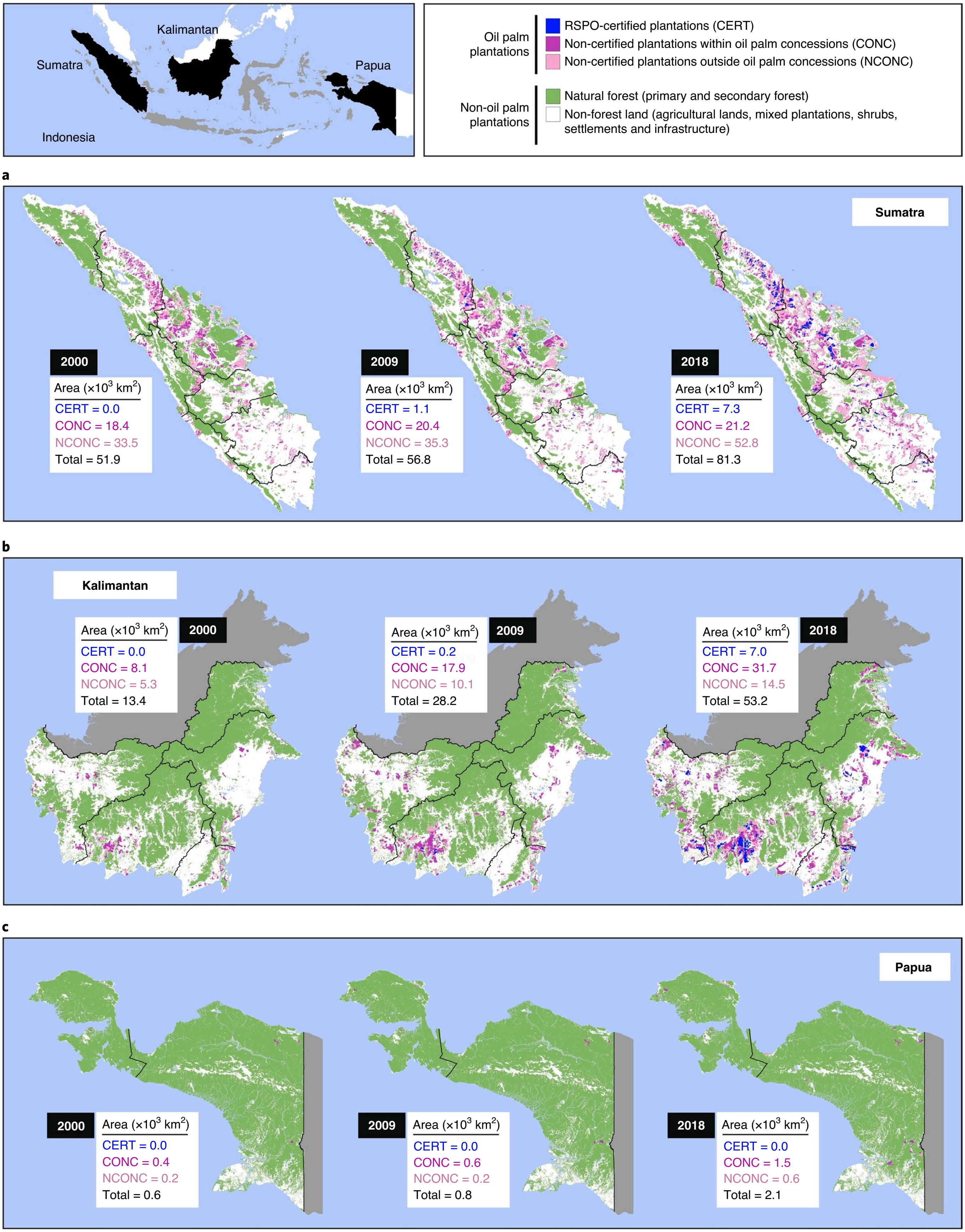
The developmental context in Sumatra, Kalimantan and Papua is also reflected in patterns of plantation ownership. In Indonesia, cultivation of more than 25 hectares of croplands by a single farmer or entity requires a concession permit (*Izin Usaha Perkebunan*), issued by the head of a regency, mayor or governor (Ministerial Decree No. 98/Permentan/2013). In Sumatra, between 2000 and 2018, oil palm plantations (planted oil palm) were largely dominated by non-concession holders (64%), which represent mostly smallholders (68%) and medium- to large-scale industrial plantations with unknown concession status (32%, Supplementary Fig. 1). There, the rate of plantation expansion outside of known concession boundaries exceeded that within large-scale concessions (that is, non-certified industrial oil palm plantations and RSPO-certified industrial plantations) (Fig. 1a and Extended Data Fig. 2). Conversely, over the same period, large-scale industrial plantations dominated oil palm expansion in Kalimantan and Papua (66% for non-certified with concessions and certified combined in Kalimantan and 69% for non-certified with concessions in Papua) (Fig. 1b,c and Extended Data Figs. 3 and 4).

Analysis of the primary land use or cover in villages between 2000 and 2018 indicates that those with ≥10% of village land area under industrial oil palm plantation in 2018 but <10% of area in industrial oil palm in 2000 experienced a typical sequence of land use before oil palm development (Fig. 2a and Extended Data Fig. 5). In 2000, 23% of these villages were primarily forested, and timber was frequently commercially harvested[38], resulting in degraded forest stands. These villages were then transformed to agricultural lands, mixed plantations and shrubs, then to (non-certified) industrial oil palm plantations. Some of the existing (non-certified) oil palm plantations were later granted RSPO certification. Conversion from forest to certified plantations had rarely occurred (Extended Data Fig. 5).

Each of these land uses is associated with specific livelihood systems and community composition (ethnicity) within village boundaries defined in the PODES census. According to data from 2000, 2005, 2011 and 2018 across villages in Sumatra, Kalimantan and Papua, those villages with high natural forest cover were typically dominated by subsistence-based communities (subsistence farming, fishing and forest-product gathering, in complex agroforestry systems and with weak exposure to the market economy) and comprised a high proportion of people belonging to ethnic groups native to the island (Fig. 3). Villages with agricultural lands, mixed plantations and shrubs as the primary land use or cover typically had a larger proportion of agricultural plantation communities, mainly polyculture smallholders (with some exposure to the market system[30,31]), and larger proportions of ethnic groups from other islands who were likely recent migrants (Fig. 3). Villages with non-certified oil palm plantations as the primary land use had substantially larger proportions of their community working in plantation agriculture, where monoculture oil palm was the norm (with stronger market-driven orientation[30,31]), and large proportions of migrants (Fig. 3). In villages dominated by the RSPO-certified plantations, monoculture oil palm plantation communities and migrants were also prominent (Fig. 3). Thus, primary land-use transition is likely to have important social implications for village communities through changes in livelihood systems and social structure (Fig. 2b). These transitions are not necessarily unidirectional; for example, if oil palm fails, the system can return to mixed plantations and shrubs. We do not consider such transitions away from oil palm here.

Fig. 1 | Change in distribution of forest and oil palm plantations in Sumatra, Kalimantan and Papua. a–c, The change in the distribution of forest and oil palm plantations every nine years between 2000 and 2018 across three major Indonesian islands: Sumatra (**a**), Kalimantan (**b**) and Papua (**c**). Oil palm plantations are grouped into three categories: (1) RSPO-certified plantations (certified large-scale industrial plantations; CERT), (2) non-certified plantations within oil palm concessions (non-RSPO-certified large-scale industrial plantations; CONC) and (3) non-certified plantations outside known oil palm concessions (mainly independent small-scale landholders and medium- to large-scale plantations with unknown concession status; NCONC) (Methods). Detailed maps for portions of each island are provided in Extended Data Figs. 2–4.

Rural development has traditionally been, and often still is, pushed by governments to achieve development targets measured mostly through economic material attainment (large industry and manufacturing and the market-based economy) rather than improving underlying human capital (capability and adaptation of technology within local culture, knowledge and outlook)[39]. Relying



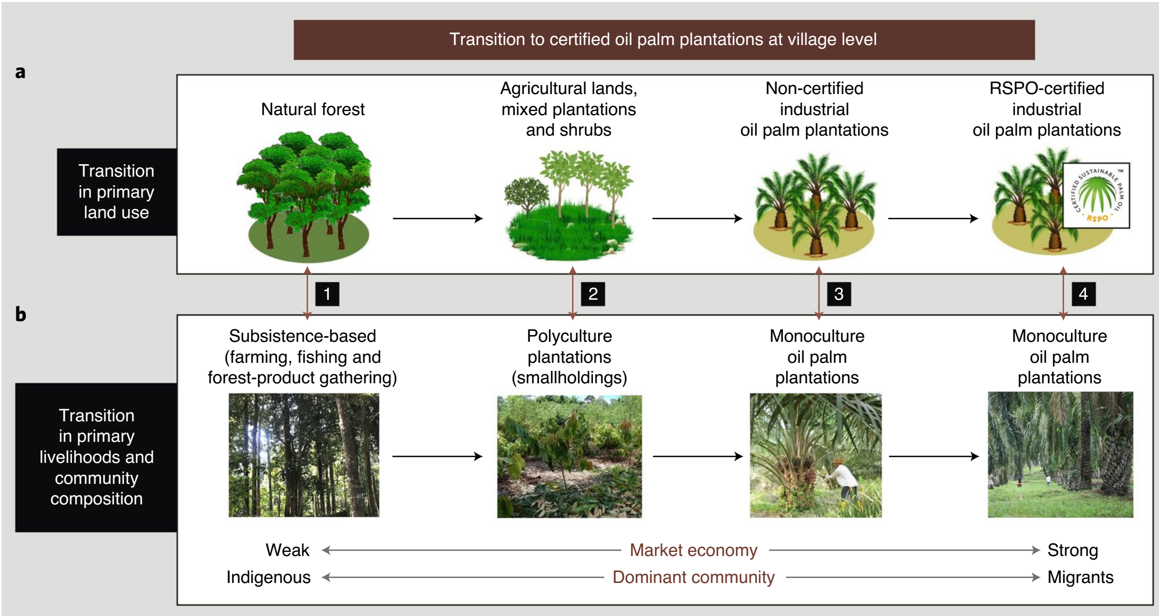


Fig. 2 | Village land-use (and associated livelihood) pathways to oil palm certification. a, The change in village primary land use, from (1) high natural forest cover to (2) agricultural lands, mixed plantations and shrubs, followed by (3) industrial oil palm plantations (non-certified), then finally becoming (4) RSPO-certified industrial plantations. **b**, The change in village primary livelihoods and community composition most likely associated with the change in village primary land use, from (1) subsistence-based livelihoods in complex agroforestry systems (weak market exposure) dominated by indigenous communities, to (2) polyculture plantation (smallholding) livelihoods (moderate market exposure) dominated by indigenous communities and a higher proportion of migrants, then finally becoming (3) monoculture oil palm plantation livelihoods (stronger market driven) with a high proportion of migrants.

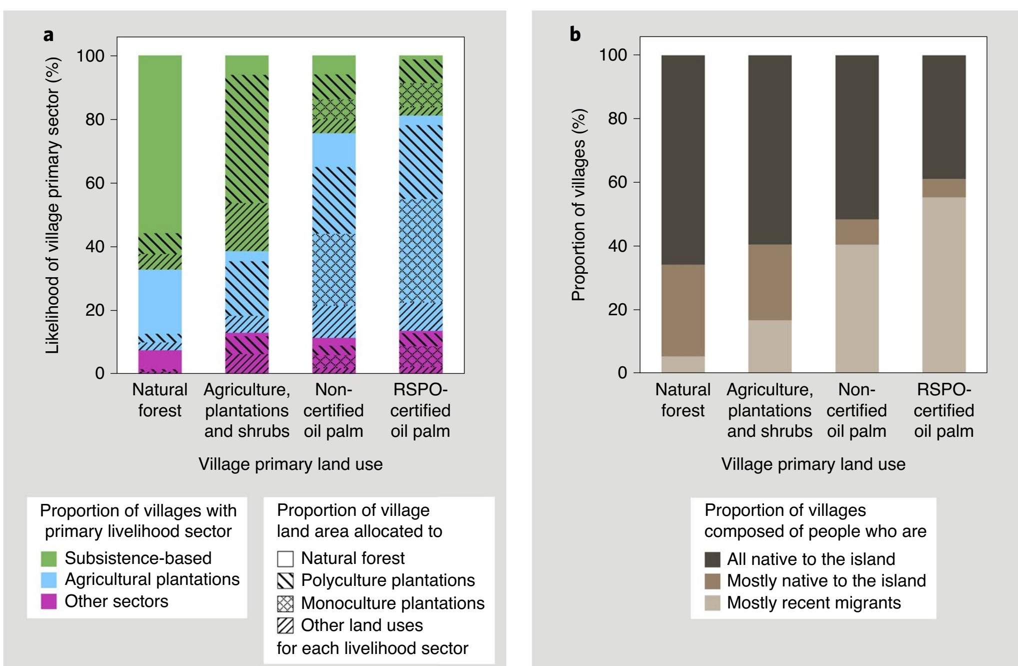


Fig. 3 | Village primary livelihoods and ethnic features or identities by village primary land use. a, Proportion of villages with primary livelihoods subsistence-based, agricultural plantations and other sectors, and proportion of village land area allocated to natural forest, polyculture plantations, monoculture plantations and other land uses for each livelihood class, by village primary land use (natural forest; agricultural lands, plantations and shrubs; non-certified industrial oil palm plantations; and RSPO-certified industrial oil palm plantations), averaged across 2000, 2005, 2011 and 2018 data. **b**, Proportion of villages within each land-use type that are composed of people who all, or mostly, identify themselves as belonging to ethnic groups native, versus non-native, to the island.

heavily on industry and market-driven systems to meet development targets can result in immense social costs to rural communities because doing so allows little opportunity and time for people to adapt[40]. Kalimantan exemplifies this type of rapid development over the past two decades, as evident from the high prevalence (52%) of villages experiencing drastic change in dominant land use from

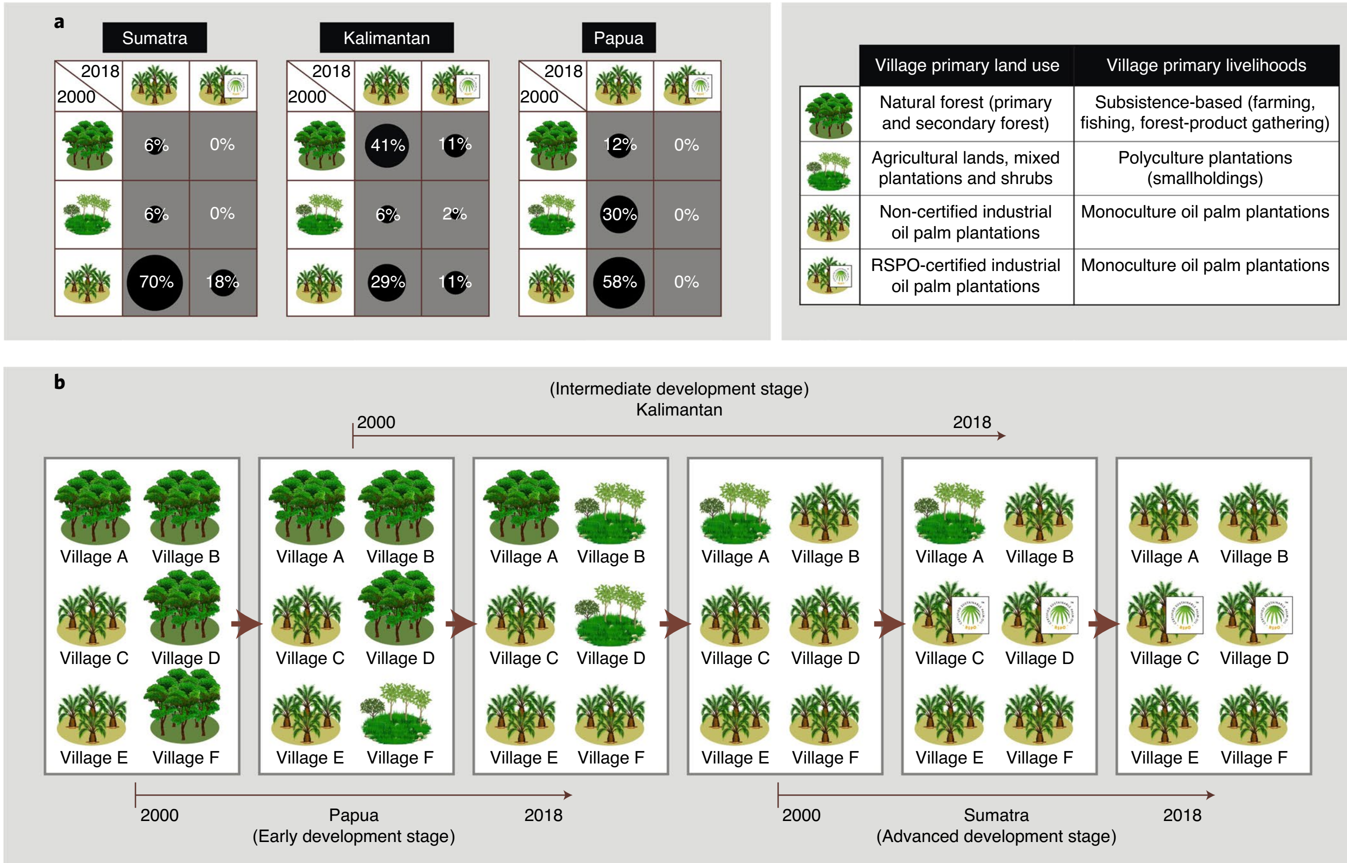


Fig. 4 | Village land-use (and the associated livelihood) change matrix to oil palm plantation and certification. a, Change in village primary land use (and the associated primary livelihoods) between 2000 and 2018, from natural forest; agricultural lands, mixed plantations and shrubs; and non-certified industrial oil palm plantations in 2000 to non-certified industrial oil palm plantations and RSPO-certified plantations in 2018, in Sumatra, Kalimantan and Papua. **b**, Schematic diagram of transition of village primary land use (and the associated livelihoods) between 2000 and 2018 from left to right, representing different development stages of the industrial oil palm plantations for Papua, Kalimantan and Sumatra: early, intermediate and advanced stages, respectively. The boxes in **b** represent the development stage of the island, not necessarily the parts where oil palm expanded. We used six villages in each box to best resemble the matrix described in **a**.

high natural forest cover to primarily oil palm monoculture (41%) and from forest to certified plantations (11%) between 2000 and 2018 (Fig. 4a). Comparatively, in Sumatra and Papua, 88% of villages with industrial oil palm plantations or certified plantations as the primary land use in 2018 were already dominated by industrial monoculture plantations in 2000 (Fig. 4a).

Land-use changes in villages shifting to industrial oil palm plantations (Fig. 4a) reflect an underlying pattern of oil palm development and expansion in Indonesia. Papua represents an early stage of the oil palm industry, where plantation development is mainly confined within former or current transmigration villages and operated mostly by large oil palm companies[41] (Fig. 4a and Extended Data Fig. 4). Kalimantan represents the intermediate stage of industrial oil palm development, where company plantations have expanded rapidly into villages in forested landscapes that are dominated by subsistence-based communities (Fig. 4a and Extended Data Fig. 3). These expansions lead to an influx of workers and stimulate spontaneous migrations to the newly opened oil palm areas[42]. At this intermediate stage, oil palm smallholdings also expand, but the expansion rate is slower than that of the industrial-scale plantations (Extended Data Fig. 3). Sumatra represents the advanced stage of oil palm development, where the number of smallholders, who migrated either in the preceding intermediate stage or more recently, continues to grow and expand, exceeding the rate of expansion of the company plantations (Fig. 4a and Extended Data Fig. 2). This in turn creates a complex company and smallholder relationship[43,44]. The intermediate stage of oil palm development that occurred over the past two decades in Kalimantan (Fig. 4b) generated swift radical transformation in village life systems in many parts of the island, which often led to conflict[30,31]. On the basis of the PODES data, during this transformation period, social conflicts were 22% more prevalent in villages with industrial oil palm plantation development compared with those without, and such conflicts were more prevalent in Kalimantan than in Sumatra and Papua (Supplementary Fig. 2).

Impacts of oil palm and certification on well-being

We assessed the impact of RSPO certification on village well-being by comparing the change in equally weighted indicators in villages with plantations certified for 5–11 years with those with non-certified plantations over the same time interval, while ensuring similar baseline characteristics in both types of villages (Supplementary Table 2). Results aggregated across the three Indonesian islands indicate that the impact of certification varied by baseline village primary livelihood sector before certification. Compared with similar villages with non-certified plantations, those with certified plantations experienced an overall reduction in well-being. Combined measures of socioeconomic and socioecological well-being declined by 11% on average in communities that relied on subsistence-based livelihoods before certification compared with non-certified

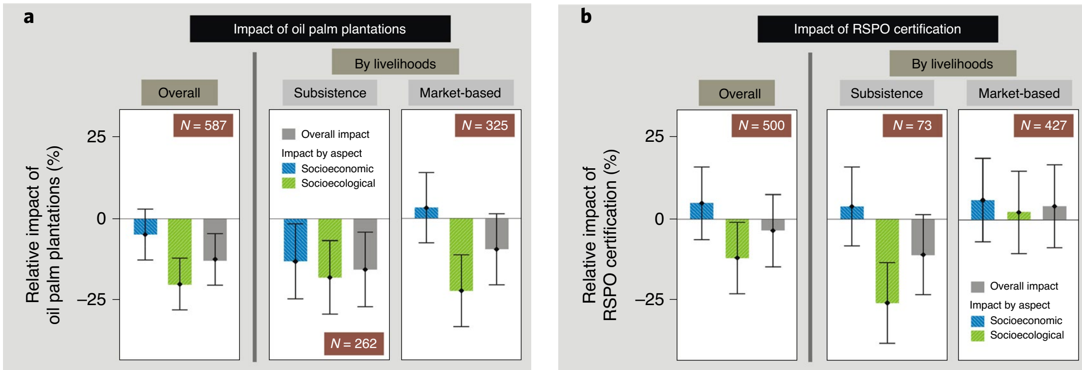


Fig. 5 | Impact of oil palm plantation development and certification on well-being in oil palm-growing villages. a, Impact of oil palm plantations on village-level well-being, evaluated by comparing the change in well-being indicators in villages with oil palm after 5–11 years of plantation development against the change in well-being in villages without oil palm across Sumatra, Kalimantan and Papua. **b**, Impact of RSPO certification on village-level well-being, evaluated by comparing the change in well-being indicators in villages with certified plantation after 5–11 years of certification against the change in well-being in villages with non-certified oil palm plantations across Sumatra and Kalimantan. In both analyses, comparisons are made between village types with similar baseline characteristics appropriate to the datasets analysed. *N* represents the number of villages assessed in each panel. Error bars represent 95% confidence intervals of combination of all indicators in the groups.

villages (Fig. 5b). This decline was driven mainly by the fall in socioecological indicators, predominantly via a significant increase in the prevalence of conflicts, low-wage agricultural labourers, and water and air pollution (Extended Data Fig. 6). Conversely, the overall well-being marginally improved by 4% in communities that relied on market-based livelihoods before certification (polyculture plantations or monoculture non-certified oil palm plantations) (Fig. 5b).

We found that expansion of oil palm into new areas resulted in similar well-being change patterns as certification (Fig. 5). Villages that relied on subsistence livelihoods before oil palm development experienced an overall reduction in well-being by 16% on average after 5–11 years compared with the counterfactual of no oil palm development across all three islands (Fig. 5a). The reduction in overall well-being was driven by the decline in both socioeconomic and socioecological components, primarily the reduction in electricity access, adequate sanitation and cooking energy, and secondary schools, as well as the increased prevalence of conflicts, low-wage agricultural labourers, water pollution and floods (Extended Data Fig. 7). Villages with oil palm plantations where the majority of communities had relied on market-based livelihoods before oil palm development (polyculture plantations outside concessions) also experienced reduced overall well-being by 9% compared with the counterfactual, but the impact on socioeconomic well-being was marginally positive (improved by 3% on average) (Fig. 5a). Thus, the immediate impact of oil palm development in the production villages with market-based livelihoods appears to be better than that observed in villages dominated by subsistence-based livelihoods; socioecological losses appear to be partially compensated by socioeconomic gains.

Because in Kalimantan certification has taken place disproportionately in areas where village communities were still dependent on subsistence-based livelihoods (Fig. 4a), the impact of certification on well-being in this region has been negative overall (Extended Data Fig. 8b). However, the impact of certification in Sumatra has been positive overall (albeit marginal) (Extended Data Fig. 8b), mitigating negative impacts on socioecological well-being indicators associated with non-certified oil palm. Unlike in Kalimantan, a higher proportion of plantations in Sumatra has been certified in villages where market-based communities are more dominant (Fig. 4a). This demonstrates that failing to account for the influence of baseline livelihoods on the potential benefit flows of certification could lead to misplaced inferences from the impact evaluation.

Well-being change through oil palm and certification processes

Trends in the change of village well-being through the process of oil palm expansion and certification provide a more comprehensive picture of the underlying mechanisms driving the impact (Fig. 6). In villages with subsistence livelihoods, socioeconomic improvements in oil palm villages were slightly slower to accumulate than those in non-oil palm villages, but this trend improved marginally following RSPO certification. Socioecological well-being in these subsistence-based villages worsened following oil palm development, a trend that continued after certification (Fig. 6a). This pattern was widespread in Kalimantan (Extended Data Fig. 8b), particularly in lowland peatland areas near the coast, which have experienced the most certification efforts to date. Conversely, improvements to socioeconomic well-being experienced in Indonesia were greater where oil palm, and later certification, was established in villages with market-based livelihoods. Measures of socioecological well-being in these market-based villages deteriorated following expansion of the oil palm sector but later improved following certification, albeit marginally (Fig. 6b). Thus, socioecological well-being in market-based villages with certification at the current state is indeed worse than without oil palm development two decades ago, but slightly better than the counterfactual of no certification a decade ago. This pattern is prevalent in Sumatra (Extended Data Fig. 8b). Thus, focusing merely on the immediate effect of certification could lead to missed crucial information and insights about what happened in village communities before certification even existed.

The overall negative association between certification in subsistence-based villages and outcome variables (compared with a counterfactual of non-certified plantations) reflects not an adverse outcome from certification itself, but the overwhelming social impact of large-scale industrial oil palm plantations on the well-being of communities that still depend on forest and associated natural capital, which indeed may be difficult to compensate even within a sound regulatory certification framework. In Indonesia, individual RSPO-certified plantations are significantly larger than non-certified industrial plantations (median plantations area of 8,000 and 2,500 ha for certified and non-certified plantations, respectively, on the basis of data from Sumatra and Kalimantan) (Extended Data Fig. 9a). A certified plantation company typically manages 10% of village land areas across three adjoining villages

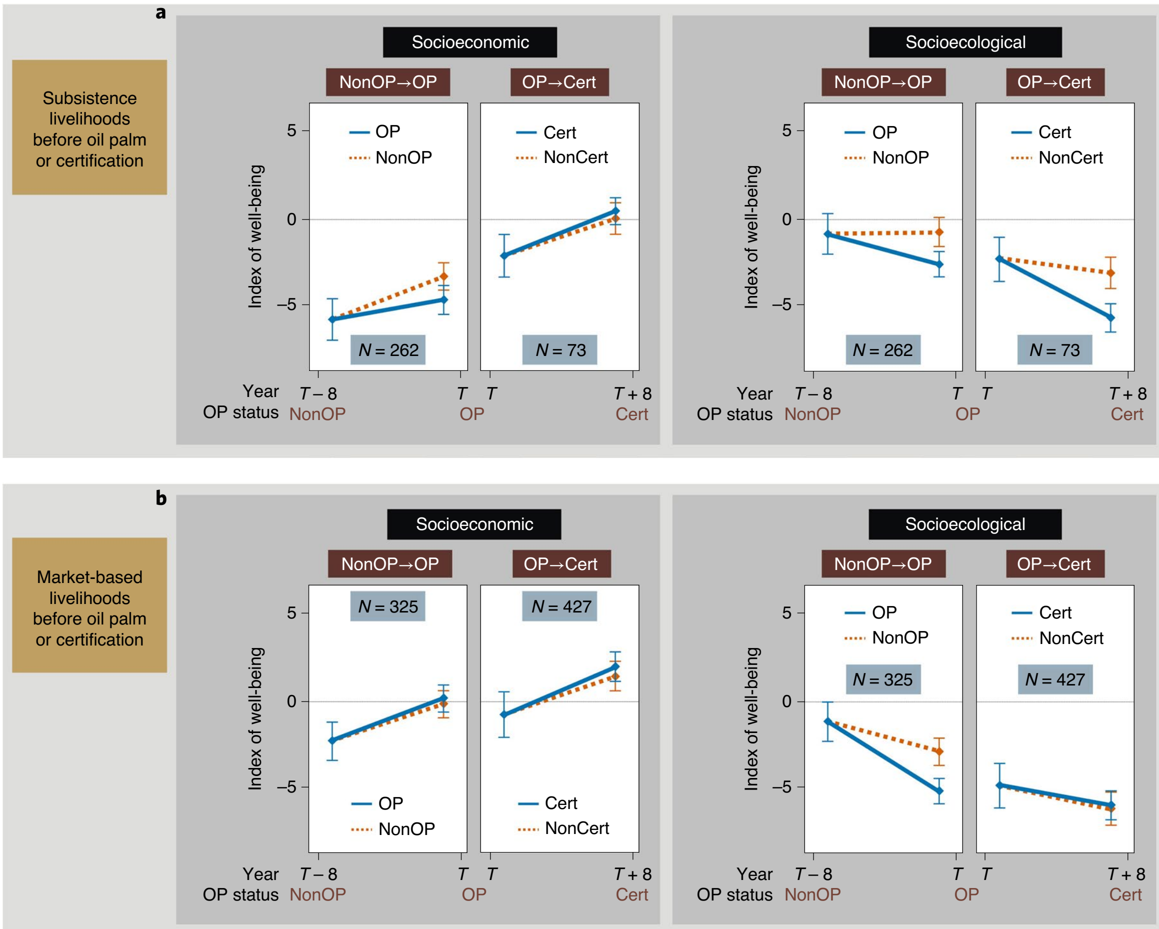


Fig. 6 | Trends in the change of village well-being through the oil palm and certification processes. a,**b**, Trends in the change of socioeconomic and socioecological well-being indices within 5–11 years (median 8 years) before and after oil palm development, and within 5–11 years (median 8 years) after oil palm certification. Villages are partitioned by their baseline primary livelihoods: subsistence-based livelihoods typical of the majority of plantations in Kalimantan (**a**) or market-based livelihoods typical of most villages with oil palm in Sumatra and Papua (**b**). *N* represents the number of villages assessed in each panel. Error bars represent 95% confidence intervals. Note that the baseline characteristics of samples for generating the left (NonOP→OP) and right (OP→Cert) panels are different; thus, the counterfactual comparisons should be made only within panels. The estimates in year *T* − 8 time period are the same between the treated and control villages because the samples were matched. OP, oil palm; Cert, certified.

(Extended Data Fig. 9b). Comparatively, one non-certified industrial plantation company typically manages only 3% of a village land area (Extended Data Fig. 9b). These differences are probably related to the high costs and technical capacities required for the RSPO membership participation and further for certification, which only large companies can bear[45]. This implies that there is likely an immense pressure being placed on the environment (soil, air and water quality and quantity) by certified plantations and the associated mills relative to non-certified ones simply due to the total plantation size and production scale across broader landscapes comprising several neighbouring villages[29,46,47]. Further, the scale of certified plantations compared with the non-certified ones indicates that the certified companies tend to have a much larger influence over village land use, environment and economy compared with those managing non-certified plantations. This could create more unbalanced social power structures in certified plantations in which traditional communities and their local governance have a relatively limited say over what happens on their land[40]. Thus, although here we have carefully controlled for the total size of all industrial plantations at village level to fairly compare certified versus non-certified plantation villages (Supplementary Table 2), the effect observed in certified plantation villages is likely to be masked by the overall plantation impact over larger jurisdictional scales. This suggests that the amount of land under cultivation by a single entity has important implications for the extent to which the perceived benefits of certification translate to improvements in community well-being. Our findings for the subsistence villages also imply that similar negative implications for community well-being recorded for certified plantations will probably occur for similarly extensive non-certified plantations.

Conclusions

The effectiveness of RSPO certification in upholding social and environmental standards within the oil palm industry has been called into question[23,24]. Using a comprehensive counterfactual assessment of longitudinal census data from Indonesia, the world's leading palm oil-producing country, we show that the association between RSPO certification and village-level well-being varies by location and baseline village livelihood conditions before certification was initiated. While marginal positive impacts were observed in villages where most communities relied on market-based livelihoods before certification, RSPO certification was associated with largely negative outcomes in rural villages oriented towards subsistence agriculture. The latter was probably because certified plantations under single companies tend to be substantially larger than non-certified plantations and cover several neighbouring villages. As a result, social and environmental externalities are difficult to remediate.

A potential caveat to these findings is that our analysis specifically focuses on the direct impact of certification and oil palm development on villages with oil palm production. We did not assess the possibility that impacts of oil palm or certification may be spatially autocorrelated or could lead to spillover effects[29] over a broader extent beyond the production areas, for example, in neighbouring villages without the oil palm industry. If this kind of spillover mechanism exists, the oil palm industry could even generate a wider welfare gap among villages at broader jurisdictional scales (for example, regency level) by accruing socioeconomic and socioecological costs to rural subsistence-based villages with the oil palm industry while accumulating most of the welfare benefits to suburban market-based villages. We also did not assess how different categories of oil palm production (different types of smallholders such as independent versus tied smallholders, and non-certified plantations) within villages classified as certified may have contributed to well-being since data are not currently resolved to these levels. Our evaluation focuses on localized impacts collectively over large spatial scales but does not incorporate national-level socioeconomic benefits obtained through taxation of palm oil production. Additional indirect impacts of the RSPO on government sustainability policies and practices for oil palm, such as the development of the national Indonesian Sustainable Palm Oil certification standard, are also so far immeasurable. These potential caveats notwithstanding, our appraisal has established important baseline information for further impacts to be monitored as the RSPO standard develops.

Our finding that oil palm development has failed to improve well-being in rural subsistence villages calls for careful consideration by key decision makers of unintended indirect impacts of pushing large-scale industrial oil palm into frontier forest areas where local communities still rely heavily on environmental services. We feel that it is important for governments in oil palm-producing countries to consider limiting the extent of industrial-scale plantations that can be developed until more positive impacts on community well-being can be guaranteed. This applies not only to existing rural areas in Indonesia but also to other world regions such as Central and West Africa and Latin America where the oil palm industry is expanding. RSPO's recent commitment to zero deforestation and avoidance of peatlands[20], as well as Indonesia's moratorium on concession allocation in primary forests and on peatlands, should help steer the industry towards already-developed agricultural lands with primarily market-based livelihoods.

Given that challenges associated with the oil palm industry vary by village baseline primary livelihoods, specific targeting of these livelihoods in certification criteria, as well as ensuring compliance with existing criteria with respect to livelihoods and communities, is recommended. In rural subsistence villages where industrial plantations have been established, we recommend further scrutiny by certification assessors on stringent compliance of social and environmental measures by companies—not only on zero deforestation, but also on preventing and mitigating pollution and water scarcity and the avoidance of plantation expansion without free, prior and informed consent, as defined in the RSPO Principles and Criteria. In market-based villages, in addition to the aforementioned activities, the RSPO should continue focusing on supporting smallholder participation and encouraging company–smallholder cooperation. The RSPO jurisdictional approach to certification[22] has recently been piloted in several former transmigration villages (for example, in Seruyan Regency in Central Kalimantan) and holds great promise for these market-based villages in supporting 'shared responsibilities' and cooperation across multiple stakeholders to work together towards improving sustainability at village jurisdictional levels.

Methods

Data. *Oil palm plantations and certification and land cover.* Throughout, the term 'plantation' refers to the area planted with oil palm, and 'concession' refers to the area where a land permit has been granted to develop oil palm, but where the land has not necessarily been planted. Therefore, a concession owned by a company can either cover a larger area than the plantation if the concession is not fully developed or cover roughly the same area as the plantation if the concession is entirely planted with palm. A plantation can also be developed outside a company concession, either as a smallholding or illegally[43].

We used plantation maps of every three years between 1997 and 2014, described by Santika et al.[30,31], but extended to 2018 and to cover Sumatra and Papua. These include medium- and large-scale industrial plantations (25–100 ha and >100 ha, respectively) and smallholder plots (<25 ha). We also used spatial data on oil palm concessions and RSPO-member plantations (certified and non-certified) across Indonesia described by Carlson et al.[26]. The data contain concessions certified by 2015, which we updated through web searching of records of RSPO-certified mills and supply estates to include those certified or proposed for certification between 2015 and 2018 . Annual forest cover 2001–2018 was estimated by overlaying the extent of natural forest (primary and secondary) across Indonesia in 2000 provided by Margono et al.[48] and the locations of annual deforestation derived from the Global Forest Change website[49].

Combining information on forest cover, plantations, concession boundaries and RSPO-member plantations (certified and non-certified), we estimated the distributions of natural forest and three plantation ownership types (Fig. 1): (1) RSPO-certified industrial plantations; (2) non-certified plantations within concession boundaries (which includes mainly the non-certified RSPO-member plantations and non-RSPO industrial-scale plantations); (3) non-certified plantations outside concessions (largely includes independent smallholders (<25 ha) and a small proportion of medium to large plantations (≥25 ha) with unknown concession permit) (Supplementary Fig. 1). Areas outside natural forest and oil palm plantations comprise mainly agricultural lands, mixed plantations (for example, rubber, coffee), shrubs, settlements and infrastructure (Fig. 1). Our impact evaluation focused specifically on non-certified oil palm plantations within concession boundaries and RSPO-certified plantations and excluded those outside known concession permits. Detailed methodologies for generating these spatial data are provided in Supplementary Methods 3.

Village primary livelihoods. Primary livelihood sectors across the villages in Sumatra, Kalimantan and Papua were derived from the PODES census, collected from village heads by the BPS of Indonesia roughly every three years between 2000 and 2018[37]. These data contain information on the socioeconomic and development status for each village administrative boundary. Three major livelihoods were identified via PODES: (1) subsistence production, including small-scale farming for staple foods, fishing and the collection of forest products; (2) agricultural plantations, including both polyculture and monoculture plantations; (3) other sectors, including horticulture, aquaculture, livestock, agricultural services and non-agricultural activities (Fig. 3a). In the analysis, market-based livelihoods include agricultural plantations (polyculture and monoculture) and other sectors[30,31].

Indicators of well-being. Village-level PODES data from 2000, 2003, 2005, 2008, 2011, 2014 and 2018 were used as proxy indicators for two aspects of village well-being: socioeconomic and socioecological (Santika et al.[30,31]; Supplementary Table 1). The socioeconomic aspect includes living conditions, infrastructure and income support, and the socioecological aspect includes security, social equity and natural hazard prevention[50,51]. PODES provides the most comprehensive public information on land use, population demographics and village infrastructure available in Indonesia and has been used extensively to inform government policy and development studies[52,53]. The choice of indicators and directionality of the effects on well-being listed in Supplementary Table 1 correspond to existing methodologies used to assess poverty and livelihoods[30,31], such as the Sustainable Livelihood Approach[34], the Multidimensional Poverty Index[54] and the Nested Spheres of Poverty[55]. Our categorization of indicators closely follows that advocated by the Sustainable Livelihood Approach[34,35], in which the socioeconomic grouping encapsulates the human (basic), physical and financial dimensions of well-being, and the socioecological encapsulates social and natural dimensions (Supplementary Methods 2).

Analysis of land-use and livelihood change at village level. To capture the patterns of transition in primary land use towards RSPO-certified plantations at the village level, we classified each village into one of four categories on the basis of the dominant land cover: (1) natural forest; (2) agricultural lands, mixed plantations and shrubs; (3) non-certified industrial oil palm plantations; (4) RSPO-certified industrial oil palm plantations. Following a classification tree (Supplementary Fig. 3), we first sorted villages on the basis of the percentage of natural forest cover (primary and secondary forest): (1) villages with ≥50% of the land area allocated to natural forest (hereafter termed as 'villages with primarily natural forest') and (2) the remaining villages (>50% of the land areas allocated to agriculture, plantations, shrubs and other land uses). We then divided the second category on the basis of the extent of industrial-scale plantations: (1) villages with ≥10% of the land area allocated to planted industrial oil palm concession (hereafter termed as 'oil palm plantation villages') and (2) those otherwise (hereafter termed as 'villages with primarily agricultural lands, mixed plantations and shrubs'). Finally, we divided the oil palm villages on the basis of the extent of certified plantations: (1) villages with ≥10% of the land area allocated to planted certified oil palm concession (hereafter termed as 'RSPO-certified plantation villages') and (2) those otherwise (hereafter termed as 'non-certified plantation villages'). We used the 10% threshold for defining the oil palm plantation villages on the basis of the median proportion of village land area allocated to industrial oil palm plantations across Sumatra, Kalimantan and Papua (Supplementary Fig. 4c, left plot). We also used the 10% threshold for defining RSPO-certified plantation villages for the same reason across Sumatra and Kalimantan, noting there were insufficient certified plantations in Papua to evaluate impact there (Supplementary Fig. 4d).

We tracked the change in village primary land use that leads to predominantly industrial-scale oil palm plantations and RSPO certification between 2000 and 2018 across villages in Sumatra, Kalimantan and Papua (see Supplementary Table 3 for the number of villages assessed). To obtain an approximation of the latent structure of land-use change, we used the observed village primary land use in 2000, 2005, 2011 and 2018 (Supplementary Fig. 3).

To determine the livelihood dynamics associated with land-use change, we quantified the likelihood of a village falling within the three livelihood classes (subsistence livelihoods, agricultural plantations, and other sectors) for each primary land-use category (natural forest; agricultural lands, mixed plantations and shrubs; non-certified industrial oil palm plantations; and RSPO-certified industrial oil palm plantations) in 2000, 2005, 2011 and 2018 (Fig. 3a). To provide a nuanced understanding of the scale of plantations (either small to medium landholders or large-scale industrial plantations) associated with each livelihood class, we calculated the average proportion of village plantations located within the boundaries of oil palm concession. Larger proportions indicate a higher likelihood of the primary livelihood sector and economy in a village being driven by large-scale monoculture oil palm plantations compared with small- and medium-scale plantations (Fig. 3a). To assess the change in community composition and migration in the village, we also quantified the likelihood of each village falling within three broad ethnic identities or classes (all people identify as belonging to ethnic groups native to the island in question, the majority belong to ethnic groups native to the island or the majority belong to ethnic groups from outside the island) for each village primary land-use category over the same period (Fig. 3b).

Analysis of impact evaluation. *Spatial and temporal unit of analysis.* We conducted two separate impact evaluation analyses on poverty: (A) the impact of industrial oil palm plantations and (B) the impact of RSPO certification. For both analyses, we used the village administrative boundary as the spatial unit of analysis, which was defined in the BPS census in 2014[56]. The impact of oil palm on the change in village well-being (analysis A) was determined 5–11 years after plantation development to allow for time delays in the accrual of well-being benefits (for example, profits from harvesting[57] and infrastructure development[58]) as well as manifestation of social and environmental impacts (for example, conflicts[7–9], influx of workers[5] and pollution[12]). The impact of certification on the change in village well-being (analysis B) was also determined 5–11 years after certification. To do so, we compared the change in indicators between paired PODES censuses: 2000 and 2005 (5 years); 2000 and 2008 (8 years); 2000 and 2011 (11 years). The oil palm impact analysis covered 11 paired census data, and the analysis of certification impact covered three (Supplementary Table 4).

Units for treatment and counterfactual (control). When evaluating the impact of industrial oil palm plantation development (analysis A), the units receiving treatment were villages with ≥10% of their land area allocated to industrial oil palm plantation over the full study periods, but not within the previous five years. We used the 10% threshold on the basis of the approximate median proportion of village land area allocated to industrial oil palm plantations across Sumatra, Kalimantan and Papua (Supplementary Fig. 4c, left plot). As the unit for counterfactuals or controls, we used villages where none of the land areas were allocated to industrial oil palm plantations over the range of the analysis period or in the five years before that (see conceptual diagram outlining the definitions in Supplementary Fig. 5).

For the certification impact analysis (analysis B), the units receiving treatment were oil palm villages (villages with ≥10% of the land areas allocated to industrial oil palm plantations) where ≥10% of the land area was assigned to certified plantations over the full analysis periods but no certified plantations were detected within the previous three years. Again the 10% threshold for certification was based on the approximate median proportion of village land area allocated to certified plantations across Sumatra and Kalimantan (excluding Papua as few plantations were certified) (Supplementary Fig. 4d). For the counterfactual, we used oil palm villages with the same proportion of their areas allocated to industrial oil palm plantations as that in the treated villages and where none of the plantations were certified over the analysis period or in the previous three years (Supplementary Fig. 6).

Analytical framework. For each of two impact evaluations (oil palm and certification, separately) we followed four steps. First, for each island and period (or paired PODES censuses), we generated the propensity score or likelihood for the spatial assignment of industrial oil palm plantations or certification on the basis of a given set of biophysical and socioeconomic variables. Second, we applied a binary matching method for each island and period to select control villages with similar baseline characteristics to those in the treated villages through nearest-neighbour matching or search of propensity score and exact matching of key categorical variables. Third, we applied difference-in-difference regression to the matched dataset. Fourth, we conducted diagnostic tests and sensitivity analyses to verify the robustness of our estimates against modelling specification and approach. Detailed steps for conducting each impact evaluation are provided in Supplementary Methods 4.

Step 1: generating propensity scores. We generated the propensity scores for each island (Sumatra, Kalimantan and Papua for analysis A; Sumatra and Kalimantan for analysis B) and period by employing a non-parametric generalized boosted regression model (GBM) for binary outcomes implemented in the R-package gbm[59]. The GBM model allows flexibility in fitting non-linear response curves for predicting treatment assignment and can incorporate a large number of covariates without negatively affecting model prediction. We controlled for potentially confounding variables in each impact assessment in terms of both selections of villages for treatment and the outcome being measured (Supplementary Table 2). To achieve this, we included variables representing (1) sociopolitical factors, (2) accessibility, (3) agricultural productivity and (4) baseline village socioeconomic conditions. This selection is based on previous analyses of oil palm expansion without certification in Kalimantan[30,31].

Step 2: applying the matching method. For analysis A, we employed a binary matching method[60] to select a set of control villages in which oil palm plantations had not been developed and that exhibited the same baseline characteristics as villages where plantations had been established. For analysis B, we applied the matching to select a set of control oil palm villages without certification that exhibited the same baseline characteristics as oil palm villages where certification had been granted. Both analyses A and B were performed on the basis of nearest-neighbour matching of propensity scores using all variables described in Supplementary Table 2 and exact matching of the categorical baseline variables (KBPT, regency; LZON, land-use zone; FORB, forest cover class; SOIL, dominant soil type; and LVHD, village primary livelihood class). We applied a 0.25 caliper width of each propensity score standard deviation in the nearest-neighbour approach as this width was previously shown to be optimal[61]. Matching algorithms were implemented separately for each of the 18 indicators of well-being (Supplementary Table 1) in the R-package Matching[62].

For analysis A, the matching method was applied for each of the indicators (Supplementary Table 1), 3 islands (Sumatra, Kalimantan and Papua), and 11 periods (Supplementary Table 4), separately. We observed substantial improvement in the extent of overlapping areas of all continuous variables (ELEV, elevation; SLOP, slope; CITY, distance to city or arterial road; POPB, human population density; SDRY, average monthly rainfall during the dry season; SWET, average monthly rainfall during the wet season; TRNS, distance to transmigration areas prior to oil palm; and VILA, the village extent) between villages with and without industrial oil palm plantation development in the matched dataset compared with the original (unmatched) dataset (Supplementary Fig. 7 and Supplementary Table 5; aggregated across 18 indicators of well-being, 3 islands and 11 periods). For analysis B, the matching method was applied for each indicator (Supplementary Table 1), two islands (Sumatra and Kalimantan) and three periods (Supplementary Table 4), separately. Again, we observed substantial improvement in the extent of overlapping areas of all continuous variables (ELEV, SLOP, CITY, POPB, SDRY, SWET, TRNS, VILA, and OPV, the proportion of village area allocated to oil palm prior to certification) in the oil palm villages with and without certification after matching was performed (Supplementary Fig. 8 and Supplementary Table 6; aggregated across 18 indicators of well-being, 2 islands and 3 periods).

Step 3: difference-in-difference regression. For each indicator of well-being k, we first calculated the change or difference over 5–11 years (between two PODES censuses) and then multiplied the change by w_k (Supplementary Table 1). The value of w_k represents the directional effect of the change in indicator k that defines improvement in well-being: $w_k = 1$ if positive change (or an increase) in indicator k represents improvement in well-being (for example, proportion of household with electricity) and $w_k = -1$ if negative change (or a reduction) in indicator k represents improvement in well-being (for example, prevalence of malnutrition, frequency of conflicts). We then divided the value by the maximum of the absolute change of well-being across all villages and periods within each island. Thus, we obtained values that ranged roughly between −1 and 1, where −1 and 1 denote the largest reduction and improvement in the well-being indicator across all study villages in each island, respectively, and 0 denotes no change in the well-being indicator after 5–11 years. We applied this transformation approach mainly to preserve information about the directionality of change in well-being (relative improvement or reduction) over time and to allow comparable measures across different indicators.

The impact of industrial oil palm plantations (analysis A) on village-level well-being was estimated by comparing the change in well-being indicators in villages with oil palm plantation development with the change in control villages without plantations (the difference in the differences in well-being indicators between two PODES censuses between oil palm and non-oil palm villages) for each island and village livelihood type. The impact of oil palm certification (analysis B) on village-level well-being was estimated by comparing the change in well-being indicators in oil palm villages with certified plantations with the change in control oil palm villages without certification (the difference in the differences in well-being indicators between two PODES censuses between certified and non-certified oil palm villages) for each island and village livelihood type. The number of villages assessed for both analyses is shown in Supplementary Table 3. The overall effect (and confidence interval) of industrial oil palm plantations or RSPO certification on improving each aspect of well-being for each island and livelihood type was obtained by pooling estimates across all indicators belonging to the same group of well-being aspect (Supplementary Table 1).

Step 4: diagnostic tests and sensitivity analyses. To assess the quality of our matched dataset, we examined the change in the distributions of variables potentially affecting the assignments of industrial oil palm plantation villages (for analysis A) or certified plantation villages (for analysis B) before and after matching procedure. We achieved bias reduction of 92.9–98.6% for covariates matched in analysis A (Supplementary Table 5) and 81.7–98.3% for analysis B (Supplementary Table 6), indicating that samples were strongly matched in both assessments.

We conducted a series of sensitivity analyses to verify the robustness of our estimates against modelling specification and approach. This included (1) generating propensity scores separately within island, period and livelihood type, in contrast to our main approach of generating the scores within island and period, and (2) applying different categorization of well-being indicators by shifting indicators security and social equity from socioecological to socioeconomic aspects. The alternative method for generating the propensity scores yielded similar conclusions about the impact of oil palm development (analysis A) and certification (analysis B) on well-being as those generated by the main approach (Supplementary Fig. 9). The alternative grouping of indicators under the socioeconomic and socioecological aspects resulted in worsened performance of industrial oil palm development (analysis A) and certification (analysis B) on village well-being relative to those obtained from the main approach (Supplementary Fig. 10). This is because the negative impact of oil palm development or certification on key indicators of social well-being (prevalence of conflicts and low-wage agricultural labourers) tended to be less pronounced than the negative impact on natural hazard prevalence but worse than the impact on living conditions, infrastructure provision and income support (Extended Data Figs. 6 and 7).

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Key datasets used to conduct our analysis are publicly available from the cited references (forest cover data available from https://glad.umd.edu/dataset/primary-forest-cover-loss-indonesia-2000-2012 and https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html and socioeconomic data from https://mikrodata.bps.go.id/mikrodata/index.php/catalog/PODES). Source data are provided with this paper.

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Author contributions

T.S., M.J.S., E.M. and K.A.W. conceived the idea. T.S. designed the study, processed the socioeconomic and environmental data and performed the analyses. M.J.S. coordinated the project and obtained funding with E.M. and K.A.W. K.M.C. and H.G. provided the concessions data. E.A.L., F.A.V.S.J., C.L.M. and M.A. assisted with the socioeconomic and environmental datasets. T.S. and M.J.S. led the manuscript, which was critically reviewed and edited by the other authors. All authors contributed to the interpretation of analyses and gave final approval for publication.

Competing interests

The authors declare no competing interests.

Additional information

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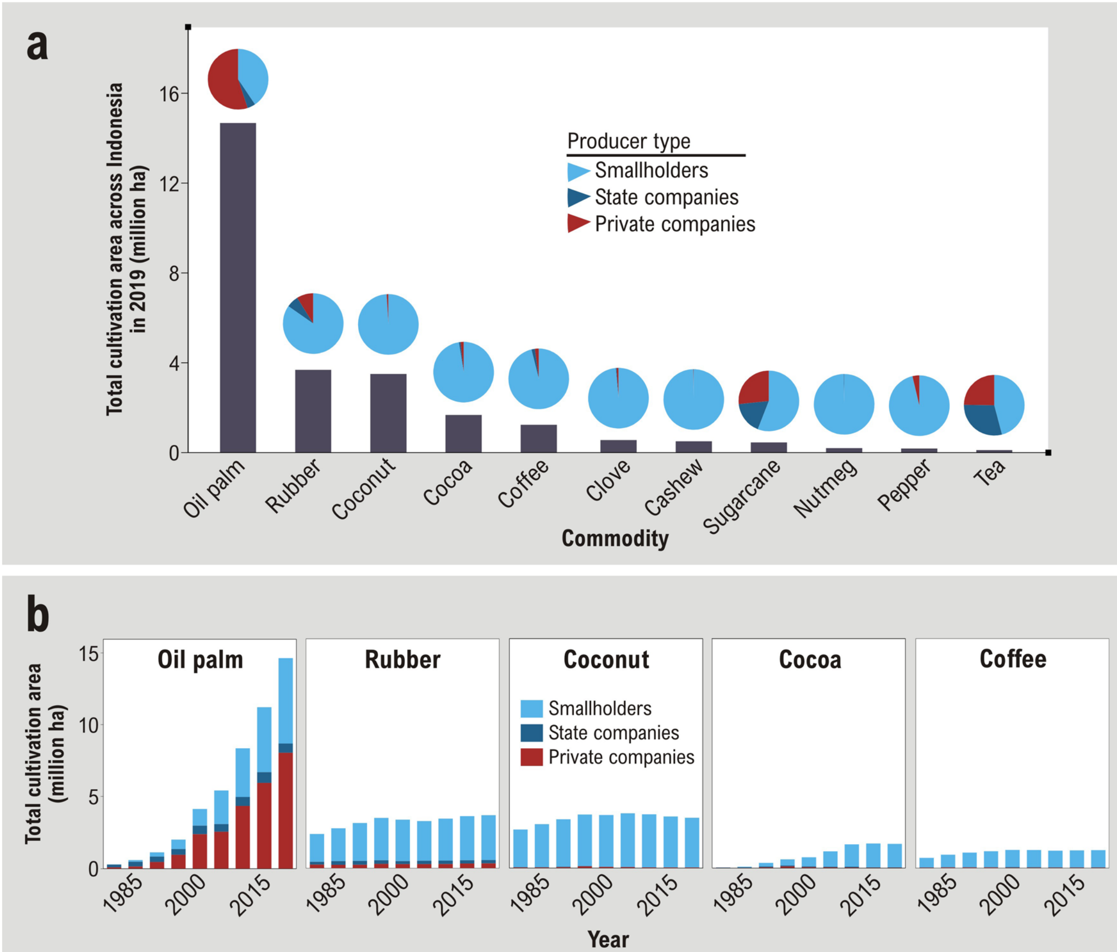
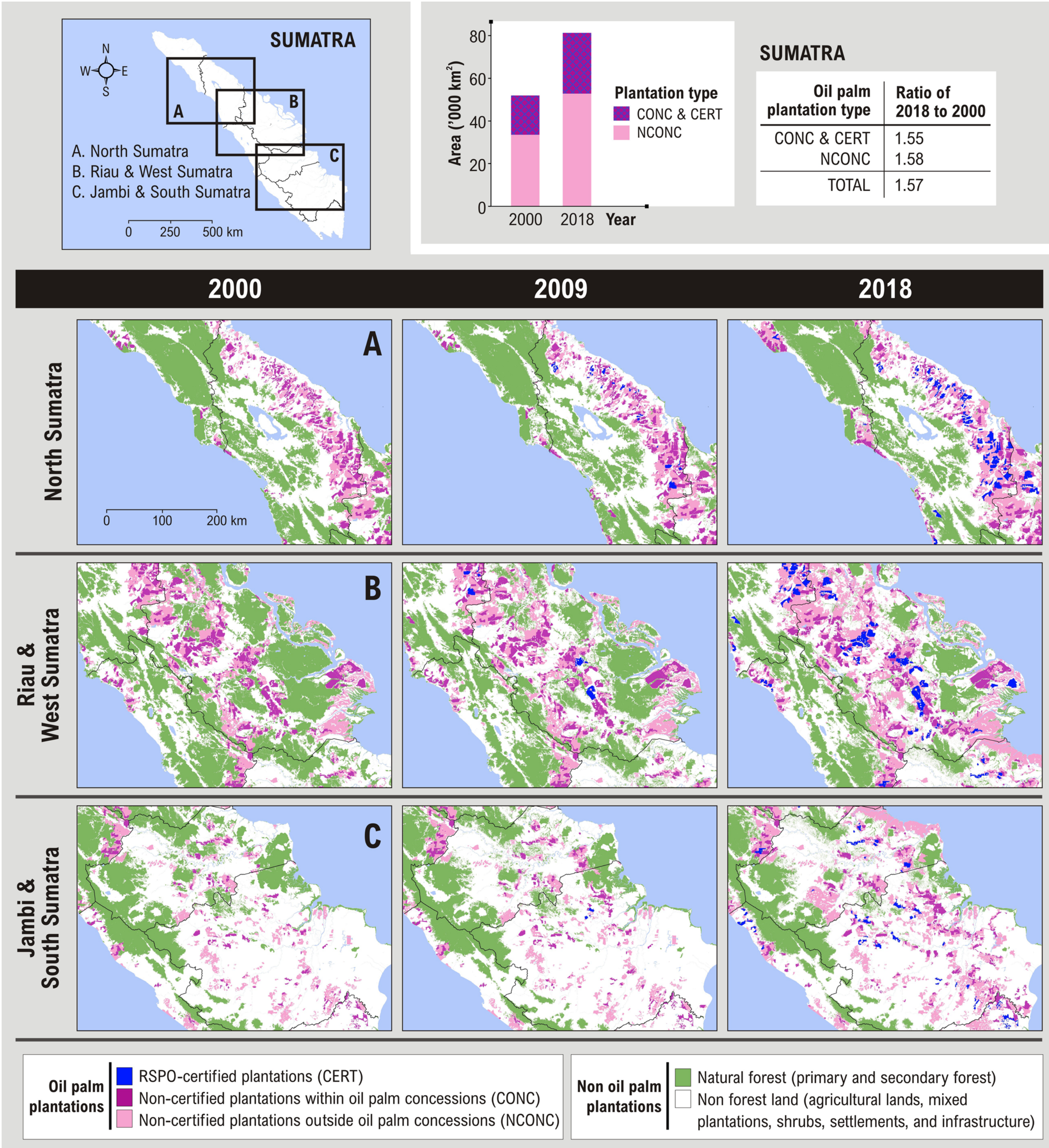
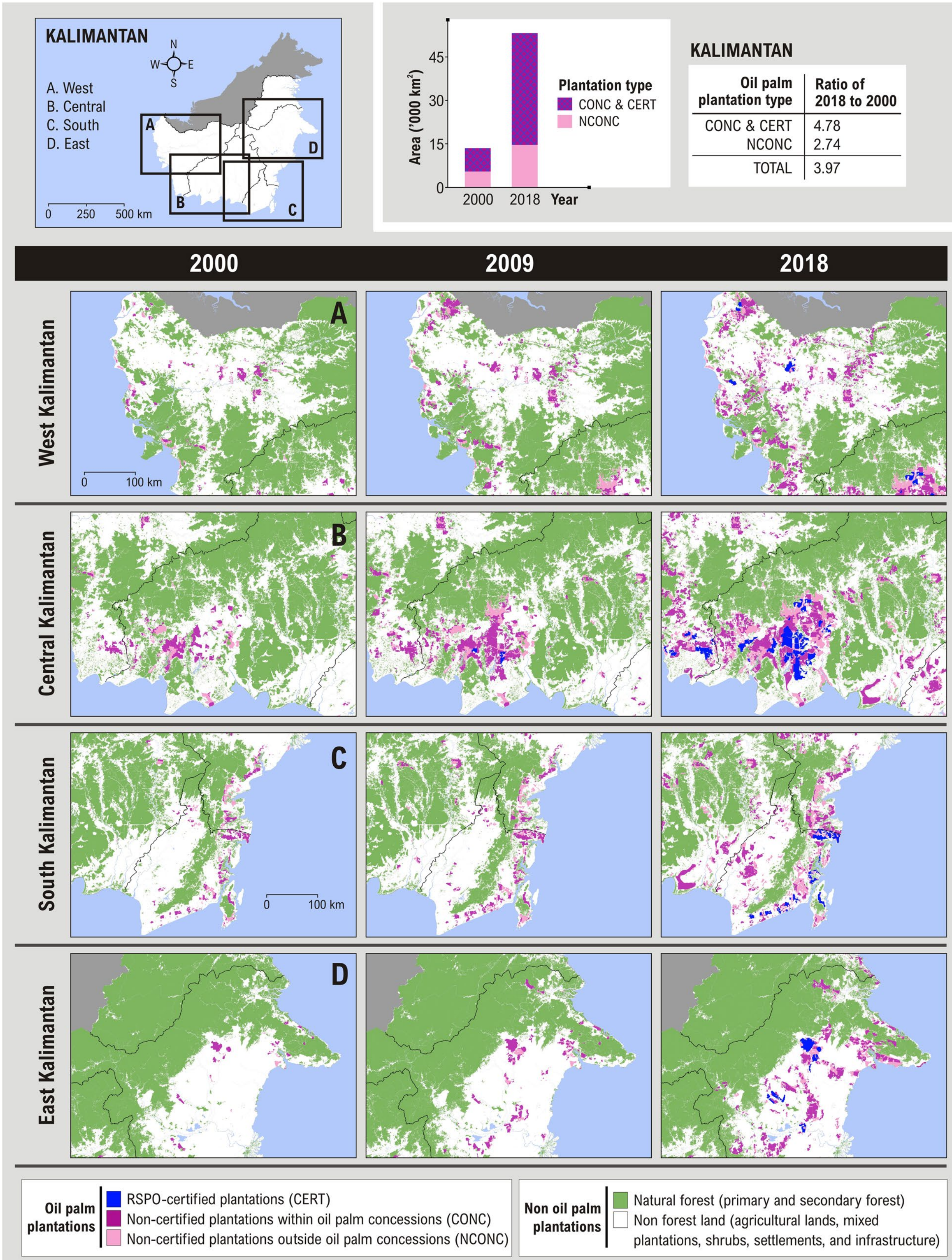


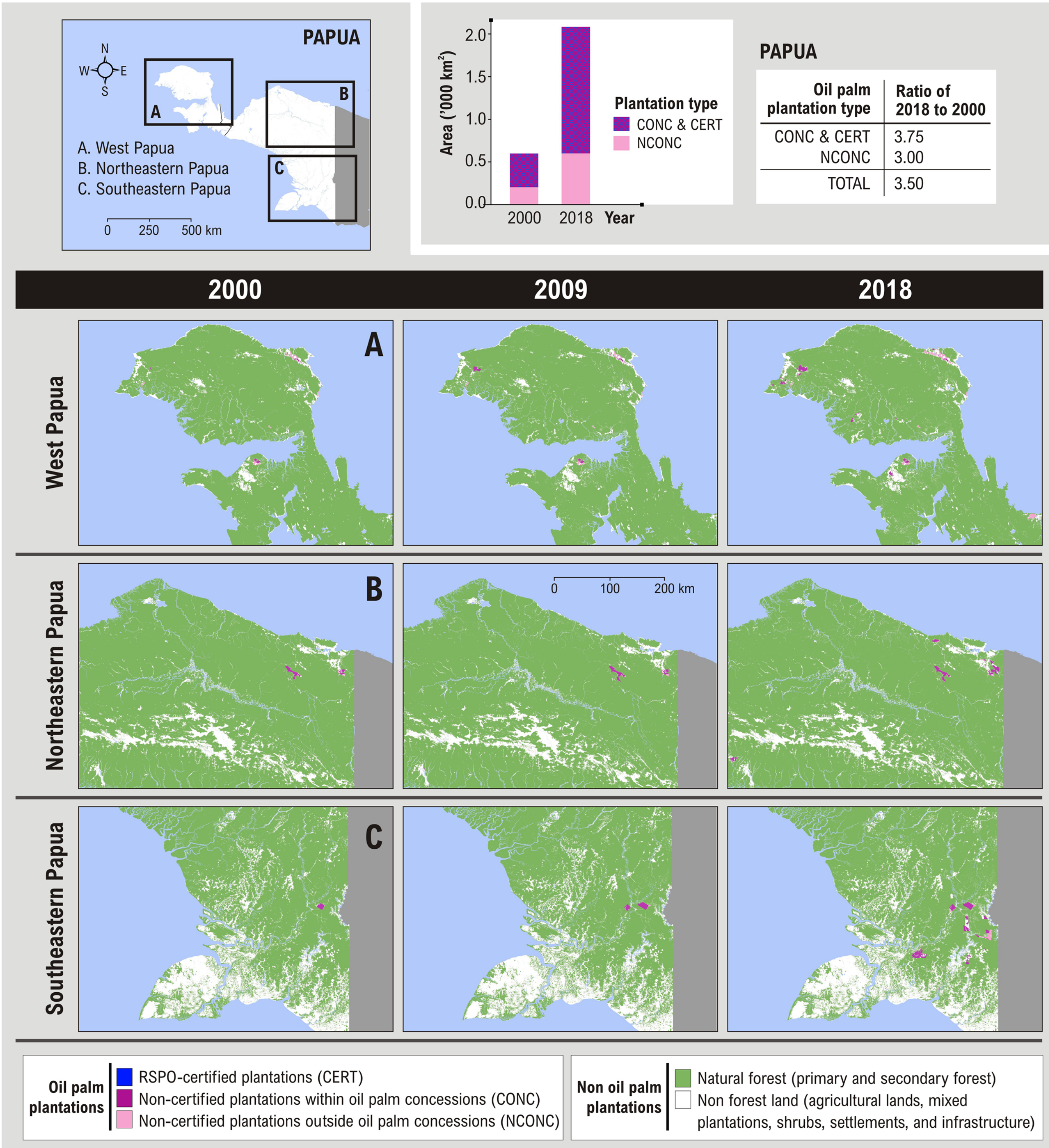
Extended Data Fig. 1 | Total plantation area for key agricultural commodities across Indonesia and types of ownerships. (**a**) Bar chart representing the total plantation area in 2019 for key agricultural commodities across Indonesia, and pie chart (above the bar) representing the proportion of different type of producer for each commodity, including smallholders, state or public-run companies, and private companies. (**b**) The change in cultivation area of the top five commodities (oil palm, rubber, coconut, cocoa, and coffee) every five years between 1980 and 2019, by producer type. Data were obtained from the Directorate General of Estate Crops Indonesia (2019).



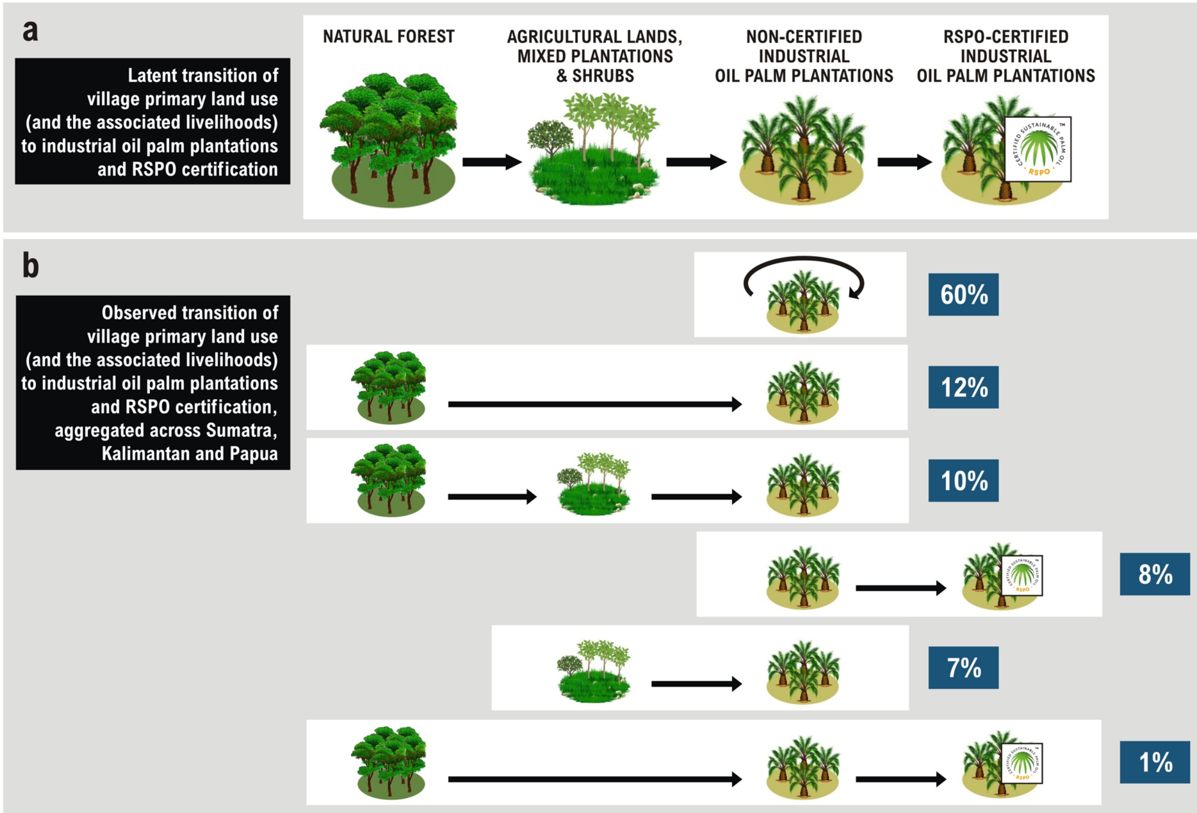
Extended Data Fig. 2 | Detailed change in distribution of forest and oil palm plantations in Sumatra. Detailed change in the distribution of natural forest and oil palm plantations every 9 years between 2000 and 2018 in three major oil palm regions in Sumatra. Oil palm plantations are grouped into three categories: (1) RSPO-certified plantations (CERT), (2) non-certified plantations within oil palm concessions (CONC), and (3) non-certified plantations outside known oil palm concessions (NCONC).



Extended Data Fig. 3 | Detailed change in distribution of forest and oil palm plantations in Kalimantan. Detailed change in the distribution of natural forest and oil palm plantations every 9 years between 2000 and 2018 in four oil palm regions in Kalimantan. Oil palm plantations are grouped into three categories: (1) RSPO-certified plantations (CERT), (2) non-certified plantations within oil palm concessions (CONC), and (3) non-certified plantations outside known oil palm concessions (NCONC).



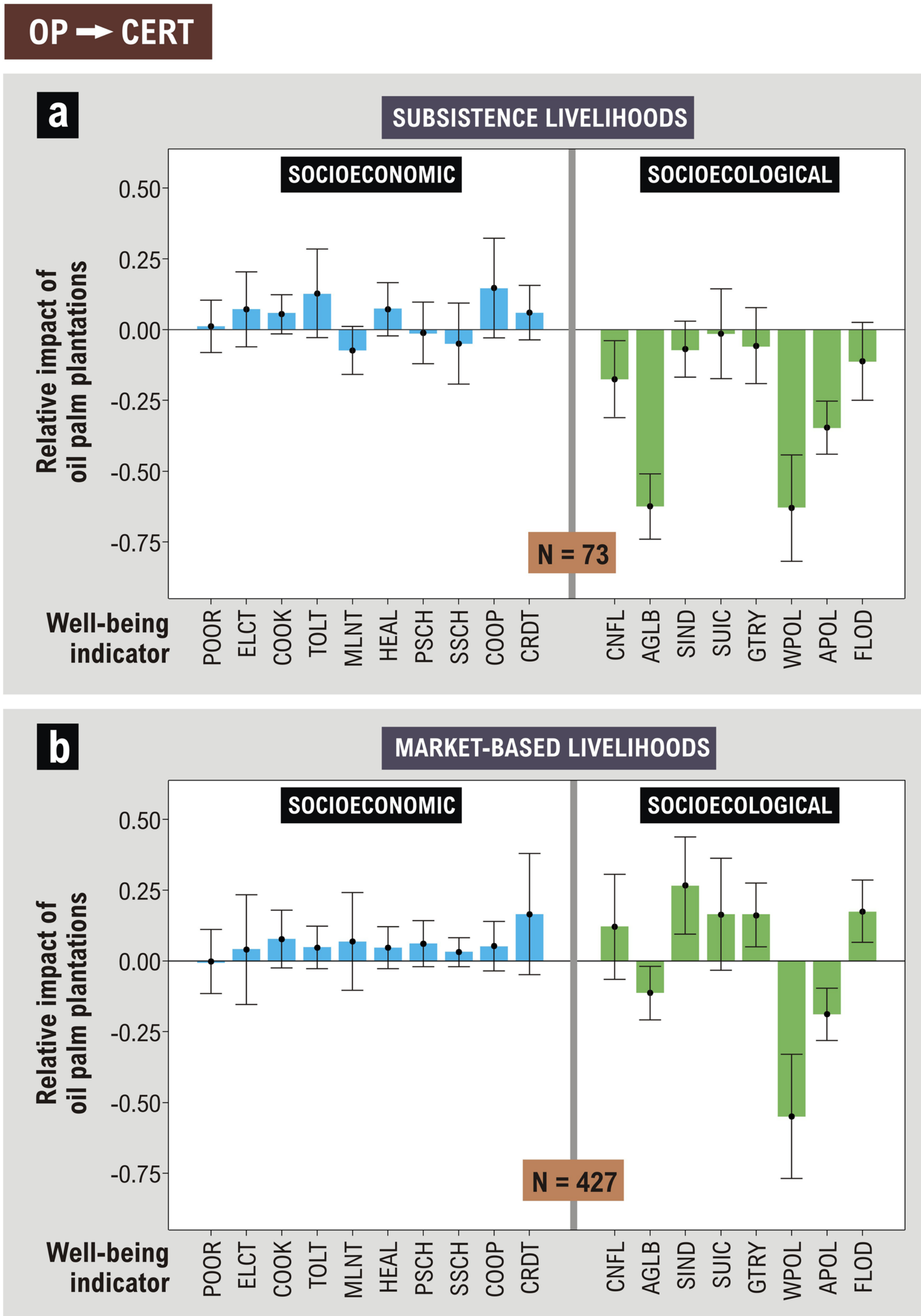
Extended Data Fig. 4 | Detailed change in distribution of forest and oil palm plantations in Papua. Detailed change in the distribution of natural forest and oil palm plantations every 9 years between 2000 and 2018 in three oil palm regions in Papua. Oil palm plantations are grouped into three categories: (1) RSPO-certified plantations (CERT), (2) non-certified plantations within oil palm concessions (CONC), and (3) non-certified plantations outside known oil palm concessions (NCONC).



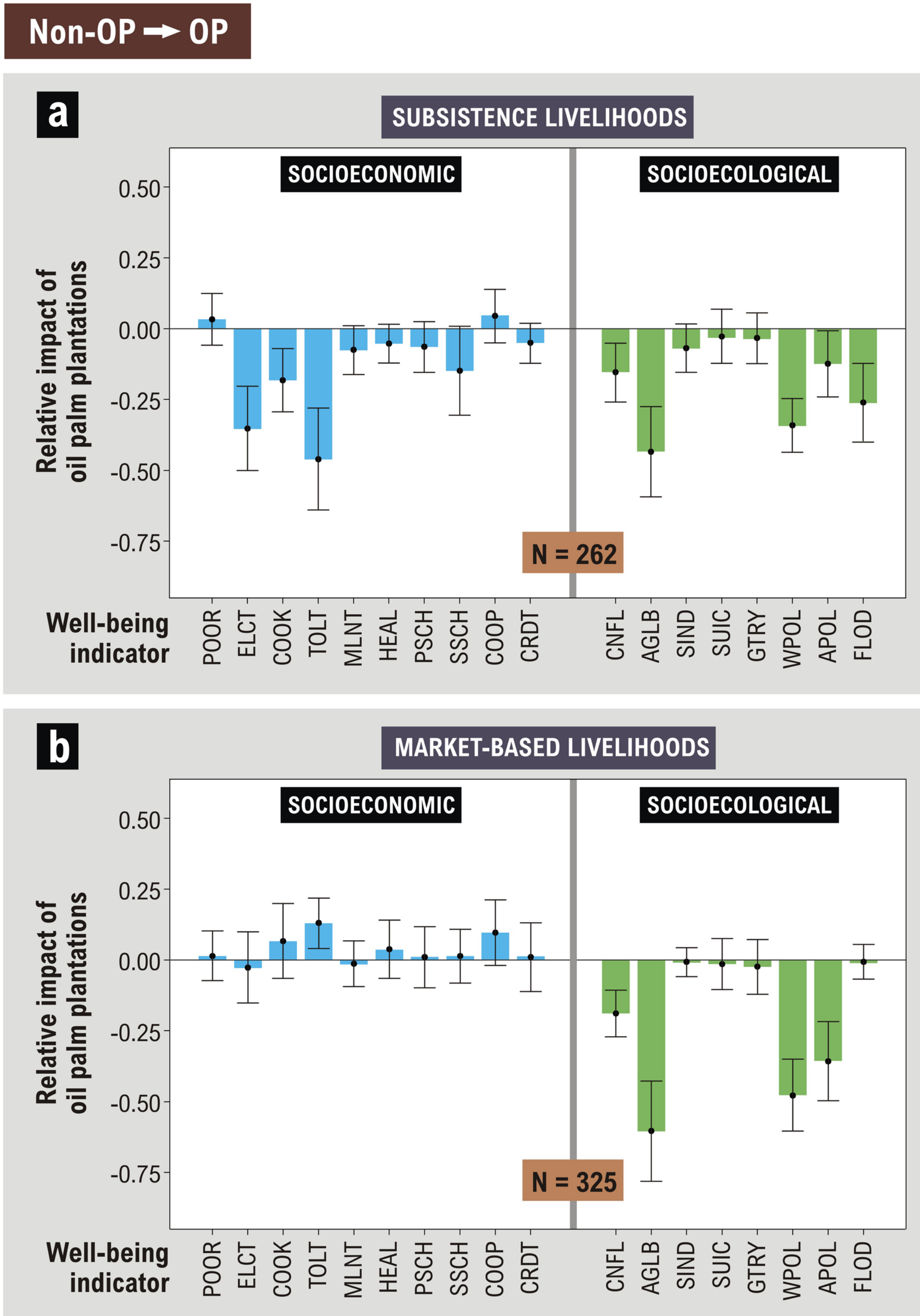
	Village primary land use	Village primary livelihoods
(natural forest icon)	Natural forest (primary & secondary forest)	Subsistence-based (farming, fishing, forest product gathering)
(agricultural lands icon)	Agricultural lands, mixed plantations & shrubs	Polyculture plantations (smallholdings)

	Village primary land use	Village primary livelihoods
(oil palm icon)	Non-certified industrial oil palm plantations	Monoculture oil palm plantations
(certified oil palm icon)	RSPO-certified industrial oil palm plantations	Monoculture oil palm plantations

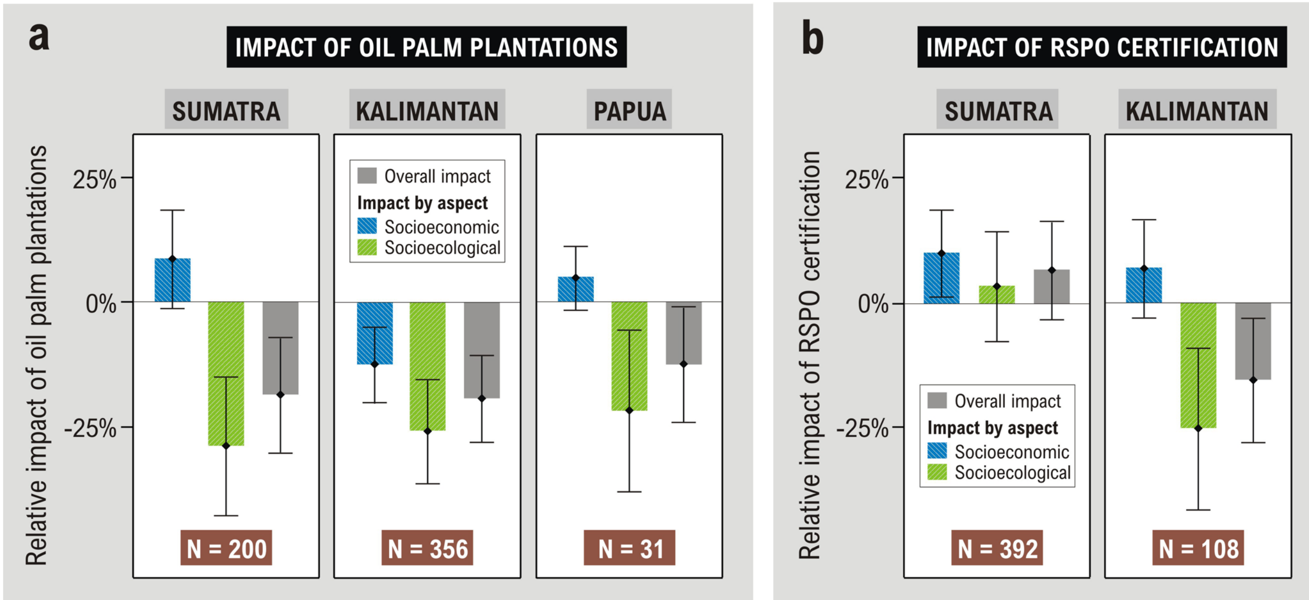
Extended Data Fig. 5 | Latent and observed change in village primary land use (and the associated livelihoods) to oil palm certification. (**a**) Latent change in village primary land use (and the associated livelihoods), from high natural forest cover, to agricultural lands, mixed plantations and shrubs, followed by industrial oil palm plantations (non-certified), then finally becoming RSPO-certified industrial plantations. (**b**) Observed change in village primary land use (and the associated livelihoods) to industrial oil palm plantations and certification based on land cover data and PODES censuses 2000, 2005, 2011, and 2018 (see Methods), aggregated across Sumatra, Kalimantan, and Papua. Percentage on the right hand side of each row represents the proportion of villages with the associated transition between 2000 and 2018.



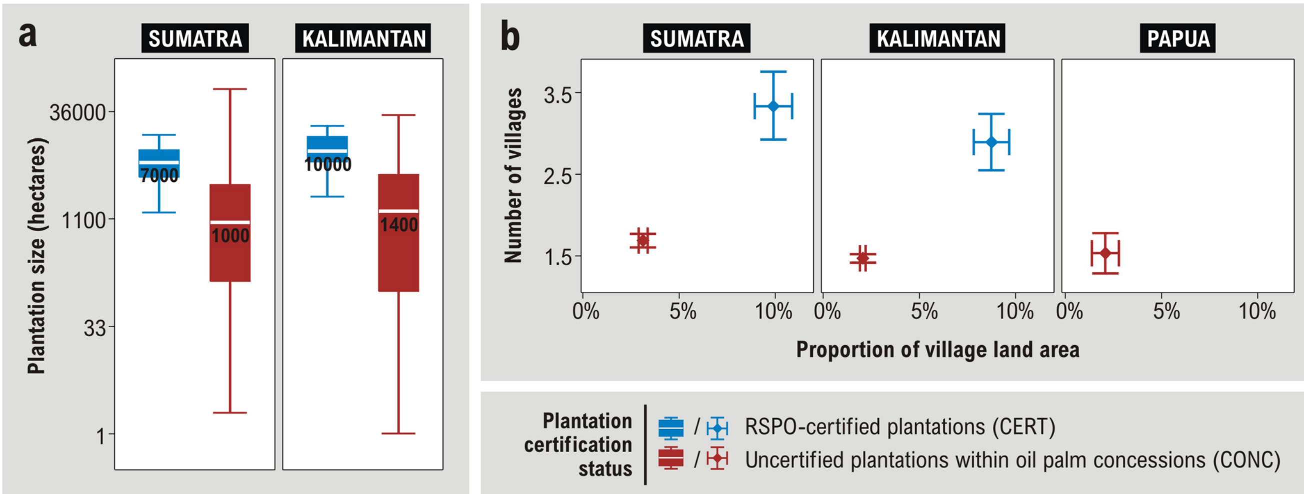
Extended Data Fig. 6 | Impacts of RSPO-certification on indicators of well-being by village primary livelihoods. The impact of oil palm certification (transition from oil palm villages to certified plantation villages) on each indicator of well-being in villages with primary livelihoods: (**a**) subsistence production, and (**b**) market-based. Indicators of well-being were grouped to socioeconomic and socioecological dimensions. Socioeconomic indicators include housing conditions (POOR), access to electricity (ELCT), cooking fuel (COOK), and toilet facilities (TOLT), child malnutrition incidence (MLNT), distance to healthcare facility (HEAL), primary school (PSCH), and secondary school (SSCH), and access to cooperative scheme (COOP) and credit facilities (CRDT). Socioecological indicators include the prevalence of conflicts (CNFL), agricultural labourers (AGLB), small industries (SIND), suicide rates (SUIC), voluntary cleaning and maintenance (GTRY), water pollution (WPOL), air pollution (APOL), and floods and landslides (FLOD). Results were derived across 3 time periods and two islands (Sumatra and Kalimantan). N represents the number of villages used to derive the impact estimates for each well-being indicator. Error bars represent 95% confidence intervals. See Supplementary Table 1 for description of each well-being indicator.



Extended Data Fig. 7 | Impacts of industrial oil palm plantation development on indicators of well-being by village primary livelihoods. 7The impact of industrial oil palm plantation development (transition from non oil palm villages to oil palm villages) on each indicator of well-being in villages with primary livelihoods: (**a**) subsistence production, and (**b**) market-based. Indicators of well-being were grouped to socioeconomic and socioecological dimensions. . Socioeconomic indicators include housing conditions (POOR), access to electricity (ELCT), cooking fuel (COOK), and toilet facilities (TOLT), child malnutrition incidence (MLNT), distance to healthcare facility (HEAL), primary school (PSCH), and secondary school (SSCH), and access to cooperative scheme (COOP) and credit facilities (CRDT). Socioecological indicators include the prevalence of conflicts (CNFL), agricultural labourers (AGLB), small industries (SIND), suicide rates (SUIC), voluntary cleaning and maintenance (GTRY), water pollution (WPOL), air pollution (APOL), and floods and landslides (FLOD). Results were derived across 11 time periods and three islands (Sumatra, Kalimantan, and Papua). N represents the number of villages used to derive the impact estimates for each well-being indicator. Error bars represent 95% confidence intervals. See Supplementary Table 1 for description of each well-being indicator.



Extended Data Fig. 8 | Impact of oil palm plantation development and certification on well-being in oil palm growing villages by island. (**a**) Impact of oil palm plantations on village well-being in Sumatra, Kalimantan, and Papua, evaluated by comparing the change in well-being indicators in villages 5-11 years after industrial oil palm plantation development against the change in well-being in villages without industrial oil palm plantation, while ensuring similar baseline characteristics in both types of villages. (**b**) Impact of RSPO certification on village well-being in Sumatra and Kalimantan, evaluated by comparing the change in well-being indicators in villages 5-11 years after certification against the change in well-being in villages with non-certified industrial oil palm plantations, while ensuring similar baseline characteristics in both types of villages. N represents the number of villages assessed in each panel. Error bars represent 95% confidence intervals.



Extended Data Fig. 9 | Size of individual industrial oil palm plantation and number of villages covered by one plantation, by certification status. (**a**) Size of each large-scale plantation by certification status in the islands of Sumatra, Kalimantan, and Papua. (**b**) Number of villages covered by each large-scale industrial plantation and the proportion of village land area allocated to each plantation, by certification status. Plantation certification status includes (1) RSPO-certified plantations, that is certified large-scale industrial plantations (CERT) and (2) non-certified plantations within oil palm concession boundaries, that is non-certified large-scale industrial plantations (CONC).

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☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used in data collection.
Data analysis	Open-sourced R software and licensed ArcGIS software were used for data analysis.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

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- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

Key datasets used to conduct our analysis are publicly available from the cited references (forest cover data available from https://glad.umd.edu/dataset/primary-forest-cover-loss-indonesia-2000-2012 and https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html and socioeconomic data from https://mikrodata.bps.go.id/mikrodata/index.php/catalog/PODES).

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We used a quasi-experimental design based on matching methods to evaluate the impact of industrial-scale oil palm plantations and the subsequent certification on wellbeing indicators in Indonesia. We used 18 indicators (as applied in our previous impact analyses published in World Development, Land Use Policy, and People and Nature) from the PODES dataset collected by the Indonesian Central Bureau of Statistics.
Research sample	The research sample are villages across Indonesian islands of Sumatra (24,259 villages), Kalimantan (7095 villages), and Papua (4957 villages). This includes 2602 villages with expansive non-certified industrial oil palm plantations and 794 villages with expansive RSPO-certified plantations. We evaluated poverty change in 587 villages 5-11 years after the development of industrial oil palm plantations and 500 villages 5-11 years after the issuance of oil palm certification.
Sampling strategy	The sample sizes include 587 villages to assess poverty change 5-11 years after the development of industrial oil palm plantations and 500 villages to assess poverty change 5-11 years after the issuance of oil palm certification. These are all villages in the study region with oil palm and certification respectively. Counterfactuals are drawn from the remaining pool of villages in the PODES data.
Data collection	Data on indicators of poverty were derived from the PODES datasets collected by the Indonesian Central Bureau of Statistics. Mapped data on oil palm concessions were provided by the coauthors, and supplemented by the lead author (direct digitizing from remotely sensed imagery).
Timing	The temporal scale of the analysis for poverty change was between 5 and 11 years. With the PODES data available for 2000, 2003, 2005, 2008, 2011, 2014 and 2018 censuses, we assessed poverty change for 2000-2005, 2000-2008, 2000-2011, 2003-2008, and so on, which resulted in 11 time-frames for the oil palm impact and 3 time-frames for the certification impact. The spatial scale of analysis is the entire islands of Sumatra, Kalimantan, and Papua, with village as the spatial unit.
Data exclusions	No data were excluded in the analysis.
Non-participation	Not applicable
Randomization	We controlled for potentially confounding variables in the assessment of oil palm and certification impacts in terms of both selections of villages for treatment and the outcome being measured. To achieve this we included variables representing: (a) socio-political factors, (b) accessibility, (c) agricultural productivity, and (d) baseline village socioeconomic conditions.

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Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging